

T H E

SSSS		OOOOO		FFFFFFFFFFFF		AAAAAA
SSSSSSSSSS		OOOOOOOOOOO		FFFFFFFFFFFF		AAAAAA
SSSSSSSSSS		OOOOOOOOOOO		FFFFFFFFFFFF		AAAA AAAA
SSSS	S	OOOOO	OOOO	FFFF		AAAA AAAA
SSSS		OOOOO	OOO	FFFF		AAAA AAAA
SSSSSSSSSS		OOOO	OOOOO	FFFFFFFFFFFF		AAAA AAAA
SSSSSSSSSS		OOOOO	OOO	FFFFFFFFFFFF		AAAAAAAAAAAA
	SSSS	OOO	OOO	FFFF		AAAAAAAAAAAA
S	SSSS	OOOOO	OOOOO	FFFF		AAAAAAAAAAAA
SSSSSSSSSS		OOOOOOOOOOO		FFFF	AAAA	AAAA
SSSSSSSS		OOOOOOOOO		FFFF	AAAA	AAAA
SSSS		OOOOO		FFFF	AAAA	AAAA

S O F T W A R E

L I B R A R I E S

International Astronomical Union

Division A: Fundamental Astronomy

Standards Of Fundamental Astronomy Board

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THE IAU-SOFA SOFTWARE LIBRARIES  
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SOFA stands for "Standards Of Fundamental Astronomy". The SOFA software libraries are a collection of subprograms, in source-code form, which implement official IAU algorithms for fundamental-astronomy computations. The subprograms at present comprise 176 "astronomy" routines supported by 55 "vector/matrix" routines, available in both Fortran77 and C implementations.

#### THE SOFA INITIATIVE

SOFA is an IAU Service which operates as a Standing Working Group under Division A (Fundamental Astronomy).

The IAU set up the SOFA initiative at the 1994 General Assembly, to promulgate an authoritative set of fundamental-astronomy constants and algorithms. At the subsequent General Assembly, in 1997, the appointment of a review board and the selection of a site for the SOFA Center (the outlet for SOFA products) were announced.

The SOFA initiative was originally proposed by the IAU Working Group on Astronomical Standards (WGAS), under the chairmanship of Toshio Fukushima. The proposal was for "...new arrangements to establish and maintain an accessible and authoritative set of constants, algorithms and procedures that implement standard models used in fundamental astronomy". The SOFA Software Libraries implement the "algorithms" part of the SOFA initiative. They were developed under the supervision of an international panel called the SOFA Board. The current membership of this panel is listed in an appendix.

A feature of the original SOFA software proposals was that the products would be self-contained and not depend on other software. This includes basic documentation, which, like the present file, will mostly be plain ASCII text. It should also be noted that there is no assumption that the software will be used on a particular computer and Operating System. Although OS-related facilities may be present (Unix make files for instance, use by the SOFA Center of automatic code management systems, HTML versions of some documentation), the routines themselves will be visible as individual text files and will run on a variety of platforms.

#### ALGORITHMS

The SOFA Board's initial goal has been to create a set of callable subprograms. Whether "subroutines" or "functions", they are all referred to simply as "routines". They are designed for use by software developers wishing to write complete applications; no runnable, free-standing applications are included in SOFA's present plans.

The algorithms are drawn from a variety of sources. Because most of the routines so far developed have either been standard "text-book" operations or implement well-documented standard algorithms, it has not been necessary to invite the whole community to submit algorithms, though consultation with authorities has occurred where necessary. It should also be noted that consistency with the conventions published by the International Earth Rotation Service was a stipulation in the original SOFA proposals, further constraining the software designs. This state of affairs will continue to exist for some time, as there is a large backlog of agreed extensions to work on. However, in the future the Board may decide to call for proposals, and is in the meantime willing to look into any suggestions that are received by the SOFA Center.

#### SCOPE

The routines currently available are listed in the next two chapters of this document.

The "astronomy" library comprises 176 routines (plus one obsolete Fortran routine that now appears under a revised name). The areas addressed include calendars, astrometry, time scales, Earth rotation, ephemerides, precession-nutation, star catalog transformations, and geodetic/geocentric transformations.

The "vector-matrix" library, comprising 55 routines, contains a collection of simple tools for manipulating the vectors, matrices and angles used by the astronomy routines.

There is no explicit commitment by SOFA to support historical models, though as time goes on a legacy of superseded models will naturally accumulate. There is, for example, no support of B1950/FK4 star coordinates, or pre-1976 precession models, though these capabilities could be added were there significant demand.

Though the SOFA software libraries are rather limited in scope, and are likely to remain so for a considerable time, they do offer distinct advantages to prospective users. In particular, the routines are:

- \* authoritative: they are IAU-backed and have been constructed with great care;
- \* practical: they are straightforward to use in spite of being precise and rigorous (to some stated degree);
- \* accessible and supported: they are downloadable from an easy-to-find place, they are in an integrated and consistent form, they come with adequate internal documentation, and help for users is available.

#### VERSIONS

Once it has been published, an issue is never revised or updated, and remains accessible indefinitely. Subsequent issues may, however, include corrected versions under the original routine name and filenames. However, where a different model is introduced, it will have a different name.

The issues will be referred to by the date when they were announced. The frequency of re-issue will be decided by the Board, taking into account the importance of the changes and the impact on the user community.

#### DOCUMENTATION

At present there is little free-standing documentation about individual routines. However, each routine has preamble comments which specify in detail what the routine does and how it is used.

The files `sofa_pn_f.pdf` and `sofa_pn_c.pdf` (for Fortran and C users respectively) describe the SOFA tools for precession-nutation and other aspects of Earth attitude, and include example code and, in an appendix, diagrams showing the interrelationships between the routines supporting the latest (IAU 2006/2000A) models. Two other pairs of documents introduce time scale transformations (`sofa_ts_f.pdf` and `sofa_ts_c.pdf`) and astrometric transformations (`sofa_ast_f.pdf` and `sofa_ast_c.pdf`).

#### PROGRAMMING LANGUAGES AND STANDARDS

The SOFA routines are available in two programming languages at present: Fortran77 and ANSI C. Related software in other languages is under consideration.

The Fortran code conforms to ANSI X3.9-1978 in all but two minor respects: each has an IMPLICIT NONE declaration, and its name has a

prefix of "iau\_" and may be longer than 6 characters. A global edit to erase both of these will produce ANSI-compliant code with no change in its function.

Coding style, and restrictions on the range of language features, have been much debated by the Board, and the results comply with the majority view. There is (at present) no document that defines the standards, but the code itself offers a wide range of examples of what is acceptable.

The Fortran routines contain explicit numerical constants (the INCLUDE statement is not part of ANSI Fortran77). These are drawn from the file constslis, which is listed in an appendix. Constants for the SOFA/C functions are defined in a header file sofam.h.

The naming convention is such that a SOFA routine referred to generically as "EXAMPL" exists as a Fortran subprogram iau\_EXAMPL and a C function iauExempl. The calls for the two versions are very similar, with the same arguments in the same order. In a few cases, the C equivalent of a Fortran SUBROUTINE subprogram uses a return value rather than an argument.

Each language version includes a "testbed" main-program that can be used to verify that the SOFA routines have been correctly compiled on the end user's system. The Fortran and C versions are called t\_sofa\_f.for and t\_sofa\_c.c respectively. The testbeds execute every SOFA routine and check that the results are within expected accuracy margins. It is not possible to guarantee that all platforms will meet the rather stringent criteria that have been used, and an occasional warning message may be encountered on some systems.

#### COPYRIGHT ISSUES

Copyright for all of the SOFA software and documentation is owned by the IAU SOFA Board. The Software is made available free of charge for all classes of user, including commercial. However, there are strict rules designed to avoid unauthorized variants coming into circulation. It is permissible to distribute derived works and other modifications, but they must be clearly marked to avoid confusion with the SOFA originals.

Further details are included in the block of comments which concludes every routine. The text is also set out in an appendix to the present document.

#### ACCURACY

The SOFA policy is to organize the calculations so that the machine accuracy is fully exploited. The gap between the precision of the underlying model or theory and the computational resolution has to be kept as large as possible, hopefully leaving several orders of magnitude of headroom.

The SOFA routines in some cases involve design compromises between rigor and ease of use (and also speed, though nowadays this is seldom a major concern).

#### ACKNOWLEDGEMENTS

The Board is indebted to a number of contributors, who are acknowledged in the preamble comments of the routines concerned.

The Board's effort is provided by the members' individual institutes.

Resources for operating the SOFA Center are provided by Her Majesty's Nautical Almanac Office, operated by the United Kingdom Hydrographic Office.

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SOFA Astronomy Library  
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## PREFACE

The routines described here comprise the SOFA astronomy library. Their general appearance and coding style conforms to conventions agreed by the SOFA Board, and their functions, names and algorithms have been ratified by the Board. Procedures for soliciting and agreeing additions to the library are still evolving.

## PROGRAMMING LANGUAGES

The SOFA routines are available in two programming languages at present: Fortran 77 and ANSI C.

Except for a single obsolete Fortran routine, which has no C equivalent, there is a one-to-one relationship between the two language versions. The naming convention is such that a SOFA routine referred to generically as "EXAMPL" exists as a Fortran subprogram `iau_EXAMPL` and a C function `iauExempl`. The calls for the two versions are very similar, with the same arguments in the same order. In a few cases, the C equivalent of a Fortran SUBROUTINE subprogram uses a return value rather than an argument.

## GENERAL PRINCIPLES

The principal function of the SOFA Astronomy Library is to provide definitive algorithms. A secondary function is to provide software suitable for convenient direct use by writers of astronomical applications.

The astronomy routines call on the SOFA vector/matrix library routines, which are separately listed.

The routines are designed to exploit the full floating-point accuracy of the machines on which they run, and not to rely on compiler optimizations. Within these constraints, the intention is that the code corresponds to the published formulation (if any).

Dates are always Julian Dates (except in calendar conversion routines) and are expressed as two double precision numbers which sum to the required value.

A distinction is made between routines that implement IAU-approved models and those that use those models to create other results. The former are referred to as "canonical models" in the preamble comments; the latter are described as "support routines".

Using the library requires knowledge of positional astronomy and time-scales. These topics are covered in "Explanatory Supplement to the Astronomical Almanac", 3rd Edition, Sean E. Urban & P. Kenneth Seidelmann (eds.), University Science Books, 2013. Recent developments are documented in the scientific journals, and references to the relevant papers are given in the SOFA code as required. The IERS Conventions are also an essential reference. The routines concerned with Earth attitude (precession-nutation etc.) are described in the SOFA document `sofa_pn.pdf`. Those concerned with transformations between different time scales are described in `sofa_ts_f.pdf` (Fortran) and `sofa_ts_c.pdf` (C). Those concerned with astrometric transformations are described in `sofa_ast_f.pdf` (Fortran) and `sofa_ast_c` (C).

## ROUTINES

Calendars

CAL2JD	Gregorian calendar to Julian Day number
EPB	Julian Date to Besselian Epoch
EPB2JD	Besselian Epoch to Julian Date
EPJ	Julian Date to Julian Epoch
EPJ2JD	Julian Epoch to Julian Date
JD2CAL	Julian Date to Gregorian year, month, day, fraction
JDCALF	Julian Date to Gregorian date for formatted output

#### Astrometry

AB	apply stellar aberration
APCG	prepare for ICRS <-> GCRS, geocentric, special
APCG13	prepare for ICRS <-> GCRS, geocentric
APCI	prepare for ICRS <-> CIRS, terrestrial, special
APCI13	prepare for ICRS <-> CIRS, terrestrial
APCO	prepare for ICRS <-> observed, terrestrial, special
APCO13	prepare for ICRS <-> observed, terrestrial
APCS	prepare for ICRS <-> CIRS, space, special
APCS13	prepare for ICRS <-> CIRS, space
APER	insert ERA into context
APER13	update context for Earth rotation
APIO	prepare for CIRS <-> observed, terrestrial, special
APIO13	prepare for CIRS <-> observed, terrestrial
ATCI13	catalog -> CIRS
ATCIQ	quick ICRS -> CIRS
ATCIQN	quick ICRS -> CIRS, multiple deflections
ATCIQZ	quick astrometric ICRS -> CIRS
ATCO13	ICRS -> observed
ATIC13	CIRS -> ICRS
ATICQ	quick CIRS -> ICRS
ATICQN	quick CIRS -> ICRS, multiple deflections
ATIO13	CIRS -> observed
ATIOQ	quick CIRS -> observed
ATOC13	observed -> astrometric ICRS
ATOI13	observed -> CIRS
ATIOQ	quick observed -> CIRS
LD	light deflection by a single solar-system body
LDN	light deflection by multiple solar-system bodies
LDSUN	light deflection by the Sun
PMPX	apply proper motion and parallax
PMSAFE	apply proper motion, with zero-parallax precautions
PVTOB	observatory position and velocity
PVSTAR	space motion pv-vector to star catalog data
REFCO	refraction constants
STARPM	apply proper motion
STARPV	star catalog data to space motion pv-vector

#### Time scales

D2DTF	format 2-part JD for output
DAT	Delta(AT) (=TAI-UTC) for a given UTC date
DTDB	TDB-TT
DTF2D	encode time and date fields into 2-part JD
TAITT	TAI to TT
TAIUT1	TAI to UT1
TAIUTC	TAI to UTC
TCBTDB	TCB to TDB
TCGTT	TCG to TT
TDBTCB	TDB to TCB
TDBTT	TDB to TT
TTTAI	TT to TAI
TTTCG	TT to TCG
TTTDB	TT to TDB
TTUT1	TT to UT1
UT1TAI	UT1 to TAI
UT1TT	UT1 to TT
UT1UTC	UT1 to UTC
UTCTAI	UTC to TAI
UTCUT1	UTC to UT1

#### Earth rotation angle and sidereal time

EE00	equation of the equinoxes, IAU 2000
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EE00A equation of the equinoxes, IAU 2000A  
 EE00B equation of the equinoxes, IAU 2000B  
 EE06A equation of the equinoxes, IAU 2006/2000A  
 EECT00 equation of the equinoxes complementary terms, IAU 2000  
 EQEQ94 equation of the equinoxes, IAU 1994  
 ERA00 Earth rotation angle, IAU 2000  
 GMST00 Greenwich mean sidereal time, IAU 2000  
 GMST06 Greenwich mean sidereal time, IAU 2006  
 GMST82 Greenwich mean sidereal time, IAU 1982  
 GST00A Greenwich apparent sidereal time, IAU 2000A  
 GST00B Greenwich apparent sidereal time, IAU 2000B  
 GST06 Greenwich apparent ST, IAU 2006, given NPB matrix  
 GST06A Greenwich apparent sidereal time, IAU 2006/2000A  
 GST94 Greenwich apparent sidereal time, IAU 1994

Ephemerides (limited precision)

EPV00 Earth position and velocity  
 PLAN94 major-planet position and velocity

Precession, nutation, polar motion

BI00 frame bias components, IAU 2000  
 BP00 frame bias and precession matrices, IAU 2000  
 BP06 frame bias and precession matrices, IAU 2006  
 BPN2XY extract CIP X,Y coordinates from NPB matrix  
 C2I00A celestial-to-intermediate matrix, IAU 2000A  
 C2I00B celestial-to-intermediate matrix, IAU 2000B  
 C2I06A celestial-to-intermediate matrix, IAU 2006/2000A  
 C2IBPN celestial-to-intermediate matrix, given NPB matrix, IAU 2000  
 C2IXY celestial-to-intermediate matrix, given X,Y, IAU 2000  
 C2IXYS celestial-to-intermediate matrix, given X,Y and s  
 C2T00A celestial-to-terrestrial matrix, IAU 2000A  
 C2T00B celestial-to-terrestrial matrix, IAU 2000B  
 C2T06A celestial-to-terrestrial matrix, IAU 2006/2000A  
 C2TCIO form CIO-based celestial-to-terrestrial matrix  
 C2TEQX form equinox-based celestial-to-terrestrial matrix  
 C2TPE celestial-to-terrestrial matrix given nutation, IAU 2000  
 C2TXY celestial-to-terrestrial matrix given CIP, IAU 2000  
 EO06A equation of the origins, IAU 2006/2000A  
 EORS equation of the origins, given NPB matrix and s  
 FW2M Fukushima-Williams angles to r-matrix  
 FW2XY Fukushima-Williams angles to X,Y  
 LTP long-term precession matrix  
 LTPB long-term precession matrix, including ICRS frame bias  
 LTPECL long-term precession of the ecliptic  
 LTPEQU long-term precession of the equator  
 NUM00A nutation matrix, IAU 2000A  
 NUM00B nutation matrix, IAU 2000B  
 NUM06A nutation matrix, IAU 2006/2000A  
 NUMAT form nutation matrix  
 NUT00A nutation, IAU 2000A  
 NUT00B nutation, IAU 2000B  
 NUT06A nutation, IAU 2006/2000A  
 NUT80 nutation, IAU 1980  
 NUTM80 nutation matrix, IAU 1980  
 OBL06 mean obliquity, IAU 2006  
 OBL80 mean obliquity, IAU 1980  
 PB06 zeta,z,theta precession angles, IAU 2006, including bias  
 PFW06 bias-precession Fukushima-Williams angles, IAU 2006  
 PMAT00 precession matrix (including frame bias), IAU 2000  
 PMAT06 PB matrix, IAU 2006  
 PMAT76 precession matrix, IAU 1976  
 PN00 bias/precession/nutation results, IAU 2000  
 PN00A bias/precession/nutation, IAU 2000A  
 PN00B bias/precession/nutation, IAU 2000B  
 PN06 bias/precession/nutation results, IAU 2006  
 PN06A bias/precession/nutation results, IAU 2006/2000A  
 PNM00A classical NPB matrix, IAU 2000A  
 PNM00B classical NPB matrix, IAU 2000B  
 PNM06A classical NPB matrix, IAU 2006/2000A  
 PNM80 precession/nutation matrix, IAU 1976/1980  
 P06E precession angles, IAU 2006, equinox based

POM00 polar motion matrix  
 PR00 IAU 2000 precession adjustments  
 PREC76 accumulated precession angles, IAU 1976  
 S00 the CIO locator  $s$ , given  $X, Y$ , IAU 2000A  
 S00A the CIO locator  $s$ , IAU 2000A  
 S00B the CIO locator  $s$ , IAU 2000B  
 S06 the CIO locator  $s$ , given  $X, Y$ , IAU 2006  
 S06A the CIO locator  $s$ , IAU 2006/2000A  
 SP00 the TIO locator  $s'$ , IERS 2003  
 XY06 CIP, IAU 2006/2000A, from series  
 XYS00A CIP and  $s$ , IAU 2000A  
 XYS00B CIP and  $s$ , IAU 2000B  
 XYS06A CIP and  $s$ , IAU 2006/2000A

#### Fundamental arguments for nutation etc.

FAD03 mean elongation of the Moon from the Sun  
 FAE03 mean longitude of Earth  
 FAF03 mean argument of the latitude of the Moon  
 FAJU03 mean longitude of Jupiter  
 FAL03 mean anomaly of the Moon  
 FALP03 mean anomaly of the Sun  
 FAMA03 mean longitude of Mars  
 FAME03 mean longitude of Mercury  
 FANE03 mean longitude of Neptune  
 FAOM03 mean longitude of the Moon's ascending node  
 FAPA03 general accumulated precession in longitude  
 FASA03 mean longitude of Saturn  
 FAUR03 mean longitude of Uranus  
 FAVE03 mean longitude of Venus

#### Star catalog conversions

FK52H transform FK5 star data into the Hipparcos system  
 FK5HIP FK5 to Hipparcos rotation and spin  
 FK5HZ FK5 to Hipparcos assuming zero Hipparcos proper motion  
 H2FK5 transform Hipparcos star data into the FK5 system  
 HFK5Z Hipparcos to FK5 assuming zero Hipparcos proper motion

#### Ecliptic coordinates

ECEQ06 ecliptic to ICRS, IAU 2006  
 ECM06 rotation matrix, ICRS to ecliptic, IAU 2006  
 EQEC06 ICRS to ecliptic, IAU 2006  
 LTECEQ ecliptic to ICRS, long term  
 LTECM rotation matrix, ICRS to ecliptic, long-term  
 LTEQEC ICRS to ecliptic, long term

#### Galactic coordinates

G2ICRS transform IAU 1958 galactic coordinates to ICRS  
 ICRS2G transform ICRS coordinates to IAU 1958 Galactic

#### Geodetic/geocentric

EFORM  $a, f$  for a nominated Earth reference ellipsoid  
 GC2GD geocentric to geodetic for a nominated ellipsoid  
 GC2GDE geocentric to geodetic given ellipsoid  $a, f$   
 GD2GC geodetic to geocentric for a nominated ellipsoid  
 GD2GCE geodetic to geocentric given ellipsoid  $a, f$

#### Obsolete

C2TCEO former name of C2TCIO

#### CALLS: FORTRAN VERSION

CALL iau\_AB ( PNAT, V, S, BM1, PPR )  
 CALL iau\_APCG ( DATE1, DATE2, EB, EH, ASTROM )  
 CALL iau\_APCG13 ( DATE1, DATE2, ASTROM )  
 CALL iau\_APCI ( DATE1, DATE2, EB, EH, X, Y, S, ASTROM )  
 CALL iau\_APCI13 ( DATE1, DATE2, ASTROM, EO )

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CALL iau_APCO ( DATE1, DATE2, EB, EH, X, Y, S,
: THETA, ELONG, PHI, HM, XP, YP, SP,
: REFA, REFB, ASTROM )
CALL iau_APCO13 ( UTC1, UTC2, DUT1, ELONG, PHI, HM, XP, YP,
: PHPA, TC, RH, WL, ASTROM, EO, J )
CALL iau_APCS ( DATE1, DATE2, PV, EB, EH, ASTROM )
CALL iau_APCS13 ( DATE1, DATE2, PV, ASTROM )
CALL iau_APER ( THETA, ASTROM )
CALL iau_APER13 ( UT11, UT12, ASTROM )
CALL iau_APIO ( SP, THETA, ELONG, PHI, HM, XP, YP,
: REFA, REFB, ASTROM )
CALL iau_APIO13 ( UTC1, UTC2, DUT1, ELONG, PHI, HM, XP, YP,
: PHPA, TC, RH, WL, ASTROM, J )
CALL iau_ATCI13 ( RC, DC, PR, PD, PX, RV, DATE1, DATE2, RI, DI, EO )
CALL iau_ATCIQ ( RC, DC, PR, PD, PX, RV, ASTROM, RI, DI )
CALL iau_ATCIQN ( RC, DC, PR, PD, PX, RV, ASTROM, N, B, RI, DI )
CALL iau_ATCIQZ ( RC, DC, ASTROM, RI, DI )
CALL iau_ATCO13 ( RC, DC, PR, PD, PX, RV, UTC1, UTC2, DUT1, ELONG,
: PHI, HM, XP, YP, PHPA, TC, RH, WL,
: AOB, ZOB, HOB, DOB, ROB, EO, J )
CALL iau_ATIC13 ( RI, DI, DATE1, DATE2, RC, DC, EO )
CALL iau_ATICQ ( RI, DI, ASTROM, RC, DC )
CALL iau_ATCIQN ( RI, DI, ASTROM, N, B, RC, DC )
CALL iau_ATIO13 ( RI, DI, UTC1, UTC2, DUT1, ELONG, PHI, HM, XP, YP,
: PHPA, TC, RH, WL, AOB, ZOB, HOB, DOB, ROB, J )
CALL iau_ATIOQ ( RI, DI, ASTROM, AOB, ZOB, HOB, DOB, ROB )
CALL iau_ATOC13 ( TYPE, OB1, OB2, UTC1, UTC2, DUT1,
: ELONG, PHI, HM, XP, YP, PHPA, TC, RH, WL,
: RC, DC, J )
CALL iau_ATOI13 ( TYPE, OB1, OB2, UTC1, UTC2, DUT1,
: ELONG, PHI, HM, XP, YP, PHPA, TC, RH, WL,
: RI, DI, J )
CALL iau_ATOIQ ( TYPE, OB1, OB2, ASTROM, RI, DI )
CALL iau_BI00 ( DPSIBI, DEPSBI, DRA )
CALL iau_BP00 ( DATE1, DATE2, RB, RP, RBP )
CALL iau_BP06 ( DATE1, DATE2, RB, RP, RBP )
CALL iau_BPN2XY ( RBPN, X, Y )
CALL iau_C2I00A ( DATE1, DATE2, RC2I )
CALL iau_C2I00B ( DATE1, DATE2, RC2I )
CALL iau_C2I06A ( DATE1, DATE2, RC2I )
CALL iau_C2IBPN ( DATE1, DATE2, RBPN, RC2I )
CALL iau_C2IXY ( DATE1, DATE2, X, Y, RC2I )
CALL iau_C2IXYS ( X, Y, S, RC2I )
CALL iau_C2T00A ( TTA, TTb, UTA, UTB, XP, YP, RC2T )
CALL iau_C2T00B ( TTA, TTb, UTA, UTB, XP, YP, RC2T )
CALL iau_C2T06A ( TTA, TTb, UTA, UTB, XP, YP, RC2T )
CALL iau_C2TCEO ( RC2I, ERA, RPOM, RC2T )
CALL iau_C2TCIO ( RC2I, ERA, RPOM, RC2T )
CALL iau_C2TEQX ( RBPN, GST, RPOM, RC2T )
CALL iau_C2TPE ( TTA, TTb, UTA, UTB, DPSI, DEPS, XP, YP, RC2T )
CALL iau_C2TXY ( TTA, TTb, UTA, UTB, X, Y, XP, YP, RC2T )
CALL iau_CAL2JD ( IY, IM, ID, DJM0, DJM, J )
CALL iau_D2DTF ( SCALE, NDP, D1, D2, IY, IM, ID, IHMSF, J )
CALL iau_DAT ( IY, IM, ID, FD, DELTAT, J )
D = iau_DTDB ( DATE1, DATE2, UT, ELONG, U, V )
CALL iau_DTF2D ( SCALE, IY, IM, ID, IHR, IMN, SEC, D1, D2, J )
CALL iau_ECEQ06 ( DATE1, DATE2, DL, DB, DR, DD )
CALL iau_ECM06 ( DATE1, DATE2, RM );
D = iau_EE00 ( DATE1, DATE2, EPSA, DPSI )
D = iau_EE00A ( DATE1, DATE2 )
D = iau_EE00B ( DATE1, DATE2 )
D = iau_EE06A ( DATE1, DATE2 )
D = iau_EECT00 ( DATE1, DATE2 )
CALL iau_EFORM ( N, A, F, J )
D = iau_EO06A ( DATE1, DATE2 )
D = iau_EORS ( RNPB, S )
D = iau_EPB ( DJ1, DJ2 )
CALL iau_EPB2JD ( EPB, DJM0, DJM )
D = iau_EPJ ( DJ1, DJ2 )
CALL iau_EPJ2JD ( EPJ, DJM0, DJM )
CALL iau_EPV00 ( DJ1, DJ2, PVH, PVB, J )
CALL iau_EQEC06 ( DATE1, DATE2, DR, DD, DL, DB )
D = iau_EQEQ94 ( DATE1, DATE2 )

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D = iau_ERA00 ( DJ1, DJ2 )
D = iau_FAD03 ( T )
D = iau_FAE03 ( T )
D = iau_FAF03 ( T )
D = iau_FAJU03 ( T )
D = iau_FAL03 ( T )
D = iau_FALP03 ( T )
D = iau_FAMA03 ( T )
D = iau_FAME03 ( T )
D = iau_FANE03 ( T )
D = iau_FAOM03 ( T )
D = iau_FAPA03 ( T )
D = iau_FASA03 ( T )
D = iau_FAUR03 ( T )
D = iau_FAVE03 ( T )
CALL iau_FK52H ( R5, D5, DR5, DD5, PX5, RV5,
:              RH, DH, DRH, DDH, PXH, RVH )
CALL iau_FK5HIP ( R5H, S5H )
CALL iau_FK5HZ ( R5, D5, DATE1, DATE2, RH, DH )
CALL iau_FW2M ( GAMB, PHIB, PSI, EPS, R )
CALL iau_FW2XY ( GAMB, PHIB, PSI, EPS, X, Y )
CALL iau_G2ICRS ( DL, DB, DR, DD )
CALL iau_GC2GD ( N, XYZ, ELONG, PHI, HEIGHT, J )
CALL iau_GC2GDE ( A, F, XYZ, ELONG, PHI, HEIGHT, J )
CALL iau_GD2GC ( N, ELONG, PHI, HEIGHT, XYZ, J )
CALL iau_GD2GCE ( A, F, ELONG, PHI, HEIGHT, XYZ, J )
D = iau_GMST00 ( UTA, UTB, TTA, TTB )
D = iau_GMST06 ( UTA, UTB, TTA, TTB )
D = iau_GMST82 ( UTA, UTB )
D = iau_GST00A ( UTA, UTB, TTA, TTB )
D = iau_GST00B ( UTA, UTB )
D = iau_GST06 ( UTA, UTB, TTA, TTB, RNPB )
D = iau_GST06A ( UTA, UTB, TTA, TTB )
D = iau_GST94 ( UTA, UTB )
CALL iau_H2FK5 ( RH, DH, DRH, DDH, PXH, RVH,
:              R5, D5, DR5, DD5, PX5, RV5 )
CALL iau_HFK5Z ( RH, DH, DATE1, DATE2, R5, D5, DR5, DD5 )
CALL iau_ICRS2G ( DR, DD, DL, DB )
CALL iau_JD2CAL ( DJ1, DJ2, IY, IM, ID, FD, J )
CALL iau_JDCALF ( NDP, DJ1, DJ2, IY MDF, J )
CALL iau_LD ( BM, P, Q, E, EM, DLIM, P1 )
CALL iau_LDN ( N, B, OB, SC, SN )
CALL iau_LDSUN ( P, E, EM, P1 )
CALL iau_LTECEQ ( EPJ, DL, DB, DR, DD )
CALL iau_LTECM ( EPJ, RM ] )
CALL iau_LTEQEC ( EPJ, DR, DD, DL, DB )
CALL iau_LTP ( EPJ, RP )
CALL iau_LTPB ( EPJ, RPB )
CALL iau_LTPECL ( EPJ, VEC )
CALL iau_LTPEQU ( EPJ, VEQ )
CALL iau_NUM00A ( DATE1, DATE2, RMATN )
CALL iau_NUM00B ( DATE1, DATE2, RMATN )
CALL iau_NUM06A ( DATE1, DATE2, RMATN )
CALL iau_NUMAT ( EPSA, DPSI, DEPS, RMATN )
CALL iau_NUT00A ( DATE1, DATE2, DPSI, DEPS )
CALL iau_NUT00B ( DATE1, DATE2, DPSI, DEPS )
CALL iau_NUT06A ( DATE1, DATE2, DPSI, DEPS )
CALL iau_NUT80 ( DATE1, DATE2, DPSI, DEPS )
CALL iau_NUTM80 ( DATE1, DATE2, RMATN )
D = iau_OBL06 ( DATE1, DATE2 )
D = iau_OBL80 ( DATE1, DATE2 )
CALL iau_PB06 ( DATE1, DATE2, BZETA, BZ, BTHETA )
CALL iau_PFW06 ( DATE1, DATE2, GAMB, PHIB, PSIB, EPSA )
CALL iau_PLAN94 ( DATE1, DATE2, NP, PV, J )
CALL iau_PMAT00 ( DATE1, DATE2, RBP )
CALL iau_PMAT06 ( DATE1, DATE2, RBP )
CALL iau_PMAT76 ( DATE1, DATE2, RMATP )
CALL iau_PMPX ( RC, DC, PR, PD, PX, RV, PMT, POB, PCO )
CALL iau_PMSAFE ( RA1, DEC1, PMR1, PMD1, PX1, RV1,
:               EP1A, EP1B, EP2A, EP2B,
:               RA2, DEC2, PMR2, PMD2, PX2, RV2, J )
CALL iau_PN00 ( DATE1, DATE2, DPSI, DEPS,
:               EPSA, RB, RP, RBP, RN, RBPB )

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CALL iau_PN00A ( DATE1, DATE2,
:             DPSI, DEPS, EPSA, RB, RP, RBP, RN, RBPN )
CALL iau_PN00B ( DATE1, DATE2,
:             DPSI, DEPS, EPSA, RB, RP, RBP, RN, RBPN )
CALL iau_PN06 ( DATE1, DATE2, DPSI, DEPS,
:             EPSA, RB, RP, RBP, RN, RBPN )
CALL iau_PN06A ( DATE1, DATE2,
:             DPSI, DEPS, RB, RP, RBP, RN, RBPN )
CALL iau_PNM00A ( DATE1, DATE2, RBPN )
CALL iau_PNM00B ( DATE1, DATE2, RBPN )
CALL iau_PNM06A ( DATE1, DATE2, RNPB )
CALL iau_PNM80 ( DATE1, DATE2, RMATPN )
CALL iau_P06E ( DATE1, DATE2,
:             EPS0, PSIA, OMA, BPA, BQA, PIA, BPIA,
:             EPSA, CHIA, ZA, ZETAA, THETAA, PA, GAM, PHI, PSI )
CALL iau_POM00 ( XP, YP, SP, RPOM )
CALL iau_PR00 ( DATE1, DATE2, DPSIPR, DEPSPR )
CALL iau_PREC76 ( DATE01, DATE02, DATE11, DATE12, ZETA, Z, THETA )
CALL iau_PVSTAR ( PV, RA, DEC, PMR, PMD, PX, RV, J )
CALL iau_PVTOB ( ELONG, PHI, HM, XP, YP, SP, THETA, PV )
CALL iau_REFCO ( PHPA, TC, RH, WL, REFA, REFB )
D = iau_S00 ( DATE1, DATE2, X, Y )
D = iau_S00A ( DATE1, DATE2 )
D = iau_S00B ( DATE1, DATE2 )
D = iau_S06 ( DATE1, DATE2, X, Y )
D = iau_S06A ( DATE1, DATE2 )
D = iau_SP00 ( DATE1, DATE2 )
CALL iau_STARPM ( RA1, DEC1, PMR1, PMD1, PX1, RV1,
:             EP1A, EP1B, EP2A, EP2B,
:             RA2, DEC2, PMR2, PMD2, PX2, RV2, J )
CALL iau_STARPV ( RA, DEC, PMR, PMD, PX, RV, PV, J )
CALL iau_TAITT ( TAI1, TAI2, TT1, TT2, J )
CALL iau_TAIUT1 ( TAI1, TAI2, DTA, UT11, UT12, J )
CALL iau_TAIUTC ( TAI1, TAI2, UTC1, UTC2, J )
CALL iau_TCBTDB ( TCB1, TCB2, TDB1, TDB2, J )
CALL iau_TCGTT ( TCG1, TCG2, TT1, TT2, J )
CALL iau_TDBTCB ( TDB1, TDB2, TCB1, TCB2, J )
CALL iau_TDBTT ( TDB1, TDB2, DTR, TT1, TT2, J )
CALL iau_TTTAI ( TT1, TT2, TAI1, TAI2, J )
CALL iau_TTTCG ( TT1, TT2, TCG1, TCG2, J )
CALL iau_TTTDB ( TT1, TT2, DTR, TDB1, TDB2, J )
CALL iau_TTUT1 ( TT1, TT2, DT, UT11, UT12, J )
CALL iau_UT1TAI ( UT11, UT12, TAI1, TAI2, J )
CALL iau_UT1TT ( UT11, UT12, DT, TT1, TT2, J )
CALL iau_UT1UTC ( UT11, UT12, DUT, UTC1, UTC2, J )
CALL iau_UTCTAI ( UTC1, UTC2, DTA, TAI1, TAI2, J )
CALL iau_UTCUT1 ( UTC1, UTC2, DUT, UT11, UT12, J )
CALL iau_XY06 ( DATE1, DATE2, X, Y )
CALL iau_XYS00A ( DATE1, DATE2, X, Y, S )
CALL iau_XYS00B ( DATE1, DATE2, X, Y, S )
CALL iau_XYS06A ( DATE1, DATE2, X, Y, S )

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CALLS: C VERSION

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iauAb ( pnat, v, s, bml, ppr );
iauApcg ( datel, date2, eb, eh, &astrom );
iauApcg13 ( datel, date2, &astrom );
iauApci ( datel, date2, eb, eh, x, y, s, &astrom );
iauApci13 ( datel, date2, &astrom, &eo );
iauApco ( datel, date2, eb, eh, x, y, s,
theta, elong, phi, hm, xp, yp, sp,
refa, refb, &astrom );
i = iauApcol3 ( utc1, utc2, dut1, elong, phi, hm, xp, yp,
phpa, tc, rh, wl, &astrom, &eo );
iauApcs ( datel, date2, pv, eb, eh, &astrom );
iauApcs13 ( datel, date2, pv, &astrom );
iauAper ( theta, &astrom );
iauAper13 ( utl1, utl2, &astrom );
iauApio ( sp, theta, elong, phi, hm, xp, yp, refa, refb,
&astrom );
i = iauApiol3 ( utc1, utc2, dut1, elong, phi, hm, xp, yp,
phpa, tc, rh, wl, &astrom );

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iauAtci13 ( rc, dc, pr, pd, px, rv, datel, date2,
            &ri, &di, &eo );
iauAtciq  ( rc, dc, pr, pd, px, rv, &astrom, &ri, &di );
iauAtciqn ( rc, dc, pr, pd, px, rv, astrom, n, b, &ri, &di );
iauAtciqz ( rc, dc, &astrom, &ri, &di );
i = iauAtcol3 ( rc, dc, pr, pd, px, rv, utc1, utc2, dut1,
                elong, phi, hm, xp, yp, phpa, tc, rh, wl,
                aob, zob, hob, dob, rob, eo );
iauAtic13 ( ri, di, datel, date2, &rc, &dc, &eo );
iauAticq  ( ri, di, &astrom, &rc, &dc );
iauAtciqn ( ri, di, astrom, n, b, &rc, &dc );
i = iauAtiol3 ( ri, di, utc1, utc2, dut1, elong, phi, hm, xp, yp,
                phpa, tc, rh, wl, aob, zob, hob, dob, rob );
iauAtioq  ( ri, di, &astrom, &aob, &zob, &hob, &dob, &rob );
i = iauAtocl3 ( type, obl, ob2, utc1, utc2, dut1,
                elong, phi, hm, xp, yp, phpa, tc, rh, wl,
                &rc, &dc );
i = iauAtoil3 ( type, obl, ob2, utc1, utc2, dut1, elong, phi, hm,
                xp, yp, phpa, tc, rh, wl, &ri, &di );
iauAtoiq  ( type, obl, ob2, &astrom, &ri, &di );
iauBi00   ( &dpsibi, &depsbi, &dra );
iauBp00   ( datel, date2, rb, rp, rbp );
iauBp06   ( datel, date2, rb, rp, rbp );
iauBpn2xy ( rbpn, &x, &y );
iauC2i00a ( datel, date2, rc2i );
iauC2i00b ( datel, date2, rc2i );
iauC2i06a ( datel, date2, rc2i );
iauC2ibpn ( datel, date2, rbpn, rc2i );
iauC2ixy  ( datel, date2, x, y, rc2i );
iauC2ixys ( x, y, s, rc2i );
iauC2t00a ( tta, ttb, uta, utb, xp, yp, rc2t );
iauC2t00b ( tta, ttb, uta, utb, xp, yp, rc2t );
iauC2t06a ( tta, ttb, uta, utb, xp, yp, rc2t );
iauC2tcio ( rc2i, era, rpom, rc2t );
iauC2teqx ( rbpn, gst, rpom, rc2t );
iauC2tpe  ( tta, ttb, uta, utb, dps, deps, xp, yp, rc2t );
iauC2txy  ( tta, ttb, uta, utb, x, y, xp, yp, rc2t );
i = iauCal2jd ( iy, im, id, &djm0, &djm );
i = iauD2dtf ( scale, ndp, dl, d2, &iy, &im, &id, ihmsf );
i = iauDat   ( iy, im, id, fd, &deltat );
d = iauDtdb  ( datel, date2, ut, elong, u, v );
i = iauDtf2d ( scale, iy, im, id, ihr, imm, sec, &dl, &d2 );
iauEceq06  ( datel, date2, dl, db, &dr, &dd );
iauEcm06   ( datel, date2, rm );
d = iauEe00 ( datel, date2, epsa, dps );
d = iauEe00a ( datel, date2 );
d = iauEe00b ( datel, date2 );
d = iauEe06 ( datel, date2 );
d = iauEect00 ( datel, date2 );
i = iauEform ( n, &a, &f );
d = iauEo06 ( datel, date2 );
d = iauEors  ( rnpb, s );
d = iauEpb   ( dj1, dj2 );
iauEpb2jd   ( epb, &djm0, &djm );
d = iauEpj   ( dj1, dj2 );
iauEpj2jd   ( epj, &djm0, &djm );
i = iauEpv00 ( dj1, dj2, pvh, pvb );
iauEqec06   ( datel, date2, dr, dd, &dl, &db );
d = iauEqeq94 ( datel, date2 );
d = iauEra00 ( dj1, dj2 );
d = iauFad03 ( t );
d = iauFae03 ( t );
d = iauFaf03 ( t );
d = iauFaju03 ( t );
d = iauFal03 ( t );
d = iauFalp03 ( t );
d = iauFama03 ( t );
d = iauFame03 ( t );
d = iauFane03 ( t );
d = iauFaom03 ( t );
d = iauFapa03 ( t );
d = iauFasa03 ( t );
d = iauFaur03 ( t );

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d = iauFave03 ( t );
    iauFk52h ( r5, d5, dr5, dd5, px5, rv5,
              &rh, &dh, &drh, &ddh, &pxh, &rvh );
    iauFk5hip ( r5h, s5h );
    iauFk5hz ( r5, d5, datel, date2, &rh, &dh );
    iauFw2m ( gamb, phib, psi, eps, r );
    iauFw2xy ( gamb, phib, psi, eps, &x, &y );
    iauG2icrs ( dl, db, &dr, &dd );
i = iauGc2gd ( n, xyz, &elong, &phi, &height );
i = iauGc2gde ( a, f, xyz, &elong, &phi, &height );
i = iauGd2gc ( n, elong, phi, height, xyz );
i = iauGd2gce ( a, f, elong, phi, height, xyz );
d = iauGmst00 ( uta, utb, tta, ttb );
d = iauGmst06 ( uta, utb, tta, ttb );
d = iauGmst82 ( uta, utb );
d = iauGst00a ( uta, utb, tta, ttb );
d = iauGst00b ( uta, utb );
d = iauGst06 ( uta, utb, tta, ttb, rnpb );
d = iauGst06a ( uta, utb, tta, ttb );
d = iauGst94 ( uta, utb );
    iauH2fk5 ( rh, dh, drh, ddh, pxh, rvh,
              &r5, &d5, &dr5, &dd5, &px5, &rv5 );
    iauHfk5z ( rh, dh, datel, date2,
              &r5, &d5, &dr5, &dd5 );
    iauIcrs2g ( dr, dd, &dl, &db );
i = iauJd2cal ( dj1, dj2, &iy, &im, &id, &fd );
i = iauJdcalf ( ndp, dj1, dj2, iymdf );
    iauLd ( bm, p, q, e, em, dlim, pl );
    iauLdn ( n, b, ob, sc, sn );
    iauLdsun ( p, e, em, pl );
    iauLteceq ( epj, dl, db, &dr, &dd );
    iauLtecm ( epj, rm );
    iauLteqec ( epj, dr, dd, &dl, &db );
    iauLtp ( epj, rp );
    iauLtpb ( epj, rpb );
    iauLtpecl ( epj, vec );
    iauLtpequ ( epj, veq );
    iauNum00a ( datel, date2, rmatn );
    iauNum00b ( datel, date2, rmatn );
    iauNum06a ( datel, date2, rmatn );
    iauNumat ( epsa, dpsi, deps, rmatn );
    iauNut00a ( datel, date2, &dpsi, &deps );
    iauNut00b ( datel, date2, &dpsi, &deps );
    iauNut06a ( datel, date2, &dpsi, &deps );
    iauNut80 ( datel, date2, &dpsi, &deps );
    iauNutm80 ( datel, date2, rmatn );
d = iauObl06 ( datel, date2 );
d = iauObl80 ( datel, date2 );
    iauPb06 ( datel, date2, &bzeta, &bz, &btheta );
    iauPfw06 ( datel, date2, &gamb, &phib, &psib, &epsa );
i = iauPlan94 ( datel, date2, np, pv );
    iauPmat00 ( datel, date2, rbp );
    iauPmat06 ( datel, date2, rbp );
    iauPmat76 ( datel, date2, rmatp );
    iauPmpx ( rc, dc, pr, pd, px, rv, pmt, pob, pco );
i = iauPmsafe ( ral, decl, pmr1, pmd1, px1, rv1,
               epla, eplb, ep2a, ep2b,
               &ra2, &dec2, &pmr2, &pmd2, &px2, &rv2 );
    iauPn00 ( datel, date2, dpsi, deps,
            &epsa, rb, rp, rbp, rn, rbpn );
    iauPn00a ( datel, date2,
            &dpsi, &deps, &epsa, rb, rp, rbp, rn, rbpn );
    iauPn00b ( datel, date2,
            &dpsi, &deps, &epsa, rb, rp, rbp, rn, rbpn );
    iauPn06 ( datel, date2, dpsi, deps,
            &epsa, rb, rp, rbp, rn, rbpn );
    iauPn06a ( datel, date2,
            &dpsi, &deps, &epsa, rb, rp, rbp, rn, rbpn );
    iauPnm00a ( datel, date2, rbpn );
    iauPnm00b ( datel, date2, rbpn );
    iauPnm06a ( datel, date2, rnpb );
    iauPnm80 ( datel, date2, rmatpn );
    iauP06e ( datel, date2,

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&eps0, &psia, &oma, &bpa, &bqa, &pia, &bpia,
&epsa, &chia, &za, &zetaa, &thetaa, &pa,
&gam, &phi, &psi );
iauPom00 ( xp, yp, sp, rpom );
iauPr00 ( datel, date2, &dpsipr, &depspr );
iauPrec76 ( date01, date02, datel1, datel2, &zeta, &z, &theta );
i = iauPvstar ( pv, &ra, &dec, &pmr, &pmd, &px, &rv );
iauPvtob ( elong, phi, hm, xp, yp, sp, theta, pv );
iauRefco ( phpa, tc, rh, wl, refa, refb );
d = iauS00 ( datel, date2, x, y );
d = iauS00a ( datel, date2 );
d = iauS00b ( datel, date2 );
d = iauS06 ( datel, date2, x, y );
d = iauS06a ( datel, date2 );
d = iauSp00 ( datel, date2 );
i = iauStarpm ( ral, decl, pmr1, pmd1, px1, rv1,
ep1a, ep1b, ep2a, ep2b,
&ra2, &dec2, &pmr2, &pmd2, &px2, &rv2 );
i = iauStarpv ( ra, dec, pmr, pmd, px, rv, pv );
i = iauTaitt ( tail, tai2, &tt1, &tt2 );
i = iauTaiut1 ( tail, tai2, dta, &ut11, &ut12 );
i = iauTaiutc ( tail, tai2, &utc1, &utc2 );
i = iauTcbtdb ( tcb1, tcb2, &tdb1, &tdb2 );
i = iauTcgtdt ( tcg1, tcg2, &tt1, &tt2 );
i = iauTdbtdb ( tdb1, tdb2, &tcb1, &tcb2 );
i = iauTdbtdt ( tdb1, tdb2, dtr, &tt1, &tt2 );
i = iauTttai ( tt1, tt2, &tail, &tai2 );
i = iauTttcg ( tt1, tt2, &tcg1, &tcg2 );
i = iauTtttdb ( tt1, tt2, dtr, &tdb1, &tdb2 );
i = iauTttut1 ( tt1, tt2, dt, &ut11, &ut12 );
i = iauUtltai ( ut11, ut12, &tail, &tai2 );
i = iauUtltdt ( ut11, ut12, dt, &tt1, &tt2 );
i = iauUtlutc ( ut11, ut12, dut, &utc1, &utc2 );
i = iauUtctai ( utc1, utc2, dta, &tail, &tai2 );
i = iauUtcut1 ( utc1, utc2, dut, &ut11, &ut12 );
iauXy06 ( datel, date2, &x, &y );
iauXys00a ( datel, date2, &x, &y, &s );
iauXys00b ( datel, date2, &x, &y, &s );
iauXys06a ( datel, date2, &x, &y, &s );

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-----  
SOFA Vector/Matrix Library  
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## PREFACE

The routines described here comprise the SOFA vector/matrix library. Their general appearance and coding style conforms to conventions agreed by the SOFA Board, and their functions, names and algorithms have been ratified by the Board. Procedures for soliciting and agreeing additions to the library are still evolving.

## PROGRAMMING LANGUAGES

The SOFA routines are available in two programming languages at present: Fortran 77 and ANSI C.

There is a one-to-one relationship between the two language versions. The naming convention is such that a SOFA routine referred to generically as "EXAMPL" exists as a Fortran subprogram iau\_EXAMPL and a C function iauExempl. The calls for the two versions are very similar, with the same arguments in the same order. In a few cases, the C equivalent of a Fortran SUBROUTINE subprogram uses a return value rather than an argument.

## GENERAL PRINCIPLES

The library consists mostly of routines which operate on ordinary Cartesian vectors (x,y,z) and 3x3 rotation matrices. However, there is also support for vectors which represent velocity as well as position and vectors which represent rotation instead of position. The vectors which represent both position and velocity may be considered still to have dimensions (3), but to comprise elements each of which is two numbers, representing the value itself and the time derivative. Thus:

- \* "Position" or "p" vectors (or just plain 3-vectors) have dimension (3) in Fortran and [3] in C.
- \* "Position/velocity" or "pv" vectors have dimensions (3,2) in Fortran and [2][3] in C.
- \* "Rotation" or "r" matrices have dimensions (3,3) in Fortran and [3][3] in C. When used for rotation, they are "orthogonal"; the inverse of such a matrix is equal to the transpose. Most of the routines in this library do not assume that r-matrices are necessarily orthogonal and in fact work on any 3x3 matrix.
- \* "Rotation" or "r" vectors have dimensions (3) in Fortran and [3] in C. Such vectors are a combination of the Euler axis and angle and are convertible to and from r-matrices. The direction is the axis of rotation and the magnitude is the angle of rotation, in radians. Because the amount of rotation can be scaled up and down simply by multiplying the vector by a scalar, r-vectors are useful for representing spins about an axis which is fixed.
- \* The above rules mean that in terms of memory address, the three velocity components of a pv-vector follow the three position components. Application code is permitted to exploit this and all other knowledge of the internal layouts: that x, y and z appear in that order and are in a right-handed Cartesian coordinate system etc. For example, the cp function (copy a p-vector) can be used to copy the velocity component of a pv-vector (indeed, this is how the CPV routine is coded).
- \* The routines provided do not completely fill the range of operations that link all the various vector and matrix options, but are confined to functions that are required by other parts of the SOFA software or which are likely to prove useful.

In addition to the vector/matrix routines, the library contains some routines related to spherical angles, including conversions to and from sexagesimal format.

Using the library requires knowledge of vector/matrix methods, spherical trigonometry, and methods of attitude representation. These topics are covered in many textbooks, including "Spacecraft Attitude Determination and Control", James R. Wertz (ed.), Astrophysics and Space Science Library, Vol. 73, D. Reidel Publishing Company, 1986.

#### OPERATIONS INVOLVING P-VECTORS AND R-MATRICES

##### Initialize

ZP	zero p-vector
ZR	initialize r-matrix to null
IR	initialize r-matrix to identity

##### Copy/extend/extract

CP	copy p-vector
CR	copy r-matrix

##### Build rotations

RX	rotate r-matrix about x
RY	rotate r-matrix about y
RZ	rotate r-matrix about z

##### Spherical/Cartesian conversions

S2C	spherical to unit vector
C2S	unit vector to spherical
S2P	spherical to p-vector
P2S	p-vector to spherical

##### Operations on vectors

PPP	p-vector plus p-vector
PMP	p-vector minus p-vector
PPSP	p-vector plus scaled p-vector
PDP	inner (=scalar=dot) product of two p-vectors
PXP	outer (=vector=cross) product of two p-vectors
PM	modulus of p-vector
PN	normalize p-vector returning modulus
SXP	multiply p-vector by scalar

##### Operations on matrices

RXR	r-matrix multiply
TR	transpose r-matrix

##### Matrix-vector products

RXP	product of r-matrix and p-vector
TRXP	product of transpose of r-matrix and p-vector

##### Separation and position-angle

SEPP	angular separation from p-vectors
SEPS	angular separation from spherical coordinates
PAP	position-angle from p-vectors
PAS	position-angle from spherical coordinates

##### Rotation vectors

RV2M	r-vector to r-matrix
RM2V	r-matrix to r-vector

#### OPERATIONS INVOLVING PV-VECTORS

## Initialize

ZPV            zero pv-vector

## Copy/extend/extract

CPV            copy pv-vector  
P2PV           append zero velocity to p-vector  
PV2P           discard velocity component of pv-vector

## Spherical/Cartesian conversions

S2PV           spherical to pv-vector  
PV2S           pv-vector to spherical

## Operations on vectors

PVPPV          pv-vector plus pv-vector  
PVMPV          pv-vector minus pv-vector  
PVDPV          inner (=scalar=dot) product of two pv-vectors  
PVXPV          outer (=vector=cross) product of two pv-vectors  
PVM            modulus of pv-vector  
SXPV           multiply pv-vector by scalar  
S2XPV          multiply pv-vector by two scalars  
PVU            update pv-vector  
PVUP           update pv-vector discarding velocity

## Matrix-vector products

RXPV           product of r-matrix and pv-vector  
TRXPV          product of transpose of r-matrix and pv-vector

## OPERATIONS ON ANGLES

ANP            normalize radians to range 0 to 2pi  
ANPM           normalize radians to range -pi to +pi  
A2TF           decompose radians into hours, minutes, seconds  
A2AF           decompose radians into degrees, arcminutes, arcseconds  
AF2A           degrees, arcminutes, arcseconds to radians  
D2TF           decompose days into hours, minutes, seconds  
TF2A           hours, minutes, seconds to radians  
TF2D           hours, minutes, seconds to days

## CALLS: FORTRAN VERSION

CALL iau\_A2AF ( NDP, ANGLE, SIGN, IDMSF )  
CALL iau\_A2TF ( NDP, ANGLE, SIGN, IHMSF )  
CALL iau\_AF2A ( S, IDEG, IAMIN, ASEC, RAD, J )  
D = iau\_ANP ( A )  
D = iau\_ANPM ( A )  
CALL iau\_C2S ( P, THETA, PHI )  
CALL iau\_CP ( P, C )  
CALL iau\_CPV ( PV, C )  
CALL iau\_CR ( R, C )  
CALL iau\_D2TF ( NDP, DAYS, SIGN, IHMSF )  
CALL iau\_IR ( R )  
CALL iau\_P2PV ( P, PV )  
CALL iau\_P2S ( P, THETA, PHI, R )  
CALL iau\_PAP ( A, B, THETA )  
CALL iau\_PAS ( AL, AP, BL, BP, THETA )  
CALL iau\_PDP ( A, B, ADB )  
CALL iau\_PM ( P, R )  
CALL iau\_PMP ( A, B, AMB )  
CALL iau\_PN ( P, R, U )  
CALL iau\_PPP ( A, B, APB )  
CALL iau\_PPSP ( A, S, B, APSB )  
CALL iau\_PV2P ( PV, P )  
CALL iau\_PV2S ( PV, THETA, PHI, R, TD, PD, RD )  
CALL iau\_PVDPV ( A, B, ADB )  
CALL iau\_PVM ( PV, R, S )  
CALL iau\_PVMPV ( A, B, AMB )

```

CALL iau_PVPPV ( A, B, APB )
CALL iau_PVU   ( DT, PV, UPV )
CALL iau_PVUP  ( DT, PV, P )
CALL iau_PVXPV ( A, B, AXB )
CALL iau_PXP   ( A, B, AXB )
CALL iau_RM2V  ( R, P )
CALL iau_RV2M  ( P, R )
CALL iau_RX    ( PHI, R )
CALL iau_RXP   ( R, P, RP )
CALL iau_RXPV  ( R, PV, RPV )
CALL iau_RXR   ( A, B, ATB )
CALL iau_RY    ( THETA, R )
CALL iau_RZ    ( PSI, R )
CALL iau_S2C   ( THETA, PHI, C )
CALL iau_S2P   ( THETA, PHI, R, P )
CALL iau_S2PV  ( THETA, PHI, R, TD, PD, RD, PV )
CALL iau_S2XPV ( S1, S2, PV )
CALL iau_SEPP  ( A, B, S )
CALL iau_SEPS  ( AL, AP, BL, BP, S )
CALL iau_SXP   ( S, P, SP )
CALL iau_SXPV  ( S, PV, SPV )
CALL iau_TF2A  ( S, IHOURL, IMIN, SEC, RAD, J )
CALL iau_TF2D  ( S, IHOURL, IMIN, SEC, DAYS, J )
CALL iau_TR    ( R, RT )
CALL iau_TRXP  ( R, P, TRP )
CALL iau_TRXPV ( R, PV, TRPV )
CALL iau_ZP    ( P )
CALL iau_ZPV   ( PV )
CALL iau_ZR    ( R )

```

CALLS: C VERSION

```

        iauA2af ( ndp, angle, &sign, idmsf );
        iauA2tf ( ndp, angle, &sign, ihmsf );
i = iauAf2a ( s, ideg, iamin, asec, &rad );
d = iauAnp ( a );
d = iauAnpm ( a );
        iauC2s ( p, &theta, &phi );
        iauCp ( p, c );
        iauCpv ( pv, c );
        iauCr ( r, c );
        iauD2tf ( ndp, days, &sign, ihmsf );
        iauIr ( r );
        iauP2pv ( p, pv );
        iauP2s ( p, &theta, &phi, &r );
d = iauPap ( a, b );
d = iauPas ( al, ap, bl, bp );
d = iauPdp ( a, b );
d = iauPm ( p );
        iauPmp ( a, b, amb );
        iauPn ( p, &r, u );
        iauPpp ( a, b, apb );
        iauPpsp ( a, s, b, apsb );
        iauPv2p ( pv, p );
        iauPv2s ( pv, &theta, &phi, &r, &td, &pd, &rd );
        iauPvdpv ( a, b, adb );
        iauPvm ( pv, &r, &s );
        iauPvmpv ( a, b, amb );
        iauPvppv ( a, b, apb );
        iauPvu ( dt, pv, upv );
        iauPvup ( dt, pv, p );
        iauPvxp ( a, b, axb );
        iauPxp ( a, b, axb );
        iauRm2v ( r, p );
        iauRv2m ( p, r );
        iauRx ( phi, r );
        iauRxp ( r, p, rp );
        iauRxp ( r, pv, rpv );
        iauRxr ( a, b, atb );
        iauRy ( theta, r );
        iauRz ( psi, r );
        iauS2c ( theta, phi, c );

```

```
    iauS2p   ( theta, phi, r, p );
    iauS2pv  ( theta, phi, r, td, pd, rd, pV );
    iauS2xpv ( s1, s2, pv );
d = iauSepp ( a, b );
d = iauSeps ( al, ap, bl, bp );
    iauSxp   ( s, p, sp );
    iauSxpv  ( s, pv, spv );
i = iauTf2a ( s, ihour, imin, sec, &rad );
i = iauTf2d ( s, ihour, imin, sec, &days );
    iauTr    ( r, rt );
    iauTrxp  ( r, p, trp );
    iauTrxpv ( r, pv, trpv );
    iauZp    ( p );
    iauZpv   ( pv );
    iauZr    ( r );
```

```

void iauA2af(int ndp, double angle, char *sign, int idmsf[4])
/*
**  - - - - -
**  i a u A 2 a f
**  - - - - -
**
**  Decompose radians into degrees, arcminutes, arcseconds, fraction.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    ndp      int      resolution (Note 1)
**    angle    double   angle in radians
**
**  Returned:
**    sign     char     '+' or '-'
**    idmsf    int[4]   degrees, arcminutes, arcseconds, fraction
**
**  Called:
**    iauD2tf      decompose days to hms
**
**  Notes:
**
**  1) The argument ndp is interpreted as follows:
**
**      ndp      resolution
**      :      ...0000 00 00
**      -7      1000 00 00
**      -6      100 00 00
**      -5      10 00 00
**      -4      1 00 00
**      -3      0 10 00
**      -2      0 01 00
**      -1      0 00 10
**      0       0 00 01
**      1       0 00 00.1
**      2       0 00 00.01
**      3       0 00 00.001
**      :       0 00 00.000...
**
**  2) The largest positive useful value for ndp is determined by the
**  size of angle, the format of doubles on the target platform, and
**  the risk of overflowing idmsf[3].  On a typical platform, for
**  angle up to 2pi, the available floating-point precision might
**  correspond to ndp=12.  However, the practical limit is typically
**  ndp=9, set by the capacity of a 32-bit int, or ndp=4 if int is
**  only 16 bits.
**
**  3) The absolute value of angle may exceed 2pi.  In cases where it
**  does not, it is up to the caller to test for and handle the
**  case where angle is very nearly 2pi and rounds up to 360 degrees,
**  by testing for idmsf[0]=360 and setting idmsf[0-3] to zero.
**
*/

```

```

void iauA2tf(int ndp, double angle, char *sign, int ihmsf[4])
/*
**  - - - - -
**  i a u A 2 t f
**  - - - - -
**
**  Decompose radians into hours, minutes, seconds, fraction.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    ndp      int      resolution (Note 1)
**    angle    double   angle in radians
**
**  Returned:
**    sign     char     '+' or '-'
**    ihmsf    int[4]   hours, minutes, seconds, fraction
**
**  Called:
**    iauD2tf      decompose days to hms
**
**  Notes:
**
**  1) The argument ndp is interpreted as follows:
**
**      ndp      resolution
**      :      ...0000 00 00
**      -7      1000 00 00
**      -6      100 00 00
**      -5      10 00 00
**      -4      1 00 00
**      -3      0 10 00
**      -2      0 01 00
**      -1      0 00 10
**      0       0 00 01
**      1       0 00 00.1
**      2       0 00 00.01
**      3       0 00 00.001
**      :       0 00 00.000...
**
**  2) The largest positive useful value for ndp is determined by the
**  size of angle, the format of doubles on the target platform, and
**  the risk of overflowing ihmsf[3].  On a typical platform, for
**  angle up to 2pi, the available floating-point precision might
**  correspond to ndp=12.  However, the practical limit is typically
**  ndp=9, set by the capacity of a 32-bit int, or ndp=4 if int is
**  only 16 bits.
**
**  3) The absolute value of angle may exceed 2pi.  In cases where it
**  does not, it is up to the caller to test for and handle the
**  case where angle is very nearly 2pi and rounds up to 24 hours,
**  by testing for ihmsf[0]=24 and setting ihmsf[0-3] to zero.
**
**  */

```

```

void iauAb(double pnat[3], double v[3], double s, double bml,
           double ppr[3])
/*
**   - - - - -
**   i a u A b
**   - - - - -
**
**   Apply aberration to transform natural direction into proper
**   direction.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     pnat   double[3]   natural direction to the source (unit vector)
**     v      double[3]   observer barycentric velocity in units of c
**     s      double     distance between the Sun and the observer (au)
**     bml    double     sqrt(1-|v|^2): reciprocal of Lorentz factor
**
**   Returned:
**     ppr    double[3]   proper direction to source (unit vector)
**
**   Notes:
**
**   1) The algorithm is based on Expr. (7.40) in the Explanatory
**      Supplement (Urban & Seidelmann 2013), but with the following
**      changes:
**
**      o Rigorous rather than approximate normalization is applied.
**
**      o The gravitational potential term from Expr. (7) in
**        Klioner (2003) is added, taking into account only the Sun's
**        contribution. This has a maximum effect of about
**        0.4 microarcsecond.
**
**   2) In almost all cases, the maximum accuracy will be limited by the
**      supplied velocity. For example, if the SOFA iauEpv00 function is
**      used, errors of up to 5 microarcseconds could occur.
**
**   References:
**
**     Urban, S. & Seidelmann, P. K. (eds), Explanatory Supplement to
**     the Astronomical Almanac, 3rd ed., University Science Books
**     (2013).
**
**     Klioner, Sergei A., "A practical relativistic model for micro-
**     arcsecond astrometry in space", Astr. J. 125, 1580-1597 (2003).
**
**   Called:
**     iauPdp      scalar product of two p-vectors
**
*/

```

```

int iauAf2a(char s, int ideg, int iamin, double asec, double *rad)
/*
**  - - - - -
**  i a u A f 2 a
**  - - - - -
**
**  Convert degrees, arcminutes, arcseconds to radians.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    s          char    sign:  '-' = negative, otherwise positive
**    ideg       int     degrees
**    iamin      int     arcminutes
**    asec       double  arcseconds
**
**  Returned:
**    rad        double  angle in radians
**
**  Returned (function value):
**    int        status:  0 = OK
**                      1 = ideg outside range 0-359
**                      2 = iamin outside range 0-59
**                      3 = asec outside range 0-59.999...
**
**  Notes:
**
**  1)  The result is computed even if any of the range checks fail.
**
**  2)  Negative ideg, iamin and/or asec produce a warning status, but
**      the absolute value is used in the conversion.
**
**  3)  If there are multiple errors, the status value reflects only the
**      first, the smallest taking precedence.
**
*/

```

```
double iauAnp(double a)
/*
**  - - - - -
**   i a u A n p
**  - - - - -
**
**  Normalize angle into the range  $0 \leq a < 2\pi$ .
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    a          double      angle (radians)
**
**  Returned (function value):
**    double     angle in range 0-2pi
**
**/
```

```
double iauAnpm(double a)
/*
**  - - - - -
**   i a u A n p m
**  - - - - -
**
**  Normalize angle into the range  $-\pi \leq a < +\pi$ .
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    a          double      angle (radians)
**
**  Returned (function value):
**    double     angle in range  $\pm\pi$ 
**
**/
```

```

void iauApcg(double date1, double date2,
             double ebpv[2][3], double ehp[3],
             iauASTROM *astrom)
/*
**   - - - - -
**   i a u A p c g
**   - - - - -
**
**   For a geocentric observer, prepare star-independent astrometry
**   parameters for transformations between ICRS and GCRS coordinates.
**   The Earth ephemeris is supplied by the caller.
**
**   The parameters produced by this function are required in the
**   parallax, light deflection and aberration parts of the astrometric
**   transformation chain.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status: support function.
**
**   Given:
**     date1 double      TDB as a 2-part...
**     date2 double      ...Julian Date (Note 1)
**     ebpv  double[2][3] Earth barycentric pos/vel (au, au/day)
**     ehp   double[3]   Earth heliocentric position (au)
**
**   Returned:
**     astrom iauASTROM* star-independent astrometry parameters:
**     pmt    double     PM time interval (SSB, Julian years)
**     eb     double[3]   SSB to observer (vector, au)
**     eh     double[3]   Sun to observer (unit vector)
**     em     double     distance from Sun to observer (au)
**     v      double[3]   barycentric observer velocity (vector, c)
**     bml    double     sqrt(1-|v|^2): reciprocal of Lorentz factor
**     bpn    double[3][3] bias-precession-nutation matrix
**     along  double     unchanged
**     xpl    double     unchanged
**     ypl    double     unchanged
**     sphi   double     unchanged
**     cphi   double     unchanged
**     diurab double     unchanged
**     eral   double     unchanged
**     refa   double     unchanged
**     refb   double     unchanged
**
**   Notes:
**
**   1) The TDB date date1+date2 is a Julian Date, apportioned in any
**   convenient way between the two arguments. For example,
**   JD(TDB)=2450123.7 could be expressed in any of these ways, among
**   others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0        -1421.3        (J2000 method)
**           2400000.5         50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in cases
**   where the loss of several decimal digits of resolution is
**   acceptable. The J2000 method is best matched to the way the
**   argument is handled internally and will deliver the optimum
**   resolution. The MJD method and the date & time methods are both
**   good compromises between resolution and convenience. For most
**   applications of this function the choice will not be at all
**   critical.
**
**   TT can be used instead of TDB without any significant impact on
**   accuracy.

```

```

**
** 2) All the vectors are with respect to BCRS axes.
**
** 3) This is one of several functions that inserts into the astrom
** structure star-independent parameters needed for the chain of
** astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
** The various functions support different classes of observer and
** portions of the transformation chain:
**
**      functions          observer          transformation
**
**      iauApcg iauApcg13   geocentric      ICRS <-> GCRS
**      iauApci iauApci13   terrestrial    ICRS <-> CIRS
**      iauApc0 iauApc013   terrestrial    ICRS <-> observed
**      iauApcs iauApcs13   space          ICRS <-> GCRS
**      iauAper iauAper13   terrestrial    update Earth rotation
**      iauApio iauApio13   terrestrial    CIRS <-> observed
**
** Those with names ending in "13" use contemporary SOFA models to
** compute the various ephemerides. The others accept ephemerides
** supplied by the caller.
**
** The transformation from ICRS to GCRS covers space motion,
** parallax, light deflection, and aberration. From GCRS to CIRS
** comprises frame bias and precession-nutation. From CIRS to
** observed takes account of Earth rotation, polar motion, diurnal
** aberration and parallax (unless subsumed into the ICRS <-> GCRS
** transformation), and atmospheric refraction.
**
** 4) The context structure astrom produced by this function is used by
** iauAtciq* and iauAticq*.
**
** Called:
**      iauApcs          astrometry parameters, ICRS-GCRS, space observer
**
*/

```

```

void iauApcg13(double date1, double date2, iauASTROM *astrom)
/*
**   - - - - -
**   i a u A p c g 1 3
**   - - - - -
**
**   For a geocentric observer, prepare star-independent astrometry
**   parameters for transformations between ICRS and GCRS coordinates.
**   The caller supplies the date, and SOFA models are used to predict
**   the Earth ephemeris.
**
**   The parameters produced by this function are required in the
**   parallax, light deflection and aberration parts of the astrometric
**   transformation chain.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     date1  double      TDB as a 2-part...
**     date2  double      ...Julian Date (Note 1)
**
**   Returned:
**     astrom iauASTROM*  star-independent astrometry parameters:
**     pmt    double      PM time interval (SSB, Julian years)
**     eb     double[3]    SSB to observer (vector, au)
**     eh     double[3]    Sun to observer (unit vector)
**     em     double      distance from Sun to observer (au)
**     v      double[3]    barycentric observer velocity (vector, c)
**     bml    double      sqrt(1-|v|^2): reciprocal of Lorenz factor
**     bpn    double[3][3] bias-precession-nutation matrix
**     along  double      unchanged
**     xpl    double      unchanged
**     ypl    double      unchanged
**     sphl   double      unchanged
**     cphi   double      unchanged
**     diurab double      unchanged
**     eral   double      unchanged
**     refa   double      unchanged
**     refb   double      unchanged
**
**   Notes:
**
**   1) The TDB date date1+date2 is a Julian Date, apportioned in any
**   convenient way between the two arguments.  For example,
**   JD(TDB)=2450123.7 could be expressed in any of these ways, among
**   others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
**   The JD method is the most natural and convenient to use in cases
**   where the loss of several decimal digits of resolution is
**   acceptable.  The J2000 method is best matched to the way the
**   argument is handled internally and will deliver the optimum
**   resolution.  The MJD method and the date & time methods are both
**   good compromises between resolution and convenience.  For most
**   applications of this function the choice will not be at all
**   critical.
**
**   TT can be used instead of TDB without any significant impact on
**   accuracy.
**
**   2) All the vectors are with respect to BCRS axes.
**

```

```

** 3) In cases where the caller wishes to supply his own Earth
** ephemeris, the function iauApcg can be used instead of the present
** function.
**
** 4) This is one of several functions that inserts into the astrom
** structure star-independent parameters needed for the chain of
** astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
** The various functions support different classes of observer and
** portions of the transformation chain:
**
**          functions          observer          transformation
**
**          iauApcg iauApcg13    geocentric    ICRS <-> GCRS
**          iauApci iauApci13    terrestrial    ICRS <-> CIRS
**          iauApc0 iauApc013    terrestrial    ICRS <-> observed
**          iauApcs iauApcs13    space          ICRS <-> GCRS
**          iauAper iauAper13    terrestrial    update Earth rotation
**          iauApio iauApio13    terrestrial    CIRS <-> observed
**
** Those with names ending in "13" use contemporary SOFA models to
** compute the various ephemerides. The others accept ephemerides
** supplied by the caller.
**
** The transformation from ICRS to GCRS covers space motion,
** parallax, light deflection, and aberration. From GCRS to CIRS
** comprises frame bias and precession-nutation. From CIRS to
** observed takes account of Earth rotation, polar motion, diurnal
** aberration and parallax (unless subsumed into the ICRS <-> GCRS
** transformation), and atmospheric refraction.
**
** 5) The context structure astrom produced by this function is used by
** iauAtciq* and iauAticq*.
**
** Called:
** iauEpv00      Earth position and velocity
** iauApcg      astrometry parameters, ICRS-GCRS, geocenter
**
** /

```

```

void iauApci(double date1, double date2,
            double ebpv[2][3], double ehp[3],
            double x, double y, double s,
            iauASTROM *astrom)
/*
**  - - - - -
**    i a u A p c i
**  - - - - -
**
**  For a terrestrial observer, prepare star-independent astrometry
**  parameters for transformations between ICRS and geocentric CIRS
**  coordinates. The Earth ephemeris and CIP/CIO are supplied by the
**  caller.
**
**  The parameters produced by this function are required in the
**  parallax, light deflection, aberration, and bias-precession-nutation
**  parts of the astrometric transformation chain.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards of Fundamental Astronomy) software collection.
**
**  Status: support function.
**
**  Given:
**    date1 double      TDB as a 2-part...
**    date2 double      ...Julian Date (Note 1)
**    ebpv  double[2][3] Earth barycentric position/velocity (au, au/day)
**    ehp   double[3]   Earth heliocentric position (au)
**    x,y   double      CIP X,Y (components of unit vector)
**    s     double      the CIO locator s (radians)
**
**  Returned:
**    astrom iauASTROM* star-independent astrometry parameters:
**    pmt   double      PM time interval (SSB, Julian years)
**    eb    double[3]   SSB to observer (vector, au)
**    eh    double[3]   Sun to observer (unit vector)
**    em    double      distance from Sun to observer (au)
**    v     double[3]   barycentric observer velocity (vector, c)
**    bml   double      sqrt(1-|v|^2): reciprocal of Lorenz factor
**    bpn   double[3][3] bias-precession-nutation matrix
**    along double      unchanged
**    xpl   double      unchanged
**    ypl   double      unchanged
**    sphi  double      unchanged
**    cphi  double      unchanged
**    diurab double     unchanged
**    eral  double      unchanged
**    refa  double      unchanged
**    refb  double      unchanged
**
**  Notes:
**
**  1) The TDB date date1+date2 is a Julian Date, apportioned in any
**  convenient way between the two arguments. For example,
**  JD(TDB)=2450123.7 could be expressed in any of these ways, among
**  others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2       (MJD method)
**          2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in cases
**  where the loss of several decimal digits of resolution is
**  acceptable. The J2000 method is best matched to the way the
**  argument is handled internally and will deliver the optimum
**  resolution. The MJD method and the date & time methods are both
**  good compromises between resolution and convenience. For most
**  applications of this function the choice will not be at all

```

```

**      critical.
**
**      TT can be used instead of TDB without any significant impact on
**      accuracy.
**
**      2) All the vectors are with respect to BCRS axes.
**
**      3) In cases where the caller does not wish to provide the Earth
**      ephemeris and CIP/CIO, the function iauApci13 can be used instead
**      of the present function. This computes the required quantities
**      using other SOFA functions.
**
**      4) This is one of several functions that inserts into the astrom
**      structure star-independent parameters needed for the chain of
**      astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
**      The various functions support different classes of observer and
**      portions of the transformation chain:
**
**      functions          observer          transformation
**
**      iauApcg iauApcg13   geocentric      ICRS <-> GCRS
**      iauApci iauApci13   terrestrial     ICRS <-> CIRS
**      iauApc0 iauApc013   terrestrial     ICRS <-> observed
**      iauApcs iauApcs13   space           ICRS <-> GCRS
**      iauAper iauAper13   terrestrial     update Earth rotation
**      iauApio iauApio13   terrestrial     CIRS <-> observed
**
**      Those with names ending in "13" use contemporary SOFA models to
**      compute the various ephemerides. The others accept ephemerides
**      supplied by the caller.
**
**      The transformation from ICRS to GCRS covers space motion,
**      parallax, light deflection, and aberration. From GCRS to CIRS
**      comprises frame bias and precession-nutation. From CIRS to
**      observed takes account of Earth rotation, polar motion, diurnal
**      aberration and parallax (unless subsumed into the ICRS <-> GCRS
**      transformation), and atmospheric refraction.
**
**      5) The context structure astrom produced by this function is used by
**      iauAtciq* and iauAticq*.
**
**      Called:
**      iauApcg          astrometry parameters, ICRS-GCRS, geocenter
**      iauC2ixys        celestial-to-intermediate matrix, given X,Y and s
**
*/

```

```

void iauApci13(double date1, double date2,
               iauASTROM *astrom, double *eo)
/*
** -----
**   i a u A p c i 1 3
** -----
**
** For a terrestrial observer, prepare star-independent astrometry
** parameters for transformations between ICRS and geocentric CIRS
** coordinates. The caller supplies the date, and SOFA models are used
** to predict the Earth ephemeris and CIP/CIO.
**
** The parameters produced by this function are required in the
** parallax, light deflection, aberration, and bias-precession-nutation
** parts of the astrometric transformation chain.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1 double      TDB as a 2-part...
**   date2 double      ...Julian Date (Note 1)
**
** Returned:
**   astrom iauASTROM* star-independent astrometry parameters:
**   pmt double        PM time interval (SSB, Julian years)
**   eb double[3]      SSB to observer (vector, au)
**   eh double[3]      Sun to observer (unit vector)
**   em double         distance from Sun to observer (au)
**   v double[3]       barycentric observer velocity (vector, c)
**   bm1 double        sqrt(1-|v|^2): reciprocal of Lorentz factor
**   bpn double[3][3]  bias-precession-nutation matrix
**   along double      unchanged
**   xpl double         unchanged
**   ypl double         unchanged
**   sphl double        unchanged
**   cphi double        unchanged
**   diurab double     unchanged
**   eral double        unchanged
**   refa double        unchanged
**   refb double        unchanged
**   eo double*        equation of the origins (ERA-GST)
**
** Notes:
**
** 1) The TDB date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TDB)=2450123.7 could be expressed in any of these ways, among
** others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable. The J2000 method is best matched to the way the
** argument is handled internally and will deliver the optimum
** resolution. The MJD method and the date & time methods are both
** good compromises between resolution and convenience. For most
** applications of this function the choice will not be at all
** critical.
**
** TT can be used instead of TDB without any significant impact on
** accuracy.
**

```

```

** 2) All the vectors are with respect to BCRS axes.
**
** 3) In cases where the caller wishes to supply his own Earth
** ephemeris and CIP/CIO, the function iauApci can be used instead
** of the present function.
**
** 4) This is one of several functions that inserts into the astrom
** structure star-independent parameters needed for the chain of
** astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
** The various functions support different classes of observer and
** portions of the transformation chain:
**
**          functions          observer          transformation
**
**          iauApcg iauApcg13   geocentric    ICRS <-> GCRS
**          iauApci iauApci13   terrestrial   ICRS <-> CIRS
**          iauApcO iauApcO13   terrestrial   ICRS <-> observed
**          iauApcs iauApcs13   space         ICRS <-> GCRS
**          iauAper iauAper13   terrestrial   update Earth rotation
**          iauApio iauApio13   terrestrial   CIRS <-> observed
**
** Those with names ending in "13" use contemporary SOFA models to
** compute the various ephemerides. The others accept ephemerides
** supplied by the caller.
**
** The transformation from ICRS to GCRS covers space motion,
** parallax, light deflection, and aberration. From GCRS to CIRS
** comprises frame bias and precession-nutation. From CIRS to
** observed takes account of Earth rotation, polar motion, diurnal
** aberration and parallax (unless subsumed into the ICRS <-> GCRS
** transformation), and atmospheric refraction.
**
** 5) The context structure astrom produced by this function is used by
** iauAtciq* and iauAticq*.
**
** Called:
** iauEpv00      Earth position and velocity
** iauPnm06a    classical NPB matrix, IAU 2006/2000A
** iauBpn2xy    extract CIP X,Y coordinates from NPB matrix
** iauS06       the CIO locator s, given X,Y, IAU 2006
** iauApci      astrometry parameters, ICRS-CIRS
** iauEors      equation of the origins, given NPB matrix and s
**
*/

```

```

void iauApco(double date1, double date2,
             double ebpv[2][3], double ehp[3],
             double x, double y, double s, double theta,
             double elong, double phi, double hm,
             double xp, double yp, double sp,
             double refa, double refb,
             iauASTROM *astrom)

/*
**      - - - - -
**      i a u A p c o
**      - - - - -
**
** For a terrestrial observer, prepare star-independent astrometry
** parameters for transformations between ICRS and observed
** coordinates. The caller supplies the Earth ephemeris, the Earth
** rotation information and the refraction constants as well as the
** site coordinates.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1 double      TDB as a 2-part...
**   date2 double      ...Julian Date (Note 1)
**   ebpv  double[2][3] Earth barycentric PV (au, au/day, Note 2)
**   ehp   double[3]   Earth heliocentric P (au, Note 2)
**   x,y   double      CIP X,Y (components of unit vector)
**   s     double      the CIO locator s (radians)
**   theta double      Earth rotation angle (radians)
**   elong double      longitude (radians, east +ve, Note 3)
**   phi   double      latitude (geodetic, radians, Note 3)
**   hm    double      height above ellipsoid (m, geodetic, Note 3)
**   xp,yp double      polar motion coordinates (radians, Note 4)
**   sp    double      the TIO locator s' (radians, Note 4)
**   refa  double      refraction constant A (radians, Note 5)
**   refb  double      refraction constant B (radians, Note 5)
**
** Returned:
**   astrom iauASTROM* star-independent astrometry parameters:
**   pmt    double      PM time interval (SSB, Julian years)
**   eb     double[3]   SSB to observer (vector, au)
**   eh     double[3]   Sun to observer (unit vector)
**   em     double      distance from Sun to observer (au)
**   v      double[3]   barycentric observer velocity (vector, c)
**   bml    double      sqrt(1-|v|^2): reciprocal of Lorentz factor
**   bpn    double[3][3] bias-precession-nutation matrix
**   along  double      longitude + s' (radians)
**   xpl    double      polar motion xp wrt local meridian (radians)
**   ypl    double      polar motion yp wrt local meridian (radians)
**   sphl   double      sine of geodetic latitude
**   cphi   double      cosine of geodetic latitude
**   diurab double      magnitude of diurnal aberration vector
**   eral   double      "local" Earth rotation angle (radians)
**   refa   double      refraction constant A (radians)
**   refb   double      refraction constant B (radians)
**
** Notes:
**
** 1) The TDB date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TDB)=2450123.7 could be expressed in any of these ways, among
** others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)

```

```

**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable. The J2000 method is best matched to the way the
** argument is handled internally and will deliver the optimum
** resolution. The MJD method and the date & time methods are both
** good compromises between resolution and convenience. For most
** applications of this function the choice will not be at all
** critical.
**
** TT can be used instead of TDB without any significant impact on
** accuracy.
**
** 2) The vectors eb, eh, and all the astrom vectors, are with respect
** to BCRS axes.
**
** 3) The geographical coordinates are with respect to the WGS84
** reference ellipsoid. TAKE CARE WITH THE LONGITUDE SIGN
** CONVENTION: the longitude required by the present function is
** right-handed, i.e. east-positive, in accordance with geographical
** convention.
**
** 4) xp and yp are the coordinates (in radians) of the Celestial
** Intermediate Pole with respect to the International Terrestrial
** Reference System (see IERS Conventions), measured along the
** meridians 0 and 90 deg west respectively. sp is the TIO locator
** s', in radians, which positions the Terrestrial Intermediate
** Origin on the equator. For many applications, xp, yp and
** (especially) sp can be set to zero.
**
** Internally, the polar motion is stored in a form rotated onto the
** local meridian.
**
** 5) The refraction constants refa and refb are for use in a
**  $dZ = A \cdot \tan(Z) + B \cdot \tan^3(Z)$  model, where Z is the observed
** (i.e. refracted) zenith distance and dZ is the amount of
** refraction.
**
** 6) It is advisable to take great care with units, as even unlikely
** values of the input parameters are accepted and processed in
** accordance with the models used.
**
** 7) In cases where the caller does not wish to provide the Earth
** Ephemeris, the Earth rotation information and refraction
** constants, the function iauApc013 can be used instead of the
** present function. This starts from UTC and weather readings etc.
** and computes suitable values using other SOFA functions.
**
** 8) This is one of several functions that inserts into the astrom
** structure star-independent parameters needed for the chain of
** astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
** The various functions support different classes of observer and
** portions of the transformation chain:
**
**          functions          observer          transformation
**
**          iauApcg iauApcg13   geocentric   ICRS <-> GCRS
**          iauApci iauApci13   terrestrial  ICRS <-> CIRS
**          iauApc0 iauApc013   terrestrial  ICRS <-> observed
**          iauApcs iauApcs13   space        ICRS <-> GCRS
**          iauAper iauAper13   terrestrial  update Earth rotation
**          iauApio iauApio13   terrestrial  CIRS <-> observed
**
** Those with names ending in "13" use contemporary SOFA models to
** compute the various ephemerides. The others accept ephemerides
** supplied by the caller.
**
** The transformation from ICRS to GCRS covers space motion,
** parallax, light deflection, and aberration. From GCRS to CIRS
** comprises frame bias and precession-nutation. From CIRS to
** observed takes account of Earth rotation, polar motion, diurnal
** aberration and parallax (unless subsumed into the ICRS <-> GCRS

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```
**      transformation), and atmospheric refraction.
**
**  9) The context structure astrom produced by this function is used by
**      iauAtioq, iauAtoiq, iauAtciq* and iauAticq*.
**
**  Called:
**      iauAper      astrometry parameters: update ERA
**      iauC2ixys    celestial-to-intermediate matrix, given X,Y and s
**      iauPvtob     position/velocity of terrestrial station
**      iauTrxpv     product of transpose of r-matrix and pv-vector
**      iauApcs      astrometry parameters, ICRS-GCRS, space observer
**      iauCr        copy r-matrix
**
**/
```

```

int iauApcol3(double utc1, double utc2, double dut1,
              double elong, double phi, double hm, double xp, double yp,
              double phpa, double tc, double rh, double wl,
              iauASTROM *astrom, double *eo)
/*
** -----
**   i a u A p c o l 3
** -----
**
** For a terrestrial observer, prepare star-independent astrometry
** parameters for transformations between ICRS and observed
** coordinates. The caller supplies UTC, site coordinates, ambient air
** conditions and observing wavelength, and SOFA models are used to
** obtain the Earth ephemeris, CIP/CIO and refraction constants.
**
** The parameters produced by this function are required in the
** parallax, light deflection, aberration, and bias-precession-nutation
** parts of the ICRS/CIRS transformations.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   utc1 double UTC as a 2-part...
**   utc2 double ...quasi Julian Date (Notes 1,2)
**   dut1 double UT1-UTC (seconds, Note 3)
**   elong double longitude (radians, east +ve, Note 4)
**   phi double latitude (geodetic, radians, Note 4)
**   hm double height above ellipsoid (m, geodetic, Notes 4,6)
**   xp,yp double polar motion coordinates (radians, Note 5)
**   phpa double pressure at the observer (hPa = mB, Note 6)
**   tc double ambient temperature at the observer (deg C)
**   rh double relative humidity at the observer (range 0-1)
**   wl double wavelength (micrometers, Note 7)
**
** Returned:
**   astrom iauASTROM* star-independent astrometry parameters:
**   pmt double PM time interval (SSB, Julian years)
**   eb double[3] SSB to observer (vector, au)
**   eh double[3] Sun to observer (unit vector)
**   em double distance from Sun to observer (au)
**   v double[3] barycentric observer velocity (vector, c)
**   bml double sqrt(1-|v|^2): reciprocal of Lorentz factor
**   bpn double[3][3] bias-precession-nutation matrix
**   along double longitude + s' (radians)
**   xpl double polar motion xp wrt local meridian (radians)
**   ypl double polar motion yp wrt local meridian (radians)
**   sphl double sine of geodetic latitude
**   cphi double cosine of geodetic latitude
**   diurab double magnitude of diurnal aberration vector
**   eral double "local" Earth rotation angle (radians)
**   refa double refraction constant A (radians)
**   refb double refraction constant B (radians)
**   eo double* equation of the origins (ERA-GST)
**
** Returned (function value):
**   int status: +1 = dubious year (Note 2)
**             0 = OK
**            -1 = unacceptable date
**
** Notes:
**
** 1) utc1+utc2 is quasi Julian Date (see Note 2), apportioned in any
** convenient way between the two arguments, for example where utc1
** is the Julian Day Number and utc2 is the fraction of a day.
**
** However, JD cannot unambiguously represent UTC during a leap
** second unless special measures are taken. The convention in the
** present function is that the JD day represents UTC days whether

```

```

** the length is 86399, 86400 or 86401 SI seconds.
**
** Applications should use the function iauDtf2d to convert from
** calendar date and time of day into 2-part quasi Julian Date, as
** it implements the leap-second-ambiguity convention just
** described.
**
** 2) The warning status "dubious year" flags UTCs that predate the
** introduction of the time scale or that are too far in the
** future to be trusted. See iauDat for further details.
**
** 3) UT1-UTC is tabulated in IERS bulletins. It increases by exactly
** one second at the end of each positive UTC leap second,
** introduced in order to keep UT1-UTC within +/- 0.9s. n.b. This
** practice is under review, and in the future UT1-UTC may grow
** essentially without limit.
**
** 4) The geographical coordinates are with respect to the WGS84
** reference ellipsoid. TAKE CARE WITH THE LONGITUDE SIGN: the
** longitude required by the present function is east-positive
** (i.e. right-handed), in accordance with geographical convention.
**
** 5) The polar motion xp,yp can be obtained from IERS bulletins. The
** values are the coordinates (in radians) of the Celestial
** Intermediate Pole with respect to the International Terrestrial
** Reference System (see IERS Conventions 2003), measured along the
** meridians 0 and 90 deg west respectively. For many
** applications, xp and yp can be set to zero.
**
** Internally, the polar motion is stored in a form rotated onto
** the local meridian.
**
** 6) If hm, the height above the ellipsoid of the observing station
** in meters, is not known but phpa, the pressure in hPa (=mB), is
** available, an adequate estimate of hm can be obtained from the
** expression
**
**      hm = -29.3 * tsl * log ( phpa / 1013.25 );
**
** where tsl is the approximate sea-level air temperature in K
** (See Astrophysical Quantities, C.W.Allen, 3rd edition, section
** 52). Similarly, if the pressure phpa is not known, it can be
** estimated from the height of the observing station, hm, as
** follows:
**
**      phpa = 1013.25 * exp ( -hm / ( 29.3 * tsl ) );
**
** Note, however, that the refraction is nearly proportional to
** the pressure and that an accurate phpa value is important for
** precise work.
**
** 7) The argument wl specifies the observing wavelength in
** micrometers. The transition from optical to radio is assumed to
** occur at 100 micrometers (about 3000 GHz).
**
** 8) It is advisable to take great care with units, as even unlikely
** values of the input parameters are accepted and processed in
** accordance with the models used.
**
** 9) In cases where the caller wishes to supply his own Earth
** ephemeris, Earth rotation information and refraction constants,
** the function iauApco can be used instead of the present function.
**
** 10) This is one of several functions that inserts into the astrom
** structure star-independent parameters needed for the chain of
** astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
** The various functions support different classes of observer and
** portions of the transformation chain:
**
**      functions          observer          transformation
**
**      iauApcg iauApcg13  geocentric        ICRS <-> GCRS

```

```

**      iauApci iauApci13   terrestrial   ICRS <-> CIRS
**      iauApco iauApco13   terrestrial   ICRS <-> observed
**      iauApcs iauApcs13   space         ICRS <-> GCRS
**      iauAper iauAper13   terrestrial   update Earth rotation
**      iauApio iauApio13   terrestrial   CIRS <-> observed
**
**      Those with names ending in "13" use contemporary SOFA models to
**      compute the various ephemerides.  The others accept ephemerides
**      supplied by the caller.
**
**      The transformation from ICRS to GCRS covers space motion,
**      parallax, light deflection, and aberration.  From GCRS to CIRS
**      comprises frame bias and precession-nutation.  From CIRS to
**      observed takes account of Earth rotation, polar motion, diurnal
**      aberration and parallax (unless subsumed into the ICRS <-> GCRS
**      transformation), and atmospheric refraction.
**
**      11) The context structure astrom produced by this function is used
**      by iauAtioq, iauAtoiq, iauAtciq* and iauAticq*.
**
**      Called:
**      iauUtctai   UTC to TAI
**      iauTaitt   TAI to TT
**      iauUtcut1  UTC to UT1
**      iauEpv00   Earth position and velocity
**      iauPnm06a  classical NPB matrix, IAU 2006/2000A
**      iauBpn2xy  extract CIP X,Y coordinates from NPB matrix
**      iauS06     the CIO locator s, given X,Y, IAU 2006
**      iauEra00   Earth rotation angle, IAU 2000
**      iauSp00    the TIO locator s', IERS 2000
**      iauRefco   refraction constants for given ambient conditions
**      iauApco    astrometry parameters, ICRS-observed
**      iauEors    equation of the origins, given NPB matrix and s
**
*/

```

```

void iauApcs(double date1, double date2, double pv[2][3],
             double ebpv[2][3], double ehp[3],
             iauASTROM *astrom)
/*
**   - - - - -
**   i a u A p c s
**   - - - - -
**
**   For an observer whose geocentric position and velocity are known,
**   prepare star-independent astrometry parameters for transformations
**   between ICRS and GCRS.  The Earth ephemeris is supplied by the
**   caller.
**
**   The parameters produced by this function are required in the space
**   motion, parallax, light deflection and aberration parts of the
**   astrometric transformation chain.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     date1  double          TDB as a 2-part...
**     date2  double          ...Julian Date (Note 1)
**     pv     double[2][3]    observer's geocentric pos/vel (m, m/s)
**     ebpv   double[2][3]    Earth barycentric PV (au, au/day)
**     ehp    double[3]       Earth heliocentric P (au)
**
**   Returned:
**     astrom iauASTROM*      star-independent astrometry parameters:
**     pmt    double          PM time interval (SSB, Julian years)
**     eb     double[3]        SSB to observer (vector, au)
**     eh     double[3]        Sun to observer (unit vector)
**     em     double           distance from Sun to observer (au)
**     v      double[3]        barycentric observer velocity (vector, c)
**     bm1    double           sqrt(1-|v|^2): reciprocal of Lorentz factor
**     bpn    double[3][3]     bias-precession-nutation matrix
**     along  double           unchanged
**     xpl    double           unchanged
**     ypl    double           unchanged
**     sphi   double           unchanged
**     cphi   double           unchanged
**     diurab double           unchanged
**     eral   double           unchanged
**     refa   double           unchanged
**     refb   double           unchanged
**
**   Notes:
**
**   1) The TDB date date1+date2 is a Julian Date, apportioned in any
**   convenient way between the two arguments.  For example,
**   JD(TDB)=2450123.7 could be expressed in any of these ways, among
**   others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in cases
**   where the loss of several decimal digits of resolution is
**   acceptable.  The J2000 method is best matched to the way the
**   argument is handled internally and will deliver the optimum
**   resolution.  The MJD method and the date & time methods are both
**   good compromises between resolution and convenience.  For most
**   applications of this function the choice will not be at all
**   critical.
**

```

```

**      TT can be used instead of TDB without any significant impact on
**      accuracy.
**
** 2) All the vectors are with respect to BCRS axes.
**
** 3) Providing separate arguments for (i) the observer's geocentric
**      position and velocity and (ii) the Earth ephemeris is done for
**      convenience in the geocentric, terrestrial and Earth orbit cases.
**      For deep space applications it maybe more convenient to specify
**      zero geocentric position and velocity and to supply the
**      observer's position and velocity information directly instead of
**      with respect to the Earth. However, note the different units:
**      m and m/s for the geocentric vectors, au and au/day for the
**      heliocentric and barycentric vectors.
**
** 4) In cases where the caller does not wish to provide the Earth
**      ephemeris, the function iauApcs13 can be used instead of the
**      present function. This computes the Earth ephemeris using the
**      SOFA function iauEpv00.
**
** 5) This is one of several functions that inserts into the astrom
**      structure star-independent parameters needed for the chain of
**      astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
**      The various functions support different classes of observer and
**      portions of the transformation chain:
**
**          functions          observer          transformation
**
**      iauApcg iauApcg13     geocentric      ICRS <-> GCRS
**      iauApci iauApci13     terrestrial     ICRS <-> CIRS
**      iauApco iauApcol3     terrestrial     ICRS <-> observed
**      iauApcs iauApcs13     space           ICRS <-> GCRS
**      iauAper iauAper13     terrestrial     update Earth rotation
**      iauApio iauApio13     terrestrial     CIRS <-> observed
**
**      Those with names ending in "13" use contemporary SOFA models to
**      compute the various ephemerides. The others accept ephemerides
**      supplied by the caller.
**
**      The transformation from ICRS to GCRS covers space motion,
**      parallax, light deflection, and aberration. From GCRS to CIRS
**      comprises frame bias and precession-nutation. From CIRS to
**      observed takes account of Earth rotation, polar motion, diurnal
**      aberration and parallax (unless subsumed into the ICRS <-> GCRS
**      transformation), and atmospheric refraction.
**
** 6) The context structure astrom produced by this function is used by
**      iauAtciq* and iauAticq*.
**
** Called:
**      iauCp          copy p-vector
**      iauPm          modulus of p-vector
**      iauPn          decompose p-vector into modulus and direction
**      iauIr          initialize r-matrix to identity
**
** /

```

```

void iauApcs13(double date1, double date2, double pv[2][3],
              iauASTROM *astrom)
/*
**  - - - - -
**   i a u A p c s 1 3
**  - - - - -
**
** For an observer whose geocentric position and velocity are known,
** prepare star-independent astrometry parameters for transformations
** between ICRS and GCRS. The Earth ephemeris is from SOFA models.
**
** The parameters produced by this function are required in the space
** motion, parallax, light deflection and aberration parts of the
** astrometric transformation chain.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1 double          TDB as a 2-part...
**   date2 double          ...Julian Date (Note 1)
**   pv    double[2][3]   observer's geocentric pos/vel (Note 3)
**
** Returned:
**   astrom iauASTROM*    star-independent astrometry parameters:
**   pmt    double        PM time interval (SSB, Julian years)
**   eb     double[3]     SSB to observer (vector, au)
**   eh     double[3]     Sun to observer (unit vector)
**   em     double        distance from Sun to observer (au)
**   v      double[3]     barycentric observer velocity (vector, c)
**   bm1    double        sqrt(1-|v|^2): reciprocal of Lorentz factor
**   bpn    double[3][3]  bias-precession-nutation matrix
**   along  double        unchanged
**   xpl    double        unchanged
**   ypl    double        unchanged
**   sphl   double        unchanged
**   cphi   double        unchanged
**   diurab double        unchanged
**   eral   double        unchanged
**   refa   double        unchanged
**   refb   double        unchanged
**
** Notes:
**
** 1) The TDB date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TDB)=2450123.7 could be expressed in any of these ways, among
** others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0        -1421.3        (J2000 method)
**          2400000.5          50123.2        (MJD method)
**          2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable. The J2000 method is best matched to the way the
** argument is handled internally and will deliver the optimum
** resolution. The MJD method and the date & time methods are both
** good compromises between resolution and convenience. For most
** applications of this function the choice will not be at all
** critical.
**
** TT can be used instead of TDB without any significant impact on
** accuracy.
**
** 2) All the vectors are with respect to BCRS axes.

```

```

**
** 3) The observer's position and velocity pv are geocentric but with
**      respect to BCRS axes, and in units of m and m/s. No assumptions
**      are made about proximity to the Earth, and the function can be
**      used for deep space applications as well as Earth orbit and
**      terrestrial.
**
** 4) In cases where the caller wishes to supply his own Earth
**      ephemeris, the function iauApcs can be used instead of the present
**      function.
**
** 5) This is one of several functions that inserts into the astrom
**      structure star-independent parameters needed for the chain of
**      astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
**      The various functions support different classes of observer and
**      portions of the transformation chain:
**
**          functions          observer          transformation
**
**          iauApcg iauApcg13   geocentric    ICRS <-> GCRS
**          iauApci iauApci13   terrestrial    ICRS <-> CIRS
**          iauApco iauApco13   terrestrial    ICRS <-> observed
**          iauApcs iauApcs13   space          ICRS <-> GCRS
**          iauAper iauAper13   terrestrial    update Earth rotation
**          iauApio iauApio13   terrestrial    CIRS <-> observed
**
**      Those with names ending in "13" use contemporary SOFA models to
**      compute the various ephemerides. The others accept ephemerides
**      supplied by the caller.
**
**      The transformation from ICRS to GCRS covers space motion,
**      parallax, light deflection, and aberration. From GCRS to CIRS
**      comprises frame bias and precession-nutation. From CIRS to
**      observed takes account of Earth rotation, polar motion, diurnal
**      aberration and parallax (unless subsumed into the ICRS <-> GCRS
**      transformation), and atmospheric refraction.
**
** 6) The context structure astrom produced by this function is used by
**      iauAtciq* and iauAticq*.
**
** Called:
**   iauEpv00      Earth position and velocity
**   iauApcs       astrometry parameters, ICRS-GCRS, space observer
**
** /

```

```

void iauAper(double theta, iauASTROM *astrom)
/*
**  - - - - -
**   i a u A p e r
**  - - - - -
**
**   In the star-independent astrometry parameters, update only the
**   Earth rotation angle, supplied by the caller explicitly.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     theta  double      Earth rotation angle (radians, Note 2)
**     astrom iauASTROM*  star-independent astrometry parameters:
**       pmt  double      not used
**       eb   double[3]   not used
**       eh   double[3]   not used
**       em   double      not used
**       v    double[3]   not used
**       bml  double      not used
**       bpn  double[3][3] not used
**       along double     longitude + s' (radians)
**       xpl  double      not used
**       ypl  double      not used
**       sphl double      not used
**       cphi double      not used
**       diurab double    not used
**       eral double      not used
**       refa double      not used
**       refb double      not used
**
**   Returned:
**     astrom iauASTROM*  star-independent astrometry parameters:
**       pmt  double      unchanged
**       eb   double[3]   unchanged
**       eh   double[3]   unchanged
**       em   double      unchanged
**       v    double[3]   unchanged
**       bml  double      unchanged
**       bpn  double[3][3] unchanged
**       along double     unchanged
**       xpl  double      unchanged
**       ypl  double      unchanged
**       sphl double      unchanged
**       cphi double      unchanged
**       diurab double    unchanged
**       eral double      "local" Earth rotation angle (radians)
**       refa double      unchanged
**       refb double      unchanged
**
**   Notes:
**
**   1) This function exists to enable sidereal-tracking applications to
**      avoid wasteful recomputation of the bulk of the astrometry
**      parameters:  only the Earth rotation is updated.
**
**   2) For targets expressed as equinox based positions, such as
**      classical geocentric apparent (RA,Dec), the supplied theta can be
**      Greenwich apparent sidereal time rather than Earth rotation
**      angle.
**
**   3) The function iauAper13 can be used instead of the present
**      function, and starts from UT1 rather than ERA itself.
**
**   4) This is one of several functions that inserts into the astrom
**      structure star-independent parameters needed for the chain of
**      astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**

```

```

**      The various functions support different classes of observer and
**      portions of the transformation chain:
**
**          functions          observer          transformation
**
**      iauApcg iauApcg13      geocentric      ICRS <-> GCRS
**      iauApci iauApci13      terrestrial    ICRS <-> CIRS
**      iauApco iauApcol3      terrestrial    ICRS <-> observed
**      iauApcs iauApcs13      space          ICRS <-> GCRS
**      iauAper iauAper13      terrestrial    update Earth rotation
**      iauApio iauApio13      terrestrial    CIRS <-> observed
**
**      Those with names ending in "13" use contemporary SOFA models to
**      compute the various ephemerides.  The others accept ephemerides
**      supplied by the caller.
**
**      The transformation from ICRS to GCRS covers space motion,
**      parallax, light deflection, and aberration.  From GCRS to CIRS
**      comprises frame bias and precession-nutation.  From CIRS to
**      observed takes account of Earth rotation, polar motion, diurnal
**      aberration and parallax (unless subsumed into the ICRS <-> GCRS
**      transformation), and atmospheric refraction.
**
*/

```

```

void iauAper13(double ut11, double ut12, iauASTROM *astrom)
/*
**  - - - - -
**   i a u A p e r 1 3
**  - - - - -
**
**   In the star-independent astrometry parameters, update only the
**   Earth rotation angle.  The caller provides UT1, (n.b. not UTC).
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     ut11  double      UT1 as a 2-part...
**     ut12  double      ...Julian Date (Note 1)
**     astrom iauASTROM* star-independent astrometry parameters:
**       pmt  double      not used
**       eb   double[3]   not used
**       eh   double[3]   not used
**       em   double      not used
**       v    double[3]   not used
**       bml  double      not used
**       bpn  double[3][3] not used
**       along double      longitude + s' (radians)
**       xpl  double      not used
**       ypl  double      not used
**       sphl double      not used
**       cphi double      not used
**       diurab double     not used
**       eral double      not used
**       refa double      not used
**       refb double      not used
**
**   Returned:
**     astrom iauASTROM* star-independent astrometry parameters:
**       pmt  double      unchanged
**       eb   double[3]   unchanged
**       eh   double[3]   unchanged
**       em   double      unchanged
**       v    double[3]   unchanged
**       bml  double      unchanged
**       bpn  double[3][3] unchanged
**       along double     unchanged
**       xpl  double      unchanged
**       ypl  double      unchanged
**       sphl double      unchanged
**       cphi double      unchanged
**       diurab double     unchanged
**       eral double      "local" Earth rotation angle (radians)
**       refa double      unchanged
**       refb double      unchanged
**
**   Notes:
**
**   1) The UT1 date (n.b. not UTC) ut11+ut12 is a Julian Date,
**      apportioned in any convenient way between the arguments ut11 and
**      ut12.  For example, JD(UT1)=2450123.7 could be expressed in any
**      of these ways, among others:
**
**           ut11          ut12
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5           0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in cases
**   where the loss of several decimal digits of resolution is
**   acceptable.  The J2000 and MJD methods are good compromises

```

```

**      between resolution and convenience.  The date & time method is
**      best matched to the algorithm used:  maximum precision is
**      delivered when the ut11 argument is for 0hrs UT1 on the day in
**      question and the ut12 argument lies in the range 0 to 1, or vice
**      versa.
**
**  2)  If the caller wishes to provide the Earth rotation angle itself,
**      the function iauAper can be used instead.  One use of this
**      technique is to substitute Greenwich apparent sidereal time and
**      thereby to support equinox based transformations directly.
**
**  3)  This is one of several functions that inserts into the astrom
**      structure star-independent parameters needed for the chain of
**      astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
**      The various functions support different classes of observer and
**      portions of the transformation chain:
**
**          functions          observer          transformation
**
**      iauApcg iauApcg13     geocentric      ICRS <-> GCRS
**      iauApci iauApci13     terrestrial   ICRS <-> CIRS
**      iauApco iauApco13     terrestrial   ICRS <-> observed
**      iauApcs iauApcs13     space          ICRS <-> GCRS
**      iauAper iauAper13     terrestrial   update Earth rotation
**      iauApio iauApio13     terrestrial   CIRS <-> observed
**
**      Those with names ending in "13" use contemporary SOFA models to
**      compute the various ephemerides.  The others accept ephemerides
**      supplied by the caller.
**
**      The transformation from ICRS to GCRS covers space motion,
**      parallax, light deflection, and aberration.  From GCRS to CIRS
**      comprises frame bias and precession-nutation.  From CIRS to
**      observed takes account of Earth rotation, polar motion, diurnal
**      aberration and parallax (unless subsumed into the ICRS <-> GCRS
**      transformation), and atmospheric refraction.
**
**      Called:
**      iauAper      astrometry parameters: update ERA
**      iauEra00     Earth rotation angle, IAU 2000
**
** /

```

```

void iauApio(double sp, double theta,
            double elong, double phi, double hm, double xp, double yp,
            double refa, double refb,
            iauASTROM *astrom)

/*
**  - - - - -
**  i a u A p i o
**  - - - - -
**
**  For a terrestrial observer, prepare star-independent astrometry
**  parameters for transformations between CIRS and observed
**  coordinates. The caller supplies the Earth orientation information
**  and the refraction constants as well as the site coordinates.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards of Fundamental Astronomy) software collection.
**
**  Status: support function.
**
**  Given:
**      sp      double      the TIO locator s' (radians, Note 1)
**      theta   double      Earth rotation angle (radians)
**      elong   double      longitude (radians, east +ve, Note 2)
**      phi     double      geodetic latitude (radians, Note 2)
**      hm     double      height above ellipsoid (m, geodetic Note 2)
**      xp,yp   double      polar motion coordinates (radians, Note 3)
**      refa    double      refraction constant A (radians, Note 4)
**      refb    double      refraction constant B (radians, Note 4)
**
**  Returned:
**      astrom  iauASTROM*  star-independent astrometry parameters:
**      pmt     double      unchanged
**      eb      double[3]   unchanged
**      eh      double[3]   unchanged
**      em      double      unchanged
**      v       double[3]   unchanged
**      bml     double      unchanged
**      bpn     double[3][3] unchanged
**      along   double      longitude + s' (radians)
**      xpl     double      polar motion xp wrt local meridian (radians)
**      ypl     double      polar motion yp wrt local meridian (radians)
**      sphl    double      sine of geodetic latitude
**      cphi    double      cosine of geodetic latitude
**      diurab  double      magnitude of diurnal aberration vector
**      eral    double      "local" Earth rotation angle (radians)
**      refa    double      refraction constant A (radians)
**      refb    double      refraction constant B (radians)
**
**  Notes:
**
**  1) sp, the TIO locator s', is a tiny quantity needed only by the
**     most precise applications. It can either be set to zero or
**     predicted using the SOFA function iauSp00.
**
**  2) The geographical coordinates are with respect to the WGS84
**     reference ellipsoid. TAKE CARE WITH THE LONGITUDE SIGN: the
**     longitude required by the present function is east-positive
**     (i.e. right-handed), in accordance with geographical convention.
**
**  3) The polar motion xp,yp can be obtained from IERS bulletins. The
**     values are the coordinates (in radians) of the Celestial
**     Intermediate Pole with respect to the International Terrestrial
**     Reference System (see IERS Conventions 2003), measured along the
**     meridians 0 and 90 deg west respectively. For many applications,
**     xp and yp can be set to zero.
**
**     Internally, the polar motion is stored in a form rotated onto the
**     local meridian.
**
**  4) The refraction constants refa and refb are for use in a
**      $dZ = A \cdot \tan(Z) + B \cdot \tan^3(Z)$  model, where Z is the observed

```

```

**      (i.e. refracted) zenith distance and dZ is the amount of
**      refraction.
**
** 5) It is advisable to take great care with units, as even unlikely
**     values of the input parameters are accepted and processed in
**     accordance with the models used.
**
** 6) In cases where the caller does not wish to provide the Earth
**     rotation information and refraction constants, the function
**     iauApoi3 can be used instead of the present function. This
**     starts from UTC and weather readings etc. and computes suitable
**     values using other SOFA functions.
**
** 7) This is one of several functions that inserts into the astrom
**     structure star-independent parameters needed for the chain of
**     astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
**     The various functions support different classes of observer and
**     portions of the transformation chain:
**
**           functions           observer           transformation
**
**     iauApcg iauApcg13        geocentric         ICRS <-> GCRS
**     iauApci iauApci13        terrestrial      ICRS <-> CIRS
**     iauApc0 iauApc013        terrestrial      ICRS <-> observed
**     iauApcs iauApcs13        space            ICRS <-> GCRS
**     iauAper iauAper13        terrestrial      update Earth rotation
**     iauApio iauApio13        terrestrial      CIRS <-> observed
**
**     Those with names ending in "13" use contemporary SOFA models to
**     compute the various ephemerides. The others accept ephemerides
**     supplied by the caller.
**
**     The transformation from ICRS to GCRS covers space motion,
**     parallax, light deflection, and aberration. From GCRS to CIRS
**     comprises frame bias and precession-nutation. From CIRS to
**     observed takes account of Earth rotation, polar motion, diurnal
**     aberration and parallax (unless subsumed into the ICRS <-> GCRS
**     transformation), and atmospheric refraction.
**
** 8) The context structure astrom produced by this function is used by
**     iauAtioq and iauAtoiq.
**
** Called:
**     iauPvtob      position/velocity of terrestrial station
**     iauAper       astrometry parameters: update ERA
**
*/

```

```

int iauApio13(double utc1, double utc2, double dut1,
              double elong, double phi, double hm, double xp, double yp,
              double phpa, double tc, double rh, double wl,
              iauASTROM *astrom)
/*
** -----
**   i a u A p i o 1 3
** -----
**
** For a terrestrial observer, prepare star-independent astrometry
** parameters for transformations between CIRS and observed
** coordinates. The caller supplies UTC, site coordinates, ambient air
** conditions and observing wavelength.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   utc1 double      UTC as a 2-part...
**   utc2 double      ...quasi Julian Date (Notes 1,2)
**   dut1 double      UT1-UTC (seconds)
**   elong double     longitude (radians, east +ve, Note 3)
**   phi  double      geodetic latitude (radians, Note 3)
**   hm   double      height above ellipsoid (m, geodetic Notes 4,6)
**   xp,yp double     polar motion coordinates (radians, Note 5)
**   phpa double      pressure at the observer (hPa = mB, Note 6)
**   tc   double      ambient temperature at the observer (deg C)
**   rh   double      relative humidity at the observer (range 0-1)
**   wl   double      wavelength (micrometers, Note 7)
**
** Returned:
**   astrom iauASTROM* star-independent astrometry parameters:
**   pmt double         unchanged
**   eb  double[3]      unchanged
**   eh  double[3]      unchanged
**   em  double         unchanged
**   v   double[3]      unchanged
**   bml double         unchanged
**   bpn double[3][3]   unchanged
**   along double       longitude + s' (radians)
**   xpl double         polar motion xp wrt local meridian (radians)
**   ypl double         polar motion yp wrt local meridian (radians)
**   sphl double        sine of geodetic latitude
**   cphi double        cosine of geodetic latitude
**   diurab double      magnitude of diurnal aberration vector
**   eral double        "local" Earth rotation angle (radians)
**   refa double        refraction constant A (radians)
**   refb double        refraction constant B (radians)
**
** Returned (function value):
**   int status: +1 = dubious year (Note 2)
**               0 = OK
**               -1 = unacceptable date
**
** Notes:
**
** 1) utc1+utc2 is quasi Julian Date (see Note 2), apportioned in any
** convenient way between the two arguments, for example where utc1
** is the Julian Day Number and utc2 is the fraction of a day.
**
** However, JD cannot unambiguously represent UTC during a leap
** second unless special measures are taken. The convention in the
** present function is that the JD day represents UTC days whether
** the length is 86399, 86400 or 86401 SI seconds.
**
** Applications should use the function iauDtf2d to convert from
** calendar date and time of day into 2-part quasi Julian Date, as
** it implements the leap-second-ambiguity convention just
** described.

```

```

**
** 2) The warning status "dubious year" flags UTCs that predate the
** introduction of the time scale or that are too far in the future
** to be trusted. See iauDat for further details.
**
** 3) UT1-UTC is tabulated in IERS bulletins. It increases by exactly
** one second at the end of each positive UTC leap second,
** introduced in order to keep UT1-UTC within +/- 0.9s. n.b. This
** practice is under review, and in the future UT1-UTC may grow
** essentially without limit.
**
** 4) The geographical coordinates are with respect to the WGS84
** reference ellipsoid. TAKE CARE WITH THE LONGITUDE SIGN: the
** longitude required by the present function is east-positive
** (i.e. right-handed), in accordance with geographical convention.
**
** 5) The polar motion xp,yp can be obtained from IERS bulletins. The
** values are the coordinates (in radians) of the Celestial
** Intermediate Pole with respect to the International Terrestrial
** Reference System (see IERS Conventions 2003), measured along the
** meridians 0 and 90 deg west respectively. For many applications,
** xp and yp can be set to zero.
**
** Internally, the polar motion is stored in a form rotated onto
** the local meridian.
**
** 6) If hm, the height above the ellipsoid of the observing station
** in meters, is not known but phpa, the pressure in hPa (=mB), is
** available, an adequate estimate of hm can be obtained from the
** expression
**
**      hm = -29.3 * tsl * log ( phpa / 1013.25 );
**
** where tsl is the approximate sea-level air temperature in K
** (See Astrophysical Quantities, C.W.Allen, 3rd edition, section
** 52). Similarly, if the pressure phpa is not known, it can be
** estimated from the height of the observing station, hm, as
** follows:
**
**      phpa = 1013.25 * exp ( -hm / ( 29.3 * tsl ) );
**
** Note, however, that the refraction is nearly proportional to the
** pressure and that an accurate phpa value is important for
** precise work.
**
** 7) The argument wl specifies the observing wavelength in
** micrometers. The transition from optical to radio is assumed to
** occur at 100 micrometers (about 3000 GHz).
**
** 8) It is advisable to take great care with units, as even unlikely
** values of the input parameters are accepted and processed in
** accordance with the models used.
**
** 9) In cases where the caller wishes to supply his own Earth
** rotation information and refraction constants, the function
** iauApc can be used instead of the present function.
**
** 10) This is one of several functions that inserts into the astrom
** structure star-independent parameters needed for the chain of
** astrometric transformations ICRS <-> GCRS <-> CIRS <-> observed.
**
** The various functions support different classes of observer and
** portions of the transformation chain:
**
**      functions          observer          transformation
**
**      iauApcg iauApcg13   geocentric          ICRS <-> GCRS
**      iauApci iauApci13   terrestrial          ICRS <-> CIRS
**      iauApco iauApcol3   terrestrial          ICRS <-> observed
**      iauApcs iauApcs13   space                ICRS <-> GCRS
**      iauAper iauAper13   terrestrial          update Earth rotation
**      iauApio iauApio13   terrestrial          CIRS <-> observed
**

```

```

**      Those with names ending in "13" use contemporary SOFA models to
**      compute the various ephemerides.  The others accept ephemerides
**      supplied by the caller.
**
**      The transformation from ICRS to GCRS covers space motion,
**      parallax, light deflection, and aberration.  From GCRS to CIRS
**      comprises frame bias and precession-nutation.  From CIRS to
**      observed takes account of Earth rotation, polar motion, diurnal
**      aberration and parallax (unless subsumed into the ICRS <-> GCRS
**      transformation), and atmospheric refraction.
**
**      11) The context structure astrom produced by this function is used
**          by iauAtioq and iauAtoiq.
**
**      Called:
**          iauUtctai      UTC to TAI
**          iauTaitt      TAI to TT
**          iauUtcutl     UTC to UT1
**          iauSp00       the TIO locator s', IERS 2000
**          iauEra00      Earth rotation angle, IAU 2000
**          iauRefco      refraction constants for given ambient conditions
**          iauApio       astrometry parameters, CIRS-observed
**
*/

```

```

void iauAtcil3(double rc, double dc,
              double pr, double pd, double px, double rv,
              double datel, double date2,
              double *ri, double *di, double *eo)
/*
** -----
**   i a u A t c i l 3
** -----
**
** Transform ICRS star data, epoch J2000.0, to CIRS.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rc      double   ICRS right ascension at J2000.0 (radians, Note 1)
**   dc      double   ICRS declination at J2000.0 (radians, Note 1)
**   pr      double   RA proper motion (radians/year; Note 2)
**   pd      double   Dec proper motion (radians/year)
**   px      double   parallax (arcsec)
**   rv      double   radial velocity (km/s, +ve if receding)
**   datel   double   TDB as a 2-part...
**   date2   double   ...Julian Date (Note 3)
**
** Returned:
**   ri,di   double*  CIRS geocentric RA,Dec (radians)
**   eo      double*  equation of the origins (ERA-GST, Note 5)
**
** Notes:
**
** 1) Star data for an epoch other than J2000.0 (for example from the
**    Hipparcos catalog, which has an epoch of J1991.25) will require a
**    preliminary call to iauPmsafe before use.
**
** 2) The proper motion in RA is dRA/dt rather than cos(Dec)*dRA/dt.
**
** 3) The TDB date datel+date2 is a Julian Date, apportioned in any
**    convenient way between the two arguments.  For example,
**    JD(TDB)=2450123.8g could be expressed in any of these ways, among
**    others:
**
**           datel           date2
**
**           2450123.8g           0.0           (JD method)
**           2451545.0           -1421.3        (J2000 method)
**           2400000.5           50123.2        (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable.  The J2000 method is best matched to the way the
** argument is handled internally and will deliver the optimum
** resolution.  The MJD method and the date & time methods are both
** good compromises between resolution and convenience.  For most
** applications of this function the choice will not be at all
** critical.
**
** TT can be used instead of TDB without any significant impact on
** accuracy.
**
** 4) The available accuracy is better than 1 milliarcsecond, limited
**    mainly by the precession-nutation model that is used, namely
**    IAU 2000A/2006.  Very close to solar system bodies, additional
**    errors of up to several milliarcseconds can occur because of
**    unmodeled light deflection; however, the Sun's contribution is
**    taken into account, to first order.  The accuracy limitations of
**    the SOFA function iauEpv00 (used to compute Earth position and
**    velocity) can contribute aberration errors of up to
**    5 microarcseconds.  Light deflection at the Sun's limb is

```

```
**      uncertain at the 0.4 mas level.
**
** 5) Should the transformation to (equinox based) apparent place be
**      required rather than (CIO based) intermediate place, subtract the
**      equation of the origins from the returned right ascension:
**      RA = RI - EO. (The iauAnp function can then be applied, as
**      required, to keep the result in the conventional 0-2pi range.)
**
** Called:
**      iauApci13      astrometry parameters, ICRS-CIRS, 2013
**      iauAtciq      quick ICRS to CIRS
**
*/
```

```

void iauAtciq(double rc, double dc,
              double pr, double pd, double px, double rv,
              iauASTROM *astrom, double *ri, double *di)
/*
**   - - - - -
**   i a u A t c i q
**   - - - - -
**
** Quick ICRS, epoch J2000.0, to CIRS transformation, given precomputed
** star-independent astrometry parameters.
**
** Use of this function is appropriate when efficiency is important and
** where many star positions are to be transformed for one date. The
** star-independent parameters can be obtained by calling one of the
** functions iauApci[13], iauApcg[13], iauApco[13] or iauApcs[13].
**
** If the parallax and proper motions are zero the iauAtciqz function
** can be used instead.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   rc,dc double      ICRS RA,Dec at J2000.0 (radians)
**   pr   double      RA proper motion (radians/year; Note 3)
**   pd   double      Dec proper motion (radians/year)
**   px   double      parallax (arcsec)
**   rv   double      radial velocity (km/s, +ve if receding)
**   astrom iauASTROM* star-independent astrometry parameters:
**   pmt  double      PM time interval (SSB, Julian years)
**   eb   double[3]   SSB to observer (vector, au)
**   eh   double[3]   Sun to observer (unit vector)
**   em   double      distance from Sun to observer (au)
**   v    double[3]   barycentric observer velocity (vector, c)
**   bml  double      sqrt(1-|v|^2): reciprocal of Lorentz factor
**   bpn  double[3][3] bias-precession-nutation matrix
**   along double     longitude + s' (radians)
**   xpl  double      polar motion xp wrt local meridian (radians)
**   ypl  double      polar motion yp wrt local meridian (radians)
**   sphl double      sine of geodetic latitude
**   cphi double      cosine of geodetic latitude
**   diurab double    magnitude of diurnal aberration vector
**   eral  double     "local" Earth rotation angle (radians)
**   refa  double     refraction constant A (radians)
**   refb  double     refraction constant B (radians)
**
** Returned:
**   ri,di double     CIRS RA,Dec (radians)
**
** Notes:
**
** 1) All the vectors are with respect to BCRS axes.
**
** 2) Star data for an epoch other than J2000.0 (for example from the
** Hipparcos catalog, which has an epoch of J1991.25) will require a
** preliminary call to iauPmsafe before use.
**
** 3) The proper motion in RA is dRA/dt rather than cos(Dec)*dRA/dt.
**
** Called:
**   iauPmpx      proper motion and parallax
**   iauLdsun     light deflection by the Sun
**   iauAb        stellar aberration
**   iauRxp       product of r-matrix and pv-vector
**   iauC2s       p-vector to spherical
**   iauAnp       normalize angle into range 0 to 2pi
**
** */

```

```

void iauAtciqn(double rc, double dc, double pr, double pd,
               double px, double rv, iauASTROM *astrom,
               int n, iauLDBODY b[], double *ri, double *di)
/*
**  - - - - -
**   i a u A t c i q n
**  - - - - -
**
** Quick ICRS, epoch J2000.0, to CIRS transformation, given precomputed
** star-independent astrometry parameters plus a list of light-
** deflecting bodies.
**
** Use of this function is appropriate when efficiency is important and
** where many star positions are to be transformed for one date. The
** star-independent parameters can be obtained by calling one of the
** functions iauApci[13], iauApcg[13], iauApco[13] or iauApcs[13].
**
** If the only light-deflecting body to be taken into account is the
** Sun, the iauAtciq function can be used instead. If in addition the
** parallax and proper motions are zero, the iauAtciqz function can be
** used.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rc,dc  double      ICRS RA,Dec at J2000.0 (radians)
**   pr     double      RA proper motion (radians/year; Note 3)
**   pd     double      Dec proper motion (radians/year)
**   px     double      parallax (arcsec)
**   rv     double      radial velocity (km/s, +ve if receding)
**   astrom iauASTROM*  star-independent astrometry parameters:
**   pmt    double      PM time interval (SSB, Julian years)
**   eb     double[3]   SSB to observer (vector, au)
**   eh     double[3]   Sun to observer (unit vector)
**   em     double      distance from Sun to observer (au)
**   v      double[3]   barycentric observer velocity (vector, c)
**   bml    double      sqrt(1-|v|^2): reciprocal of Lorentz factor
**   bpn    double[3][3] bias-precession-nutation matrix
**   along  double      longitude + s' (radians)
**   xpl    double      polar motion xp wrt local meridian (radians)
**   ypl    double      polar motion yp wrt local meridian (radians)
**   sphl   double      sine of geodetic latitude
**   cphi   double      cosine of geodetic latitude
**   diurab double      magnitude of diurnal aberration vector
**   eral   double      "local" Earth rotation angle (radians)
**   refa   double      refraction constant A (radians)
**   refb   double      refraction constant B (radians)
**   n      int         number of bodies (Note 3)
**   b      iauLDBODY[n] data for each of the n bodies (Notes 3,4):
**   bm     double      mass of the body (solar masses, Note 5)
**   dl     double      deflection limiter (Note 6)
**   pv     [2][3]      barycentric PV of the body (au, au/day)
**
** Returned:
**   ri,di  double      CIRS RA,Dec (radians)
**
** Notes:
**
** 1) Star data for an epoch other than J2000.0 (for example from the
** Hipparcos catalog, which has an epoch of J1991.25) will require a
** preliminary call to iauPmsafe before use.
**
** 2) The proper motion in RA is dRA/dt rather than cos(Dec)*dRA/dt.
**
** 3) The struct b contains n entries, one for each body to be
** considered. If n = 0, no gravitational light deflection will be
** applied, not even for the Sun.

```

```

**
** 4) The struct b should include an entry for the Sun as well as for
** any planet or other body to be taken into account. The entries
** should be in the order in which the light passes the body.
**
** 5) In the entry in the b struct for body i, the mass parameter
** b[i].bm can, as required, be adjusted in order to allow for such
** effects as quadrupole field.
**
** 6) The deflection limiter parameter b[i].dl is  $\phi^2/2$ , where  $\phi$  is
** the angular separation (in radians) between star and body at
** which limiting is applied. As  $\phi$  shrinks below the chosen
** threshold, the deflection is artificially reduced, reaching zero
** for  $\phi = 0$ . Example values suitable for a terrestrial
** observer, together with masses, are as follows:
**
**      body i      b[i].bm      b[i].dl
**
**      Sun         1.0           6e-6
**      Jupiter     0.00095435    3e-9
**      Saturn      0.00028574    3e-10
**
** 7) For efficiency, validation of the contents of the b array is
** omitted. The supplied masses must be greater than zero, the
** position and velocity vectors must be right, and the deflection
** limiter greater than zero.
**
** Called:
**   iauPmpx      proper motion and parallax
**   iauLdn      light deflection by n bodies
**   iauAb       stellar aberration
**   iauRxp      product of r-matrix and pv-vector
**   iauC2s      p-vector to spherical
**   iauAnp      normalize angle into range 0 to 2pi
**
** */

```

```

void iauAtciqz(double rc, double dc, iauASTROM *astrom,
              double *ri, double *di)
/*
**  - - - - -
**   i a u A t c i q z
**  - - - - -
**
** Quick ICRS to CIRS transformation, given precomputed star-
** independent astrometry parameters, and assuming zero parallax and
** proper motion.
**
** Use of this function is appropriate when efficiency is important and
** where many star positions are to be transformed for one date. The
** star-independent parameters can be obtained by calling one of the
** functions iauApci[13], iauApcg[13], iauApc0[13] or iauApcs[13].
**
** The corresponding function for the case of non-zero parallax and
** proper motion is iauAtciq.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rc,dc  double      ICRS astrometric RA,Dec (radians)
**   astrom iauASTROM*  star-independent astrometry parameters:
**   pmt    double      PM time interval (SSB, Julian years)
**   eb     double[3]   SSB to observer (vector, au)
**   eh     double[3]   Sun to observer (unit vector)
**   em     double      distance from Sun to observer (au)
**   v      double[3]   barycentric observer velocity (vector, c)
**   bm1    double      sqrt(1-|v|^2): reciprocal of Lorenz factor
**   bpn    double[3][3] bias-precession-nutation matrix
**   along  double      longitude + s' (radians)
**   xpl    double      polar motion xp wrt local meridian (radians)
**   ypl    double      polar motion yp wrt local meridian (radians)
**   sphl   double      sine of geodetic latitude
**   cphi   double      cosine of geodetic latitude
**   diurab double      magnitude of diurnal aberration vector
**   eral   double      "local" Earth rotation angle (radians)
**   refa   double      refraction constant A (radians)
**   refb   double      refraction constant B (radians)
**
** Returned:
**   ri,di  double      CIRS RA,Dec (radians)
**
** Note:
**
**   All the vectors are with respect to BCRS axes.
**
** References:
**
**   Urban, S. & Seidelmann, P. K. (eds), Explanatory Supplement to
**   the Astronomical Almanac, 3rd ed., University Science Books
**   (2013).
**
**   Klioner, Sergei A., "A practical relativistic model for micro-
**   arcsecond astrometry in space", Astr. J. 125, 1580-1597 (2003).
**
** Called:
**   iauS2c      spherical coordinates to unit vector
**   iauLdsun    light deflection due to Sun
**   iauAb       stellar aberration
**   iauRxp      product of r-matrix and p-vector
**   iauC2s      p-vector to spherical
**   iauAnp      normalize angle into range +/- pi
**
*/

```

```

int iauAtcol3(double rc, double dc,
              double pr, double pd, double px, double rv,
              double utc1, double utc2, double dut1,
              double elong, double phi, double hm, double xp, double yp,
              double phpa, double tc, double rh, double wl,
              double *aob, double *zob, double *hob,
              double *dob, double *rob, double *eo)

/*
**   - - - - -
**   i a u A t c o l 3
**   - - - - -
**
**   ICRS RA,Dec to observed place.  The caller supplies UTC, site
**   coordinates, ambient air conditions and observing wavelength.
**
**   SOFA models are used for the Earth ephemeris, bias-precession-
**   nutation, Earth orientation and refraction.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     rc,dc  double   ICRS right ascension at J2000.0 (radians, Note 1)
**     pr     double   RA proper motion (radians/year; Note 2)
**     pd     double   Dec proper motion (radians/year)
**     px     double   parallax (arcsec)
**     rv     double   radial velocity (km/s, +ve if receding)
**     utc1   double   UTC as a 2-part...
**     utc2   double   ...quasi Julian Date (Notes 3-4)
**     dut1   double   UT1-UTC (seconds, Note 5)
**     elong  double   longitude (radians, east +ve, Note 6)
**     phi    double   latitude (geodetic, radians, Note 6)
**     hm     double   height above ellipsoid (m, geodetic, Notes 6,8)
**     xp,yp  double   polar motion coordinates (radians, Note 7)
**     phpa   double   pressure at the observer (hPa = mB, Note 8)
**     tc     double   ambient temperature at the observer (deg C)
**     rh     double   relative humidity at the observer (range 0-1)
**     wl     double   wavelength (micrometers, Note 9)
**
**   Returned:
**     aob    double*  observed azimuth (radians: N=0,E=90)
**     zob    double*  observed zenith distance (radians)
**     hob    double*  observed hour angle (radians)
**     dob    double*  observed declination (radians)
**     rob    double*  observed right ascension (CIO-based, radians)
**     eo     double*  equation of the origins (ERA-GST)
**
**   Returned (function value):
**     int    status: +1 = dubious year (Note 4)
**              0 = OK
**             -1 = unacceptable date
**
**   Notes:
**
**   1)  Star data for an epoch other than J2000.0 (for example from the
**       Hipparcos catalog, which has an epoch of J1991.25) will require
**       a preliminary call to iauPmsafe before use.
**
**   2)  The proper motion in RA is dRA/dt rather than cos(Dec)*dRA/dt.
**
**   3)  utc1+utc2 is quasi Julian Date (see Note 2), apportioned in any
**       convenient way between the two arguments, for example where utc1
**       is the Julian Day Number and utc2 is the fraction of a day.
**
**       However, JD cannot unambiguously represent UTC during a leap
**       second unless special measures are taken.  The convention in the
**       present function is that the JD day represents UTC days whether
**       the length is 86399, 86400 or 86401 SI seconds.
**

```

```

** Applications should use the function iauDtf2d to convert from
** calendar date and time of day into 2-part quasi Julian Date, as
** it implements the leap-second-ambiguity convention just
** described.
**
** 4) The warning status "dubious year" flags UTCs that predate the
** introduction of the time scale or that are too far in the
** future to be trusted. See iauDat for further details.
**
** 5) UT1-UTC is tabulated in IERS bulletins. It increases by exactly
** one second at the end of each positive UTC leap second,
** introduced in order to keep UT1-UTC within +/- 0.9s. n.b. This
** practice is under review, and in the future UT1-UTC may grow
** essentially without limit.
**
** 6) The geographical coordinates are with respect to the WGS84
** reference ellipsoid. TAKE CARE WITH THE LONGITUDE SIGN: the
** longitude required by the present function is east-positive
** (i.e. right-handed), in accordance with geographical convention.
**
** 7) The polar motion xp,yp can be obtained from IERS bulletins. The
** values are the coordinates (in radians) of the Celestial
** Intermediate Pole with respect to the International Terrestrial
** Reference System (see IERS Conventions 2003), measured along the
** meridians 0 and 90 deg west respectively. For many
** applications, xp and yp can be set to zero.
**
** 8) If hm, the height above the ellipsoid of the observing station
** in meters, is not known but phpa, the pressure in hPa (=mB),
** is available, an adequate estimate of hm can be obtained from
** the expression
**
**          hm = -29.3 * tsl * log ( phpa / 1013.25 );
**
** where tsl is the approximate sea-level air temperature in K
** (See Astrophysical Quantities, C.W.Allen, 3rd edition, section
** 52). Similarly, if the pressure phpa is not known, it can be
** estimated from the height of the observing station, hm, as
** follows:
**
**          phpa = 1013.25 * exp ( -hm / ( 29.3 * tsl ) );
**
** Note, however, that the refraction is nearly proportional to
** the pressure and that an accurate phpa value is important for
** precise work.
**
** 9) The argument wl specifies the observing wavelength in
** micrometers. The transition from optical to radio is assumed to
** occur at 100 micrometers (about 3000 GHz).
**
** 10) The accuracy of the result is limited by the corrections for
** refraction, which use a simple A*tan(z) + B*tan^3(z) model.
** Providing the meteorological parameters are known accurately and
** there are no gross local effects, the predicted observed
** coordinates should be within 0.05 arcsec (optical) or 1 arcsec
** (radio) for a zenith distance of less than 70 degrees, better
** than 30 arcsec (optical or radio) at 85 degrees and better
** than 20 arcmin (optical) or 30 arcmin (radio) at the horizon.
**
** Without refraction, the complementary functions iauAtcol3 and
** iauAtocl3 are self-consistent to better than 1 microarcsecond
** all over the celestial sphere. With refraction included,
** consistency falls off at high zenith distances, but is still
** better than 0.05 arcsec at 85 degrees.
**
** 11) "Observed" Az,ZD means the position that would be seen by a
** perfect geodetically aligned theodolite. (Zenith distance is
** used rather than altitude in order to reflect the fact that no
** allowance is made for depression of the horizon.) This is
** related to the observed HA,Dec via the standard rotation, using
** the geodetic latitude (corrected for polar motion), while the
** observed HA and RA are related simply through the Earth rotation
** angle and the site longitude. "Observed" RA,Dec or HA,Dec thus

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```
**      means the position that would be seen by a perfect equatorial
**      with its polar axis aligned to the Earth's axis of rotation.
**
**      12) It is advisable to take great care with units, as even unlikely
**      values of the input parameters are accepted and processed in
**      accordance with the models used.
**
**      Called:
**      iauApc03      astrometry parameters, ICRS-observed, 2013
**      iauAtciq      quick ICRS to CIRS
**      iauAtioq      quick CIRS to observed
**
*/
```

```

void iauAtic13(double ri, double di, double datel, double date2,
              double *rc, double *dc, double *eo)
/*
** - - - - -
**   i a u A t i c 1 3
** - - - - -
**
** Transform star RA,Dec from geocentric CIRS to ICRS astrometric.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   ri,di double CIRS geocentric RA,Dec (radians)
**   datel double TDB as a 2-part...
**   date2 double ...Julian Date (Note 1)
**
** Returned:
**   rc,dc double ICRS astrometric RA,Dec (radians)
**   eo double equation of the origins (ERA-GST, Note 4)
**
** Notes:
**
** 1) The TDB date datel+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TDB)=2450123.7 could be expressed in any of these ways, among
** others:
**
**           datel           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3        (J2000 method)
**           2400000.5           50123.2       (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable. The J2000 method is best matched to the way the
** argument is handled internally and will deliver the optimum
** resolution. The MJD method and the date & time methods are both
** good compromises between resolution and convenience. For most
** applications of this function the choice will not be at all
** critical.
**
** TT can be used instead of TDB without any significant impact on
** accuracy.
**
** 2) Iterative techniques are used for the aberration and light
** deflection corrections so that the functions iauAtic13 (or
** iauAticq) and iauAtci13 (or iauAtciq) are accurate inverses;
** even at the edge of the Sun's disk the discrepancy is only about
** 1 nanoarcsecond.
**
** 3) The available accuracy is better than 1 milliarcsecond, limited
** mainly by the precession-nutation model that is used, namely
** IAU 2000A/2006. Very close to solar system bodies, additional
** errors of up to several milliarcseconds can occur because of
** unmodeled light deflection; however, the Sun's contribution is
** taken into account, to first order. The accuracy limitations of
** the SOFA function iauEpv00 (used to compute Earth position and
** velocity) can contribute aberration errors of up to
** 5 microarcseconds. Light deflection at the Sun's limb is
** uncertain at the 0.4 mas level.
**
** 4) Should the transformation to (equinox based) J2000.0 mean place
** be required rather than (CIO based) ICRS coordinates, subtract the
** equation of the origins from the returned right ascension:
** RA = RI - EO. (The iauAnp function can then be applied, as
** required, to keep the result in the conventional 0-2pi range.)

```

```
**
** Called:
**   iauApci13   astrometry parameters, ICRS-CIRS, 2013
**   iauAticq   quick CIRS to ICRS astrometric
**
**/
```

```

void iauAticq(double ri, double di, iauASTROM *astrom,
              double *rc, double *dc)
/*
**  - - - - -
**   i a u A t i c q
**  - - - - -
**
** Quick CIRS RA,Dec to ICRS astrometric place, given the star-
** independent astrometry parameters.
**
** Use of this function is appropriate when efficiency is important and
** where many star positions are all to be transformed for one date.
** The star-independent astrometry parameters can be obtained by
** calling one of the functions iauApci[13], iauApcg[13], iauApco[13]
** or iauApcs[13].
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   ri,di double      CIRS RA,Dec (radians)
**   astrom iauASTROM* star-independent astrometry parameters:
**   pmt double        PM time interval (SSB, Julian years)
**   eb double[3]      SSB to observer (vector, au)
**   eh double[3]      Sun to observer (unit vector)
**   em double         distance from Sun to observer (au)
**   v double[3]       barycentric observer velocity (vector, c)
**   bml double        sqrt(1-|v|^2): reciprocal of Lorentz factor
**   bpn double[3][3]  bias-precession-nutation matrix
**   along double      longitude + s' (radians)
**   xpl double        polar motion xp wrt local meridian (radians)
**   ypl double        polar motion yp wrt local meridian (radians)
**   sphl double       sine of geodetic latitude
**   cphi double       cosine of geodetic latitude
**   diurab double     magnitude of diurnal aberration vector
**   eral double       "local" Earth rotation angle (radians)
**   refa double       refraction constant A (radians)
**   refb double       refraction constant B (radians)
**
** Returned:
**   rc,dc double      ICRS astrometric RA,Dec (radians)
**
** Notes:
**
** 1) Only the Sun is taken into account in the light deflection
** correction.
**
** 2) Iterative techniques are used for the aberration and light
** deflection corrections so that the functions iauAtic13 (or
** iauAticq) and iauAtci13 (or iauAtciq) are accurate inverses;
** even at the edge of the Sun's disk the discrepancy is only about
** 1 nanoarcsecond.
**
** Called:
**   iauS2c spherical coordinates to unit vector
**   iauTrxp product of transpose of r-matrix and p-vector
**   iauZp zero p-vector
**   iauAb stellar aberration
**   iauLdsun light deflection by the Sun
**   iauC2s p-vector to spherical
**   iauAnp normalize angle into range +/- pi
**
*/

```

```

void iauAticqn(double ri, double di, iauASTROM *astrom,
               int n, iauLDBODY b[], double *rc, double *dc)
/*
**   - - - - -
**   i a u A t i c q n
**   - - - - -
**
** Quick CIRS to ICRS astrometric place transformation, given the star-
** independent astrometry parameters plus a list of light-deflecting
** bodies.
**
** Use of this function is appropriate when efficiency is important and
** where many star positions are all to be transformed for one date.
** The star-independent astrometry parameters can be obtained by
** calling one of the functions iauApci[13], iauApcg[13], iauApco[13]
** or iauApcs[13].
*
* If the only light-deflecting body to be taken into account is the
* Sun, the iauAticq function can be used instead.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   ri,di double      CIRS RA,Dec (radians)
**   astrom iauASTROM* star-independent astrometry parameters:
**   pmt double        PM time interval (SSB, Julian years)
**   eb double[3]      SSB to observer (vector, au)
**   eh double[3]      Sun to observer (unit vector)
**   em double         distance from Sun to observer (au)
**   v double[3]       barycentric observer velocity (vector, c)
**   bml double        sqrt(1-|v|^2): reciprocal of Lorentz factor
**   bpn double[3][3]  bias-precession-nutation matrix
**   along double      longitude + s' (radians)
**   xpl double        polar motion xp wrt local meridian (radians)
**   ypl double        polar motion yp wrt local meridian (radians)
**   sphl double       sine of geodetic latitude
**   cphi double       cosine of geodetic latitude
**   diurab double     magnitude of diurnal aberration vector
**   eral double       "local" Earth rotation angle (radians)
**   refa double       refraction constant A (radians)
**   refb double       refraction constant B (radians)
**   n int             number of bodies (Note 3)
**   b iauLDBODY[n]   data for each of the n bodies (Notes 3,4):
**   bm double        mass of the body (solar masses, Note 5)
**   dl double        deflection limiter (Note 6)
**   pv [2][3]        barycentric PV of the body (au, au/day)
**
** Returned:
**   rc,dc double     ICRS astrometric RA,Dec (radians)
**
** Notes:
**
** 1) Iterative techniques are used for the aberration and light
** deflection corrections so that the functions iauAticqn and
** iauAtciqn are accurate inverses; even at the edge of the Sun's
** disk the discrepancy is only about 1 nanoarcsecond.
**
** 2) If the only light-deflecting body to be taken into account is the
** Sun, the iauAticq function can be used instead.
**
** 3) The struct b contains n entries, one for each body to be
** considered. If n = 0, no gravitational light deflection will be
** applied, not even for the Sun.
**
** 4) The struct b should include an entry for the Sun as well as for
** any planet or other body to be taken into account. The entries
** should be in the order in which the light passes the body.
**

```

```

** 5) In the entry in the b struct for body i, the mass parameter
** b[i].bm can, as required, be adjusted in order to allow for such
** effects as quadrupole field.
**
** 6) The deflection limiter parameter b[i].dl is  $\phi^2/2$ , where  $\phi$  is
** the angular separation (in radians) between star and body at
** which limiting is applied. As  $\phi$  shrinks below the chosen
** threshold, the deflection is artificially reduced, reaching zero
** for  $\phi = 0$ . Example values suitable for a terrestrial
** observer, together with masses, are as follows:
**
**      body i      b[i].bm      b[i].dl
**
**      Sun         1.0          6e-6
**      Jupiter     0.00095435    3e-9
**      Saturn      0.00028574    3e-10
**
** 7) For efficiency, validation of the contents of the b array is
** omitted. The supplied masses must be greater than zero, the
** position and velocity vectors must be right, and the deflection
** limiter greater than zero.
**
** Called:
** iauS2c          spherical coordinates to unit vector
** iauTrxp         product of transpose of r-matrix and p-vector
** iauZp           zero p-vector
** iauAb           stellar aberration
** iauLdn          light deflection by n bodies
** iauC2s          p-vector to spherical
** iauAnp          normalize angle into range +/- pi
**
*/

```

```

int iauAtio13(double ri, double di,
              double utc1, double utc2, double dut1,
              double elong, double phi, double hm, double xp, double yp,
              double phpa, double tc, double rh, double wl,
              double *aob, double *zob, double *hob,
              double *dob, double *rob)

/*
** -----
**   i a u A t i o 1 3
** -----
**
** CIRS RA,Dec to observed place. The caller supplies UTC, site
** coordinates, ambient air conditions and observing wavelength.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   ri      double   CIRS right ascension (CIO-based, radians)
**   di      double   CIRS declination (radians)
**   utc1    double   UTC as a 2-part...
**   utc2    double   ...quasi Julian Date (Notes 1,2)
**   dut1    double   UT1-UTC (seconds, Note 3)
**   elong  double   longitude (radians, east +ve, Note 4)
**   phi     double   geodetic latitude (radians, Note 4)
**   hm      double   height above ellipsoid (m, geodetic Notes 4,6)
**   xp,yp   double   polar motion coordinates (radians, Note 5)
**   phpa    double   pressure at the observer (hPa = mB, Note 6)
**   tc      double   ambient temperature at the observer (deg C)
**   rh      double   relative humidity at the observer (range 0-1)
**   wl      double   wavelength (micrometers, Note 7)
**
** Returned:
**   aob     double*  observed azimuth (radians: N=0,E=90)
**   zob     double*  observed zenith distance (radians)
**   hob     double*  observed hour angle (radians)
**   dob     double*  observed declination (radians)
**   rob     double*  observed right ascension (CIO-based, radians)
**
** Returned (function value):
**   int     status: +1 = dubious year (Note 2)
**              0 = OK
**              -1 = unacceptable date
**
** Notes:
**
** 1) utc1+utc2 is quasi Julian Date (see Note 2), apportioned in any
** convenient way between the two arguments, for example where utc1
** is the Julian Day Number and utc2 is the fraction of a day.
**
** However, JD cannot unambiguously represent UTC during a leap
** second unless special measures are taken. The convention in the
** present function is that the JD day represents UTC days whether
** the length is 86399, 86400 or 86401 SI seconds.
**
** Applications should use the function iauDtf2d to convert from
** calendar date and time of day into 2-part quasi Julian Date, as
** it implements the leap-second-ambiguity convention just
** described.
**
** 2) The warning status "dubious year" flags UTCs that predate the
** introduction of the time scale or that are too far in the
** future to be trusted. See iauDat for further details.
**
** 3) UT1-UTC is tabulated in IERS bulletins. It increases by exactly
** one second at the end of each positive UTC leap second,
** introduced in order to keep UT1-UTC within +/- 0.9s. n.b. This
** practice is under review, and in the future UT1-UTC may grow
** essentially without limit.

```

```

**
** 4) The geographical coordinates are with respect to the WGS84
** reference ellipsoid. TAKE CARE WITH THE LONGITUDE SIGN: the
** longitude required by the present function is east-positive
** (i.e. right-handed), in accordance with geographical convention.
**
** 5) The polar motion xp,yp can be obtained from IERS bulletins. The
** values are the coordinates (in radians) of the Celestial
** Intermediate Pole with respect to the International Terrestrial
** Reference System (see IERS Conventions 2003), measured along the
** meridians 0 and 90 deg west respectively. For many
** applications, xp and yp can be set to zero.
**
** 6) If hm, the height above the ellipsoid of the observing station
** in meters, is not known but phpa, the pressure in hPa (=mB), is
** available, an adequate estimate of hm can be obtained from the
** expression
**
**      hm = -29.3 * tsl * log ( phpa / 1013.25 );
**
** where tsl is the approximate sea-level air temperature in K
** (See Astrophysical Quantities, C.W.Allen, 3rd edition, section
** 52). Similarly, if the pressure phpa is not known, it can be
** estimated from the height of the observing station, hm, as
** follows:
**
**      phpa = 1013.25 * exp ( -hm / ( 29.3 * tsl ) );
**
** Note, however, that the refraction is nearly proportional to
** the pressure and that an accurate phpa value is important for
** precise work.
**
** 7) The argument wl specifies the observing wavelength in
** micrometers. The transition from optical to radio is assumed to
** occur at 100 micrometers (about 3000 GHz).
**
** 8) "Observed" Az,ZD means the position that would be seen by a
** perfect geodetically aligned theodolite. (Zenith distance is
** used rather than altitude in order to reflect the fact that no
** allowance is made for depression of the horizon.) This is
** related to the observed HA,Dec via the standard rotation, using
** the geodetic latitude (corrected for polar motion), while the
** observed HA and RA are related simply through the Earth rotation
** angle and the site longitude. "Observed" RA,Dec or HA,Dec thus
** means the position that would be seen by a perfect equatorial
** with its polar axis aligned to the Earth's axis of rotation.
**
** 9) The accuracy of the result is limited by the corrections for
** refraction, which use a simple A*tan(z) + B*tan^3(z) model.
** Providing the meteorological parameters are known accurately and
** there are no gross local effects, the predicted astrometric
** coordinates should be within 0.05 arcsec (optical) or 1 arcsec
** (radio) for a zenith distance of less than 70 degrees, better
** than 30 arcsec (optical or radio) at 85 degrees and better
** than 20 arcmin (optical) or 30 arcmin (radio) at the horizon.
**
** 10) The complementary functions iauAtio13 and iauAtoi13 are self-
** consistent to better than 1 microarcsecond all over the
** celestial sphere.
**
** 11) It is advisable to take great care with units, as even unlikely
** values of the input parameters are accepted and processed in
** accordance with the models used.
**
** Called:
**   iauApi13      astrometry parameters, CIRS-observed, 2013
**   iauAtioq     quick CIRS to observed
**
*/

```

```

void iauAtioq(double ri, double di, iauASTROM *astrom,
             double *aob, double *zob,
             double *hob, double *dob, double *rob)
/*
**  - - - - -
**   i a u A t i o q
**  - - - - -
**
**   Quick CIRS to observed place transformation.
**
**   Use of this function is appropriate when efficiency is important and
**   where many star positions are all to be transformed for one date.
**   The star-independent astrometry parameters can be obtained by
**   calling iauApio[13] or iauApcO[13].
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     ri      double      CIRS right ascension
**     di      double      CIRS declination
**     astrom  iauASTROM*  star-independent astrometry parameters:
**     pmt     double      PM time interval (SSB, Julian years)
**     eb      double[3]   SSB to observer (vector, au)
**     eh      double[3]   Sun to observer (unit vector)
**     em      double      distance from Sun to observer (au)
**     v       double[3]   barycentric observer velocity (vector, c)
**     bml     double      sqrt(1-|v|^2): reciprocal of Lorentz factor
**     bpn     double[3][3] bias-precession-nutation matrix
**     along   double      longitude + s' (radians)
**     xpl     double      polar motion xp wrt local meridian (radians)
**     ypl     double      polar motion yp wrt local meridian (radians)
**     sphl    double      sine of geodetic latitude
**     cphi    double      cosine of geodetic latitude
**     diurab  double      magnitude of diurnal aberration vector
**     eral    double      "local" Earth rotation angle (radians)
**     refa    double      refraction constant A (radians)
**     refb    double      refraction constant B (radians)
**
**   Returned:
**     aob     double*     observed azimuth (radians: N=0,E=90)
**     zob     double*     observed zenith distance (radians)
**     hob     double*     observed hour angle (radians)
**     dob     double*     observed declination (radians)
**     rob     double*     observed right ascension (CIO-based, radians)
**
**   Notes:
**
**   1) This function returns zenith distance rather than altitude in
**      order to reflect the fact that no allowance is made for
**      depression of the horizon.
**
**   2) The accuracy of the result is limited by the corrections for
**      refraction, which use a simple A*tan(z) + B*tan^3(z) model.
**      Providing the meteorological parameters are known accurately and
**      there are no gross local effects, the predicted observed
**      coordinates should be within 0.05 arcsec (optical) or 1 arcsec
**      (radio) for a zenith distance of less than 70 degrees, better
**      than 30 arcsec (optical or radio) at 85 degrees and better
**      than 20 arcmin (optical) or 30 arcmin (radio) at the horizon.
**
**      Without refraction, the complementary functions iauAtioq and
**      iauAtoiq are self-consistent to better than 1 microarcsecond all
**      over the celestial sphere. With refraction included, consistency
**      falls off at high zenith distances, but is still better than
**      0.05 arcsec at 85 degrees.
**
**   3) It is advisable to take great care with units, as even unlikely
**      values of the input parameters are accepted and processed in

```

```

**      accordance with the models used.
**
**      4) The CIRS RA,Dec is obtained from a star catalog mean place by
**      allowing for space motion, parallax, the Sun's gravitational lens
**      effect, annual aberration and precession-nutation. For star
**      positions in the ICRS, these effects can be applied by means of
**      the iauAtcil3 (etc.) functions. Starting from classical "mean
**      place" systems, additional transformations will be needed first.
**
**      5) "Observed" Az,El means the position that would be seen by a
**      perfect geodetically aligned theodolite. This is obtained from
**      the CIRS RA,Dec by allowing for Earth orientation and diurnal
**      aberration, rotating from equator to horizon coordinates, and
**      then adjusting for refraction. The HA,Dec is obtained by
**      rotating back into equatorial coordinates, and is the position
**      that would be seen by a perfect equatorial with its polar axis
**      aligned to the Earth's axis of rotation. Finally, the RA is
**      obtained by subtracting the HA from the local ERA.
**
**      6) The star-independent CIRS-to-observed-place parameters in ASTROM
**      may be computed with iauApio[13] or iauApco[13]. If nothing has
**      changed significantly except the time, iauAper[13] may be used to
**      perform the requisite adjustment to the astrom structure.
**
**      Called:
**      iauS2c      spherical coordinates to unit vector
**      iauC2s      p-vector to spherical
**      iauAnp      normalize angle into range 0 to 2pi
**
*/

```

```

int iauAtoc13(const char *type, double ob1, double ob2,
              double utc1, double utc2, double dut1,
              double elong, double phi, double hm, double xp, double yp,
              double phpa, double tc, double rh, double wl,
              double *rc, double *dc)

/*
** - - - - -
**   i a u A t o c 1 3
** - - - - -
**
** Observed place at a groundbased site to to ICRS astrometric RA,Dec.
** The caller supplies UTC, site coordinates, ambient air conditions
** and observing wavelength.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   type   char[]   type of coordinates - "R", "H" or "A" (Notes 1,2)
**   ob1    double   observed Az, HA or RA (radians; Az is N=0,E=90)
**   ob2    double   observed ZD or Dec (radians)
**   utc1   double   UTC as a 2-part...
**   utc2   double   ...quasi Julian Date (Notes 3,4)
**   dut1   double   UT1-UTC (seconds, Note 5)
**   elong  double   longitude (radians, east +ve, Note 6)
**   phi    double   geodetic latitude (radians, Note 6)
**   hm     double   height above ellipsoid (m, geodetic Notes 6,8)
**   xp,yp  double   polar motion coordinates (radians, Note 7)
**   phpa   double   pressure at the observer (hPa = mB, Note 8)
**   tc     double   ambient temperature at the observer (deg C)
**   rh     double   relative humidity at the observer (range 0-1)
**   wl     double   wavelength (micrometers, Note 9)
**
** Returned:
**   rc,dc  double   ICRS astrometric RA,Dec (radians)
**
** Returned (function value):
**   int     status: +1 = dubious year (Note 4)
**              0 = OK
**              -1 = unacceptable date
**
** Notes:
**
** 1) "Observed" Az,ZD means the position that would be seen by a
**    perfect geodetically aligned theodolite. (Zenith distance is
**    used rather than altitude in order to reflect the fact that no
**    allowance is made for depression of the horizon.) This is
**    related to the observed HA,Dec via the standard rotation, using
**    the geodetic latitude (corrected for polar motion), while the
**    observed HA and RA are related simply through the Earth rotation
**    angle and the site longitude. "Observed" RA,Dec or HA,Dec thus
**    means the position that would be seen by a perfect equatorial
**    with its polar axis aligned to the Earth's axis of rotation.
**
** 2) Only the first character of the type argument is significant.
**    "R" or "r" indicates that ob1 and ob2 are the observed right
**    ascension and declination; "H" or "h" indicates that they are
**    hour angle (west +ve) and declination; anything else ("A" or
**    "a" is recommended) indicates that ob1 and ob2 are azimuth
**    (north zero, east 90 deg) and zenith distance.
**
** 3) utc1+utc2 is quasi Julian Date (see Note 2), apportioned in any
**    convenient way between the two arguments, for example where utc1
**    is the Julian Day Number and utc2 is the fraction of a day.
**
**    However, JD cannot unambiguously represent UTC during a leap
**    second unless special measures are taken. The convention in the
**    present function is that the JD day represents UTC days whether
**    the length is 86399, 86400 or 86401 SI seconds.

```

```

**
** Applications should use the function iauDtf2d to convert from
** calendar date and time of day into 2-part quasi Julian Date, as
** it implements the leap-second-ambiguity convention just
** described.
**
** 4) The warning status "dubious year" flags UTCs that predate the
** introduction of the time scale or that are too far in the
** future to be trusted. See iauDat for further details.
**
** 5) UT1-UTC is tabulated in IERS bulletins. It increases by exactly
** one second at the end of each positive UTC leap second,
** introduced in order to keep UT1-UTC within +/- 0.9s. n.b. This
** practice is under review, and in the future UT1-UTC may grow
** essentially without limit.
**
** 6) The geographical coordinates are with respect to the WGS84
** reference ellipsoid. TAKE CARE WITH THE LONGITUDE SIGN: the
** longitude required by the present function is east-positive
** (i.e. right-handed), in accordance with geographical convention.
**
** 7) The polar motion xp,yp can be obtained from IERS bulletins. The
** values are the coordinates (in radians) of the Celestial
** Intermediate Pole with respect to the International Terrestrial
** Reference System (see IERS Conventions 2003), measured along the
** meridians 0 and 90 deg west respectively. For many
** applications, xp and yp can be set to zero.
**
** 8) If hm, the height above the ellipsoid of the observing station
** in meters, is not known but phpa, the pressure in hPa (=mB), is
** available, an adequate estimate of hm can be obtained from the
** expression
**
**      hm = -29.3 * tsl * log ( phpa / 1013.25 );
**
** where tsl is the approximate sea-level air temperature in K
** (See Astrophysical Quantities, C.W.Allen, 3rd edition, section
** 52). Similarly, if the pressure phpa is not known, it can be
** estimated from the height of the observing station, hm, as
** follows:
**
**      phpa = 1013.25 * exp ( -hm / ( 29.3 * tsl ) );
**
** Note, however, that the refraction is nearly proportional to
** the pressure and that an accurate phpa value is important for
** precise work.
**
** 9) The argument wl specifies the observing wavelength in
** micrometers. The transition from optical to radio is assumed to
** occur at 100 micrometers (about 3000 GHz).
**
** 10) The accuracy of the result is limited by the corrections for
** refraction, which use a simple A*tan(z) + B*tan^3(z) model.
** Providing the meteorological parameters are known accurately and
** there are no gross local effects, the predicted astrometric
** coordinates should be within 0.05 arcsec (optical) or 1 arcsec
** (radio) for a zenith distance of less than 70 degrees, better
** than 30 arcsec (optical or radio) at 85 degrees and better
** than 20 arcmin (optical) or 30 arcmin (radio) at the horizon.
**
** Without refraction, the complementary functions iauAtcol3 and
** iauAtocl3 are self-consistent to better than 1 microarcsecond
** all over the celestial sphere. With refraction included,
** consistency falls off at high zenith distances, but is still
** better than 0.05 arcsec at 85 degrees.
**
** 11) It is advisable to take great care with units, as even unlikely
** values of the input parameters are accepted and processed in
** accordance with the models used.
**
** Called:
** iauApcol3      astrometry parameters, ICRS-observed
** iauAtoi3      quick observed to CIRS

```

```
**      iauAticq      quick CIRS to ICRS
**
*/
```

```

int iauAtoi13(const char *type, double ob1, double ob2,
              double utc1, double utc2, double dut1,
              double elong, double phi, double hm, double xp, double yp,
              double phpa, double tc, double rh, double wl,
              double *ri, double *di)
/*
** - - - - -
**   i a u A t o i 1 3
** - - - - -
**
** Observed place to CIRS. The caller supplies UTC, site coordinates,
** ambient air conditions and observing wavelength.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   type   char[]   type of coordinates - "R", "H" or "A" (Notes 1,2)
**   ob1    double   observed Az, HA or RA (radians; Az is N=0,E=90)
**   ob2    double   observed ZD or Dec (radians)
**   utc1   double   UTC as a 2-part...
**   utc2   double   ...quasi Julian Date (Notes 3,4)
**   dut1   double   UT1-UTC (seconds, Note 5)
**   elong  double   longitude (radians, east +ve, Note 6)
**   phi    double   geodetic latitude (radians, Note 6)
**   hm     double   height above the ellipsoid (meters, Notes 6,8)
**   xp,yp  double   polar motion coordinates (radians, Note 7)
**   phpa   double   pressure at the observer (hPa = mB, Note 8)
**   tc     double   ambient temperature at the observer (deg C)
**   rh     double   relative humidity at the observer (range 0-1)
**   wl     double   wavelength (micrometers, Note 9)
**
** Returned:
**   ri     double*   CIRS right ascension (CIO-based, radians)
**   di     double*   CIRS declination (radians)
**
** Returned (function value):
**   int     status: +1 = dubious year (Note 2)
**              0 = OK
**              -1 = unacceptable date
**
** Notes:
**
** 1) "Observed" Az,ZD means the position that would be seen by a
**    perfect geodetically aligned theodolite. (Zenith distance is
**    used rather than altitude in order to reflect the fact that no
**    allowance is made for depression of the horizon.) This is
**    related to the observed HA,Dec via the standard rotation, using
**    the geodetic latitude (corrected for polar motion), while the
**    observed HA and RA are related simply through the Earth rotation
**    angle and the site longitude. "Observed" RA,Dec or HA,Dec thus
**    means the position that would be seen by a perfect equatorial
**    with its polar axis aligned to the Earth's axis of rotation.
**
** 2) Only the first character of the type argument is significant.
**    "R" or "r" indicates that ob1 and ob2 are the observed right
**    ascension and declination; "H" or "h" indicates that they are
**    hour angle (west +ve) and declination; anything else ("A" or
**    "a" is recommended) indicates that ob1 and ob2 are azimuth
**    (north zero, east 90 deg) and zenith distance.
**
** 3) utc1+utc2 is quasi Julian Date (see Note 2), apportioned in any
**    convenient way between the two arguments, for example where utc1
**    is the Julian Day Number and utc2 is the fraction of a day.
**
**    However, JD cannot unambiguously represent UTC during a leap
**    second unless special measures are taken. The convention in the
**    present function is that the JD day represents UTC days whether
**    the length is 86399, 86400 or 86401 SI seconds.

```

```

**
** Applications should use the function iauDtf2d to convert from
** calendar date and time of day into 2-part quasi Julian Date, as
** it implements the leap-second-ambiguity convention just
** described.
**
** 4) The warning status "dubious year" flags UTCs that predate the
** introduction of the time scale or that are too far in the
** future to be trusted. See iauDat for further details.
**
** 5) UT1-UTC is tabulated in IERS bulletins. It increases by exactly
** one second at the end of each positive UTC leap second,
** introduced in order to keep UT1-UTC within +/- 0.9s. n.b. This
** practice is under review, and in the future UT1-UTC may grow
** essentially without limit.
**
** 6) The geographical coordinates are with respect to the WGS84
** reference ellipsoid. TAKE CARE WITH THE LONGITUDE SIGN: the
** longitude required by the present function is east-positive
** (i.e. right-handed), in accordance with geographical convention.
**
** 7) The polar motion xp,yp can be obtained from IERS bulletins. The
** values are the coordinates (in radians) of the Celestial
** Intermediate Pole with respect to the International Terrestrial
** Reference System (see IERS Conventions 2003), measured along the
** meridians 0 and 90 deg west respectively. For many
** applications, xp and yp can be set to zero.
**
** 8) If hm, the height above the ellipsoid of the observing station
** in meters, is not known but phpa, the pressure in hPa (=mB), is
** available, an adequate estimate of hm can be obtained from the
** expression
**
**      hm = -29.3 * tsl * log ( phpa / 1013.25 );
**
** where tsl is the approximate sea-level air temperature in K
** (See Astrophysical Quantities, C.W.Allen, 3rd edition, section
** 52). Similarly, if the pressure phpa is not known, it can be
** estimated from the height of the observing station, hm, as
** follows:
**
**      phpa = 1013.25 * exp ( -hm / ( 29.3 * tsl ) );
**
** Note, however, that the refraction is nearly proportional to
** the pressure and that an accurate phpa value is important for
** precise work.
**
** 9) The argument wl specifies the observing wavelength in
** micrometers. The transition from optical to radio is assumed to
** occur at 100 micrometers (about 3000 GHz).
**
** 10) The accuracy of the result is limited by the corrections for
** refraction, which use a simple A*tan(z) + B*tan^3(z) model.
** Providing the meteorological parameters are known accurately and
** there are no gross local effects, the predicted astrometric
** coordinates should be within 0.05 arcsec (optical) or 1 arcsec
** (radio) for a zenith distance of less than 70 degrees, better
** than 30 arcsec (optical or radio) at 85 degrees and better
** than 20 arcmin (optical) or 30 arcmin (radio) at the horizon.
**
** Without refraction, the complementary functions iauAti013 and
** iauAtoi13 are self-consistent to better than 1 microarcsecond
** all over the celestial sphere. With refraction included,
** consistency falls off at high zenith distances, but is still
** better than 0.05 arcsec at 85 degrees.
**
** 12) It is advisable to take great care with units, as even unlikely
** values of the input parameters are accepted and processed in
** accordance with the models used.
**
** Called:
** iauApi013      astrometry parameters, CIRS-observed, 2013
** iauAtoi13     quick observed to CIRS

```



```

void iauAtoiq(const char *type,
              double obl, double ob2, iauASTROM *astrom,
              double *ri, double *di)
/*
**   - - - - -
**   i a u A t o i q
**   - - - - -
**
** Quick observed place to CIRS, given the star-independent astrometry
** parameters.
**
** Use of this function is appropriate when efficiency is important and
** where many star positions are all to be transformed for one date.
** The star-independent astrometry parameters can be obtained by
** calling iauApio[13] or iauApc0[13].
**
** Status: support function.
**
** Given:
**   type   char[]   type of coordinates: "R", "H" or "A" (Note 1)
**   obl    double   observed Az, HA or RA (radians; Az is N=0,E=90)
**   ob2    double   observed ZD or Dec (radians)
**   astrom iauASTROM* star-independent astrometry parameters:
**   pmt    double   PM time interval (SSB, Julian years)
**   eb     double[3] SSB to observer (vector, au)
**   eh     double[3] Sun to observer (unit vector)
**   em     double   distance from Sun to observer (au)
**   v      double[3] barycentric observer velocity (vector, c)
**   bml    double   sqrt(1-|v|^2): reciprocal of Lorentz factor
**   bpn    double[3][3] bias-precession-nutation matrix
**   along  double   longitude + s' (radians)
**   xpl    double   polar motion xp wrt local meridian (radians)
**   ypl    double   polar motion yp wrt local meridian (radians)
**   sphl   double   sine of geodetic latitude
**   cphi   double   cosine of geodetic latitude
**   diurab double   magnitude of diurnal aberration vector
**   eral   double   "local" Earth rotation angle (radians)
**   refa   double   refraction constant A (radians)
**   refb   double   refraction constant B (radians)
**
** Returned:
**   ri     double*   CIRS right ascension (CIO-based, radians)
**   di     double*   CIRS declination (radians)
**
** Notes:
**
** 1) "Observed" Az,El means the position that would be seen by a
**    perfect geodetically aligned theodolite. This is related to
**    the observed HA,Dec via the standard rotation, using the geodetic
**    latitude (corrected for polar motion), while the observed HA and
**    RA are related simply through the Earth rotation angle and the
**    site longitude. "Observed" RA,Dec or HA,Dec thus means the
**    position that would be seen by a perfect equatorial with its
**    polar axis aligned to the Earth's axis of rotation. By removing
**    from the observed place the effects of atmospheric refraction and
**    diurnal aberration, the CIRS RA,Dec is obtained.
**
** 2) Only the first character of the type argument is significant.
**    "R" or "r" indicates that obl and ob2 are the observed right
**    ascension and declination; "H" or "h" indicates that they are
**    hour angle (west +ve) and declination; anything else ("A" or
**    "a" is recommended) indicates that obl and ob2 are azimuth (north
**    zero, east 90 deg) and zenith distance. (Zenith distance is used
**    rather than altitude in order to reflect the fact that no
**    allowance is made for depression of the horizon.)
**
** 3) The accuracy of the result is limited by the corrections for
**    refraction, which use a simple A*tan(z) + B*tan^3(z) model.
**    Providing the meteorological parameters are known accurately and
**    there are no gross local effects, the predicted observed
**    coordinates should be within 0.05 arcsec (optical) or 1 arcsec

```

```
**      (radio) for a zenith distance of less than 70 degrees, better
**      than 30 arcsec (optical or radio) at 85 degrees and better than
**      20 arcmin (optical) or 30 arcmin (radio) at the horizon.
**
**      Without refraction, the complementary functions iauAtioq and
**      iauAtoiq are self-consistent to better than 1 microarcsecond all
**      over the celestial sphere. With refraction included, consistency
**      falls off at high zenith distances, but is still better than
**      0.05 arcsec at 85 degrees.
**
**      4) It is advisable to take great care with units, as even unlikely
**      values of the input parameters are accepted and processed in
**      accordance with the models used.
**
**      Called:
**      iauS2c      spherical coordinates to unit vector
**      iauC2s      p-vector to spherical
**      iauAnp      normalize angle into range 0 to 2pi
**
**/
```

```

void iauBi00(double *dpsibi, double *depsbi, double *dra)
/*
**  - - - - -
**   i a u B i 0 0
**  - - - - -
**
**  Frame bias components of IAU 2000 precession-nutation models (part
**  of MHB2000 with additions).
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Returned:
**    dpsibi,depsbi  double  longitude and obliquity corrections
**    dra            double  the ICRS RA of the J2000.0 mean equinox
**
**  Notes:
**
**  1) The frame bias corrections in longitude and obliquity (radians)
**     are required in order to correct for the offset between the GCRS
**     pole and the mean J2000.0 pole.  They define, with respect to the
**     GCRS frame, a J2000.0 mean pole that is consistent with the rest
**     of the IAU 2000A precession-nutation model.
**
**  2) In addition to the displacement of the pole, the complete
**     description of the frame bias requires also an offset in right
**     ascension.  This is not part of the IAU 2000A model, and is from
**     Chapront et al. (2002).  It is returned in radians.
**
**  3) This is a supplemented implementation of one aspect of the IAU
**     2000A nutation model, formally adopted by the IAU General
**     Assembly in 2000, namely MHB2000 (Mathews et al. 2002).
**
**  References:
**
**     Chapront, J., Chapront-Touze, M. & Francou, G., Astron.
**     Astrophys., 387, 700, 2002.
**
**     Mathews, P.M., Herring, T.A., Buffet, B.A., "Modeling of nutation
**     and precession  New nutation series for nonrigid Earth and
**     insights into the Earth's interior", J.Geophys.Res., 107, B4,
**     2002.  The MHB2000 code itself was obtained on 9th September 2002
**     from ftp://maia.usno.navy.mil/conv2000/chapter5/IAU2000A.
**
*/

```

```

void iauBp00(double date1, double date2,
             double rb[3][3], double rp[3][3], double rbp[3][3])
/*
**  - - - - -
**  i a u B p 0 0
**  - - - - -
**
**  Frame bias and precession, IAU 2000.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    rb          double[3][3]    frame bias matrix (Note 2)
**    rp          double[3][3]    precession matrix (Note 3)
**    rbp         double[3][3]    bias-precession matrix (Note 4)
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
**     The JD method is the most natural and convenient to use in
**     cases where the loss of several decimal digits of resolution
**     is acceptable.  The J2000 method is best matched to the way
**     the argument is handled internally and will deliver the
**     optimum resolution.  The MJD method and the date & time methods
**     are both good compromises between resolution and convenience.
**
**  2) The matrix rb transforms vectors from GCRS to mean J2000.0 by
**     applying frame bias.
**
**  3) The matrix rp transforms vectors from J2000.0 mean equator and
**     equinox to mean equator and equinox of date by applying
**     precession.
**
**  4) The matrix rbp transforms vectors from GCRS to mean equator and
**     equinox of date by applying frame bias then precession.  It is
**     the product rp x rb.
**
**  5) It is permissible to re-use the same array in the returned
**     arguments.  The arrays are filled in the order given.
**
**  Called:
**    iauBi00      frame bias components, IAU 2000
**    iauPr00      IAU 2000 precession adjustments
**    iauIr        initialize r-matrix to identity
**    iauRx        rotate around X-axis
**    iauRy        rotate around Y-axis
**    iauRz        rotate around Z-axis
**    iauCr        copy r-matrix
**    iauRxx       product of two r-matrices
**
**  Reference:
**    "Expressions for the Celestial Intermediate Pole and Celestial
**    Ephemeris Origin consistent with the IAU 2000A precession-
**    nutation model", Astron.Astrophys. 400, 1145-1154 (2003)

```

\*\*  
\*\* n.b. The celestial ephemeris origin (CEO) was renamed "celestial  
\*\* intermediate origin" (CIO) by IAU 2006 Resolution 2.  
\*\*  
\*/

```

void iauBp06(double date1, double date2,
             double rb[3][3], double rp[3][3], double rbp[3][3])
/*
**  - - - - -
**  i a u B p 0 6
**  - - - - -
**
**  Frame bias and precession, IAU 2006.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    rb          double[3][3]    frame bias matrix (Note 2)
**    rp          double[3][3]    precession matrix (Note 3)
**    rbp         double[3][3]    bias-precession matrix (Note 4)
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**     The JD method is the most natural and convenient to use in
**     cases where the loss of several decimal digits of resolution
**     is acceptable.  The J2000 method is best matched to the way
**     the argument is handled internally and will deliver the
**     optimum resolution.  The MJD method and the date & time methods
**     are both good compromises between resolution and convenience.
**
**  2) The matrix rb transforms vectors from GCRS to mean J2000.0 by
**     applying frame bias.
**
**  3) The matrix rp transforms vectors from mean J2000.0 to mean of
**     date by applying precession.
**
**  4) The matrix rbp transforms vectors from GCRS to mean of date by
**     applying frame bias then precession.  It is the product rp x rb.
**
**  5) It is permissible to re-use the same array in the returned
**     arguments.  The arrays are filled in the order given.
**
**  Called:
**    iauPfw06      bias-precession F-W angles, IAU 2006
**    iauFw2m       F-W angles to r-matrix
**    iauPmat06     PB matrix, IAU 2006
**    iauTr         transpose r-matrix
**    iauRxr        product of two r-matrices
**    iauCr         copy r-matrix
**
**  References:
**
**    Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**    Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

void iauBpn2xy(double rbpn[3][3], double *x, double *y)
/*
**  - - - - -
**   i a u B p n 2 x y
**  - - - - -
**
**  Extract from the bias-precession-nutation matrix the X,Y coordinates
**  of the Celestial Intermediate Pole.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    rbpn      double[3][3]  celestial-to-true matrix (Note 1)
**
**  Returned:
**    x,y       double        Celestial Intermediate Pole (Note 2)
**
**  Notes:
**
**  1) The matrix rbpn transforms vectors from GCRS to true equator (and
**     CIO or equinox) of date, and therefore the Celestial Intermediate
**     Pole unit vector is the bottom row of the matrix.
**
**  2) The arguments x,y are components of the Celestial Intermediate
**     Pole unit vector in the Geocentric Celestial Reference System.
**
**  Reference:
**
**     "Expressions for the Celestial Intermediate Pole and Celestial
**     Ephemeris Origin consistent with the IAU 2000A precession-
**     nutation model", Astron.Astrophys. 400, 1145-1154
**     (2003)
**
**     n.b. The celestial ephemeris origin (CEO) was renamed "celestial
**     intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
*/

```

```

void iauC2i00a(double date1, double date2, double rc2i[3][3])
/*
**   - - - - -
**   i a u C 2 i 0 0 a
**   - - - - -
**
** Form the celestial-to-intermediate matrix for a given date using the
** IAU 2000A precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rc2i          double[3][3] celestial-to-intermediate matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix rc2i is the first stage in the transformation from
** celestial to terrestrial coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), ERA is the Earth
** Rotation Angle and RPOM is the polar motion matrix.
**
** 3) A faster, but slightly less accurate result (about 1 mas), can be
** obtained by using instead the iauC2i00b function.
**
** Called:
**   iauPnm00a    classical NPB matrix, IAU 2000A
**   iauC2ibpn    celestial-to-intermediate matrix, given NPB matrix
**
** References:
**
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astron.Astrophys. 400, 1145-1154
** (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),

```

\*\* IERS Technical Note No. 32, BKG (2004)  
\*\*  
\*/

```

void iauC2i00b(double date1, double date2, double rc2i[3][3])
/*
**   - - - - -
**   i a u C 2 i 0 0 b
**   - - - - -
**
** Form the celestial-to-intermediate matrix for a given date using the
** IAU 2000B precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rc2i          double[3][3] celestial-to-intermediate matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix rc2i is the first stage in the transformation from
** celestial to terrestrial coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), ERA is the Earth
** Rotation Angle and RPOM is the polar motion matrix.
**
** 3) The present function is faster, but slightly less accurate (about
** 1 mas), than the iauC2i00a function.
**
** Called:
**   iauPnm00b    classical NPB matrix, IAU 2000B
**   iauC2ibpn    celestial-to-intermediate matrix, given NPB matrix
**
** References:
**
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astron.Astrophys. 400, 1145-1154
** (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),

```

\*\* IERS Technical Note No. 32, BKG (2004)  
\*\*  
\*/

```

void iauC2i06a(double date1, double date2, double rc2i[3][3])
/*
**   - - - - -
**   i a u C 2 i 0 6 a
**   - - - - -
**
** Form the celestial-to-intermediate matrix for a given date using the
** IAU 2006 precession and IAU 2000A nutation models.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rc2i          double[3][3] celestial-to-intermediate matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix rc2i is the first stage in the transformation from
** celestial to terrestrial coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = RC2T * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), ERA is the Earth
** Rotation Angle and RPOM is the polar motion matrix.
**
** Called:
**   iauPnm06a    classical NPB matrix, IAU 2006/2000A
**   iauBpn2xy    extract CIP X,Y coordinates from NPB matrix
**   iauS06       the CIO locator s, given X,Y, IAU 2006
**   iauC2ixys    celestial-to-intermediate matrix, given X,Y and s
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG
**
*/

```

```

void iauC2ibpn(double date1, double date2, double rbpn[3][3],
              double rc2i[3][3])
/*
**  - - - - -
**   i a u C 2 i b p n
**  - - - - -
**
** Form the celestial-to-intermediate matrix for a given date given
** the bias-precession-nutation matrix.  IAU 2000.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**   rbpn        double[3][3]  celestial-to-true matrix (Note 2)
**
** Returned:
**   rc2i        double[3][3]  celestial-to-intermediate matrix (Note 3)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix rbpn transforms vectors from GCRS to true equator (and
** CIO or equinox) of date.  Only the CIP (bottom row) is used.
**
** 3) The matrix rc2i is the first stage in the transformation from
** celestial to terrestrial coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = RC2T * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), ERA is the Earth
** Rotation Angle and RPOM is the polar motion matrix.
**
** 4) Although its name does not include "00", This function is in fact
** specific to the IAU 2000 models.
**
** Called:
**   iauBpn2xy    extract CIP X,Y coordinates from NPB matrix
**   iauC2ixy    celestial-to-intermediate matrix, given X,Y
**
** References:
**   "Expressions for the Celestial Intermediate Pole and Celestial
**   Ephemeris Origin consistent with the IAU 2000A precession-
**   nutation model", Astron.Astrophys. 400, 1145-1154 (2003)
**
**   n.b. The celestial ephemeris origin (CEO) was renamed "celestial

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\*\* intermediate origin" (CIO) by IAU 2006 Resolution 2.  
\*\*  
\*\* McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),  
\*\* IERS Technical Note No. 32, BKG (2004)  
\*\*  
\*/

```

void iauC2ixy(double date1, double date2, double x, double y,
              double rc2i[3][3])
/*
**  - - - - -
**   i a u C 2 i x y
**  - - - - -
**
** Form the celestial to intermediate-frame-of-date matrix for a given
** date when the CIP X,Y coordinates are known.  IAU 2000.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2 double      TT as a 2-part Julian Date (Note 1)
**   x,y         double      Celestial Intermediate Pole (Note 2)
**
** Returned:
**   rc2i        double[3][3] celestial-to-intermediate matrix (Note 3)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The Celestial Intermediate Pole coordinates are the x,y components
** of the unit vector in the Geocentric Celestial Reference System.
**
** 3) The matrix rc2i is the first stage in the transformation from
** celestial to terrestrial coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**           = RC2T * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), ERA is the Earth
** Rotation Angle and RPOM is the polar motion matrix.
**
** 4) Although its name does not include "00", This function is in fact
** specific to the IAU 2000 models.
**
** Called:
**   iauC2ixys    celestial-to-intermediate matrix, given X,Y and s
**   iauS00       the CIO locator s, given X,Y, IAU 2000A
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```



```

void iauC2ixys(double x, double y, double s, double rc2i[3][3])
/*
**  - - - - -
**   i a u C 2 i x y s
**  - - - - -
**
** Form the celestial to intermediate-frame-of-date matrix given the CIP
** X,Y and the CIO locator s.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   x,y      double      Celestial Intermediate Pole (Note 1)
**   s        double      the CIO locator s (Note 2)
**
** Returned:
**   rc2i     double[3][3]  celestial-to-intermediate matrix (Note 3)
**
** Notes:
**
** 1) The Celestial Intermediate Pole coordinates are the x,y
**    components of the unit vector in the Geocentric Celestial
**    Reference System.
**
** 2) The CIO locator s (in radians) positions the Celestial
**    Intermediate Origin on the equator of the CIP.
**
** 3) The matrix rc2i is the first stage in the transformation from
**    celestial to terrestrial coordinates:
**
**      [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**            = RC2T * [CRS]
**
**    where [CRS] is a vector in the Geocentric Celestial Reference
**    System and [TRS] is a vector in the International Terrestrial
**    Reference System (see IERS Conventions 2003), ERA is the Earth
**    Rotation Angle and RPOM is the polar motion matrix.
**
** Called:
**   iauIr      initialize r-matrix to identity
**   iauRz      rotate around Z-axis
**   iauRy      rotate around Y-axis
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

void iauC2s(double p[3], double *theta, double *phi)
/*
**  - - - - -
**   i a u C 2 s
**  - - - - -
**
**   P-vector to spherical coordinates.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     p      double[3]    p-vector
**
**   Returned:
**     theta  double       longitude angle (radians)
**     phi    double       latitude angle (radians)
**
**   Notes:
**
**   1) The vector p can have any magnitude; only its direction is used.
**
**   2) If p is null, zero theta and phi are returned.
**
**   3) At either pole, zero theta is returned.
**
*/

```

```

void iauC2t00a(double tta, double ttb, double uta, double utb,
               double xp, double yp, double rc2t[3][3])
/*
**  - - - - -
**   i a u C 2 t 0 0 a
**  - - - - -
**
** Form the celestial to terrestrial matrix given the date, the UT1 and
** the polar motion, using the IAU 2000A nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   tta,ttb  double          TT as a 2-part Julian Date (Note 1)
**   uta,utb  double          UT1 as a 2-part Julian Date (Note 1)
**   xp,yp    double          coordinates of the pole (radians, Note 2)
**
** Returned:
**   rc2t     double[3][3]    celestial-to-terrestrial matrix (Note 3)
**
** Notes:
**
** 1) The TT and UT1 dates tta+ttb and uta+utb are Julian Dates,
** apportioned in any convenient way between the arguments uta and
** utb.  For example, JD(UT1)=2450123.7 could be expressed in any of
** these ways, among others:
**
**           uta           utb
**
**   2450123.7           0.0       (JD method)
**   2451545.0          -1421.3     (J2000 method)
**   2400000.5           50123.2    (MJD method)
**   2450123.5           0.2       (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution is
** acceptable.  The J2000 and MJD methods are good compromises
** between resolution and convenience.  In the case of uta,utb, the
** date & time method is best matched to the Earth rotation angle
** algorithm used:  maximum precision is delivered when the uta
** argument is for 0hrs UT1 on the day in question and the utb
** argument lies in the range 0 to 1, or vice versa.
**
** 2) The arguments xp and yp are the coordinates (in radians) of the
** Celestial Intermediate Pole with respect to the International
** Terrestrial Reference System (see IERS Conventions 2003),
** measured along the meridians to 0 and 90 deg west respectively.
**
** 3) The matrix rc2t transforms from celestial to terrestrial
** coordinates:
**
**       [TRS] = RPOM * R_3(ERA) * RC2I * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), RC2I is the
** celestial-to-intermediate matrix, ERA is the Earth rotation
** angle and RPOM is the polar motion matrix.
**
** 4) A faster, but slightly less accurate result (about 1 mas), can
** be obtained by using instead the iauC2t00b function.
**
** Called:
**   iauC2i00a  celestial-to-intermediate matrix, IAU 2000A
**   iauEra00   Earth rotation angle, IAU 2000
**   iauSp00    the TIO locator s', IERS 2000

```

```
**      iauPom00      polar motion matrix
**      iauC2tcio     form CIO-based celestial-to-terrestrial matrix
**
** Reference:
**
**      McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**      IERS Technical Note No. 32, BKG (2004)
**
**/
```

```

void iauC2t00b(double tta, double ttb, double uta, double utb,
               double xp, double yp, double rc2t[3][3])
/*
**  - - - - -
**   i a u C 2 t 0 0 b
**  - - - - -
**
** Form the celestial to terrestrial matrix given the date, the UT1 and
** the polar motion, using the IAU 2000B nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   tta,ttb  double          TT as a 2-part Julian Date (Note 1)
**   uta,utb  double          UT1 as a 2-part Julian Date (Note 1)
**   xp,yp    double          coordinates of the pole (radians, Note 2)
**
** Returned:
**   rc2t     double[3][3]    celestial-to-terrestrial matrix (Note 3)
**
** Notes:
**
** 1) The TT and UT1 dates tta+ttb and uta+utb are Julian Dates,
** apportioned in any convenient way between the arguments uta and
** utb.  For example, JD(UT1)=2450123.7 could be expressed in any of
** these ways, among others:
**
**           uta           utb
**
**   2450123.7           0.0           (JD method)
**   2451545.0          -1421.3         (J2000 method)
**   2400000.5           50123.2        (MJD method)
**   2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution is
** acceptable.  The J2000 and MJD methods are good compromises
** between resolution and convenience.  In the case of uta,utb, the
** date & time method is best matched to the Earth rotation angle
** algorithm used:  maximum precision is delivered when the uta
** argument is for 0hrs UT1 on the day in question and the utb
** argument lies in the range 0 to 1, or vice versa.
**
** 2) The arguments xp and yp are the coordinates (in radians) of the
** Celestial Intermediate Pole with respect to the International
** Terrestrial Reference System (see IERS Conventions 2003),
** measured along the meridians to 0 and 90 deg west respectively.
**
** 3) The matrix rc2t transforms from celestial to terrestrial
** coordinates:
**
**       [TRS] = RPOM * R_3(ERA) * RC2I * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), RC2I is the
** celestial-to-intermediate matrix, ERA is the Earth rotation
** angle and RPOM is the polar motion matrix.
**
** 4) The present function is faster, but slightly less accurate (about
** 1 mas), than the iauC2t00a function.
**
** Called:
**   iauC2i00b  celestial-to-intermediate matrix, IAU 2000B
**   iauEra00   Earth rotation angle, IAU 2000
**   iauPom00   polar motion matrix

```

```
**      iauC2tcio      form CIO-based celestial-to-terrestrial matrix
**
** Reference:
**
**      McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**      IERS Technical Note No. 32, BKG (2004)
**
*/
```

```

void iauC2t06a(double tta, double ttb, double uta, double utb,
               double xp, double yp, double rc2t[3][3])
/*
**   - - - - -
**   i a u C 2 t 0 6 a
**   - - - - -
**
** Form the celestial to terrestrial matrix given the date, the UT1 and
** the polar motion, using the IAU 2006 precession and IAU 2000A
** nutation models.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   tta,ttb double      TT as a 2-part Julian Date (Note 1)
**   uta,utb double      UT1 as a 2-part Julian Date (Note 1)
**   xp,yp   double      coordinates of the pole (radians, Note 2)
**
** Returned:
**   rc2t     double[3][3] celestial-to-terrestrial matrix (Note 3)
**
** Notes:
**
** 1) The TT and UT1 dates tta+ttb and uta+utb are Julian Dates,
** apportioned in any convenient way between the arguments uta and
** utb. For example, JD(UT1)=2450123.7 could be expressed in any of
** these ways, among others:
**
**           uta           utb
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution is
** acceptable. The J2000 and MJD methods are good compromises
** between resolution and convenience. In the case of uta,utb, the
** date & time method is best matched to the Earth rotation angle
** algorithm used: maximum precision is delivered when the uta
** argument is for 0hrs UT1 on the day in question and the utb
** argument lies in the range 0 to 1, or vice versa.
**
** 2) The arguments xp and yp are the coordinates (in radians) of the
** Celestial Intermediate Pole with respect to the International
** Terrestrial Reference System (see IERS Conventions 2003),
** measured along the meridians to 0 and 90 deg west respectively.
**
** 3) The matrix rc2t transforms from celestial to terrestrial
** coordinates:
**
**           [TRS] = RPOM * R_3(ERA) * RC2I * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003), RC2I is the
** celestial-to-intermediate matrix, ERA is the Earth rotation
** angle and RPOM is the polar motion matrix.
**
** Called:
**   iauC2i06a celestial-to-intermediate matrix, IAU 2006/2000A
**   iauEra00  Earth rotation angle, IAU 2000
**   iauSp00   the TIO locator s', IERS 2000
**   iauPom00  polar motion matrix
**   iauC2tcio form CIO-based celestial-to-terrestrial matrix

```

\*\*  
\*\* Reference:  
\*\*  
\*\*     McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),  
\*\*     IERS Technical Note No. 32, BKG  
\*\*  
\*/

```

void iauC2tcio(double rc2i[3][3], double era, double rpom[3][3],
              double rc2t[3][3])
/*
**  - - - - -
**   i a u C 2 t c i o
**  - - - - -
**
** Assemble the celestial to terrestrial matrix from CIO-based
** components (the celestial-to-intermediate matrix, the Earth Rotation
** Angle and the polar motion matrix).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rc2i      double[3][3]   celestial-to-intermediate matrix
**   era       double         Earth rotation angle (radians)
**   rpom      double[3][3]   polar-motion matrix
**
** Returned:
**   rc2t      double[3][3]   celestial-to-terrestrial matrix
**
** Notes:
**
** 1) This function constructs the rotation matrix that transforms
** vectors in the celestial system into vectors in the terrestrial
** system. It does so starting from precomputed components, namely
** the matrix which rotates from celestial coordinates to the
** intermediate frame, the Earth rotation angle and the polar motion
** matrix. One use of the present function is when generating a
** series of celestial-to-terrestrial matrices where only the Earth
** Rotation Angle changes, avoiding the considerable overhead of
** recomputing the precession-nutation more often than necessary to
** achieve given accuracy objectives.
**
** 2) The relationship between the arguments is as follows:
**
**      [TRS] = RPOM * R_3(ERA) * rc2i * [CRS]
**
**          = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003).
**
** Called:
**   iauCr      copy r-matrix
**   iauRz      rotate around Z-axis
**   iauRxr     product of two r-matrices
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG
**
*/

```

```

void iauC2teqx(double rbpn[3][3], double gst, double rpom[3][3],
              double rc2t[3][3])
/*
**  - - - - -
**   i a u C 2 t e q x
**  - - - - -
**
** Assemble the celestial to terrestrial matrix from equinox-based
** components (the celestial-to-true matrix, the Greenwich Apparent
** Sidereal Time and the polar motion matrix).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rbpn   double[3][3]  celestial-to-true matrix
**   gst    double        Greenwich (apparent) Sidereal Time (radians)
**   rpom   double[3][3]  polar-motion matrix
**
** Returned:
**   rc2t   double[3][3]  celestial-to-terrestrial matrix (Note 2)
**
** Notes:
**
** 1) This function constructs the rotation matrix that transforms
** vectors in the celestial system into vectors in the terrestrial
** system. It does so starting from precomputed components, namely
** the matrix which rotates from celestial coordinates to the
** true equator and equinox of date, the Greenwich Apparent Sidereal
** Time and the polar motion matrix. One use of the present function
** is when generating a series of celestial-to-terrestrial matrices
** where only the Sidereal Time changes, avoiding the considerable
** overhead of recomputing the precession-nutation more often than
** necessary to achieve given accuracy objectives.
**
** 2) The relationship between the arguments is as follows:
**
**       [TRS] = rpom * R_3(gst) * rbpn * [CRS]
**
**           = rc2t * [CRS]
**
** where [CRS] is a vector in the Geocentric Celestial Reference
** System and [TRS] is a vector in the International Terrestrial
** Reference System (see IERS Conventions 2003).
**
** Called:
**   iauCr          copy r-matrix
**   iauRz          rotate around Z-axis
**   iauRxr         product of two r-matrices
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

void iauC2tpe(double tta, double ttb, double uta, double utb,
             double dpsl, double depl, double xp, double yp,
             double rc2t[3][3])
/*
**   - - - - -
**   i a u C 2 t p e
**   - - - - -
**
**   Form the celestial to terrestrial matrix given the date, the UT1,
**   the nutation and the polar motion.  IAU 2000.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     tta,ttb      double          TT as a 2-part Julian Date (Note 1)
**     uta,utb      double          UT1 as a 2-part Julian Date (Note 1)
**     dpsl,depl    double          nutation (Note 2)
**     xp,yp        double          coordinates of the pole (radians, Note 3)
**
**   Returned:
**     rc2t         double[3][3]    celestial-to-terrestrial matrix (Note 4)
**
**   Notes:
**
**   1) The TT and UT1 dates tta+ttb and uta+utb are Julian Dates,
**      apportioned in any convenient way between the arguments uta and
**      utb.  For example, JD(UT1)=2450123.7 could be expressed in any of
**      these ways, among others:
**
**          uta          utb
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2       (MJD method)
**          2450123.5          0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution is
**   acceptable.  The J2000 and MJD methods are good compromises
**   between resolution and convenience.  In the case of uta,utb, the
**   date & time method is best matched to the Earth rotation angle
**   algorithm used:  maximum precision is delivered when the uta
**   argument is for 0hrs UT1 on the day in question and the utb
**   argument lies in the range 0 to 1, or vice versa.
**
**   2) The caller is responsible for providing the nutation components;
**      they are in longitude and obliquity, in radians and are with
**      respect to the equinox and ecliptic of date.  For high-accuracy
**      applications, free core nutation should be included as well as
**      any other relevant corrections to the position of the CIP.
**
**   3) The arguments xp and yp are the coordinates (in radians) of the
**      Celestial Intermediate Pole with respect to the International
**      Terrestrial Reference System (see IERS Conventions 2003),
**      measured along the meridians to 0 and 90 deg west respectively.
**
**   4) The matrix rc2t transforms from celestial to terrestrial
**      coordinates:
**
**          [TRS] = RPOM * R_3(GST) * RBPN * [CRS]
**
**          = rc2t * [CRS]
**
**   where [CRS] is a vector in the Geocentric Celestial Reference
**   System and [TRS] is a vector in the International Terrestrial
**   Reference System (see IERS Conventions 2003), RBPN is the
**   bias-precession-nutation matrix, GST is the Greenwich (apparent)
**   Sidereal Time and RPOM is the polar motion matrix.

```

```
**
** 5) Although its name does not include "00", This function is in fact
**     specific to the IAU 2000 models.
**
** Called:
**   iauPn00      bias/precession/nutation results, IAU 2000
**   iauGmst00   Greenwich mean sidereal time, IAU 2000
**   iauSp00     the TIO locator s', IERS 2000
**   iauEe00     equation of the equinoxes, IAU 2000
**   iauPom00    polar motion matrix
**   iauC2teqx   form equinox-based celestial-to-terrestrial matrix
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**/
```

```

void iauC2txy(double tta, double ttb, double uta, double utb,
              double x, double y, double xp, double yp,
              double rc2t[3][3])
/*
**   - - - - -
**   i a u C 2 t x y
**   - - - - -
**
**   Form the celestial to terrestrial matrix given the date, the UT1,
**   the CIP coordinates and the polar motion.  IAU 2000.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     tta,ttb  double          TT as a 2-part Julian Date (Note 1)
**     uta,utb  double          UT1 as a 2-part Julian Date (Note 1)
**     x,y      double          Celestial Intermediate Pole (Note 2)
**     xp,yp    double          coordinates of the pole (radians, Note 3)
**
**   Returned:
**     rc2t     double[3][3]    celestial-to-terrestrial matrix (Note 4)
**
**   Notes:
**
**   1) The TT and UT1 dates tta+ttb and uta+utb are Julian Dates,
**      apportioned in any convenient way between the arguments uta and
**      utb.  For example, JD(UT1)=2450123.7 could be expressed in any o
**      these ways, among others:
**
**          uta          utb
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2        (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution is
**      acceptable.  The J2000 and MJD methods are good compromises
**      between resolution and convenience.  In the case of uta,utb, the
**      date & time method is best matched to the Earth rotation angle
**      algorithm used:  maximum precision is delivered when the uta
**      argument is for 0hrs UT1 on the day in question and the utb
**      argument lies in the range 0 to 1, or vice versa.
**
**   2) The Celestial Intermediate Pole coordinates are the x,y
**      components of the unit vector in the Geocentric Celestial
**      Reference System.
**
**   3) The arguments xp and yp are the coordinates (in radians) of the
**      Celestial Intermediate Pole with respect to the International
**      Terrestrial Reference System (see IERS Conventions 2003),
**      measured along the meridians to 0 and 90 deg west respectively.
**
**   4) The matrix rc2t transforms from celestial to terrestrial
**      coordinates:
**
**          [TRS] = RPOM * R_3(ERA) * RC2I * [CRS]
**
**          = rc2t * [CRS]
**
**      where [CRS] is a vector in the Geocentric Celestial Reference
**      System and [TRS] is a vector in the International Terrestrial
**      Reference System (see IERS Conventions 2003), ERA is the Earth
**      Rotation Angle and RPOM is the polar motion matrix.
**
**   5) Although its name does not include "00", This function is in fact
**      specific to the IAU 2000 models.

```

```
**
** Called:
**   iauC2ixy      celestial-to-intermediate matrix, given X,Y
**   iauEra00     Earth rotation angle, IAU 2000
**   iauSp00      the TIO locator s', IERS 2000
**   iauPom00     polar motion matrix
**   iauC2tcio    form CIO-based celestial-to-terrestrial matrix
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**/
```

```

int iauCal2jd(int iy, int im, int id, double *djm0, double *djm)
/*
**   - - - - -
**   i a u C a l 2 j d
**   - - - - -
**
**   Gregorian Calendar to Julian Date.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     iy,im,id  int      year, month, day in Gregorian calendar (Note 1)
**
**   Returned:
**     djm0      double   MJD zero-point: always 2400000.5
**     djm       double   Modified Julian Date for 0 hrs
**
**   Returned (function value):
**     int      status:
**             0 = OK
**            -1 = bad year   (Note 3: JD not computed)
**            -2 = bad month  (JD not computed)
**            -3 = bad day    (JD computed)
**
**   Notes:
**
**   1) The algorithm used is valid from -4800 March 1, but this
**      implementation rejects dates before -4799 January 1.
**
**   2) The Julian Date is returned in two pieces, in the usual SOFA
**      manner, which is designed to preserve time resolution.  The
**      Julian Date is available as a single number by adding djm0 and
**      djm.
**
**   3) In early eras the conversion is from the "Proleptic Gregorian
**      Calendar"; no account is taken of the date(s) of adoption of
**      the Gregorian Calendar, nor is the AD/BC numbering convention
**      observed.
**
**   Reference:
**
**     Explanatory Supplement to the Astronomical Almanac,
**     P. Kenneth Seidelmann (ed), University Science Books (1992),
**     Section 12.92 (p604).
**
*/

```

```
void iauCp(double p[3], double c[3])
/*
**  - - - - -
**   i a u C p
**  - - - - -
**
**   Copy a p-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     p      double[3]    p-vector to be copied
**
**   Returned:
**     c      double[3]    copy
**
**/
```

```
void iauCpv(double pv[2][3], double c[2][3])
/*
** - - - - -
**   i a u C p v
** - - - - -
**
** Copy a position/velocity vector.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   pv      double[2][3]    position/velocity vector to be copied
**
** Returned:
**   c       double[2][3]    copy
**
** Called:
**   iauCp      copy p-vector
**
** */
```

```
void iauCr(double r[3][3], double c[3][3])
/*
**  - - - - -
**    i a u C r
**  - - - - -
**
**  Copy an r-matrix.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    r          double[3][3]    r-matrix to be copied
**
**  Returned:
**    c          double[3][3]    copy
**
**  Called:
**    iauCp          copy p-vector
**
**  */
```

```

int iauD2dtf(const char *scale, int ndp, double d1, double d2,
            int *iy, int *im, int *id, int ihmsf[4])
/*
**  - - - - -
**   i a u D 2 d t f
**  - - - - -
**
**  Format for output a 2-part Julian Date (or in the case of UTC a
**  quasi-JD form that includes special provision for leap seconds).
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    scale      char[]  time scale ID (Note 1)
**    ndp        int     resolution (Note 2)
**    d1,d2      double  time as a 2-part Julian Date (Notes 3,4)
**
**  Returned:
**    iy,im,id   int     year, month, day in Gregorian calendar (Note 5)
**    ihmsf      int[4]  hours, minutes, seconds, fraction (Note 1)
**
**  Returned (function value):
**    int        status: +1 = dubious year (Note 5)
**                  0 = OK
**                  -1 = unacceptable date (Note 6)
**
**  Notes:
**
**  1) scale identifies the time scale.  Only the value "UTC" (in upper
**     case) is significant, and enables handling of leap seconds (see
**     Note 4).
**
**  2) ndp is the number of decimal places in the seconds field, and can
**     have negative as well as positive values, such as:
**
**     ndp          resolution
**     -4           1 00 00
**     -3           0 10 00
**     -2           0 01 00
**     -1           0 00 10
**     0            0 00 01
**     1            0 00 00.1
**     2            0 00 00.01
**     3            0 00 00.001
**
**     The limits are platform dependent, but a safe range is -5 to +9.
**
**  3) d1+d2 is Julian Date, apportioned in any convenient way between
**     the two arguments, for example where d1 is the Julian Day Number
**     and d2 is the fraction of a day.  In the case of UTC, where the
**     use of JD is problematical, special conventions apply:  see the
**     next note.
**
**  4) JD cannot unambiguously represent UTC during a leap second unless
**     special measures are taken.  The SOFA internal convention is that
**     the quasi-JD day represents UTC days whether the length is 86399,
**     86400 or 86401 SI seconds.  In the 1960-1972 era there were
**     smaller jumps (in either direction) each time the linear UTC(TAI)
**     expression was changed, and these "mini-leaps" are also included
**     in the SOFA convention.
**
**  5) The warning status "dubious year" flags UTCs that predate the
**     introduction of the time scale or that are too far in the future
**     to be trusted.  See iauDat for further details.
**
**  6) For calendar conventions and limitations, see iauCal2jd.
**
**  Called:

```

```
**      iauJd2cal   JD to Gregorian calendar
**      iauD2tf    decompose days to hms
**      iauDat     delta(AT) = TAI-UTC
**
*/
```

```

void iauD2tf(int ndp, double days, char *sign, int ihmsf[4])
/*
**  - - - - -
**   i a u D 2 t f
**  - - - - -
**
**  Decompose days to hours, minutes, seconds, fraction.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    ndp      int      resolution (Note 1)
**    days     double   interval in days
**
**  Returned:
**    sign     char     '+' or '-'
**    ihmsf    int[4]   hours, minutes, seconds, fraction
**
**  Notes:
**
**  1) The argument ndp is interpreted as follows:
**
**      ndp      resolution
**      :        ...0000 00 00
**      -7       1000 00 00
**      -6       100 00 00
**      -5       10 00 00
**      -4       1 00 00
**      -3       0 10 00
**      -2       0 01 00
**      -1       0 00 10
**      0        0 00 01
**      1        0 00 00.1
**      2        0 00 00.01
**      3        0 00 00.001
**      :        0 00 00.000...
**
**  2) The largest positive useful value for ndp is determined by the
**  size of days, the format of double on the target platform, and
**  the risk of overflowing ihmsf[3].  On a typical platform, for
**  days up to 1.0, the available floating-point precision might
**  correspond to ndp=12.  However, the practical limit is typically
**  ndp=9, set by the capacity of a 32-bit int, or ndp=4 if int is
**  only 16 bits.
**
**  3) The absolute value of days may exceed 1.0.  In cases where it
**  does not, it is up to the caller to test for and handle the
**  case where days is very nearly 1.0 and rounds up to 24 hours,
**  by testing for ihmsf[0]=24 and setting ihmsf[0-3] to zero.
**
*/

```



```

**      advance, a reliable check for dates beyond the valid range is
**      impossible. To guard against gross errors, a year five or more
**      after the release year of the present function (see the constant
**      IYV) is considered dubious. In this case a warning status is
**      returned but the result is computed in the normal way.
**
**      For both too-early and too-late years, the warning status is +1.
**      This is distinct from the error status -1, which signifies a year
**      so early that JD could not be computed.
**
**      2) If the specified date is for a day which ends with a leap second,
**      the UTC-TAI value returned is for the period leading up to the
**      leap second. If the date is for a day which begins as a leap
**      second ends, the UTC-TAI returned is for the period following the
**      leap second.
**
**      3) The day number must be in the normal calendar range, for example
**      1 through 30 for April. The "almanac" convention of allowing
**      such dates as January 0 and December 32 is not supported in this
**      function, in order to avoid confusion near leap seconds.
**
**      4) The fraction of day is used only for dates before the
**      introduction of leap seconds, the first of which occurred at the
**      end of 1971. It is tested for validity (0 to 1 is the valid
**      range) even if not used; if invalid, zero is used and status -4
**      is returned. For many applications, setting fd to zero is
**      acceptable; the resulting error is always less than 3 ms (and
**      occurs only pre-1972).
**
**      5) The status value returned in the case where there are multiple
**      errors refers to the first error detected. For example, if the
**      month and day are 13 and 32 respectively, status -2 (bad month)
**      will be returned. The "internal error" status refers to a
**      case that is impossible but causes some compilers to issue a
**      warning.
**
**      6) In cases where a valid result is not available, zero is returned.
**
**      References:
**
**      1) For dates from 1961 January 1 onwards, the expressions from the
**      file ftp://maia.usno.navy.mil/ser7/tai-utc.dat are used.
**
**      2) The 5ms timestep at 1961 January 1 is taken from 2.58.1 (p87) of
**      the 1992 Explanatory Supplement.
**
**      Called:
**      iauCal2jd      Gregorian calendar to JD
**
**/

```

```

double iauDtdb(double date1, double date2,
               double ut, double along, double u, double v)
/*
**   - - - - -
**   i a u D t d b
**   - - - - -
**
**   An approximation to TDB-TT, the difference between barycentric
**   dynamical time and terrestrial time, for an observer on the Earth.
**
**   The different time scales - proper, coordinate and realized - are
**   related to each other:
**
**           TAI           <- physically realized
**           :
**           offset       <- observed (nominally +32.184s)
**           :
**           TT           <- terrestrial time
**           :
**           rate adjustment (L_G) <- definition of TT
**           :
**           TCG         <- time scale for GCRS
**           :
**           "periodic" terms <- iauDtdb is an implementation
**           :
**           rate adjustment (L_C) <- function of solar-system ephemeris
**           :
**           TCB         <- time scale for BCRS
**           :
**           rate adjustment (-L_B) <- definition of TDB
**           :
**           TDB         <- TCB scaled to track TT
**           :
**           "periodic" terms <- -iauDtdb is an approximation
**           :
**           TT          <- terrestrial time
**
**   Adopted values for the various constants can be found in the IERS
**   Conventions (McCarthy & Petit 2003).
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status: support routine.
**
**   Given:
**       date1,date2  double  date, TDB (Notes 1-3)
**       ut          double  universal time (UT1, fraction of one day)
**       along       double  longitude (east positive, radians)
**       u           double  distance from Earth spin axis (km)
**       v           double  distance north of equatorial plane (km)
**
**   Returned (function value):
**       double      TDB-TT (seconds)
**
**   Notes:
**
**   1) The date date1+date2 is a Julian Date, apportioned in any
**   convenient way between the two arguments. For example,
**   JD(TT)=2450123.7 could be expressed in any of these ways,
**   among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0        -1421.3        (J2000 method)
**           2400000.5         50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution

```

```

**      is acceptable.  The J2000 method is best matched to the way
**      the argument is handled internally and will deliver the
**      optimum resolution.  The MJD method and the date & time methods
**      are both good compromises between resolution and convenience.
**
**      Although the date is, formally, barycentric dynamical time (TDB),
**      the terrestrial dynamical time (TT) can be used with no practical
**      effect on the accuracy of the prediction.
**
**      2) TT can be regarded as a coordinate time that is realized as an
**      offset of 32.184s from International Atomic Time, TAI.  TT is a
**      specific linear transformation of geocentric coordinate time TCG,
**      which is the time scale for the Geocentric Celestial Reference
**      System, GCRS.
**
**      3) TDB is a coordinate time, and is a specific linear transformation
**      of barycentric coordinate time TCB, which is the time scale for
**      the Barycentric Celestial Reference System, BCRS.
**
**      4) The difference TCG-TCB depends on the masses and positions of the
**      bodies of the solar system and the velocity of the Earth.  It is
**      dominated by a rate difference, the residual being of a periodic
**      character.  The latter, which is modeled by the present function,
**      comprises a main (annual) sinusoidal term of amplitude
**      approximately 0.00166 seconds, plus planetary terms up to about
**      20 microseconds, and lunar and diurnal terms up to 2 microseconds.
**      These effects come from the changing transverse Doppler effect
**      and gravitational red-shift as the observer (on the Earth's
**      surface) experiences variations in speed (with respect to the
**      BCRS) and gravitational potential.
**
**      5) TDB can be regarded as the same as TCB but with a rate adjustment
**      to keep it close to TT, which is convenient for many applications.
**      The history of successive attempts to define TDB is set out in
**      Resolution 3 adopted by the IAU General Assembly in 2006, which
**      defines a fixed TDB(TCB) transformation that is consistent with
**      contemporary solar-system ephemerides.  Future ephemerides will
**      imply slightly changed transformations between TCG and TCB, which
**      could introduce a linear drift between TDB and TT; however, any
**      such drift is unlikely to exceed 1 nanosecond per century.
**
**      6) The geocentric TDB-TT model used in the present function is that of
**      Fairhead & Bretagnon (1990), in its full form.  It was originally
**      supplied by Fairhead (private communications with P.T.Wallace,
**      1990) as a Fortran subroutine.  The present C function contains an
**      adaptation of the Fairhead code.  The numerical results are
**      essentially unaffected by the changes, the differences with
**      respect to the Fairhead & Bretagnon original being at the 1e-20 s
**      level.
**
**      The topocentric part of the model is from Moyer (1981) and
**      Murray (1983), with fundamental arguments adapted from
**      Simon et al. 1994.  It is an approximation to the expression
**       $(v/c) \cdot (r/c)$ , where  $v$  is the barycentric velocity of
**      the Earth,  $r$  is the geocentric position of the observer and
**       $c$  is the speed of light.
**
**      By supplying zeroes for  $u$  and  $v$ , the topocentric part of the
**      model can be nullified, and the function will return the Fairhead
**      & Bretagnon result alone.
**
**      7) During the interval 1950-2050, the absolute accuracy is better
**      than +/- 3 nanoseconds relative to time ephemerides obtained by
**      direct numerical integrations based on the JPL DE405 solar system
**      ephemeris.
**
**      8) It must be stressed that the present function is merely a model,
**      and that numerical integration of solar-system ephemerides is the
**      definitive method for predicting the relationship between TCG and
**      TCB and hence between TT and TDB.
**
**      References:
**

```

\*\* Fairhead, L., & Bretagnon, P., *Astron.Astrophys.*, 229, 240-247  
\*\* (1990).  
\*\*  
\*\* IAU 2006 Resolution 3.  
\*\*  
\*\* McCarthy, D. D., Petit, G. (eds.), *IERS Conventions* (2003),  
\*\* *IERS Technical Note No. 32*, BKG (2004)  
\*\*  
\*\* Moyer, T.D., *Cel.Mech.*, 23, 33 (1981).  
\*\*  
\*\* Murray, C.A., *Vectorial Astrometry*, Adam Hilger (1983).  
\*\*  
\*\* Seidelmann, P.K. et al., *Explanatory Supplement to the*  
\*\* *Astronomical Almanac*, Chapter 2, University Science Books (1992).  
\*\*  
\*\* Simon, J.L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,  
\*\* Francou, G. & Laskar, J., *Astron.Astrophys.*, 282, 663-683 (1994).  
\*\*  
\*\*/  
\*/

```

int iauDtf2d(const char *scale, int iy, int im, int id,
             int ihr, int imm, double sec, double *d1, double *d2)
/*
**  - - - - -
**   i a u D t f 2 d
**  - - - - -
**
** Encode date and time fields into 2-part Julian Date (or in the case
** of UTC a quasi-JD form that includes special provision for leap
** seconds).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   scale      char[]  time scale ID (Note 1)
**   iy,im,id   int     year, month, day in Gregorian calendar (Note 2)
**   ihr,imm    int     hour, minute
**   sec        double  seconds
**
** Returned:
**   d1,d2      double  2-part Julian Date (Notes 3,4)
**
** Returned (function value):
**   int        status: +3 = both of next two
**                   +2 = time is after end of day (Note 5)
**                   +1 = dubious year (Note 6)
**                   0  = OK
**                   -1 = bad year
**                   -2 = bad month
**                   -3 = bad day
**                   -4 = bad hour
**                   -5 = bad minute
**                   -6 = bad second (<0)
**
** Notes:
**
** 1) scale identifies the time scale.  Only the value "UTC" (in upper
** case) is significant, and enables handling of leap seconds (see
** Note 4).
**
** 2) For calendar conventions and limitations, see iauCal2jd.
**
** 3) The sum of the results, d1+d2, is Julian Date, where normally d1
** is the Julian Day Number and d2 is the fraction of a day.  In the
** case of UTC, where the use of JD is problematical, special
** conventions apply:  see the next note.
**
** 4) JD cannot unambiguously represent UTC during a leap second unless
** special measures are taken.  The SOFA internal convention is that
** the quasi-JD day represents UTC days whether the length is 86399,
** 86400 or 86401 SI seconds.  In the 1960-1972 era there were
** smaller jumps (in either direction) each time the linear UTC(TAI)
** expression was changed, and these "mini-leaps" are also included
** in the SOFA convention.
**
** 5) The warning status "time is after end of day" usually means that
** the sec argument is greater than 60.0.  However, in a day ending
** in a leap second the limit changes to 61.0 (or 59.0 in the case
** of a negative leap second).
**
** 6) The warning status "dubious year" flags UTCs that predate the
** introduction of the time scale or that are too far in the future
** to be trusted.  See iauDat for further details.
**
** 7) Only in the case of continuous and regular time scales (TAI, TT,
** TCG, TCB and TDB) is the result d1+d2 a Julian Date, strictly
** speaking.  In the other cases (UT1 and UTC) the result must be
** used with circumspection;  in particular the difference between

```

```
**      two such results cannot be interpreted as a precise time
**      interval.
**
**      Called:
**      iauCal2jd      Gregorian calendar to JD
**      iauDat        delta(AT) = TAI-UTC
**      iauJd2cal     JD to Gregorian calendar
**
**/
```

```

void iauEceq06(double date1, double date2, double dl, double db,
               double *dr, double *dd)
/*
**  - - - - -
**   i a u E c e q 0 6
**  - - - - -
**
** Transformation from ecliptic coordinates (mean equinox and ecliptic
** of date) to ICRS RA,Dec, using the IAU 2006 precession model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2 double TT as a 2-part Julian date (Note 1)
**   dl,db      double ecliptic longitude and latitude (radians)
**
** Returned:
**   dr,dd      double ICRS right ascension and declination (radians)
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) No assumptions are made about whether the coordinates represent
** starlight and embody astrometric effects such as parallax or
** aberration.
**
** 3) The transformation is approximately that from ecliptic longitude
** and latitude (mean equinox and ecliptic of date) to mean J2000.0
** right ascension and declination, with only frame bias (always
** less than 25 mas) to disturb this classical picture.
**
** Called:
**   iauS2c      spherical coordinates to unit vector
**   iauEcm06    J2000.0 to ecliptic rotation matrix, IAU 2006
**   iauTrxp     product of transpose of r-matrix and p-vector
**   iauC2s      unit vector to spherical coordinates
**   iauAnp      normalize angle into range 0 to 2pi
**   iauAnpm     normalize angle into range +/- pi
**
*/

```

```

void iauEcm06(double date1, double date2, double rm[3][3])
/*
**  - - - - -
**   i a u E c m 0 6
**  - - - - -
**
**   ICRS equatorial to ecliptic rotation matrix, IAU 2006.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     date1,date2  double          TT as a 2-part Julian date (Note 1)
**
**   Returned:
**     rm          double[3][3]    ICRS to ecliptic rotation matrix
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution
**   is acceptable.  The J2000 method is best matched to the way
**   the argument is handled internally and will deliver the
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**
**   1) The matrix is in the sense
**
**           E_ep = rm x P_ICRS,
**
**   where P_ICRS is a vector with respect to ICRS right ascension
**   and declination axes and E_ep is the same vector with respect to
**   the (inertial) ecliptic and equinox of date.
**
**   2) P_ICRS is a free vector, merely a direction, typically of unit
**   magnitude, and not bound to any particular spatial origin, such
**   as the Earth, Sun or SSB.  No assumptions are made about whether
**   it represents starlight and embodies astrometric effects such as
**   parallax or aberration.  The transformation is approximately that
**   between mean J2000.0 right ascension and declination and ecliptic
**   longitude and latitude, with only frame bias (always less than
**   25 mas) to disturb this classical picture.
**
**   Called:
**     iauObl06    mean obliquity, IAU 2006
**     iauPmat06   PB matrix, IAU 2006
**     iauIr       initialize r-matrix to identity
**     iauRx       rotate around X-axis
**     iauRxx      product of two r-matrices
**
*/

```

```

double iauEe00(double date1, double date2, double epsa, double dpsi)
/*
**   - - - - -
**   i a u E e 0 0
**   - - - - -
**
** The equation of the equinoxes, compatible with IAU 2000 resolutions,
** given the nutation in longitude and the mean obliquity.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2  double   TT as a 2-part Julian Date (Note 1)
**   epsa        double   mean obliquity (Note 2)
**   dpsi        double   nutation in longitude (Note 3)
**
** Returned (function value):
**   double      equation of the equinoxes (Note 4)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The obliquity, in radians, is mean of date.
**
** 3) The result, which is in radians, operates in the following sense:
**
**           Greenwich apparent ST = GMST + equation of the equinoxes
**
** 4) The result is compatible with the IAU 2000 resolutions. For
** further details, see IERS Conventions 2003 and Capitaine et al.
** (2002).
**
** Called:
**   iauEect00      equation of the equinoxes complementary terms
**
** References:
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003)
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

double iauEe00a(double date1, double date2)
/*
**  - - - - -
**   i a u E e 0 0 a
**  - - - - -
**
** Equation of the equinoxes, compatible with IAU 2000 resolutions.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double    TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      equation of the equinoxes (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result, which is in radians, operates in the following sense:
**
**           Greenwich apparent ST = GMST + equation of the equinoxes
**
** 3) The result is compatible with the IAU 2000 resolutions.  For
** further details, see IERS Conventions 2003 and Capitaine et al.
** (2002).
**
** Called:
**   iauPr00      IAU 2000 precession adjustments
**   iauObl80     mean obliquity, IAU 1980
**   iauNut00a    nutation, IAU 2000A
**   iauEe00     equation of the equinoxes, IAU 2000
**
** References:
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003).
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004).
**
*/

```

```

double iauEe00b(double date1, double date2)
/*
**   - - - - -
**   i a u E e 0 0 b
**   - - - - -
**
** Equation of the equinoxes, compatible with IAU 2000 resolutions but
** using the truncated nutation model IAU 2000B.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double equation of the equinoxes (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result, which is in radians, operates in the following sense:
**
**           Greenwich apparent ST = GMST + equation of the equinoxes
**
** 3) The result is compatible with the IAU 2000 resolutions except
** that accuracy has been compromised for the sake of speed. For
** further details, see McCarthy & Luzum (2001), IERS Conventions
** 2003 and Capitaine et al. (2003).
**
** Called:
**   iauPr00 IAU 2000 precession adjustments
**   iauObl80 mean obliquity, IAU 1980
**   iauNut00b nutation, IAU 2000B
**   iauEe00 equation of the equinoxes, IAU 2000
**
** References:
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003)
**
** McCarthy, D.D. & Luzum, B.J., "An abridged model of the
** precession-nutation of the celestial pole", Celestial Mechanics &
** Dynamical Astronomy, 85, 37-49 (2003)
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

double iauEe06a(double date1, double date2)
/*
**   - - - - -
**   i a u E e 0 6 a
**   - - - - -
**
** Equation of the equinoxes, compatible with IAU 2000 resolutions and
** IAU 2006/2000A precession-nutation.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   date1,date2 double TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double equation of the equinoxes (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result, which is in radians, operates in the following sense:
**
**           Greenwich apparent ST = GMST + equation of the equinoxes
**
** Called:
**   iauAnpm normalize angle into range +/- pi
**   iauGst06a Greenwich apparent sidereal time, IAU 2006/2000A
**   iauGmst06 Greenwich mean sidereal time, IAU 2006
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG
**
*/

```

```

double iauEect00(double date1, double date2)
/*
**  - - - - -
**   i a u E e c t 0 0
**  - - - - -
**
** Equation of the equinoxes complementary terms, consistent with
** IAU 2000 resolutions.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  canonical model.
**
** Given:
**   date1,date2  double   TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      complementary terms (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The "complementary terms" are part of the equation of the
** equinoxes (EE), classically the difference between apparent and
** mean Sidereal Time:
**
**           GAST = GMST + EE
**
** with:
**
**           EE = dps_i * cos(eps)
**
** where dps_i is the nutation in longitude and eps is the obliquity
** of date.  However, if the rotation of the Earth were constant in
** an inertial frame the classical formulation would lead to
** apparent irregularities in the UT1 timescale traceable to side-
** effects of precession-nutation.  In order to eliminate these
** effects from UT1, "complementary terms" were introduced in 1994
** (IAU, 1994) and took effect from 1997 (Capitaine and Gontier,
** 1993):
**
**           GAST = GMST + CT + EE
**
** By convention, the complementary terms are included as part of
** the equation of the equinoxes rather than as part of the mean
** Sidereal Time.  This slightly compromises the "geometrical"
** interpretation of mean sidereal time but is otherwise
** inconsequential.
**
** The present function computes CT in the above expression,
** compatible with IAU 2000 resolutions (Capitaine et al., 2002, and
** IERS Conventions 2003).

```

```
**
** Called:
**   iauFal03   mean anomaly of the Moon
**   iauFalp03  mean anomaly of the Sun
**   iauFaf03   mean argument of the latitude of the Moon
**   iauFad03   mean elongation of the Moon from the Sun
**   iauFaom03  mean longitude of the Moon's ascending node
**   iauFave03  mean longitude of Venus
**   iauFae03   mean longitude of Earth
**   iauFapa03  general accumulated precession in longitude
**
** References:
**
**   Capitaine, N. & Gontier, A.-M., Astron. Astrophys., 275,
**   645-650 (1993)
**
**   Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
**   implement the IAU 2000 definition of UT1", Astronomy &
**   Astrophysics, 406, 1135-1149 (2003)
**
**   IAU Resolution C7, Recommendation 3 (1994)
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
** /
```

```

int iauEform ( int n, double *a, double *f )
/*
**  - - - - -
**   i a u E f o r m
**  - - - - -
**
** Earth reference ellipsoids.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  canonical.
**
** Given:
**   n      int           ellipsoid identifier (Note 1)
**
** Returned:
**   a      double        equatorial radius (meters, Note 2)
**   f      double        flattening (Note 2)
**
** Returned (function value):
**   int     status:      0 = OK
**                       -1 = illegal identifier (Note 3)
**
** Notes:
**
** 1) The identifier n is a number that specifies the choice of
**    reference ellipsoid.  The following are supported:
**
**      n      ellipsoid
**
**      1      WGS84
**      2      GRS80
**      3      WGS72
**
** The n value has no significance outside the SOFA software.  For
** convenience, symbols WGS84 etc. are defined in sofam.h.
**
** 2) The ellipsoid parameters are returned in the form of equatorial
**    radius in meters (a) and flattening (f).  The latter is a number
**    around 0.00335, i.e. around 1/298.
**
** 3) For the case where an unsupported n value is supplied, zero a and
**    f are returned, as well as error status.
**
** References:
**
** Department of Defense World Geodetic System 1984, National
** Imagery and Mapping Agency Technical Report 8350.2, Third
** Edition, p3-2.
**
** Moritz, H., Bull. Geodesique 66-2, 187 (1992).
**
** The Department of Defense World Geodetic System 1972, World
** Geodetic System Committee, May 1974.
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** p220.
**
** */

```

```

double iauEo06a(double datel, double date2)
/*
**  - - - - -
**   i a u E o 0 6 a
**  - - - - -
**
** Equation of the origins, IAU 2006 precession and IAU 2000A nutation.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   datel,date2  double    TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      equation of the origins in radians
**
** Notes:
**
** 1) The TT date datel+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           datel      date2
**
**           2450123.7      0.0      (JD method)
**           2451545.0     -1421.3    (J2000 method)
**           2400000.5      50123.2    (MJD method)
**           2450123.5      0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The equation of the origins is the distance between the true
** equinox and the celestial intermediate origin and, equivalently,
** the difference between Earth rotation angle and Greenwich
** apparent sidereal time (ERA-GST).  It comprises the precession
** (since J2000.0) in right ascension plus the equation of the
** equinoxes (including the small correction terms).
**
** Called:
**   iauPnm06a  classical NPB matrix, IAU 2006/2000A
**   iauBpn2xy  extract CIP X,Y coordinates from NPB matrix
**   iauS06     the CIO locator s, given X,Y, IAU 2006
**   iauEors    equation of the origins, given NPB matrix and s
**
** References:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**   Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

double iauEors(double rnpb[3][3], double s)
/*
**  - - - - -
**   i a u E o r s
**  - - - - -
**
** Equation of the origins, given the classical NPB matrix and the
** quantity s.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rnpb  double[3][3]  classical nutation x precession x bias matrix
**   s     double       the quantity s (the CIO locator)
**
** Returned (function value):
**   double       the equation of the origins in radians.
**
** Notes:
**
** 1) The equation of the origins is the distance between the true
**    equinox and the celestial intermediate origin and, equivalently,
**    the difference between Earth rotation angle and Greenwich
**    apparent sidereal time (ERA-GST). It comprises the precession
**    (since J2000.0) in right ascension plus the equation of the
**    equinoxes (including the small correction terms).
**
** 2) The algorithm is from Wallace & Capitaine (2006).
**
** References:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**   Wallace, P. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

double iauEpb(double dj1, double dj2)
/*
**  - - - - -
**   i a u E p b
**  - - - - -
**
**   Julian Date to Besselian Epoch.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     dj1,dj2    double    Julian Date (see note)
**
**   Returned (function value):
**     double    Besselian Epoch.
**
**   Note:
**
**     The Julian Date is supplied in two pieces, in the usual SOFA
**     manner, which is designed to preserve time resolution.  The
**     Julian Date is available as a single number by adding dj1 and
**     dj2.  The maximum resolution is achieved if dj1 is 2451545.0
**     (J2000.0).
**
**   Reference:
**
**     Lieske, J.H., 1979. Astron.Astrophys., 73, 282.
**
*/

```

```

void iauEpb2jd(double epb, double *djm0, double *djm)
/*
**  - - - - -
**   i a u E p b 2 j d
**  - - - - -
**
**   Besselian Epoch to Julian Date.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     epb      double      Besselian Epoch (e.g. 1957.3)
**
**   Returned:
**     djm0     double      MJD zero-point: always 2400000.5
**     djm      double      Modified Julian Date
**
**   Note:
**
**     The Julian Date is returned in two pieces, in the usual SOFA
**     manner, which is designed to preserve time resolution.  The
**     Julian Date is available as a single number by adding djm0 and
**     djm.
**
**   Reference:
**
**     Lieske, J.H., 1979, Astron.Astrophys. 73, 282.
**
*/

```

```

double iauEpj(double dj1, double dj2)
/*
**  - - - - -
**   i a u E p j
**  - - - - -
**
**   Julian Date to Julian Epoch.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     dj1,dj2    double    Julian Date (see note)
**
**   Returned (function value):
**     double    Julian Epoch
**
**   Note:
**
**     The Julian Date is supplied in two pieces, in the usual SOFA
**     manner, which is designed to preserve time resolution.  The
**     Julian Date is available as a single number by adding dj1 and
**     dj2.  The maximum resolution is achieved if dj1 is 2451545.0
**     (J2000.0).
**
**   Reference:
**
**     Lieske, J.H., 1979, Astron.Astrophys. 73, 282.
**
*/

```

```

void iauEpj2jd(double epj, double *djm0, double *djm)
/*
**  - - - - -
**   i a u E p j 2 j d
**  - - - - -
**
**   Julian Epoch to Julian Date.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     epj      double      Julian Epoch (e.g. 1996.8)
**
**   Returned:
**     djm0     double      MJD zero-point: always 2400000.5
**     djm      double      Modified Julian Date
**
**   Note:
**
**     The Julian Date is returned in two pieces, in the usual SOFA
**     manner, which is designed to preserve time resolution.  The
**     Julian Date is available as a single number by adding djm0 and
**     djm.
**
**   Reference:
**
**     Lieske, J.H., 1979, Astron.Astrophys. 73, 282.
**
*/

```

```

int iauEpv00(double date1, double date2,
             double pvh[2][3], double pvb[2][3])
/*
**   - - - - -
**   i a u E p v 0 0
**   - - - - -
**
** Earth position and velocity, heliocentric and barycentric, with
** respect to the Barycentric Celestial Reference System.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double          TDB date (Note 1)
**
** Returned:
**   pvh          double[2][3]    heliocentric Earth position/velocity
**   pvb          double[2][3]    barycentric Earth position/velocity
**
** Returned (function value):
**   int          status: 0 = OK
**                   +1 = warning: date outside
**                   the range 1900-2100 AD
**
** Notes:
**
** 1) The TDB date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TDB)=2450123.7 could be expressed in any of these ways, among
** others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable.  The J2000 method is best matched to the way the
** argument is handled internally and will deliver the optimum
** resolution.  The MJD method and the date & time methods are both
** good compromises between resolution and convenience.  However,
** the accuracy of the result is more likely to be limited by the
** algorithm itself than the way the date has been expressed.
**
** n.b. TT can be used instead of TDB in most applications.
**
** 2) On return, the arrays pvh and pvb contain the following:
**
**   pvh[0][0]  x          }
**   pvh[0][1]  y          } heliocentric position, AU
**   pvh[0][2]  z          }
**
**   pvh[1][0]  xdot       }
**   pvh[1][1]  ydot       } heliocentric velocity, AU/d
**   pvh[1][2]  zdot       }
**
**   pvb[0][0]  x          }
**   pvb[0][1]  y          } barycentric position, AU
**   pvb[0][2]  z          }
**
**   pvb[1][0]  xdot       }
**   pvb[1][1]  ydot       } barycentric velocity, AU/d
**   pvb[1][2]  zdot       }
**
** The vectors are with respect to the Barycentric Celestial

```

```

**      Reference System.  The time unit is one day in TDB.
**
**      3) The function is a SIMPLIFIED SOLUTION from the planetary theory
**      VSOP2000 (X. Moisson, P. Bretagnon, 2001, Celes. Mechanics &
**      Dyn. Astron., 80, 3/4, 205-213) and is an adaptation of original
**      Fortran code supplied by P. Bretagnon (private comm., 2000).
**
**      4) Comparisons over the time span 1900-2100 with this simplified
**      solution and the JPL DE405 ephemeris give the following results:
**
**
**              RMS      max
**      Heliocentric:
**          position error  3.7  11.2  km
**          velocity error  1.4   5.0  mm/s
**
**      Barycentric:
**          position error  4.6  13.4  km
**          velocity error  1.4   4.9  mm/s
**
**      Comparisons with the JPL DE406 ephemeris show that by 1800 and
**      2200 the position errors are approximately double their 1900-2100
**      size.  By 1500 and 2500 the deterioration is a factor of 10 and
**      by 1000 and 3000 a factor of 60.  The velocity accuracy falls off
**      at about half that rate.
**
**      5) It is permissible to use the same array for pvh and pvb, which
**      will receive the barycentric values.
**
**/

```

```

void iauEqec06(double date1, double date2, double dr, double dd,
               double *dl, double *db)
/*
**  - - - - -
**   i a u E q e c 0 6
**  - - - - -
**
** Transformation from ICRS equatorial coordinates to ecliptic
** coordinates (mean equinox and ecliptic of date) using IAU 2006
** precession model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2 double TT as a 2-part Julian date (Note 1)
**   dr,dd      double ICRS right ascension and declination (radians)
**
** Returned:
**   dl,db      double ecliptic longitude and latitude (radians)
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1      date2
**
**           2450123.7      0.0      (JD method)
**           2451545.0     -1421.3    (J2000 method)
**           2400000.5      50123.2    (MJD method)
**           2450123.5      0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) No assumptions are made about whether the coordinates represent
** starlight and embody astrometric effects such as parallax or
** aberration.
**
** 3) The transformation is approximately that from mean J2000.0 right
** ascension and declination to ecliptic longitude and latitude
** (mean equinox and ecliptic of date), with only frame bias (always
** less than 25 mas) to disturb this classical picture.
**
** Called:
**   iauS2c      spherical coordinates to unit vector
**   iauEcm06   J2000.0 to ecliptic rotation matrix, IAU 2006
**   iauRxp     product of r-matrix and p-vector
**   iauC2s     unit vector to spherical coordinates
**   iauAnp     normalize angle into range 0 to 2pi
**   iauAnpm    normalize angle into range +/- pi
**
*/

```

```

double iauEgeq94(double date1, double date2)
/*
**   - - - - -
**   i a u E q e q 9 4
**   - - - - -
**
**   Equation of the equinoxes, IAU 1994 model.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status: canonical model.
**
**   Given:
**     date1,date2  double      TDB date (Note 1)
**
**   Returned (function value):
**     double      equation of the equinoxes (Note 2)
**
**   Notes:
**
**   1) The date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution
**   is acceptable.  The J2000 method is best matched to the way
**   the argument is handled internally and will deliver the
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**
**   2) The result, which is in radians, operates in the following sense:
**
**           Greenwich apparent ST = GMST + equation of the equinoxes
**
**   Called:
**     iauAnpm      normalize angle into range +/- pi
**     iauNut80     nutation, IAU 1980
**     iauObl80     mean obliquity, IAU 1980
**
**   References:
**
**     IAU Resolution C7, Recommendation 3 (1994).
**
**     Capitaine, N. & Gontier, A.-M., 1993, Astron. Astrophys., 275,
**     645-650.
**
*/

```

```

double iauEra00(double dj1, double dj2)
/*
**   - - - - -
**   i a u E r a 0 0
**   - - - - -
**
** Earth rotation angle (IAU 2000 model).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   dj1,dj2   double   UT1 as a 2-part Julian Date (see note)
**
** Returned (function value):
**   double    Earth rotation angle (radians), range 0-2pi
**
** Notes:
**
** 1) The UT1 date dj1+dj2 is a Julian Date, apportioned in any
** convenient way between the arguments dj1 and dj2. For example,
** JD(UT1)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           dj1           dj2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3        (J2000 method)
**           2400000.5           50123.2       (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 and MJD methods are good compromises
** between resolution and convenience. The date & time method is
** best matched to the algorithm used: maximum precision is
** delivered when the dj1 argument is for 0hrs UT1 on the day in
** question and the dj2 argument lies in the range 0 to 1, or vice
** versa.
**
** 2) The algorithm is adapted from Expression 22 of Capitaine et al.
** 2000. The time argument has been expressed in days directly,
** and, to retain precision, integer contributions have been
** eliminated. The same formulation is given in IERS Conventions
** (2003), Chap. 5, Eq. 14.
**
** Called:
**   iauAnp           normalize angle into range 0 to 2pi
**
** References:
**
**   Capitaine N., Guinot B. and McCarthy D.D, 2000, Astron.
**   Astrophys., 355, 398-405.
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

double iauFad03(double t)
/*
**  - - - - -
**   i a u F a d 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean elongation of the Moon from the Sun.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double   D, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFae03(double t)
/*
**  - - - - -
**   i a u F a e 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Earth.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Earth, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

double iauFaf03(double t)
/*
**  - - - - -
**   i a u F a f 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of the Moon minus mean longitude of the ascending
**  node.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double  F, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is from Simon et al. (1994).
**
**  References:
**
**     McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**     IERS Technical Note No. 32, BKG (2004)
**
**     Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**     Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFaju03(double t)
/*
**  - - - - -
**   i a u F a j u 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Jupiter.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Jupiter, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

double iauFal03(double t)
/*
**  - - - - -
**   i a u F a l 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean anomaly of the Moon.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double  l, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFalp03(double t)
/*
**  - - - - -
**   i a u F a l p 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean anomaly of the Sun.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double  l', radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFama03(double t)
/*
**  - - - - -
**   i a u F a m a 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Mars.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Mars, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

double iauFame03(double t)
/*
**  - - - - -
**   i a u F a m e 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Mercury.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Mercury, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

double iauFane03(double t)
/*
**  - - - - -
**   i a u F a n e 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Neptune.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Neptune, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is adapted from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFaom03(double t)
/*
**  - - - - -
**   i a u F a o m 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of the Moon's ascending node.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double      Omega, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFapa03(double t)
/*
**  - - - - -
**   i a u F a p a 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  general accumulated precession in longitude.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double   general precession in longitude, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003).  It
**     is taken from Kinoshita & Souchay (1990) and comes originally
**     from Lieske et al. (1977).
**
**  References:
**
**     Kinoshita, H. and Souchay J. 1990, Celest.Mech. and Dyn.Astron.
**     48, 187
**
**     Lieske, J.H., Lederle, T., Fricke, W. & Morando, B. 1977,
**     Astron.Astrophys. 58, 1-16
**
**     McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**     IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

double iauFasa03(double t)
/*
**  - - - - -
**   i a u F a s a 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Saturn.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Saturn, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

double iauFaur03(double t)
/*
**  - - - - -
**   i a u F a u r 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Uranus.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double   mean longitude of Uranus, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     is adapted from Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
*/

```

```

double iauFave03(double t)
/*
**  - - - - -
**   i a u F a v e 0 3
**  - - - - -
**
**  Fundamental argument, IERS Conventions (2003):
**  mean longitude of Venus.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    t      double      TDB, Julian centuries since J2000.0 (Note 1)
**
**  Returned (function value):
**    double      mean longitude of Venus, radians (Note 2)
**
**  Notes:
**
**  1) Though t is strictly TDB, it is usually more convenient to use
**     TT, which makes no significant difference.
**
**  2) The expression used is as adopted in IERS Conventions (2003) and
**     comes from Souchay et al. (1999) after Simon et al. (1994).
**
**  References:
**
**    McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**    IERS Technical Note No. 32, BKG (2004)
**
**    Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**    Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**
**    Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,
**    Astron.Astrophys.Supp.Ser. 135, 111
**
*/

```

```

void iauFk52h(double r5, double d5,
              double dr5, double dd5, double px5, double rv5,
              double *rh, double *dh,
              double *drh, double *ddh, double *pxh, double *rvh)
/*
** -----
**   i a u F k 5 2 h
**   -----
**
** Transform FK5 (J2000.0) star data into the Hipparcos system.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given (all FK5, equinox J2000.0, epoch J2000.0):
**   r5      double    RA (radians)
**   d5      double    Dec (radians)
**   dr5     double    proper motion in RA (dRA/dt, rad/Jyear)
**   dd5     double    proper motion in Dec (dDec/dt, rad/Jyear)
**   px5     double    parallax (arcsec)
**   rv5     double    radial velocity (km/s, positive = receding)
**
** Returned (all Hipparcos, epoch J2000.0):
**   rh      double    RA (radians)
**   dh      double    Dec (radians)
**   drh     double    proper motion in RA (dRA/dt, rad/Jyear)
**   ddh     double    proper motion in Dec (dDec/dt, rad/Jyear)
**   pxh     double    parallax (arcsec)
**   rvh     double    radial velocity (km/s, positive = receding)
**
** Notes:
**
** 1) This function transforms FK5 star positions and proper motions
**    into the system of the Hipparcos catalog.
**
** 2) The proper motions in RA are dRA/dt rather than
**    cos(Dec)*dRA/dt, and are per year rather than per century.
**
** 3) The FK5 to Hipparcos transformation is modeled as a pure
**    rotation and spin; zonal errors in the FK5 catalog are not
**    taken into account.
**
** 4) See also iauH2fk5, iauFk5hz, iauHfk5z.
**
** Called:
**   iauStarpv  star catalog data to space motion pv-vector
**   iauFk5hip  FK5 to Hipparcos rotation and spin
**   iauRxp     product of r-matrix and p-vector
**   iauPxp     vector product of two p-vectors
**   iauPpp     p-vector plus p-vector
**   iauPvstar  space motion pv-vector to star catalog data
**
** Reference:
**
**   F.Mignard & M.Froeschle, Astron. Astrophys. 354, 732-739 (2000).
**
*/

```

```

void iauFk5hip(double r5h[3][3], double s5h[3])
/*
**  - - - - -
**   i a u F k 5 h i p
**  - - - - -
**
**   FK5 to Hipparcos rotation and spin.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Returned:
**     r5h   double[3][3]  r-matrix: FK5 rotation wrt Hipparcos (Note 2)
**     s5h   double[3]     r-vector: FK5 spin wrt Hipparcos (Note 3)
**
**   Notes:
**
**   1) This function models the FK5 to Hipparcos transformation as a
**      pure rotation and spin; zonal errors in the FK5 catalogue are
**      not taken into account.
**
**   2) The r-matrix r5h operates in the sense:
**
**          P_Hipparcos = r5h x P_FK5
**
**      where P_FK5 is a p-vector in the FK5 frame, and P_Hipparcos is
**      the equivalent Hipparcos p-vector.
**
**   3) The r-vector s5h represents the time derivative of the FK5 to
**      Hipparcos rotation.  The units are radians per year (Julian,
**      TDB).
**
**   Called:
**     iauRv2m      r-vector to r-matrix
**
**   Reference:
**
**     F.Mignard & M.Froeschle, Astron. Astrophys. 354, 732-739 (2000).
**
*/

```

```

void iauFk5hz(double r5, double d5, double date1, double date2,
              double *rh, double *dh)
/*
**  - - - - -
**   i a u F k 5 h z
**  - - - - -
**
** Transform an FK5 (J2000.0) star position into the system of the
** Hipparcos catalogue, assuming zero Hipparcos proper motion.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   r5          double    FK5 RA (radians), equinox J2000.0, at date
**   d5          double    FK5 Dec (radians), equinox J2000.0, at date
**   date1,date2 double    TDB date (Notes 1,2)
**
** Returned:
**   rh          double    Hipparcos RA (radians)
**   dh          double    Hipparcos Dec (radians)
**
** Notes:
**
** 1) This function converts a star position from the FK5 system to
** the Hipparcos system, in such a way that the Hipparcos proper
** motion is zero. Because such a star has, in general, a non-zero
** proper motion in the FK5 system, the function requires the date
** at which the position in the FK5 system was determined.
**
** 2) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 3) The FK5 to Hipparcos transformation is modeled as a pure
** rotation and spin; zonal errors in the FK5 catalogue are not
** taken into account.
**
** 4) The position returned by this function is in the Hipparcos
** reference system but at date date1+date2.
**
** 5) See also iauFk52h, iauH2fk5, iauHfk5z.
**
** Called:
**   iauS2c          spherical coordinates to unit vector
**   iauFk5hip       FK5 to Hipparcos rotation and spin
**   iauSxp          multiply p-vector by scalar
**   iauRv2m        r-vector to r-matrix
**   iauTrxp        product of transpose of r-matrix and p-vector
**   iauPxp          vector product of two p-vectors
**   iauC2s          p-vector to spherical
**   iauAnp          normalize angle into range 0 to 2pi
**
** Reference:

```

\*\*  
\*\* F.Mignard & M.Froeschle, 2000, Astron.Astrophys. 354, 732-739.  
\*\*  
\*/

```

void iauFw2m(double gamb, double phib, double psi, double eps,
             double r[3][3])
/*
**  - - - - -
**   i a u F w 2 m
**  - - - - -
**
**   Form rotation matrix given the Fukushima-Williams angles.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     gamb      double          F-W angle gamma_bar (radians)
**     phib      double          F-W angle phi_bar (radians)
**     psi       double          F-W angle psi (radians)
**     eps       double          F-W angle epsilon (radians)
**
**   Returned:
**     r         double[3][3]    rotation matrix
**
**   Notes:
**
**   1) Naming the following points:
**
**         e = J2000.0 ecliptic pole,
**         p = GCRS pole,
**         E = ecliptic pole of date,
**         and P = CIP,
**
**         the four Fukushima-Williams angles are as follows:
**
**         gamb = gamma = epE
**         phib = phi = pE
**         psi = psi = pEP
**         eps = epsilon = EP
**
**   2) The matrix representing the combined effects of frame bias,
**       precession and nutation is:
**
**         NxPxB = R_1(-eps).R_3(-psi).R_1(phib).R_3(gamb)
**
**   3) Three different matrices can be constructed, depending on the
**       supplied angles:
**
**       o To obtain the nutation x precession x frame bias matrix,
**         generate the four precession angles, generate the nutation
**         components and add them to the psi_bar and epsilon_A angles,
**         and call the present function.
**
**       o To obtain the precession x frame bias matrix, generate the
**         four precession angles and call the present function.
**
**       o To obtain the frame bias matrix, generate the four precession
**         angles for date J2000.0 and call the present function.
**
**       The nutation-only and precession-only matrices can if necessary
**       be obtained by combining these three appropriately.
**
**   Called:
**     iauIr      initialize r-matrix to identity
**     iauRz      rotate around Z-axis
**     iauRx      rotate around X-axis
**
**   Reference:
**
**     Hilton, J. et al., 2006, Celest.Mech.Dyn.Astron. 94, 351
**
*/

```



```

void iauFw2xy(double gamb, double phib, double psi, double eps,
              double *x, double *y)
/*
**  - - - - -
**   i a u F w 2 x y
**  - - - - -
**
**   CIP X,Y given Fukushima-Williams bias-precession-nutation angles.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     gamb      double      F-W angle gamma_bar (radians)
**     phib      double      F-W angle phi_bar (radians)
**     psi       double      F-W angle psi (radians)
**     eps       double      F-W angle epsilon (radians)
**
**   Returned:
**     x,y       double      CIP unit vector X,Y
**
**   Notes:
**
**   1) Naming the following points:
**
**         e = J2000.0 ecliptic pole,
**         p = GCRS pole
**         E = ecliptic pole of date,
**         and P = CIP,
**
**         the four Fukushima-Williams angles are as follows:
**
**         gamb = gamma = epE
**         phib = phi = pE
**         psi = psi = pEP
**         eps = epsilon = EP
**
**   2) The matrix representing the combined effects of frame bias,
**       precession and nutation is:
**
**         NxPxB = R_1(-epsA).R_3(-psi).R_1(phib).R_3(gamb)
**
**       The returned values x,y are elements [2][0] and [2][1] of the
**       matrix.  Near J2000.0, they are essentially angles in radians.
**
**   Called:
**     iauFw2m      F-W angles to r-matrix
**     iauBpn2xy   extract CIP X,Y coordinates from NPB matrix
**
**   Reference:
**
**     Hilton, J. et al., 2006, Celest.Mech.Dyn.Astron. 94, 351
**
*/

```

```

void iauG2icrs ( double dl, double db, double *dr, double *dd )
/*
**  - - - - -
**   i a u G 2 i c r s
**  - - - - -
**
** Transformation from Galactic Coordinates to ICRS.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support routine.
**
** Given:
**   dl      double      galactic longitude (radians)
**   db      double      galactic latitude (radians)
**
** Returned:
**   dr      double      ICRS right ascension (radians)
**   dd      double      ICRS declination (radians)
**
** Notes:
**
** 1) The IAU 1958 system of Galactic coordinates was defined with
**    respect to the now obsolete reference system FK4 B1950.0.  When
**    interpreting the system in a modern context, several factors have
**    to be taken into account:
**
**    . The inclusion in FK4 positions of the E-terms of aberration.
**
**    . The distortion of the FK4 proper motion system by differential
**      Galactic rotation.
**
**    . The use of the B1950.0 equinox rather than the now-standard
**      J2000.0.
**
**    . The frame bias between ICRS and the J2000.0 mean place system.
**
** The Hipparcos Catalogue (Perryman & ESA 1997) provides a rotation
** matrix that transforms directly between ICRS and Galactic
** coordinates with the above factors taken into account.  The
** matrix is derived from three angles, namely the ICRS coordinates
** of the Galactic pole and the longitude of the ascending node of
** the galactic equator on the ICRS equator.  They are given in
** degrees to five decimal places and for canonical purposes are
** regarded as exact.  In the Hipparcos Catalogue the matrix
** elements are given to 10 decimal places (about 20 microarcsec).
** In the present SOFA function the matrix elements have been
** recomputed from the canonical three angles and are given to 30
** decimal places.
**
** 2) The inverse transformation is performed by the function iauIcrs2g.
**
** Called:
**   iauAnp      normalize angle into range 0 to 2pi
**   iauAnpm     normalize angle into range +/- pi
**   iauS2c      spherical coordinates to unit vector
**   iauTrxp     product of transpose of r-matrix and p-vector
**   iauC2s      p-vector to spherical
**
** Reference:
**   Perryman M.A.C. & ESA, 1997, ESA SP-1200, The Hipparcos and Tycho
**   catalogues.  Astrometric and photometric star catalogues
**   derived from the ESA Hipparcos Space Astrometry Mission.  ESA
**   Publications Division, Noordwijk, Netherlands.
**
*/

```

```

int iauGc2gd ( int n, double xyz[3],
              double *elong, double *phi, double *height )
/*
**  - - - - -
**   i a u G c 2 g d
**  - - - - -
**
** Transform geocentric coordinates to geodetic using the specified
** reference ellipsoid.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical transformation.
**
** Given:
**   n      int      ellipsoid identifier (Note 1)
**   xyz    double[3] geocentric vector (Note 2)
**
** Returned:
**   elong  double    longitude (radians, east +ve, Note 3)
**   phi    double    latitude (geodetic, radians, Note 3)
**   height double    height above ellipsoid (geodetic, Notes 2,3)
**
** Returned (function value):
**   int      status:  0 = OK
**                  -1 = illegal identifier (Note 3)
**                  -2 = internal error (Note 3)
**
** Notes:
**
** 1) The identifier n is a number that specifies the choice of
** reference ellipsoid. The following are supported:
**
**   n      ellipsoid
**
**   1      WGS84
**   2      GRS80
**   3      WGS72
**
** The n value has no significance outside the SOFA software. For
** convenience, symbols WGS84 etc. are defined in sofam.h.
**
** 2) The geocentric vector (xyz, given) and height (height, returned)
** are in meters.
**
** 3) An error status -1 means that the identifier n is illegal. An
** error status -2 is theoretically impossible. In all error cases,
** all three results are set to -1e9.
**
** 4) The inverse transformation is performed in the function iauGd2gc.
**
** Called:
**   iauEform      Earth reference ellipsoids
**   iauGc2gde    geocentric to geodetic transformation, general
**
*/

```

```

int iauGc2gde ( double a, double f, double xyz[3],
                double *elong, double *phi, double *height )
/*
**  - - - - -
**   i a u G c 2 g d e
**  - - - - -
**
** Transform geocentric coordinates to geodetic for a reference
** ellipsoid of specified form.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   a      double      equatorial radius (Notes 2,4)
**   f      double      flattening (Note 3)
**   xyz    double[3]   geocentric vector (Note 4)
**
** Returned:
**   elong  double      longitude (radians, east +ve)
**   phi    double      latitude (geodetic, radians)
**   height double      height above ellipsoid (geodetic, Note 4)
**
** Returned (function value):
**   int          status:  0 = OK
**                   -1 = illegal f
**                   -2 = illegal a
**
** Notes:
**
** 1) This function is based on the GCONV2H Fortran subroutine by
**    Toshio Fukushima (see reference).
**
** 2) The equatorial radius, a, can be in any units, but meters is
**    the conventional choice.
**
** 3) The flattening, f, is (for the Earth) a value around 0.00335,
**    i.e. around 1/298.
**
** 4) The equatorial radius, a, and the geocentric vector, xyz,
**    must be given in the same units, and determine the units of
**    the returned height, height.
**
** 5) If an error occurs (status < 0), elong, phi and height are
**    unchanged.
**
** 6) The inverse transformation is performed in the function
**    iauGd2gce.
**
** 7) The transformation for a standard ellipsoid (such as WGS84) can
**    more conveniently be performed by calling iauGc2gd, which uses a
**    numerical code to identify the required A and F values.
**
** Reference:
**
** Fukushima, T., "Transformation from Cartesian to geodetic
** coordinates accelerated by Halley's method", J.Geodesy (2006)
** 79: 689-693
**
*/

```

```

int iauGd2gc ( int n, double along, double phi, double height,
              double xyz[3] )
/*
** - - - - -
**   i a u G d 2 g c
** - - - - -
**
** Transform geodetic coordinates to geocentric using the specified
** reference ellipsoid.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical transformation.
**
** Given:
**   n          int          ellipsoid identifier (Note 1)
**   along      double       longitude (radians, east +ve)
**   phi        double       latitude (geodetic, radians, Note 3)
**   height     double       height above ellipsoid (geodetic, Notes 2,3)
**
** Returned:
**   xyz        double[3]    geocentric vector (Note 2)
**
** Returned (function value):
**   int        status:     0 = OK
**                       -1 = illegal identifier (Note 3)
**                       -2 = illegal case (Note 3)
**
** Notes:
**
** 1) The identifier n is a number that specifies the choice of
**    reference ellipsoid. The following are supported:
**
**      n    ellipsoid
**
**      1    WGS84
**      2    GRS80
**      3    WGS72
**
**    The n value has no significance outside the SOFA software. For
**    convenience, symbols WGS84 etc. are defined in sofam.h.
**
** 2) The height (height, given) and the geocentric vector (xyz,
**    returned) are in meters.
**
** 3) No validation is performed on the arguments along, phi and
**    height. An error status -1 means that the identifier n is
**    illegal. An error status -2 protects against cases that would
**    lead to arithmetic exceptions. In all error cases, xyz is set
**    to zeros.
**
** 4) The inverse transformation is performed in the function iauGc2gd.
**
** Called:
**   iauEform      Earth reference ellipsoids
**   iauGd2gce     geodetic to geocentric transformation, general
**   iauZp         zero p-vector
**
*/

```

```

int iauGd2gce ( double a, double f, double along, double phi,
                double height, double xyz[3] )
/*
**  - - - - -
**   i a u G d 2 g c e
**  - - - - -
**
** Transform geodetic coordinates to geocentric for a reference
** ellipsoid of specified form.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   a      double      equatorial radius (Notes 1,4)
**   f      double      flattening (Notes 2,4)
**   along  double      longitude (radians, east +ve)
**   phi    double      latitude (geodetic, radians, Note 4)
**   height double      height above ellipsoid (geodetic, Notes 3,4)
**
** Returned:
**   xyz    double[3]   geocentric vector (Note 3)
**
** Returned (function value):
**   int     status:    0 = OK
**                   -1 = illegal case (Note 4)
**
** Notes:
**
** 1) The equatorial radius, a, can be in any units, but meters is
**    the conventional choice.
**
** 2) The flattening, f, is (for the Earth) a value around 0.00335,
**    i.e. around 1/298.
**
** 3) The equatorial radius, a, and the height, height, must be
**    given in the same units, and determine the units of the
**    returned geocentric vector, xyz.
**
** 4) No validation is performed on individual arguments.  The error
**    status -1 protects against (unrealistic) cases that would lead
**    to arithmetic exceptions.  If an error occurs, xyz is unchanged.
**
** 5) The inverse transformation is performed in the function
**    iauGc2gde.
**
** 6) The transformation for a standard ellipsoid (such as WGS84) can
**    more conveniently be performed by calling iauGd2gc, which uses a
**    numerical code to identify the required a and f values.
**
** References:
**
**   Green, R.M., Spherical Astronomy, Cambridge University Press,
**   (1985) Section 4.5, p96.
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992),
**   Section 4.22, p202.
**
*/

```

```

double iauGmst00(double uta, double utb, double tta, double ttb)
/*
**  - - - - -
**   i a u G m s t 0 0
**  - - - - -
**
** Greenwich mean sidereal time (model consistent with IAU 2000
** resolutions).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  canonical model.
**
** Given:
**   uta,utb   double   UT1 as a 2-part Julian Date (Notes 1,2)
**   tta,ttb   double   TT as a 2-part Julian Date (Notes 1,2)
**
** Returned (function value):
**   double    Greenwich mean sidereal time (radians)
**
** Notes:
**
** 1) The UT1 and TT dates uta+utb and tta+ttb respectively, are both
** Julian Dates, apportioned in any convenient way between the
** argument pairs.  For example, JD=2450123.7 could be expressed in
** any of these ways, among others:
**
**           Part A           Part B
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable (in the case of UT; the TT is not at all critical
** in this respect).  The J2000 and MJD methods are good compromises
** between resolution and convenience.  For UT, the date & time
** method is best matched to the algorithm that is used by the Earth
** Rotation Angle function, called internally: maximum precision is
** delivered when the uta argument is for 0hrs UT1 on the day in
** question and the utb argument lies in the range 0 to 1, or vice
** versa.
**
** 2) Both UT1 and TT are required, UT1 to predict the Earth rotation
** and TT to predict the effects of precession.  If UT1 is used for
** both purposes, errors of order 100 microarcseconds result.
**
** 3) This GMST is compatible with the IAU 2000 resolutions and must be
** used only in conjunction with other IAU 2000 compatible
** components such as precession-nutation and equation of the
** equinoxes.
**
** 4) The result is returned in the range 0 to 2pi.
**
** 5) The algorithm is from Capitaine et al. (2003) and IERS
** Conventions 2003.
**
** Called:
**   iauEra00   Earth rotation angle, IAU 2000
**   iauAnp     normalize angle into range 0 to 2pi
**
** References:
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003)
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),

```

\*\* IERS Technical Note No. 32, BKG (2004)  
\*\*  
\*/

```

double iauGmst06(double uta, double utb, double tta, double ttb)
/*
**  - - - - -
**   i a u G m s t 0 6
**  - - - - -
**
** Greenwich mean sidereal time (consistent with IAU 2006 precession).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  canonical model.
**
** Given:
**   uta,utb   double   UT1 as a 2-part Julian Date (Notes 1,2)
**   tta,ttb   double   TT as a 2-part Julian Date (Notes 1,2)
**
** Returned (function value):
**   double    Greenwich mean sidereal time (radians)
**
** Notes:
**
** 1) The UT1 and TT dates uta+utb and tta+ttb respectively, are both
** Julian Dates, apportioned in any convenient way between the
** argument pairs.  For example, JD=2450123.7 could be expressed in
** any of these ways, among others:
**
**           Part A           Part B
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable (in the case of UT; the TT is not at all critical
** in this respect).  The J2000 and MJD methods are good compromises
** between resolution and convenience.  For UT, the date & time
** method is best matched to the algorithm that is used by the Earth
** rotation angle function, called internally:  maximum precision is
** delivered when the uta argument is for 0hrs UT1 on the day in
** question and the utb argument lies in the range 0 to 1, or vice
** versa.
**
** 2) Both UT1 and TT are required, UT1 to predict the Earth rotation
** and TT to predict the effects of precession.  If UT1 is used for
** both purposes, errors of order 100 microarcseconds result.
**
** 3) This GMST is compatible with the IAU 2006 precession and must not
** be used with other precession models.
**
** 4) The result is returned in the range 0 to 2pi.
**
** Called:
**   iauEra00   Earth rotation angle, IAU 2000
**   iauAnp    normalize angle into range 0 to 2pi
**
** Reference:
**
** Capitaine, N., Wallace, P.T. & Chapront, J., 2005,
** Astron.Astrophys. 432, 355
**
*/

```

```

double iauGmst82(double dj1, double dj2)
/*
**  - - - - -
**   i a u G m s t 8 2
**  - - - - -
**
** Universal Time to Greenwich mean sidereal time (IAU 1982 model).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   dj1,dj2    double    UT1 Julian Date (see note)
**
** Returned (function value):
**             double    Greenwich mean sidereal time (radians)
**
** Notes:
**
** 1) The UT1 date dj1+dj2 is a Julian Date, apportioned in any
**    convenient way between the arguments dj1 and dj2.  For example,
**    JD(UT1)=2450123.7 could be expressed in any of these ways,
**    among others:
**
**           dj1           dj2
**
**           2450123.7           0           (JD method)
**           2451545           -1421.3      (J2000 method)
**           2400000.5          50123.2      (MJD method)
**           2450123.5           0.2        (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 and MJD methods are good compromises
** between resolution and convenience.  The date & time method is
** best matched to the algorithm used: maximum accuracy (or, at
** least, minimum noise) is delivered when the dj1 argument is for
** 0hrs UT1 on the day in question and the dj2 argument lies in the
** range 0 to 1, or vice versa.
**
** 2) The algorithm is based on the IAU 1982 expression.  This is
**    always described as giving the GMST at 0 hours UT1.  In fact, it
**    gives the difference between the GMST and the UT, the steady
**    4-minutes-per-day drawing-ahead of ST with respect to UT.  When
**    whole days are ignored, the expression happens to equal the GMST
**    at 0 hours UT1 each day.
**
** 3) In this function, the entire UT1 (the sum of the two arguments
**    dj1 and dj2) is used directly as the argument for the standard
**    formula, the constant term of which is adjusted by 12 hours to
**    take account of the noon phasing of Julian Date.  The UT1 is then
**    added, but omitting whole days to conserve accuracy.
**
** Called:
**   iauAnp           normalize angle into range 0 to 2pi
**
** References:
**
**   Transactions of the International Astronomical Union,
**   XVIII B, 67 (1983).
**
**   Aoki et al., Astron. Astrophys. 105, 359-361 (1982).
**
*/

```

```

double iauGst00a(double uta, double utb, double tta, double ttb)
/*
**  - - - - -
**   i a u G s t 0 0 a
**  - - - - -
**
** Greenwich apparent sidereal time (consistent with IAU 2000
** resolutions).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   uta,utb   double   UT1 as a 2-part Julian Date (Notes 1,2)
**   tta,ttb   double   TT as a 2-part Julian Date (Notes 1,2)
**
** Returned (function value):
**   double    Greenwich apparent sidereal time (radians)
**
** Notes:
**
** 1) The UT1 and TT dates uta+utb and tta+ttb respectively, are both
** Julian Dates, apportioned in any convenient way between the
** argument pairs. For example, JD=2450123.7 could be expressed in
** any of these ways, among others:
**
**           Part A      Part B
**
**           2450123.7      0.0      (JD method)
**           2451545.0     -1421.3    (J2000 method)
**           2400000.5      50123.2    (MJD method)
**           2450123.5      0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable (in the case of UT; the TT is not at all critical
** in this respect). The J2000 and MJD methods are good compromises
** between resolution and convenience. For UT, the date & time
** method is best matched to the algorithm that is used by the Earth
** Rotation Angle function, called internally: maximum precision is
** delivered when the uta argument is for 0hrs UT1 on the day in
** question and the utb argument lies in the range 0 to 1, or vice
** versa.
**
** 2) Both UT1 and TT are required, UT1 to predict the Earth rotation
** and TT to predict the effects of precession-nutation. If UT1 is
** used for both purposes, errors of order 100 microarcseconds
** result.
**
** 3) This GAST is compatible with the IAU 2000 resolutions and must be
** used only in conjunction with other IAU 2000 compatible
** components such as precession-nutation.
**
** 4) The result is returned in the range 0 to 2pi.
**
** 5) The algorithm is from Capitaine et al. (2003) and IERS
** Conventions 2003.
**
** Called:
**   iauGmst00   Greenwich mean sidereal time, IAU 2000
**   iauEe00a    equation of the equinoxes, IAU 2000A
**   iauAnp      normalize angle into range 0 to 2pi
**
** References:
**
** Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to
** implement the IAU 2000 definition of UT1", Astronomy &
** Astrophysics, 406, 1135-1149 (2003)
**

```

\*\*  
\*\*  
\*\*  
\*/

McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),  
IERS Technical Note No. 32, BKG (2004)

```

double iauGst00b(double uta, double utb)
/*
**  - - - - -
**   i a u G s t 0 0 b
**  - - - - -
**
**  Greenwich apparent sidereal time (consistent with IAU 2000
**  resolutions but using the truncated nutation model IAU 2000B).
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    uta,utb    double    UT1 as a 2-part Julian Date (Notes 1,2)
**
**  Returned (function value):
**    double     Greenwich apparent sidereal time (radians)
**
**  Notes:
**
**  1) The UT1 date uta+utb is a Julian Date, apportioned in any
**     convenient way between the argument pair.  For example,
**     JD=2450123.7 could be expressed in any of these ways, among
**     others:
**
**           uta          utb
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3    (J2000 method)
**           2400000.5          50123.2    (MJD method)
**           2450123.5           0.2      (date & time method)
**
**     The JD method is the most natural and convenient to use in cases
**     where the loss of several decimal digits of resolution is
**     acceptable.  The J2000 and MJD methods are good compromises
**     between resolution and convenience.  For UT, the date & time
**     method is best matched to the algorithm that is used by the Earth
**     Rotation Angle function, called internally:  maximum precision is
**     delivered when the uta argument is for 0hrs UT1 on the day in
**     question and the utb argument lies in the range 0 to 1, or vice
**     versa.
**
**  2) The result is compatible with the IAU 2000 resolutions, except
**     that accuracy has been compromised for the sake of speed and
**     convenience in two respects:
**
**     . UT is used instead of TDB (or TT) to compute the precession
**       component of GMST and the equation of the equinoxes.  This
**       results in errors of order 0.1 mas at present.
**
**     . The IAU 2000B abridged nutation model (McCarthy & Luzum, 2001)
**       is used, introducing errors of up to 1 mas.
**
**  3) This GAST is compatible with the IAU 2000 resolutions and must be
**     used only in conjunction with other IAU 2000 compatible
**     components such as precession-nutation.
**
**  4) The result is returned in the range 0 to 2pi.
**
**  5) The algorithm is from Capitaine et al. (2003) and IERS
**     Conventions 2003.
**
**  Called:
**    iauGmst00  Greenwich mean sidereal time, IAU 2000
**    iauEe00b   equation of the equinoxes, IAU 2000B
**    iauAnp     normalize angle into range 0 to 2pi
**
**  References:
**

```

\*\* Capitaine, N., Wallace, P.T. and McCarthy, D.D., "Expressions to  
\*\* implement the IAU 2000 definition of UT1", Astronomy &  
\*\* Astrophysics, 406, 1135-1149 (2003)  
\*\*  
\*\* McCarthy, D.D. & Luzum, B.J., "An abridged model of the  
\*\* precession-nutation of the celestial pole", Celestial Mechanics &  
\*\* Dynamical Astronomy, 85, 37-49 (2003)  
\*\*  
\*\* McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),  
\*\* IERS Technical Note No. 32, BKG (2004)  
\*\*  
\*/

```

double iauGst06(double uta, double utb, double tta, double ttb,
                double rnpb[3][3])
/*
**   - - - - -
**   i a u G s t 0 6
**   - - - - -
**
**   Greenwich apparent sidereal time, IAU 2006, given the NPB matrix.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     uta,utb  double          UT1 as a 2-part Julian Date (Notes 1,2)
**     tta,ttb  double          TT as a 2-part Julian Date (Notes 1,2)
**     rnpb     double[3][3]    nutation x precession x bias matrix
**
**   Returned (function value):
**     double          Greenwich apparent sidereal time (radians)
**
**   Notes:
**
**   1) The UT1 and TT dates uta+utb and tta+ttb respectively, are both
**      Julian Dates, apportioned in any convenient way between the
**      argument pairs.  For example, JD=2450123.7 could be expressed in
**      any of these ways, among others:
**
**          Part A          Part B
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2        (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution
**      is acceptable (in the case of UT; the TT is not at all critical
**      in this respect).  The J2000 and MJD methods are good compromises
**      between resolution and convenience.  For UT, the date & time
**      method is best matched to the algorithm that is used by the Earth
**      rotation angle function, called internally:  maximum precision is
**      delivered when the uta argument is for 0hrs UT1 on the day in
**      question and the utb argument lies in the range 0 to 1, or vice
**      versa.
**
**   2) Both UT1 and TT are required, UT1 to predict the Earth rotation
**      and TT to predict the effects of precession-nutation.  If UT1 is
**      used for both purposes, errors of order 100 microarcseconds
**      result.
**
**   3) Although the function uses the IAU 2006 series for s+XY/2, it is
**      otherwise independent of the precession-nutation model and can in
**      practice be used with any equinox-based NPB matrix.
**
**   4) The result is returned in the range 0 to 2pi.
**
**   Called:
**     iauBpn2xy  extract CIP X,Y coordinates from NPB matrix
**     iauS06     the CIO locator s, given X,Y, IAU 2006
**     iauAnp     normalize angle into range 0 to 2pi
**     iauEra00   Earth rotation angle, IAU 2000
**     iauEors    equation of the origins, given NPB matrix and s
**
**   Reference:
**
**     Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

double iauGst06a(double uta, double utb, double tta, double ttb)
/*
**  - - - - -
**   i a u G s t 0 6 a
**  - - - - -
**
** Greenwich apparent sidereal time (consistent with IAU 2000 and 2006
** resolutions).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   uta,utb   double   UT1 as a 2-part Julian Date (Notes 1,2)
**   tta,ttb   double   TT as a 2-part Julian Date (Notes 1,2)
**
** Returned (function value):
**   double    Greenwich apparent sidereal time (radians)
**
** Notes:
**
** 1) The UT1 and TT dates uta+utb and tta+ttb respectively, are both
** Julian Dates, apportioned in any convenient way between the
** argument pairs. For example, JD=2450123.7 could be expressed in
** any of these ways, among others:
**
**           Part A           Part B
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable (in the case of UT; the TT is not at all critical
** in this respect). The J2000 and MJD methods are good compromises
** between resolution and convenience. For UT, the date & time
** method is best matched to the algorithm that is used by the Earth
** rotation angle function, called internally: maximum precision is
** delivered when the uta argument is for 0hrs UT1 on the day in
** question and the utb argument lies in the range 0 to 1, or vice
** versa.
**
** 2) Both UT1 and TT are required, UT1 to predict the Earth rotation
** and TT to predict the effects of precession-nutation. If UT1 is
** used for both purposes, errors of order 100 microarcseconds
** result.
**
** 3) This GAST is compatible with the IAU 2000/2006 resolutions and
** must be used only in conjunction with IAU 2006 precession and
** IAU 2000A nutation.
**
** 4) The result is returned in the range 0 to 2pi.
**
** Called:
**   iauPnm06a   classical NPB matrix, IAU 2006/2000A
**   iauGst06    Greenwich apparent ST, IAU 2006, given NPB matrix
**
** Reference:
**
**   Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

double iauGst94(double uta, double utb)
/*
**  - - - - -
**   i a u G s t 9 4
**  - - - - -
**
** Greenwich apparent sidereal time (consistent with IAU 1982/94
** resolutions).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   uta,utb   double   UT1 as a 2-part Julian Date (Notes 1,2)
**
** Returned (function value):
**   double    Greenwich apparent sidereal time (radians)
**
** Notes:
**
** 1) The UT1 date uta+utb is a Julian Date, apportioned in any
**    convenient way between the argument pair.  For example,
**    JD=2450123.7 could be expressed in any of these ways, among
**    others:
**
**           uta           utb
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable.  The J2000 and MJD methods are good compromises
** between resolution and convenience.  For UT, the date & time
** method is best matched to the algorithm that is used by the Earth
** Rotation Angle function, called internally: maximum precision is
** delivered when the uta argument is for 0hrs UT1 on the day in
** question and the utb argument lies in the range 0 to 1, or vice
** versa.
**
** 2) The result is compatible with the IAU 1982 and 1994 resolutions,
**    except that accuracy has been compromised for the sake of
**    convenience in that UT is used instead of TDB (or TT) to compute
**    the equation of the equinoxes.
**
** 3) This GAST must be used only in conjunction with contemporaneous
**    IAU standards such as 1976 precession, 1980 obliquity and 1982
**    nutation.  It is not compatible with the IAU 2000 resolutions.
**
** 4) The result is returned in the range 0 to 2pi.
**
** Called:
**   iauGmst82   Greenwich mean sidereal time, IAU 1982
**   iauEgeq94   equation of the equinoxes, IAU 1994
**   iauAnp      normalize angle into range 0 to 2pi
**
** References:
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
**   IAU Resolution C7, Recommendation 3 (1994)
**
*/

```

```

void iauH2fk5(double rh, double dh,
              double drh, double ddh, double pxh, double rvh,
              double *r5, double *d5,
              double *dr5, double *dd5, double *px5, double *rv5)
/*
** -----
**   i a u H 2 f k 5
** -----
**
** Transform Hipparcos star data into the FK5 (J2000.0) system.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given (all Hipparcos, epoch J2000.0):
**   rh      double   RA (radians)
**   dh      double   Dec (radians)
**   drh     double   proper motion in RA (dRA/dt, rad/Jyear)
**   ddh     double   proper motion in Dec (dDec/dt, rad/Jyear)
**   pxh     double   parallax (arcsec)
**   rvh     double   radial velocity (km/s, positive = receding)
**
** Returned (all FK5, equinox J2000.0, epoch J2000.0):
**   r5      double   RA (radians)
**   d5      double   Dec (radians)
**   dr5     double   proper motion in RA (dRA/dt, rad/Jyear)
**   dd5     double   proper motion in Dec (dDec/dt, rad/Jyear)
**   px5     double   parallax (arcsec)
**   rv5     double   radial velocity (km/s, positive = receding)
**
** Notes:
**
** 1) This function transforms Hipparcos star positions and proper
**    motions into FK5 J2000.0.
**
** 2) The proper motions in RA are dRA/dt rather than
**    cos(Dec)*dRA/dt, and are per year rather than per century.
**
** 3) The FK5 to Hipparcos transformation is modeled as a pure
**    rotation and spin; zonal errors in the FK5 catalog are not
**    taken into account.
**
** 4) See also iauFk52h, iauFk5hz, iauHfk5z.
**
** Called:
**   iauStarpv   star catalog data to space motion pv-vector
**   iauFk5hip   FK5 to Hipparcos rotation and spin
**   iauRv2m     r-vector to r-matrix
**   iauRxp     product of r-matrix and p-vector
**   iauTrxp    product of transpose of r-matrix and p-vector
**   iauPxp     vector product of two p-vectors
**   iauPmp     p-vector minus p-vector
**   iauPvstar   space motion pv-vector to star catalog data
**
** Reference:
**
**   F.Mignard & M.Froeschle, Astron. Astrophys. 354, 732-739 (2000).
**
*/

```

```

void iauHfk5z(double rh, double dh, double date1, double date2,
              double *r5, double *d5, double *dr5, double *dd5)
/*
**  - - - - -
**   i a u H f k 5 z
**  - - - - -
**
** Transform a Hipparcos star position into FK5 J2000.0, assuming
** zero Hipparcos proper motion.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rh          double      Hipparcos RA (radians)
**   dh          double      Hipparcos Dec (radians)
**   date1,date2 double      TDB date (Note 1)
**
** Returned (all FK5, equinox J2000.0, date date1+date2):
**   r5          double      RA (radians)
**   d5          double      Dec (radians)
**   dr5        double      FK5 RA proper motion (rad/year, Note 4)
**   dd5        double      Dec proper motion (rad/year, Note 4)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The proper motion in RA is dRA/dt rather than cos(Dec)*dRA/dt.
**
** 3) The FK5 to Hipparcos transformation is modeled as a pure rotation
** and spin; zonal errors in the FK5 catalogue are not taken into
** account.
**
** 4) It was the intention that Hipparcos should be a close
** approximation to an inertial frame, so that distant objects have
** zero proper motion; such objects have (in general) non-zero
** proper motion in FK5, and this function returns those fictitious
** proper motions.
**
** 5) The position returned by this function is in the FK5 J2000.0
** reference system but at date date1+date2.
**
** 6) See also iauFk52h, iauH2fk5, iauFk5zhh.
**
** Called:
**   iauS2c          spherical coordinates to unit vector
**   iauFk5hip       FK5 to Hipparcos rotation and spin
**   iauRxp          product of r-matrix and p-vector
**   iauSxp          multiply p-vector by scalar
**   iauRxr          product of two r-matrices
**   iauTrxp        product of transpose of r-matrix and p-vector

```

```
**      iauPxp      vector product of two p-vectors
**      iauPv2s    pv-vector to spherical
**      iauAnp     normalize angle into range 0 to 2pi
**
** Reference:
**
**      F.Mignard & M.Froeschle, 2000, Astron.Astrophys. 354, 732-739.
**
**/
```

```

void iauIcrs2g ( double dr, double dd, double *dl, double *db )
/*
**  - - - - -
**   i a u I c r s 2 g
**  - - - - -
**
** Transformation from ICRS to Galactic Coordinates.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support routine.
**
** Given:
**   dr      double      ICRS right ascension (radians)
**   dd      double      ICRS declination (radians)
**
** Returned:
**   dl      double      galactic longitude (radians)
**   db      double      galactic latitude (radians)
**
** Notes:
**
** 1) The IAU 1958 system of Galactic coordinates was defined with
**    respect to the now obsolete reference system FK4 B1950.0.  When
**    interpreting the system in a modern context, several factors have
**    to be taken into account:
**
**    . The inclusion in FK4 positions of the E-terms of aberration.
**
**    . The distortion of the FK4 proper motion system by differential
**      Galactic rotation.
**
**    . The use of the B1950.0 equinox rather than the now-standard
**      J2000.0.
**
**    . The frame bias between ICRS and the J2000.0 mean place system.
**
** The Hipparcos Catalogue (Perryman & ESA 1997) provides a rotation
** matrix that transforms directly between ICRS and Galactic
** coordinates with the above factors taken into account.  The
** matrix is derived from three angles, namely the ICRS coordinates
** of the Galactic pole and the longitude of the ascending node of
** the galactic equator on the ICRS equator.  They are given in
** degrees to five decimal places and for canonical purposes are
** regarded as exact.  In the Hipparcos Catalogue the matrix
** elements are given to 10 decimal places (about 20 microarcsec).
** In the present SOFA function the matrix elements have been
** recomputed from the canonical three angles and are given to 30
** decimal places.
**
** 2) The inverse transformation is performed by the function iauG2icrs.
**
** Called:
**   iauAnp      normalize angle into range 0 to 2pi
**   iauAnpm     normalize angle into range +/- pi
**   iauS2c      spherical coordinates to unit vector
**   iauRxp      product of r-matrix and p-vector
**   iauC2s      p-vector to spherical
**
** Reference:
**   Perryman M.A.C. & ESA, 1997, ESA SP-1200, The Hipparcos and Tycho
**   catalogues.  Astrometric and photometric star catalogues
**   derived from the ESA Hipparcos Space Astrometry Mission.  ESA
**   Publications Division, Noordwijk, Netherlands.
**
*/

```

```
void iauIr(double r[3][3])
/*
**  - - - - -
**   i a u I r
**  - - - - -
**
**   Initialize an r-matrix to the identity matrix.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Returned:
**     r      double[3][3]    r-matrix
**
**/
```

```

int iauJd2cal(double dj1, double dj2,
              int *iy, int *im, int *id, double *fd)
/*
** - - - - -
**   i a u J d 2 c a l
** - - - - -
**
** Julian Date to Gregorian year, month, day, and fraction of a day.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   dj1,dj2   double   Julian Date (Notes 1, 2)
**
** Returned (arguments):
**   iy        int      year
**   im        int      month
**   id        int      day
**   fd        double   fraction of day
**
** Returned (function value):
**   int       status:
**           0 = OK
**          -1 = unacceptable date (Note 3)
**
** Notes:
**
** 1) The earliest valid date is -68569.5 (-4900 March 1).  The
**    largest value accepted is 1e9.
**
** 2) The Julian Date is apportioned in any convenient way between
**    the arguments dj1 and dj2.  For example, JD=2450123.7 could
**    be expressed in any of these ways, among others:
**
**           dj1           dj2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3        (J2000 method)
**           2400000.5           50123.2       (MJD method)
**           2450123.5           0.2           (date & time method)
**
** 3) In early eras the conversion is from the "proleptic Gregorian
**    calendar"; no account is taken of the date(s) of adoption of
**    the Gregorian calendar, nor is the AD/BC numbering convention
**    observed.
**
** Reference:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** Section 12.92 (p604).
**
*/

```

```

int iauJdcalf(int ndp, double dj1, double dj2, int iymdf[4])
/*
**  - - - - -
**   i a u J d c a l f
**  - - - - -
**
** Julian Date to Gregorian Calendar, expressed in a form convenient
** for formatting messages: rounded to a specified precision.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: support function.
**
** Given:
**   ndp      int      number of decimal places of days in fraction
**   dj1,dj2  double   dj1+dj2 = Julian Date (Note 1)
**
** Returned:
**   iymdf    int[4]   year, month, day, fraction in Gregorian
**                   calendar
**
** Returned (function value):
**   int      status:
**           -1 = date out of range
**            0 = OK
**           +1 = NDP not 0-9 (interpreted as 0)
**
** Notes:
**
** 1) The Julian Date is apportioned in any convenient way between
** the arguments dj1 and dj2. For example, JD=2450123.7 could
** be expressed in any of these ways, among others:
**
**           dj1          dj2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5           0.2     (date & time method)
**
** 2) In early eras the conversion is from the "Proleptic Gregorian
** Calendar"; no account is taken of the date(s) of adoption of
** the Gregorian Calendar, nor is the AD/BC numbering convention
** observed.
**
** 3) Refer to the function iauJd2cal.
**
** 4) NDP should be 4 or less if internal overflows are to be
** avoided on machines which use 16-bit integers.
**
** Called:
**   iauJd2cal   JD to Gregorian calendar
**
** Reference:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** Section 12.92 (p604).
**
*/

```

```

void iauLd(double bm, double p[3], double q[3], double e[3],
          double em, double dlim, double p1[3])
/*
**   - - - - -
**   i a u L d
**   - - - - -
**
**   Apply light deflection by a solar-system body, as part of
**   transforming coordinate direction into natural direction.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     bm      double      mass of the gravitating body (solar masses)
**     p       double[3]   direction from observer to source (unit vector)
**     q       double[3]   direction from body to source (unit vector)
**     e       double[3]   direction from body to observer (unit vector)
**     em      double      distance from body to observer (au)
**     dlim    double      deflection limiter (Note 4)
**
**   Returned:
**     p1      double[3]   observer to deflected source (unit vector)
**
**   Notes:
**
**   1) The algorithm is based on Expr. (70) in Klioner (2003) and
**      Expr. (7.63) in the Explanatory Supplement (Urban & Seidelmann
**      2013), with some rearrangement to minimize the effects of machine
**      precision.
**
**   2) The mass parameter bm can, as required, be adjusted in order to
**      allow for such effects as quadrupole field.
**
**   3) The barycentric position of the deflecting body should ideally
**      correspond to the time of closest approach of the light ray to
**      the body.
**
**   4) The deflection limiter parameter dlim is  $\phi^2/2$ , where  $\phi$  is
**      the angular separation (in radians) between source and body at
**      which limiting is applied. As  $\phi$  shrinks below the chosen
**      threshold, the deflection is artificially reduced, reaching zero
**      for  $\phi = 0$ .
**
**   5) The returned vector p1 is not normalized, but the consequential
**      departure from unit magnitude is always negligible.
**
**   6) The arguments p and p1 can be the same array.
**
**   7) To accumulate total light deflection taking into account the
**      contributions from several bodies, call the present function for
**      each body in succession, in decreasing order of distance from the
**      observer.
**
**   8) For efficiency, validation is omitted. The supplied vectors must
**      be of unit magnitude, and the deflection limiter non-zero and
**      positive.
**
**   References:
**
**     Urban, S. & Seidelmann, P. K. (eds), Explanatory Supplement to
**     the Astronomical Almanac, 3rd ed., University Science Books
**     (2013).
**
**     Klioner, Sergei A., "A practical relativistic model for micro-
**     arcsecond astrometry in space", Astr. J. 125, 1580-1597 (2003).
**
**   Called:
**     iauPdp      scalar product of two p-vectors

```

```
**      iauPxp      vector product of two p-vectors
**
*/
```

```

void iauLdn(int n, iauLDBODY b[], double ob[3], double sc[3],
            double sn[3])
/*+
**  - - - - -
**    i a u L d n
**  - - - - -
**
**  For a star, apply light deflection by multiple solar-system bodies,
**  as part of transforming coordinate direction into natural direction.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    n      int           number of bodies (note 1)
**    b      iauLDBODY[n] data for each of the n bodies (Notes 1,2):
**    bm     double        mass of the body (solar masses, Note 3)
**    dl     double        deflection limiter (Note 4)
**    pv     [2][3]        barycentric PV of the body (au, au/day)
**    ob     double[3]     barycentric position of the observer (au)
**    sc     double[3]     observer to star coord direction (unit vector)
**
**  Returned:
**    sn     double[3]     observer to deflected star (unit vector)
**
**  1) The array b contains n entries, one for each body to be
**     considered.  If n = 0, no gravitational light deflection will be
**     applied, not even for the Sun.
**
**  2) The array b should include an entry for the Sun as well as for
**     any planet or other body to be taken into account.  The entries
**     should be in the order in which the light passes the body.
**
**  3) In the entry in the b array for body i, the mass parameter
**     b[i].bm can, as required, be adjusted in order to allow for such
**     effects as quadrupole field.
**
**  4) The deflection limiter parameter b[i].dl is  $\phi^2/2$ , where  $\phi$  is
**     the angular separation (in radians) between star and body at
**     which limiting is applied.  As  $\phi$  shrinks below the chosen
**     threshold, the deflection is artificially reduced, reaching zero
**     for  $\phi = 0$ .  Example values suitable for a terrestrial
**     observer, together with masses, are as follows:
**
**          body i      b[i].bm      b[i].dl
**
**          Sun         1.0           6e-6
**          Jupiter     0.00095435    3e-9
**          Saturn      0.00028574    3e-10
**
**  5) For cases where the starlight passes the body before reaching the
**     observer, the body is placed back along its barycentric track by
**     the light time from that point to the observer.  For cases where
**     the body is "behind" the observer no such shift is applied.  If
**     a different treatment is preferred, the user has the option of
**     instead using the iauLd function.  Similarly, iauLd can be used
**     for cases where the source is nearby, not a star.
**
**  6) The returned vector sn is not normalized, but the consequential
**     departure from unit magnitude is always negligible.
**
**  7) The arguments sc and sn can be the same array.
**
**  8) For efficiency, validation is omitted.  The supplied masses must
**     be greater than zero, the position and velocity vectors must be
**     right, and the deflection limiter greater than zero.
**
**  Reference:
**

```

```
**      Urban, S. & Seidelmann, P. K. (eds), Explanatory Supplement to
**      the Astronomical Almanac, 3rd ed., University Science Books
**      (2013), Section 7.2.4.
**
**      Called:
**      iauCp      copy p-vector
**      iauPdp     scalar product of two p-vectors
**      iauPmp     p-vector minus p-vector
**      iauPppsp   p-vector plus scaled p-vector
**      iauPn      decompose p-vector into modulus and direction
**      iauLd      light deflection by a solar-system body
**
** /
```

```

void iauLdsun(double p[3], double e[3], double em, double p1[3])
/*
**  - - - - -
**   i a u L d s u n
**  - - - - -
**
**  Deflection of starlight by the Sun.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    p      double[3]  direction from observer to star (unit vector)
**    e      double[3]  direction from Sun to observer (unit vector)
**    em     double     distance from Sun to observer (au)
**
**  Returned:
**    p1     double[3]  observer to deflected star (unit vector)
**
**  Notes:
**
**  1) The source is presumed to be sufficiently distant that its
**     directions seen from the Sun and the observer are essentially
**     the same.
**
**  2) The deflection is restrained when the angle between the star and
**     the center of the Sun is less than a threshold value, falling to
**     zero deflection for zero separation.  The chosen threshold value
**     is within the solar limb for all solar-system applications, and
**     is about 5 arcminutes for the case of a terrestrial observer.
**
**  3) The arguments p and p1 can be the same array.
**
**  Called:
**    iauLd      light deflection by a solar-system body
**
*/

```

```

void iauLteceq(double epj, double dl, double db, double *dr, double *dd)
/*
**  - - - - -
**   i a u L t e c e q
**  - - - - -
**
** Transformation from ecliptic coordinates (mean equinox and ecliptic
** of date) to ICRS RA,Dec, using a long-term precession model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   epj      double      Julian epoch (TT)
**   dl,db    double      ecliptic longitude and latitude (radians)
**
** Returned:
**   dr,dd    double      ICRS right ascension and declination (radians)
**
** 1) No assumptions are made about whether the coordinates represent
** starlight and embody astrometric effects such as parallax or
** aberration.
**
** 2) The transformation is approximately that from ecliptic longitude
** and latitude (mean equinox and ecliptic of date) to mean J2000.0
** right ascension and declination, with only frame bias (always
** less than 25 mas) to disturb this classical picture.
**
** 3) The Vondrak et al. (2011, 2012) 400 millennia precession model
** agrees with the IAU 2006 precession at J2000.0 and stays within
** 100 microarcseconds during the 20th and 21st centuries. It is
** accurate to a few arcseconds throughout the historical period,
** worsening to a few tenths of a degree at the end of the
** +/- 200,000 year time span.
**
** Called:
**   iauS2c      spherical coordinates to unit vector
**   iauLtecm    J2000.0 to ecliptic rotation matrix, long term
**   iauTrxp     product of transpose of r-matrix and p-vector
**   iauC2s      unit vector to spherical coordinates
**   iauAnp      normalize angle into range 0 to 2pi
**   iauAnpm     normalize angle into range +/- pi
**
** References:
**
** Vondrak, J., Capitaine, N. and Wallace, P., 2011, New precession
** expressions, valid for long time intervals, Astron.Astrophys. 534,
** A22
**
** Vondrak, J., Capitaine, N. and Wallace, P., 2012, New precession
** expressions, valid for long time intervals (Corrigendum),
** Astron.Astrophys. 541, C1
**
*/

```

```

void iauLtecm(double epj, double rm[3][3])
/*
**  - - - - -
**   i a u L t e c m
**  - - - - -
**
**   ICRS equatorial to ecliptic rotation matrix, long-term.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     epj      double          Julian epoch (TT)
**
**   Returned:
**     rm       double[3][3]    ICRS to ecliptic rotation matrix
**
**   Notes:
**
**   1) The matrix is in the sense
**
**        $E_{ep} = rm \times P_{ICRS},$ 
**
**       where  $P_{ICRS}$  is a vector with respect to ICRS right ascension
**       and declination axes and  $E_{ep}$  is the same vector with respect to
**       the (inertial) ecliptic and equinox of epoch epj.
**
**   2)  $P_{ICRS}$  is a free vector, merely a direction, typically of unit
**       magnitude, and not bound to any particular spatial origin, such
**       as the Earth, Sun or SSB.  No assumptions are made about whether
**       it represents starlight and embodies astrometric effects such as
**       parallax or aberration.  The transformation is approximately that
**       between mean J2000.0 right ascension and declination and ecliptic
**       longitude and latitude, with only frame bias (always less than
**       25 mas) to disturb this classical picture.
**
**   3) The Vondrak et al. (2011, 2012) 400 millennia precession model
**       agrees with the IAU 2006 precession at J2000.0 and stays within
**       100 microarcseconds during the 20th and 21st centuries.  It is
**       accurate to a few arcseconds throughout the historical period,
**       worsening to a few tenths of a degree at the end of the
**       +/- 200,000 year time span.
**
**   Called:
**     iauLtpequ  equator pole, long term
**     iauLtpecl  ecliptic pole, long term
**     iauPxp     vector product
**     iauPn      normalize vector
**
**   References:
**
**     Vondrak, J., Capitaine, N. and Wallace, P., 2011, New precession
**     expressions, valid for long time intervals, Astron.Astrophys. 534,
**     A22
**
**     Vondrak, J., Capitaine, N. and Wallace, P., 2012, New precession
**     expressions, valid for long time intervals (Corrigendum),
**     Astron.Astrophys. 541, C1
**
*/

```

```

void iauLteqec(double epj, double dr, double dd, double *dl, double *db)
/*
**  - - - - -
**   i a u L t e q e c
**  - - - - -
**
** Transformation from ICRS equatorial coordinates to ecliptic
** coordinates (mean equinox and ecliptic of date) using a long-term
** precession model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   epj   double      Julian epoch (TT)
**   dr,dd double      ICRS right ascension and declination (radians)
**
** Returned:
**   dl,db double      ecliptic longitude and latitude (radians)
**
** 1) No assumptions are made about whether the coordinates represent
** starlight and embody astrometric effects such as parallax or
** aberration.
**
** 2) The transformation is approximately that from mean J2000.0 right
** ascension and declination to ecliptic longitude and latitude
** (mean equinox and ecliptic of date), with only frame bias (always
** less than 25 mas) to disturb this classical picture.
**
** 3) The Vondrak et al. (2011, 2012) 400 millennia precession model
** agrees with the IAU 2006 precession at J2000.0 and stays within
** 100 microarcseconds during the 20th and 21st centuries. It is
** accurate to a few arcseconds throughout the historical period,
** worsening to a few tenths of a degree at the end of the
** +/- 200,000 year time span.
**
** Called:
**   iauS2c      spherical coordinates to unit vector
**   iauLtecm    J2000.0 to ecliptic rotation matrix, long term
**   iauRxp      product of r-matrix and p-vector
**   iauC2s      unit vector to spherical coordinates
**   iauAnp      normalize angle into range 0 to 2pi
**   iauAnpm     normalize angle into range +/- pi
**
** References:
**
** Vondrak, J., Capitaine, N. and Wallace, P., 2011, New precession
** expressions, valid for long time intervals, Astron.Astrophys. 534,
** A22
**
** Vondrak, J., Capitaine, N. and Wallace, P., 2012, New precession
** expressions, valid for long time intervals (Corrigendum),
** Astron.Astrophys. 541, C1
**
*/

```

```

void iauLtp(double epj, double rp[3][3])
/*
**   - - - - -
**   i a u L t p
**   - - - - -
**
**   Long-term precession matrix.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     epj      double          Julian epoch (TT)
**
**   Returned:
**     rp       double[3][3]    precession matrix, J2000.0 to date
**
**   Notes:
**
**   1) The matrix is in the sense
**
**       P_date = rp x P_J2000,
**
**       where P_J2000 is a vector with respect to the J2000.0 mean
**       equator and equinox and P_date is the same vector with respect to
**       the equator and equinox of epoch epj.
**
**   2) The Vondrak et al. (2011, 2012) 400 millennia precession model
**       agrees with the IAU 2006 precession at J2000.0 and stays within
**       100 microarcseconds during the 20th and 21st centuries. It is
**       accurate to a few arcseconds throughout the historical period,
**       worsening to a few tenths of a degree at the end of the
**       +/- 200,000 year time span.
**
**   Called:
**     iauLtpequ  equator pole, long term
**     iauLtpecl  ecliptic pole, long term
**     iauPxp     vector product
**     iauPn      normalize vector
**
**   References:
**
**     Vondrak, J., Capitaine, N. and Wallace, P., 2011, New precession
**     expressions, valid for long time intervals, Astron.Astrophys. 534,
**     A22
**
**     Vondrak, J., Capitaine, N. and Wallace, P., 2012, New precession
**     expressions, valid for long time intervals (Corrigendum),
**     Astron.Astrophys. 541, C1
**
*/

```

```

void iauLtpb(double epj, double rpb[3][3])
/*
**  - - - - -
**   i a u L t p b
**  - - - - -
**
** Long-term precession matrix, including ICRS frame bias.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   epj      double          Julian epoch (TT)
**
** Returned:
**   rpb      double[3][3]    precession-bias matrix, J2000.0 to date
**
** Notes:
**
** 1) The matrix is in the sense
**
**      P_date = rpb x P_ICRS,
**
**      where P_ICRS is a vector in the Geocentric Celestial Reference
**      System, and P_date is the vector with respect to the Celestial
**      Intermediate Reference System at that date but with nutation
**      neglected.
**
** 2) A first order frame bias formulation is used, of sub-
**      microarcsecond accuracy compared with a full 3D rotation.
**
** 3) The Vondrak et al. (2011, 2012) 400 millennia precession model
**      agrees with the IAU 2006 precession at J2000.0 and stays within
**      100 microarcseconds during the 20th and 21st centuries. It is
**      accurate to a few arcseconds throughout the historical period,
**      worsening to a few tenths of a degree at the end of the
**      +/- 200,000 year time span.
**
** References:
**
** Vondrak, J., Capitaine, N. and Wallace, P., 2011, New precession
** expressions, valid for long time intervals, Astron.Astrophys. 534,
** A22
**
** Vondrak, J., Capitaine, N. and Wallace, P., 2012, New precession
** expressions, valid for long time intervals (Corrigendum),
** Astron.Astrophys. 541, C1
**
*/

```

```

void iauLtpecl(double epj, double vec[3])
/*
**  - - - - -
**   i a u L t p e c l
**  - - - - -
**
** Long-term precession of the ecliptic.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   epj      double          Julian epoch (TT)
**
** Returned:
**   vec      double[3]       ecliptic pole unit vector
**
** Notes:
**
** 1) The returned vector is with respect to the J2000.0 mean equator
**    and equinox.
**
** 2) The Vondrak et al. (2011, 2012) 400 millennia precession model
**    agrees with the IAU 2006 precession at J2000.0 and stays within
**    100 microarcseconds during the 20th and 21st centuries. It is
**    accurate to a few arcseconds throughout the historical period,
**    worsening to a few tenths of a degree at the end of the
**    +/- 200,000 year time span.
**
** References:
**
** Vondrak, J., Capitaine, N. and Wallace, P., 2011, New precession
** expressions, valid for long time intervals, Astron.Astrophys. 534,
** A22
**
** Vondrak, J., Capitaine, N. and Wallace, P., 2012, New precession
** expressions, valid for long time intervals (Corrigendum),
** Astron.Astrophys. 541, C1
**
*/

```

```

void iauLtpequ(double epj, double veq[3])
/*
**   - - - - -
**   i a u L t p e q u
**   - - - - -
**
** Long-term precession of the equator.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   epj      double          Julian epoch (TT)
**
** Returned:
**   veq      double[3]       equator pole unit vector
**
** Notes:
**
** 1) The returned vector is with respect to the J2000.0 mean equator
**    and equinox.
**
** 2) The Vondrak et al. (2011, 2012) 400 millennia precession model
**    agrees with the IAU 2006 precession at J2000.0 and stays within
**    100 microarcseconds during the 20th and 21st centuries. It is
**    accurate to a few arcseconds throughout the historical period,
**    worsening to a few tenths of a degree at the end of the
**    +/- 200,000 year time span.
**
** References:
**
** Vondrak, J., Capitaine, N. and Wallace, P., 2011, New precession
** expressions, valid for long time intervals, Astron.Astrophys. 534,
** A22
**
** Vondrak, J., Capitaine, N. and Wallace, P., 2012, New precession
** expressions, valid for long time intervals (Corrigendum),
** Astron.Astrophys. 541, C1
**
*/

```

```

void iauNum00a(double date1, double date2, double rmatn[3][3])
/*
**   - - - - -
**   i a u N u m 0 0 a
**   - - - - -
**
**   Form the matrix of nutation for a given date, IAU 2000A model.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**   Returned:
**     rmatn        double[3][3]    nutation matrix
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution
**   is acceptable.  The J2000 method is best matched to the way
**   the argument is handled internally and will deliver the
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**
**   2) The matrix operates in the sense  $V(\text{true}) = \text{rmatn} * V(\text{mean})$ , where
**      the p-vector  $V(\text{true})$  is with respect to the true equatorial triad
**      of date and the p-vector  $V(\text{mean})$  is with respect to the mean
**      equatorial triad of date.
**
**   3) A faster, but slightly less accurate result (about 1 mas), can be
**      obtained by using instead the iauNum00b function.
**
**   Called:
**     iauPn00a      bias/precession/nutation, IAU 2000A
**
**   Reference:
**
**     Explanatory Supplement to the Astronomical Almanac,
**     P. Kenneth Seidelmann (ed), University Science Books (1992),
**     Section 3.222-3 (p114).
**
*/

```

```

void iauNum00b(double date1, double date2, double rmatn[3][3])
/*
**   - - - - -
**   i a u N u m 0 0 b
**   - - - - -
**
** Form the matrix of nutation for a given date, IAU 2000B model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rmatn        double[3][3]    nutation matrix
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{true}) = \text{rmatn} * V(\text{mean})$ , where
** the p-vector  $V(\text{true})$  is with respect to the true equatorial triad
** of date and the p-vector  $V(\text{mean})$  is with respect to the mean
** equatorial triad of date.
**
** 3) The present function is faster, but slightly less accurate (about
** 1 mas), than the iauNum00a function.
**
** Called:
**   iauPn00b      bias/precession/nutation, IAU 2000B
**
** Reference:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** Section 3.222-3 (p114).
**
*/

```

```

void iauNum06a(double date1, double date2, double rmatn[3][3])
/*
**   - - - - -
**   i a u N u m 0 6 a
**   - - - - -
**
**   Form the matrix of nutation for a given date, IAU 2006/2000A model.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**   Returned:
**     rmatn        double[3][3]    nutation matrix
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution
**   is acceptable.  The J2000 method is best matched to the way
**   the argument is handled internally and will deliver the
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**
**   2) The matrix operates in the sense  $V(\text{true}) = \text{rmatn} * V(\text{mean})$ , where
**      the p-vector  $V(\text{true})$  is with respect to the true equatorial triad
**      of date and the p-vector  $V(\text{mean})$  is with respect to the mean
**      equatorial triad of date.
**
**   Called:
**     iauObl06      mean obliquity, IAU 2006
**     iauNut06a     nutation, IAU 2006/2000A
**     iauNumat      form nutation matrix
**
**   Reference:
**
**     Explanatory Supplement to the Astronomical Almanac,
**     P. Kenneth Seidelmann (ed), University Science Books (1992),
**     Section 3.222-3 (p114).
**
*/

```

```

void iauNumat(double epsa, double dpsl, double depl, double rmatn[3][3])
/*
**  - - - - -
**   i a u N u m a t
**  - - - - -
**
**   Form the matrix of nutation.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     epsa      double      mean obliquity of date (Note 1)
**     dpsl,depl double      nutation (Note 2)
**
**   Returned:
**     rmatn     double[3][3] nutation matrix (Note 3)
**
**   Notes:
**
**   1) The supplied mean obliquity epsa, must be consistent with the
**      precession-nutation models from which dpsl and depl were obtained.
**
**   2) The caller is responsible for providing the nutation components;
**      they are in longitude and obliquity, in radians and are with
**      respect to the equinox and ecliptic of date.
**
**   3) The matrix operates in the sense  $V(\text{true}) = \text{rmatn} * V(\text{mean})$ ,
**      where the p-vector  $V(\text{true})$  is with respect to the true
**      equatorial triad of date and the p-vector  $V(\text{mean})$  is with
**      respect to the mean equatorial triad of date.
**
**   Called:
**     iauIr      initialize r-matrix to identity
**     iauRx      rotate around X-axis
**     iauRz      rotate around Z-axis
**
**   Reference:
**
**     Explanatory Supplement to the Astronomical Almanac,
**     P. Kenneth Seidelmann (ed), University Science Books (1992),
**     Section 3.222-3 (p114).
**
*/

```

```

void iauNut00a(double date1, double date2, double *dpsi, double *deps)
/*
**  - - - - -
**   i a u N u t 0 0 a
**  - - - - -
**
**  Nutation, IAU 2000A model (MHB2000 luni-solar and planetary nutation
**  with free core nutation omitted).
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    date1,date2  double  TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    dpsi,deps   double  nutation, luni-solar + planetary (Note 2)
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0        -1421.3        (J2000 method)
**           2400000.5          50123.2      (MJD method)
**           2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in
**  cases where the loss of several decimal digits of resolution
**  is acceptable.  The J2000 method is best matched to the way
**  the argument is handled internally and will deliver the
**  optimum resolution.  The MJD method and the date & time methods
**  are both good compromises between resolution and convenience.
**
**  2) The nutation components in longitude and obliquity are in radians
**     and with respect to the equinox and ecliptic of date.  The
**     obliquity at J2000.0 is assumed to be the Lieske et al. (1977)
**     value of 84381.448 arcsec.
**
**     Both the luni-solar and planetary nutations are included.  The
**     latter are due to direct planetary nutations and the
**     perturbations of the lunar and terrestrial orbits.
**
**  3) The function computes the MHB2000 nutation series with the
**     associated corrections for planetary nutations.  It is an
**     implementation of the nutation part of the IAU 2000A precession-
**     nutation model, formally adopted by the IAU General Assembly in
**     2000, namely MHB2000 (Mathews et al. 2002), but with the free
**     core nutation (FCN - see Note 4) omitted.
**
**  4) The full MHB2000 model also contains contributions to the
**     nutations in longitude and obliquity due to the free-excitation
**     of the free-core-nutation during the period 1979-2000.  These FCN
**     terms, which are time-dependent and unpredictable, are NOT
**     included in the present function and, if required, must be
**     independently computed.  With the FCN corrections included, the
**     present function delivers a pole which is at current epochs
**     accurate to a few hundred microarcseconds.  The omission of FCN
**     introduces further errors of about that size.
**
**  5) The present function provides classical nutation.  The MHB2000
**     algorithm, from which it is adapted, deals also with (i) the
**     offsets between the GCRS and mean poles and (ii) the adjustments
**     in longitude and obliquity due to the changed precession rates.

```

```

**      These additional functions, namely frame bias and precession
**      adjustments, are supported by the SOFA functions iauBi00 and
**      iauPr00.
**
**      6) The MHB2000 algorithm also provides "total" nutations, comprising
**      the arithmetic sum of the frame bias, precession adjustments,
**      luni-solar nutation and planetary nutation. These total
**      nutations can be used in combination with an existing IAU 1976
**      precession implementation, such as iauPmat76, to deliver GCRS-
**      to-true predictions of sub-mas accuracy at current dates.
**      However, there are three shortcomings in the MHB2000 model that
**      must be taken into account if more accurate or definitive results
**      are required (see Wallace 2002):
**
**      (i) The MHB2000 total nutations are simply arithmetic sums,
**      yet in reality the various components are successive Euler
**      rotations. This slight lack of rigor leads to cross terms
**      that exceed 1 mas after a century. The rigorous procedure
**      is to form the GCRS-to-true rotation matrix by applying the
**      bias, precession and nutation in that order.
**
**      (ii) Although the precession adjustments are stated to be with
**      respect to Lieske et al. (1977), the MHB2000 model does
**      not specify which set of Euler angles are to be used and
**      how the adjustments are to be applied. The most literal
**      and straightforward procedure is to adopt the 4-rotation
**      epsilon_0, psi_A, omega_A, xi_A option, and to add DPSIPR
**      to psi_A and DEPSR to both omega_A and eps_A.
**
**      (iii) The MHB2000 model predates the determination by Chapront
**      et al. (2002) of a 14.6 mas displacement between the
**      J2000.0 mean equinox and the origin of the ICRS frame. It
**      should, however, be noted that neglecting this displacement
**      when calculating star coordinates does not lead to a
**      14.6 mas change in right ascension, only a small second-
**      order distortion in the pattern of the precession-nutation
**      effect.
**
**      For these reasons, the SOFA functions do not generate the "total
**      nutations" directly, though they can of course easily be
**      generated by calling iauBi00, iauPr00 and the present function
**      and adding the results.
**
**      7) The MHB2000 model contains 41 instances where the same frequency
**      appears multiple times, of which 38 are duplicates and three are
**      triplicates. To keep the present code close to the original MHB
**      algorithm, this small inefficiency has not been corrected.
**
**      Called:
**      iauFal03      mean anomaly of the Moon
**      iauFaf03      mean argument of the latitude of the Moon
**      iauFaom03     mean longitude of the Moon's ascending node
**      iauFame03     mean longitude of Mercury
**      iauFave03     mean longitude of Venus
**      iauFae03      mean longitude of Earth
**      iauFama03     mean longitude of Mars
**      iauFaju03     mean longitude of Jupiter
**      iauFasa03     mean longitude of Saturn
**      iauFaur03     mean longitude of Uranus
**      iauFapa03     general accumulated precession in longitude
**
**      References:
**
**      Chapront, J., Chapront-Touze, M. & Francou, G. 2002,
**      Astron.Astrophys. 387, 700
**
**      Lieske, J.H., Lederle, T., Fricke, W. & Morando, B. 1977,
**      Astron.Astrophys. 58, 1-16
**
**      Mathews, P.M., Herring, T.A., Buffet, B.A. 2002, J.Geophys.Res.
**      107, B4. The MHB_2000 code itself was obtained on 9th September
**      2002 from ftp://maia.usno.navy.mil/conv2000/chapter5/IAU2000A.
**

```

\*\* Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,  
\*\* Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683  
\*\*  
\*\* Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,  
\*\* Astron.Astrophys.Supp.Ser. 135, 111  
\*\*  
\*\* Wallace, P.T., "Software for Implementing the IAU 2000  
\*\* Resolutions", in IERS Workshop 5.1 (2002)  
\*\*  
\*/

```

void iauNut00b(double date1, double date2, double *dpsi, double *deps)
/*
**  - - - - -
**   i a u N u t 0 0 b
**  - - - - -
**
**  Nutation, IAU 2000B model.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    dpsi,deps   double      nutation, luni-solar + planetary (Note 2)
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
**  The JD method is the most natural and convenient to use in
**  cases where the loss of several decimal digits of resolution
**  is acceptable.  The J2000 method is best matched to the way
**  the argument is handled internally and will deliver the
**  optimum resolution.  The MJD method and the date & time methods
**  are both good compromises between resolution and convenience.
**
**  2) The nutation components in longitude and obliquity are in radians
**     and with respect to the equinox and ecliptic of date.  The
**     obliquity at J2000.0 is assumed to be the Lieske et al. (1977)
**     value of 84381.448 arcsec.  (The errors that result from using
**     this function with the IAU 2006 value of 84381.406 arcsec can be
**     neglected.)
**
**     The nutation model consists only of luni-solar terms, but
**     includes also a fixed offset which compensates for certain long-
**     period planetary terms (Note 7).
**
**  3) This function is an implementation of the IAU 2000B abridged
**     nutation model formally adopted by the IAU General Assembly in
**     2000.  The function computes the MHB_2000_SHORT luni-solar
**     nutation series (Luzum 2001), but without the associated
**     corrections for the precession rate adjustments and the offset
**     between the GCRS and J2000.0 mean poles.
**
**  4) The full IAU 2000A (MHB2000) nutation model contains nearly 1400
**     terms.  The IAU 2000B model (McCarthy & Luzum 2003) contains only
**     77 terms, plus additional simplifications, yet still delivers
**     results of 1 mas accuracy at present epochs.  This combination of
**     accuracy and size makes the IAU 2000B abridged nutation model
**     suitable for most practical applications.
**
**  The function delivers a pole accurate to 1 mas from 1900 to 2100
**  (usually better than 1 mas, very occasionally just outside
**  1 mas).  The full IAU 2000A model, which is implemented in the
**  function iauNut00a (q.v.), delivers considerably greater accuracy
**  at current dates; however, to realize this improved accuracy,
**  corrections for the essentially unpredictable free-core-nutation

```

```

**      (FCN) must also be included.
**
** 5) The present function provides classical nutation. The
** MHB_2000_SHORT algorithm, from which it is adapted, deals also
** with (i) the offsets between the GCRS and mean poles and (ii) the
** adjustments in longitude and obliquity due to the changed
** precession rates. These additional functions, namely frame bias
** and precession adjustments, are supported by the SOFA functions
** iauBi00 and iauPr00.
**
** 6) The MHB_2000_SHORT algorithm also provides "total" nutations,
** comprising the arithmetic sum of the frame bias, precession
** adjustments, and nutation (luni-solar + planetary). These total
** nutations can be used in combination with an existing IAU 1976
** precession implementation, such as iauPmat76, to deliver GCRS-
** to-true predictions of mas accuracy at current epochs. However,
** for symmetry with the iauNut00a function (q.v. for the reasons),
** the SOFA functions do not generate the "total nutations"
** directly. Should they be required, they could of course easily
** be generated by calling iauBi00, iauPr00 and the present function
** and adding the results.
**
** 7) The IAU 2000B model includes "planetary bias" terms that are
** fixed in size but compensate for long-period nutations. The
** amplitudes quoted in McCarthy & Luzum (2003), namely
** Dpsi = -1.5835 mas and Dpsilon = +1.6339 mas, are optimized for
** the "total nutations" method described in Note 6. The Luzum
** (2001) values used in this SOFA implementation, namely -0.135 mas
** and +0.388 mas, are optimized for the "rigorous" method, where
** frame bias, precession and nutation are applied separately and in
** that order. During the interval 1995-2050, the SOFA
** implementation delivers a maximum error of 1.001 mas (not
** including FCN).
**
** References:
**
** Lieske, J.H., Lederle, T., Fricke, W., Morando, B., "Expressions
** for the precession quantities based upon the IAU /1976/ system of
** astronomical constants", Astron.Astrophys. 58, 1-2, 1-16. (1977)
**
** Luzum, B., private communication, 2001 (Fortran code
** MHB_2000_SHORT)
**
** McCarthy, D.D. & Luzum, B.J., "An abridged model of the
** precession-nutation of the celestial pole", Cel.Mech.Dyn.Astron.
** 85, 37-49 (2003)
**
** Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
** Francou, G., Laskar, J., Astron.Astrophys. 282, 663-683 (1994)
**
** /

```

```

void iauNut06a(double date1, double date2, double *dpsi, double *deps)
/*
**   - - - - -
**   i a u N u t 0 6 a
**   - - - - -
**
**   IAU 2000A nutation with adjustments to match the IAU 2006
**   precession.
**
**   Given:
**     date1,date2   double   TT as a 2-part Julian Date (Note 1)
**
**   Returned:
**     dpsi,deps    double   nutation, luni-solar + planetary (Note 2)
**
**   Status:   canonical model.
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**           date1           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3        (J2000 method)
**           2400000.5           50123.2       (MJD method)
**           2450123.5           0.2           (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution
**   is acceptable.  The J2000 method is best matched to the way
**   the argument is handled internally and will deliver the
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**
**   2) The nutation components in longitude and obliquity are in radians
**      and with respect to the mean equinox and ecliptic of date,
**      IAU 2006 precession model (Hilton et al. 2006, Capitaine et al.
**      2005).
**
**   3) The function first computes the IAU 2000A nutation, then applies
**      adjustments for (i) the consequences of the change in obliquity
**      from the IAU 1980 ecliptic to the IAU 2006 ecliptic and (ii) the
**      secular variation in the Earth's dynamical form factor J2.
**
**   4) The present function provides classical nutation, complementing
**      the IAU 2000 frame bias and IAU 2006 precession.  It delivers a
**      pole which is at current epochs accurate to a few tens of
**      microarcseconds, apart from the free core nutation.
**
**   Called:
**     iauNut00a   nutation, IAU 2000A
**
**   References:
**
**     Chapront, J., Chapront-Touze, M. & Francou, G. 2002,
**     Astron.Astrophys. 387, 700
**
**     Lieske, J.H., Lederle, T., Fricke, W. & Morando, B. 1977,
**     Astron.Astrophys. 58, 1-16
**
**     Mathews, P.M., Herring, T.A., Buffet, B.A. 2002, J.Geophys.Res.
**     107, B4.  The MHB_2000 code itself was obtained on 9th September
**     2002 from ftp://maia.usno.navy.mil/conv2000/chapter5/IAU2000A.
**
**     Simon, J.-L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,
**     Francou, G., Laskar, J. 1994, Astron.Astrophys. 282, 663-683
**

```

\*\* Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M. 1999,  
\*\* Astron.Astrophys.Supp.Ser. 135, 111  
\*\*  
\*\* Wallace, P.T., "Software for Implementing the IAU 2000  
\*\* Resolutions", in IERS Workshop 5.1 (2002)  
\*\*  
\*/

```

void iauNut80(double date1, double date2, double *dpsi, double *deps)
/*
**  - - - - -
**   i a u N u t 8 0
**  - - - - -
**
**  Nutation, IAU 1980 model.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical model.
**
**  Given:
**    date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    dpsi         double      nutation in longitude (radians)
**    deps         double      nutation in obliquity (radians)
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
**     The JD method is the most natural and convenient to use in
**     cases where the loss of several decimal digits of resolution
**     is acceptable.  The J2000 method is best matched to the way
**     the argument is handled internally and will deliver the
**     optimum resolution.  The MJD method and the date & time methods
**     are both good compromises between resolution and convenience.
**
**  2) The nutation components are with respect to the ecliptic of
**     date.
**
**  Called:
**    iauAnpm          normalize angle into range +/- pi
**
**  Reference:
**
**    Explanatory Supplement to the Astronomical Almanac,
**    P. Kenneth Seidelmann (ed), University Science Books (1992),
**    Section 3.222 (p111).
**
*/

```

```

void iauNutm80(double date1, double date2, double rmatn[3][3])
/*
**  - - - - -
**   i a u N u t m 8 0
**  - - - - -
**
** Form the matrix of nutation for a given date, IAU 1980 model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2    double          TDB date (Note 1)
**
** Returned:
**   rmatn          double[3][3]    nutation matrix
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{true}) = \text{rmatn} * V(\text{mean})$ ,
** where the p-vector  $V(\text{true})$  is with respect to the true
** equatorial triad of date and the p-vector  $V(\text{mean})$  is with
** respect to the mean equatorial triad of date.
**
** Called:
**   iauNut80      nutation, IAU 1980
**   iauObl80     mean obliquity, IAU 1980
**   iauNumat     form nutation matrix
**
*/

```

```

double iauObl06(double date1, double date2)
/*
**  - - - - -
**   i a u O b l 0 6
**  - - - - -
**
** Mean obliquity of the ecliptic, IAU 2006 precession model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2 double TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double obliquity of the ecliptic (radians, Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result is the angle between the ecliptic and mean equator of
** date date1+date2.
**
** Reference:
**
** Hilton, J. et al., 2006, Celest.Mech.Dyn.Astron. 94, 351
**
*/

```

```

double iauObl80(double date1, double date2)
/*
**  - - - - -
**   i a u O b l 8 0
**  - - - - -
**
** Mean obliquity of the ecliptic, IAU 1980 model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  canonical model.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      obliquity of the ecliptic (radians, Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
**    convenient way between the two arguments.  For example,
**    JD(TT)=2450123.7 could be expressed in any of these ways,
**    among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The result is the angle between the ecliptic and mean equator of
**    date date1+date2.
**
** Reference:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** Expression 3.222-1 (p114).
**
*/

```

```

void iauP06e(double date1, double date2,
             double *eps0, double *psia, double *oma, double *bpa,
             double *bqa, double *pia, double *bpia,
             double *epsa, double *chia, double *za, double *zetaa,
             double *thetaa, double *pa,
             double *gam, double *phi, double *psi)
/*
**  - - - - -
**  i a u P 0 6 e
**  - - - - -
**
**  Precession angles, IAU 2006, equinox based.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  canonical models.
**
**  Given:
**    date1,date2  double  TT as a 2-part Julian Date (Note 1)
**
**  Returned (see Note 2):
**    eps0         double  epsilon_0
**    psia         double  psi_A
**    oma         double  omega_A
**    bpa         double  P_A
**    bqa         double  Q_A
**    pia         double  pi_A
**    bpia        double  Pi_A
**    epsa        double  obliquity epsilon_A
**    chia         double  chi_A
**    za         double  z_A
**    zetaa       double  zeta_A
**    thetaa      double  theta_A
**    pa         double  p_A
**    gam         double  F-W angle gamma_J2000
**    phi         double  F-W angle phi_J2000
**    psi         double  F-W angle psi_J2000
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
**     The JD method is the most natural and convenient to use in
**     cases where the loss of several decimal digits of resolution
**     is acceptable.  The J2000 method is best matched to the way
**     the argument is handled internally and will deliver the
**     optimum resolution.  The MJD method and the date & time methods
**     are both good compromises between resolution and convenience.
**
**  2) This function returns the set of equinox based angles for the
**     Capitaine et al. "P03" precession theory, adopted by the IAU in
**     2006.  The angles are set out in Table 1 of Hilton et al. (2006):
**
**    eps0  epsilon_0  obliquity at J2000.0
**    psia  psi_A     luni-solar precession
**    oma   omega_A   inclination of equator wrt J2000.0 ecliptic
**    bpa   P_A       ecliptic pole x, J2000.0 ecliptic triad
**    bqa   Q_A       ecliptic pole -y, J2000.0 ecliptic triad
**    pia   pi_A      angle between moving and J2000.0 ecliptics
**    bpia  Pi_A      longitude of ascending node of the ecliptic

```

```

**      epsa   epsilon_A   obliquity of the ecliptic
**      chia   chi_A       planetary precession
**      za     z_A         equatorial precession: -3rd 323 Euler angle
**      zetaa  zeta_A      equatorial precession: -1st 323 Euler angle
**      thetaa theta_A    equatorial precession: 2nd 323 Euler angle
**      pa     p_A         general precession
**      gam    gamma_J2000 J2000.0 RA difference of ecliptic poles
**      phi    phi_J2000   J2000.0 codeclination of ecliptic pole
**      psi    psi_J2000   longitude difference of equator poles, J2000.0
**
**      The returned values are all radians.
**
**      3) Hilton et al. (2006) Table 1 also contains angles that depend on
**      models distinct from the P03 precession theory itself, namely the
**      IAU 2000A frame bias and nutation. The quoted polynomials are
**      used in other SOFA functions:
**
**      . iauXy06 contains the polynomial parts of the X and Y series.
**
**      . iauS06 contains the polynomial part of the s+XY/2 series.
**
**      . iauPfw06 implements the series for the Fukushima-Williams
**      angles that are with respect to the GCRS pole (i.e. the variants
**      that include frame bias).
**
**      4) The IAU resolution stipulated that the choice of parameterization
**      was left to the user, and so an IAU compliant precession
**      implementation can be constructed using various combinations of
**      the angles returned by the present function.
**
**      5) The parameterization used by SOFA is the version of the Fukushima-
**      Williams angles that refers directly to the GCRS pole. These
**      angles may be calculated by calling the function iauPfw06. SOFA
**      also supports the direct computation of the CIP GCRS X,Y by
**      series, available by calling iauXy06.
**
**      6) The agreement between the different parameterizations is at the
**      1 microarcsecond level in the present era.
**
**      7) When constructing a precession formulation that refers to the GCRS
**      pole rather than the dynamical pole, it may (depending on the
**      choice of angles) be necessary to introduce the frame bias
**      explicitly.
**
**      8) It is permissible to re-use the same variable in the returned
**      arguments. The quantities are stored in the stated order.
**
**      Reference:
**
**      Hilton, J. et al., 2006, Celest.Mech.Dyn.Astron. 94, 351
**
**      Called:
**      iauObl06      mean obliquity, IAU 2006
**
*/

```

```

void iauP2pv(double p[3], double pv[2][3])
/*
**  - - - - -
**   i a u P 2 p v
**  - - - - -
**
**   Extend a p-vector to a pv-vector by appending a zero velocity.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     p      double[3]      p-vector
**
**   Returned:
**     pv     double[2][3]   pv-vector
**
**   Called:
**     iauCp      copy p-vector
**     iauZp      zero p-vector
**
*/

```

```

void iauP2s(double p[3], double *theta, double *phi, double *r)
/*
**  - - - - -
**   i a u P 2 s
**  - - - - -
**
**   P-vector to spherical polar coordinates.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     p          double[3]    p-vector
**
**   Returned:
**     theta      double        longitude angle (radians)
**     phi        double        latitude angle (radians)
**     r          double        radial distance
**
**   Notes:
**
**   1) If P is null, zero theta, phi and r are returned.
**
**   2) At either pole, zero theta is returned.
**
**   Called:
**     iauC2s      p-vector to spherical
**     iauPm      modulus of p-vector
**
*/

```

```

double iauPap(double a[3], double b[3])
/*
**  - - - - -
**   i a u P a p
**  - - - - -
**
**   Position-angle from two p-vectors.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[3]  direction of reference point
**     b      double[3]  direction of point whose PA is required
**
**   Returned (function value):
**     double      position angle of b with respect to a (radians)
**
**   Notes:
**
**   1) The result is the position angle, in radians, of direction b with
**      respect to direction a.  It is in the range  $-\pi$  to  $+\pi$ .  The
**      sense is such that if b is a small distance "north" of a the
**      position angle is approximately zero, and if b is a small
**      distance "east" of a the position angle is approximately  $+\pi/2$ .
**
**   2) The vectors a and b need not be of unit length.
**
**   3) Zero is returned if the two directions are the same or if either
**      vector is null.
**
**   4) If vector a is at a pole, the result is ill-defined.
**
**   Called:
**     iauPn      decompose p-vector into modulus and direction
**     iauPm      modulus of p-vector
**     iauPxp     vector product of two p-vectors
**     iauPmp     p-vector minus p-vector
**     iauPdp     scalar product of two p-vectors
**
*/

```

```

double iauPas(double al, double ap, double bl, double bp)
/*
**  - - - - -
**   i a u P a s
**  - - - - -
**
**   Position-angle from spherical coordinates.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     al      double      longitude of point A (e.g. RA) in radians
**     ap      double      latitude of point A (e.g. Dec) in radians
**     bl      double      longitude of point B
**     bp      double      latitude of point B
**
**   Returned (function value):
**     double      position angle of B with respect to A
**
**   Notes:
**
**   1) The result is the bearing (position angle), in radians, of point
**      B with respect to point A.  It is in the range  $-\pi$  to  $+\pi$ .  The
**      sense is such that if B is a small distance "east" of point A,
**      the bearing is approximately  $+\pi/2$ .
**
**   2) Zero is returned if the two points are coincident.
**
*/

```

```

void iauPb06(double date1, double date2,
             double *bzeta, double *bz, double *btheta)
/*
**  - - - - -
**  i a u P b 0 6
**  - - - - -
**
**  This function forms three Euler angles which implement general
**  precession from epoch J2000.0, using the IAU 2006 model. Frame
**  bias (the offset between ICRS and mean J2000.0) is included.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double    TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    bzeta       double    1st rotation: radians cw around z
**    bz          double    3rd rotation: radians cw around z
**    btheta      double    2nd rotation: radians ccw around y
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**  convenient way between the two arguments.  For example,
**  JD(TT)=2450123.7 could be expressed in any of these ways,
**  among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2       (MJD method)
**          2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in
**  cases where the loss of several decimal digits of resolution
**  is acceptable.  The J2000 method is best matched to the way
**  the argument is handled internally and will deliver the
**  optimum resolution.  The MJD method and the date & time methods
**  are both good compromises between resolution and convenience.
**
**  2) The traditional accumulated precession angles zeta_A, z_A,
**  theta_A cannot be obtained in the usual way, namely through
**  polynomial expressions, because of the frame bias.  The latter
**  means that two of the angles undergo rapid changes near this
**  date.  They are instead the results of decomposing the
**  precession-bias matrix obtained by using the Fukushima-Williams
**  method, which does not suffer from the problem.  The
**  decomposition returns values which can be used in the
**  conventional formulation and which include frame bias.
**
**  3) The three angles are returned in the conventional order, which
**  is not the same as the order of the corresponding Euler
**  rotations.  The precession-bias matrix is
**  R_3(-z) x R_2(+theta) x R_3(-zeta).
**
**  4) Should zeta_A, z_A, theta_A angles be required that do not
**  contain frame bias, they are available by calling the SOFA
**  function iauP06e.
**
**  Called:
**    iauPmat06  PB matrix, IAU 2006
**    iauRz      rotate around Z-axis
**
*/

```

```
double iauPdp(double a[3], double b[3])
/*
**  - - - - -
**   i a u P d p
**  - - - - -
**
**  p-vector inner (=scalar=dot) product.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    a      double[3]    first p-vector
**    b      double[3]    second p-vector
**
**  Returned (function value):
**    double      a . b
**
**/
```

```

void iauPfw06(double date1, double date2,
              double *gamb, double *phib, double *psib, double *epsa)
/*
**   - - - - -
**   i a u P f w 0 6
**   - - - - -
**
**   Precession angles, IAU 2006 (Fukushima-Williams 4-angle formulation).
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:   canonical model.
**
**   Given:
**     date1,date2  double    TT as a 2-part Julian Date (Note 1)
**
**   Returned:
**     gamb         double    F-W angle gamma_bar (radians)
**     phib         double    F-W angle phi_bar (radians)
**     psib         double    F-W angle psi_bar (radians)
**     epsa         double    F-W angle epsilon_A (radians)
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2        (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution
**      is acceptable.  The J2000 method is best matched to the way
**      the argument is handled internally and will deliver the
**      optimum resolution.  The MJD method and the date & time methods
**      are both good compromises between resolution and convenience.
**
**   2) Naming the following points:
**
**          e = J2000.0 ecliptic pole,
**          p = GCRS pole,
**          E = mean ecliptic pole of date,
**      and  P = mean pole of date,
**
**      the four Fukushima-Williams angles are as follows:
**
**          gamb = gamma_bar = epE
**          phib = phi_bar = pE
**          psib = psi_bar = pEP
**          epsa = epsilon_A = EP
**
**   3) The matrix representing the combined effects of frame bias and
**      precession is:
**
**          PxB = R_1(-epsa).R_3(-psib).R_1(phib).R_3(gamb)
**
**   4) The matrix representing the combined effects of frame bias,
**      precession and nutation is simply:
**
**          NxPxB = R_1(-epsa-dE).R_3(-psib-dP).R_1(phib).R_3(gamb)
**
**      where dP and dE are the nutation components with respect to the
**      ecliptic of date.
**
**

```

```
** Reference:
**
**   Hilton, J. et al., 2006, Celest.Mech.Dyn.Astron. 94, 351
**
** Called:
**   iauObl06      mean obliquity, IAU 2006
**
**/
```

```

int iauPlan94(double date1, double date2, int np, double pv[2][3])
/*
**   - - - - -
**   i a u P l a n 9 4
**   - - - - -
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Approximate heliocentric position and velocity of a nominated major
** planet:  Mercury, Venus, EMB, Mars, Jupiter, Saturn, Uranus or
** Neptune (but not the Earth itself).
**
** Given:
**   date1 double      TDB date part A (Note 1)
**   date2 double      TDB date part B (Note 1)
**   np    int         planet (1=Mercury, 2=Venus, 3=EMB, 4=Mars,
**                        5=Jupiter, 6=Saturn, 7=Uranus, 8=Neptune)
**
** Returned (argument):
**   pv    double[2][3] planet p,v (heliocentric, J2000.0, AU,AU/d)
**
** Returned (function value):
**   int    status:  -1 = illegal NP (outside 1-8)
**                0 = OK
**                +1 = warning: year outside 1000-3000
**                +2 = warning: failed to converge
**
** Notes:
**
** 1) The date date1+date2 is in the TDB time scale (in practice TT can
** be used) and is a Julian Date, apportioned in any convenient way
** between the two arguments.  For example, JD(TDB)=2450123.7 could
** be expressed in any of these ways, among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in cases
** where the loss of several decimal digits of resolution is
** acceptable.  The J2000 method is best matched to the way the
** argument is handled internally and will deliver the optimum
** resolution.  The MJD method and the date & time methods are both
** good compromises between resolution and convenience.  The limited
** accuracy of the present algorithm is such that any of the methods
** is satisfactory.
**
** 2) If an np value outside the range 1-8 is supplied, an error status
** (function value -1) is returned and the pv vector set to zeroes.
**
** 3) For np=3 the result is for the Earth-Moon Barycenter.  To obtain
** the heliocentric position and velocity of the Earth, use instead
** the SOFA function iauEpv00.
**
** 4) On successful return, the array pv contains the following:
**
**           pv[0][0]  x      }
**           pv[0][1]  y      } heliocentric position, AU
**           pv[0][2]  z      }
**
**           pv[1][0]  xdot   }
**           pv[1][1]  ydot   } heliocentric velocity, AU/d
**           pv[1][2]  zdot   }
**
** The reference frame is equatorial and is with respect to the

```

```

**      mean equator and equinox of epoch J2000.0.
**
** 5) The algorithm is due to J.L. Simon, P. Bretagnon, J. Chapront,
**      M. Chapront-Touze, G. Francou and J. Laskar (Bureau des
**      Longitudes, Paris, France). From comparisons with JPL
**      ephemeris DE102, they quote the following maximum errors
**      over the interval 1800-2050:
**
**              L (arcsec)   B (arcsec)   R (km)
**
**      Mercury           4             1           300
**      Venus              5             1           800
**      EMB                 6             1          1000
**      Mars                17            1          7700
**      Jupiter            71             5          76000
**      Saturn             81            13         267000
**      Uranus             86             7          712000
**      Neptune           11             1          253000
**
** Over the interval 1000-3000, they report that the accuracy is no
** worse than 1.5 times that over 1800-2050. Outside 1000-3000 the
** accuracy declines.
**
** Comparisons of the present function with the JPL DE200 ephemeris
** give the following RMS errors over the interval 1960-2025:
**
**              position (km)   velocity (m/s)
**
**      Mercury           334             0.437
**      Venus            1060             0.855
**      EMB               2010             0.815
**      Mars              7690             1.98
**      Jupiter          71700             7.70
**      Saturn           199000            19.4
**      Uranus           564000            16.4
**      Neptune         158000            14.4
**
** Comparisons against DE200 over the interval 1800-2100 gave the
** following maximum absolute differences. (The results using
** DE406 were essentially the same.)
**
**              L (arcsec)   B (arcsec)   R (km)   Rdot (m/s)
**
**      Mercury           7             1           500       0.7
**      Venus              7             1          1100       0.9
**      EMB                 9             1          1300       1.0
**      Mars                26            1          9000       2.5
**      Jupiter            78             6          82000       8.2
**      Saturn             87            14         263000      24.6
**      Uranus             86             7          661000      27.4
**      Neptune           11             2          248000      21.4
**
** 6) The present SOFA re-implementation of the original Simon et al.
**      Fortran code differs from the original in the following respects:
**
**      * C instead of Fortran.
**
**      * The date is supplied in two parts.
**
**      * The result is returned only in equatorial Cartesian form;
**        the ecliptic longitude, latitude and radius vector are not
**        returned.
**
**      * The result is in the J2000.0 equatorial frame, not ecliptic.
**
**      * More is done in-line: there are fewer calls to subroutines.
**
**      * Different error/warning status values are used.
**
**      * A different Kepler's-equation-solver is used (avoiding
**        use of double precision complex).
**
**      * Polynomials in t are nested to minimize rounding errors.

```

```
**
**      * Explicit double constants are used to avoid mixed-mode
**      expressions.
**
**      None of the above changes affects the result significantly.
**
**      7) The returned status indicates the most serious condition
**      encountered during execution of the function. Illegal np is
**      considered the most serious, overriding failure to converge,
**      which in turn takes precedence over the remote date warning.
**
**      Called:
**      iauAnp          normalize angle into range 0 to 2pi
**
**      Reference:  Simon, J.L, Bretagnon, P., Chapront, J.,
**                  Chapront-Touze, M., Francou, G., and Laskar, J.,
**                  Astron. Astrophys. 282, 663 (1994).
**
**      */
```

```
double iauPm(double p[3])
/*
**  - - - - -
**   i a u P m
**  - - - - -
**
**  Modulus of p-vector.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    p      double[3]      p-vector
**
**  Returned (function value):
**    double      modulus
**
**/
```

```

void iauPmat00(double date1, double date2, double rbp[3][3])
/*
**  - - - - -
**   i a u P m a t 0 0
**  - - - - -
**
** Precession matrix (including frame bias) from GCRS to a specified
** date, IAU 2000 model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rbp          double[3][3]    bias-precession matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rbp} * V(\text{GCRS})$ , where
** the p-vector  $V(\text{GCRS})$  is with respect to the Geocentric Celestial
** Reference System (IAU, 2000) and the p-vector  $V(\text{date})$  is with
** respect to the mean equatorial triad of the given date.
**
** Called:
**   iauBp00      frame bias and precession matrices, IAU 2000
**
** Reference:
**
** IAU: Trans. International Astronomical Union, Vol. XXIVB; Proc.
** 24th General Assembly, Manchester, UK. Resolutions B1.3, B1.6.
** (2000)
**
*/

```

```

void iauPmat06(double date1, double date2, double rbp[3][3])
/*
**  - - - - -
**   i a u P m a t 0 6
**  - - - - -
**
** Precession matrix (including frame bias) from GCRS to a specified
** date, IAU 2006 model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rbp          double[3][3]    bias-precession matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rbp} * V(\text{GCRS})$ , where
** the p-vector  $V(\text{GCRS})$  is with respect to the Geocentric Celestial
** Reference System (IAU, 2000) and the p-vector  $V(\text{date})$  is with
** respect to the mean equatorial triad of the given date.
**
** Called:
**   iauPfw06      bias-precession F-W angles, IAU 2006
**   iauFw2m      F-W angles to r-matrix
**
** References:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**   Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```

void iauPmat76(double date1, double date2, double rmatp[3][3])
/*
**  - - - - -
**   i a u P m a t 7 6
**  - - - - -
**
**  Precession matrix from J2000.0 to a specified date, IAU 1976 model.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2 double          ending date, TT (Note 1)
**
**  Returned:
**    rmatp          double[3][3] precession matrix, J2000.0 -> date1+date2
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in
**  cases where the loss of several decimal digits of resolution
**  is acceptable.  The J2000 method is best matched to the way
**  the argument is handled internally and will deliver the
**  optimum resolution.  The MJD method and the date & time methods
**  are both good compromises between resolution and convenience.
**
**  2) The matrix operates in the sense  $V(\text{date}) = \text{RMATP} * V(\text{J2000})$ ,
**     where the p-vector  $V(\text{J2000})$  is with respect to the mean
**     equatorial triad of epoch J2000.0 and the p-vector  $V(\text{date})$ 
**     is with respect to the mean equatorial triad of the given
**     date.
**
**  3) Though the matrix method itself is rigorous, the precession
**     angles are expressed through canonical polynomials which are
**     valid only for a limited time span.  In addition, the IAU 1976
**     precession rate is known to be imperfect.  The absolute accuracy
**     of the present formulation is better than 0.1 arcsec from
**     1960AD to 2040AD, better than 1 arcsec from 1640AD to 2360AD,
**     and remains below 3 arcsec for the whole of the period
**     500BC to 3000AD.  The errors exceed 10 arcsec outside the
**     range 1200BC to 3900AD, exceed 100 arcsec outside 4200BC to
**     5600AD and exceed 1000 arcsec outside 6800BC to 8200AD.
**
**  Called:
**    iauPrec76    accumulated precession angles, IAU 1976
**    iauIr        initialize r-matrix to identity
**    iauRz        rotate around Z-axis
**    iauRy        rotate around Y-axis
**    iauCr        copy r-matrix
**
**  References:
**
**    Lieske, J.H., 1979, Astron.Astrophys. 73, 282.
**    equations (6) & (7), p283.
**
**    Kaplan,G.H., 1981. USNO circular no. 163, pA2.
**

```



```

void iauPmp(double a[3], double b[3], double amb[3])
/*
**  - - - - -
**   i a u P m p
**  - - - - -
**
**   P-vector subtraction.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[3]      first p-vector
**     b      double[3]      second p-vector
**
**   Returned:
**     amb    double[3]      a - b
**
**   Note:
**     It is permissible to re-use the same array for any of the
**     arguments.
**
*/

```

```

void iauPmpx(double rc, double dc, double pr, double pd,
             double px, double rv, double pmt, double pob[3],
             double pco[3])
/*
**  - - - - -
**   i a u P m p x
**  - - - - -
**
** Proper motion and parallax.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   rc,dc  double      ICRS RA,Dec at catalog epoch (radians)
**   pr     double      RA proper motion (radians/year; Note 1)
**   pd     double      Dec proper motion (radians/year)
**   px     double      parallax (arcsec)
**   rv     double      radial velocity (km/s, +ve if receding)
**   pmt    double      proper motion time interval (SSB, Julian years)
**   pob    double[3]   SSB to observer vector (au)
**
** Returned:
**   pco    double[3]   coordinate direction (BCRS unit vector)
**
** Notes:
**
** 1) The proper motion in RA is dRA/dt rather than cos(Dec)*dRA/dt.
**
** 2) The proper motion time interval is for when the starlight
**    reaches the solar system barycenter.
**
** 3) To avoid the need for iteration, the Roemer effect (i.e. the
**    small annual modulation of the proper motion coming from the
**    changing light time) is applied approximately, using the
**    direction of the star at the catalog epoch.
**
** References:
**
**   1984 Astronomical Almanac, pp B39-B41.
**
**   Urban, S. & Seidelmann, P. K. (eds), Explanatory Supplement to
**   the Astronomical Almanac, 3rd ed., University Science Books
**   (2013), Section 7.2.
**
** Called:
**   iauPdp      scalar product of two p-vectors
**   iauPn      decompose p-vector into modulus and direction
**
*/

```

```

int iauPmsafe(double ra1, double decl1, double pmr1, double pmd1,
              double px1, double rv1,
              double ep1a, double ep1b, double ep2a, double ep2b,
              double *ra2, double *dec2, double *pmr2, double *pmd2,
              double *px2, double *rv2)
/*
**  - - - - -
**  i a u P m s a f e
**  - - - - -
**
**  Star proper motion: update star catalog data for space motion, with
**  special handling to handle the zero parallax case.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards of Fundamental Astronomy) software collection.
**
**  Status: support function.
**
**  Given:
**  ra1    double    right ascension (radians), before
**  decl1  double    declination (radians), before
**  pmr1   double    RA proper motion (radians/year), before
**  pmd1   double    Dec proper motion (radians/year), before
**  px1    double    parallax (arcseconds), before
**  rv1    double    radial velocity (km/s, +ve = receding), before
**  ep1a   double    "before" epoch, part A (Note 1)
**  ep1b   double    "before" epoch, part B (Note 1)
**  ep2a   double    "after" epoch, part A (Note 1)
**  ep2b   double    "after" epoch, part B (Note 1)
**
**  Returned:
**  ra2    double    right ascension (radians), after
**  dec2   double    declination (radians), after
**  pmr2   double    RA proper motion (radians/year), after
**  pmd2   double    Dec proper motion (radians/year), after
**  px2    double    parallax (arcseconds), after
**  rv2    double    radial velocity (km/s, +ve = receding), after
**
**  Returned (function value):
**  int     status:
**          -1 = system error (should not occur)
**           0 = no warnings or errors
**           1 = distance overridden (Note 6)
**           2 = excessive velocity (Note 7)
**           4 = solution didn't converge (Note 8)
**          else = binary logical OR of the above warnings
**
**  Notes:
**
**  1) The starting and ending TDB epochs ep1a+ep1b and ep2a+ep2b are
**  Julian Dates, apportioned in any convenient way between the two
**  parts (A and B). For example, JD(TDB)=2450123.7 could be
**  expressed in any of these ways, among others:
**
**          epNa          epNb
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2       (MJD method)
**          2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in cases
**  where the loss of several decimal digits of resolution is
**  acceptable. The J2000 method is best matched to the way the
**  argument is handled internally and will deliver the optimum
**  resolution. The MJD method and the date & time methods are both
**  good compromises between resolution and convenience.
**
**  2) In accordance with normal star-catalog conventions, the object's
**  right ascension and declination are freed from the effects of
**  secular aberration. The frame, which is aligned to the catalog

```

```

**      equator and equinox, is Lorentzian and centered on the SSB.
**
**      The proper motions are the rate of change of the right ascension
**      and declination at the catalog epoch and are in radians per TDB
**      Julian year.
**
**      The parallax and radial velocity are in the same frame.
**
**      3) Care is needed with units.  The star coordinates are in radians
**      and the proper motions in radians per Julian year, but the
**      parallax is in arcseconds.
**
**      4) The RA proper motion is in terms of coordinate angle, not true
**      angle.  If the catalog uses arcseconds for both RA and Dec proper
**      motions, the RA proper motion will need to be divided by cos(Dec)
**      before use.
**
**      5) Straight-line motion at constant speed, in the inertial frame, is
**      assumed.
**
**      6) An extremely small (or zero or negative) parallax is overridden
**      to ensure that the object is at a finite but very large distance,
**      but not so large that the proper motion is equivalent to a large
**      but safe speed (about 0.1c using the chosen constant).  A warning
**      status of 1 is added to the status if this action has been taken.
**
**      7) If the space velocity is a significant fraction of c (see the
**      constant VMAX in the function iauStarpv), it is arbitrarily set
**      to zero.  When this action occurs, 2 is added to the status.
**
**      8) The relativistic adjustment carried out in the iauStarpv function
**      involves an iterative calculation.  If the process fails to
**      converge within a set number of iterations, 4 is added to the
**      status.
**
**      Called:
**      iauSeps      angle between two points
**      iauStarpm    update star catalog data for space motion
**
*/

```

```

void iauPn(double p[3], double *r, double u[3])
/*
**  - - - - -
**   i a u P n
**  - - - - -
**
**   Convert a p-vector into modulus and unit vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     p          double[3]      p-vector
**
**   Returned:
**     r          double         modulus
**     u          double[3]      unit vector
**
**   Notes:
**
**   1) If p is null, the result is null.  Otherwise the result is a unit
**      vector.
**
**   2) It is permissible to re-use the same array for any of the
**      arguments.
**
**   Called:
**     iauPm          modulus of p-vector
**     iauZp          zero p-vector
**     iauSxp         multiply p-vector by scalar
**
*/

```

```

void iauPn00(double date1, double date2, double dpsi, double deps,
            double *epsa,
            double rb[3][3], double rp[3][3], double rbp[3][3],
            double rn[3][3], double rbpn[3][3])
/*
**  - - - - -
**  i a u P n 0 0
**  - - - - -
**
**  Precession-nutation, IAU 2000 model:  a multi-purpose function,
**  supporting classical (equinox-based) use directly and CIO-based
**  use indirectly.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**      date1,date2  double          TT as a 2-part Julian Date (Note 1)
**      dpsi,deps   double          nutation (Note 2)
**
**  Returned:
**      epsa        double          mean obliquity (Note 3)
**      rb          double[3][3]    frame bias matrix (Note 4)
**      rp          double[3][3]    precession matrix (Note 5)
**      rbp        double[3][3]    bias-precession matrix (Note 6)
**      rn         double[3][3]    nutation matrix (Note 7)
**      rbpn       double[3][3]    GCRS-to-true matrix (Note 8)
**
**  Notes:
**
**  1) The TT date date1+date2 is a Julian Date, apportioned in any
**     convenient way between the two arguments.  For example,
**     JD(TT)=2450123.7 could be expressed in any of these ways,
**     among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in
**  cases where the loss of several decimal digits of resolution
**  is acceptable.  The J2000 method is best matched to the way
**  the argument is handled internally and will deliver the
**  optimum resolution.  The MJD method and the date & time methods
**  are both good compromises between resolution and convenience.
**
**  2) The caller is responsible for providing the nutation components;
**     they are in longitude and obliquity, in radians and are with
**     respect to the equinox and ecliptic of date.  For high-accuracy
**     applications, free core nutation should be included as well as
**     any other relevant corrections to the position of the CIP.
**
**  3) The returned mean obliquity is consistent with the IAU 2000
**     precession-nutation models.
**
**  4) The matrix rb transforms vectors from GCRS to J2000.0 mean
**     equator and equinox by applying frame bias.
**
**  5) The matrix rp transforms vectors from J2000.0 mean equator and
**     equinox to mean equator and equinox of date by applying
**     precession.
**
**  6) The matrix rbp transforms vectors from GCRS to mean equator and
**     equinox of date by applying frame bias then precession.  It is
**     the product rp x rb.
**
**

```

```

** 7) The matrix rn transforms vectors from mean equator and equinox of
** date to true equator and equinox of date by applying the nutation
** (luni-solar + planetary).
**
** 8) The matrix rbpn transforms vectors from GCRS to true equator and
** equinox of date. It is the product rn x rbp, applying frame
** bias, precession and nutation in that order.
**
** 9) It is permissible to re-use the same array in the returned
** arguments. The arrays are filled in the order given.
**
** Called:
**   iauPr00      IAU 2000 precession adjustments
**   iauObl80     mean obliquity, IAU 1980
**   iauBp00     frame bias and precession matrices, IAU 2000
**   iauCr        copy r-matrix
**   iauNumat     form nutation matrix
**   iauRxr       product of two r-matrices
**
** Reference:
**
**   Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
**   "Expressions for the Celestial Intermediate Pole and Celestial
**   Ephemeris Origin consistent with the IAU 2000A precession-
**   nutation model", Astron.Astrophys. 400, 1145-1154 (2003)
**
**   n.b. The celestial ephemeris origin (CEO) was renamed "celestial
**   intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
*/

```

```

void iauPn00a(double date1, double date2,
              double *dpsi, double *deps, double *epsa,
              double rb[3][3], double rp[3][3], double rbp[3][3],
              double rn[3][3], double rbpn[3][3])
/*
**  - - - - -
**  i a u P n 0 0 a
**  - - - - -
**
**  Precession-nutation, IAU 2000A model:  a multi-purpose function,
**  supporting classical (equinox-based) use directly and CIO-based
**  use indirectly.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    dpsi,deps   double          nutation (Note 2)
**    epsa        double          mean obliquity (Note 3)
**    rb          double[3][3]    frame bias matrix (Note 4)
**    rp          double[3][3]    precession matrix (Note 5)
**    rbp        double[3][3]    bias-precession matrix (Note 6)
**    rn         double[3][3]    nutation matrix (Note 7)
**    rbpn       double[3][3]    GCRS-to-true matrix (Notes 8,9)
**
**  Notes:
**
**  1)  The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2       (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution
**      is acceptable.  The J2000 method is best matched to the way
**      the argument is handled internally and will deliver the
**      optimum resolution.  The MJD method and the date & time methods
**      are both good compromises between resolution and convenience.
**
**  2)  The nutation components (luni-solar + planetary, IAU 2000A) in
**      longitude and obliquity are in radians and with respect to the
**      equinox and ecliptic of date.  Free core nutation is omitted;
**      for the utmost accuracy, use the iauPn00 function, where the
**      nutation components are caller-specified.  For faster but
**      slightly less accurate results, use the iauPn00b function.
**
**  3)  The mean obliquity is consistent with the IAU 2000 precession.
**
**  4)  The matrix rb transforms vectors from GCRS to J2000.0 mean
**      equator and equinox by applying frame bias.
**
**  5)  The matrix rp transforms vectors from J2000.0 mean equator and
**      equinox to mean equator and equinox of date by applying
**      precession.
**
**  6)  The matrix rbp transforms vectors from GCRS to mean equator and
**      equinox of date by applying frame bias then precession.  It is
**      the product rp x rb.
**
**

```

```

** 7) The matrix rn transforms vectors from mean equator and equinox
** of date to true equator and equinox of date by applying the
** nutation (luni-solar + planetary).
**
** 8) The matrix rbpn transforms vectors from GCRS to true equator and
** equinox of date. It is the product rn x rbp, applying frame
** bias, precession and nutation in that order.
**
** 9) The X,Y,Z coordinates of the IAU 2000A Celestial Intermediate
** Pole are elements (3,1-3) of the GCRS-to-true matrix,
** i.e. rbpn[2][0-2].
**
** 10) It is permissible to re-use the same array in the returned
** arguments. The arrays are filled in the order given.
**
** Called:
**   iauNut00a      nutation, IAU 2000A
**   iauPn00       bias/precession/nutation results, IAU 2000
**
** Reference:
**
**   Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
**   "Expressions for the Celestial Intermediate Pole and Celestial
**   Ephemeris Origin consistent with the IAU 2000A precession-
**   nutation model", Astron.Astrophys. 400, 1145-1154 (2003)
**
**   n.b. The celestial ephemeris origin (CEO) was renamed "celestial
**   intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
*/

```

```

void iauPn00b(double date1, double date2,
              double *dpsi, double *deps, double *epsa,
              double rb[3][3], double rp[3][3], double rbp[3][3],
              double rn[3][3], double rbpn[3][3])
/*
**  - - - - -
**  i a u P n 0 0 b
**  - - - - -
**
**  Precession-nutation, IAU 2000B model:  a multi-purpose function,
**  supporting classical (equinox-based) use directly and CIO-based
**  use indirectly.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    dpsi,deps   double          nutation (Note 2)
**    epsa        double          mean obliquity (Note 3)
**    rb          double[3][3]    frame bias matrix (Note 4)
**    rp          double[3][3]    precession matrix (Note 5)
**    rbp         double[3][3]    bias-precession matrix (Note 6)
**    rn          double[3][3]    nutation matrix (Note 7)
**    rbpn       double[3][3]    GCRS-to-true matrix (Notes 8,9)
**
**  Notes:
**
**  1)  The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2        (MJD method)
**          2450123.5          0.2          (date & time method)
**
**  The JD method is the most natural and convenient to use in
**  cases where the loss of several decimal digits of resolution
**  is acceptable.  The J2000 method is best matched to the way
**  the argument is handled internally and will deliver the
**  optimum resolution.  The MJD method and the date & time methods
**  are both good compromises between resolution and convenience.
**
**  2)  The nutation components (luni-solar + planetary, IAU 2000B) in
**      longitude and obliquity are in radians and with respect to the
**      equinox and ecliptic of date.  For more accurate results, but
**      at the cost of increased computation, use the iauPn00a function.
**      For the utmost accuracy, use the iauPn00 function, where the
**      nutation components are caller-specified.
**
**  3)  The mean obliquity is consistent with the IAU 2000 precession.
**
**  4)  The matrix rb transforms vectors from GCRS to J2000.0 mean
**      equator and equinox by applying frame bias.
**
**  5)  The matrix rp transforms vectors from J2000.0 mean equator and
**      equinox to mean equator and equinox of date by applying
**      precession.
**
**  6)  The matrix rbp transforms vectors from GCRS to mean equator and
**      equinox of date by applying frame bias then precession.  It is
**      the product rp x rb.
**
**

```

```
** 7) The matrix rn transforms vectors from mean equator and equinox
** of date to true equator and equinox of date by applying the
** nutation (luni-solar + planetary).
**
** 8) The matrix rbpn transforms vectors from GCRS to true equator and
** equinox of date. It is the product rn x rbp, applying frame
** bias, precession and nutation in that order.
**
** 9) The X,Y,Z coordinates of the IAU 2000B Celestial Intermediate
** Pole are elements (3,1-3) of the GCRS-to-true matrix,
** i.e. rbpn[2][0-2].
**
** 10) It is permissible to re-use the same array in the returned
** arguments. The arrays are filled in the stated order.
**
** Called:
**   iauNut00b      nutation, IAU 2000B
**   iauPn00       bias/precession/nutation results, IAU 2000
**
** Reference:
**
**   Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
**   "Expressions for the Celestial Intermediate Pole and Celestial
**   Ephemeris Origin consistent with the IAU 2000A precession-
**   nutation model", Astron.Astrophys. 400, 1145-1154 (2003).
**
**   n.b. The celestial ephemeris origin (CEO) was renamed "celestial
**   intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
**/
```

```

void iauPn06(double date1, double date2, double dpsi, double deps,
            double *epsa,
            double rb[3][3], double rp[3][3], double rbp[3][3],
            double rn[3][3], double rbpn[3][3])
/*
**  - - - - -
**  i a u P n 0 6
**  - - - - -
**
**  Precession-nutation, IAU 2006 model:  a multi-purpose function,
**  supporting classical (equinox-based) use directly and CIO-based use
**  indirectly.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**      date1,date2  double          TT as a 2-part Julian Date (Note 1)
**      dpsi,deps   double          nutation (Note 2)
**
**  Returned:
**      epsa        double          mean obliquity (Note 3)
**      rb          double[3][3]    frame bias matrix (Note 4)
**      rp          double[3][3]    precession matrix (Note 5)
**      rbp        double[3][3]    bias-precession matrix (Note 6)
**      rn          double[3][3]    nutation matrix (Note 7)
**      rbpn       double[3][3]    GCRS-to-true matrix (Note 8)
**
**  Notes:
**
**  1)  The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2        (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution
**      is acceptable.  The J2000 method is best matched to the way
**      the argument is handled internally and will deliver the
**      optimum resolution.  The MJD method and the date & time methods
**      are both good compromises between resolution and convenience.
**
**  2)  The caller is responsible for providing the nutation components;
**      they are in longitude and obliquity, in radians and are with
**      respect to the equinox and ecliptic of date.  For high-accuracy
**      applications, free core nutation should be included as well as
**      any other relevant corrections to the position of the CIP.
**
**  3)  The returned mean obliquity is consistent with the IAU 2006
**      precession.
**
**  4)  The matrix rb transforms vectors from GCRS to J2000.0 mean
**      equator and equinox by applying frame bias.
**
**  5)  The matrix rp transforms vectors from J2000.0 mean equator and
**      equinox to mean equator and equinox of date by applying
**      precession.
**
**  6)  The matrix rbp transforms vectors from GCRS to mean equator and
**      equinox of date by applying frame bias then precession.  It is
**      the product rp x rb.
**
**

```

```
** 7) The matrix rn transforms vectors from mean equator and equinox
** of date to true equator and equinox of date by applying the
** nutation (luni-solar + planetary).
**
** 8) The matrix rbpn transforms vectors from GCRS to true equator and
** equinox of date. It is the product rn x rbp, applying frame
** bias, precession and nutation in that order.
**
** 9) The X,Y,Z coordinates of the Celestial Intermediate Pole are
** elements (3,1-3) of the GCRS-to-true matrix, i.e. rbpn[2][0-2].
**
** 10) It is permissible to re-use the same array in the returned
** arguments. The arrays are filled in the stated order.
**
** Called:
**   iauPfw06      bias-precession F-W angles, IAU 2006
**   iauFw2m      F-W angles to r-matrix
**   iauCr        copy r-matrix
**   iauTr        transpose r-matrix
**   iauRxr       product of two r-matrices
**
** References:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**   Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
**/
```

```

void iauPn06a(double date1, double date2,
              double *dpsi, double *deps, double *epsa,
              double rb[3][3], double rp[3][3], double rbp[3][3],
              double rn[3][3], double rbpn[3][3])
/*
**  - - - - -
**  i a u P n 0 6 a
**  - - - - -
**
**  Precession-nutation, IAU 2006/2000A models:  a multi-purpose function,
**  supporting classical (equinox-based) use directly and CIO-based use
**  indirectly.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    date1,date2  double          TT as a 2-part Julian Date (Note 1)
**
**  Returned:
**    dpsi,deps   double          nutation (Note 2)
**    epsa        double          mean obliquity (Note 3)
**    rb          double[3][3]    frame bias matrix (Note 4)
**    rp          double[3][3]    precession matrix (Note 5)
**    rbp        double[3][3]    bias-precession matrix (Note 6)
**    rn         double[3][3]    nutation matrix (Note 7)
**    rbpn       double[3][3]    GCRS-to-true matrix (Notes 8,9)
**
**  Notes:
**
**  1)  The TT date date1+date2 is a Julian Date, apportioned in any
**      convenient way between the two arguments.  For example,
**      JD(TT)=2450123.7 could be expressed in any of these ways,
**      among others:
**
**          date1          date2
**
**          2450123.7          0.0          (JD method)
**          2451545.0         -1421.3        (J2000 method)
**          2400000.5          50123.2        (MJD method)
**          2450123.5          0.2          (date & time method)
**
**      The JD method is the most natural and convenient to use in
**      cases where the loss of several decimal digits of resolution
**      is acceptable.  The J2000 method is best matched to the way
**      the argument is handled internally and will deliver the
**      optimum resolution.  The MJD method and the date & time methods
**      are both good compromises between resolution and convenience.
**
**  2)  The nutation components (luni-solar + planetary, IAU 2000A) in
**      longitude and obliquity are in radians and with respect to the
**      equinox and ecliptic of date.  Free core nutation is omitted;
**      for the utmost accuracy, use the iauPn06 function, where the
**      nutation components are caller-specified.
**
**  3)  The mean obliquity is consistent with the IAU 2006 precession.
**
**  4)  The matrix rb transforms vectors from GCRS to mean J2000.0 by
**      applying frame bias.
**
**  5)  The matrix rp transforms vectors from mean J2000.0 to mean of
**      date by applying precession.
**
**  6)  The matrix rbp transforms vectors from GCRS to mean of date by
**      applying frame bias then precession.  It is the product rp x rb.
**
**  7)  The matrix rn transforms vectors from mean of date to true of
**      date by applying the nutation (luni-solar + planetary).
**

```

```
** 8) The matrix rbpn transforms vectors from GCRS to true of date
** (CIP/equinox). It is the product rn x rbp, applying frame bias,
** precession and nutation in that order.
**
** 9) The X,Y,Z coordinates of the IAU 2006/2000A Celestial
** Intermediate Pole are elements (3,1-3) of the GCRS-to-true
** matrix, i.e. rbpn[2][0-2].
**
** 10) It is permissible to re-use the same array in the returned
** arguments. The arrays are filled in the stated order.
**
** Called:
**   iauNut06a      nutation, IAU 2006/2000A
**   iauPn06       bias/precession/nutation results, IAU 2006
**
** Reference:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
** /
```

```

void iauPnm00a(double date1, double date2, double rbpn[3][3])
/*
**   - - - - -
**   i a u P n m 0 0 a
**   - - - - -
**
** Form the matrix of precession-nutation for a given date (including
** frame bias), equinox-based, IAU 2000A model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rbpn         double[3][3]  classical NPB matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1         date2
**
**           2450123.7         0.0      (JD method)
**           2451545.0        -1421.3   (J2000 method)
**           2400000.5         50123.2   (MJD method)
**           2450123.5         0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rbpn} * V(\text{GCRS})$ , where
** the p-vector  $V(\text{date})$  is with respect to the true equatorial triad
** of date date1+date2 and the p-vector  $V(\text{GCRS})$  is with respect to
** the Geocentric Celestial Reference System (IAU, 2000).
**
** 3) A faster, but slightly less accurate result (about 1 mas), can be
** obtained by using instead the iauPnm00b function.
**
** Called:
**   iauPn00a      bias/precession/nutation, IAU 2000A
**
** Reference:
**
** IAU: Trans. International Astronomical Union, Vol. XXIVB; Proc.
** 24th General Assembly, Manchester, UK. Resolutions B1.3, B1.6.
** (2000)
**
*/

```

```

void iauPnm00b(double date1, double date2, double rbpn[3][3])
/*
**   - - - - -
**   i a u P n m 0 0 b
**   - - - - -
**
** Form the matrix of precession-nutation for a given date (including
** frame bias), equinox-based, IAU 2000B model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rbpn          double[3][3] bias-precession-nutation matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rbpn} * V(\text{GCRS})$ , where
** the p-vector  $V(\text{date})$  is with respect to the true equatorial triad
** of date date1+date2 and the p-vector  $V(\text{GCRS})$  is with respect to
** the Geocentric Celestial Reference System (IAU, 2000).
**
** 3) The present function is faster, but slightly less accurate (about
** 1 mas), than the iauPnm00a function.
**
** Called:
**   iauPn00b          bias/precession/nutation, IAU 2000B
**
** Reference:
**
** IAU: Trans. International Astronomical Union, Vol. XXIVB; Proc.
** 24th General Assembly, Manchester, UK. Resolutions B1.3, B1.6.
** (2000)
**
*/

```

```

void iauPnm06a(double date1, double date2, double rnpb[3][3])
/*
**   - - - - -
**   i a u P n m 0 6 a
**   - - - - -
**
** Form the matrix of precession-nutation for a given date (including
** frame bias), IAU 2006 precession and IAU 2000A nutation models.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2 double          TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   rnpb          double[3][3] bias-precession-nutation matrix (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rnpb} * V(\text{GCRS})$ , where
** the p-vector  $V(\text{date})$  is with respect to the true equatorial triad
** of date date1+date2 and the p-vector  $V(\text{GCRS})$  is with respect to
** the Geocentric Celestial Reference System (IAU, 2000).
**
** Called:
**   iauPfw06      bias-precession F-W angles, IAU 2006
**   iauNut06a     nutation, IAU 2006/2000A
**   iauFw2m       F-W angles to r-matrix
**
** Reference:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855.
**
*/

```

```

void iauPnm80(double date1, double date2, double rmatpn[3][3])
/*
**  - - - - -
**   i a u P n m 8 0
**  - - - - -
**
** Form the matrix of precession/nutation for a given date, IAU 1976
** precession model, IAU 1980 nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2      double          TDB date (Note 1)
**
** Returned:
**   rmatpn           double[3][3]    combined precession/nutation matrix
**
** Notes:
**
** 1) The TDB date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TDB)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The matrix operates in the sense  $V(\text{date}) = \text{rmatpn} * V(\text{J2000})$ ,
** where the p-vector  $V(\text{date})$  is with respect to the true equatorial
** triad of date date1+date2 and the p-vector  $V(\text{J2000})$  is with
** respect to the mean equatorial triad of epoch J2000.0.
**
** Called:
**   iauPmat76      precession matrix, IAU 1976
**   iauNutm80      nutation matrix, IAU 1980
**   iauRxr         product of two r-matrices
**
** Reference:
**
** Explanatory Supplement to the Astronomical Almanac,
** P. Kenneth Seidelmann (ed), University Science Books (1992),
** Section 3.3 (p145).
**
*/

```

```

void iauPom00(double xp, double yp, double sp, double rpom[3][3])
/*
**  - - - - -
**   i a u P o m 0 0
**  - - - - -
**
** Form the matrix of polar motion for a given date, IAU 2000.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   xp,yp   double   coordinates of the pole (radians, Note 1)
**   sp      double   the TIO locator s' (radians, Note 2)
**
** Returned:
**   rpom    double[3][3]   polar-motion matrix (Note 3)
**
** Notes:
**
** 1) The arguments xp and yp are the coordinates (in radians) of the
**    Celestial Intermediate Pole with respect to the International
**    Terrestrial Reference System (see IERS Conventions 2003),
**    measured along the meridians to 0 and 90 deg west respectively.
**
** 2) The argument sp is the TIO locator s', in radians, which
**    positions the Terrestrial Intermediate Origin on the equator. It
**    is obtained from polar motion observations by numerical
**    integration, and so is in essence unpredictable. However, it is
**    dominated by a secular drift of about 47 microarcseconds per
**    century, and so can be taken into account by using  $s' = -47*t$ ,
**    where t is centuries since J2000.0. The function iauSp00
**    implements this approximation.
**
** 3) The matrix operates in the sense  $V(\text{TRS}) = \text{rpom} * V(\text{CIP})$ , meaning
**    that it is the final rotation when computing the pointing
**    direction to a celestial source.
**
** Called:
**   iauIr      initialize r-matrix to identity
**   iauRz      rotate around Z-axis
**   iauRy      rotate around Y-axis
**   iauRx      rotate around X-axis
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

void iauPpp(double a[3], double b[3], double apb[3])
/*
**  - - - - -
**   i a u P p p
**  - - - - -
**
**   P-vector addition.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[3]      first p-vector
**     b      double[3]      second p-vector
**
**   Returned:
**     apb    double[3]      a + b
**
**   Note:
**     It is permissible to re-use the same array for any of the
**     arguments.
**
*/

```

```

void iauPpsp(double a[3], double s, double b[3], double apsb[3])
/*
**  - - - - -
**   i a u P p s p
**  - - - - -
**
**   P-vector plus scaled p-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[3]    first p-vector
**     s      double      scalar (multiplier for b)
**     b      double[3]    second p-vector
**
**   Returned:
**     apsb   double[3]    a + s*b
**
**   Note:
**     It is permissible for any of a, b and apsb to be the same array.
**
**   Called:
**     iauSxp      multiply p-vector by scalar
**     iauPpp      p-vector plus p-vector
**
*/

```

```

void iauPr00(double date1, double date2, double *dpsipr, double *depspr)
/*
**  - - - - -
**   i a u P r 0 0
**  - - - - -
**
** Precession-rate part of the IAU 2000 precession-nutation models
** (part of MHB2000).
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  canonical model.
**
** Given:
**   date1,date2    double  TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   dpsipr,depspr double  precession corrections (Notes 2,3)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
**    convenient way between the two arguments.  For example,
**    JD(TT)=2450123.7 could be expressed in any of these ways,
**    among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0        -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The precession adjustments are expressed as "nutation
**    components", corrections in longitude and obliquity with respect
**    to the J2000.0 equinox and ecliptic.
**
** 3) Although the precession adjustments are stated to be with respect
**    to Lieske et al. (1977), the MHB2000 model does not specify which
**    set of Euler angles are to be used and how the adjustments are to
**    be applied.  The most literal and straightforward procedure is to
**    adopt the 4-rotation epsilon_0, psi_A, omega_A, xi_A option, and
**    to add dpsipr to psi_A and depspr to both omega_A and eps_A.
**
** 4) This is an implementation of one aspect of the IAU 2000A nutation
**    model, formally adopted by the IAU General Assembly in 2000,
**    namely MHB2000 (Mathews et al. 2002).
**
** References:
**
** Lieske, J.H., Lederle, T., Fricke, W. & Morando, B., "Expressions
** for the precession quantities based upon the IAU (1976) System of
** Astronomical Constants", Astron.Astrophys., 58, 1-16 (1977)
**
** Mathews, P.M., Herring, T.A., Buffet, B.A., "Modeling of nutation
** and precession  New nutation series for nonrigid Earth and
** insights into the Earth's interior", J.Geophys.Res., 107, B4,
** 2002.  The MHB2000 code itself was obtained on 9th September 2002
** from ftp://maia.usno.navy.mil/conv2000/chapter5/IAU2000A.
**
** Wallace, P.T., "Software for Implementing the IAU 2000
** Resolutions", in IERS Workshop 5.1 (2002).
**

```



```

void iauPrec76(double date01, double date02, double date11, double date12,
              double *zeta, double *z, double *theta)
/*
**  - - - - -
**   i a u P r e c 7 6
**  - - - - -
**
**   IAU 1976 precession model.
**
**   This function forms the three Euler angles which implement general
**   precession between two dates, using the IAU 1976 model (as for the
**   FK5 catalog).
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  canonical model.
**
**   Given:
**     date01,date02  double      TDB starting date (Note 1)
**     date11,date12  double      TDB ending date (Note 1)
**
**   Returned:
**     zeta           double      1st rotation: radians cw around z
**     z              double      3rd rotation: radians cw around z
**     theta          double      2nd rotation: radians ccw around y
**
**   Notes:
**
**   1) The dates date01+date02 and date11+date12 are Julian Dates,
**      apportioned in any convenient way between the arguments daten1
**      and daten2.  For example, JD(TDB)=2450123.7 could be expressed in
**      any of these ways, among others:
**
**           daten1      daten2
**
**           2450123.7      0.0      (JD method)
**           2451545.0      -1421.3   (J2000 method)
**           2400000.5      50123.2   (MJD method)
**           2450123.5      0.2      (date & time method)
**
**   The JD method is the most natural and convenient to use in cases
**   where the loss of several decimal digits of resolution is
**   acceptable.  The J2000 method is best matched to the way the
**   argument is handled internally and will deliver the optimum
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**   The two dates may be expressed using different methods, but at
**   the risk of losing some resolution.
**
**   2) The accumulated precession angles zeta, z, theta are expressed
**      through canonical polynomials which are valid only for a limited
**      time span.  In addition, the IAU 1976 precession rate is known to
**      be imperfect.  The absolute accuracy of the present formulation
**      is better than 0.1 arcsec from 1960AD to 2040AD, better than
**      1 arcsec from 1640AD to 2360AD, and remains below 3 arcsec for
**      the whole of the period 500BC to 3000AD.  The errors exceed
**      10 arcsec outside the range 1200BC to 3900AD, exceed 100 arcsec
**      outside 4200BC to 5600AD and exceed 1000 arcsec outside 6800BC to
**      8200AD.
**
**   3) The three angles are returned in the conventional order, which
**      is not the same as the order of the corresponding Euler
**      rotations.  The precession matrix is
**      R_3(-z) x R_2(+theta) x R_3(-zeta).
**
**   Reference:
**
**     Lieske, J.H., 1979, Astron.Astrophys. 73, 282, equations
**     (6) & (7), p283.
**

```



```
void iauPv2p(double pv[2][3], double p[3])
/*
**  - - - - -
**  i a u P v 2 p
**  - - - - -
**
**  Discard velocity component of a pv-vector.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    pv      double[2][3]    pv-vector
**
**  Returned:
**    p       double[3]      p-vector
**
**  Called:
**    iauCp      copy p-vector
**
**/
```

```

void iauPv2s(double pv[2][3],
             double *theta, double *phi, double *r,
             double *td, double *pd, double *rd)
/*
** - - - - -
**   i a u P v 2 s
** - - - - -
**
** Convert position/velocity from Cartesian to spherical coordinates.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   pv      double[2][3]  pv-vector
**
** Returned:
**   theta   double        longitude angle (radians)
**   phi     double        latitude angle (radians)
**   r       double        radial distance
**   td      double        rate of change of theta
**   pd      double        rate of change of phi
**   rd      double        rate of change of r
**
** Notes:
**
** 1) If the position part of pv is null, theta, phi, td and pd
** are indeterminate. This is handled by extrapolating the
** position through unit time by using the velocity part of
** pv. This moves the origin without changing the direction
** of the velocity component. If the position and velocity
** components of pv are both null, zeroes are returned for all
** six results.
**
** 2) If the position is a pole, theta, td and pd are indeterminate.
** In such cases zeroes are returned for all three.
**
*/

```

```

void iauPvdpv(double a[2][3], double b[2][3], double adb[2])
/*
**  - - - - -
**   i a u P v d p v
**  - - - - -
**
**   Inner (=scalar=dot) product of two pv-vectors.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[2][3]      first pv-vector
**     b      double[2][3]      second pv-vector
**
**   Returned:
**     adb    double[2]         a . b (see note)
**
**   Note:
**
**     If the position and velocity components of the two pv-vectors are
**     ( ap, av ) and ( bp, bv ), the result, a . b, is the pair of
**     numbers ( ap . bp , ap . bv + av . bp ). The two numbers are the
**     dot-product of the two p-vectors and its derivative.
**
**   Called:
**     iauPdp      scalar product of two p-vectors
**
*/

```

```

void iauPvm(double pv[2][3], double *r, double *s)
/*
** - - - - -
**   i a u P v m
** - - - - -
**
** Modulus of pv-vector.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   pv      double[2][3]   pv-vector
**
** Returned:
**   r      double          modulus of position component
**   s      double          modulus of velocity component
**
** Called:
**   iauPm          modulus of p-vector
**
*/

```

```

void iauPvmpv(double a[2][3], double b[2][3], double amb[2][3])
/*
**  - - - - -
**   i a u P v m p v
**  - - - - -
**
** Subtract one pv-vector from another.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   a      double[2][3]    first pv-vector
**   b      double[2][3]    second pv-vector
**
** Returned:
**   amb    double[2][3]    a - b
**
** Note:
**   It is permissible to re-use the same array for any of the
**   arguments.
**
** Called:
**   iauPmp      p-vector minus p-vector
**
*/

```

```

void iauPvppv(double a[2][3], double b[2][3], double apb[2][3])
/*
**  - - - - -
**   i a u P v p p v
**  - - - - -
**
**   Add one pv-vector to another.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[2][3]    first pv-vector
**     b      double[2][3]    second pv-vector
**
**   Returned:
**     apb    double[2][3]    a + b
**
**   Note:
**     It is permissible to re-use the same array for any of the
**     arguments.
**
**   Called:
**     iauPpp      p-vector plus p-vector
**
*/

```

```

int iauPvstar(double pv[2][3], double *ra, double *dec,
             double *pmr, double *pmd, double *px, double *rv)
/*
**  - - - - -
**   i a u P v s t a r
**  - - - - -
**
** Convert star position+velocity vector to catalog coordinates.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given (Note 1):
**   pv      double[2][3]   pv-vector (AU, AU/day)
**
** Returned (Note 2):
**   ra      double         right ascension (radians)
**   dec     double         declination (radians)
**   pmr     double         RA proper motion (radians/year)
**   pmd     double         Dec proper motion (radians/year)
**   px      double         parallax (arcsec)
**   rv      double         radial velocity (km/s, positive = receding)
**
** Returned (function value):
**   int      status:
**           0 = OK
**          -1 = superluminal speed (Note 5)
**          -2 = null position vector
**
** Notes:
**
** 1) The specified pv-vector is the coordinate direction (and its rate
**    of change) for the date at which the light leaving the star
**    reached the solar-system barycenter.
**
** 2) The star data returned by this function are "observables" for an
**    imaginary observer at the solar-system barycenter. Proper motion
**    and radial velocity are, strictly, in terms of barycentric
**    coordinate time, TCB. For most practical applications, it is
**    permissible to neglect the distinction between TCB and ordinary
**    "proper" time on Earth (TT/TAI). The result will, as a rule, be
**    limited by the intrinsic accuracy of the proper-motion and
**    radial-velocity data; moreover, the supplied pv-vector is likely
**    to be merely an intermediate result (for example generated by the
**    function iauStarpv), so that a change of time unit will cancel
**    out overall.
**
** In accordance with normal star-catalog conventions, the object's
** right ascension and declination are freed from the effects of
** secular aberration. The frame, which is aligned to the catalog
** equator and equinox, is Lorentzian and centered on the SSB.
**
** Summarizing, the specified pv-vector is for most stars almost
** identical to the result of applying the standard geometrical
** "space motion" transformation to the catalog data. The
** differences, which are the subject of the Stumpff paper cited
** below, are:
**
** (i) In stars with significant radial velocity and proper motion,
** the constantly changing light-time distorts the apparent proper
** motion. Note that this is a classical, not a relativistic,
** effect.
**
** (ii) The transformation complies with special relativity.
**
** 3) Care is needed with units. The star coordinates are in radians
** and the proper motions in radians per Julian year, but the
** parallax is in arcseconds; the radial velocity is in km/s, but
** the pv-vector result is in AU and AU/day.

```

```

**
** 4) The proper motions are the rate of change of the right ascension
** and declination at the catalog epoch and are in radians per Julian
** year. The RA proper motion is in terms of coordinate angle, not
** true angle, and will thus be numerically larger at high
** declinations.
**
** 5) Straight-line motion at constant speed in the inertial frame is
** assumed. If the speed is greater than or equal to the speed of
** light, the function aborts with an error status.
**
** 6) The inverse transformation is performed by the function iauStarpv.
**
** Called:
**   iauPn          decompose p-vector into modulus and direction
**   iauPdp         scalar product of two p-vectors
**   iauSxp         multiply p-vector by scalar
**   iauPmp         p-vector minus p-vector
**   iauPm          modulus of p-vector
**   iauPpp         p-vector plus p-vector
**   iauPv2s        pv-vector to spherical
**   iauAnp         normalize angle into range 0 to 2pi
**
** Reference:
**
**   Stumpff, P., 1985, Astron.Astrophys. 144, 232-240.
**
*/

```

```

void iauPvtob(double elong, double phi, double hm,
              double xp, double yp, double sp, double theta,
              double pv[2][3])
/*
**  - - - - -
**   i a u P v t o b
**  - - - - -
**
**   Position and velocity of a terrestrial observing station.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     elong  double      longitude (radians, east +ve, Note 1)
**     phi    double      latitude (geodetic, radians, Note 1)
**     hm     double      height above ref. ellipsoid (geodetic, m)
**     xp,yp  double      coordinates of the pole (radians, Note 2)
**     sp     double      the TIO locator s' (radians, Note 2)
**     theta  double      Earth rotation angle (radians, Note 3)
**
**   Returned:
**     pv     double[2][3] position/velocity vector (m, m/s, CIRS)
**
**   Notes:
**
**   1) The terrestrial coordinates are with respect to the WGS84
**      reference ellipsoid.
**
**   2) xp and yp are the coordinates (in radians) of the Celestial
**      Intermediate Pole with respect to the International Terrestrial
**      Reference System (see IERS Conventions), measured along the
**      meridians 0 and 90 deg west respectively.  sp is the TIO locator
**      s', in radians, which positions the Terrestrial Intermediate
**      Origin on the equator.  For many applications, xp, yp and
**      (especially) sp can be set to zero.
**
**   3) If theta is Greenwich apparent sidereal time instead of Earth
**      rotation angle, the result is with respect to the true equator
**      and equinox of date, i.e. with the x-axis at the equinox rather
**      than the celestial intermediate origin.
**
**   4) The velocity units are meters per UT1 second, not per SI second.
**      This is unlikely to have any practical consequences in the modern
**      era.
**
**   5) No validation is performed on the arguments.  Error cases that
**      could lead to arithmetic exceptions are trapped by the iauGd2gc
**      function, and the result set to zeros.
**
**   References:
**
**     McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**     IERS Technical Note No. 32, BKG (2004)
**
**     Urban, S. & Seidelmann, P. K. (eds), Explanatory Supplement to
**     the Astronomical Almanac, 3rd ed., University Science Books
**     (2013), Section 7.4.3.3.
**
**   Called:
**     iauGd2gc      geodetic to geocentric transformation
**     iauPom00      polar motion matrix
**     iauTrxp       product of transpose of r-matrix and p-vector
**
*/

```

```

void iauPvu(double dt, double pv[2][3], double upv[2][3])
/*
**  - - - - -
**   i a u P v u
**  - - - - -
**
**   Update a pv-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     dt      double      time interval
**     pv      double[2][3]  pv-vector
**
**   Returned:
**     upv     double[2][3]   p updated, v unchanged
**
**   Notes:
**
**   1) "Update" means "refer the position component of the vector
**      to a new date dt time units from the existing date".
**
**   2) The time units of dt must match those of the velocity.
**
**   3) It is permissible for pv and upv to be the same array.
**
**   Called:
**     iauPpsp   p-vector plus scaled p-vector
**     iauCp     copy p-vector
**
**   */

```

```

void iauPvup(double dt, double pv[2][3], double p[3])
/*
**  - - - - -
**   i a u P v u p
**  - - - - -
**
**   Update a pv-vector, discarding the velocity component.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     dt      double          time interval
**     pv      double[2][3]    pv-vector
**
**   Returned:
**     p       double[3]       p-vector
**
**   Notes:
**
**   1) "Update" means "refer the position component of the vector to a
**      new date dt time units from the existing date".
**
**   2) The time units of dt must match those of the velocity.
**
*/

```

```

void iauPvxpv(double a[2][3], double b[2][3], double axb[2][3])
/*
**  - - - - -
**   i a u P v x p v
**  - - - - -
**
** Outer (=vector=cross) product of two pv-vectors.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   a      double[2][3]      first pv-vector
**   b      double[2][3]      second pv-vector
**
** Returned:
**   axb    double[2][3]      a x b
**
** Notes:
**
** 1) If the position and velocity components of the two pv-vectors are
**    ( ap, av ) and ( bp, bv ), the result, a x b, is the pair of
**    vectors ( ap x bp, ap x bv + av x bp ). The two vectors are the
**    cross-product of the two p-vectors and its derivative.
**
** 2) It is permissible to re-use the same array for any of the
**    arguments.
**
** Called:
**   iauCpv      copy pv-vector
**   iauPxp     vector product of two p-vectors
**   iauPpp     p-vector plus p-vector
**
*/

```

```

void iauPxp(double a[3], double b[3], double axb[3])
/*
**  - - - - -
**   i a u P x p
**  - - - - -
**
**  p-vector outer (=vector=cross) product.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    a      double[3]      first p-vector
**    b      double[3]      second p-vector
**
**  Returned:
**    axb    double[3]      a x b
**
**  Note:
**    It is permissible to re-use the same array for any of the
**    arguments.
**
*/

```

```

void iauRefco(double phpa, double tc, double rh, double wl,
              double *refa, double *refb)
/*
**   - - - - -
**   i a u R e f c o
**   - - - - -
**
** Determine the constants A and B in the atmospheric refraction model
**  $dZ = A \tan Z + B \tan^3 Z$ .
**
** Z is the "observed" zenith distance (i.e. affected by refraction)
** and dZ is what to add to Z to give the "topocentric" (i.e. in vacuo)
** zenith distance.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   phpa  double    pressure at the observer (hPa = millibar)
**   tc    double    ambient temperature at the observer (deg C)
**   rh    double    relative humidity at the observer (range 0-1)
**   wl    double    wavelength (micrometers)
**
** Returned:
**   refa  double*   tan Z coefficient (radians)
**   refb  double*   tan^3 Z coefficient (radians)
**
** Notes:
**
** 1) The model balances speed and accuracy to give good results in
** applications where performance at low altitudes is not paramount.
** Performance is maintained across a range of conditions, and
** applies to both optical/IR and radio.
**
** 2) The model omits the effects of (i) height above sea level (apart
** from the reduced pressure itself), (ii) latitude (i.e. the
** flattening of the Earth), (iii) variations in tropospheric lapse
** rate and (iv) dispersive effects in the radio.
**
** The model was tested using the following range of conditions:
**
**   lapse rates 0.0055, 0.0065, 0.0075 deg/meter
**   latitudes 0, 25, 50, 75 degrees
**   heights 0, 2500, 5000 meters ASL
**   pressures mean for height -10% to +5% in steps of 5%
**   temperatures -10 deg to +20 deg with respect to 280 deg at SL
**   relative humidity 0, 0.5, 1
**   wavelengths 0.4, 0.6, ... 2 micron, + radio
**   zenith distances 15, 45, 75 degrees
**
** The accuracy with respect to raytracing through a model
** atmosphere was as follows:
**
**
**           worst           RMS
**
**   optical/IR       62 mas       8 mas
**   radio            319 mas      49 mas
**
** For this particular set of conditions:
**
**   lapse rate 0.0065 K/meter
**   latitude 50 degrees
**   sea level
**   pressure 1005 mb
**   temperature 280.15 K
**   humidity 80%
**   wavelength 5740 Angstroms
**
** the results were as follows:

```

```

**
**      ZD      raytrace      iauRefco      Saastamoinen
**
**      10      10.27      10.27      10.27
**      20      21.19      21.20      21.19
**      30      33.61      33.61      33.60
**      40      48.82      48.83      48.81
**      45      58.16      58.18      58.16
**      50      69.28      69.30      69.27
**      55      82.97      82.99      82.95
**      60      100.51      100.54      100.50
**      65      124.23      124.26      124.20
**      70      158.63      158.68      158.61
**      72      177.32      177.37      177.31
**      74      200.35      200.38      200.32
**      76      229.45      229.43      229.42
**      78      267.44      267.29      267.41
**      80      319.13      318.55      319.10
**
**      deg      arcsec      arcsec      arcsec
**
**      The values for Saastamoinen's formula (which includes terms
**      up to  $\tan^5$ ) are taken from Hohenkerk and Sinclair (1985).
**
**      3) A wl value in the range 0-100 selects the optical/IR case and is
**      wavelength in micrometers. Any value outside this range selects
**      the radio case.
**
**      4) Outlandish input parameters are silently limited to
**      mathematically safe values. Zero pressure is permissible, and
**      causes zeroes to be returned.
**
**      5) The algorithm draws on several sources, as follows:
**
**      a) The formula for the saturation vapour pressure of water as
**      a function of temperature and temperature is taken from
**      Equations (A4.5-A4.7) of Gill (1982).
**
**      b) The formula for the water vapour pressure, given the
**      saturation pressure and the relative humidity, is from
**      Crane (1976), Equation (2.5.5).
**
**      c) The refractivity of air is a function of temperature,
**      total pressure, water-vapour pressure and, in the case
**      of optical/IR, wavelength. The formulae for the two cases are
**      developed from Hohenkerk & Sinclair (1985) and Rueger (2002).
**
**      d) The formula for beta, the ratio of the scale height of the
**      atmosphere to the geocentric distance of the observer, is
**      an adaption of Equation (9) from Stone (1996). The
**      adaptations, arrived at empirically, consist of (i) a small
**      adjustment to the coefficient and (ii) a humidity term for the
**      radio case only.
**
**      e) The formulae for the refraction constants as a function of
**      n-1 and beta are from Green (1987), Equation (4.31).
**
**      References:
**
**      Crane, R.K., Meeks, M.L. (ed), "Refraction Effects in the Neutral
**      Atmosphere", Methods of Experimental Physics: Astrophysics 12B,
**      Academic Press, 1976.
**
**      Gill, Adrian E., "Atmosphere-Ocean Dynamics", Academic Press,
**      1982.
**
**      Green, R.M., "Spherical Astronomy", Cambridge University Press,
**      1987.
**
**      Hohenkerk, C.Y., & Sinclair, A.T., NAO Technical Note No. 63,
**      1985.
**
**      Rueger, J.M., "Refractive Index Formulae for Electronic Distance

```

\*\* Measurement with Radio and Millimetre Waves", in Unisurv Report  
\*\* S-68, School of Surveying and Spatial Information Systems,  
\*\* University of New South Wales, Sydney, Australia, 2002.  
\*\*  
\*\* Stone, Ronald C., P.A.S.P. 108, 1051-1058, 1996.  
\*\*  
\*/

```

void iauRm2v(double r[3][3], double w[3])
/*
**  - - - - -
**   i a u R m 2 v
**  - - - - -
**
** Express an r-matrix as an r-vector.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   r          double[3][3]    rotation matrix
**
** Returned:
**   w          double[3]       rotation vector (Note 1)
**
** Notes:
**
** 1) A rotation matrix describes a rotation through some angle about
**    some arbitrary axis called the Euler axis.  The "rotation vector"
**    returned by this function has the same direction as the Euler axis,
**    and its magnitude is the angle in radians.  (The magnitude and
**    direction can be separated by means of the function iauPn.)
**
** 2) If r is null, so is the result.  If r is not a rotation matrix
**    the result is undefined; r must be proper (i.e. have a positive
**    determinant) and real orthogonal (inverse = transpose).
**
** 3) The reference frame rotates clockwise as seen looking along
**    the rotation vector from the origin.
**
** */

```

```

void iauRv2m(double w[3], double r[3][3])
/*
**  - - - - -
**   i a u R v 2 m
**  - - - - -
**
**   Form the r-matrix corresponding to a given r-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     w      double[3]      rotation vector (Note 1)
**
**   Returned:
**     r      double[3][3]   rotation matrix
**
**   Notes:
**
**   1) A rotation matrix describes a rotation through some angle about
**      some arbitrary axis called the Euler axis.  The "rotation vector"
**      supplied to This function has the same direction as the Euler
**      axis, and its magnitude is the angle in radians.
**
**   2) If w is null, the unit matrix is returned.
**
**   3) The reference frame rotates clockwise as seen looking along the
**      rotation vector from the origin.
**
**/

```

```

void iauRx(double phi, double r[3][3])
/*
**  - - - - -
**   i a u R x
**  - - - - -
**
** Rotate an r-matrix about the x-axis.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   phi      double          angle (radians)
**
** Given and returned:
**   r        double[3][3]    r-matrix, rotated
**
** Notes:
**
** 1) Calling this function with positive phi incorporates in the
**    supplied r-matrix r an additional rotation, about the x-axis,
**    anticlockwise as seen looking towards the origin from positive x.
**
** 2) The additional rotation can be represented by this matrix:
**
**      ( 1      0      0      )
**      (
**      ( 0  + cos(phi)  + sin(phi) )
**      (
**      ( 0  - sin(phi)  + cos(phi) )
**
** */

```

```

void iauRxp(double r[3][3], double p[3], double rp[3])
/*
**  - - - - -
**   i a u R x p
**  - - - - -
**
** Multiply a p-vector by an r-matrix.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   r      double[3][3]   r-matrix
**   p      double[3]     p-vector
**
** Returned:
**   rp     double[3]     r * p
**
** Note:
**   It is permissible for p and rp to be the same array.
**
** Called:
**   iauCp      copy p-vector
**
*/

```

```

void iauRxpv(double r[3][3], double pv[2][3], double rpv[2][3])
/*
**  - - - - -
**   i a u R x p v
**  - - - - -
**
** Multiply a pv-vector by an r-matrix.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   r          double[3][3]   r-matrix
**   pv         double[2][3]   pv-vector
**
** Returned:
**   rpv        double[2][3]   r * pv
**
** Note:
**   It is permissible for pv and rpv to be the same array.
**
** Called:
**   iauRxp          product of r-matrix and p-vector
**
*/

```

```

void iauRxr(double a[3][3], double b[3][3], double atb[3][3])
/*
**  - - - - -
**   i a u R x r
**  - - - - -
**
**  Multiply two r-matrices.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    a      double[3][3]   first r-matrix
**    b      double[3][3]   second r-matrix
**
**  Returned:
**    atb    double[3][3]   a * b
**
**  Note:
**    It is permissible to re-use the same array for any of the
**    arguments.
**
**  Called:
**    iauCr      copy r-matrix
**
*/

```

```

void iauRy(double theta, double r[3][3])
/*
**  - - - - -
**   i a u R y
**  - - - - -
**
** Rotate an r-matrix about the y-axis.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   theta  double          angle (radians)
**
** Given and returned:
**   r      double[3][3]    r-matrix, rotated
**
** Notes:
**
** 1) Calling this function with positive theta incorporates in the
**    supplied r-matrix r an additional rotation, about the y-axis,
**    anticlockwise as seen looking towards the origin from positive y.
**
** 2) The additional rotation can be represented by this matrix:
**
**      ( + cos(theta)   0   - sin(theta) )
**      (                1           0   )
**      (                0           1           )
**      ( + sin(theta)   0   + cos(theta) )
**
*/

```

```

void iauRz(double psi, double r[3][3])
/*
**  - - - - -
**   i a u R z
**  - - - - -
**
** Rotate an r-matrix about the z-axis.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   psi      double          angle (radians)
**
** Given and returned:
**   r        double[3][3]    r-matrix, rotated
**
** Notes:
**
** 1) Calling this function with positive psi incorporates in the
**    supplied r-matrix r an additional rotation, about the z-axis,
**    anticlockwise as seen looking towards the origin from positive z.
**
** 2) The additional rotation can be represented by this matrix:
**
**      ( + cos(psi)  + sin(psi)   0 )
**      (              )
**      ( - sin(psi)  + cos(psi)   0 )
**      (              )
**      (          0          0     1 )
**
** */

```

```

double iauS00(double date1, double date2, double x, double y)
/*
**  - - - - -
**   i a u S 0 0
**  - - - - -
**
** The CIO locator s, positioning the Celestial Intermediate Origin on
** the equator of the Celestial Intermediate Pole, given the CIP's X,Y
** coordinates. Compatible with IAU 2000A precession-nutation.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**   x,y          double      CIP coordinates (Note 3)
**
** Returned (function value):
**   double       the CIO locator s in radians (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0         -1421.3   (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The CIO locator s is the difference between the right ascensions
** of the same point in two systems: the two systems are the GCRS
** and the CIP,CIO, and the point is the ascending node of the
** CIP equator. The quantity s remains below 0.1 arcsecond
** throughout 1900-2100.
**
** 3) The series used to compute s is in fact for s+XY/2, where X and Y
** are the x and y components of the CIP unit vector; this series
** is more compact than a direct series for s would be. This
** function requires X,Y to be supplied by the caller, who is
** responsible for providing values that are consistent with the
** supplied date.
**
** 4) The model is consistent with the IAU 2000A precession-nutation.
**
** Called:
**   iauFal03      mean anomaly of the Moon
**   iauFalp03     mean anomaly of the Sun
**   iauFaf03      mean argument of the latitude of the Moon
**   iauFad03      mean elongation of the Moon from the Sun
**   iauFaom03     mean longitude of the Moon's ascending node
**   iauFave03     mean longitude of Venus
**   iauFae03      mean longitude of Earth
**   iauFapa03     general accumulated precession in longitude
**
** References:
**
**   Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,

```

\*\* "Expressions for the Celestial Intermediate Pole and Celestial  
\*\* Ephemeris Origin consistent with the IAU 2000A precession-  
\*\* nutation model", Astron.Astrophys. 400, 1145-1154 (2003)  
\*\*  
\*\* n.b. The celestial ephemeris origin (CEO) was renamed "celestial  
\*\* intermediate origin" (CIO) by IAU 2006 Resolution 2.  
\*\*  
\*\* McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),  
\*\* IERS Technical Note No. 32, BKG (2004)  
\*\*  
\*/

```

double iauS00a(double date1, double date2)
/*
**  - - - - -
**   i a u S 0 0 a
**  - - - - -
**
** The CIO locator s, positioning the Celestial Intermediate Origin on
** the equator of the Celestial Intermediate Pole, using the IAU 2000A
** precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      the CIO locator s in radians (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The CIO locator s is the difference between the right ascensions
** of the same point in two systems.  The two systems are the GCRS
** and the CIP,CIO, and the point is the ascending node of the
** CIP equator.  The CIO locator s remains a small fraction of
** 1 arcsecond throughout 1900-2100.
**
** 3) The series used to compute s is in fact for s+XY/2, where X and Y
** are the x and y components of the CIP unit vector; this series
** is more compact than a direct series for s would be.  The present
** function uses the full IAU 2000A nutation model when predicting
** the CIP position.  Faster results, with no significant loss of
** accuracy, can be obtained via the function iauS00b, which uses
** instead the IAU 2000B truncated model.
**
** Called:
**   iauPnm00a    classical NPB matrix, IAU 2000A
**   iauBnp2xy    extract CIP X,Y from the BPN matrix
**   iauS00       the CIO locator s, given X,Y, IAU 2000A
**
** References:
**
** Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astron.Astrophys. 400, 1145-1154 (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**

```

\*\*  
\*\*  
\*\*  
\*/

McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),  
IERS Technical Note No. 32, BKG (2004)

```

double iauS00b(double date1, double date2)
/*
**  - - - - -
**   i a u S 0 0 b
**  - - - - -
**
** The CIO locator s, positioning the Celestial Intermediate Origin on
** the equator of the Celestial Intermediate Pole, using the IAU 2000B
** precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      the CIO locator s in radians (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The CIO locator s is the difference between the right ascensions
** of the same point in two systems.  The two systems are the GCRS
** and the CIP,CIO, and the point is the ascending node of the
** CIP equator.  The CIO locator s remains a small fraction of
** 1 arcsecond throughout 1900-2100.
**
** 3) The series used to compute s is in fact for s+XY/2, where X and Y
** are the x and y components of the CIP unit vector; this series
** is more compact than a direct series for s would be.  The present
** function uses the IAU 2000B truncated nutation model when
** predicting the CIP position.  The function iauS00a uses instead
** the full IAU 2000A model, but with no significant increase in
** accuracy and at some cost in speed.
**
** Called:
**   iauPnm00b    classical NPB matrix, IAU 2000B
**   iauBnp2xy    extract CIP X,Y from the BPN matrix
**   iauS00       the CIO locator s, given X,Y, IAU 2000A
**
** References:
**
** Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astron.Astrophys. 400, 1145-1154 (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**

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McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),  
IERS Technical Note No. 32, BKG (2004)

```

double iauS06(double date1, double date2, double x, double y)
/*
**   - - - - -
**   i a u S 0 6
**   - - - - -
**
** The CIO locator s, positioning the Celestial Intermediate Origin on
** the equator of the Celestial Intermediate Pole, given the CIP's X,Y
** coordinates. Compatible with IAU 2006/2000A precession-nutation.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2  double      TT as a 2-part Julian Date (Note 1)
**   x,y         double      CIP coordinates (Note 3)
**
** Returned (function value):
**   double      the CIO locator s in radians (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The CIO locator s is the difference between the right ascensions
** of the same point in two systems: the two systems are the GCRS
** and the CIP,CIO, and the point is the ascending node of the
** CIP equator. The quantity s remains below 0.1 arcsecond
** throughout 1900-2100.
**
** 3) The series used to compute s is in fact for s+XY/2, where X and Y
** are the x and y components of the CIP unit vector; this series
** is more compact than a direct series for s would be. This
** function requires X,Y to be supplied by the caller, who is
** responsible for providing values that are consistent with the
** supplied date.
**
** 4) The model is consistent with the "P03" precession (Capitaine et
** al. 2003), adopted by IAU 2006 Resolution 1, 2006, and the
** IAU 2000A nutation (with P03 adjustments).
**
** Called:
**   iauFal03      mean anomaly of the Moon
**   iauFalp03     mean anomaly of the Sun
**   iauFaf03      mean argument of the latitude of the Moon
**   iauFad03      mean elongation of the Moon from the Sun
**   iauFaom03     mean longitude of the Moon's ascending node
**   iauFave03     mean longitude of Venus
**   iauFae03      mean longitude of Earth
**   iauFapa03     general accumulated precession in longitude
**
** References:

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\*\*  
\*\* Capitaine, N., Wallace, P.T. & Chapront, J., 2003, Astron.  
\*\* Astrophys. 432, 355  
\*\*  
\*\* McCarthy, D.D., Petit, G. (eds.) 2004, IERS Conventions (2003),  
\*\* IERS Technical Note No. 32, BKG  
\*\*  
\*/

```

double iauS06a(double datel, double date2)
/*
**  - - - - -
**   i a u S 0 6 a
**  - - - - -
**
** The CIO locator s, positioning the Celestial Intermediate Origin on
** the equator of the Celestial Intermediate Pole, using the IAU 2006
** precession and IAU 2000A nutation models.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   datel,date2  double      TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double      the CIO locator s in radians (Note 2)
**
** Notes:
**
** 1) The TT date datel+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           datel          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5         50123.2    (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The CIO locator s is the difference between the right ascensions
** of the same point in two systems.  The two systems are the GCRS
** and the CIP,CIO, and the point is the ascending node of the
** CIP equator.  The CIO locator s remains a small fraction of
** 1 arcsecond throughout 1900-2100.
**
** 3) The series used to compute s is in fact for s+XY/2, where X and Y
** are the x and y components of the CIP unit vector; this series is
** more compact than a direct series for s would be.  The present
** function uses the full IAU 2000A nutation model when predicting
** the CIP position.
**
** Called:
**   iauPnm06a    classical NPB matrix, IAU 2006/2000A
**   iauBpn2xy    extract CIP X,Y coordinates from NPB matrix
**   iauS06       the CIO locator s, given X,Y, IAU 2006
**
** References:
**
** Capitaine, N., Chapront, J., Lambert, S. and Wallace, P.,
** "Expressions for the Celestial Intermediate Pole and Celestial
** Ephemeris Origin consistent with the IAU 2000A precession-
** nutation model", Astron.Astrophys. 400, 1145-1154 (2003)
**
** n.b. The celestial ephemeris origin (CEO) was renamed "celestial
** intermediate origin" (CIO) by IAU 2006 Resolution 2.
**
** Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**

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\*/

McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),  
IERS Technical Note No. 32, BKG

Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981

```
void iauS2c(double theta, double phi, double c[3])
/*
**  - - - - -
**   i a u S 2 c
**  - - - - -
**
**   Convert spherical coordinates to Cartesian.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     theta   double      longitude angle (radians)
**     phi     double      latitude angle (radians)
**
**   Returned:
**     c       double[3]   direction cosines
**
**/
```

```

void iauS2p(double theta, double phi, double r, double p[3])
/*
**  - - - - -
**   i a u S 2 p
**  - - - - -
**
**   Convert spherical polar coordinates to p-vector.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     theta  double      longitude angle (radians)
**     phi    double      latitude angle (radians)
**     r      double      radial distance
**
**   Returned:
**     p      double[3]    Cartesian coordinates
**
**   Called:
**     iauS2c      spherical coordinates to unit vector
**     iauSxp      multiply p-vector by scalar
**
*/

```

```

void iauS2pv(double theta, double phi, double r,
             double td, double pd, double rd,
             double pv[2][3])
/*
**  - - - - -
**   i a u S 2 p v
**  - - - - -
**
**   Convert position/velocity from spherical to Cartesian coordinates.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     theta  double          longitude angle (radians)
**     phi    double          latitude angle (radians)
**     r      double          radial distance
**     td     double          rate of change of theta
**     pd     double          rate of change of phi
**     rd     double          rate of change of r
**
**   Returned:
**     pv     double[2][3]    pv-vector
**
*/

```

```

void iauS2xpv(double s1, double s2, double pv[2][3], double spv[2][3])
/*
**  - - - - -
**   i a u S 2 x p v
**  - - - - -
**
** Multiply a pv-vector by two scalars.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   s1      double          scalar to multiply position component by
**   s2      double          scalar to multiply velocity component by
**   pv      double[2][3]    pv-vector
**
** Returned:
**   spv     double[2][3]    pv-vector: p scaled by s1, v scaled by s2
**
** Note:
**   It is permissible for pv and spv to be the same array.
**
** Called:
**   iauSxp          multiply p-vector by scalar
**
*/

```

```

double iauSepp(double a[3], double b[3])
/*
**  - - - - -
**   i a u S e p p
**  - - - - -
**
**   Angular separation between two p-vectors.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     a      double[3]    first p-vector (not necessarily unit length)
**     b      double[3]    second p-vector (not necessarily unit length)
**
**   Returned (function value):
**     double      angular separation (radians, always positive)
**
**   Notes:
**
**   1) If either vector is null, a zero result is returned.
**
**   2) The angular separation is most simply formulated in terms of
**      scalar product. However, this gives poor accuracy for angles
**      near zero and pi. The present algorithm uses both cross product
**      and dot product, to deliver full accuracy whatever the size of
**      the angle.
**
**   Called:
**     iauPxp      vector product of two p-vectors
**     iauPm      modulus of p-vector
**     iauPdp      scalar product of two p-vectors
**
*/

```

```

double iauSeps(double al, double ap, double bl, double bp)
/*
**  - - - - -
**   i a u S e p s
**  - - - - -
**
**   Angular separation between two sets of spherical coordinates.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Given:
**     al      double      first longitude (radians)
**     ap      double      first latitude (radians)
**     bl      double      second longitude (radians)
**     bp      double      second latitude (radians)
**
**   Returned (function value):
**     double      angular separation (radians)
**
**   Called:
**     iauS2c      spherical coordinates to unit vector
**     iauSepp     angular separation between two p-vectors
**
*/

```

```

double iauSp00(double datel, double date2)
/*
**  - - - - -
**   i a u S p 0 0
**  - - - - -
**
** The TIO locator s', positioning the Terrestrial Intermediate Origin
** on the equator of the Celestial Intermediate Pole.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   datel,date2 double TT as a 2-part Julian Date (Note 1)
**
** Returned (function value):
**   double the TIO locator s' in radians (Note 2)
**
** Notes:
**
** 1) The TT date datel+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           datel           date2
**
**           2450123.7           0.0           (JD method)
**           2451545.0          -1421.3          (J2000 method)
**           2400000.5           50123.2          (MJD method)
**           2450123.5           0.2           (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The TIO locator s' is obtained from polar motion observations by
** numerical integration, and so is in essence unpredictable.
** However, it is dominated by a secular drift of about
** 47 microarcseconds per century, which is the approximation
** evaluated by the present function.
**
** Reference:
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

int iauStarpm(double ral, double decl,
              double pmr1, double pmd1, double px1, double rv1,
              double ep1a, double ep1b, double ep2a, double ep2b,
              double *ra2, double *dec2,
              double *pmr2, double *pmd2, double *px2, double *rv2)
/*
**  - - - - -
**  i a u S t a r p m
**  - - - - -
**
**  Star proper motion:  update star catalog data for space motion.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  support function.
**
**  Given:
**    ral    double    right ascension (radians), before
**    decl   double    declination (radians), before
**    pmr1   double    RA proper motion (radians/year), before
**    pmd1   double    Dec proper motion (radians/year), before
**    px1    double    parallax (arcseconds), before
**    rv1    double    radial velocity (km/s, +ve = receding), before
**    ep1a   double    "before" epoch, part A (Note 1)
**    ep1b   double    "before" epoch, part B (Note 1)
**    ep2a   double    "after" epoch, part A (Note 1)
**    ep2b   double    "after" epoch, part B (Note 1)
**
**  Returned:
**    ra2    double    right ascension (radians), after
**    dec2   double    declination (radians), after
**    pmr2   double    RA proper motion (radians/year), after
**    pmd2   double    Dec proper motion (radians/year), after
**    px2    double    parallax (arcseconds), after
**    rv2    double    radial velocity (km/s, +ve = receding), after
**
**  Returned (function value):
**    int     status:
**            -1 = system error (should not occur)
**            0 = no warnings or errors
**            1 = distance overridden (Note 6)
**            2 = excessive velocity (Note 7)
**            4 = solution didn't converge (Note 8)
**            else = binary logical OR of the above warnings
**
**  Notes:
**
**  1) The starting and ending TDB dates ep1a+ep1b and ep2a+ep2b are
**     Julian Dates, apportioned in any convenient way between the two
**     parts (A and B).  For example, JD(TDB)=2450123.7 could be
**     expressed in any of these ways, among others:
**
**           epna          epnb
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
**     The JD method is the most natural and convenient to use in
**     cases where the loss of several decimal digits of resolution
**     is acceptable.  The J2000 method is best matched to the way
**     the argument is handled internally and will deliver the
**     optimum resolution.  The MJD method and the date & time methods
**     are both good compromises between resolution and convenience.
**
**  2) In accordance with normal star-catalog conventions, the object's
**     right ascension and declination are freed from the effects of
**     secular aberration.  The frame, which is aligned to the catalog
**     equator and equinox, is Lorentzian and centered on the SSB.

```

```

**
** The proper motions are the rate of change of the right ascension
** and declination at the catalog epoch and are in radians per TDB
** Julian year.
**
** The parallax and radial velocity are in the same frame.
**
** 3) Care is needed with units. The star coordinates are in radians
** and the proper motions in radians per Julian year, but the
** parallax is in arcseconds.
**
** 4) The RA proper motion is in terms of coordinate angle, not true
** angle. If the catalog uses arcseconds for both RA and Dec proper
** motions, the RA proper motion will need to be divided by cos(Dec)
** before use.
**
** 5) Straight-line motion at constant speed, in the inertial frame,
** is assumed.
**
** 6) An extremely small (or zero or negative) parallax is interpreted
** to mean that the object is on the "celestial sphere", the radius
** of which is an arbitrary (large) value (see the iauStarpv
** function for the value used). When the distance is overridden in
** this way, the status, initially zero, has 1 added to it.
**
** 7) If the space velocity is a significant fraction of c (see the
** constant VMAX in the function iauStarpv), it is arbitrarily set
** to zero. When this action occurs, 2 is added to the status.
**
** 8) The relativistic adjustment carried out in the iauStarpv function
** involves an iterative calculation. If the process fails to
** converge within a set number of iterations, 4 is added to the
** status.
**
** Called:
** iauStarpv      star catalog data to space motion pv-vector
** iauPvu        update a pv-vector
** iauPdp        scalar product of two p-vectors
** iauPvstar     space motion pv-vector to star catalog data
**
** /

```

```

int iauStarpv(double ra, double dec,
              double pmr, double pmd, double px, double rv,
              double pv[2][3])
/*
**  - - - - -
**   i a u S t a r p v
**  - - - - -
**
** Convert star catalog coordinates to position+velocity vector.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given (Note 1):
**   ra      double      right ascension (radians)
**   dec     double      declination (radians)
**   pmr     double      RA proper motion (radians/year)
**   pmd     double      Dec proper motion (radians/year)
**   px      double      parallax (arcseconds)
**   rv      double      radial velocity (km/s, positive = receding)
**
** Returned (Note 2):
**   pv      double[2][3]  pv-vector (AU, AU/day)
**
** Returned (function value):
**   int      status:
**           0 = no warnings
**           1 = distance overridden (Note 6)
**           2 = excessive speed (Note 7)
**           4 = solution didn't converge (Note 8)
**           else = binary logical OR of the above
**
** Notes:
**
** 1) The star data accepted by this function are "observables" for an
** imaginary observer at the solar-system barycenter. Proper motion
** and radial velocity are, strictly, in terms of barycentric
** coordinate time, TCB. For most practical applications, it is
** permissible to neglect the distinction between TCB and ordinary
** "proper" time on Earth (TT/TAI). The result will, as a rule, be
** limited by the intrinsic accuracy of the proper-motion and
** radial-velocity data; moreover, the pv-vector is likely to be
** merely an intermediate result, so that a change of time unit
** would cancel out overall.
**
** In accordance with normal star-catalog conventions, the object's
** right ascension and declination are freed from the effects of
** secular aberration. The frame, which is aligned to the catalog
** equator and equinox, is Lorentzian and centered on the SSB.
**
** 2) The resulting position and velocity pv-vector is with respect to
** the same frame and, like the catalog coordinates, is freed from
** the effects of secular aberration. Should the "coordinate
** direction", where the object was located at the catalog epoch, be
** required, it may be obtained by calculating the magnitude of the
** position vector pv[0][0-2] dividing by the speed of light in
** AU/day to give the light-time, and then multiplying the space
** velocity pv[1][0-2] by this light-time and adding the result to
** pv[0][0-2].
**
** Summarizing, the pv-vector returned is for most stars almost
** identical to the result of applying the standard geometrical
** "space motion" transformation. The differences, which are the
** subject of the Stumpff paper referenced below, are:
**
** (i) In stars with significant radial velocity and proper motion,
** the constantly changing light-time distorts the apparent proper
** motion. Note that this is a classical, not a relativistic,
** effect.

```

```

**
**      (ii) The transformation complies with special relativity.
**
**
**  3) Care is needed with units.  The star coordinates are in radians
**      and the proper motions in radians per Julian year, but the
**      parallax is in arcseconds; the radial velocity is in km/s, but
**      the pv-vector result is in AU and AU/day.
**
**  4) The RA proper motion is in terms of coordinate angle, not true
**      angle.  If the catalog uses arcseconds for both RA and Dec proper
**      motions, the RA proper motion will need to be divided by cos(Dec)
**      before use.
**
**  5) Straight-line motion at constant speed, in the inertial frame,
**      is assumed.
**
**  6) An extremely small (or zero or negative) parallax is interpreted
**      to mean that the object is on the "celestial sphere", the radius
**      of which is an arbitrary (large) value (see the constant PXMIN).
**      When the distance is overridden in this way, the status,
**      initially zero, has 1 added to it.
**
**  7) If the space velocity is a significant fraction of c (see the
**      constant VMAX), it is arbitrarily set to zero.  When this action
**      occurs, 2 is added to the status.
**
**  8) The relativistic adjustment involves an iterative calculation.
**      If the process fails to converge within a set number (IMAX) of
**      iterations, 4 is added to the status.
**
**  9) The inverse transformation is performed by the function
**      iauPvstar.
**
** Called:
**   iauS2pv      spherical coordinates to pv-vector
**   iauPm        modulus of p-vector
**   iauZp        zero p-vector
**   iauPn        decompose p-vector into modulus and direction
**   iauPdp       scalar product of two p-vectors
**   iauSxp       multiply p-vector by scalar
**   iauPmp       p-vector minus p-vector
**   iauPpp       p-vector plus p-vector
**
** Reference:
**
**   Stumpff, P., 1985, Astron.Astrophys. 144, 232-240.
**
**/

```

```

void iauSxp(double s, double p[3], double sp[3])
/*
**  - - - - -
**   i a u S x p
**  - - - - -
**
** Multiply a p-vector by a scalar.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   s      double      scalar
**   p      double[3]   p-vector
**
** Returned:
**   sp     double[3]   s * p
**
** Note:
**   It is permissible for p and sp to be the same array.
**
*/

```

```

void iauSxpv(double s, double pv[2][3], double spv[2][3])
/*
**  - - - - -
**   i a u S x p v
**  - - - - -
**
** Multiply a pv-vector by a scalar.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   s      double      scalar
**   pv     double[2][3]  pv-vector
**
** Returned:
**   spv    double[2][3]  s * pv
**
** Note:
**   It is permissible for pv and spv to be the same array
**
** Called:
**   iauS2xpv      multiply pv-vector by two scalars
**
*/

```

```

int iauTaitt(double tail, double tai2, double *tt1, double *tt2)
/*
**  - - - - -
**   i a u T a i t t
**  - - - - -
**
** Time scale transformation:  International Atomic Time, TAI, to
** Terrestrial Time, TT.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  canonical.
**
** Given:
**   tail,tai2  double      TAI as a 2-part Julian Date
**
** Returned:
**   tt1,tt2   double      TT as a 2-part Julian Date
**
** Returned (function value):
**           int          status:  0 = OK
**
** Note:
**
**   tail+tai2 is Julian Date, apportioned in any convenient way
**   between the two arguments, for example where tail is the Julian
**   Day Number and tai2 is the fraction of a day.  The returned
**   tt1,tt2 follow suit.
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
*/

```

```

int iauTaiut1(double tai1, double tai2, double dta,
              double *ut11, double *ut12)
/*
**  - - - - -
**   i a u T a i u t 1
**  - - - - -
**
** Time scale transformation:  International Atomic Time, TAI, to
** Universal Time, UT1.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status:  canonical.
**
** Given:
**   tai1,tai2  double    TAI as a 2-part Julian Date
**   dta        double    UT1-TAI in seconds
**
** Returned:
**   ut11,ut12 double    UT1 as a 2-part Julian Date
**
** Returned (function value):
**   int        status:  0 = OK
**
** Notes:
**
** 1) tai1+tai2 is Julian Date, apportioned in any convenient way
**    between the two arguments, for example where tai1 is the Julian
**    Day Number and tai2 is the fraction of a day.  The returned
**    UT11,UT12 follow suit.
**
** 2) The argument dta, i.e. UT1-TAI, is an observed quantity, and is
**    available from IERS tabulations.
**
** Reference:
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
*/

```

```

int iauTaiutc(double tail, double tai2, double *utc1, double *utc2)
/*
**  - - - - -
**    i a u T a i u t c
**  - - - - -
**
** Time scale transformation: International Atomic Time, TAI, to
** Coordinated Universal Time, UTC.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   tail,tai2 double   TAI as a 2-part Julian Date (Note 1)
**
** Returned:
**   utc1,utc2 double   UTC as a 2-part quasi Julian Date (Notes 1-3)
**
** Returned (function value):
**   int          status: +1 = dubious year (Note 4)
**                   0 = OK
**                   -1 = unacceptable date
**
** Notes:
**
** 1) tail+tai2 is Julian Date, apportioned in any convenient way
** between the two arguments, for example where tail is the Julian
** Day Number and tai2 is the fraction of a day. The returned utc1
** and utc2 form an analogous pair, except that a special convention
** is used, to deal with the problem of leap seconds - see the next
** note.
**
** 2) JD cannot unambiguously represent UTC during a leap second unless
** special measures are taken. The convention in the present
** function is that the JD day represents UTC days whether the
** length is 86399, 86400 or 86401 SI seconds. In the 1960-1972 era
** there were smaller jumps (in either direction) each time the
** linear UTC(TAI) expression was changed, and these "mini-leaps"
** are also included in the SOFA convention.
**
** 3) The function iauD2dtf can be used to transform the UTC quasi-JD
** into calendar date and clock time, including UTC leap second
** handling.
**
** 4) The warning status "dubious year" flags UTCs that predate the
** introduction of the time scale or that are too far in the future
** to be trusted. See iauDat for further details.
**
** Called:
**   iauUtctai   UTC to TAI
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
*/

```

```

int iauTcbtdb(double tcb1, double tcb2, double *tdb1, double *tdb2)
/*
**  - - - - -
**   i a u T c b t d b
**  - - - - -
**
** Time scale transformation: Barycentric Coordinate Time, TCB, to
** Barycentric Dynamical Time, TDB.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   tcb1,tcb2 double   TCB as a 2-part Julian Date
**
** Returned:
**   tdb1,tdb2 double   TDB as a 2-part Julian Date
**
** Returned (function value):
**   int          status:  0 = OK
**
** Notes:
**
** 1) tcb1+tcb2 is Julian Date, apportioned in any convenient way
** between the two arguments, for example where tcb1 is the Julian
** Day Number and tcb2 is the fraction of a day. The returned
** tdb1,tdb2 follow suit.
**
** 2) The 2006 IAU General Assembly introduced a conventional linear
** transformation between TDB and TCB. This transformation
** compensates for the drift between TCB and terrestrial time TT,
** and keeps TDB approximately centered on TT. Because the
** relationship between TT and TCB depends on the adopted solar
** system ephemeris, the degree of alignment between TDB and TT over
** long intervals will vary according to which ephemeris is used.
** Former definitions of TDB attempted to avoid this problem by
** stipulating that TDB and TT should differ only by periodic
** effects. This is a good description of the nature of the
** relationship but eluded precise mathematical formulation. The
** conventional linear relationship adopted in 2006 sidestepped
** these difficulties whilst delivering a TDB that in practice was
** consistent with values before that date.
**
** 3) TDB is essentially the same as Teph, the time argument for the
** JPL solar system ephemerides.
**
** Reference:
**
** IAU 2006 Resolution B3
**
*/

```

```

int iauTcgtt(double tcg1, double tcg2, double *tt1, double *tt2)
/*
**   - - - - -
**   i a u T c g t t
**   - - - - -
**
** Time scale transformation: Geocentric Coordinate Time, TCG, to
** Terrestrial Time, TT.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   tcg1,tcg2 double    TCG as a 2-part Julian Date
**
** Returned:
**   tt1,tt2 double    TT as a 2-part Julian Date
**
** Returned (function value):
**   int          status:  0 = OK
**
** Note:
**
**   tcg1+tcg2 is Julian Date, apportioned in any convenient way
**   between the two arguments, for example where tcg1 is the Julian
**   Day Number and tcg22 is the fraction of a day. The returned
**   tt1,tt2 follow suit.
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),.
**   IERS Technical Note No. 32, BKG (2004)
**
**   IAU 2000 Resolution B1.9
**
*/

```

```

int iauTdbtcb(double tdb1, double tdb2, double *tcb1, double *tcb2)
/*
**  - - - - -
**   i a u T d b t c b
**  - - - - -
**
** Time scale transformation: Barycentric Dynamical Time, TDB, to
** Barycentric Coordinate Time, TCB.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   tdb1,tdb2 double    TDB as a 2-part Julian Date
**
** Returned:
**   tcb1,tcb2 double    TCB as a 2-part Julian Date
**
** Returned (function value):
**   int          status:  0 = OK
**
** Notes:
**
** 1) tdb1+tdb2 is Julian Date, apportioned in any convenient way
** between the two arguments, for example where tdb1 is the Julian
** Day Number and tdb2 is the fraction of a day. The returned
** tcb1,tcb2 follow suit.
**
** 2) The 2006 IAU General Assembly introduced a conventional linear
** transformation between TDB and TCB. This transformation
** compensates for the drift between TCB and terrestrial time TT,
** and keeps TDB approximately centered on TT. Because the
** relationship between TT and TCB depends on the adopted solar
** system ephemeris, the degree of alignment between TDB and TT over
** long intervals will vary according to which ephemeris is used.
** Former definitions of TDB attempted to avoid this problem by
** stipulating that TDB and TT should differ only by periodic
** effects. This is a good description of the nature of the
** relationship but eluded precise mathematical formulation. The
** conventional linear relationship adopted in 2006 sidestepped
** these difficulties whilst delivering a TDB that in practice was
** consistent with values before that date.
**
** 3) TDB is essentially the same as Teph, the time argument for the
** JPL solar system ephemerides.
**
** Reference:
**
** IAU 2006 Resolution B3
**
*/

```

```

int iauTdbtt(double tdb1, double tdb2, double dtr,
             double *tt1, double *tt2 )
/*
**  - - - - -
**   i a u T d b t t
**  - - - - -
**
** Time scale transformation: Barycentric Dynamical Time, TDB, to
** Terrestrial Time, TT.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   tdb1,tdb2  double   TDB as a 2-part Julian Date
**   dtr        double   TDB-TT in seconds
**
** Returned:
**   tt1,tt2   double   TT as a 2-part Julian Date
**
** Returned (function value):
**   int        status:  0 = OK
**
** Notes:
**
** 1) tdb1+tdb2 is Julian Date, apportioned in any convenient way
**    between the two arguments, for example where tdb1 is the Julian
**    Day Number and tdb2 is the fraction of a day. The returned
**    tt1,tt2 follow suit.
**
** 2) The argument dtr represents the quasi-periodic component of the
**    GR transformation between TT and TCB. It is dependent upon the
**    adopted solar-system ephemeris, and can be obtained by numerical
**    integration, by interrogating a precomputed time ephemeris or by
**    evaluating a model such as that implemented in the SOFA function
**    iauDtdb. The quantity is dominated by an annual term of 1.7 ms
**    amplitude.
**
** 3) TDB is essentially the same as Teph, the time argument for the
**    JPL solar system ephemerides.
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**   IAU 2006 Resolution 3
**
*/

```

```

int iauTf2a(char s, int ihour, int imin, double sec, double *rad)
/*
**  - - - - -
**   i a u T f 2 a
**  - - - - -
**
**   Convert hours, minutes, seconds to radians.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     s          char    sign:  '-' = negative, otherwise positive
**     ihour      int     hours
**     imin       int     minutes
**     sec        double  seconds
**
**   Returned:
**     rad        double  angle in radians
**
**   Returned (function value):
**     int        status:  0 = OK
**                       1 = ihour outside range 0-23
**                       2 = imin outside range 0-59
**                       3 = sec outside range 0-59.999...
**
**   Notes:
**
**   1)  The result is computed even if any of the range checks fail.
**
**   2)  Negative ihour, imin and/or sec produce a warning status, but
**       the absolute value is used in the conversion.
**
**   3)  If there are multiple errors, the status value reflects only the
**       first, the smallest taking precedence.
**
*/

```

```

int iauTf2d(char s, int ihour, int imin, double sec, double *days)
/*
**  - - - - -
**   i a u T f 2 d
**  - - - - -
**
**   Convert hours, minutes, seconds to days.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     s          char    sign:  '-' = negative, otherwise positive
**     ihour      int     hours
**     imin       int     minutes
**     sec        double  seconds
**
**   Returned:
**     days       double  interval in days
**
**   Returned (function value):
**     int        status:  0 = OK
**                       1 = ihour outside range 0-23
**                       2 = imin outside range 0-59
**                       3 = sec outside range 0-59.999...
**
**   Notes:
**
**   1)  The result is computed even if any of the range checks fail.
**
**   2)  Negative ihour, imin and/or sec produce a warning status, but
**       the absolute value is used in the conversion.
**
**   3)  If there are multiple errors, the status value reflects only the
**       first, the smallest taking precedence.
**
*/

```

```
void iauTr(double r[3][3], double rt[3][3])
/*
**  - - - - -
**  i a u T r
**  - - - - -
**
**  Transpose an r-matrix.
**
**  This function is part of the International Astronomical Union's
**  SOFA (Standards Of Fundamental Astronomy) software collection.
**
**  Status:  vector/matrix support function.
**
**  Given:
**    r          double[3][3]    r-matrix
**
**  Returned:
**    rt         double[3][3]    transpose
**
**  Note:
**    It is permissible for r and rt to be the same array.
**
**  Called:
**    iauCr      copy r-matrix
**
**/
```

```

void iauTrxp(double r[3][3], double p[3], double trp[3])
/*
**  - - - - -
**   i a u T r x p
**  - - - - -
**
** Multiply a p-vector by the transpose of an r-matrix.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   r      double[3][3]  r-matrix
**   p      double[3]     p-vector
**
** Returned:
**   trp    double[3]     r * p
**
** Note:
**   It is permissible for p and trp to be the same array.
**
** Called:
**   iauTr      transpose r-matrix
**   iauRxp    product of r-matrix and p-vector
**
*/

```

```

void iauTrxpv(double r[3][3], double pv[2][3], double trpv[2][3])
/*
**  - - - - -
**   i a u T r x p v
**  - - - - -
**
** Multiply a pv-vector by the transpose of an r-matrix.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Given:
**   r          double[3][3]   r-matrix
**   pv         double[2][3]   pv-vector
**
** Returned:
**   trpv       double[2][3]   r * pv
**
** Note:
**   It is permissible for pv and trpv to be the same array.
**
** Called:
**   iauTr      transpose r-matrix
**   iauRxpv    product of r-matrix and pv-vector
**
*/

```

```

int iauTttai(double tt1, double tt2, double *tai1, double *tai2)
/*
**  - - - - -
**   i a u T t t a i
**  - - - - -
**
** Time scale transformation: Terrestrial Time, TT, to International
** Atomic Time, TAI.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   tt1,tt2   double   TT as a 2-part Julian Date
**
** Returned:
**   tai1,tai2 double   TAI as a 2-part Julian Date
**
** Returned (function value):
**   int       status:  0 = OK
**
** Note:
**
**   tt1+tt2 is Julian Date, apportioned in any convenient way between
**   the two arguments, for example where tt1 is the Julian Day Number
**   and tt2 is the fraction of a day. The returned tai1,tai2 follow
**   suit.
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
*/

```

```

int iauTttcg(double tt1, double tt2, double *tcg1, double *tcg2)
/*
**   - - - - -
**   i a u T t t c g
**   - - - - -
**
** Time scale transformation: Terrestrial Time, TT, to Geocentric
** Coordinate Time, TCG.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   tt1,tt2   double   TT as a 2-part Julian Date
**
** Returned:
**   tcg1,tcg2 double   TCG as a 2-part Julian Date
**
** Returned (function value):
**   int       status:  0 = OK
**
** Note:
**
**   tt1+tt2 is Julian Date, apportioned in any convenient way between
**   the two arguments, for example where tt1 is the Julian Day Number
**   and tt2 is the fraction of a day. The returned tcg1,tcg2 follow
**   suit.
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**   IAU 2000 Resolution B1.9
**
*/

```

```

int iauTttdb(double tt1, double tt2, double dtr,
             double *tdb1, double *tdb2)
/*
**  - - - - -
**   i a u T t t d b
**  - - - - -
**
** Time scale transformation: Terrestrial Time, TT, to Barycentric
** Dynamical Time, TDB.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   tt1,tt2    double    TT as a 2-part Julian Date
**   dtr        double    TDB-TT in seconds
**
** Returned:
**   tdb1,tdb2 double    TDB as a 2-part Julian Date
**
** Returned (function value):
**   int        status:  0 = OK
**
** Notes:
**
** 1) tt1+tt2 is Julian Date, apportioned in any convenient way between
** the two arguments, for example where tt1 is the Julian Day Number
** and tt2 is the fraction of a day. The returned tdb1,tdb2 follow
** suit.
**
** 2) The argument dtr represents the quasi-periodic component of the
** GR transformation between TT and TCB. It is dependent upon the
** adopted solar-system ephemeris, and can be obtained by numerical
** integration, by interrogating a precomputed time ephemeris or by
** evaluating a model such as that implemented in the SOFA function
** iauDtdb. The quantity is dominated by an annual term of 1.7 ms
** amplitude.
**
** 3) TDB is essentially the same as Teph, the time argument for the JPL
** solar system ephemerides.
**
** References:
**
** McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
** IERS Technical Note No. 32, BKG (2004)
**
** IAU 2006 Resolution 3
**
*/

```

```

int iauTtut1(double tt1, double tt2, double dt,
             double *ut11, double *ut12)
/*
**  - - - - -
**   i a u T t u t 1
**  - - - - -
**
** Time scale transformation: Terrestrial Time, TT, to Universal Time,
** UT1.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   tt1,tt2   double   TT as a 2-part Julian Date
**   dt        double   TT-UT1 in seconds
**
** Returned:
**   ut11,ut12 double   UT1 as a 2-part Julian Date
**
** Returned (function value):
**   int       status:  0 = OK
**
** Notes:
**
** 1) tt1+tt2 is Julian Date, apportioned in any convenient way between
**    the two arguments, for example where tt1 is the Julian Day Number
**    and tt2 is the fraction of a day. The returned ut11,ut12 follow
**    suit.
**
** 2) The argument dt is classical Delta T.
**
** Reference:
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
*/

```

```

int iauUtltai(double ut11, double ut12, double dta,
              double *tail, double *tai2)
/*
**  - - - - -
**   i a u U t 1 t a i
**  - - - - -
**
** Time scale transformation: Universal Time, UT1, to International
** Atomic Time, TAI.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   ut11,ut12  double    UT1 as a 2-part Julian Date
**   dta        double    UT1-TAI in seconds
**
** Returned:
**   tail,tai2  double    TAI as a 2-part Julian Date
**
** Returned (function value):
**   int        status:  0 = OK
**
** Notes:
**
** 1) ut11+ut12 is Julian Date, apportioned in any convenient way
**    between the two arguments, for example where ut11 is the Julian
**    Day Number and ut12 is the fraction of a day. The returned
**    tail,tai2 follow suit.
**
** 2) The argument dta, i.e. UT1-TAI, is an observed quantity, and is
**    available from IERS tabulations.
**
** Reference:
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
*/

```

```

int iauUtl1tt(double ut11, double ut12, double dt,
              double *tt1, double *tt2)
/*
**  - - - - -
**   i a u U t 1 t t
**  - - - - -
**
** Time scale transformation: Universal Time, UT1, to Terrestrial
** Time, TT.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   ut11,ut12  double    UT1 as a 2-part Julian Date
**   dt         double    TT-UT1 in seconds
**
** Returned:
**   tt1,tt2   double    TT as a 2-part Julian Date
**
** Returned (function value):
**   int       status:  0 = OK
**
** Notes:
**
** 1) ut11+ut12 is Julian Date, apportioned in any convenient way
**    between the two arguments, for example where ut11 is the Julian
**    Day Number and ut12 is the fraction of a day. The returned
**    tt1,tt2 follow suit.
**
** 2) The argument dt is classical Delta T.
**
** Reference:
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
*/

```

```

int iauUtlutc(double ut11, double ut12, double dut1,
              double *utcl, double *utc2)
/*
**   - - - - -
**   i a u U t l u t c
**   - - - - -
**
** Time scale transformation: Universal Time, UT1, to Coordinated
** Universal Time, UTC.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   ut11,ut12  double   UT1 as a 2-part Julian Date (Note 1)
**   dut1       double   Delta UT1: UT1-UTC in seconds (Note 2)
**
** Returned:
**   utcl,utc2  double   UTC as a 2-part quasi Julian Date (Notes 3,4)
**
** Returned (function value):
**   int        status: +1 = dubious year (Note 5)
**                   0 = OK
**                   -1 = unacceptable date
**
** Notes:
**
** 1) ut11+ut12 is Julian Date, apportioned in any convenient way
**    between the two arguments, for example where ut11 is the Julian
**    Day Number and ut12 is the fraction of a day. The returned utcl
**    and utc2 form an analogous pair, except that a special convention
**    is used, to deal with the problem of leap seconds - see Note 3.
**
** 2) Delta UT1 can be obtained from tabulations provided by the
**    International Earth Rotation and Reference Systems Service. The
**    value changes abruptly by 1s at a leap second; however, close to
**    a leap second the algorithm used here is tolerant of the "wrong"
**    choice of value being made.
**
** 3) JD cannot unambiguously represent UTC during a leap second unless
**    special measures are taken. The convention in the present
**    function is that the returned quasi JD day UTC1+UTC2 represents
**    UTC days whether the length is 86399, 86400 or 86401 SI seconds.
**
** 4) The function iauD2dtf can be used to transform the UTC quasi-JD
**    into calendar date and clock time, including UTC leap second
**    handling.
**
** 5) The warning status "dubious year" flags UTCs that predate the
**    introduction of the time scale or that are too far in the future
**    to be trusted. See iauDat for further details.
**
** Called:
**   iauJd2cal   JD to Gregorian calendar
**   iauDat     delta(AT) = TAI-UTC
**   iauCal2jd  Gregorian calendar to JD
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
*/

```

```

int iauUtctai(double utc1, double utc2, double *tai1, double *tai2)
/*
**   - - - - -
**   i a u U t c t a i
**   - - - - -
**
** Time scale transformation: Coordinated Universal Time, UTC, to
** International Atomic Time, TAI.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   utc1,utc2 double   UTC as a 2-part quasi Julian Date (Notes 1-4)
**
** Returned:
**   tai1,tai2 double   TAI as a 2-part Julian Date (Note 5)
**
** Returned (function value):
**   int          status: +1 = dubious year (Note 3)
**                   0 = OK
**                   -1 = unacceptable date
**
** Notes:
**
** 1) utc1+utc2 is quasi Julian Date (see Note 2), apportioned in any
**    convenient way between the two arguments, for example where utc1
**    is the Julian Day Number and utc2 is the fraction of a day.
**
** 2) JD cannot unambiguously represent UTC during a leap second unless
**    special measures are taken. The convention in the present
**    function is that the JD day represents UTC days whether the
**    length is 86399, 86400 or 86401 SI seconds. In the 1960-1972 era
**    there were smaller jumps (in either direction) each time the
**    linear UTC(TAI) expression was changed, and these "mini-leaps"
**    are also included in the SOFA convention.
**
** 3) The warning status "dubious year" flags UTCs that predate the
**    introduction of the time scale or that are too far in the future
**    to be trusted. See iauDat for further details.
**
** 4) The function iauDtf2d converts from calendar date and time of day
**    into 2-part Julian Date, and in the case of UTC implements the
**    leap-second-ambiguity convention described above.
**
** 5) The returned TAI1,TAI2 are such that their sum is the TAI Julian
**    Date.
**
** Called:
**   iauJd2cal   JD to Gregorian calendar
**   iauDat     delta(AT) = TAI-UTC
**   iauCal2jd  Gregorian calendar to JD
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
*/

```

```

int iauUtcut1(double utc1, double utc2, double dut1,
              double *ut11, double *ut12)
/*
**   - - - - -
**   i a u U t c u t 1
**   - - - - -
**
** Time scale transformation: Coordinated Universal Time, UTC, to
** Universal Time, UT1.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards of Fundamental Astronomy) software collection.
**
** Status: canonical.
**
** Given:
**   utc1,utc2  double   UTC as a 2-part quasi Julian Date (Notes 1-4)
**   dut1       double   Delta UT1 = UT1-UTC in seconds (Note 5)
**
** Returned:
**   ut11,ut12 double   UT1 as a 2-part Julian Date (Note 6)
**
** Returned (function value):
**   int        status: +1 = dubious year (Note 3)
**                   0 = OK
**                   -1 = unacceptable date
**
** Notes:
**
** 1) utc1+utc2 is quasi Julian Date (see Note 2), apportioned in any
** convenient way between the two arguments, for example where utc1
** is the Julian Day Number and utc2 is the fraction of a day.
**
** 2) JD cannot unambiguously represent UTC during a leap second unless
** special measures are taken. The convention in the present
** function is that the JD day represents UTC days whether the
** length is 86399, 86400 or 86401 SI seconds.
**
** 3) The warning status "dubious year" flags UTCs that predate the
** introduction of the time scale or that are too far in the future
** to be trusted. See iauDat for further details.
**
** 4) The function iauDtf2d converts from calendar date and time of
** day into 2-part Julian Date, and in the case of UTC implements
** the leap-second-ambiguity convention described above.
**
** 5) Delta UT1 can be obtained from tabulations provided by the
** International Earth Rotation and Reference Systems Service.
** It is the caller's responsibility to supply a dut1 argument
** containing the UT1-UTC value that matches the given UTC.
**
** 6) The returned ut11,ut12 are such that their sum is the UT1 Julian
** Date.
**
** References:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
**   Explanatory Supplement to the Astronomical Almanac,
**   P. Kenneth Seidelmann (ed), University Science Books (1992)
**
** Called:
**   iauJd2cal   JD to Gregorian calendar
**   iauDat     delta(AT) = TAI-UTC
**   iauUtctai  UTC to TAI
**   iauTaiut1  TAI to UT1
**
*/

```

```

void iauXy06(double date1, double date2, double *x, double *y)
/*
**   - - - - -
**   i a u X y 0 6
**   - - - - -
**
** X,Y coordinates of celestial intermediate pole from series based
** on IAU 2006 precession and IAU 2000A nutation.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status: canonical model.
**
** Given:
**   date1,date2 double      TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   x,y          double     CIP X,Y coordinates (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments. For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0      (JD method)
**           2451545.0        -1421.3    (J2000 method)
**           2400000.5          50123.2   (MJD method)
**           2450123.5          0.2      (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable. The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution. The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The X,Y coordinates are those of the unit vector towards the
** celestial intermediate pole. They represent the combined effects
** of frame bias, precession and nutation.
**
** 3) The fundamental arguments used are as adopted in IERS Conventions
** (2003) and are from Simon et al. (1994) and Souchay et al.
** (1999).
**
** 4) This is an alternative to the angles-based method, via the SOFA
** function iauFw2xy and as used in iauXys06a for example. The two
** methods agree at the 1 microarcsecond level (at present), a
** negligible amount compared with the intrinsic accuracy of the
** models. However, it would be unwise to mix the two methods
** (angles-based and series-based) in a single application.
**
** Called:
**   iauFal03      mean anomaly of the Moon
**   iauFalp03     mean anomaly of the Sun
**   iauFaf03      mean argument of the latitude of the Moon
**   iauFad03      mean elongation of the Moon from the Sun
**   iauFaom03     mean longitude of the Moon's ascending node
**   iauFame03     mean longitude of Mercury
**   iauFave03     mean longitude of Venus
**   iauFae03      mean longitude of Earth
**   iauFama03     mean longitude of Mars
**   iauFaju03     mean longitude of Jupiter
**   iauFasa03     mean longitude of Saturn
**   iauFaur03     mean longitude of Uranus
**   iauFane03     mean longitude of Neptune
**   iauFapa03     general accumulated precession in longitude

```

\*\*  
\*\* References:  
\*\*  
\*\* Capitaine, N., Wallace, P.T. & Chapront, J., 2003,  
\*\* Astron.Astrophys., 412, 567  
\*\*  
\*\* Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855  
\*\*  
\*\* McCarthy, D. D., Petit, G. (eds.), 2004, IERS Conventions (2003),  
\*\* IERS Technical Note No. 32, BKG  
\*\*  
\*\* Simon, J.L., Bretagnon, P., Chapront, J., Chapront-Touze, M.,  
\*\* Francou, G. & Laskar, J., Astron.Astrophys., 1994, 282, 663  
\*\*  
\*\* Souchay, J., Loysel, B., Kinoshita, H., Folgueira, M., 1999,  
\*\* Astron.Astrophys.Supp.Ser. 135, 111  
\*\*  
\*\* Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981  
\*\*  
\*/

```

void iauXys00a(double date1, double date2,
               double *x, double *y, double *s)
/*
**  - - - - -
**   i a u X y s 0 0 a
**  - - - - -
**
**   For a given TT date, compute the X,Y coordinates of the Celestial
**   Intermediate Pole and the CIO locator s, using the IAU 2000A
**   precession-nutation model.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  support function.
**
**   Given:
**     date1,date2  double    TT as a 2-part Julian Date (Note 1)
**
**   Returned:
**     x,y         double    Celestial Intermediate Pole (Note 2)
**     s          double    the CIO locator s (Note 2)
**
**   Notes:
**
**   1) The TT date date1+date2 is a Julian Date, apportioned in any
**   convenient way between the two arguments.  For example,
**   JD(TT)=2450123.7 could be expressed in any of these ways,
**   among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
**   The JD method is the most natural and convenient to use in
**   cases where the loss of several decimal digits of resolution
**   is acceptable.  The J2000 method is best matched to the way
**   the argument is handled internally and will deliver the
**   optimum resolution.  The MJD method and the date & time methods
**   are both good compromises between resolution and convenience.
**
**   2) The Celestial Intermediate Pole coordinates are the x,y
**   components of the unit vector in the Geocentric Celestial
**   Reference System.
**
**   3) The CIO locator s (in radians) positions the Celestial
**   Intermediate Origin on the equator of the CIP.
**
**   4) A faster, but slightly less accurate result (about 1 mas for
**   X,Y), can be obtained by using instead the iauXys00b function.
**
**   Called:
**     iauPnm00a    classical NPB matrix, IAU 2000A
**     iauBpn2xy   extract CIP X,Y coordinates from NPB matrix
**     iauS00      the CIO locator s, given X,Y, IAU 2000A
**
**   Reference:
**
**     McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**     IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

void iauXys00b(double date1, double date2,
               double *x, double *y, double *s)
/*
**  - - - - -
**   i a u X y s 0 0 b
**  - - - - -
**
** For a given TT date, compute the X,Y coordinates of the Celestial
** Intermediate Pole and the CIO locator s, using the IAU 2000B
** precession-nutation model.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double    TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   x,y          double    Celestial Intermediate Pole (Note 2)
**   s            double    the CIO locator s (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2        (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The Celestial Intermediate Pole coordinates are the x,y
** components of the unit vector in the Geocentric Celestial
** Reference System.
**
** 3) The CIO locator s (in radians) positions the Celestial
** Intermediate Origin on the equator of the CIP.
**
** 4) The present function is faster, but slightly less accurate (about
** 1 mas in X,Y), than the iauXys00a function.
**
** Called:
**   iauPnm00b    classical NPB matrix, IAU 2000B
**   iauBpn2xy    extract CIP X,Y coordinates from NPB matrix
**   iauS00       the CIO locator s, given X,Y, IAU 2000A
**
** Reference:
**
**   McCarthy, D. D., Petit, G. (eds.), IERS Conventions (2003),
**   IERS Technical Note No. 32, BKG (2004)
**
*/

```

```

void iauXys06a(double date1, double date2,
               double *x, double *y, double *s)
/*
**  - - - - -
**   i a u X y s 0 6 a
**  - - - - -
**
** For a given TT date, compute the X,Y coordinates of the Celestial
** Intermediate Pole and the CIO locator s, using the IAU 2006
** precession and IAU 2000A nutation models.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  support function.
**
** Given:
**   date1,date2  double  TT as a 2-part Julian Date (Note 1)
**
** Returned:
**   x,y         double  Celestial Intermediate Pole (Note 2)
**   s           double  the CIO locator s (Note 2)
**
** Notes:
**
** 1) The TT date date1+date2 is a Julian Date, apportioned in any
** convenient way between the two arguments.  For example,
** JD(TT)=2450123.7 could be expressed in any of these ways,
** among others:
**
**           date1          date2
**
**           2450123.7          0.0          (JD method)
**           2451545.0         -1421.3        (J2000 method)
**           2400000.5          50123.2       (MJD method)
**           2450123.5          0.2          (date & time method)
**
** The JD method is the most natural and convenient to use in
** cases where the loss of several decimal digits of resolution
** is acceptable.  The J2000 method is best matched to the way
** the argument is handled internally and will deliver the
** optimum resolution.  The MJD method and the date & time methods
** are both good compromises between resolution and convenience.
**
** 2) The Celestial Intermediate Pole coordinates are the x,y components
** of the unit vector in the Geocentric Celestial Reference System.
**
** 3) The CIO locator s (in radians) positions the Celestial
** Intermediate Origin on the equator of the CIP.
**
** 4) Series-based solutions for generating X and Y are also available:
** see Capitaine & Wallace (2006) and iauXy06.
**
** Called:
**   iauPnm06a  classical NPB matrix, IAU 2006/2000A
**   iauBpn2xy  extract CIP X,Y coordinates from NPB matrix
**   iauS06     the CIO locator s, given X,Y, IAU 2006
**
** References:
**
**   Capitaine, N. & Wallace, P.T., 2006, Astron.Astrophys. 450, 855
**
**   Wallace, P.T. & Capitaine, N., 2006, Astron.Astrophys. 459, 981
**
*/

```

```
void iauZp(double p[3])
/*
**  - - - - -
**   i a u Z p
**  - - - - -
**
** Zero a p-vector.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Returned:
**   p          double[3]          p-vector
**
** */
```

```
void iauZpv(double pv[2][3])
/*
**  - - - - -
**   i a u Z p v
**  - - - - -
**
** Zero a pv-vector.
**
** This function is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Status:  vector/matrix support function.
**
** Returned:
**   pv      double[2][3]      pv-vector
**
** Called:
**   iauZp      zero p-vector
**
**/
```

```
void iauZr(double r[3][3])
/*
**  - - - - -
**   i a u Z r
**  - - - - -
**
**   Initialize an r-matrix to the null matrix.
**
**   This function is part of the International Astronomical Union's
**   SOFA (Standards Of Fundamental Astronomy) software collection.
**
**   Status:  vector/matrix support function.
**
**   Returned:
**     r      double[3][3]   r-matrix
**
**/
```

## COPYRIGHT NOTICE

Text equivalent to the following appears at the end of every SOFA routine. (There are small formatting differences between the Fortran and C versions.)

```
*+-----
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*
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* =====
*
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\* Somerset, TA1 2DN  
\* United Kingdom  
\*

\*-----

## SOFA Fortran constants

-----

These must be used exactly as presented below.

```
* Pi
  DOUBLE PRECISION DPI
  PARAMETER ( DPI = 3.141592653589793238462643D0 )

* 2Pi
  DOUBLE PRECISION D2PI
  PARAMETER ( D2PI = 6.283185307179586476925287D0 )

* Radians to hours
  DOUBLE PRECISION DR2H
  PARAMETER ( DR2H = 3.819718634205488058453210D0 )

* Radians to seconds
  DOUBLE PRECISION DR2S
  PARAMETER ( DR2S = 13750.98708313975701043156D0 )

* Radians to degrees
  DOUBLE PRECISION DR2D
  PARAMETER ( DR2D = 57.29577951308232087679815D0 )

* Radians to arc seconds
  DOUBLE PRECISION DR2AS
  PARAMETER ( DR2AS = 206264.8062470963551564734D0 )

* Hours to radians
  DOUBLE PRECISION DH2R
  PARAMETER ( DH2R = 0.2617993877991494365385536D0 )

* Seconds to radians
  DOUBLE PRECISION DS2R
  PARAMETER ( DS2R = 7.272205216643039903848712D-5 )

* Degrees to radians
  DOUBLE PRECISION DD2R
  PARAMETER ( DD2R = 1.745329251994329576923691D-2 )

* Arc seconds to radians
  DOUBLE PRECISION DAS2R
  PARAMETER ( DAS2R = 4.848136811095359935899141D-6 )
```

## SOFA C constants

-----

The constants used by the C version of SOFA are defined in the header file sofam.h.

```

#ifndef SOFAHDEF
#define SOFAHDEF

/*
** - - - - -
**   s o f a . h
** - - - - -
**
** Prototype function declarations for SOFA library.
**
** This file is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** This revision:   2016 March 10
**
** SOFA release 2016-05-03
**
** Copyright (C) 2016 IAU SOFA Board.  See notes at end.
**
*/

#include "sofam.h"
#include "math.h"

#ifdef __cplusplus
extern "C" {
#endif

/* Astronomy/Calendars */
int iauCal2jd(int iy, int im, int id, double *djm0, double *djm);
double iauEpb(double dj1, double dj2);
void iauEpb2jd(double epb, double *djm0, double *djm);
double iauEpj(double dj1, double dj2);
void iauEpj2jd(double epj, double *djm0, double *djm);
int iauJd2cal(double dj1, double dj2,
              int *iy, int *im, int *id, double *fd);
int iauJdcalf(int ndp, double dj1, double dj2, int iymdf[4]);

/* Astronomy/Astrometry */
void iauAb(double pnat[3], double v[3], double s, double bml,
           double ppr[3]);
void iauApcg(double datel, double date2,
             double ebpv[2][3], double ehp[3],
             iauASTROM *astrom);
void iauApcg13(double datel, double date2, iauASTROM *astrom);
void iauApci(double datel, double date2,
             double ebpv[2][3], double ehp[3],
             double x, double y, double s,
             iauASTROM *astrom);
void iauApci13(double datel, double date2,
               iauASTROM *astrom, double *eo);
void iauApco(double datel, double date2,
             double ebpv[2][3], double ehp[3],
             double x, double y, double s, double theta,
             double elong, double phi, double hm,
             double xp, double yp, double sp,
             double refa, double refb,
             iauASTROM *astrom);
int iauApcol13(double utcl, double utc2, double dut1,
               double elong, double phi, double hm, double xp, double yp,
               double phpa, double tc, double rh, double wl,
               iauASTROM *astrom, double *eo);
void iauApcs(double datel, double date2, double pv[2][3],
             double ebpv[2][3], double ehp[3],
             iauASTROM *astrom);
void iauApcs13(double datel, double date2, double pv[2][3],
               iauASTROM *astrom);
void iauAper(double theta, iauASTROM *astrom);
void iauAper13(double utl1, double utl2, iauASTROM *astrom);
void iauApio(double sp, double theta,
             double elong, double phi, double hm, double xp, double yp,
             double refa, double refb,
             iauASTROM *astrom);
int iauApio13(double utcl, double utc2, double dut1,

```

```

        double elong, double phi, double hm, double xp, double yp,
        double phpa, double tc, double rh, double wl,
        iauASTROM *astrom);
void iauAtci13(double rc, double dc,
               double pr, double pd, double px, double rv,
               double datel, double date2,
               double *ri, double *di, double *eo);
void iauAtciq(double rc, double dc, double pr, double pd,
              double px, double rv, iauASTROM *astrom,
              double *ri, double *di);
void iauAtciqn(double rc, double dc, double pr, double pd,
               double px, double rv, iauASTROM *astrom,
               int n, iauLDBODY b[], double *ri, double *di);
void iauAtciqz(double rc, double dc, iauASTROM *astrom,
               double *ri, double *di);
int iauAtcol13(double rc, double dc,
               double pr, double pd, double px, double rv,
               double utcl, double utc2, double dutl,
               double elong, double phi, double hm, double xp, double yp,
               double phpa, double tc, double rh, double wl,
               double *aob, double *zob, double *hob,
               double *dob, double *rob, double *eo);
void iauAticl13(double ri, double di,
                double datel, double date2,
                double *rc, double *dc, double *eo);
void iauAticq(double ri, double di, iauASTROM *astrom,
              double *rc, double *dc);
void iauAticqn(double ri, double di, iauASTROM *astrom,
               int n, iauLDBODY b[], double *rc, double *dc);
int iauAtiol13(double ri, double di,
               double utcl, double utc2, double dutl,
               double elong, double phi, double hm, double xp, double yp,
               double phpa, double tc, double rh, double wl,
               double *aob, double *zob, double *hob,
               double *dob, double *rob);
void iauAtioq(double ri, double di, iauASTROM *astrom,
              double *aob, double *zob,
              double *hob, double *dob, double *rob);
int iauAtocl13(const char *type, double ob1, double ob2,
               double utcl, double utc2, double dutl,
               double elong, double phi, double hm, double xp, double yp,
               double phpa, double tc, double rh, double wl,
               double *rc, double *dc);
int iauAtoi13(const char *type, double ob1, double ob2,
               double utcl, double utc2, double dutl,
               double elong, double phi, double hm, double xp, double yp,
               double phpa, double tc, double rh, double wl,
               double *ri, double *di);
void iauAtoiq(const char *type,
              double ob1, double ob2, iauASTROM *astrom,
              double *ri, double *di);
void iauLd(double bm, double p[3], double q[3], double e[3],
           double em, double dlim, double p1[3]);
void iauLdn(int n, iauLDBODY b[], double ob[3], double sc[3],
            double sn[3]);
void iauLdsun(double p[3], double e[3], double em, double p1[3]);
void iauPmpx(double rc, double dc, double pr, double pd,
             double px, double rv, double pmt, double pob[3],
             double pco[3]);
int iauPmsafe(double ral, double decl, double pmr1, double pmd1,
              double px1, double rv1,
              double epla, double ep1b, double ep2a, double ep2b,
              double *ra2, double *dec2, double *pmr2, double *pmd2,
              double *px2, double *rv2);
void iauPvtob(double elong, double phi, double height, double xp,
              double yp, double sp, double theta, double pv[2][3]);
void iauRefco(double phpa, double tc, double rh, double wl,
              double *refa, double *refb);

/* Astronomy/Ephemerides */
int iauEpv00(double datel, double date2,
             double pvh[2][3], double pvb[2][3]);
int iauPlan94(double datel, double date2, int np, double pv[2][3]);

```

```

/* Astronomy/FundamentalArgs */
double iauFad03(double t);
double iauFae03(double t);
double iauFaf03(double t);
double iauFaju03(double t);
double iauFal03(double t);
double iauFalp03(double t);
double iauFama03(double t);
double iauFame03(double t);
double iauFane03(double t);
double iauFaom03(double t);
double iauFapa03(double t);
double iauFasa03(double t);
double iauFaur03(double t);
double iauFave03(double t);

/* Astronomy/PrecNutPolar */
void iauBi00(double *dpsibi, double *depsbi, double *dra);
void iauBp00(double datel, double date2,
             double rb[3][3], double rp[3][3], double rbp[3][3]);
void iauBp06(double datel, double date2,
             double rb[3][3], double rp[3][3], double rbp[3][3]);
void iauBpn2xy(double rbpn[3][3], double *x, double *y);
void iauC2i00a(double datel, double date2, double rc2i[3][3]);
void iauC2i00b(double datel, double date2, double rc2i[3][3]);
void iauC2i06a(double datel, double date2, double rc2i[3][3]);
void iauC2ibpn(double datel, double date2, double rbpn[3][3],
              double rc2i[3][3]);
void iauC2ixy(double datel, double date2, double x, double y,
             double rc2i[3][3]);
void iauC2ixys(double x, double y, double s, double rc2i[3][3]);
void iauC2t00a(double tta, double ttb, double uta, double utb,
             double xp, double yp, double rc2t[3][3]);
void iauC2t00b(double tta, double ttb, double uta, double utb,
             double xp, double yp, double rc2t[3][3]);
void iauC2t06a(double tta, double ttb, double uta, double utb,
             double xp, double yp, double rc2t[3][3]);
void iauC2tcio(double rc2i[3][3], double era, double rpom[3][3],
             double rc2t[3][3]);
void iauC2teqx(double rbpn[3][3], double gst, double rpom[3][3],
             double rc2t[3][3]);
void iauC2tpe(double tta, double ttb, double uta, double utb,
             double dpsci, double deps, double xp, double yp,
             double rc2t[3][3]);
void iauC2txy(double tta, double ttb, double uta, double utb,
             double x, double y, double xp, double yp,
             double rc2t[3][3]);
double iauEo06a(double datel, double date2);
double iauEors(double rnpb[3][3], double s);
void iauFw2m(double gamb, double phib, double psi, double eps,
            double r[3][3]);
void iauFw2xy(double gamb, double phib, double psi, double eps,
            double *x, double *y);
void iauLtp(double epj, double rp[3][3]);
void iauLtpb(double epj, double rpb[3][3]);
void iauLtpecl(double epj, double vec[3]);
void iauLtpequ(double epj, double veq[3]);
void iauNum00a(double datel, double date2, double rmatn[3][3]);
void iauNum00b(double datel, double date2, double rmatn[3][3]);
void iauNum06a(double datel, double date2, double rmatn[3][3]);
void iauNumat(double epsa, double dpsci, double deps, double rmatn[3][3]);
void iauNut00a(double datel, double date2, double *dpsci, double *deps);
void iauNut00b(double datel, double date2, double *dpsci, double *deps);
void iauNut06a(double datel, double date2, double *dpsci, double *deps);
void iauNut80(double datel, double date2, double *dpsci, double *deps);
void iauNutm80(double datel, double date2, double rmatn[3][3]);
double iauObl06(double datel, double date2);
double iauObl80(double datel, double date2);
void iauP06e(double datel, double date2,
            double *eps0, double *psia, double *oma, double *bpa,
            double *bqa, double *pia, double *bpia,
            double *epsa, double *chia, double *za, double *zetaa,

```

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        double *thetaa, double *pa,
        double *gam, double *phi, double *psi);
void iauPb06(double datel, double date2,
        double *bzeta, double *bz, double *btheta);
void iauPfw06(double datel, double date2,
        double *gamb, double *phib, double *psib, double *epsa);
void iauPmat00(double datel, double date2, double rbp[3][3]);
void iauPmat06(double datel, double date2, double rbp[3][3]);
void iauPmat76(double datel, double date2, double rmatp[3][3]);
void iauPn00(double datel, double date2, double dpsl, double deps,
        double *epsa,
        double rb[3][3], double rp[3][3], double rbp[3][3],
        double rn[3][3], double rbpn[3][3]);
void iauPn00a(double datel, double date2,
        double *dpsl, double *deps, double *epsa,
        double rb[3][3], double rp[3][3], double rbp[3][3],
        double rn[3][3], double rbpn[3][3]);
void iauPn00b(double datel, double date2,
        double *dpsl, double *deps, double *epsa,
        double rb[3][3], double rp[3][3], double rbp[3][3],
        double rn[3][3], double rbpn[3][3]);
void iauPn06(double datel, double date2, double dpsl, double deps,
        double *epsa,
        double rb[3][3], double rp[3][3], double rbp[3][3],
        double rn[3][3], double rbpn[3][3]);
void iauPn06a(double datel, double date2,
        double *dpsl, double *deps, double *epsa,
        double rb[3][3], double rp[3][3], double rbp[3][3],
        double rn[3][3], double rbpn[3][3]);
void iauPnm00a(double datel, double date2, double rbpn[3][3]);
void iauPnm00b(double datel, double date2, double rbpn[3][3]);
void iauPnm06a(double datel, double date2, double rnpb[3][3]);
void iauPnm80(double datel, double date2, double rmatpn[3][3]);
void iauPom00(double xp, double yp, double sp, double rpom[3][3]);
void iauPr00(double datel, double date2,
        double *dpslpr, double *depspr);
void iauPrec76(double date01, double date02,
        double datel1, double datel2,
        double *zeta, double *z, double *theta);
double iauS00(double datel, double date2, double x, double y);
double iauS00a(double datel, double date2);
double iauS00b(double datel, double date2);
double iauS06(double datel, double date2, double x, double y);
double iauS06a(double datel, double date2);
double iauSp00(double datel, double date2);
void iauXy06(double datel, double date2, double *x, double *y);
void iauXys00a(double datel, double date2,
        double *x, double *y, double *s);
void iauXys00b(double datel, double date2,
        double *x, double *y, double *s);
void iauXys06a(double datel, double date2,
        double *x, double *y, double *s);

/* Astronomy/RotationAndTime */
double iauEe00(double datel, double date2, double epsa, double dpsl);
double iauEe00a(double datel, double date2);
double iauEe00b(double datel, double date2);
double iauEe06a(double datel, double date2);
double iauEect00(double datel, double date2);
double iauEeq94(double datel, double date2);
double iauEra00(double dj1, double dj2);
double iauGmst00(double uta, double utb, double tta, double ttb);
double iauGmst06(double uta, double utb, double tta, double ttb);
double iauGmst82(double dj1, double dj2);
double iauGst00a(double uta, double utb, double tta, double ttb);
double iauGst00b(double uta, double utb);
double iauGst06(double uta, double utb, double tta, double ttb,
        double rnpb[3][3]);
double iauGst06a(double uta, double utb, double tta, double ttb);
double iauGst94(double uta, double utb);

/* Astronomy/SpaceMotion */
int iauPvstar(double pv[2][3], double *ra, double *dec,

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        double *pmr, double *pmd, double *px, double *rv);
int iauStarpv(double ra, double dec,
             double pmr, double pmd, double px, double rv,
             double pv[2][3]);

/* Astronomy/StarCatalogs */
void iauFk52h(double r5, double d5,
             double dr5, double dd5, double px5, double rv5,
             double *rh, double *dh,
             double *drh, double *ddh, double *pxh, double *rvh);
void iauFk5hip(double r5h[3][3], double s5h[3]);
void iauFk5hz(double r5, double d5, double datel, double date2,
             double *rh, double *dh);
void iauH2fk5(double rh, double dh,
             double drh, double ddh, double pxh, double rvh,
             double *r5, double *d5,
             double *dr5, double *dd5, double *px5, double *rv5);
void iauHfk5z(double rh, double dh, double datel, double date2,
             double *r5, double *d5, double *dr5, double *dd5);
int iauStarpm(double ral, double decl,
             double pmr1, double pmd1, double px1, double rv1,
             double epla, double ep1b, double ep2a, double ep2b,
             double *ra2, double *dec2,
             double *pmr2, double *pmd2, double *px2, double *rv2);

/* Astronomy/EclipticCoordinates */
void iauEceq06(double datel, double date2, double dl, double db,
             double *dr, double *dd);
void iauEcm06(double datel, double date2, double rm[3][3]);
void iauEqec06(double datel, double date2, double dr, double dd,
             double *dl, double *db);
void iauLteceq(double epj, double dl, double db, double *dr, double *dd);
void iauLtecm(double epj, double rm[3][3]);
void iauLteqec(double epj, double dr, double dd, double *dl, double *db);

/* Astronomy/GalacticCoordinates */
void iauG2icrs(double dl, double db, double *dr, double *dd);
void iauIcrs2g(double dr, double dd, double *dl, double *db);

/* Astronomy/GeodeticGeocentric */
int iauEform(int n, double *a, double *f);
int iauGc2gd(int n, double xyz[3],
             double *elong, double *phi, double *height);
int iauGc2gde(double a, double f, double xyz[3],
             double *elong, double *phi, double *height);
int iauGd2gc(int n, double elong, double phi, double height,
             double xyz[3]);
int iauGd2gce(double a, double f,
             double elong, double phi, double height, double xyz[3]);

/* Astronomy/Timescales */
int iauD2dtf(const char *scale, int ndp, double d1, double d2,
             int *iy, int *im, int *id, int ihmsf[4]);
int iauDat(int iy, int im, int id, double fd, double *deltat);
double iauDtDb(double datel, double date2,
             double ut, double elong, double u, double v);
int iauDtf2d(const char *scale, int iy, int im, int id,
             int ihr, int imm, double sec, double *d1, double *d2);
int iauTaitt(double tail, double tai2, double *tt1, double *tt2);
int iauTaiutl(double tail, double tai2, double dta,
             double *ut11, double *ut12);
int iauTaiutc(double tail, double tai2, double *utc1, double *utc2);
int iauTcbtdb(double tcb1, double tcb2, double *tdb1, double *tdb2);
int iauTcggtt(double tcg1, double tcg2, double *tt1, double *tt2);
int iauTdbtcb(double tdb1, double tdb2, double *tcb1, double *tcb2);
int iauTdbtt(double tdb1, double tdb2, double dtr,
             double *tt1, double *tt2);
int iauTttai(double tt1, double tt2, double *tail, double *tai2);
int iauTttcg(double tt1, double tt2, double *tcg1, double *tcg2);
int iauTttDb(double tt1, double tt2, double dtr,
             double *tdb1, double *tdb2);
int iauTttutl(double tt1, double tt2, double dt,
             double *ut11, double *ut12);

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```

int iauUtltai(double ut11, double ut12, double dta,
             double *tail, double *tai2);
int iauUtltt(double ut11, double ut12, double dt,
             double *tt1, double *tt2);
int iauUtlutc(double ut11, double ut12, double dut1,
             double *utc1, double *utc2);
int iauUtctai(double utc1, double utc2, double *tail, double *tai2);
int iauUtcut1(double utc1, double utc2, double dut1,
             double *ut11, double *ut12);

/* VectorMatrix/AngleOps */
void iauA2af(int ndp, double angle, char *sign, int idmsf[4]);
void iauA2tf(int ndp, double angle, char *sign, int ihmsf[4]);
int iauAf2a(char s, int ideg, int iamin, double asec, double *rad);
double iauAnp(double a);
double iauAnpm(double a);
void iauD2tf(int ndp, double days, char *sign, int ihmsf[4]);
int iauTf2a(char s, int ihour, int imin, double sec, double *rad);
int iauTf2d(char s, int ihour, int imin, double sec, double *days);

/* VectorMatrix/BuildRotations */
void iauRx(double phi, double r[3][3]);
void iauRy(double theta, double r[3][3]);
void iauRz(double psi, double r[3][3]);

/* VectorMatrix/CopyExtendExtract */
void iauCp(double p[3], double c[3]);
void iauCpv(double pv[2][3], double c[2][3]);
void iauCr(double r[3][3], double c[3][3]);
void iauP2pv(double p[3], double pv[2][3]);
void iauPv2p(double pv[2][3], double p[3]);

/* VectorMatrix/Initialization */
void iauIr(double r[3][3]);
void iauZp(double p[3]);
void iauZpv(double pv[2][3]);
void iauZr(double r[3][3]);

/* VectorMatrix/MatrixOps */
void iauRxr(double a[3][3], double b[3][3], double atb[3][3]);
void iauTr(double r[3][3], double rt[3][3]);

/* VectorMatrix/MatrixVectorProducts */
void iauRxp(double r[3][3], double p[3], double rp[3]);
void iauRxpv(double r[3][3], double pv[2][3], double rpv[2][3]);
void iauTrxp(double r[3][3], double p[3], double trp[3]);
void iauTrxpv(double r[3][3], double pv[2][3], double trpv[2][3]);

/* VectorMatrix/RotationVectors */
void iauRm2v(double r[3][3], double w[3]);
void iauRv2m(double w[3], double r[3][3]);

/* VectorMatrix/SeparationAndAngle */
double iauPap(double a[3], double b[3]);
double iauPas(double a1, double ap, double b1, double bp);
double iauSepp(double a[3], double b[3]);
double iauSeps(double a1, double ap, double b1, double bp);

/* VectorMatrix/SphericalCartesian */
void iauC2s(double p[3], double *theta, double *phi);
void iauP2s(double p[3], double *theta, double *phi, double *r);
void iauPv2s(double pv[2][3],
            double *theta, double *phi, double *r,
            double *td, double *pd, double *rd);
void iauS2c(double theta, double phi, double c[3]);
void iauS2p(double theta, double phi, double r, double p[3]);
void iauS2pv(double theta, double phi, double r,
            double td, double pd, double rd,
            double pv[2][3]);

/* VectorMatrix/VectorOps */
double iauPdp(double a[3], double b[3]);
double iauPm(double p[3]);

```

```

void iauPmp(double a[3], double b[3], double amb[3]);
void iauPn(double p[3], double *r, double u[3]);
void iauPpp(double a[3], double b[3], double apb[3]);
void iauPpsp(double a[3], double s, double b[3], double apsb[3]);
void iauPvdpv(double a[2][3], double b[2][3], double adb[2]);
void iauPvm(double pv[2][3], double *r, double *s);
void iauPvmpv(double a[2][3], double b[2][3], double amb[2][3]);
void iauPvppv(double a[2][3], double b[2][3], double apb[2][3]);
void iauPvu(double dt, double pv[2][3], double upv[2][3]);
void iauPvup(double dt, double pv[2][3], double p[3]);
void iauPvxpv(double a[2][3], double b[2][3], double axb[2][3]);
void iauPxp(double a[3], double b[3], double axb[3]);
void iauS2xpv(double s1, double s2, double pv[2][3], double spv[2][3]);
void iauSxp(double s, double p[3], double sp[3]);
void iauSxpv(double s, double pv[2][3], double spv[2][3]);

#ifdef __cplusplus
}
#endif

#endif

/*-----
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\*\*  
\*\*-----\*/

```

#ifndef SOFAMHDEF
#define SOFAMHDEF

/*
** - - - - -
**   s o f a m . h
** - - - - -
**
** Macros used by SOFA library.
**
** This file is part of the International Astronomical Union's
** SOFA (Standards Of Fundamental Astronomy) software collection.
**
** Please note that the constants defined below are to be used only in
** the context of the SOFA software, and have no other official IAU
** status. In addition, self consistency is not guaranteed.
**
** This revision:   2013 August 27
**
** SOFA release 2016-05-03
**
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*/

/* Star-independent astrometry parameters */
typedef struct {
    double pmt;          /* PM time interval (SSB, Julian years) */
    double eb[3];       /* SSB to observer (vector, au) */
    double eh[3];       /* Sun to observer (unit vector) */
    double em;          /* distance from Sun to observer (au) */
    double v[3];        /* barycentric observer velocity (vector, c) */
    double bml;         /* sqrt(1-|v|^2): reciprocal of Lorentz factor */
    double bpn[3][3];   /* bias-precession-nutation matrix */
    double along;       /* longitude + s' + dERA(DUT) (radians) */
    double phi;         /* geodetic latitude (radians) */
    double xpl;         /* polar motion xp wrt local meridian (radians) */
    double ypl;         /* polar motion yp wrt local meridian (radians) */
    double sphl;        /* sine of geodetic latitude */
    double cphi;        /* cosine of geodetic latitude */
    double diurab;      /* magnitude of diurnal aberration vector */
    double eral;        /* "local" Earth rotation angle (radians) */
    double refa;        /* refraction constant A (radians) */
    double refb;        /* refraction constant B (radians) */
} iauASTROM;
/* (Vectors eb, eh, em and v are all with respect to BCRS axes.) */

/* Body parameters for light deflection */
typedef struct {
    double bm;          /* mass of the body (solar masses) */
    double dl;          /* deflection limiter (radians^2/2) */
    double pv[2][3];    /* barycentric PV of the body (au, au/day) */
} iauLDBODY;

/* Pi */
#define DPI (3.141592653589793238462643)

/* 2Pi */
#define D2PI (6.283185307179586476925287)

/* Radians to degrees */
#define DR2D (57.29577951308232087679815)

/* Degrees to radians */
#define DD2R (1.745329251994329576923691e-2)

/* Radians to arcseconds */
#define DR2AS (206264.8062470963551564734)

/* Arcseconds to radians */
#define DAS2R (4.848136811095359935899141e-6)

/* Seconds of time to radians */
#define DS2R (7.272205216643039903848712e-5)

```

```

/* Arcseconds in a full circle */
#define TURNAS (1296000.0)

/* Milliarcseconds to radians */
#define DMAS2R (DAS2R / 1e3)

/* Length of tropical year B1900 (days) */
#define DTY (365.242198781)

/* Seconds per day. */
#define DAYSEC (86400.0)

/* Days per Julian year */
#define DJY (365.25)

/* Days per Julian century */
#define DJC (36525.0)

/* Days per Julian millennium */
#define DJM (365250.0)

/* Reference epoch (J2000.0), Julian Date */
#define DJ00 (2451545.0)

/* Julian Date of Modified Julian Date zero */
#define DJM0 (2400000.5)

/* Reference epoch (J2000.0), Modified Julian Date */
#define DJM00 (51544.5)

/* 1977 Jan 1.0 as MJD */
#define DJM77 (43144.0)

/* TT minus TAI (s) */
#define TTMTAI (32.184)

/* Astronomical unit (m) */
#define DAU (149597870e3)

/* Speed of light (m/s) */
#define CMPS 299792458.0

/* Light time for 1 au (s) */
#define AULT 499.004782

/* Speed of light (AU per day) */
#define DC (DAYSEC / AULT)

/* L_G = 1 - d(TT)/d(TCG) */
#define ELG (6.969290134e-10)

/* L_B = 1 - d(TDB)/d(TCB), and TDB (s) at TAI 1977/1/1.0 */
#define ELB (1.550519768e-8)
#define TDB0 (-6.55e-5)

/* Schwarzschild radius of the Sun (au) */
/* = 2 * 1.32712440041e20 / (2.99792458e8)^2 / 1.49597870700e11 */
#define SRS 1.97412574336e-8

/* dint(A) - truncate to nearest whole number towards zero (double) */
#define dint(A) ((A)<0.0?ceil(A):floor(A))

/* dnint(A) - round to nearest whole number (double) */
#define dnint(A) ((A)<0.0?ceil((A)-0.5):floor((A)+0.5))

/* dsign(A,B) - magnitude of A with sign of B (double) */
#define dsign(A,B) ((B)<0.0?-fabs(A):fabs(A))

/* max(A,B) - larger (most +ve) of two numbers (generic) */
#define gmax(A,B) (((A)>(B))?(A):(B))

/* min(A,B) - smaller (least +ve) of two numbers (generic) */

```

```

#define gmin(A,B) (((A)<(B))?(A):(B))

/* Reference ellipsoids */
#define WGS84 1
#define GRS80 2
#define WGS72 3

#endif

/*-----
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**
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