Recent International Recommendations on Reference Systems

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IAU Recommendations

1. Definition of Barycentric Celestial Reference System and Geocentric Celestial Reference System
2. IAU 2000 Precession-Nutation Model
3. Definition of Celestial Intermediate Pole
4. Definition and use of Celestial and Terrestrial Ephemeris Origin

Why?

- Existing definitions were not precise at the level of µseconds of arc
- Improved geophysical nutation model delivered by IAU/IUGG Working Group
- Defining astronomical observations not sensitive to the ecliptic

ICRS

"Old"

- FK5
- Unclear center, time tags
- Direction of the x axis close to dynamical equinox

"New"

- Realized by ICRF in the radio [HCRF, (epoch =1991.25) in the visual]
- barycentric with time tags in TCB
- Direction of the x axis close to dynamical mean equinox of J2000
- ICRF positions with respect to a fixed equator that does not move

Practical Concerns

- FK5 origin of right ascension is offset by 22 mas from the ICRS
- Can be considered equivalent for low-precision requirements

IAU 2000 Precession-Nutation Model

"Old"
- IAU 1976 Precession
- IAU 1980 Nutation
- Celestial Pole offsets provided by IERS

"New"
- IAU 2000 model beginning 1 January 2003
  - IAU 2000A at 0.2 mas level
  - shorter version IAU 2000B for 1 mas level
- Total nutation in longitude and obliquity with the exception of the Free Core Nutation (FCN)
- Software available to model expected FCN based on recent astronomical observations
- Celestial Pole offsets provided by IERS [Note that these are **different** from the "old" celestial pole offsets

Practical Concerns
- IAU 2000 models provide more accurate representation of motion of Earth's pole
- Use of proper celestial pole offsets makes "old" and "new" equivalent for most users
- Most low–accuracy applications ignore celestial pole offsets and FCN
- IERS provides both "old" and "new" celestial pole offsets

Celestial Pole

"Old"
- Celestial Ephemeris Pole defined by
  - IAU 1976 Precession
  - IAU 1980 Nutation
- Ambiguity in definition caused by observation of high-frequency nutation terms

"New"
- Motion specified in the GCRS by motion of axis of the Earth with periods greater than two days
- Direction at J2000.0 offset from the pole of the GCRS consistent with the IAU 2000 precession-nutation model
- Motion in GCRS realized by IAU 2000 model for precession and forced nutation for periods > two days + time-dependent corrections provided by IERS
- Motion in the International Terrestrial Reference System (ITRS) provided by the IERS through
  - astro-geodetic observations
  - models including high-frequency variations

Practical Concerns
- IERS continues to provide x, y representation of polar motion
- Nutations with periods < 2 days are considered using a model for the corresponding motion of the pole in the ITRS. Most applications can ignore them
  - Prograde diurnal nutations correspond to prograde and retrograde long periodic (13 d to 3300 d) variations in polar motion
  - Prograde semi-diurnal nutations correspond to prograde diurnal variations in polar motion.

Definition and use of Celestial and Terrestrial Ephemeris Origin

"Old"

- Equinox is the origin on the celestial equator
  - Equinox not well defined

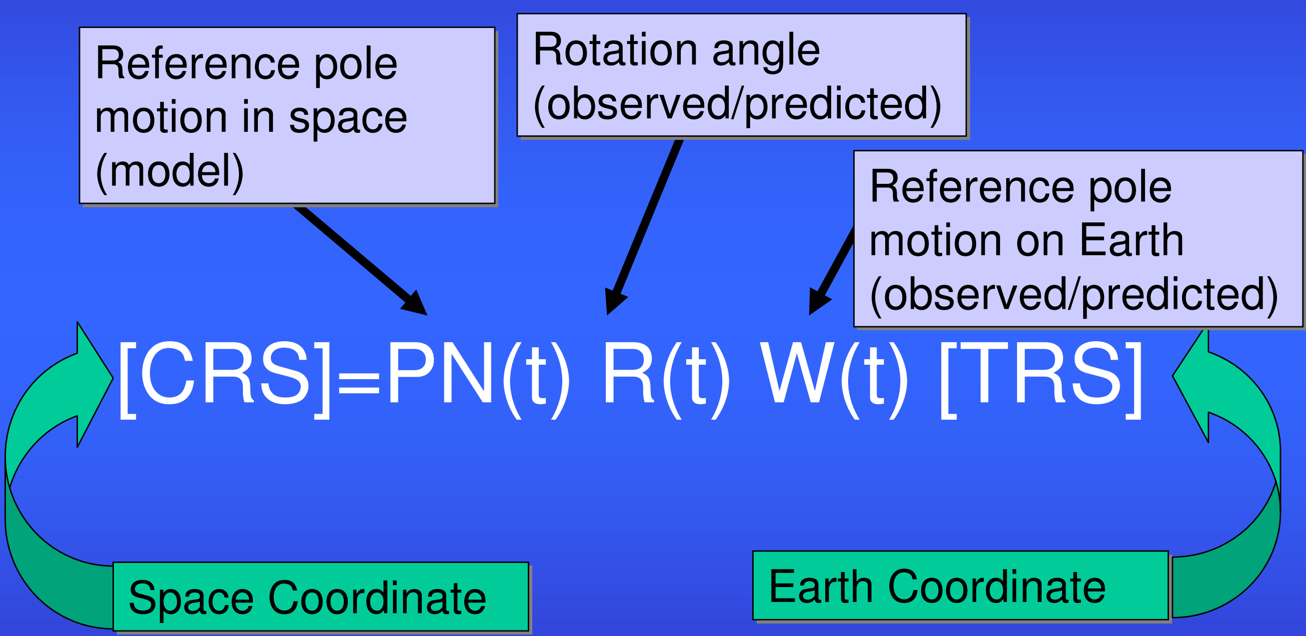
"New"

- Use of "non-rotating origin" in the GCRS
  - designated as the Celestial Ephemeris Origin (CEO) on equator of the CIP
- Use of "non-rotating origin" in the ITRS
  - designated as the Terrestrial Ephemeris Origin (TEO) on equator of CIP
- UT1 linearly proportional to the Earth Rotation Angle defined as angle measured along the equator of the CIP between unit vectors directed toward the CEO and the TEO
- Transformation between the Reference Systems specified by the position of the CIP in the GCRS, the position of the CIP in the ITRS and the Earth Rotation Angle

Practical Concerns

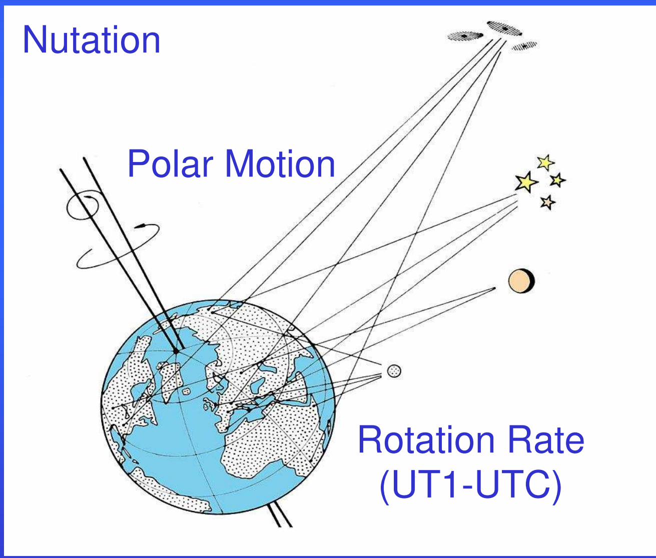
- Implementation
- Software

Transforming Coordinates

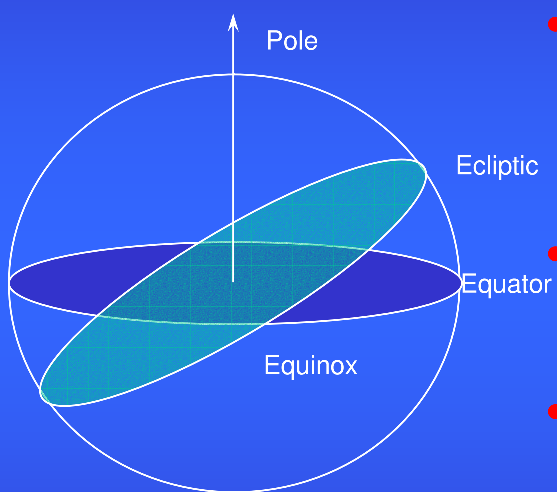


Earth Orientation Data

- Astronomical data to transform to Earth-centered, Earth-fixed frame from inertial frame



Traditional Procedure



- Uses Celestial Ephemeris Pole defined by IAU 1980 nutation/1976 Precession
- Equinox is the origin on the celestial equator
- IERS polar motion (and celestial pole offsets)

Problems:

- Equinox not well defined
- We have better precession and nutation model.

Motion of the Pole in the Celestial System

"Old"

$$PN(t) = [P][N]$$
$$[P] = R_3(\zeta_A)R_2(-\theta_A)R_3(z_A)$$
$$[N] = R_1(-\varepsilon_A)R_3(\Delta\psi)R_1(\varepsilon_A + \Delta\varepsilon)$$

where all quantities are provided as a function of time

- Free-core nutation model available from IERS (hundreds of μarcseconds)

"New"

$$PN(t) = \begin{pmatrix} 1-aX^2 & -aXY & X \\ -aXY & 1-aY^2 & Y \\ -X & -Y & 1-a(X^2+Y^2) \end{pmatrix} \bullet R_3(s)$$

where X and Y are the "coordinates" of the pole in the CRS and are provided as functions of time, and

$$a = \tfrac{1}{2} + \tfrac{1}{8}(X^2+Y^2)$$
$$s = -\tfrac{XY}{2} + f(t)$$

- Same free-core nutation model available from IERS

Software at http://maia.usno.navy.mil/ch5subs.html

- XYS2000A subroutine provides X, Y, s
- BPN2000 subroutine provides bias-precession-nutation matrix
- IAU2000A available at ftp://maia.usno.navy.mil/conv2000/chapter5/IAU2000A.f.
- IAU2000B is available at ftp://maia.usno.navy.mil/conv2000/chapter5/IAU2000B.f

CELESTIAL POLE OFFSET SERIES:

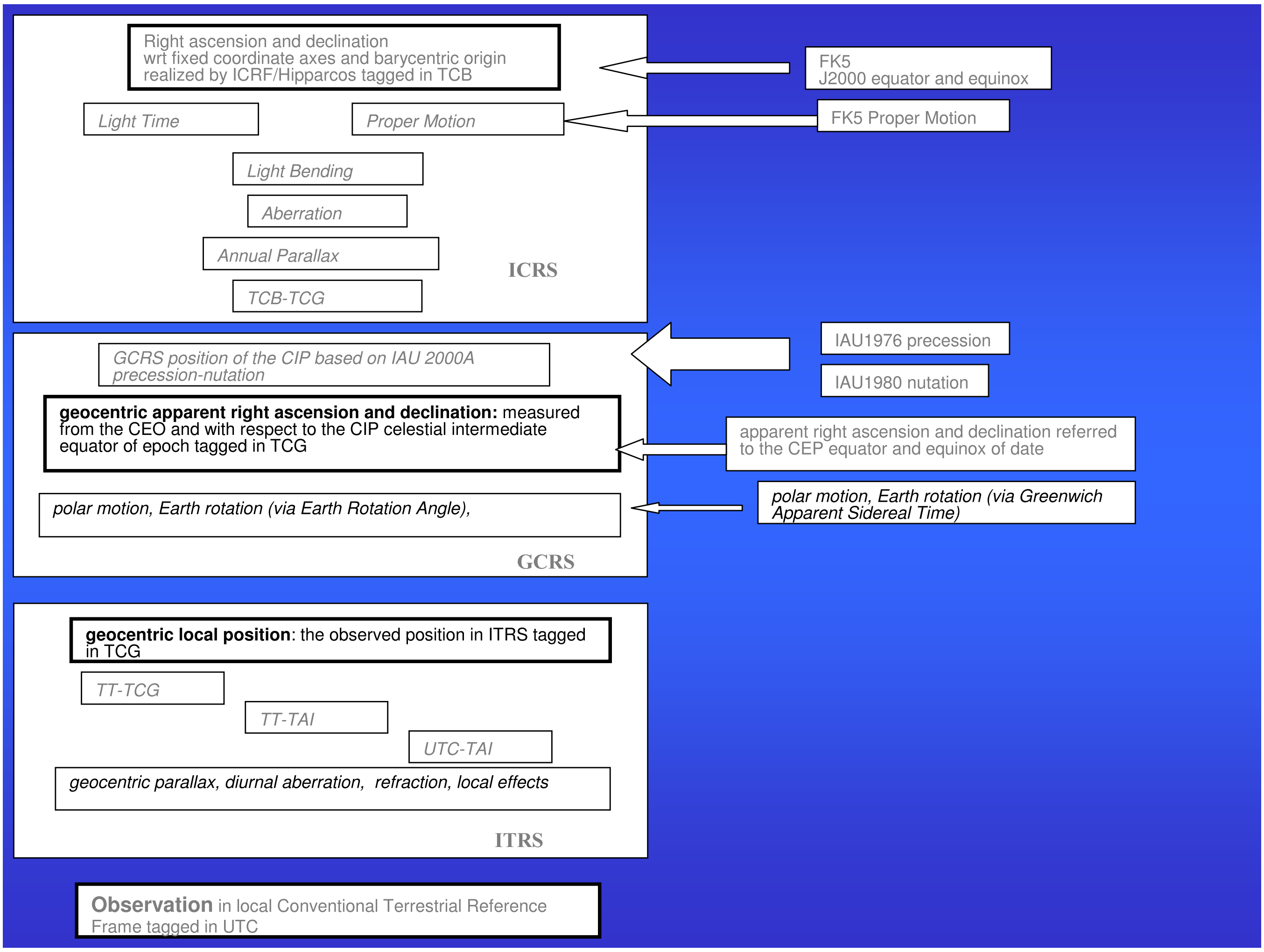
NEOS Celestial Pole Offset Series

MJD	dpsi	error	deps	error
	(msec. of arc)			
52664	-54.55	.36	-.93	.12
52665	-54.86	.40	-.82	.14
52666	-55.08	.40	-.71	.14
52667	-55.13	.18	-.66	.13
52668	-55.00	.15	-.69	.11
52669	-54.73	.15	-.82	.11
52670	-54.44	.15	-1.01	.11

NEW

IAU2000A Celestial Pole Offset Series

MJD	dX	error	dY	error
	(msec. of arc)			
52664	-0.186	0.143	-0.005	0.120
52665	-0.174	0.159	-0.002	0.140
52666	-0.165	0.159	0.020	0.140
52667	-0.158	0.072	0.039	0.130
52668	-0.161	0.060	0.042	0.110
52669	-0.161	0.060	0.015	0.110



IERS Conventions

posted on the web http://maia.usno.navy.mil/conv2003.html

Chapter 1 - Numerical Standards
Chapter 2 - Conventional Celestial Reference System and Frame
Chapter 3 - Conventional Dynamical Realization of the ICRS

- **Provides information concerning the retrieval and use of the DE405.**

Chapter 4 - Conventional Terrestrial Reference System and Frame

- **Information on ITRF2000.**
- **GCONV subroutine - Transforms geocentric coordinates to geodetic coordinates.**
- **ABSMO_Nuvel subroutine - Computes the new site position at time t from the old site position at time t0 using the recommended plate motion model.**

Chapter 5 - Transformation Between the Celestial and Terrestrial Systems

- **Chapter 5 Tables - Electronic versions of the tables for Chapter 5.**
- **Chapter 5 Subroutines - Electronic versions of the subroutines for Chapter 5.**

Chapter 6 - Geopotential

Chapter 7 - Site Displacement

- A FORTRAN subroutine to return the proper angular argument to be used with the Schwiderski phases.
- mean pole positions provided by the IERS Earth Orientation Centre (D. Gambis).
- site displacements due to atomspheric loading at specific sites; provided by T. vanDam.

Chapter 8 - Tidal Variations in the Earth's Rotation

- ortho_eop subroutine - Subdiurnal/Diurnal Subroutine.

Chapter 9 - Tropospheric Model

Chapter 10 - General Relativistic Models for Time, Coordinates and Equations of Motion

Chapter 11 - General Relativistic Models for Propagation

Glossary - List of acronyms used in the Conventions

Conclusions

- IAU recommendations provide improved precession-nutation model and definitions consistent with current observational accuracy
- Recommend use of IERS Conventions
- For reference system transformations recommend users move toward implementing IAU recommendations.
  - **Polar motion and UT1-UTC are the same in both procedures**
  - **IERS will continue to provide parameters necessary to implement current procedures.**