Diurnal excitation of Earth rotation estimated from recent geophysical models

Aleksander Brzeziński

Faculty of Geodesy and Cartography, Warsaw University of Technology, Warsaw, Poland
&
Space Research Centre, Polish Academy of Sciences, Warsaw, Poland
alek@cbk.waw.pl

presented at

Journées 2010 "Systèmes de Référence Spatio-Temporels"
Paris, 20–22 September 2010

The author expresses his sincere thanks for the travel grant provided by the Local Organizing Committee of the Journées 2010.

Introduction

The problem

- nearly diurnal variations in distribution of the atmospheric and oceanic masses and in the pattern of winds and ocean currents, associated with the daily cycle in solar heating, change the angular momentum of these two media (AAM, OAM)
- diurnal variations of AAM and OAM excite small, below 1 milliarcsecond (mas), but already well detectable variations in all components of Earth rotation including precession-nutation, polar motion and UT1/LOD
- understanding this effect is important for modeling global dynamics of the solid Earth and its external fluid layers at daily and subdaily periods.

Objectives of the presentation

- to give a general description of the perturbations of Earth rotation caused by diurnal thermal tides in the atmosphere and in the oceans and overview the modeling and observation efforts
- to estimate diurnal atmospheric and nontidal oceanic excitations of Earth rotation using a new consistent set of 20-year excitation time series produced by the IERS Associated Product Centre at the GFZ Potsdam (courtesy of Henryk Dobslaw)
- to compare the estimated parameters to earlier results based on different excitation data and to the observations by space geodesy.

General description (1)

Diurnal atmospheric tides: theory

- main origin: differential heating of the Sun
- basic frequency: 1 cycle per (solar) day (cpd)
- departures from the sinusoidal pattern and the differences near the ground (due to ocean-continent distribution, topography, cloudiness, ice coverage, vegetation, etc.) produce additional harmonics with frequencies k cpd, k=2,3,... (assumed to be negligible for k>3)
- atmospheric tides are coherent with gravitational tides therefore are usually labeled in the same way, using the standard convention introduced by George Darwin: S_1, S_2, S_3
- all diurnal and subdiurnal harmonics (S_1, S_2, S_3) of thermal origin subject to seasonal (annual, semiannual) modulations producing side lobes shifted in frequency by ± 1, ± 2 cycles per year (cpy), respectively
- harmonic components are superimposed on the background variation of stochastic character

For further details concerning the diurnal atmospheric tides see the standard textbooks like (Chapman and Lindzen, 1970; Volland, 1988; 1997).

General description (2)

Diurnal atmospheric tides: observational evidence from the high resolution geophysical excitation data

- manifested by periodic and quasi-periodic variation of the AAM
- similar effect in the nontidal OAM due to the ocean response to the atmospheric forcing
- side lobes produced by seasonal modulations:
  - S_1: annual modulation $\Rightarrow(P_1,\ K_1)$, semiannual modulation $\Rightarrow(\pi_1,\ \Psi_1)$
  - S_2: annual modulation $\Rightarrow(R_2,\ T_2)$, semiannual modulation $\Rightarrow(K_2,\ P_2)$
- after removal of the harmonic model from AAM and OAM there still remains some power around the main spectral lines, particularly S_1, which expresses stochastic component of the atmospheric tide
- when considering the influence on Earth rotation, the diurnal and semidiurnal harmonics of AAM and OAM are superimposed on the harmonics with the same frequencies but produced by the gravitational ocen tides

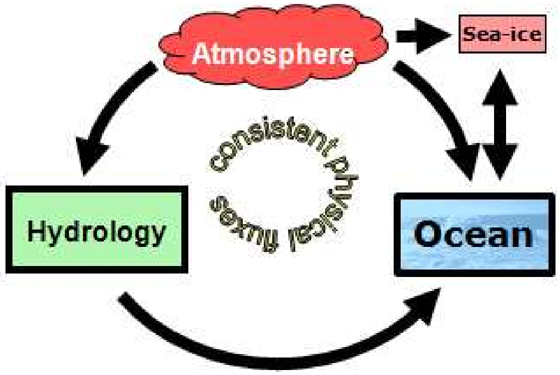
$\Longrightarrow$ With exception of S_1, in all cases the ocean tide contributions to global ocean AM are significantly larger than the corresponding terms of AAM and OAM

Diurnal atmospheric tides: observational evidence from the space geodetic measurements of Earth rotation

- the retrograde S_1 term of the equatorial AAM/OAM contributes to the prograde annual nutation; this contribution has been included in the IAU 2000 precession-nutation model as the so-called Sun-synchronous empirical correction (Mathews et al., 2002)
- diurnal and semidiurnal harmonic components of polar motion and UT1/LOD have been estimated from VLBI, SLR and GPS observations
  - only the S_1 component of the atmospheric thermal tides is significantly larger than the corresponding ocean tide effect (ca. 7:1 in our estimation)
  - problem: estimation of S_1 can be corrupted by different Sun-synchronous errors: thermal effects, direct atmospheric influence upon the instruments and the recorded signals
- there were several attempts to estimate the S_3 (8-hour) harmonic from the continuous observation campaigns, but they have been not conclusive so far
- stochastic component of excitation by the atmospheric diurnal tides needs regular monitoring

For further details about the S_1 atmospheric tide and its contribution to Earth rotation see the paper (Brzeziński, in.: Proc. Journees 2007) and the references therein.

Data sets



Produced by the IERS Associated Product Centre Deutsches GeoForschungsZentrum Potsdam

AAM: ERA Interim re-analysis from ECMWF (Uppala et al., 2008)

- $1^\circ \times 1^\circ$ regular grids,
- 37 vertical pressure levels,
- pressure term with the inverted barometer (IB) correction.

OAM: Ocean Model for Circulation and Tides (OMCT; Dobslaw and Thomas, 2007)

- discretized on a regular $1.875^\circ \times 1.875^\circ$ grid,
- 13 vertical layers,
- forced by wind stress, atmospheric pressure, 2m-temperatures, and freshwater fluxes from both atmosphere and continental hydrosphere; tidal forcing not included.

AAM and OAM series span the period between 1989.0 and 2009.0 with 6-hourly sampling.

Data analysis

We follow the scheme developed by Bizouard et al. (1998) and Brzeziński et al. (2004):

- extract diurnal components of the AAM/OAM functions by applying the procedure of complex demodulation at frequencies ± 1 cycle per sidereal day (cpsd)
  - equatorial component -1 cpsd $\Longrightarrow$ nutation
  - equatorial component $+1$ cpsd $\Longrightarrow$ prograde diurnal polar motion
  - axial component $+1$ cpsd $\Longrightarrow$ diurnal UT1/LOD variation
- perform the maximum entropy method (MEM) spectral analysis of the demodulated series
- find the best least-squares fit of the model comprising a sum of complex sinusoids with periods ± 1, $\pm 1/2$, $\pm 1/3$ years and the 1-st order polynomial
- convolve the estimated parameters of the model with theoretical transfer function in order to compute the atmospheric/oceanic contributions to nutation, polar motion and UT1/LOD
- compare results to
  - our earlier estimate (Brzeziński et al., 2004) based on the NCEP/NCAR reanalysis AAM data and OAM from the barotropic ocean model of Ponte and Ali (2002)
  - the determinations from VLBI observations by Mathews et al. (2002) and Gipson (1996).

Results: atmospheric-oceanic excitation of nutation

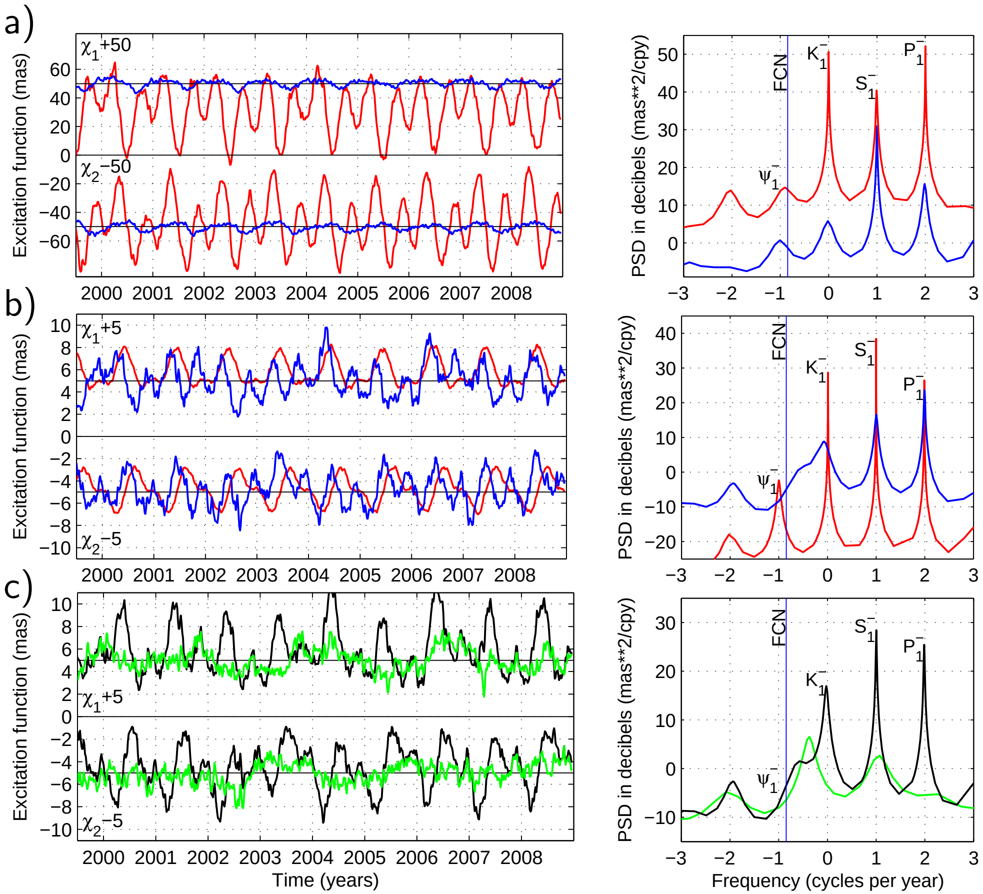


Figure 1: Equatorial EAM functions demodulated at frequency −1 cpsd (so-called celestial EAM functions) of the atmosphere (red), ocean (blue): a) motion term, b) mass term, c) mass term of AAM+OAM, original (black) and after removal of the sinusoidal-linear model (green). Period of analysis 1989.0–2009.0.

Table 1: Periodical components of the atmospheric and nontidal oceanic contributions to nutation. VLBI estimate taken from the MHB 2000 model (Mathews et al., 2002). Units are μas.

Excit. term	Brzeziński et al., 2004 in-phase	Brzeziński et al., 2004 out-of-phase	This study in-phase	This study out-of-phase
	excitation: ψ_1^- component, nutation: retrograde annual			
A presIB	51.8 ±27.2	51.3 ±27.2	50.5 ±6.4	−43.6 ±6.4
A wind	6.9 ±2.3	9.2 ±2.3	7.2 ±1.7	2.6 ±1.7
O mass	3.1 ±39.9	124.0 ± 39.9	−5.3 ±31.1	8.9 ± 31.1
O veloc.	−0.6 ±0.7	0.8 ±0.7	0.2 ±0.3	1.5 ±0.3
AIB+O	**61.2 ±48.3**	**185.3 ±48.3**	**52.6 ±31.8**	**−30.6 ±31.8**
	excitation: S_1^- component, nutation: prograde annual			
A presIB	−40.8 ±2.1	−44.0 ±2.1	27.7 ±0.4	−53.2 ±0.4
A wind	−7.1 ±0.7	−26.9 ±0.7	−2.4 ±0.5	−21.1 ±0.5
O mass	−68.6 ±4.3	−22.3 ±4.3	39.8 ±1.7	−6.4 ±1.7
O veloc.	3.4 ±0.3	−2.9 ±0.3	−4.5 ±0.2	−3.2 ±0.2
AIB+O	**−113.1 ±4.8**	**−96.1 ±4.8**	**+60.6 ±1.8**	**−83.9 ±2.8**
VLBI	10.4	−108.2	10.4	−108.2
	excitation: P_1^- component, nutation: prograde semian.			
A presIB	−11.3 ±0.9	4.7 ±0.9	4.7 ±0.3	−17.7 ±0.3
A wind	−6.2 ±0.6	−38.9 ±0.6	−12.9 ±0.6	−43.1 ±0.5
O mass	16.4 ±2.7	2.2 ±2.7	37.4 ±1.3	6.8 ±1.2
O veloc.	−0.6 ±0.2	0.1 ±0.2	−0.7 ±0.2	2.1 ±0.2
AIB+O	**−1.7 ±2.9**	**−31.9 ±2.9**	**31.5 ±1.5**	**−51.9 ±1.3**

Results: atmospheric-oceanic excitation of prograde diurnal polar motion

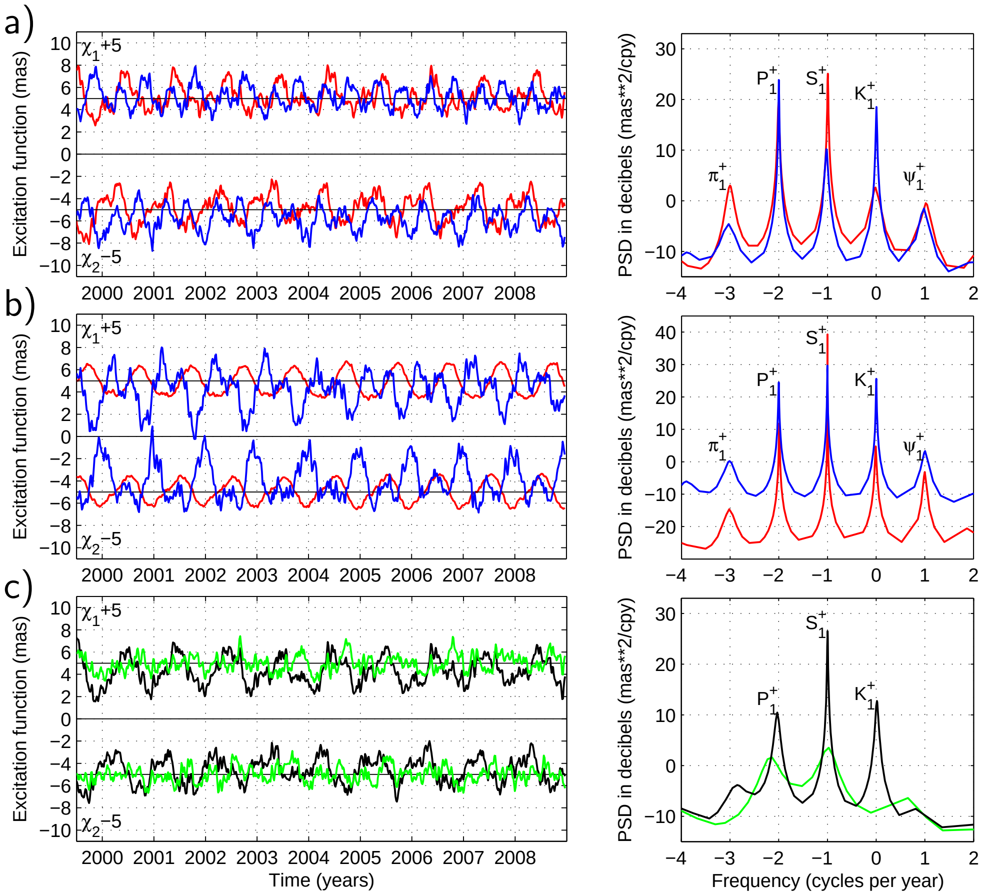


Figure 2: Equatorial EAM functions demodulated at frequency +1 cpsd, of the atmosphere (red), ocean (blue): a) motion term, b) mass term, c) mass+motion of the combination AAM+OAM, original (black) and after removal of the sinusoidal-linear model (green). Period of analysis 1989.0–2009.0.

Table 2: Atmospheric and nontidal oceanic contributions to prograde diurnal polar motion. VLBI estimate taken from Gipson (1996). Units are μas.

Term	Brzeziński et al., 2004		This study	
	x-sin	x-cos	x-sin	x-cos
	P_1^+ component, period 1.0027454 day			
A presIB	0.3 ±0.1	0.8 ±0.1	0.1 ±0.1	−0.6 ±0.1
A wind	−0.5 ±0.2	0.3 ±0.2	0.0 ±0.1	2.2 ±0.1
O mass	−1.0 ±0.3	−1.4 ±0.3	−3.0 ±0.1	−0.1 ±0.1
O veloc.	1.3 ±0.2	0.3 ±0.2	2.6 ±0.1	−0.3 ±0.1
AIB+O	**0.1 ±0.4**	**0.0 ±0.4**	**−0.3 ±0.2**	**1.2 ±0.2**
	S_1^+ component, period 0.9999999 day			
A presIB	−0.7 ±0.1	−3.8 ±0.1	−3.2 ±0.1	0.6 ±0.1
A wind	5.2 ±0.1	−0.1 ±0.1	1.9 ±0.1	2.7 ±0.1
O mass	7.2 ±0.3	−3.5 ±0.3	4.0 ±0.1	0.1 ±0.1
O veloc.	−3.4 ±0.3	4.0 ±0.3	−0.8 ±0.1	−0.1 ±0.1
AIB+O	**8.3 ±0.4**	**−3.4 ±0.4**	**1.9 ±0.2**	**3.3 ±0.2**
VLBI	7	−28	7	−28
	K_1^+ component, period 0.9972696 day			
A presIB	−0.5 ±0.1	−0.2 ±0.1	0.1 ±0.1	0.4 ±0.1
A wind	0.4 ±0.2	−0.2 ±0.2	0.1 ±0.1	−0.6 ±0.1
O mass	0.9 ±0.4	1.2 ±0.4	2.5 ±0.1	1.8 ±0.1
O veloc.	−0.9 ±0.3	−0.3 ±0.3	−1.9 ±0.1	−0.2 ±0.1
AIB+O	**−0.1 ±0.5**	**0.5 ±0.5**	**0.8 ±0.2**	**1.4 ±0.2**

Results: atmospheric-oceanic excitation of diurnal UT1/LOD variation

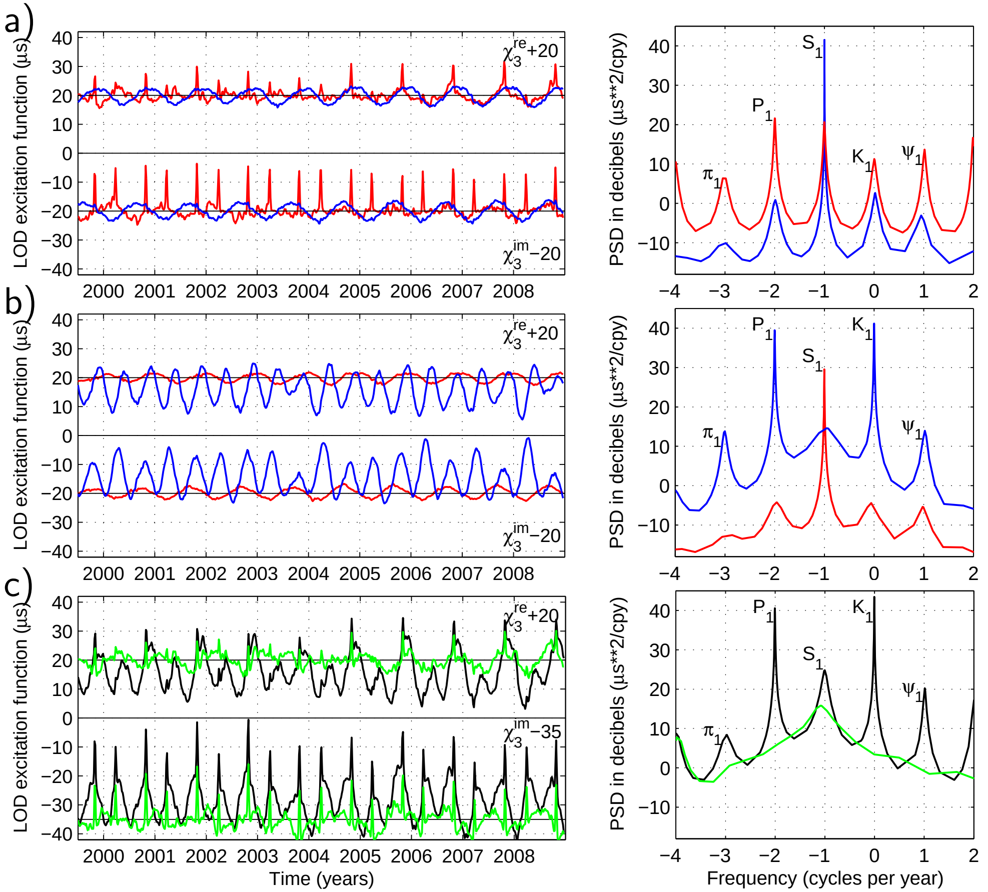


Figure 3: Axial EAM functions demodulated at frequency +1 cpsd, of the atmosphere (red), ocean (blue): a) motion term, b) mass term, c) mass+motion of the combination AAM+OAM, original (black) and after removal of the sinusoidal-linear model (green). Period of analysis 1989.0–2009.0.

Table 3: Atmospheric and nontidal oceanic contributions to diurnal UT1 variation. VLBI estimate taken from Gipson (1996). Units are μas.
(Note: 1μs of UT1 corresponds to 15μas.)

Term	Brzeziński et al., 2004				This study			
	UT1-sin		UT1-cos		UT1-sin		UT1-cos	
	P_1 component, period 1.0027454 day							
A presIB	2.2	±0.3	−0.6	±0.1	−0.4	±0.1	0.5	±0.1
A wind	−1.5	±0.2	−1.7	±0.2	0.6	±0.1	−6.4	±0.5
O mass	−0.6	±0.3	0.0	±0.1	22.5	±0.3	−21.8	±0.3
O veloc.	1.4	±0.1	2.5	±0.2	0.0	±0.1	1.1	±0.1
AIB+O	**1.5**	**±0.5**	**0.3**	**±0.3**	**22.7**	**±0.3**	**−26.6**	**±0.6**
	S_1 component, period 0.9999999 day							
A presIB	0.9	±0.1	−4.6	±0.3	−7.5	±0.1	1.5	±0.1
A wind	14.4	±0.2	−3.4	±0.1	1.2	±0.5	0.3	±0.1
O mass	−5.3	±0.2	−2.5	±0.1	6.3	±0.4	1.0	±0.1
O veloc.	−7.4	±0.2	5.0	±0.1	−10.8	±0.1	8.0	±0.1
AIB+O	**2.6**	**±0.4**	**−5.6**	**±0.3**	**−10.7**	**±0.7**	**10.9**	**±0.2**
VLBI	−31.5		16.5		−31.5		16.5	
	K_1 component, period 0.9972696 day							
A presIB	−0.8	±0.4	0.5	±0.3	0.3	±0.1	−0.7	±0.1
A wind	2.7	±0.3	−0.5	±0.2	−0.2	±0.3	−3.0	±0.4
O mass	0.5	±0.3	0.9	±0.3	19.0	±0.2	−28.2	±0.2
O veloc.	−0.7	±0.2	0.2	±0.2	1.2	±0.1	−0.3	±0.1
AIB+O	**1.7**	**±0.6**	**1.0**	**±0.5**	**20.3**	**±0.4**	**−32.2**	**±0.5**

Summary and conclusions (1)

Analysis of a new set of 20-year time series of atmospheric and nontidal ocean angular momenta confirmed several features which could be either deduced from the physics or detected from earlier investigations using alternative data, in particular:

- The spectral structure is similar in all three cases considered: it consists of the S_1 component driven by the thermal (radiational) atmospheric tide and its side lobes shifted in frequency by ± 1 and ± 2 cycles per year. The side lobes are caused by seasonal modulations of the S_1 tide.

- In case of the retrograde diurnal equatorial component of excitation contributing to nutation, there is much greater power in the wind term of AAM than in the pressure term. However, this discrepancy of power is largely counter-balanced by the opposite discrepancy of the transfer coefficients between geophysical excitation and nutation amplitudes.

- In all three cases the S_1 term of diurnal excitation contains the random component which cannot be expressed by the harmonic model. This component can only be described in the time domain therefore needs to be monitored on regular basis.

Summary and conclusions (2)

From the comparison with earlier results of Brzeziński et al. (2004) and with the VLBI estimate it can be concluded what follows:

- General: there is a rough agreement in size of the estimated atmospheric and oceanic contributions to nutation, diurnal polar motion and diurnal UT1/LOD variation, nevertheless the differences are in most cases significantly larger than the estimated formal uncertainties.

- Prograde annual nutation: this is the only nutation component for which comparison of AAM/OAM with VLBI estimate is possible. There is considerable improvement in the in-phase amplitude, but a slight increase of discrepancy in the out-of-phase amplitude.

- Prograde diurnal polar motion: the estimated geophysical contribution is at the level of only 4 μas, which is 2 times less than found previously. The amplitude of the S_1^+ component is almost 10 times smaller than estimated from VLBI observations.

- Diurnal UT1/LOD variation: the estimated geophysical contribution to the S_1 component is at the level of 10 μas, about 2 times larger than in the previous estimation but still 3 times less than derived from VLBI data. Another difference is the large size of the side lobes P_1 and K_1 of the OAM mass term and the anomalous behavior of the AAM wind term.