ON THE INFLUENCE OF DIURNAL ATMOSPHERIC TIDES ON EARTH ROTATION

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ABSTRACT. We give a general description of the perturbations of Earth rotation caused by diurnal thermal tides in the atmosphere and the oceans, and briefly overview the observation and modeling efforts. We also report on own estimation using the available high resolution atmospheric and oceanic excitation data and the space-geodetic observations of Earth rotation. Parameters of the S1 component of excitation, estimated from geophysical models and observations, are compared to each other.

1. INTRODUCTION

Diurnal atmospheric tides are global-scale waves excited by the differential heating of the Sun (thermal tides) and, to a much lesser extent, by the gravitational lunisolar tidal force; for detailed description see the review paper by Volland (1997) and the references therein. The basic frequency is 1 cycle per solar day (cpd). But the departures from the sinusoidal pattern (e.g. the diurnal cycle in solar heating is close to a slightly smoothed 2-valued step function) and the differences near the ground (due to irregular ocean-continent distribution, topography, cloudiness, ice coverage, vegetation, etc.) produce additional harmonics with frequencies k cpd, where k is integer. According to Volland (1997), only harmonics with k=1,2,3 are significant. The atmospheric tides are coherent with gravitational tides therefore it is generally accepted to label them using the standard notation introduced to the tidal research by George Darwin. Hence, components with frequencies 1, 2, and 3 cpd are designated S_1, S_2, S_3, respectively.

The main diurnal and subdiurnal harmonics of thermal origin subject to seasonal modulations (annual, semiannual) producing side lobes shifted in frequency by ± 1, ± 2 cycles per year (cpy) with respect to the main spectral line. Hence, the annual modulation of S_1 gives rise to the P_1 and K_1 harmonics, while the semiannual modulation produces the π_1 and Ψ_1 terms. The side lobes of S_2 are the R_2, T_2 components (annual modulation) and the K_2, P_2 components (semiannual modulation).

The time variation of the atmospheric angular momentum (AAM) exhibits a similar spectral structure as the contributing meteorological quantities, that is the surface pressure and the wind velocity (Bizouard et al., 1998; Brzeziński et al., 2002; Brzeziński et al., 2004). But it is important to note that the standard sampling of AAM is 6 hours which is sufficiently short for estimation in the diurnal band, but not short enough for resolving the semidiurnal band where only rough overall estimate is possible. Of course, this sampling is not adequate for studying the terdiurnal variations.

The large-scale variations in the atmosphere influences the oceans giving rise to the nontidal diurnal and subdiurnal signals. Such signals can be estimated from the available time series of nontidal ocean angular momentum (OAM) evaluated using the outputs of the numerical ocean general circulation models with subdiurnal resolution (e.g., Brzeziński et al., 2004). A more sophisticated hydrodynamic ocean models have been also developed to estimate the diurnal and subdiurnal components of OAM (e.g., Ray and Egbert, 2004). Such an approach is expected to provide more realistic results than from the OAM series; on the other hand this model expresses only the harmonic components neglecting the effects of seasonal modulations. Again, as the atmospheric fields used to force the ocean models are sampled 4-times daily, the same limitations for the use of OAM apply as in case of the AAM data.

It follows from the conservation law of angular momentum that diurnal and subdiurnal signals in AAM and OAM influence all components of Earth rotation vector, including polar motion, nutation and UT1 variation. For each harmonic component the observed effect is a mixture of thermal influence expressed by AAM+OAM, and the ocean tide contribution directly related to gravitational forcing. The ratio of contributions from the thermal and ocean tide forcings is about 10/1 for S_1 and 1/20 for S_2

(Brzeziński et al., 2004); in case of S_3 the gravitational signal is negligible therefore any possible observed effect should be entirely of thermal origin. The side lobes of S_1 and S_2 appear to be dominated by the ocean tide contributions.

Our purpose here is to estimate from geophysical models the influence of diurnal atmospheric tides on Earth rotation and compare this result to the observations by space geodesy. We neglect the terdiurnal variations which cannot be estimated from standard geophysical models. When considering the diurnal and semidiurnal variations it appears that in most cases the thermal contributions can hardly be separated from much larger ocean tide influences. The only exclusion is the S_1 Sun-synchronous term of excitation which will be considered in details below.

2. DATA ANALYSIS AND RESULTS

The equatorial retrograde component of S_1 contribute to prograde annual nutation while its prograde counterpart influences diurnal polar motion. The S_1 term in the axial component of excitation gives rise to a 24-hours component in UT1.

The estimation of the contribution of S_1 from the space-geodetic observations of Earth rotation is possible, though difficult for the following two reasons: 1) the signal is relatively small, the maximum peak-to-peak size is only 200 to 300 microarcseconds (μas); and 2) the estimation can be corrupted by different Sun-synchronous errors, e.g. those due to the thermal deformation of the VLBI antennas. We use in comparisons the following estimates of the S_1 contribution to prograde polar motion and to UT1

VLBI1: (Bolotin and Brzeziński, 2006), input data span 1984–2005;

VLBI2: (Gipson, 1996), input data span 1979–1994;

GPS: (Rothacher et al., 2001), data span 1995–1998.1.

We also use the VLBI observation of prograde annual nutation and the geophysical contributions derived by Mathews et al. (2002).

The parameters of the S_1 harmonic in the atmospheric angular momentum and the corresponding contributions to Earth rotation have been estimated from the following AAM data sets which are available from the International Earth Rotation and Reference Systems Service Special Bureau for the Atmosphere (IERS SBA):

AAM1, AAMIB1: NCEP-NCAR reanalysis data (Kalnay et al., 1996; Salstein and Rosen, 1997), period 1948–2006; sampling interval 6 hours;

AAM2: ERA-40 reanalysis model (Uppala et al., 2004)), period 1948–2004, sampling interval 6 hours;

AAM2′: ECMWF operational data, period 1993.0–1996.5, sampling interval 6 hours with gaps;

AAM3, AAMIB3: JMA operational data, period 1993.3–2000.5, sampling interval 6 hours with gaps.

The corresponding contributions of the S_1 harmonic in nontidal oceanic angular momentum have been estimated from the following models

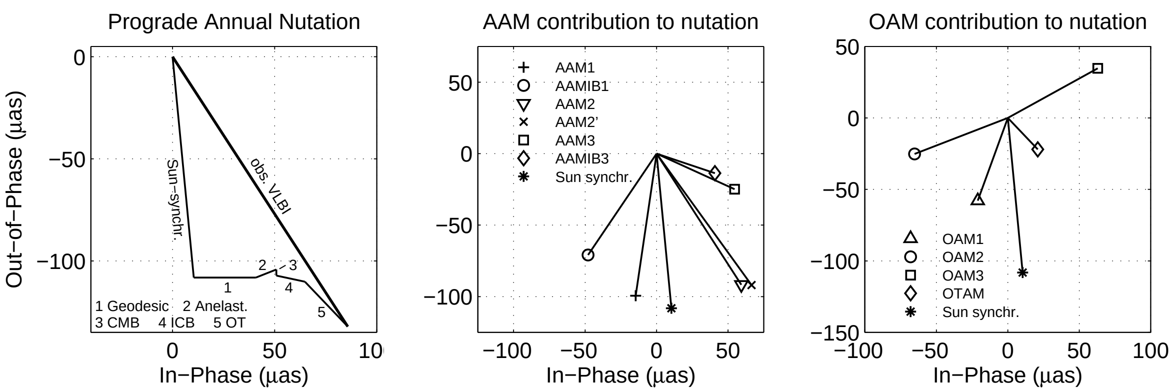

Figure 1: Atmospheric and oceanic contributions to prograde annual nutation: model MHB 2000 (left) vs. modeled geophysical contributions, atmospheric (middle) and oceanic (right).

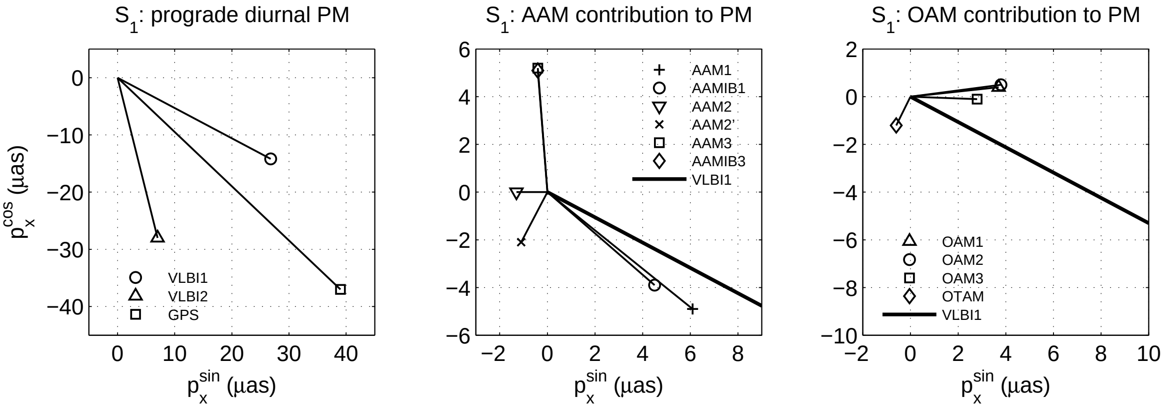

Figure 2: Atmospheric and oceanic contributions to prograde diurnal polar motion, S1 term: space-geodetic observations (left) vs. modeled geophysical contributions, atmospheric (middle) and oceanic (right).

OAM1: hydrodynamic model of the S1 component (Ray and Egbert, 2004);

OAM2: barotropic model (Ponte and Ali, 2002; Brzeziński et al., 2004) forced by wind and atmospheric pressure fields from the NCEP-NCAR reanalysis model, period 1993.0–2000.5, sampling interval 1 hour;

OAM3: ocean model for circulation and tides (OMCT) (Thomas et al., 2001) forced by wind and pressure fields from the model ERA-40, period 1963–2001, sampling interval 30 minutes.

Parameters of the S_1 term estimated from the atmospheric and oceanic models are compared to the parameters derived from observations in Figures 1, 2 and 3.

Precession-nutation (Fig.1). The left diagram shows the correction to the amplitude of the prograde annual nutation together with the theoretical contributions from 1) geodesic nutation, 2) mantle anelasticity, 3) coupling at the core-mantle boundary, 4) coupling at the inner core boundary, and 5) ocean tide (Mathews et al., 2002, Table 2). The remaining part denote "Sun-synchronous" is expected to express the combined influence of the S_1 harmonic in AAM and OAM. There is a rough agreement between the estimated contributions of AAM. The best agreement with observation is obtained the non-IB NCEP-NCAR reanalysis series. The contributions from OAM are only slightly smaller than those from AAM, but there are large differences in phase. Particularly surprising is that the OMCT and barotropic OAM yield almost opposite results. The best agreement with observations is found for the hydrodynamic model of OAM combined with ERA-40 AAM.

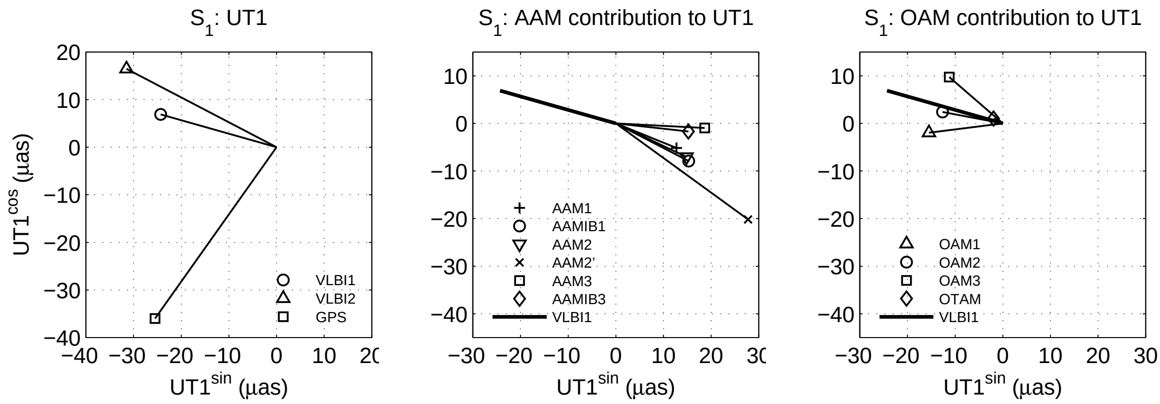

Figure 3: Atmospheric and oceanic contributions to diurnal variation of UT1, S1 term: space-geodetic observations (left) vs. modeled geophysical contributions, atmospheric (middle) and oceanic (right).

Prograde polar motion (Fig.2). The amplitudes estimated from the VLBI data are of the order of 30 μas while the analysis of data from GPS yields almost 2 times larger value. The estimated total contribution from the atmosphere and ocean is only about 8 μas, about 4 times less than the VLBI value. The OAM results are coherent while there are large differences between the estimated contributions of AAM. The best agreement with observations is found for the barotropic OAM combined with the NCEP-NCAR reanalysis AAM.

UT1 (Fig.3). The 2 estimates from VLBI are of the order of 30 μas and agree with each other, while the amplitude from GPS is larger than 40 μas and its argument differs from VLBI results by about 90 degrees. There is a good agreement between the estimated contributions of AAM with exception of the value derived from the operational ECMWF data which is of poor quality. There is also quite a good agreement between different values of OAM. Unfortunately, the contributions of AAM and OAM tend to cancel each other and the total effect does not agree with the observation.

3. SUMMARY AND CONCLUSIONS

The diurnal cycle in solar heating give rise to variations in AAM and OAM with main components S1, S2 of periods 24 and 12 hours, and their side lobes due to seasonal modulations. These variations of AAM and OAM excite small perturbations in all three components of Earth rotation, including precession-nutation, polar motion and UT1. So far, only the S1 contributions to Earth rotation could be detected in both geophysical models and space-geodetic observations. However, comparison done in this work revealed significant differences between estimates from different models and different observation techniques, as well as between the models and observation. Investigations should be continued using improved geophysical models and space-geodetic data derived by improved reduction procedures.

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