The IERS Conventions 2010: Reference Systems and New Models

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IERS Conventions

- Set of constants, models, and algorithms, used in the analysis of Earth orientation and reference systems data
- Assembled and verified by experts
- Strives to be consistent with IERS Products
  - ITRF, ICRF, EOPs
  - self-consistent
- Consistent (when possible) with international standards
- Failure to adhere to conventions results in systematic errors
  - i.e. Non-Gaussian noise

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Ch. 1: General definitions and numerical standards

- Provides definitions
  - e.g. permanent tide, zero tide, mean tide
- Provides numerical values for constants
- Change from Conventions (2003) to (2010)
  - Incorporates IAU (2009) Resolution B2
    - Recommendations of IAU Working Group for Numerical Standards of Fundamental Astronomy

Ch. 2: Conventional celestial reference system and frame

- Provides definitions
  - e.g. equator, origin of right ascension
- Provides realizations
  - ICRF2, HIPPARCOS Catalogue
- Change from Conventions (2003) to (2010)
  - Incorporates IAU (2009) Resolution B3
    - International Celestial Reference Frame (ICRF)2 adopted

Ch. 3: Conventional dynamical realization of the ICRS

- Provides dynamical realizations (i.e. ephemerides)
  - DE421, INPOP08, EPM2008
- Changes from Conventions (2003) to (2010)
  - Updated ephemerides

Ch. 4: Terrestrial reference systems and frames

- Provides basic concepts
- Provides realizations
  - ITRF2008
- Provides software
- Change from Conventions (2003) to (2010)
  - International Terrestrial Reference Frame (ITRF)2008 adopted

Ch. 5: Transformation between the ITRS and the GCRS

- Provides background
  - IAU resolutions
  - Theory
- Provides models
  - e.g. precession/nutation, diurnal/semidiurnal variations
- Provides software
- Changes from Conventions (2003) to (2010)
  - Modified to include new precession theory, libration theory, and to use terminology consistent with IAU recommendations

Ch. 6: Geopotential

- Provides conventional model
- Provides models for effects
  - e.g. solid Earth tide, solid Earth pole tide, treatment of the permanent tide, effect of the ocean tides
- Provide software
- Changes from Conventions (2003) to (2010)
  - Incorporates new geopotential model (EGM2008), new ocean tide model (FES2004), and ocean pole tide

Ch. 7: Displacement of reference points

- Provides models
  - e.g. ocean loading, solid Earth tides, permanent deformation, rotational deformation due to polar motion, atmospheric loading, VLBI Antenna thermal deformation, GNSS antenna phase center offset and variations
- Provides software
- Changes from Conventions (2003) to (2010)
  - new sections on atmospheric pressure loading and non-tidal displacement of reference markers

Ch. 8: Tidal variations in the Earth's rotation

- Provides model
  - e.g. solid earth tide
- Provides software
- Changes from Conventions (2003) to (2010)
  - Modified solid Earth tide model and software to account for additional geophysical effects

Ch. 9: Models for atmospheric propagation delays

- Provides models
  - e.g. troposphere delay (both radio and optical), troposphere horizontal gradients, ionosphere delay
- Provides software
- Changes from Conventions (2003) to (2010)
  - Uses new zenith delay/mapping function and a new section on ionospheric delay

Ch. 10: General relativistic models for space-time coordinates and equations of motion

- Provides theory
  - e.g. time coordinates, equations of motion
- Provides software
- Changes from Conventions (2003) to (2010)
  - New TDB definition, new TCB – TCG transformation, revised to include a new section on the transformation between proper time and coordinate time in the vicinity of Earth

Ch. 11: General relativistic models for propagation

- Provides theory
  - E.g. VLBI time delay, laser ranging theory
- No significant changes from Conventions (2003) to (2010)

Appendices

- App. A: IAU NFA WG Recommendations
- App. B: IAU Resolutions Adopted at the XXVIth General Assembly (2006)
- App. C: IUGG Resolution 2 Adopted at the XXVIth General Assembly (2007)
- App. D: IAU Resolutions Adopted at the XXVIIth General Assembly (2009)
- Glossary

General Improvements

- Define classification of models and criteria for choosing models
- Include magnitude of modeled effects
- Better consistency
- Improved software standardization
  - New software template
  - Improved documentation
  - Improved robustness of code
  - Include test cases
- Closer cooperation with the IAU Standards of Fundamental Astronomy (SOFA) software

Future Changes

- Update as needed
  - GPT and other "utility routines"
  - Diurnal and semidiurnal EOP variations
  - Issue of conventional mean pole to be reviewed
  - Ionosphere correction to ray bending
  - Resolve geocenter issues
- Expand
  - Models for the displacement of reference points of instruments
  - Section on ranging techniques
- New topics, following the evolution in the geodetic community
  - Non-tidal loading
  - SINEX format for modeling
- Others?

Impact of Specific Changes

Table 0.1: Estimates of accuracy of reference frames

Ch.	Reference frame	Conventions 2003	Conventions 2010	Accuracy & difference/improvement between Conventions
2	celestial reference system & frame	ICRF-Ext.1	ICRF-2	Noise floor $\approx$ 40 μas (5 times better than ICRF-Ext.1). Axis stability $\approx$ 10 μas (twice as stable as ICRF-Ext.1). From 717 to 3414 total objects; from 212 to 295 "defining" sources
3	dynamical realization of ICRS	DE405	DE421	From 1 mas to 0.25 mas for alignment to ICRF
4	terrestrial reference system & frame	ITRF2000	ITRF2008	Accuracy over 1985-2008: 1 cm in origin, 1.2 ppb in scale. Most important systematic difference vs. ITRF2000: drift in z-direction by 1.8 mm/yr.

Impact of Specific Changes

Sec.	Cl.	Phenomenon	Amplitude of effect	Conventions 2003	Conventions 2010	Accuracy & difference/improvement between Conventions
5	**Transformation between the ITRS and GCRS**					
5.5.1	1	libration in polar motion	tens of μas	No specific routine	Brzezinski PMSDNUT2 model	Specific routine
5.5.3	1	libration in the axial component of rotation	several μs in UT1	Not available	Brzezinski & Capitaine (2003) UTLIBR model	New model
5.5.4	1	precession-nutation of the CIP	tens of as/yr and tens of as for the periodic part in X and Y	IAU2000 PN	IAU2006/2000 PN	100 μas/c. + 7 mas/c.^{2} in X; 500 μas/c. in Y
5.5.5	3	FCN	Few hundred μas	not available	Lambert model	Accuracy: 50 μas rms, 100 μas at one year extrapolation
5.5.6	1	space motion of the CIO	mas/c.	IAU2000 PN	IAU2006/2000 PN	no change larger than 1 μas after one century
6	**Geopotential**					
6.1	1	Global geopotential model	10^{-3} of central potential	EGM96	EGM2008; C20 and rates of low degree coefs from other sources	EGM96: degree and order 360; EGM2008: complete to degree and order 2159; rate terms for low degree coefs.
6.2	1	Solid Earth tides	10^{-8} on C_{2m}, 10^{-12} on C_{3m}, C_{4m}	Eanes *et al.*, 1983; Mathews *et al.*, 2002	Unchanged	No change
6.3	1	Ocean tides	For LEO orbit integration: decimetric over 1 day	CSR 3.0	FES2004; Treatment of secondary waves specified	Effect of new model for LEO / MEO: few mm over several days integration; Treatment of secondary waves for LEO: 20% of total effect

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Impact of Specific Changes

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6.4	1	Solid Earth pole tide	10^{-9} on C_{21}, S_{21}	Centrifugal effect vs. conventional mean pole (2003)	Centrifugal effect vs. conventional mean pole (2010)	Change of conventional mean pole: effect of a few 10^{-11} on C_{21}, S_{21}
6.5	1	Ocean pole tide	Few 10^{-11} on low degree coefs	Not available	Desai (2002)	New model
7	**Displacement of reference points**					
7.1.1	1	Solid Earth tides	decimetric	Conventional routine from Dehant & Mathews	Unchanged	No change
7.1.2	1	Ocean loading	centimetric	Loading response from Scherneck (several tide models); no conventional implementation.	Loading response from Scherneck (several tide models); Implementation by Agnew software (342 constituent tides)	
7.1.3	1	S1-S2 Atmospheric pressure loading	millimetric	not available	Implementation of Ray & Ponte (2003) by vanDam	New model
7.1.4	1	Conventional mean pole	Hundreds of mas	linear model	cubic model from 1976.0 until 2010.0; linear model after 2010.0	tens of mas.
7.1.4	1	Pole tide	2 cm radial, few mm tangential	Centrifugal effect vs. conventional mean pole (2003)	Centrifugal effect vs. conventional mean pole (2010)	Change of conventional pole: effect may reach 1 mm
7.1.5	1	Ocean pole tide loading	2 mm radial, < 1 mm tangential	Not available	Desai (2002)	New model
7.3.1	3	Reference points of instruments: effect of temperature and pressure	~ 1 mm	Not specified	Reference temperature and pressure: GPT model, Boehm *et al.* (2007)	Between using average *in situ* temperature measurements and GPT: < 0.5 mm site height change due to antenna thermal deformation
7.3.2	1	Thermal deformation of VLBI antenna	> 10 ps on VLBI delay, several mm variation in coordinates	Nothnagel *et al.* (1995)	Nothnagel (2009)	Reference temperatures defined according to GPT model; reduction in annual scale variations of about 1 mm
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Impact of Specific Changes

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7.3.3	1	GNSS antenna phase center offsets and variations	decimetric	Not specified	Schmid *et al.* (2007)	10^{-9} on scale; tropospheric zenith delay and GPS orbit consistency improved
8	**Tidal variations in the Earth's rotation**					
8.1	3	Zonal tides on UT1	785 μs at M_f	Defraigne and Smits (1999) 62 terms	Combination of Yoder *et al.* (1981) elastic body tide, Wahr and Bergen (1986) inelastic body tide, and Kantha *et al.* (1998) ocean tide models	6 μs at M_f
8.2	1	Subdaily tides	$\sim$ 0.5 μas for PM $\sim$ 0.05 ms for UT1	Ray *et al.* (1994); conventional implementation by Eanes	No change	No change
8.3	3	long-period tides, polar motion	(pro-grade,retrograde) polar motion amplitude of (66, 74) μas at M_f	Not available	Dickman and Nam (1995), Dickman and Gross (2009)	(prograde, retrograde) polar motion amplitude of (66, 74) μas at M_f
9	**Models for atmospheric propagation delays**					
9.1	1	Troposphere; optical	$\sim$ 2.2 m at zenith to $\sim$ 14 m at 10° above horizon	Marini and Murray (1973)	Mendes and Pavlis (2004) zenith delay; Mendes and Pavlis (2003) "Fcul" mapping function (MF)	more accurate delays below 20° elevation and all the way to 3° above horizon; accurate to $\sim$ 7 mm (Total error due to ZTD and MF)
9.2	1	Troposphere; radio	Hydrostatic zenith delays $\sim$ 2.3 m Wet zenith delays typically $\sim$ 10–150 mm	Several MF *e.g.* Neill (1996) or Lanyi (1984)	MF: VMF1 based on 6-hour ECMWF data. GMF based only on latitude, site height, time of year (Boehm *et al.*, 2006)	Both VMF1 and GMF remove latitude-dependent mapping function bias (average $\sim$ 4 mm in site height). VMF1 reduces short-term vertical scatter (average $\sim$ 4–5 mm)
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Impact of Specific Changes

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9.2	1	Troposphere; horizontal gradients	can lead to systematic errors in the scale of estimated TRF at level of ~ 1 ppb	Not available	J. Boehm APG a priori model	New model
9.4	1	Ionosphere; radio: First order term	can reach 100 ns for GPS	Not available	Sources for Vertical TEC + conventional mapping function	New model
9.4	1	Ionosphere; radio: Higher order terms for dual-frequency	can reach 100 ps for GPS; a few ps for wide-band VLBI	Not available	Conventional model based on Slant TEC + Magnetic field model	New model
10	**General relativistic models for spacetime coordinates and equations of motion**					
10.1	2	Time coordinates	TCB, TDB in barycentric; TCG, TT in geocentric	IAU1991-IAU2000	IAU1991-IAU2000; IAU2006 TDB definition	New TDB definition
10.1	1	TCB-TCG transformation	1.5 ms annual; 2 μs diurnal on Earth	FB2001; TE405; HF2002	HF2002_IERS	HF2002_IERS vs. HF2002: 1.15×10^{-16} in rate;
10.2	1	transformation between proper time and coordinate time near Earth	GNSS: frequency shift of $\sim$ 4-5$\times 10^{-10}$ + periodic term of several tens of ns	Not specified	Conventional GNSS model specified; Information on next most significant term.	New model
11	**General relativistic models for propagation**					
11.1	1	VLBI delay	tens of ms	conventional 'consensus' model	no change	Uncertainty of model: 1 ps
11.2	1	time of propagation for ranging techniques	up to a few s	conventional model	no change	Uncertainty of model: 3 ps

Electronic Conventions

- IERS Conventions (2010) available at http://tai.bipm.org/iers/conv2010/conv2010.html
- Copy also available at http://maia.usno.navy.mil/conv2010/conventions.html
- Updates to IERS Conventions 2010 available at http://tai.bipm.org/iers/convupdt/convupdt.html

Backups