THE OCEAN'S RESPONSE TO SOLAR THERMAL AND GRAVITATIONAL TIDES AND IMPACTS ON EOP

M. THOMAS, H. DOBSLAW and M. SOFFEL
Lohrmann Observatory,
Dresden Technical University,
Mommsenstraße, 13, 01062 Dresden, Germany,
Maik.Thomas@tu-dresden.de

ABSTRACT. By means of simulations with the Ocean Model for Circulation and Tides (OMCT) the impact of oceanic mass redistributions due to pressure loading of atmospheric tides and gravitational tides on oceanic angular momentum is estimated. OMCT is forced with the lunisolar gravitational tidal potential as well as atmospheric data, i.e., heat and freshwater fluxes, wind stresses, and atmospheric surface pressure. Since no barometric approximation is applied, the ocean's response to atmospheric pressure is allowed to be dynamic as well as static. While the diurnal pressure tide is well resolved from 6-hourly analyses generally provided by meteorological centers, the semidiurnal tide aliases into a standing wave due to insufficient temporal resolution. It is demonstrated that ECMWF's 3-hourly forecasts can be used to represent atmospheric mass redistributions and corresponding oceanic responses down to semidiurnal timescales and, consequently, to determine short-term effects of the atmosphere-ocean system on Earth's rotation.

1. INTRODUCTION

This paper discusses the ocean's response to diurnal (S_1) and semi-diurnal (S_2) solar thermal tides in the atmosphere and corresponding direct gravitational tides and its impact for the calculation of Earth's Orientation Parameters (EOP). The specific interest for that kind of investigations results from the fact that pressure induced and gravitational ocean S_1 and S_2 tides cannot be separated in the observations. While gravitational tides dominate mass redistributions in the oceans, their effect can almost be neglected in the atmosphere due to the comparatively low air density. Instead, pressure variations basically forced by solar radiation are well pronounced in the atmosphere, and these pressure tides in turn cause additional tides in the ocean due to atmospheric pressure loading. To separate gravitational and pressure tides, e.g., for barometric correction in altimetry data, numerical modelling is obviously a promising way.

In general, real time atmospheric mass distributions are derived from operational data provided by meteorological data centers, e.g., the National Centers for Environment Prediction (NCEP) and the European Centre for Medium Range Weather Forecasts (ECMWF). However, the frequently used analyses with typical sampling rates of 6 and 12 hours are insufficient to resolve semidiurnal signals. Since, e.g., a sampling rate of 6 hours exactly matches the Nyquist frequency of S_2, semidiurnal tides alias into a standing wave causing unrealistic atmospheric mass redistributions and corresponding ocean responses. Thus, a priori information about the propagating tidal wave is required generally provided by a time invariant model approach, although pressure tides have significant modulations on seasonal timescales [Haurwitz and Cowley, 1973; Ray and Ponte, 2003]. The central question that will be adressed here is if 3-hourly short-term forecasts provided by ECMWF can be employed to recover the semidiurnal thermal tide in the atmosphere in order to study its impact on ocean dynamics and Earth's rotation.

2. MODELING THE OCEAN'S RESPONSE TO THE DIURNAL AND SEMIDIURNAL THERMAL ATMOSPHERIC TIDES

For modeling the ocean's response to atmospheric as well as to luni-solar tidal forcing the Ocean Model for Circulation and Tides (OMCT) developed by the first author (M.T.) was employed. The numerical model is based on nonlinear balance equations for momentum, the continuity equation, and balance equations for heat and salt. The time step used is half an hour, the horizontal resolution is constant 1.875° in latitude and longitude, and 13 layers exist in the vertical. Implemented is a prognostic sea-ice model that predicts ice-thickness, compactness, and drift. Secondary effects arising from loading and self-attraction of the water column are taken into account. Atmospheric forcing enters as boundary conditions at the ocean's surface embracing atmospheric pressure, wind stresses, heat and fresh-water fluxes (precipitation and evaporation). No assumption on the ocean's response to atmospheric forcing (e.g., as inverted barometer) is applied; thus, the model allows for static as well as dynamic responses to atmospheric pressure.

To estimate the gravitational contribution to the principal diurnal and semidiurnal solar tides S_1 and S_2, a first run of OMCT was exclusively driven by the complete luni-solar tidal potential. In Figure 1 simulated mean harmonic oscillation systems of gravitational ocean tides S_1 and S_2 are given. While S_2 amplitudes reach about 30 cm in large areas, S_1 amplitudes generally do not exceed 1 cm due to adverse geometric resonance conditions.

In two further simulations gravitational forcing was turned off and only atmospheric forcing was considered to estimate circulation induced mass redistributions at S_1 and S_2 frequencies. The simulations with atmospheric forcing start from an initial climatological run that was followed by a real-time simulation for the period 1958-2000 driven by 6-hourly atmospheric fields from ECMWF's reanalysis project ERA-40. The resulting model state has been used as a common initial state for the simulations with operational atmospheric forcing. In addition to frequently used 6-hourly analyses, ECMWF operationally provides short to medium range forecasts of the transient atmospheric state. Medium range forecast runs are performed twice-daily for up to 10 days ahead and forecast fields are available with a temporal resolution of 3 hours.

Figure 2 shows rms-differences of the ocean's response to atmospheric forcing with analysis

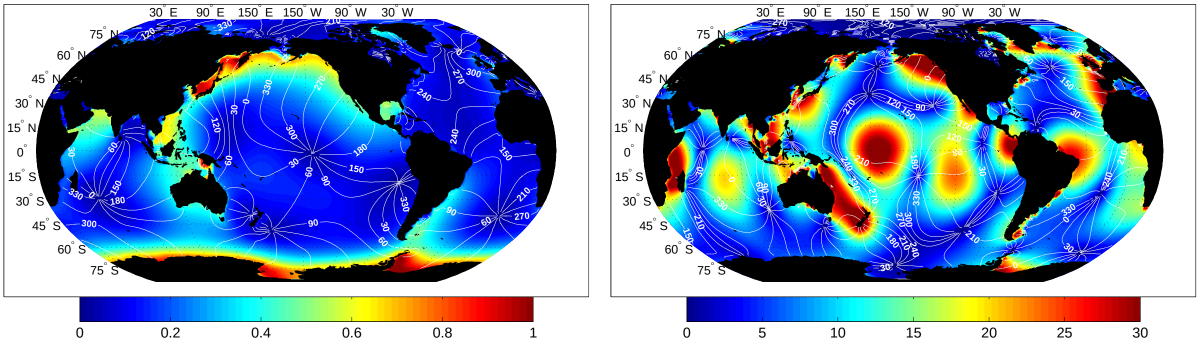

Figure 1: Simulated gravitational ocean tides S_1 (left panel) and S_2 (right panel); amplitudes are in [cm], Greenwich phases in degree.

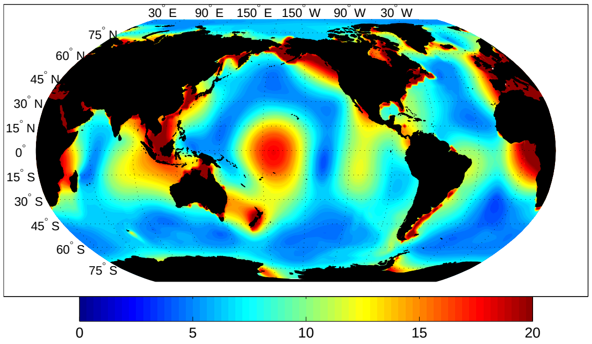

Figure 2: Total rms-differences in [cm] of the ocean's response to atmospheric forcing with analysis and forecast data.

and forecast data reaching about 20 cm in some coastal regions. These differences result from forecast errors, different wind representations (instantaneous wind velocities from analyses, accumulated wind stresses from forecasts), and different sampling rates. It can be shown that various wind representations and forecast errors are responsible for only small differences whereas the main contribution to deviations between ocean simulations driven by analyses and forecasts can be attributed to the different sampling rates.

According to Dobslaw and Thomas [2005], the mean diurnal signal in atmosphere and oceans associated with the pressure tide S_1 as deduced from 6-hourly analyses and 3-hourly forecasts and corresponding oceanic simulations are quite similar. The typical westward propagating atmospheric pressure wave is well developed, and the ocean answers, e.g., with an anticlockwise rotating wave in the Pacific with amplitudes up to about 1.5 cm. The situation is very different for S_2. Since a sampling rate of 6 hours exactly matches the Nyquist frequency, the S_2 representation within analyses aliases into an unphysical standing wave causing significant artificial momentum transfer into the oceans. In contrast to analyses, 3-hourly forecasts allow the resolution of semidiurnal waves as shown in Figure 3. The westward propagating wave in the atmosphere is well pronounced, and the corresponding oceanic response shows typical features of semidiurnal ocean tides, e.g., the anticlockwise propagating Kelvin wave around New Zealand.

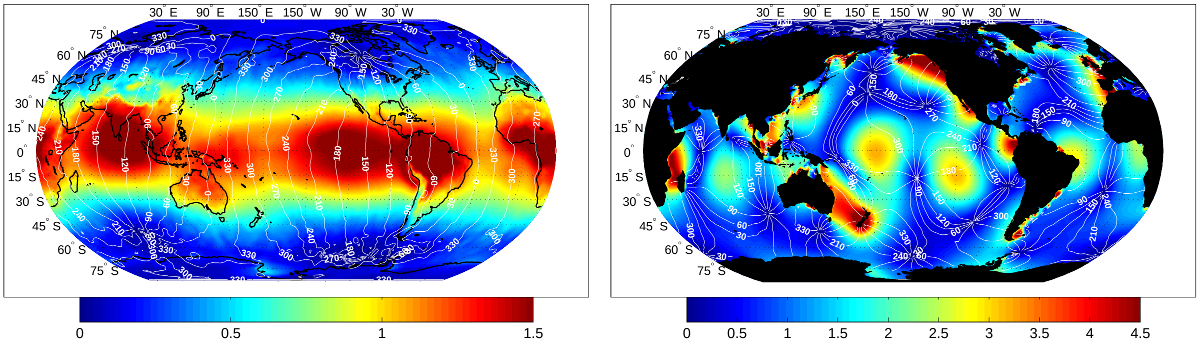

Figure 3: Pressure tide S_2 in the atmosphere (left panel, amplitudes in [hPa], phases in degree) according to 3-hourly forecasts and corresponding oceanic response (right panel, amplitudes in [cm], Greenwich phases in degree).

3. OCEANIC ANGULAR MOMENTUM

Semidiurnal and diurnal oceanic mass redistributions due to gravitational and pressure induced tides are acompanied by variations of oceanic angular momentum and, consequently, affect the Earth's rotation parameters. Corresponding mean diurnal and semidiurnal amplitudes and phases are given in Table 1. As expected for the S_1 tide the calculations with analyses and forecasts gave similar results whereas for the S_2 tide they differ significantly with deviations of order $0.25 \times 10^{24}\,\mathrm{kg\,m^2s^{-1}}$.

Table 1: Simulated mean oceanic angular momentum amplitudes A in $[10^{24}\ \mathrm{kgm^2s^{-1}}]$ and phases P in degree due to gravitational and pressure induced tides S_1 and S_2.

tide	x_1				x_2				x_3			
	mass		motion		mass		motion		mass		motion	
	A	P	A	P	A	P	A	P	A	P	A	P
$S_1(grav.)$	0.109	352.4	0.135	15.2	0.109	313.6	0.191	232.3	0.266	226.0	0.125	187.9
$S_1(press.)$	0.310	349.7	0.036	81.9	0.196	139.4	0.242	318.1	0.061	192.7	0.398	110.0
$S_2(grav.)$	0.820	24.9	4.869	291.4	1.320	33.0	8.002	199.4	3.111	115.3	6.9360	331.2
$S_2(press.)$	0.0751	119.3	0.488	48.8	0.123	196.3	0.804	320.2	0.221	214.6	0.568	106.8

4. CONCLUDING REMARKS

One may conclude by stating that 3-hourly operational forecasts allow the reconstruction of atmospheric mass redistributions and corresponding oceanic responses down to subdaily timescales and, consequently, to consider the transient impact of semidiurnal pressure tides, too. In contrast to previous calculations no a priori information about mean oscillations were introduced and the complete transient atmospheric dynamics could be used to force the ocean model. Thus, 3-hourly short-term forecasts provide an opportunity to determine the impact of semidiurnal signals in the coupled atmosphere-ocean system on high-resolution Earth rotation parameters, geocenter variations, and short-term gravity variations. Finally, the suggested approach allows a separation of gravitational and pressure induced tides at S_1 and S_2 frequency.

REFERENCES

Dobslaw, H., and M. Thomas, 2005, Atmospheric induced oceanic tides from ECMWF forecasts, Geophys. Res. Lett., 32, L10615, doi:10.1029/2005GL022990.

Haurwitz, B., and A. D. Cowley, 1973, The diurnal and semidiurnal barometric oscillations, global distribution and annual variation, Pure Appl. Geophys., 102, pp. 193–222.

Ray, R.D., and R. M. Ponte, 2003, Barometric tides from ECMWF operational analyses, Ann. Geophys., 21, pp. 1897–1910.