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

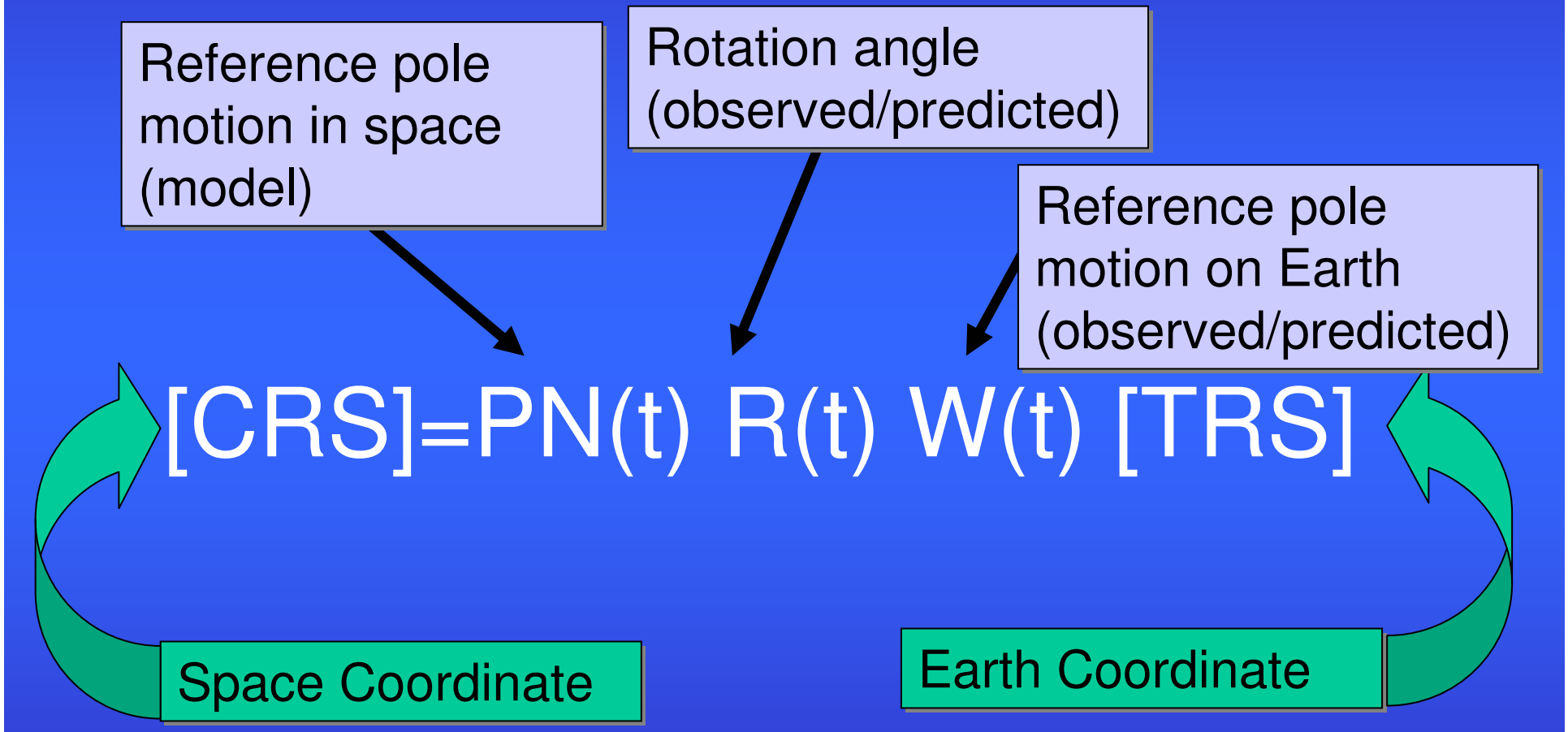
"New"

- 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

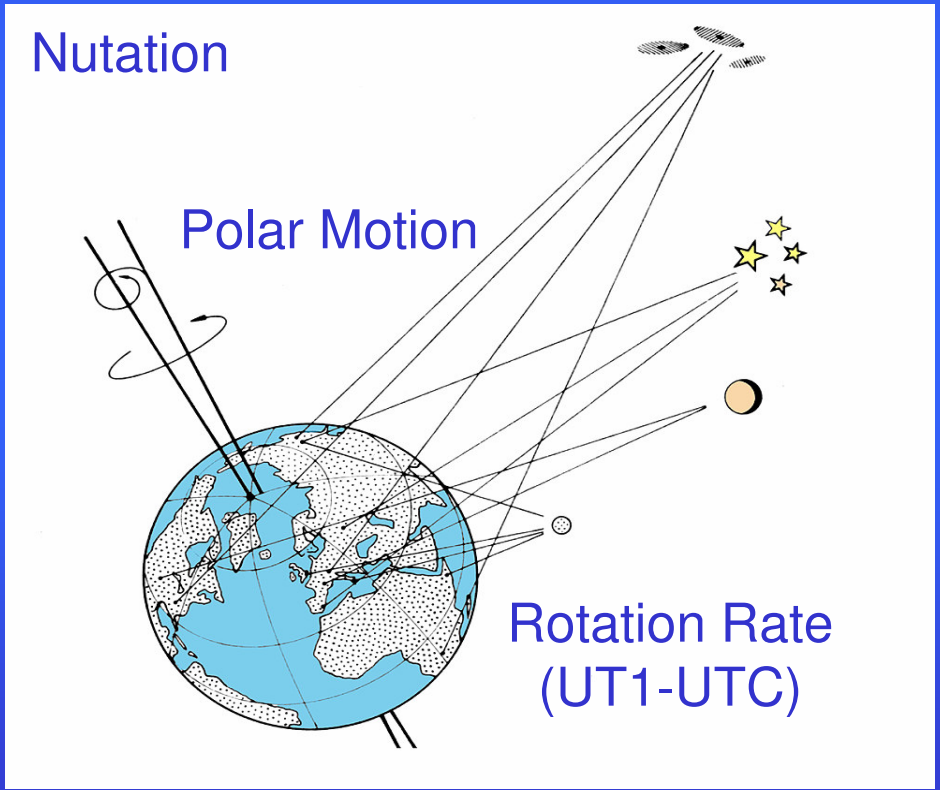
- Implementation
- Software

Transforming Coordinates

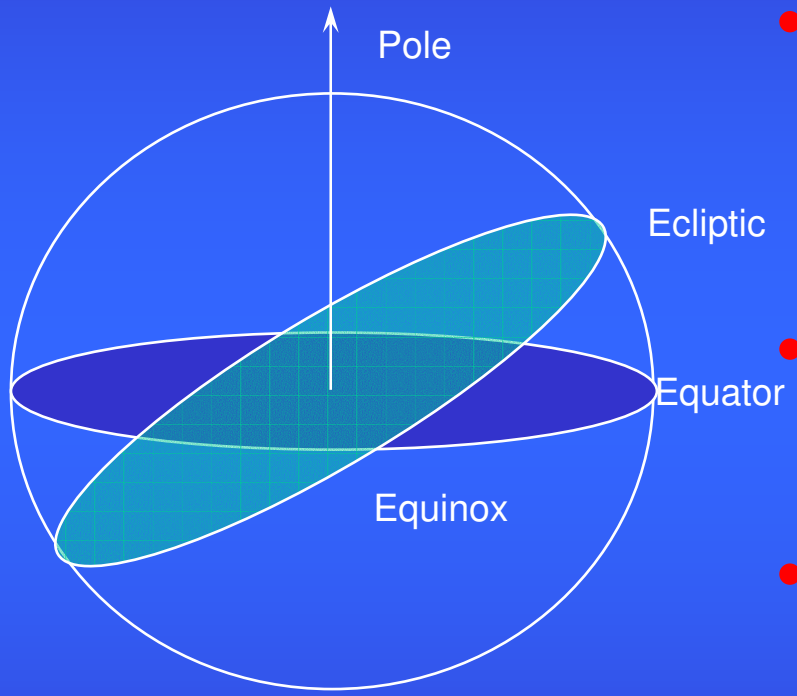


Earth Orientation Data

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



Traditional Procedure

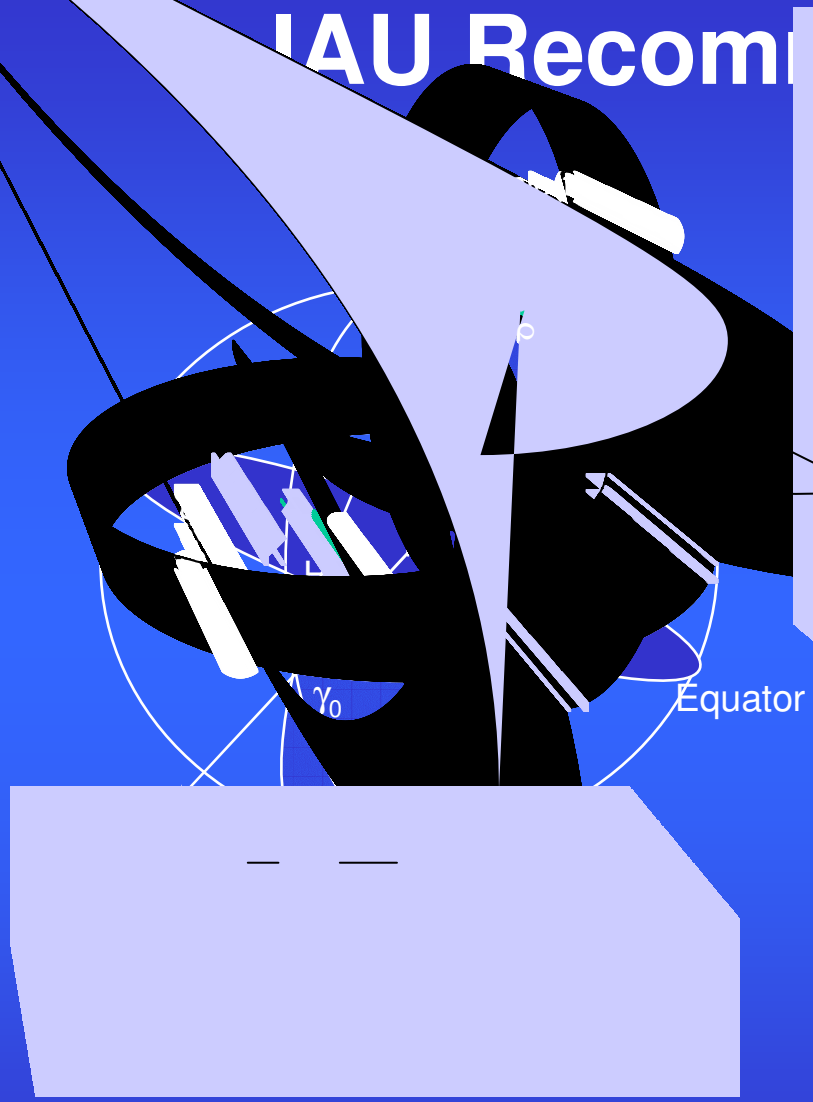


- Uses Celestial Ephemeris Pole defined by IAU 1980 nutation/1976 Precession
- Equinox is the origin on the celestial equator
- IERS polar motion (and celestial pole offsets)

Problems:

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

IAU Recom tion of 2000



- Celestial
  mediate Pole
  ed by IAU2000
  ession nutation
  -rotating" Origin on equator
- IERS polar motion (and *different* celestial pole offsets)

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:

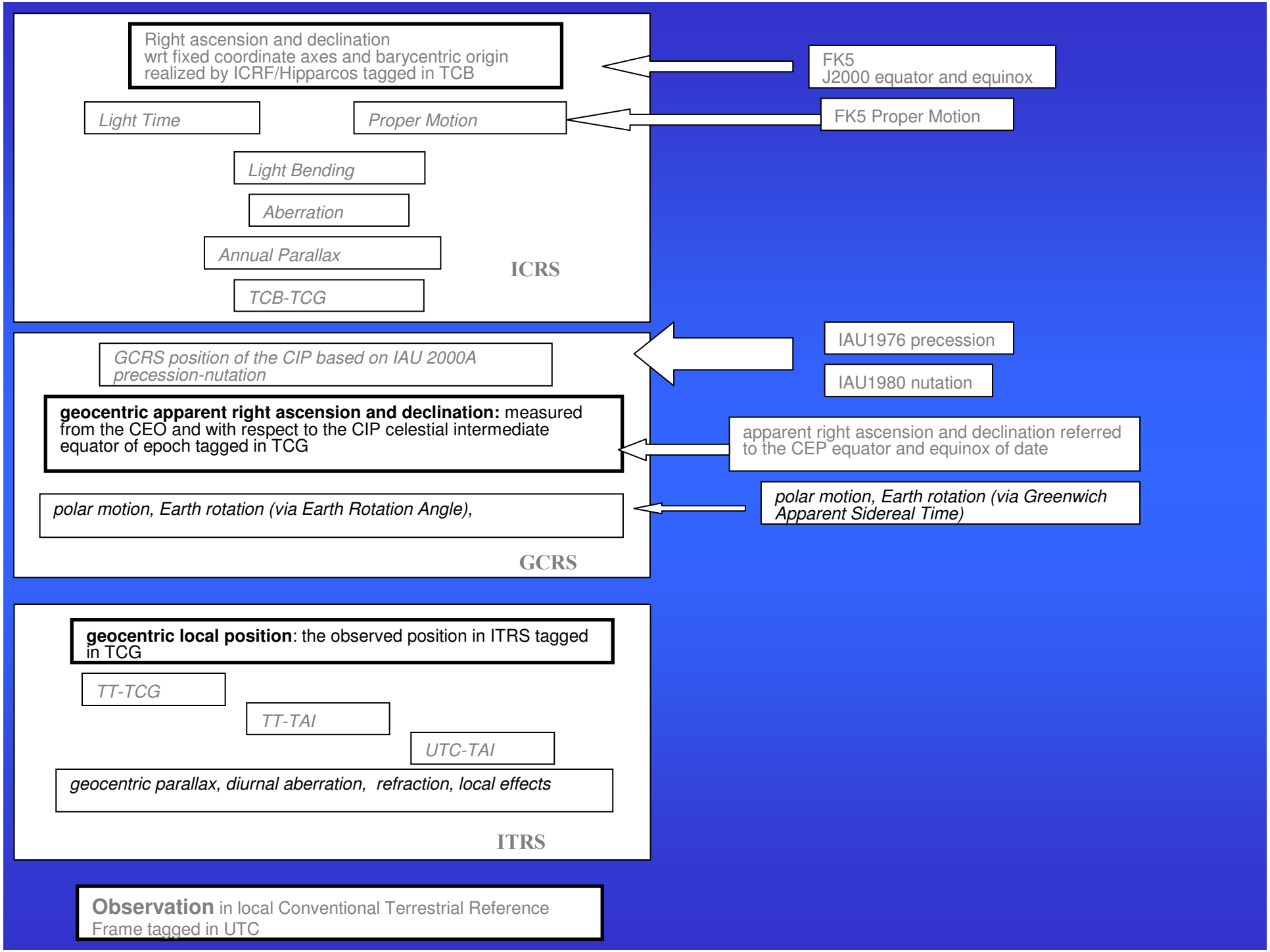
NEOS Celestial Pole Offset Series

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


Right ascension and declination
wrt fixed coordinate axes and barycentric origin
realized by ICRF/Hipparcos tagged in TCB
FK5
J2000 equator and equinox
Light Time
Proper Motion
FK5 Proper Motion
Light Bending
Aberration
Annual Parallax
TCB-TCG
ICRS
IAU1976 precession
IAU1980 nutation
GCRS position of the CIP based on IAU 2000A precession-nutation
geocentric apparent right ascension and declination: measured from the CEO and with respect to the CIP celestial intermediate equator of epoch tagged in TCG
apparent right ascension and declination referred to the CEP equator and equinox of date
polar motion, Earth rotation (via Earth Rotation Angle),
polar motion, Earth rotation (via Greenwich Apparent Sidereal Time)
GCRS
geocentric local position: the observed position in ITRS tagged in TCG
TT-TCG
TT-TAI
UTC-TAI
geocentric parallax, diurnal aberration, refraction, local effects
ITRS
Observation in local Conventional Terrestrial Reference Frame tagged in UTC

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.**