Short Period Ocean-Tidal variations in Earth rotation

J.M. Hagedoorn[1,4] , H. Schuh[1,4], M. Madzak[2], W. Bosch[3]

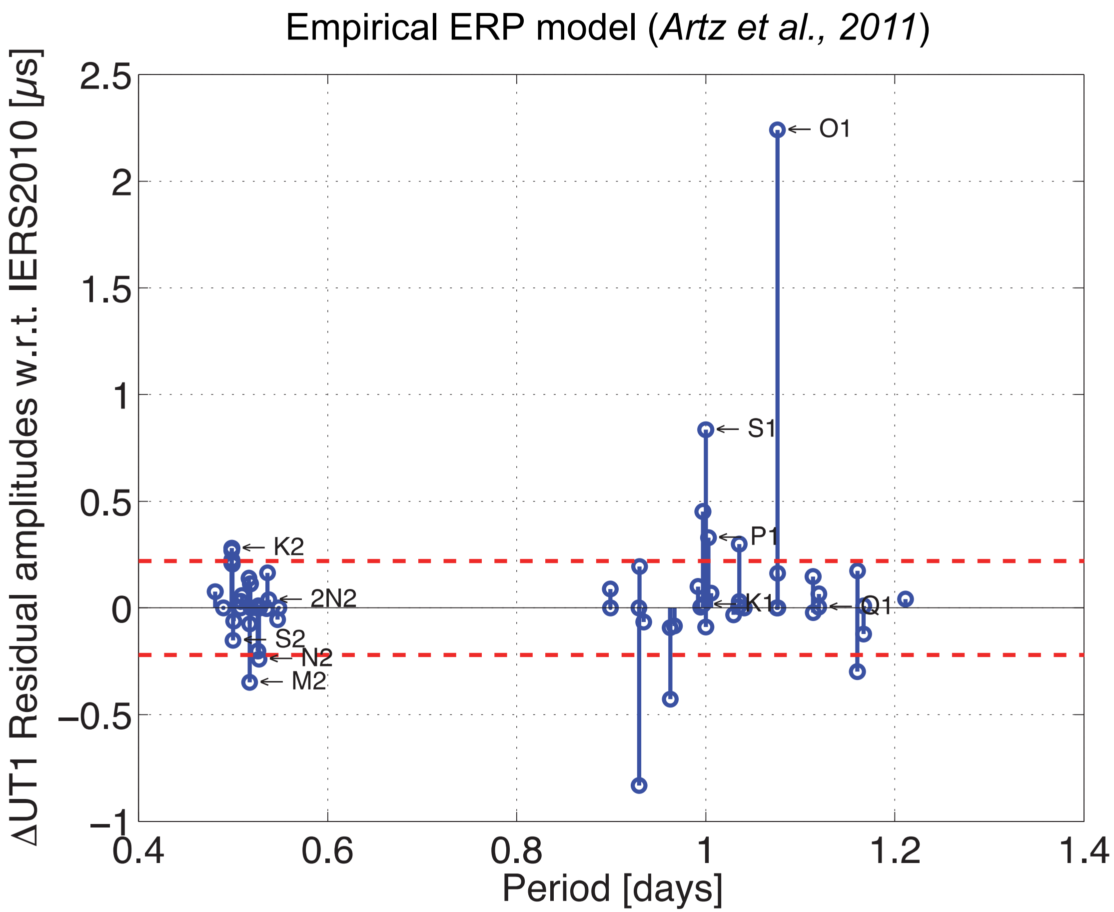
[1] Department 1: Geodesy and Remote Sensing, GFZ Potsdam German Research Center for Geosciences
[2] Research Group Advanced Geodesy, Department of Geodesy and Geoinformation, Vienna University of Technology
[3] DGFI German Geodetic Research Institute, Munich
[4] Satellite Geodesy, Department for Geodesy and Geoinformation Sciences, Technical University of Berlin

GFZ Helmholtz Centre Potsdam

FWF Austrian Science Fund Project 24813

HELMHOLTZ ASSOCIATION

Motivation: current IERS conventional model is outdated

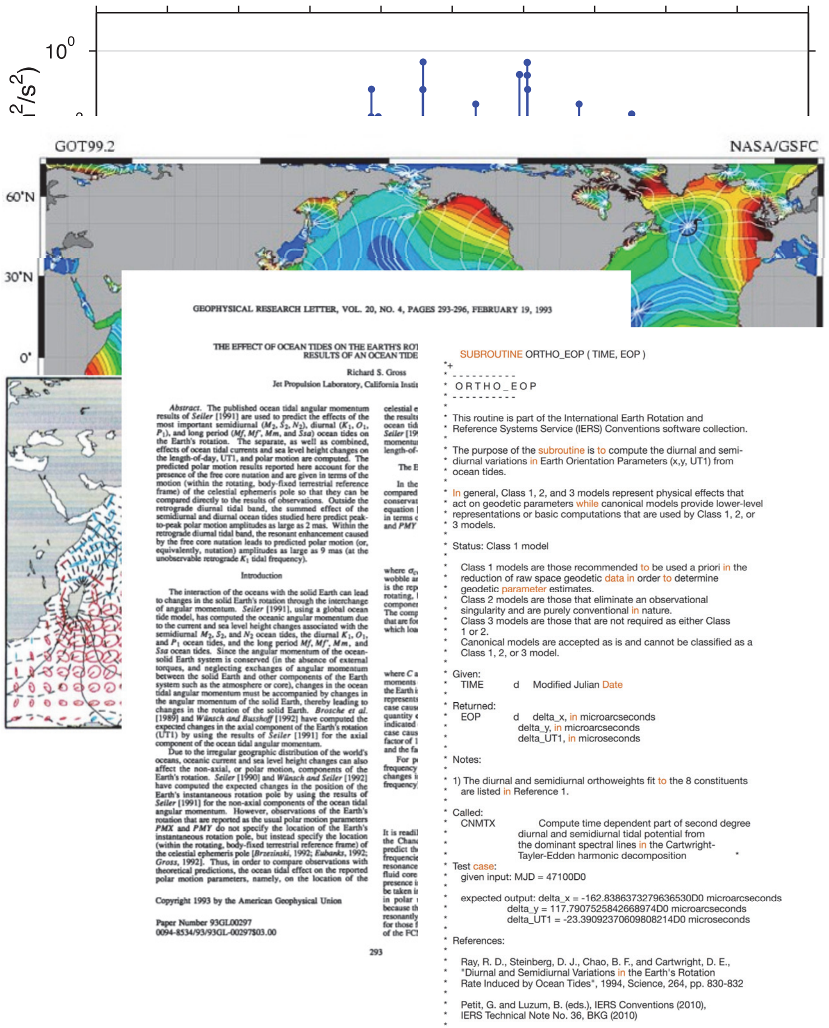


- Residual UT1 amplitudes wrt IERS2010 conventional model, estimated from VLBI solutions (*Artz et al., 2011, J Geod 85*) (other empirical models were published by e.g. Sigrid Böhm et al. 2012)

- 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)

Empirical ocean tide model

- Estimation of the major and additional minor tides from all altimetry observations till 2010 (e.g. EOT11a)
- Comparison with results from hydrodynamical models (e.g. HAMTIDE, FES2012)

Tidal current velocities

- Determination of tidal current velocities to compute mass and motion terms of OTAM
- Comparison of tidal current velocities from our approach versus FES2012 or HAMTIDE

Variation in Earth rotation

- Solving the Euler-Liouville equations for elastic mantle and liquid core
- Comparison of newly calculated Love numbers with published ones

Validation by VLBI analysis

New SPOT model

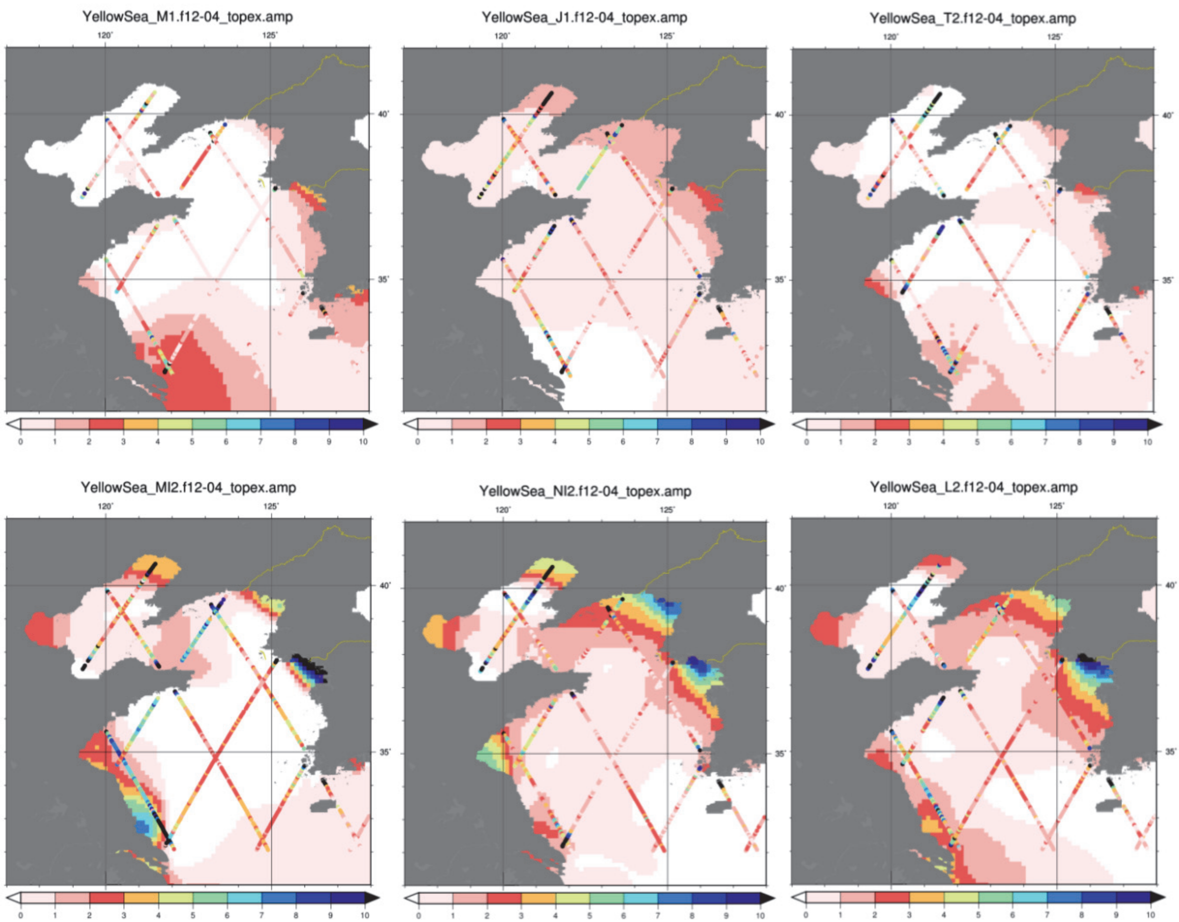
Improvements in the proposed model compared to IERS2010 conventional model

- 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,μ_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*)

GFZ Helmholtz Centre Potsdam · TU Wien · TU berlin · SPOT · HELMHOLTZ ASSOCIATION

Examples of recent work (1)

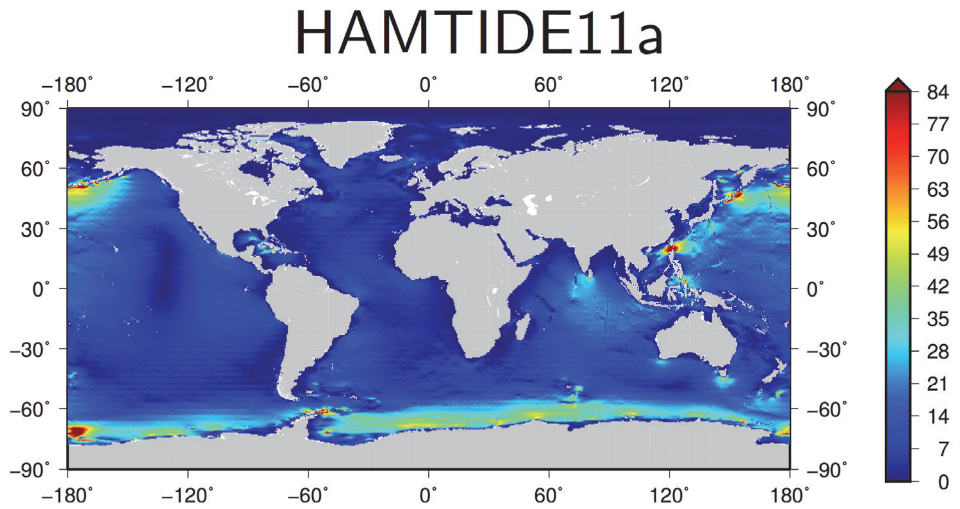
Estimation of minor tides

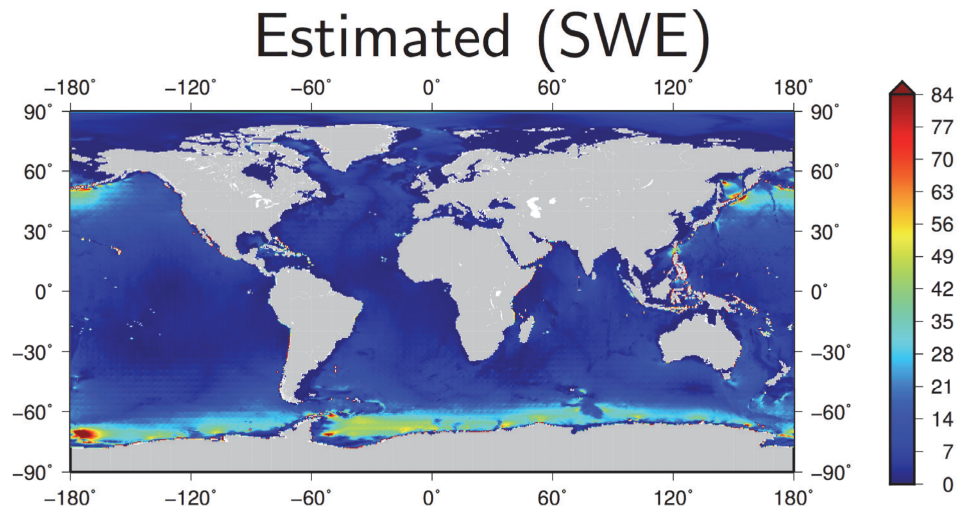


Residuals (in cm) of minor tides in the Yellow Sea wrt FES2012 results based on the admittance approach. Background color map related to FES2012 and dots along-track empirical estimations (TOPEX)

- 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

Examples of recent work (2)
Determination of tidal current velocities





- Eastwards volume transport for 0_1tide (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

$$\left(\sigma - e\Omega(\sigma+\Omega)\tau k^{\mathrm{T}}\right)A\,m + (\sigma+\Omega)\left(A_{\mathrm{c}} - A\tau k^{\mathrm{d}}\right)m_{\mathrm{c}} = -\frac{(\sigma+\Omega)}{\Omega}h + (\sigma+\Omega)(1+k^{\mathrm{L}})\tau A\phi^{\mathrm{L}}$$

$$\sigma\left(A_{\mathrm{c}} - A\tau k^{\mathrm{d}}\right)m + A_{\mathrm{c}}\left((1+\beta)\sigma + (1+\epsilon)\Omega\right)m_{\mathrm{c}} = \sigma A\tau\left(h^{\mathrm{d}} - k^{\mathrm{d}}\right)\phi^{\mathrm{L}}$$

Linearized solution for frequency dependent polar motion

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

Polar motion for certain tides

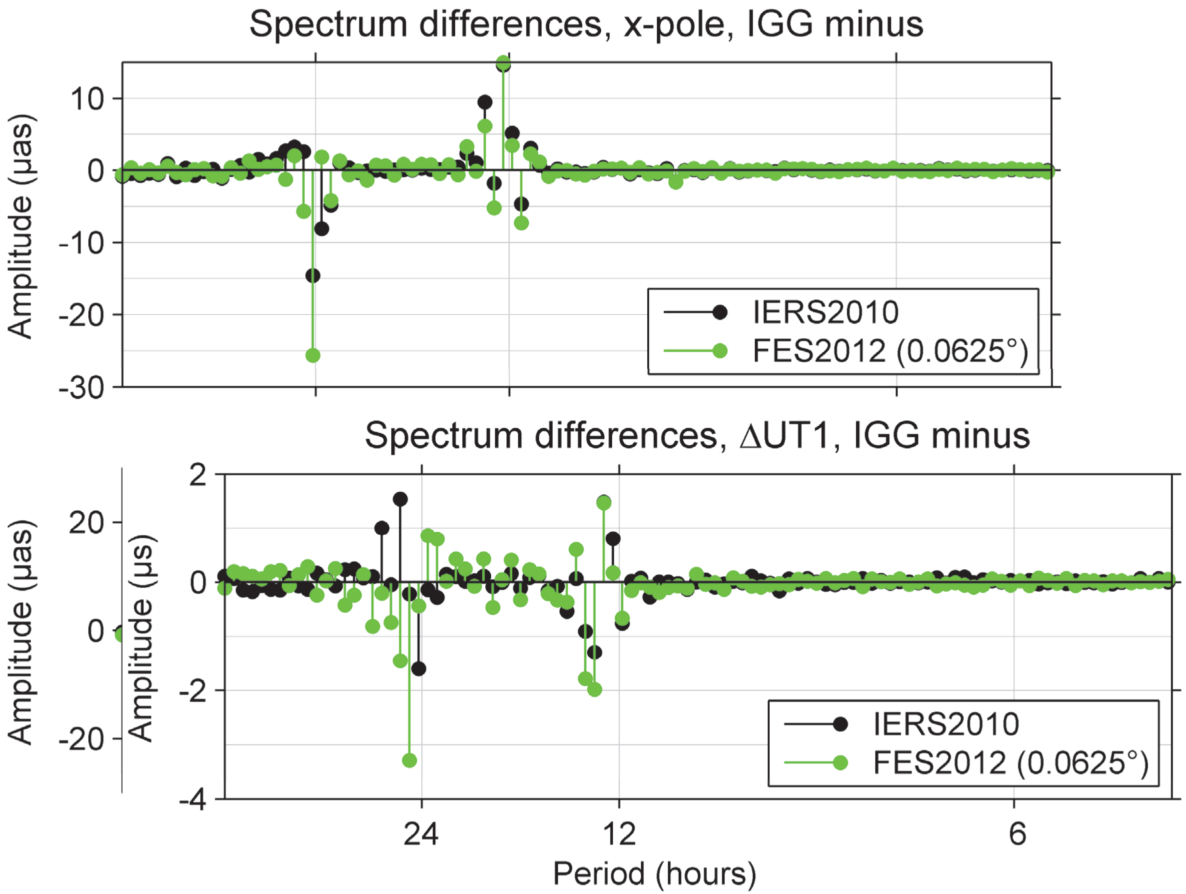
	Wang	Gutenberg	1066A	**PREM**
	polar motion for tide O1 (μas)			
p_x	268.6	263.5	265.7	269.3
p_y	−538.7	−528.4	−532.2	−540.4
	polar motion for tide K1 (μas)			
p_x	353.0	346.4	349.9	353.5
p_y	−696.0	−682.8	−688.5	−697.8
	polar motion for tide M2 (μas)			
p_x	313.0	307.2	310.7	313.3
p_y	−424.3	−416.4	−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

Earth model impact below 2%, but significant

$A, A_{\mathrm{c}}, C, C_{\mathrm{c}}$	Principle moments of inertia (Earth/Core)
$A_{\mathrm{m}} = A - A_{\mathrm{c}}$	Principle moment of inertia (Mantle)
$e = \dfrac{C-A}{A}$	Dynamical ellipticity (Earth)
$\epsilon = \dfrac{C_{\mathrm{c}}-A_{\mathrm{c}}}{A_{\mathrm{c}}}$	Dynamical ellipticity (Core)
$\tau = \dfrac{\Omega^2 a^5}{3GA}$	
$k^{\mathrm{L,T,d}}, h^{\mathrm{d}}$	Load, tidal and dynamic Love numbers
ϕ^{L}	Load potential
h	Relative angular momentum

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

2013	2014	2015
Implementation of *Ray (2001)* approach for determination of tidal current velocities	Estimation of minor tides from altimetry Extension of tidal constituents Implementation of PREM Earth model	Validation of individual components Validation of the SPOT model and first release

Thank you for your attention!

schuh@gfz-potsdam.de