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Numerical simulation of short period Earth rotation variations induced by ocean tides

Andreas Goss[1], Michael Schindelegger[2], Florian Seitz[1]

[1] Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM), Munich, Germany, Contact: andreas.goss@tum.de
[2] Vienna University of Technology, Department of Geodesy and Geoinformation, Vienna, Austria

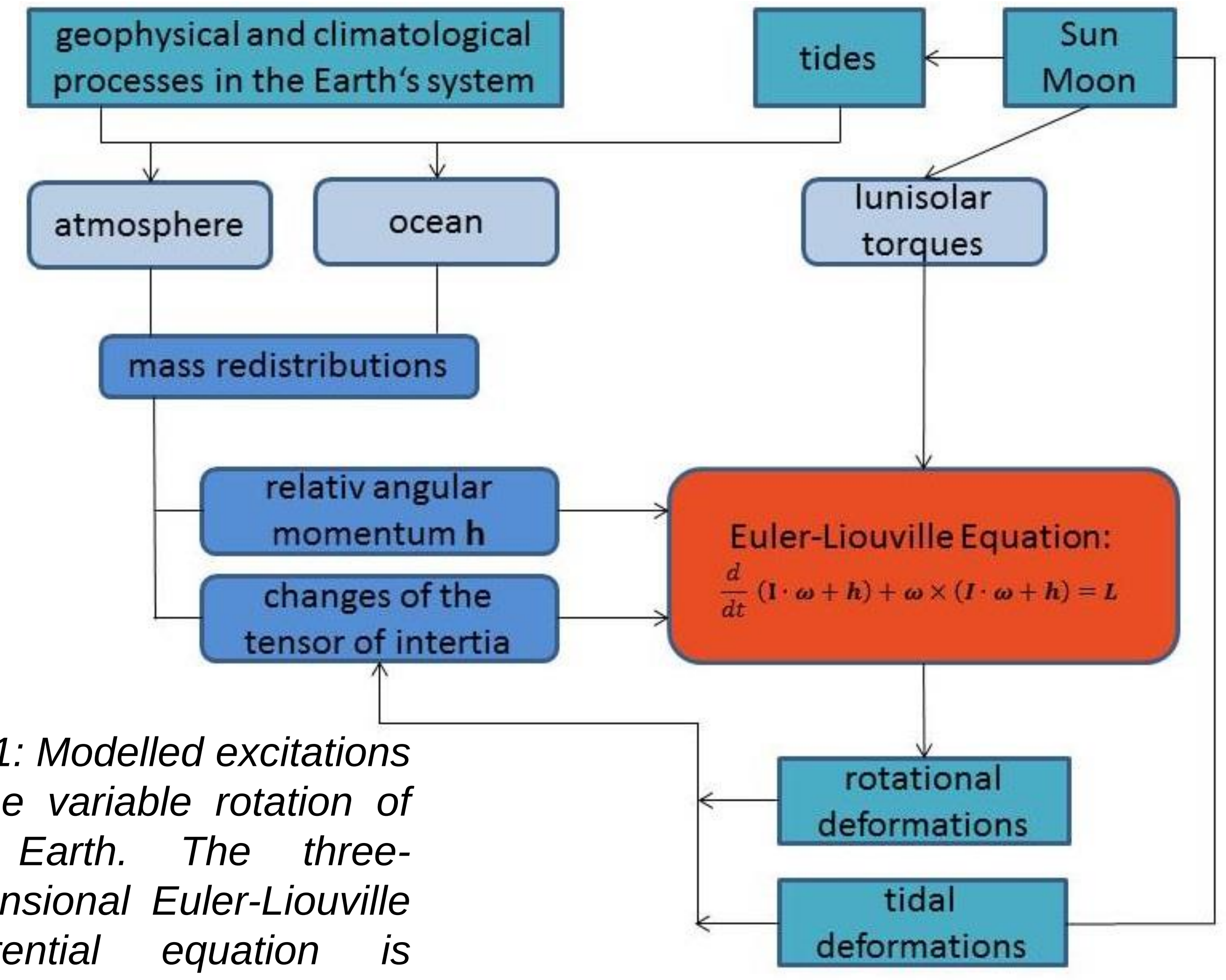
Introduction

The Dynamic Model for Earth Rotation and Gravity (DyMEG) has been used in several previous studies for the numerical simulation of Earth rotation parameters (ERP, polar motion and changes in length-of-day) on time scales from seasons to decades *(Seitz 2004*). Our current activities aim at the extension of the model and its application for the simulation of high frequency Earth rotation signals with periods of a few hours up to several days. This requires several model adaptations, such as the incorporation of additional excitation mechanisms as well as the identification and implementation of an appropriate numerical integrator.

Here, we particularly focus on simulating the effects of diurnal/semidiurnal ocean tides, non-tidal geophysical mass redistributions, and lunar gravitational torques ("libration") on the Earth's rotation. Polar motion and changes in length of day (ΔLOD) due to ocean tides and gravitational torques have a strictly periodic signal character and provide a good opportunity to evaluate the performance of the model. Specifically, we validate the simulated ERP time series against ocean tide and libration routines of the IERS (International Earth Rotation Systems Service, *Petit and Luzum 2010*) as well as analytical calculations of polar motion and ΔLOD perturbations.

Numerical Earth rotation simulator DyMEG

Temporal variations in the atmospheric and oceanic excitation cause mass redistributions in the Earth's system. Therefore temporal changes in the tensor of Inertia ***I(t)*** and relative angular momenta ***h(t)*** occur. Combined with the impact of gravitational lunisolar torques ***L(t)*** the Euler-Liouville Equation can be solved for the vector of the Earth's rotation ***ω(t)***.



geophysical and climatological processes in the Earth's system

tides

Sun
Moon

atmosphere

ocean

lunisolar torques

mass redistributions

relativ angular momentum **h**

changes of the tensor of intertia

Euler-Liouville Equation:

$$\frac{d}{dt}(\mathbf{I}\cdot\boldsymbol{\omega}+\mathbf{h})+\boldsymbol{\omega}\times(\mathbf{I}\cdot\boldsymbol{\omega}+\mathbf{h})=\mathbf{L}$$

rotational deformations

tidal deformations

*Fig. 1: Modelled excitations of the variable rotation of the Earth. The three-dimensional Euler-Liouville differential equation is solved for the vector **ω(t).***

The numerical simulations with DyMEG consider a triaxial tensor of inertia and higher order terms of the products of inertia. In analytical calculations higher order terms are usually neglected, and a biaxial tensor of inertia is applied.

Ocean tides

Mass redistributions in the ocean caused by gravitational tidal forces have the strongest impact on high-frequency Earth rotation variations. We incorporate this effect into DyMEG using time-discretized estimates of OAM (oceanic angular momentum) from *Chao et al. (1996)* for eight major ocean tides (M2, S2, N2, K2, K1, P1, O1, Q1). The correction routine of the IERS is based on the very same OAM terms and thus, both calculations (DyMEG, IERS) should yield very similar ERP signals (Figure 2). Note that in our simulations, effects of solid Earth deformations due to tides and loading are included. Rotational deformations of the Earth's mantle and the oceans are also taken into account.

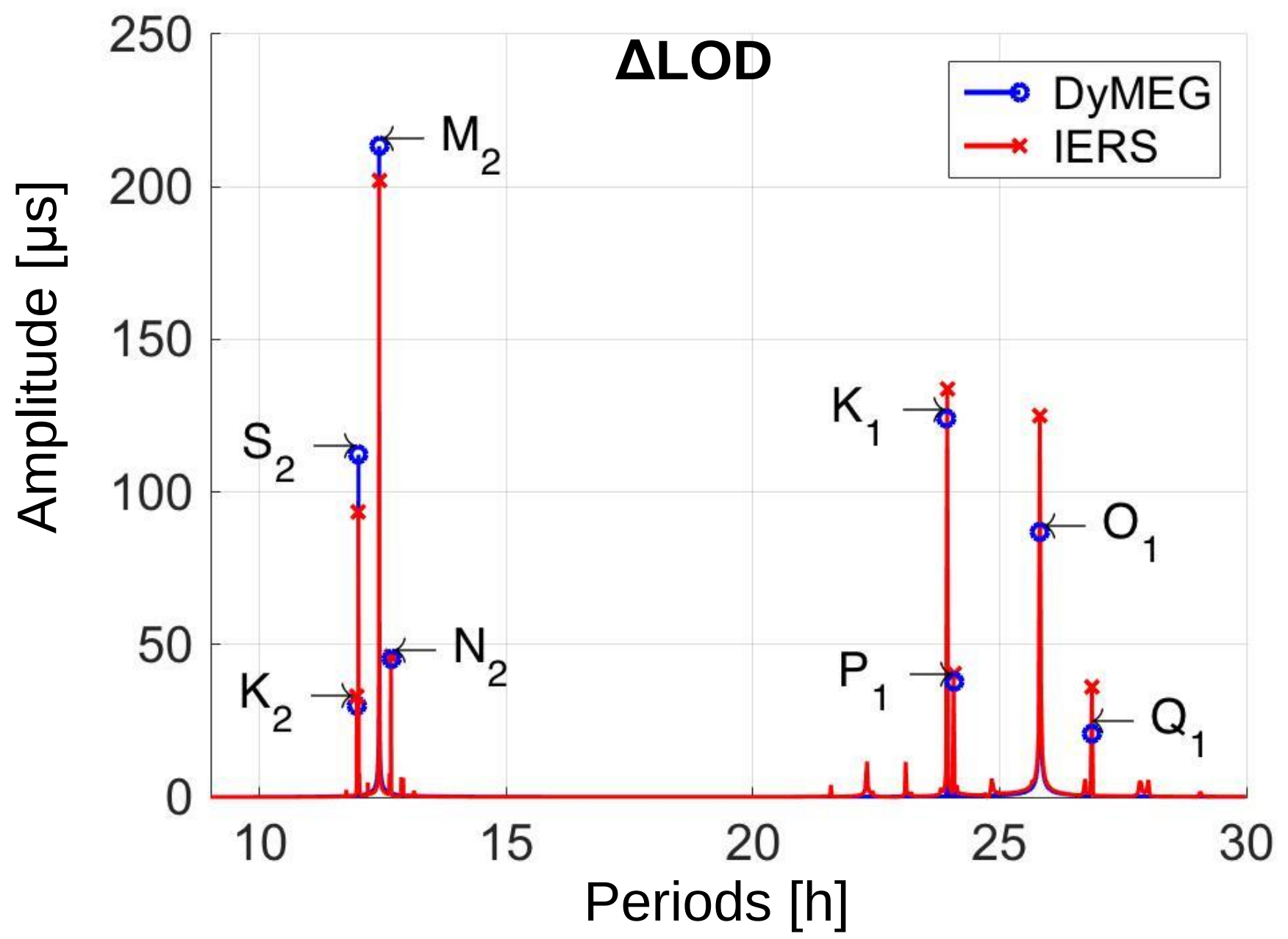


Fig. 2: Changes in length-of-day induced by diurnal/semidiurnal ocean tides as obtained from our DyMEG integration and the IERS conventional model.

Tides	DyMEG	IERS
Q1	$19^h\,55^m$	$18^h\,43^m$
O1	$19^h\,19^m$	$18^h\,23^m$
P1	$15^h\,32^m$	$16^h\,0^m$
K1	$16^h\,49^m$	$17^h\,44^m$
N2	$2^h\,16^m$	$1^h\,53^m$
M2	$3^h\,3^m$	$2^h\,28^m$
S2	$1^h\,2^m$	$0^h\,32^m$
K2	$7^h\,57^m$	$7^h\,25^m$

Table 1: Phase values of eight major ocean tides with respect to the 0 UTC, 1 January 2007.

Non-tidal atmospheric and oceanic excitation

Time series of atmospheric angular momentum for 2007-2009 were taken from MERRA (Modern-Era Retrospective Analysis for Research and Application). Consistent estimates of non-tidal OAM were derived from the pressure- and wind-driven barotropic ocean model DEBOT (David Einšpigel Barotropic Ocean Tide Model) at 3-hourly resolution. Hydrological influences are neglected. Below we compare the results from DyMEG with results obtained through the analytical deconvolution approach by *Brzeziński (1994).* Atmospheric and oceanic contributions to polar motion and ΔLOD are shown in separate panels.

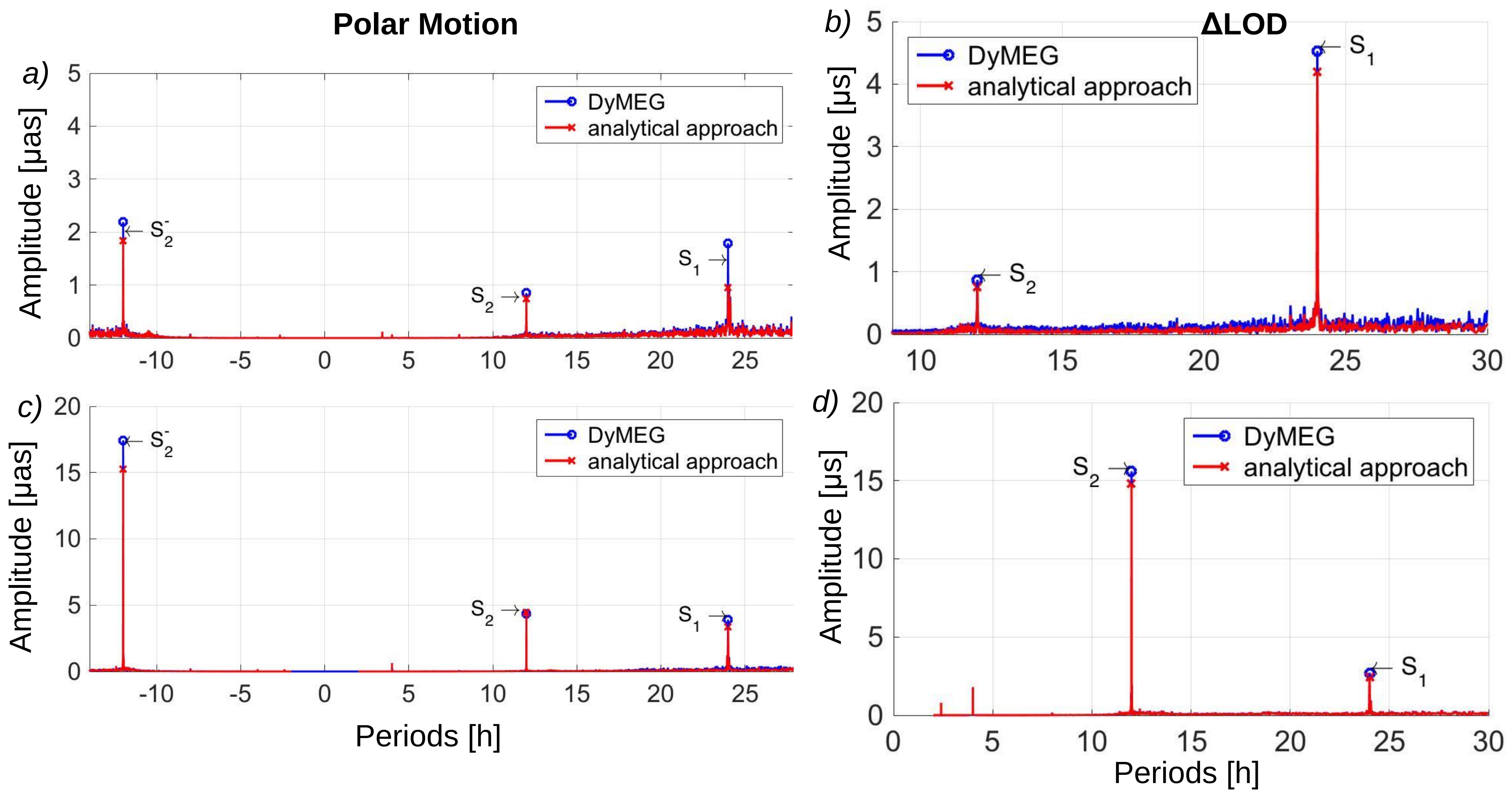


Fig. 3: Sub-diurnal variation in polar motion and ΔLOD caused by the atmosphere (a, b) and atmosphere-driven non-tidal oceanic mass redistributions (c, d).

Spin-wobble libration

External lunisolar torques on the triaxial Earth cause semidiurnal libration in ΔLOD (spin) and prograde diurnal libration in polar motion (wobble). The ephemerides data is provided by Jet Propulsion Laboratory (JPL) (*Standish* 1998) in the celestial system. The positions of the Sun and the Moon relative to the geocenter are evaluated in the terrestrial frame at each time step and transferred to torque quantities for use in the Euler-Liouville Equation.

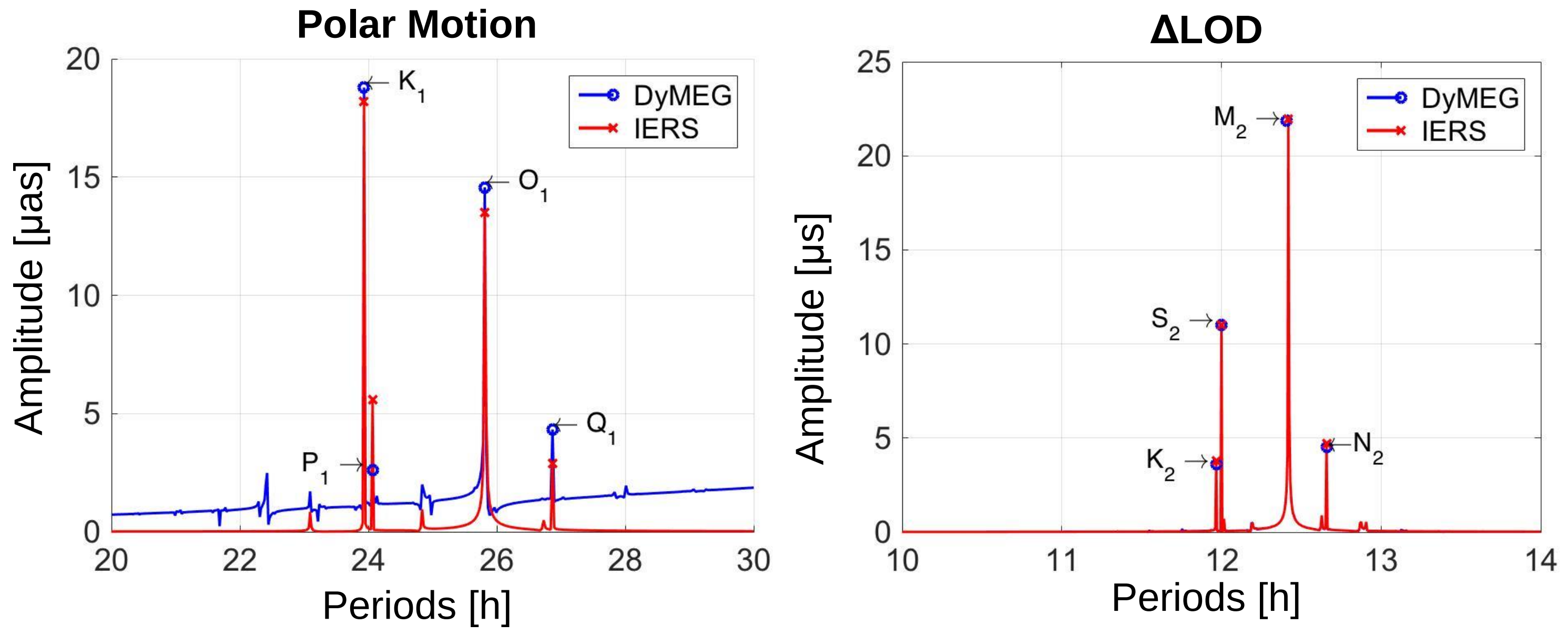


Fig. 4: Effects of the lunisolar gravitational torques on polar motion and ΔLOD at tidal frequencies. Results from DyMEG are compared with the conventional solution of the IERS.

Summary and Conclusion

ERPs have been simulated over the period between January 2007 and December 2009. The simulations with DyMEG result in realistic variations of the ERP for all tidal frequencies. Small discrepancies of the amplitudes between the numerical and the analytical solution require further analysis. They may be caused by numerical issues or by simplifications in the analytical approach. Differences in the phases are ascribed to the integration method of DyMEG. Comparisons of the ΔLOD spectra show a better analogy between the numerical and the analytical solution than the spectra for polar motion as the discrepancies of the amplitudes in the case of ΔLOD are smaller.

The strongest effect on ERP variations is caused by direct oceanic tides. Non-tidal oceanic effects induced by atmospheric tides have a larger influence than the atmospheric tides themselves. On higher frequencies the influence of the ocean is dominant in comparison to the atmosphere (Figure 3). Further investigations will address smaller discrepancies between the solutions.

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