

Short Period Ocean-Tidal variations in Earth rotation



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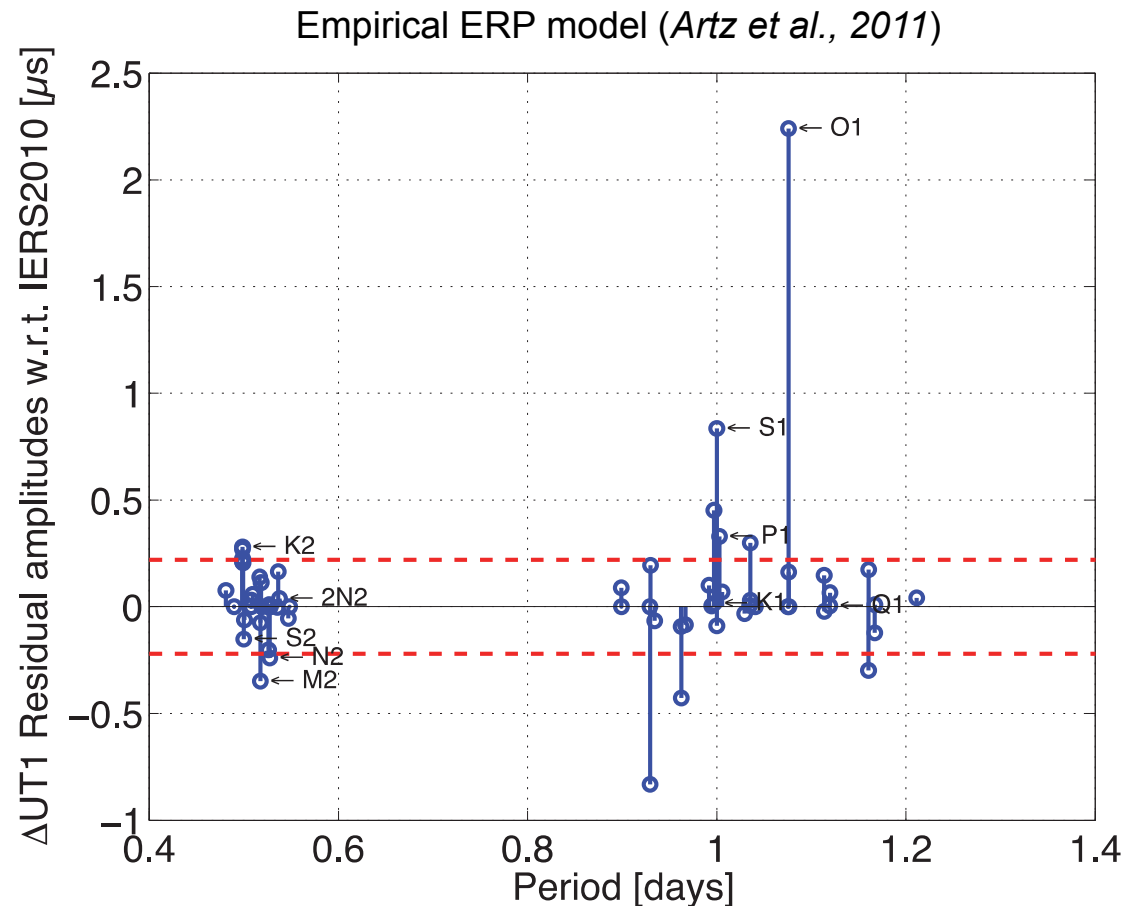
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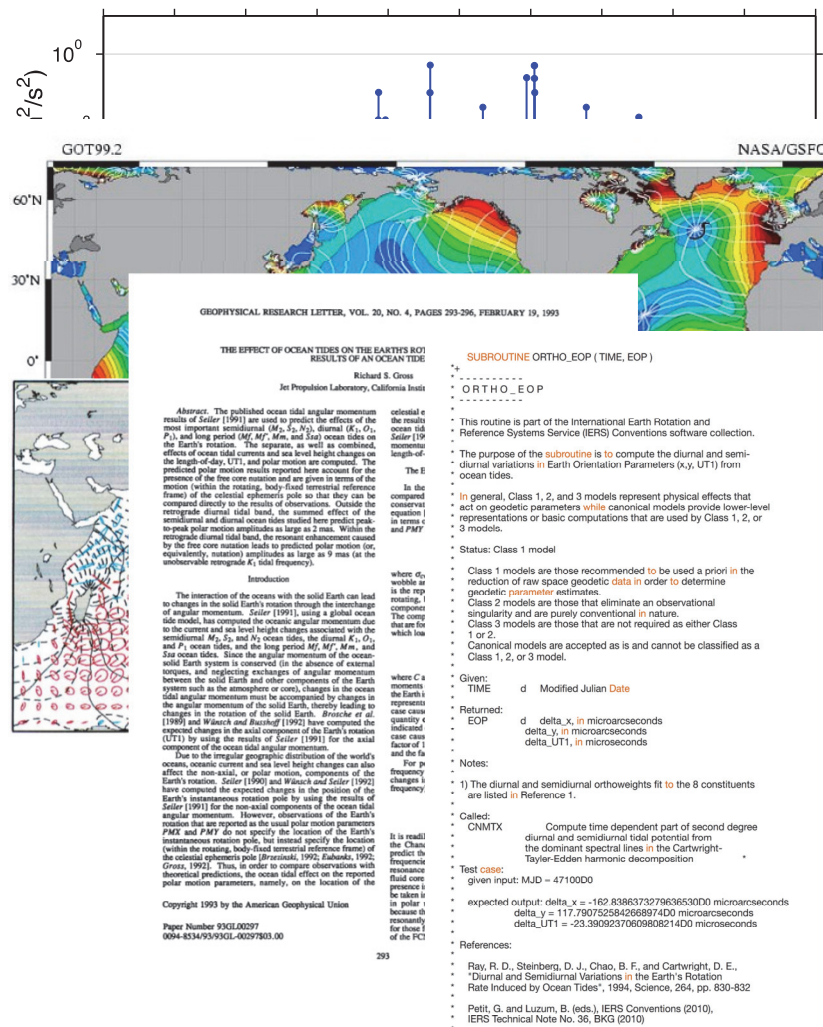
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Motivation: current IERS conventional model is outdated



- Residual UT1 amplitudes wrt IERS2010 conventional model, estimated from VLBI solutions (Artz et al., 2011, *J Geod* 85) (other empirical models were published by e.g. Sigrid Böhm et al. 2012)
 - Significant residuals for diurnal and semidiurnal ocean tidal band
- ➔ Precise model for the impact of short period ocean tides on Earth rotation is needed

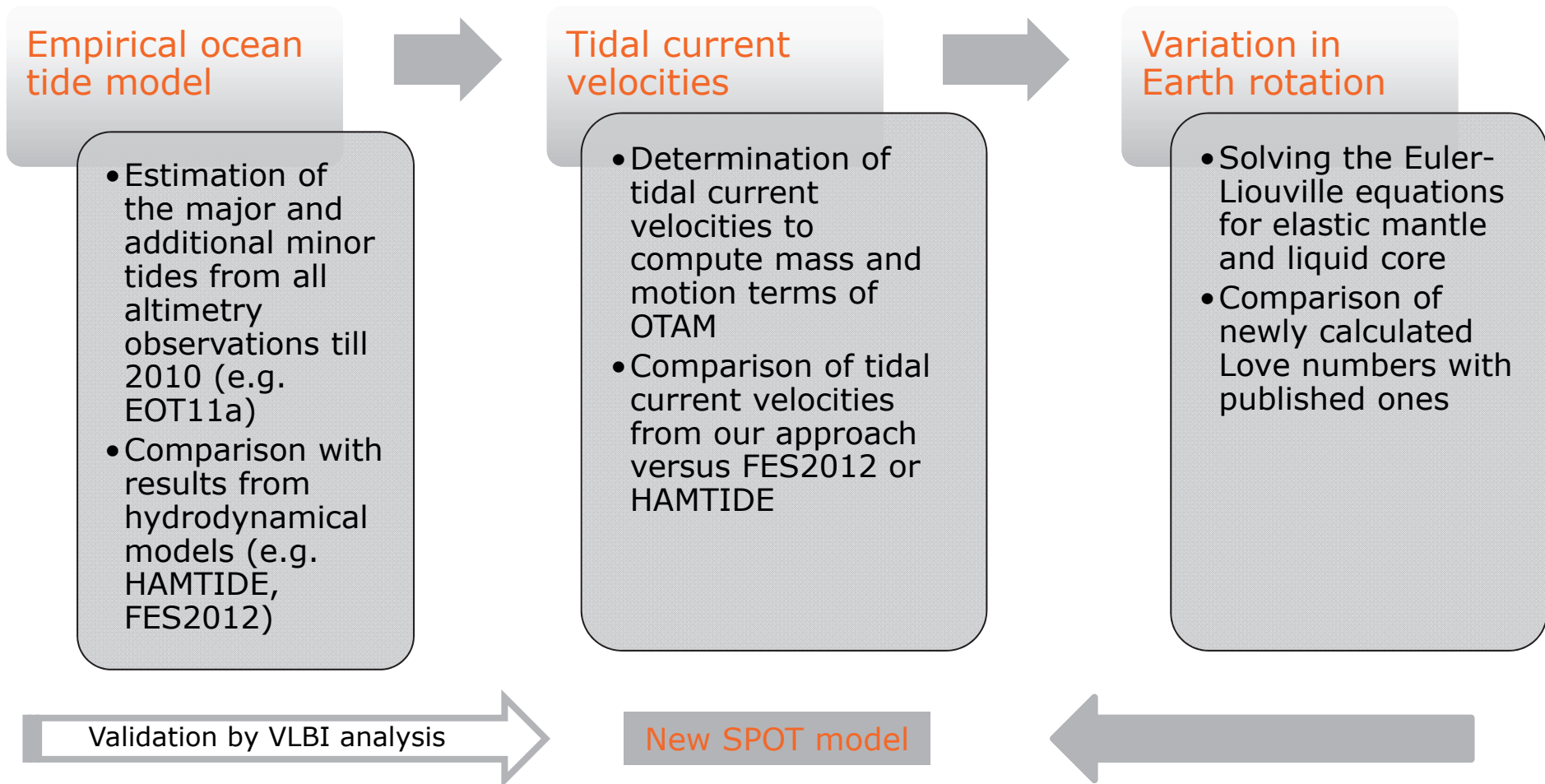
The IERS2010 conventional model (Eanes/Ray)



- 71 constituents of the tidal potential in the diurnal and semidiurnal band
- Estimation of heights for eight major tides ($Q_1, O_1, P_1, K_1, N_2, M_2, S_2, K_2$) from altimeter observations (T/P from 1992 ?)
- Determination of tidal currents for the major tides (according to Ray, 2001, J Marine Sys 28 ?)
- Calculation of impact on Earth rotation by Euler-Liouville equation (Gross, 1993; Brzezinski, 1994)? which Earth model?
- Determination of total effect in the time domain by ortho-tide /ortho-weights approach (e.g. Groves & Reynolds, 1975, JGR 80; Ray et al., 1994, Science 264)

→ IERS2010 subroutine ORTHO_EOP.F

Concept of the SPOT project (started 2013)



Improvements in the proposed model compared to IERS2010 conventional model

GEOPHYSICAL RESEARCH LETTERS, VOL. 22, NO. 24, PAGES 3553-3556, DECEMBER 15, 1995

The HW95 tidal potential catalogue

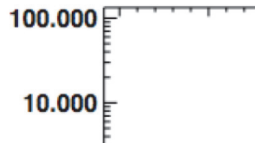
Torsten Hartmann

Theoretische Astrophysik der Universität Tübingen, Germany

Hans-Georg Wenzel

Geodätisches Institut der Universität Karlsruhe,

Abstract. The catalogue named HW95 of oceanic development of the Earth tide generation



Journal of Marine Systems 28 (2001) 1-18

JOURNAL OF
MARINE
SYSTEMS
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Inversion of oceanic tidal currents from measured elevations

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November 1999; accepted 17 August 2000

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Polar motion excitation by variations of the effective angular momentum function, II: extended-model

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Received 8 February 1992; Accepted 14 September 1993

Abstracts This paper is a complementary part of the previous study (Brzezinski, 1992a), concerning the perturbations of the Celestial Ephemeris Pole which can be interpreted either as slow celestial variation, nutation, or as nearly diurnal retrograde terrestrial variation, polar motion. We consider only geophysical perturbations having their origin in the atmosphere or in the ocean, which can be expressed by the equatorial Effective Angular Momentum function χ . The equation of motion which is derived here on the basis of the dynamical theory of Sasao and Wahr (1981) can be seen as an extension of the polar motion equation by including the effect of the Five Core Nutation resonances. Possible analytical solutions of this equation are presented. It is also shown how the excitation problem can be investigated by the Kalman filtering method combined with autoregressive modelling of the excitation process. All results presented here can equivalently be expressed either in terms of nutation or in terms of diurnal polar motion.

1. Introduction

The orientation of the earth in space is determined by modern space techniques. Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Lunar Laser Ranging (LLR) and recently also by Global Positioning System (GPS), with continually improving accuracy reaching already a level of 1 cm. At the same time we observe also a significant improvement of quality of the complementary geophysical, atmospheric, and oceanographic data. In the case of atmosphere which appears to be very important source of perturbations in Earth orientation, the excitation data has been provided on regular basis for over a decade in the form of the so-called Effective Angular Momentum (EAM) functions defined by James et al. (1985). A sampling interval for various determinations of the Earth Orientation Parameters (EOP) is at present between 1 and 5 days and in the case of the EAM functions

it is equal to 1 or 1/2 day (1991 IERS Annual Report). Recently, the sub-daily measurements of earth rotation, atmospheric angular momentum and their interpretation have been proposed as major research areas for the present decade (Münster and Zerbini, 1989). In the frame of this subject various international experiments have been carried out, coordinated by the International Earth Rotation Service (IERS) and the Joint International Union of Geodesy and Geophysics (IUGG) / International Association of Geodesy (IAG) Special Study Group 5.143 "Rapid Earth Orientation Variations", example being the SEARICHV2 (Study of Earth-Atmosphere Rapid Changes) campaign held in conjunction with the IERS92 (International GPS Service) campaign.

This dramatic progress of quality of the earth orientation data and the auxiliary atmospheric data should be followed by similar improvements of the underlying theories. The old theories containing various simplifications and long-term approximations are usually not adequate for the present observations. In the case of polar motion the classic equations of Maclaurin and MacDonald (1960) was derived under the assumption that the earth is purely elastic. This equation was reformulated by Bretlow et al. (1983) on the basis of the model comprising elastic mantle which is completely decoupled from the liquid core, and by increasing the excitation process by the EAM function. Brzezinski (1992a) modified this equation by referring it to the geometrical coordinates of the Celestial Ephemeris Pole (CEP) instead of the instantaneous rotation pole which is not observed by space geodetic techniques. A serious deficiency of this equation, preventing its use in the analysis of the high frequency variations, is the oversimplified model of the mantle-core interaction. From the observations of the amplitudes of the forced nutation it has been proved that the coupling between the mantle and the liquid core is very important in the

scities from measured tidal elevations is considered. Emphasis is given to used on satellite altimetry are readily available. Barotropic tidal currents are by solving the two-dimensional momentum equations and the continuity such represents a middle ground between commonly used data assimilation entum equations. The estimated velocities are compared with those of other y measurements, and with current meter measurements. Agreement with i discrepancies are consistently less than 2 mm s⁻¹. The method appears to s of tidal dynamics. Published by Elsevier Science B.V.

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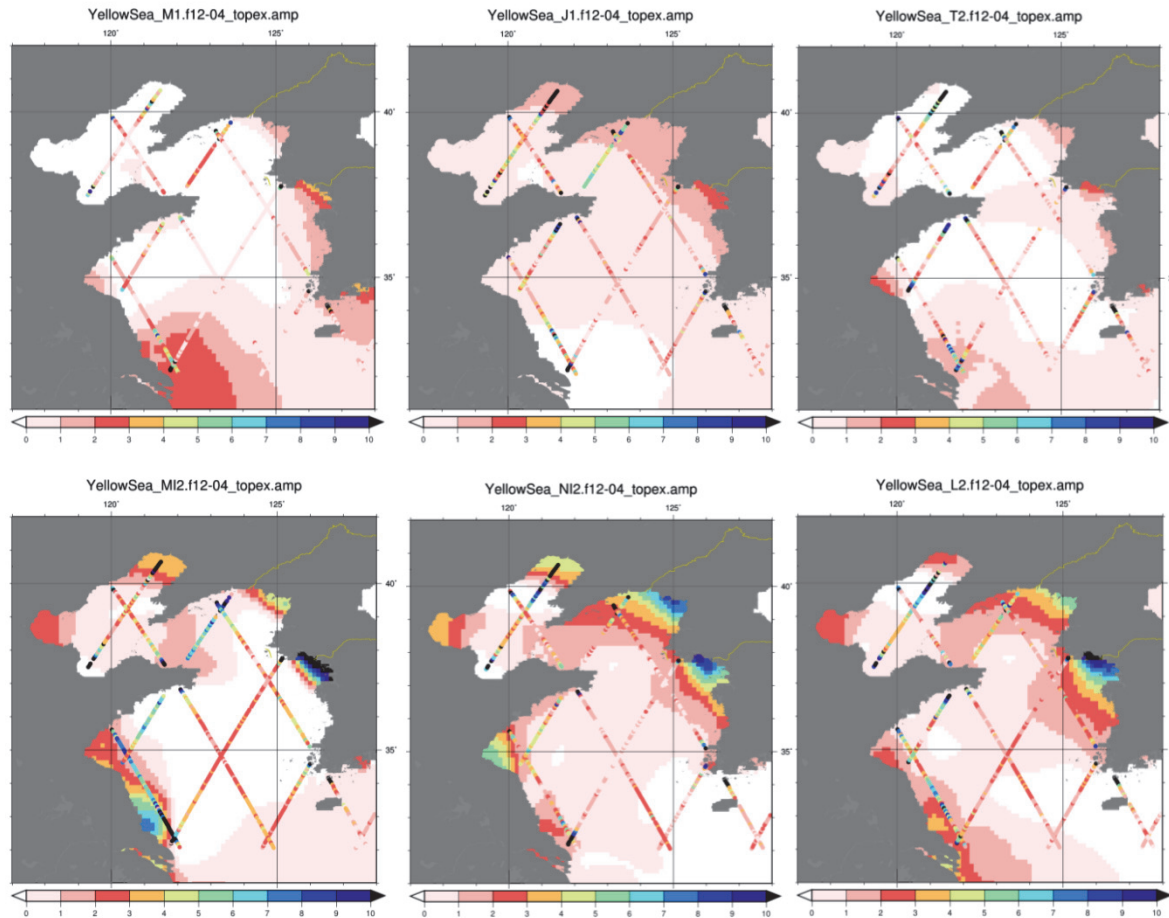
sampling by relatively widely spaced satellite ground-tracks, and some deep-water regions are susceptible to large (> 5 cm) internal-tide surface modulations that complicate tidal prediction (Ray and Mitchum, 1997). But in general, the deep-ocean tide problem has been solved by satellite altimetry to roughly the 2-3 cm accuracy level.

In contrast to tidal elevations, deep-ocean tidal currents are not well known. In situ measurements are comparatively few and many of these are corrupted by measurement difficulties (e.g., swaying moorings), inadequate vertical sampling (to isolate the barotropic component), and low signal-to-noise ratio. Yet requirements for accurate knowledge of deep-ocean tidal currents are almost as prevalent as those for tidal elevations. A few examples suffice: understanding the interaction of the general ocean circulation with tidal flows; determining the flow field responsible for generating internal tides and

- Extension of the diurnal and semidiurnal tidal band from 71 to 120 constituents (*Hartmann & Wenzel, 1995, GRL 22*)
- Estimation of minor tides (e.g. $M_1, J_1, OO_1, \mu_2, L_2$ etc.) in addition to the major tides from altimeter observations (extended EOT11a, *Savcenko & Bosch, 2012*)
- Implementation of tidal-current velocity calculation exactly according to *Ray(2001, J Marine Sys 28)*
- Re-examination of Euler-Liouville equations for elastic Earth mantle and liquid core and re-calculation of the associated Love numbers for PREM (e.g. *Gross, 1993; Brzezinski, 1994*)

Examples of recent work (1)

Estimation of minor tides



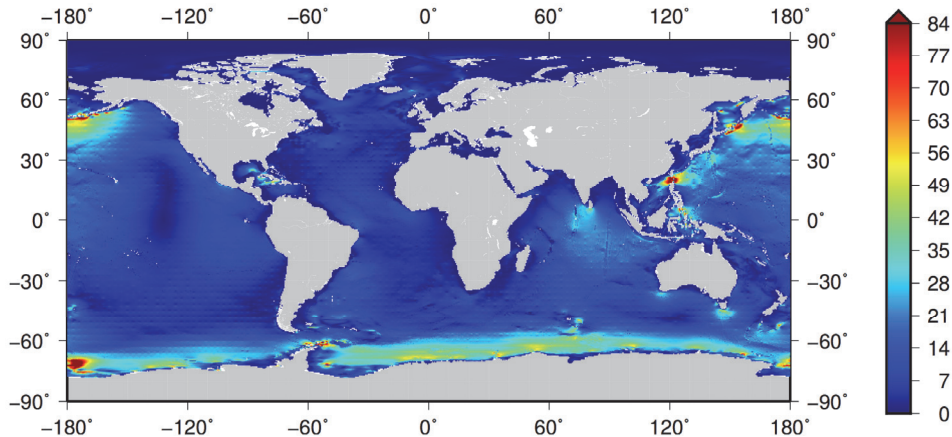
- Estimation of minor tides: Residuals wrt FES2012 and admittance approach
- First row: M_1 , J_1 , T_2
- Second row: MI_2 , NI_2 , L_2

Residuals (in cm) of minor tides in the Yellow Sea wrt FES2012 results based on the admittance approach. Background color map related to FES2012 and dots along-track empirical estimations (TOPEX)

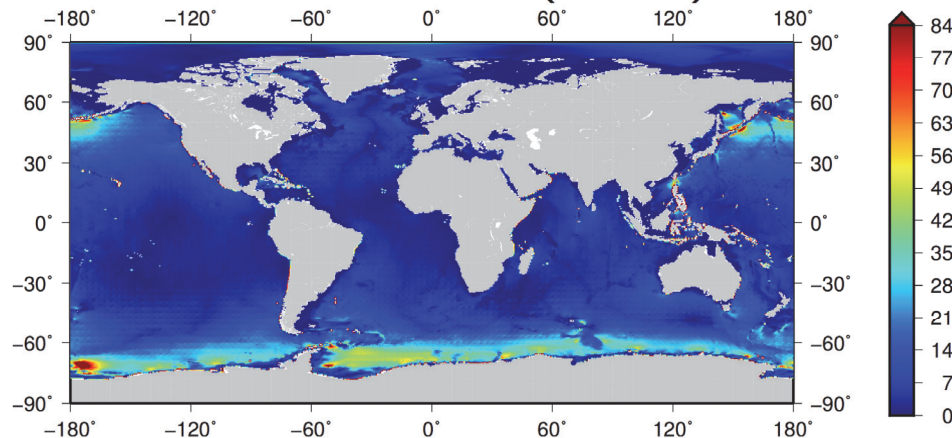
Examples of recent work (2)

Determination of tidal current velocities

HAMTIDE11a



Estimated (SWE)



- Eastwards volume transport for O_1 tide (m^2s^{-1})
- Upper figure based on tidal current velocities from HAMTIDE (*Taguchi et al., 2014, to be submitted to JGR*)
- Lower figure estimated velocities based on *Ray (2001)* approach for tidal heights from HAMTIDE
- Rather good agreement

Examples of recent work (3)

Re-examination of Euler-Liouville equations (PREM)

Euler-Liouville equations for polar motion in the frequency domain

$$(\sigma - e\Omega(\sigma + \Omega)\tau k^T) A m + (\sigma + \Omega)(A_c - A\tau k^d) m_c = -\frac{(\sigma + \Omega)}{\Omega} h + (\sigma + \Omega)(1 + k^L)\tau A\phi^L$$

$$\sigma(A_c - A\tau k^d) m + A_c((1 + \beta)\sigma + (1 + \epsilon)\Omega) m_c = \sigma A\tau(h^d - k^d)\phi^L$$

Linearized solution for frequency dependent polar motion

$$p(\sigma) = -\left[\frac{A}{A_m}\tau(1+k^L)\frac{\Omega}{\sigma_{cw}-\sigma} - \frac{A}{A_m}\tau(h^d-k^d)\frac{\Omega}{\sigma_{ndfw}-\sigma}\right]\phi^L + \left[\frac{A}{A_m}\frac{\Omega}{\sigma_{cw}-\sigma} + \frac{A}{A_m}\frac{A_c}{A_m}(\epsilon-\beta)\frac{\Omega}{\sigma_{ndfw}-\sigma}\right]\frac{h}{A\Omega}$$

Polar motion for certain tides

	Wang	Gutenberg	1066A	PREM
polar motion for tide O1 (μas)				
p_x	268.6	263.5	265.7	269.3
p_y	-538.7	-528.4	-532.2	-540.4
polar motion for tide K1 (μas)				
p_x	353.0	346.4	349.9	353.5
p_y	-696.0	-682.8	-688.5	-697.8
polar motion for tide M2 (μas)				
p_x	313.0	307.2	310.7	313.3
p_y	-424.3	-416.4	-421.7	-424.4
polar motion for tide S2 (μas)				
p_x	129.0	126.7	128.2	129.1
p_y	-235.8	-231.4	-234.2	-236.0

A, A_c, C, C_c

Principle moments of inertia (Earth/Core)

$$A_m = A - A_c$$

Principle moment of inertia (Mantle)

$$e = \frac{C - A}{A}$$

Dynamical ellipticity (Earth)

$$\epsilon = \frac{C_c - A_c}{A_c}$$

Dynamical ellipticity (Core)

$$\tau = \frac{\Omega^2 a^5}{3GA}$$

$k^{L,T,d}, h^d$

Load, tidal and dynamic Love numbers

ϕ^L

Load potential

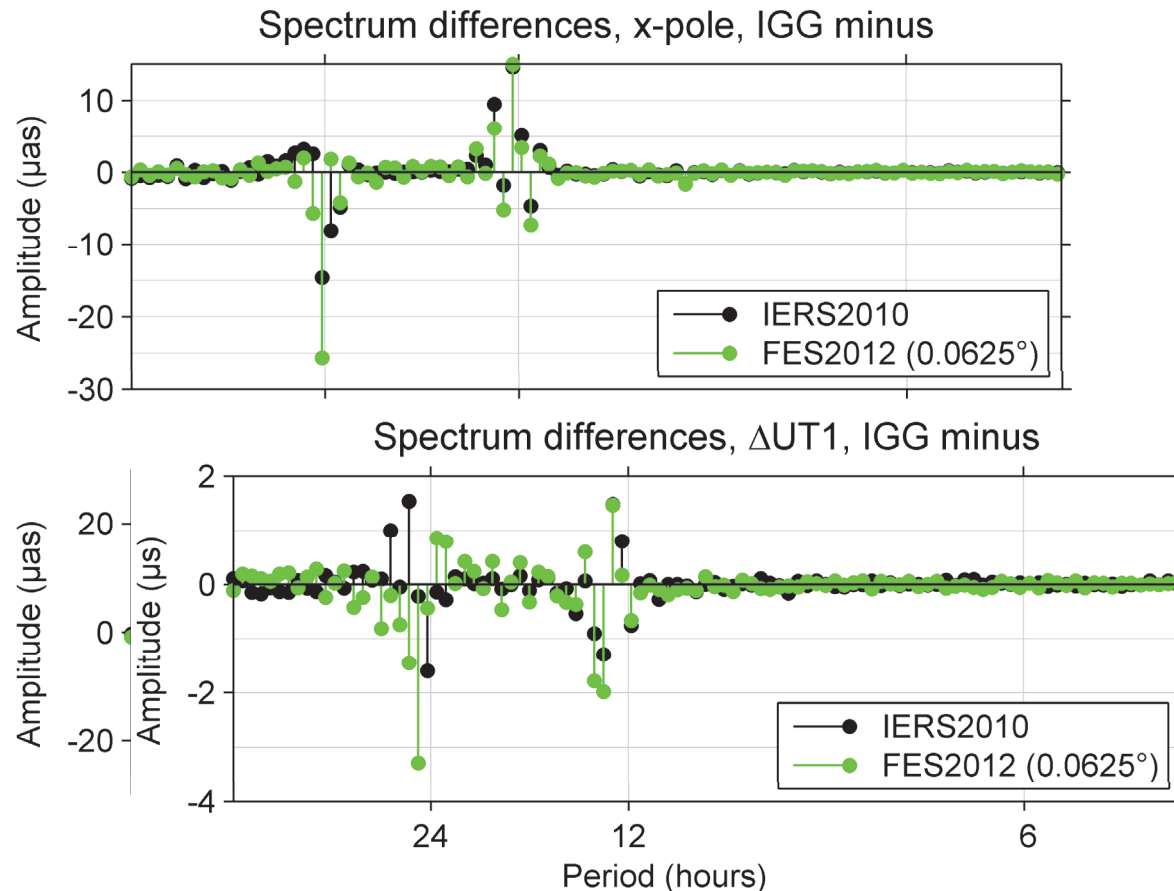
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Relative angular momentum

Earth model impact below 2%,
but significant

Validation

Comparison of empirical model from *Artz et al. (2011)* vs. IERS and FES2012 models



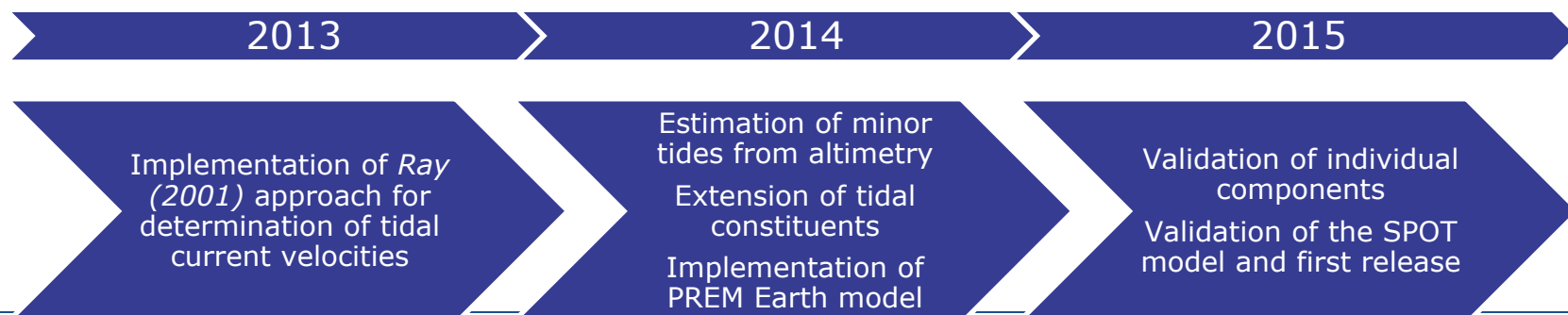
- Differences of the spectra of residuals of hourly CONT11 analysis for the different models
- Differences for x- and y-pole show large amplitudes for diurnal and semidiurnal frequencies
- Same with ΔUT1
- IERS2010 and FES2012 show significant differences with respect to *Artz et al. (2011)* model

Validation: SPOT model

- SPOT model still 'under construction'
- will be released in mid 2015
- validation still to be done

Outlook of project SPOT

- Continuation of recent work:
 - Estimation of minor tides from altimeter observations
 - Ortho-tide/ortho-weights approach for the enlarged set
 - Recalculation of tidal, load and dynamic Love numbers
- Validation within the individual tasks:
 - Minor tides estimated from altimetry vs. admittance results
 - Tidal-current velocities from *Ray (2001)* approach vs. HAMTIDE and FES2012 velocities
 - Re-computed vs. published Love numbers
- Set up of new model for short period ocean tidal variations in Earth rotation and validation by application to VLBI and GNSS analyses



Thank you for your attention!

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