REFAG 2010 Session 1, October 7

The IERS Conventions (2010)

the new reference edition of the IERS Conventions

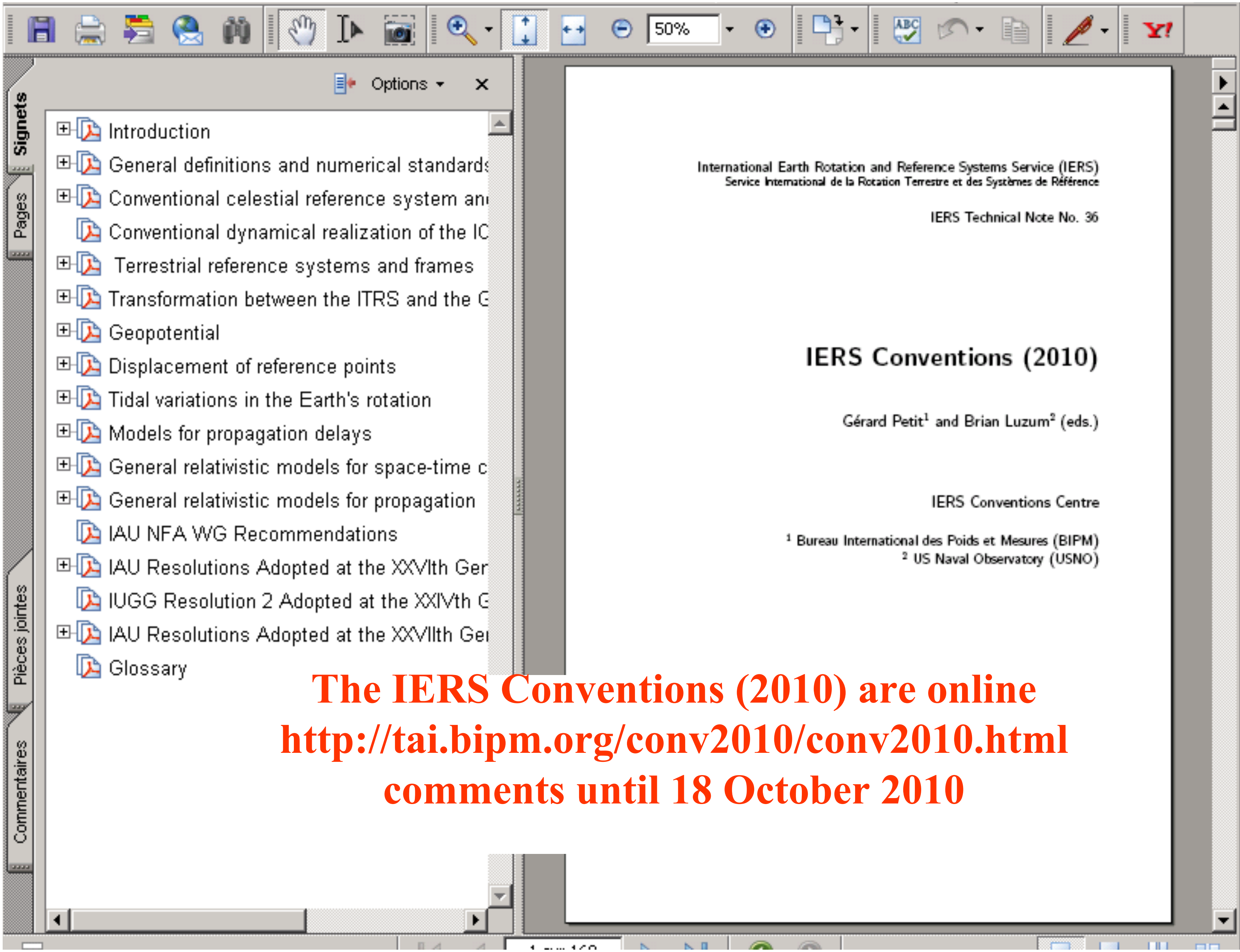
G. Petit and B. Luzum

IERS Conventions Center

BIPM

International Earth Rotation and Reference Systems Service

USNO



The IERS Conventions (2010) are online

http://tai.bipm.org/conv2010/conv2010.html

comments until 18 October 2010

Workshop on the IERS Conventions: September 2007

See http://www.bipm.org/en/events/iers/

Main topics covered:

Classification of models

Criteria for choosing models

Non tidal loading effects

New models

Possible additions to the Conventions

Technique-dependent effects

Terminology concerning reference systems

Electronic diffusion of the Conventions, including software

The next registered edition was then planned for (end) 2009

Main features of the IERS Conventions (2010) (1)

Chapters and history of updates on http://tai.bipm.org/iers/convupdt/convupdt.html

- Introduction
  - Rewritten (October 2010): Classification of models
- Ch. 1 (General definitions and numerical standards):
  - Rewritten (April 2010): Numerical standards
- Ch. 2 (Conventional celestial reference system and frame):
  - Rewritten (September 2010): ICRF-2
- Ch. 3 (Conventional dynamical realization of the ICRS):
  - Rewritten (April 2010): DE421
- Ch. 4 (Terrestrial reference systems and frames):
  - Rewritten (April 2009): ITRF2005
  - ITRF2008 (September 2010)
- Ch. 5 (Transformation between the ITRF and GCRS):
  - FCN model (October 2007)
  - Completely rewritten (June 2009): to implement IAU 2000-2006 resolutions and corresponding terminology
  - Introduction of librations (July 2010)

Main features of the IERS Conventions (2010) (2)

- Ch. 6 (Geopotential):
  - Ocean pole tide (March 2006)
  - New conventional geopotential model (April 2010)
  - Ocean tides (September 2010)
- Ch. 7 (Displacement of reference points):
  - Ocean pole tide loading (September 2006)
  - Conventional ocean tide loading (November 2006)
  - Technique-dependent effects (February 2009)
  - New conventional mean pole (April 2010), also Chapter 6
  - Reorganize chapter; S1-S2 atmosphere pressure loading (September 2010)
- Ch. 8 (Tidal variations in the Earth's rotation):
  - New model for zonal tides (March 2010)
- Ch. 9 (Models for atmospheric propagation delays):
  - Optical: New model (June 2007)
  - Radio: New conventional mapping function (June 2007); new section on ionosphere (February 2009). A priori gradients (September 2010).
- Ch. 10 (General relativistic models for space-time coordinates and equations of motion):
  - New section, implementation of IAU recommendations (October 2008)
- Ch. 11 (General relativistic models for propagation):
  - Minor changes (August 2010)

Updating the IERS Conventions (2010)

Some topics envisioned, but not yet covered

- Ch. 7 (Displacement of reference points):
  - 7.2 Other non-conventional displacements of reference markers ….
    - Loading effects **Volunteers needed**
  - 7.3 Displacement of reference points of instruments ….To be completed e.g.
    - Gravitational sag
    - Thermal expansion of monuments / bedrock
    - SLR biases
    - etc…
    - Details to be given in documentation provided by Technique centers

- Ch. 8 (Tidal Variations in the Earth's Rotation):
  - New model for diurnal and semidiurnal EOP variations

The IERS Conventions (2010): other work

- Software associated with conventional models
  - Provide documentation and test cases
  - IERS Conventions Software License included (consistent with SOFA)

- Conventions document to be fully cross-referenced.

- Glossary assembled, based *verbatim* on existing material
  - mostly based on the IAU Division I Working Group “Nomenclature for Fundamental Astronomy (NFA)” at http://syrte.obspm.fr/iauWGnfa/NFA_Glossary.html

- Web page on "additional material"
  - http://tai.bipm.org/iers/convupdt/convupdt_aux.html
  - To be expanded as needed

Conclusions

- **IERS Conventions (2010) now available**
  - Thanks to the « Advisory Board for the IERS Conventions update » chaired by Jim Ray and to the many colleagues who contributed.
  - Additional material available on the web
- IERS Conventions updates will continue, starting from the version (2010)
  - Past history of changes will be kept

Thank you

Numerical standards

- Revised to be consistent with the IAU (2009) System of Astronomical Constants and with the recommendations of IAU Commission 52

Tables reformatted

to improve readability

Table 1.1: IERS numerical standards.

Constant	Value	Uncertainty	Ref.	Description
	Natural defining constants			
c	$299792458 \text{ ms}^{-1}$	Defining	[1]	Speed of light
	Auxiliary defining constants			
k	$1.720209895 \times 10^{-2}$	Defining	[2]	Gaussian gravitational constant
L_G	$6.969290134 \times 10^{-10}$	Defining	[3]	1−d(TT)/d(TCG)
L_B	$1.550519768 \times 10^{-8}$	Defining	[4]	1−d(TDB)/d(TCB)
TDB_0	-6.55×10^{-5} s	Defining	[4]	TDB−TCB at JD 2443144.5 TAI
θ_0	0.7790572732640 rev	Defining	[3]	Earth Rotation Angle (ERA) at J2000.0
$d\theta/dt$	1.00273781191135448 rev/UT1day	Defining	[3]	Rate of advance of ERA
	Natural measurable constant			
G	$6.67428 \times 10^{-11} \text{ m}^3\text{kg}^{-1}\text{s}^{-2}$	$6.7 \times 10^{-15} \text{ m}^3\text{kg}^{-1}\text{s}^{-2}$	[1]	Constant of gravitation
	Body constants			
$GM_\odot{}^{\#}$	$1.32712442099 \times 10^{20} \text{ m}^3\text{s}^{-2}$	$5 \times 10^{10} \text{ m}^3\text{s}^{-2}$	[5]	Heliocentric gravitational constant
$J_{2\odot}$	2.0×10^{-7}	(adopted for DE421)	[5]	Dynamical form factor of the Sun
μ	0.0123000371	4×10^{-10}	[6]	Moon-Earth mass ratio
	Earth constants			
$GM_\oplus{}^{\dagger}$	$3.986004418 \times 10^{14} \text{ m}^3\text{s}^{-2}$	$8 \times 10^{5} \text{ m}^3\text{s}^{-2}$	[7]	Geocentric gravitational constant
$a_E{}^{\dagger\ddagger}$	6378136.6 m	0.1 m	[8]	Equatorial radius of the Earth
$J_{2\oplus}{}^{\ddagger}$	1.0826359×10^{-3}	1×10^{-10}	[8]	Dynamical form factor
$1/f^{\ddagger}$	298.25642	0.00001	[8]	Flattening factor of the Earth
$g_E{}^{\dagger\ddagger}$	$9.7803278 \text{ ms}^{-2}$	$1 \times 10^{-6} \text{ ms}^{-2}$	[8]	Mean equatorial gravity
W_0	$62636856.0 \text{ m}^2\text{s}^{-2}$	$0.5 \text{ m}^2\text{s}^{-2}$	[8]	Potential of the geoid
$R_0{}^{\dagger}$	6363672.6 m	0.1 m	[8]	Geopotential scale factor ($GM_\oplus/W_0$)
H	3273795×10^{-9}	1×10^{-9}	[9]	Dynamical flattening
	Initial value at J2000.0			
ϵ_0	$84381.406''$	$0.001''$	[4]	Obliquity of the ecliptic at J2000.0
	Other constants			
$au^{\dagger\dagger}$	$1.49597870700 \times 10^{11}$ m	3 m	[6]	Astronomical unit
L_C	$1.48082686741 \times 10^{-8}$	2×10^{-17}	[3]	Average value of 1−d(TCG)/d(TCB)

\# TCB-compatible value, computed from the TDB-compatible value in [5].

† The value for $GM_\oplus$ is TCG-compatible. For a_E, g_E and R_0 the difference between TCG-compatible and TT-compatible is not relevant with respect to the uncertainty.

‡ The values for a_E, $1/f$, $J_{2\oplus}$ and g_E are "zero tide" values (see the discussion in section 1.1 above). Values according to other conventions may be found in reference [8].

†† TDB-compatible value. An accepted definition for the TCB-compatible value of au is still under discussion.

Conventional geopotential model

- Based on EGM2008 (Pavlis et al. 2008)
  - Complete to degree and order 2159

Table 6.1: Suggested truncation levels for use of EGM2008 at different orbits

Orbit radius / km	Example	Truncation level
7331	Starlette	90
12270	Lageos	20
26600	GPS	12

- Low-order coefficients and rates adapted from different sources

Table 6.2: Low-degree coefficients of the conventional geopotential model

Coefficient	Value at 2000.0	Reference	Rate / yr^{-1}	Reference
$\bar{C}_{20}$ (zero-tide)	-0.48416948×10^{-3}	Cheng *et al.*, 2010	11.6×10^{-12}	Nerem *et al.*, 1993
$\bar{C}_{30}$	0.9571612×10^{-6}	EGM2008	4.9×10^{-12}	Cheng *et al.*, 1997
$\bar{C}_{40}$	0.5399659×10^{-6}	EGM2008	4.7×10^{-12}	Cheng *et al.*, 1997

- $C_{21}(t)$ and $S_{21}(t)$ designed to provide a mean figure axis corresponding to the mean pole position consistent with ITRF.

Chapter 7

7.1 Conventional displacements of reference markers ….

- Ocean loading:
  - Conventional software by D. Agnew
- Ocean pole tide loading
  - Desai (2002) model
- S1/S2 atmospheric loading
  - T. vanDam from Ray & Ponte (2003)

http://geophy.uni.lu/ggfc-atmosphere/tide-loading-calculator.html

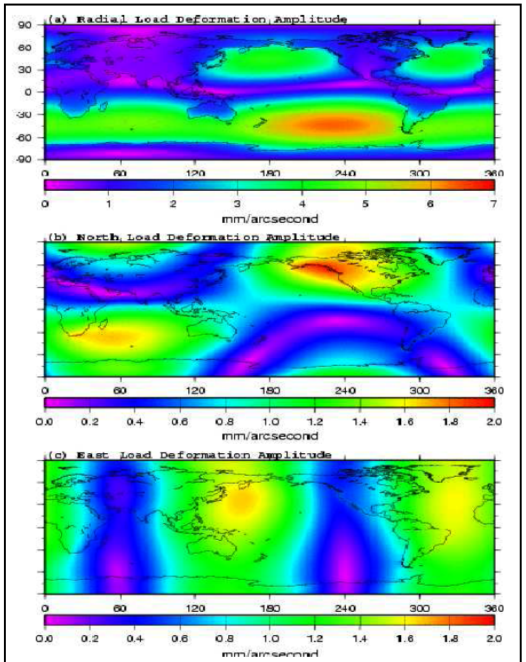


Figure 7.2: Loading from ocean pole tide: Amplitude as a function of the amplitude of wobble variable.

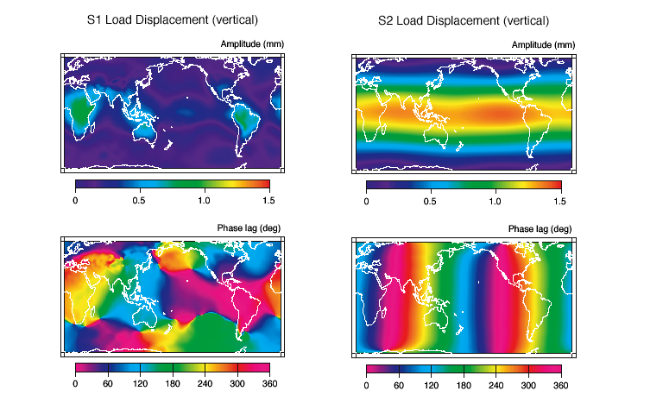
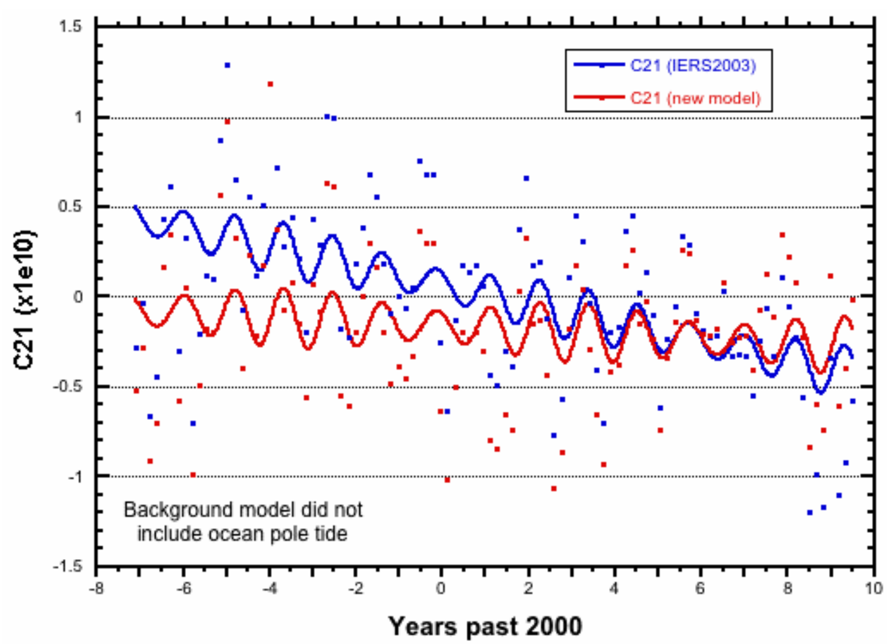
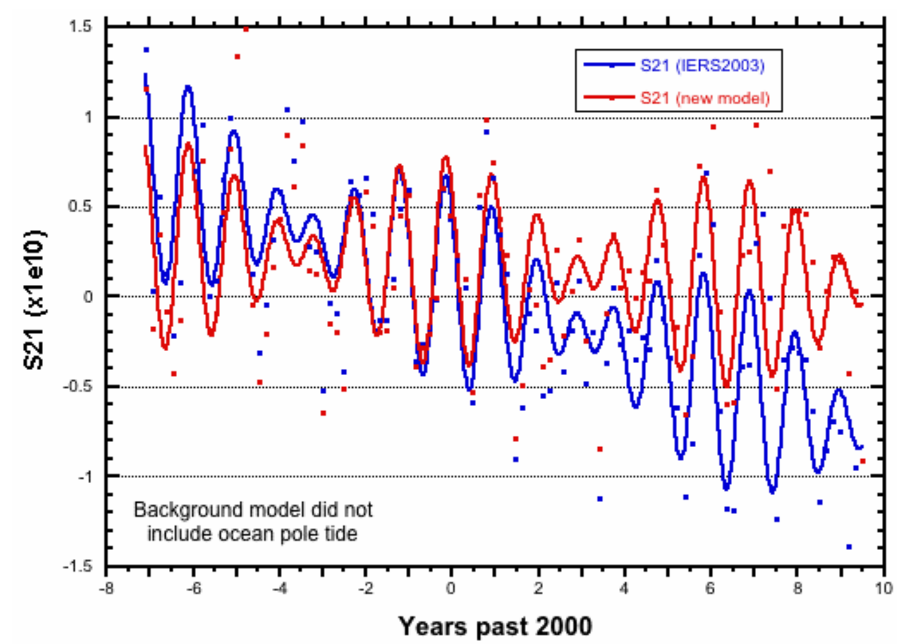


Figure 1: Amplitude (in mm) and phase (in degrees) of the predicted vertical surface displacement from the S_1 and S_2 atmospheric tides from the *Ray and Ponte* model [2003].

Conventional mean pole model (1)

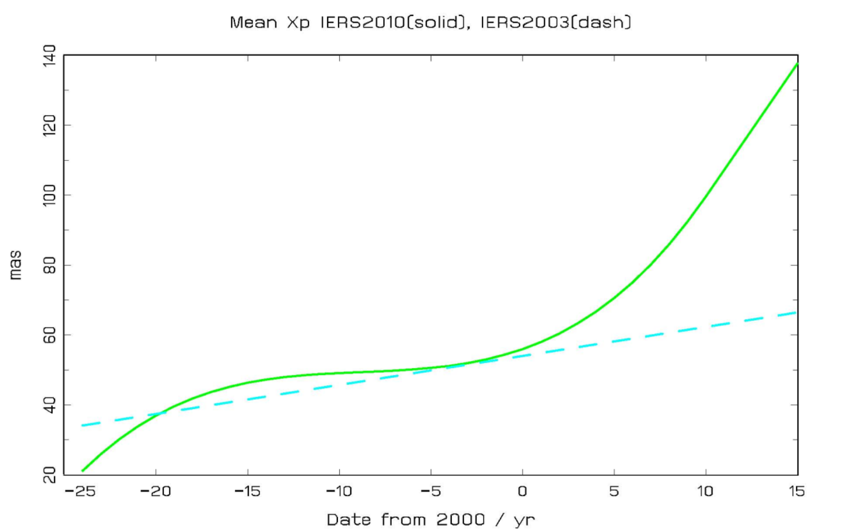
- A conventional mean pole model, that fits the "actual mean pole" to within ~ 10 mas, ensures
  - that the geopotential field is aligned to the long-term mean pole
  - that effects of the pole tide are accounted for consistently in different analyses.
- The 2003 linear model diverges from "actual mean pole" after 2000
  - Visible in C21/S21 estimates from Lageos (Analysis from John Ries)

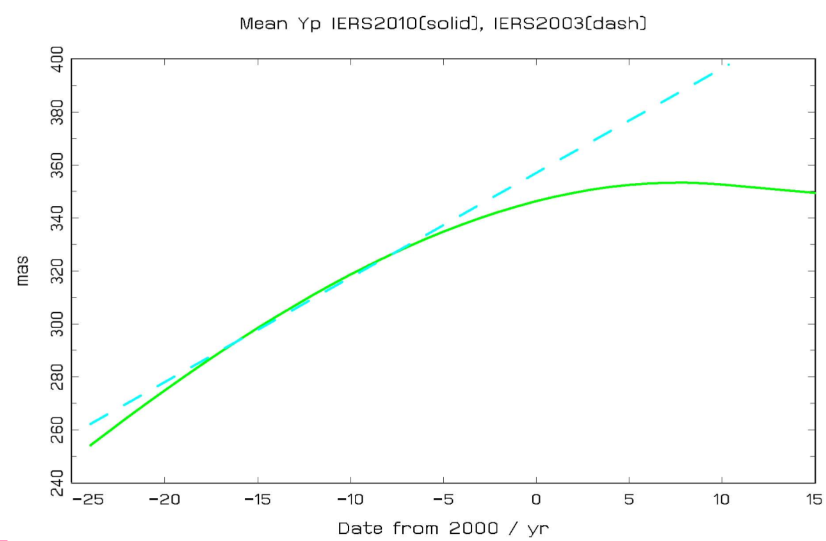




Conventional mean pole model (2)

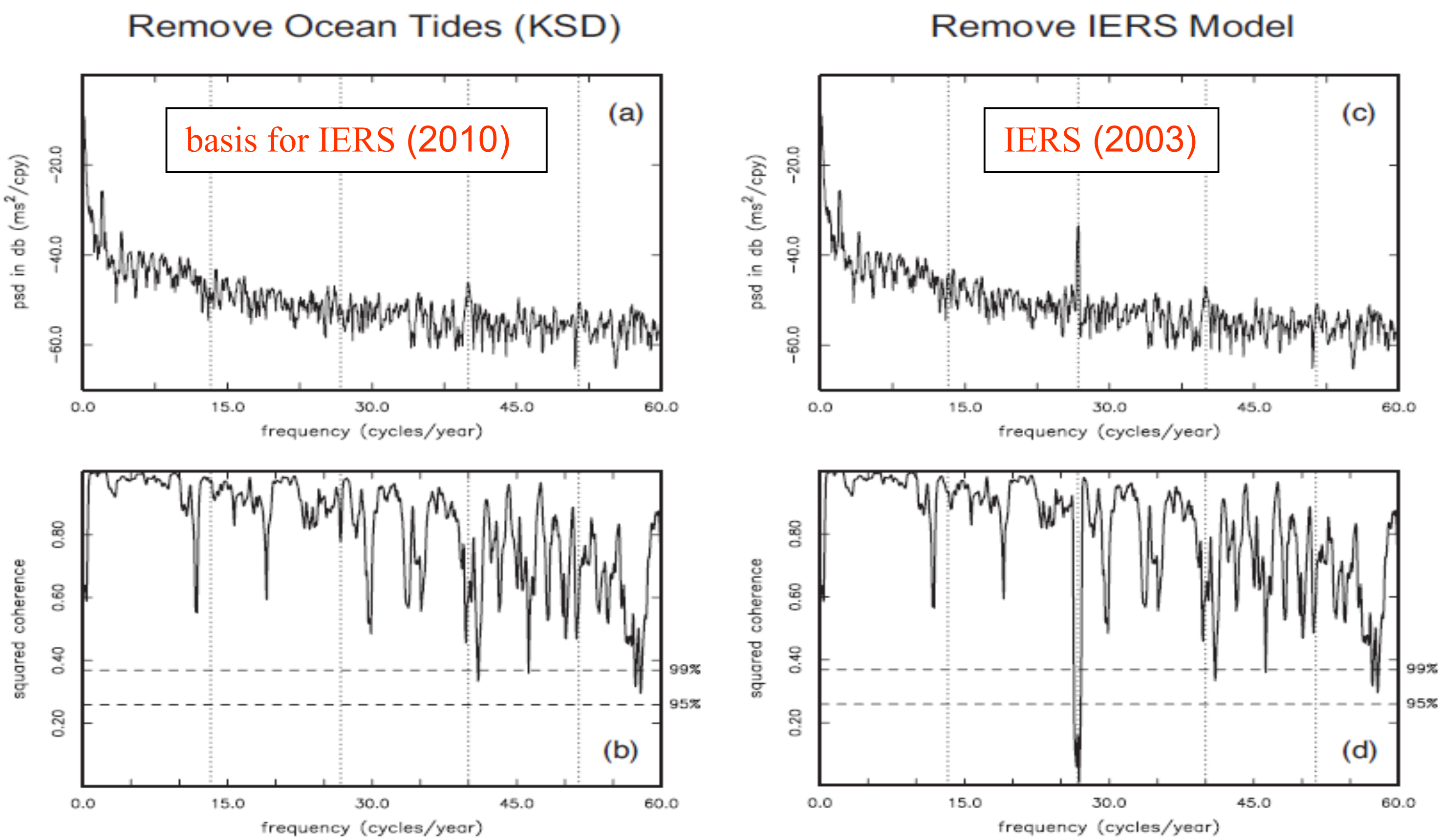
- Proposed IERS (2010) mean pole model
  - A degree 3 polynomial valid until 2010.0 and a linear extrapolation ensuring continuity and derivability at 2010.0
- To be updated as required
- However it has been shown (John Ries) that the conventional mean pole does not match very well the C21/S21 estimates from SLR and GRACE
  - General problem for low degree coefficients: simple model does not match real behavior
  - Recent surface mass trends not captured by model?





Chapter 8

- Model for the effect of zonal tides
  - Deficiency of IERS (2003) determined by R. Gross (JPL) (and others)
  - New model assembled by R. Gross reduces discrepancy particularly at fortnightly and monthly periods



Chapter 9

- Radio techniques:
  - Hydrostatic and wet mapping functions
    - VMF1 with coeffs from numerical weather model
    - GMF when VMF1 not available / necessary
  - APG a priori gradient model
  - All at http://ggosatm.hg.tuwien.ac.at/DELAY

- Correcting the ionosphere for dual-frequency users
  - Standard linear combination (possibly accounting for a time offset between measurements)
  - Models for 3rd order terms
  - Implementation software from M. Hernández-Pajares http://gage14.upc.es/MANUEL/.I2/i2_soft_update_v1d.20100218.tgz

$$\delta\rho_{I,p}^{(1)} = \frac{f_a^2\delta\rho_{I,p}^{(a)} - f_b^2\delta\rho_{I,p}^{(b)}}{f_a^2 - f_b^2} = \frac{s_2}{f_a f_b(f_a + f_b)} + \frac{s_3}{f_a^2 f_b^2}$$

$$\delta\rho_{I,c}^{(1)} = \frac{f_a^2\delta\rho_{I,c}^{(a)} - f_b^2\delta\rho_{I,c}^{(b)}}{f_a^2 - f_b^2} = -\frac{2s_2}{f_a f_b(f_a + f_b)} - \frac{3s_3}{f_a^2 f_b^2}$$

$$s_2 = 1.1284 \times 10^{12} \int_{\vec{r}_T}^{\vec{r}_R} N_e B \cos\theta dl \simeq 1.1284 \times 10^{12} B_p \cos\theta_p \cdot S$$

$$s_3 \simeq 812 \int_{\vec{r}_T}^{\vec{r}_R} N_e^2 dl \simeq 812 \eta N_m S$$

Geopotential: ocean tides

- Effect of the Ocean Tides
  - Section completely rewritten, based on input by R. Biancale
  - New conventional model based on FES2004, consistent with chapter 7

6.3 Effect of the Ocean Tides

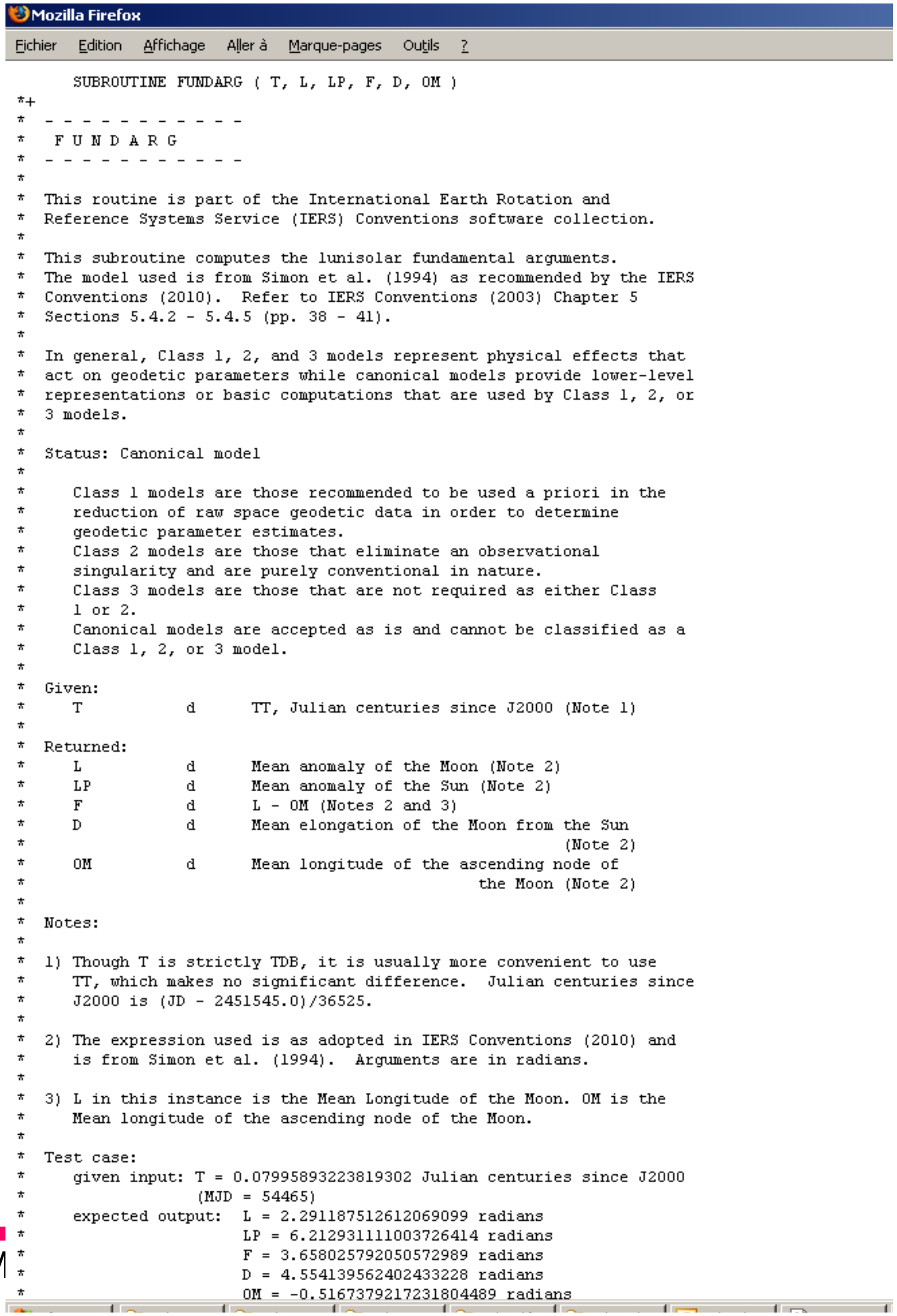
The dynamical effects of ocean tides are most easily incorporated by periodic variations in the normalized Stokes' coefficients of degree n and order m $\Delta\bar{C}_{nm}$ and $\Delta\bar{S}_{nm}$. These variations can be written as

$$[\Delta\bar{C}_{nm} - i\Delta\bar{S}_{nm}](t) = \sum_f \sum_{+}^{-} (\mathcal{C}^{\pm}_{f,nm} \mp i\mathcal{S}^{\pm}_{f,nm}) e^{\pm i\theta_f(t)}, \qquad (1)$$

- Sets of coefficients to easily compute the (variations in) Stokes coefficients are provided

IERS Conventions software (1)

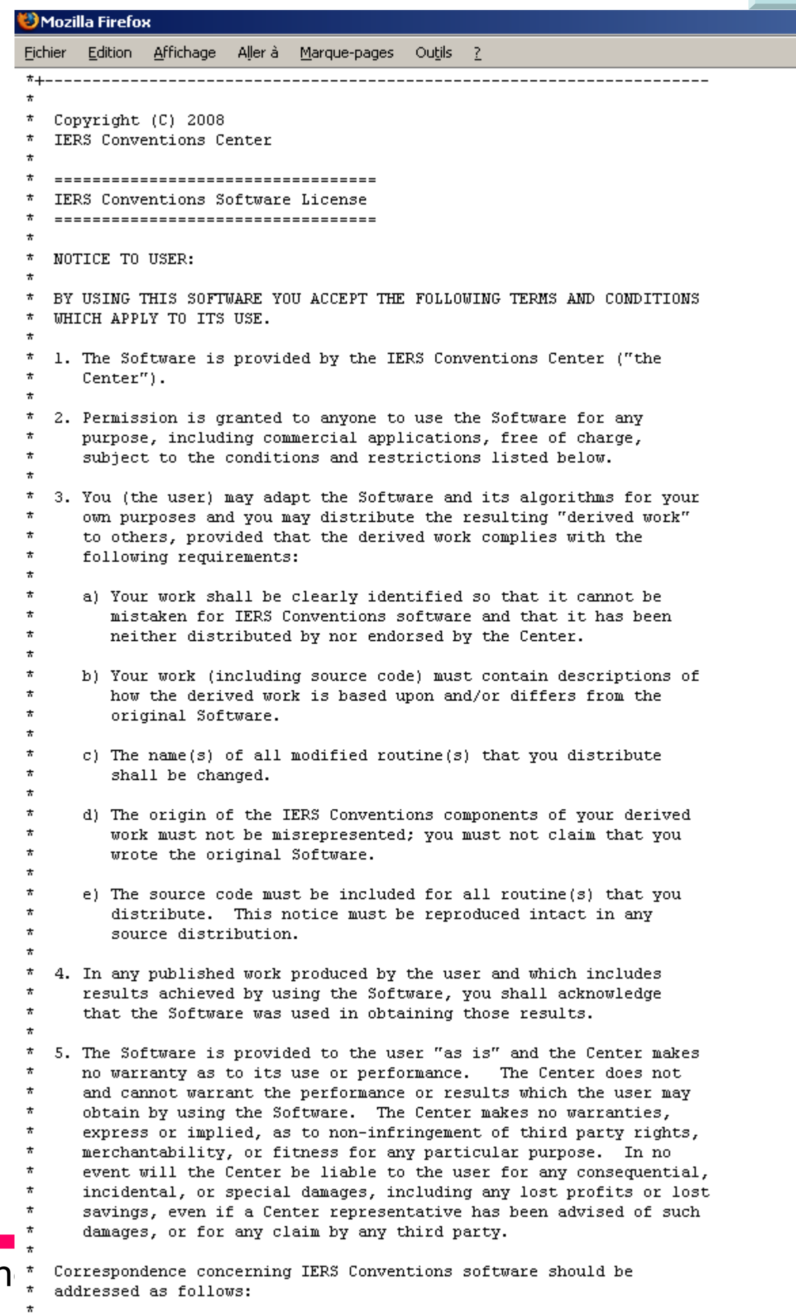
- Documentation template
- Provides structure and standard information
  - Variables defined (including units)
  - Notes on usage
  - Test case provided
  - References




```
      SUBROUTINE FUNDARG ( T, L, LP, F, D, OM )
*+
*  - - - - - - - - - - -
*   F U N D A R G
*  - - - - - - - - - - -
*
*  This routine is part of the International Earth Rotation and
*  Reference Systems Service (IERS) Conventions software collection.
*
*  This subroutine computes the lunisolar fundamental arguments.
*  The model used is from Simon et al. (1994) as recommended by the IERS
*  Conventions (2010).  Refer to IERS Conventions (2003) Chapter 5
*  Sections 5.4.2 - 5.4.5 (pp. 38 - 41).
*
*  In general, Class 1, 2, and 3 models represent physical effects that
*  act on geodetic parameters while canonical models provide lower-level
*  representations or basic computations that are used by Class 1, 2, or
*  3 models.
*
*  Status: Canonical model
*
*     Class 1 models are those recommended to be used a priori in the
*     reduction of raw space geodetic data in order to determine
*     geodetic parameter estimates.
*     Class 2 models are those that eliminate an observational
*     singularity and are purely conventional in nature.
*     Class 3 models are those that are not required as either Class
*     1 or 2.
*     Canonical models are accepted as is and cannot be classified as a
*     Class 1, 2, or 3 model.
*
*  Given:
*     T           d      TT, Julian centuries since J2000 (Note 1)
*
*  Returned:
*     L           d      Mean anomaly of the Moon (Note 2)
*     LP          d      Mean anomaly of the Sun (Note 2)
*     F           d      L - OM (Notes 2 and 3)
*     D           d      Mean elongation of the Moon from the Sun
*                                                         (Note 2)
*     OM          d      Mean longitude of the ascending node of
*                                               the Moon (Note 2)
*
*  Notes:
*
*  1) Though T is strictly TDB, it is usually more convenient to use
*     TT, which makes no significant difference.  Julian centuries since
*     J2000 is (JD - 2451545.0)/36525.
*
*  2) The expression used is as adopted in IERS Conventions (2010) and
*     is from Simon et al. (1994).  Arguments are in radians.
*
*  3) L in this instance is the Mean Longitude of the Moon. OM is the
*     Mean longitude of the ascending node of the Moon.
*
*  Test case:
*     given input: T = 0.07995893223819302 Julian centuries since J2000
*                  (MJD = 54465)
*     expected output:  L = 2.291187512612069099 radians
*                       LP = 6.212931111003726414 radians
*                       F = 3.658025792050572989 radians
*                       D = 4.554139562402433228 radians
*                       OM = -0.5167379217231804489 radians
```

IERS Conventions software (2)

- License provided
  - Explicitly states conditions under which software can be used by third parties
  - Consistent with SOFA
  - Necessary because of expanding user base

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Additional material

This page presents material that complement the IERS Conventions but are not formally part of them. They are provided as additional information, such as test cases, technical notes written by contributors to the Conventions, etc... They are not subject to the same review process as the Conventions chapters and associated programs.

This page is organized following the order of the Conventions chapters and the documents are presented with the most relevant chapter. Some of this documents have previously been available through the discussion forum which is now closed.

Comments and contributions may be sent to Gérard Petit and Brian Luzum.

- Introduction.
  Additional documents and links:
  - TBD.
- Chapter 1 - General definitions and numerical standards.
  Additional documents and links:
  - TBD.
- Chapter 2 - Conventional celestial reference system and frame.
  Additional documents and links:
  - TBD.
- Chapter 3 - Conventional dynamical realization of the ICRS.
  Additional documents and links:
  - TBD.
- Chapter 4 - Terrestrial reference systems and frames.
  Additional documents and links:
  - TBD.
- Chapter 5 - Transformation between the International Terrestrial Reference System and Geocentric Celestial Reference System.
  Additional documents and links:
  - Example application of the IAU 2000 resolutions concerning Earth orientation and rotation provided by Patrick Wallace.
  - For additional info related to the transformation between systems, see also the site of the IAU Division 1 working group (2003-2006) Nomenclature for Fundamental Astronomy (NFA), with more explanatory material here.
- Chapter 6 - Geopotential.
  Additional documents and links:
  - The IERS Conventions (2003) ocean tides model CSR 3.0 is presented in the 1995 memo "THE CSR 3.0 GLOBAL OCEAN TIDE MODEL: DIURNAL AND SEMI-DIURNAL OCEAN TIDES FROM TOPEX/POSEIDON ALTIMETRY" by Richard J. Eanes and Srinivas Bettadpur.
  - The ocean tides model FES2004 described in the IERS Conventions (2010) is presented in the paper "Modelling the global ocean tides: modern insights from FES2004" by F. Lyard et al. (2006). Additional information is provided in a presentation at the IERS Conventions workshop.
- Chapter 7 - Displacement of reference points.
  Additional documents and links:
  - Report by Duncan Agnew on the version dated June 2008 of the routine hardisp.f to compute the displacement due to ocean tidal loading.
- Chapter 8 - Tidal variations in the Earth's rotation.
  Additional documents and links:
  - TBD.
- Chapter 9 - Models for propagation delays.
  Additional documents and links:
  - Report by Flavien Mercier on the influence of non synchroneous phase measurements on the ionospheric correction in DORIS.
- Chapter 10 - General relativistic models for space-time coordinates and equations of motion.
  Additional documents and links:
  - TBD.
- Chapter 11 - General relativistic models for propagation.
  Additional documents and links:
  - TBD.