Theoretical considerations on precession and nutation referred to the GCRS

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Resolutions of the XXIVth IAU GA 2000 concerning precession and nutation

- IAU Resolution B1.3
  Definition of BCRS and GCRS
- IAU Resolution B1.6
  IAU 2000 Precession-Nutation Model
- IAU Resolution B1.7
  Definition of Celestial Intermediate Pole
- IAU Resolution B1.8
  Definition and use of CEO and TEO

IAU Resolution B1.3 : Definition of Barycentric Celestial Reference System and Geocentric Celestial Reference System

The XXIVth International Astronomical Union General Assembly,

Considering

1. that the Resolution A4 of the XXIst General Assembly (1991) has defined a system of space-time coordinates for

   (a) the solar system

(now called the Barycentric Celestial Reference System, (BCRS)) and

   (b) the Earth

(now called the Geocentric Celestial Reference System (GCRS)),
within the framework of General Relativity,

……………………..

IAU Resolution B1.6 : IAU 2000 Precession-Nutation Model

The XXIVth International Astronomical Union General Assembly,

....

Recommends

***that**,* beginning on 1 January 2003,the IAU 1976 Precession Model and IAU 1980 Theory of nutation, be replaced by the precession-nutation model IAU2000A (MHB2000)

based on the transfer function of Mathews *et al* 2001 :

- IAU 2000 A for 0.2 mas level
- IAU 2000 B (its shorter version) for 1 mas level

together with their associated precession and obliquity rates and their associated celestial pole offsets to be published in the *IERS Conventions 2000*

IAU Resolution B1.7 : Definition of Celestial Intermediate Pole (CIP)

The XXIVth International Astronomical Union General Assembly, …………

Recommends

1. that the CIP be the pole, the motion of which is specified in the GCRS by motion of the Tisserand mean axis of the Earth with periods greater than two days,
2. that the direction of the CIP at J2000.0 be offset from the direction of the pole of the GCRS in a manner consistent with the IAU 2000A precession-nutation model,
3. that the motion of the CIP in the GCRS be realised by the IAU 2000 A model for precession and forced nutation for periods greater than two days plus additional time-dependent corrections provided by the IERS through appropriate astro-geodetic observations,
4. that the motion of the CIP in the ITRS be provided by the IERS through appropriate astro-geodetic observations and models including high-frequency variations,
5. that for highest precision, corrections to the models for the motion of the CIP in the ITRS may be estimated using procedures specified by the IERS, and
6. that implementation of the CIP be on 1 January 2003.

IAU Resolution B1.8 : Definition and use of Celestial and Terrestrial Ephemeris Origins

The XXIVth International Astronomical Union General Assembly,

Recognising

1. the need for reference system definitions suitable for modern realisations of the conventional reference systems and consistent with observational precision,
2. the need for a rigorous definition of sidereal rotation of the Earth,
3. the desirability of describing the rotation of the Earth independently from its orbital motion, and

Noting

that the use of the "non-rotating origin" (Guinot, 1979) on the moving equator fulfills the above conditions and allows for a definition of UT1 which is insensitive to changes in models for precession and nutation at the microarcsecond level

IAU Resolution B1.8 (continuation)

Recommends

1. **the use of the "non-rotating origin" in the GCRS** and that this point be designated as the Celestial Ephemeris Origin (CEO) on the equator of the Celestial Intermediate Pole (CIP),
2. **the use of the "non-rotating origin" in the ITRS** and that this point be designated as the Terrestrial Ephemeris Origin (TEO) on the equator of the CIP,
3. that **UT1 be linearly proportional to the Earth Rotation Angle** defined as the angle measured along the equator of the CIP between the unit vectors directed toward the CEO and the TEO,
4. that the **transformation between the ITRS and GCRS** be specified by the **position of the CIP in the GCRS**, the **position of the CIP in the ITRS**, and the **Earth Rotation Angle**,
5. that the International Earth Rotation Service (IERS) take steps to implement this by 1 January 2003, and
6. that the IERS will continue to provide users with data and algorithms for the conventional transformations.

- The IAU 2000 Resolutions concerning precession and nutation

- **Consequences of the IAU Resolutions for precession-nutation**

- Comparison between the characteristics of the 1980 and 2000 IAU models

- Further improvements needed

Consequences of IAU Resolution B1.3

- Clarification of IAU’s 1991 definition of the coordinate systems in the framework of GR for distinction between the celestial system for Solar Sytem or for the Earth

FK5 → GCRS to refer precession nutation parameters and Earth's angle of rotation

Consequences of IAU Resolution B1.6

The IAU 1976 Precession Model (Lieske *et al.* 1977) and IAU 1980 Theory of nutation (Seidelmann 1982), are replaced by the

IAU 2000 precession-nutation model based on :

- rigid Earth nutation model (Souchay *et al.* 1999)

- transfer function of Mathews *et al* 2001
  - IAU 2000 A for 0.2 mas level
  - IAU 2000 B (its shorter version) for 1 mas level

- associated precession and obliquity rates

- associated celestial pole offsets

(IERS Conventions 2000)

Consequences of IAU Resolution B1.7

New pole of reference : Change from the CEP to the CIP

- motion of the CIP in the GCRS is realized by the best precession nutation series (periods > 2 days) plus the celestial pole offsets :

→ *the pole is defined such that it can be realized by a model as accurately as necessary and be not dependent on the technique of observation*

The forced nutations with periods less than two days are included in the model for the motion of the CIP in the ITRS.

- motion of the CIP in the ITRS is provided by observations taking into account a predictable part specified by a model including high frequency variations : → *it sharpens the definition of the CEP by taking into account the high frequency variations of polar motion*

the corrections to the model for the motion of the CIP in the ITRF may be estimated by extracting the high frequency signal in the pole coordinates

Consequences of IAU Resolution B1.8

New EOP referred to the GCRS

- abandon the current parameters in the FK5 System → abandon the current formulation combining the motions of the equator and the ecliptic w.r. the ICRS

- include both precession and nutation in the new parameters

- not reckon the Earth's angle of rotation from the true equinox

- parameters : X, Y, origin on the moving equator : NRO (CEO)

- The IAU 2000 Resolutions concerning precession and nutation

- Consequences of the IAU Resolutions for precession-nutation

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- Further improvements needed

Changes from the IAU 1976/1980 to the IAU 2000 precession-nutation

- Change FK5 → GCRS
- Improvement in the theory of the Earth rotation
- Change CEP → CIP
- Change of parameters : z_A, ε_A, ζ_A, θ_A, $\Delta\psi$, $\Delta\varepsilon$ → X, Y
  + change of origin for the Earth's angle of rotation

  → X, Y = offsets from the pole of ICRS + accumulated precession
  + nutation + precession x nutation referred to the GCRS

  s → clear separation between precession-nutation and Earth's rotation

Change from FK5 to GCRS

- FK5-

- based on positions and proper motions of bright stars
  (precision : 0.02", 0.08"/c)
- the positions are referred to the best estimates of the location of the mean pole and mean equinox of epoch
- proper motions provide the best access to the mean pole and mean equinox of epoch (J2000) at any other date
- FK5 System = FK5 + IAU1976 precession + IAU 1980 nutation + GMST/UT1 relationship

- GCRS –

- ICRS based on barycentric directions of extragalactic objects (precision : 0.4 mas)
- GCRS follows the kinematical condition of absence of global rotation of geocentric directions wrt the objects defining the ICRS
- no reference to the mean pole and mean equinox J2000 → no longer dependent on the Earth's motion
  - → further improvement of the ICRF will be accomplished without introducing any global rotation
- GCRS is independent from precession-nutation models

Improvements in the Theory of Earth rotation

- Nutation model MHB2000
  - rigid Earth model (Souchay *et al*. 1999) + transfer function
    + estimation of geophysical parameters from VLBI observations
    + correction to the precession

- Diurnal and sub-diurnal nutations → polar motion
  - rigid Earth model : Bretagnon *et al.* 1998, Souchay *et al*. 1999, Roosbeck *et al*. 1999
  - non-rigid Earth model : Chao *et al.* 1991, Brzezinski *et al. 2001*, Mathews & Bretagnon 2001, ...

- Diurnal and sub-diurnal tidal variations (polar motion, Earth's rotation)
  - Wünsch &Seiler 1992, Dickmann 1992, Gross 1993,
  - Chao *et al.* 1991, Herring & Dong 1994

The new pole of reference (CIP) for precession/nutation

- The forced nutations with periods less than two days (prograde diurnal and prograde semi-diurnal nutations) are included in the model for the motion of the CIP in the TRS :

- prograde diurnal terms in nutation = long periodic prograde and retrograde variations of polar motion 27 d, ...) : 15 µas

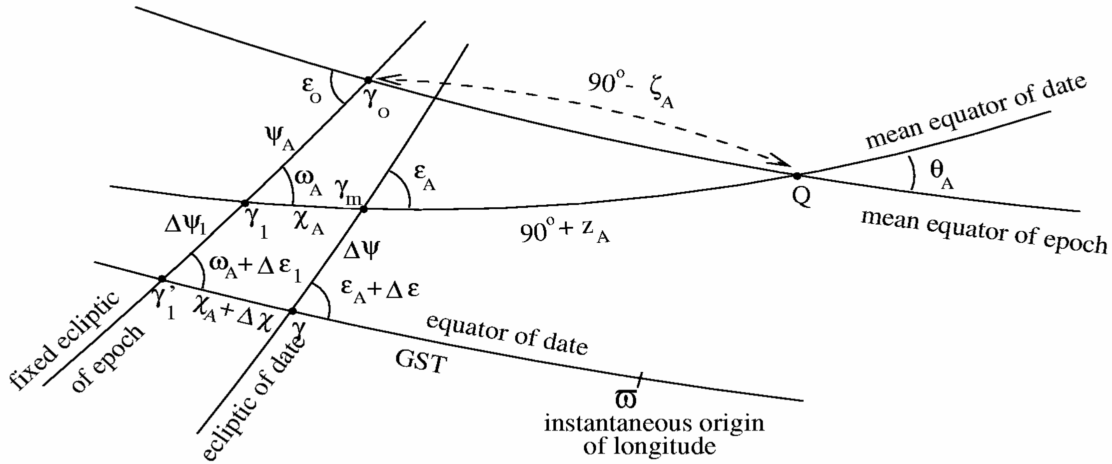
- prograde semi-diurnal terms in nutation = prograde diurnal variations of polar motion (polar libration) : 15 µas

Precession-nutation and Earth’s rotation in the FK5

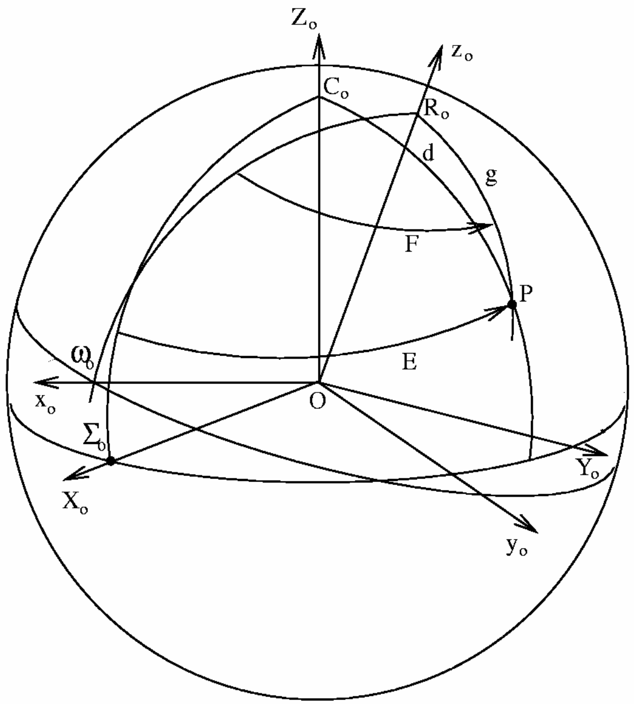
ε_A , ω_A , z_A , ζ_A , θ_A , ψ_A , χ_A : *precession* ; $\Delta\psi$, $\Delta\varepsilon$: *nutation*

GST : *Earth's rotation* + *precession* + *nutation* + *precession* x *nutation*

z_A, ε_A, χ_A , $\Delta\psi$, $\Delta\varepsilon$, GST : *referred to γ and to the ecliptic of date*



The coordinates of the CIP in the GCRS and ITRS

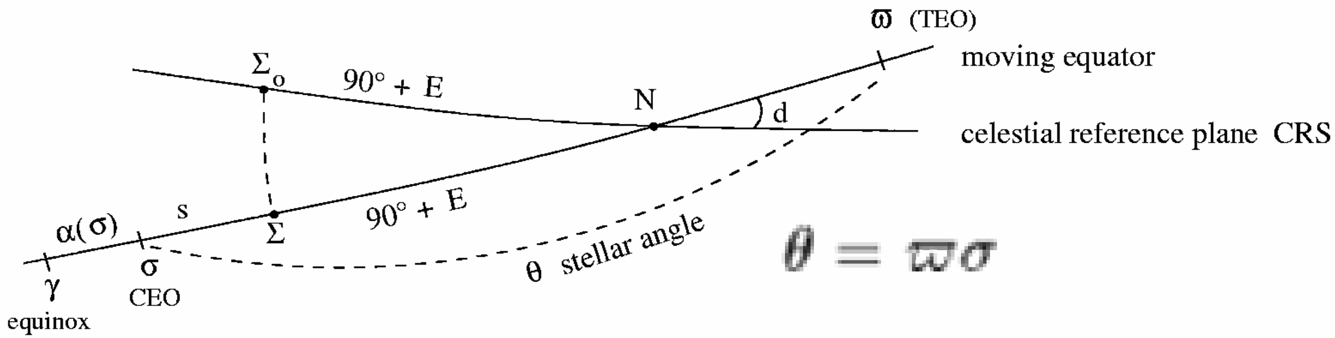


- use of an intermediate frame referred to the CIP (P) → the parameters clearly separate high frequency and low frequency motions
- reduce to 5 the parameters for transformation between ITRF ($Ox_oy_oz_o$) and GCRF ($OX_oY_oZ_o$) (Capitaine 1990) :
  - position of the CIP in the GCRS : E, d
  - position of the CIP in the ITRS : F, g
  - Earth's angle of rotation
- symmetric representation for the celestial and terrestrial parts of the motion :

$$PN(t) = R_3(-E).R_2(d).R_3(E) \quad (1)$$
$$W(t) = R_3(-F).R_2(g).R_3(F) \quad (2)$$

Realisation of the CEO

The position of the CEO in the GCRS is given by the quantity $s = \sigma\Sigma$ (3),
which can be given by a development as function of time (Capitaine *et al.* 2000)



$$\theta = \varpi\sigma$$

$$\dot{\theta} = \omega_3$$

Further improvements needed

- Solutions of Earth rotation theory referred to the GCRS
  The celestial coordinates X, Y of the CIP can be expressed as function of the parameters $\psi_A+\Delta\psi_1$, $\omega_A+\Delta\varepsilon_1$ referred to a fixed ecliptic as follows (Capitaine 1990), χ_0, ν_0 being the offset of the CIP at J2000 w.r.t the pole of the GCRS :

$$
\begin{aligned}
X = \sin d \cos E &= \chi_o + \sin(\omega_A + \Delta\epsilon_1)\sin(\psi_A + \Delta\psi_1) \\
Y = \sin d \sin E &= \eta_o + \sin\epsilon_o \cos(\omega_A + \Delta\epsilon_1) + \cos\epsilon_o \sin(\omega_A + \Delta\epsilon_1)\cos(\psi_A + \Delta\psi_1)\ , \quad (4)
\end{aligned}
$$

- Consistent theoretical developments for precession and nutation → with same precision and same solution

- Improvement of the estimated amplitudes of the « geophysical » nutations from VLBI observations