HIGH-RESOLUTION ATMOSPHERIC ANGULAR MOMENTUM FUNCTIONS FROM DIFFERENT ECMWF DATA CLASSES

M. SCHINDELEGGER[1], J. BÖHM[1], H. SCHUH[1], D.A. SALSTEIN[2]

[1] Institute of Geodesy and Geophysics, Vienna University of Technology
27-29 Gußhausstraße, A-1040 Wien, Austria
e-mail: michael.schindelegger@tuwien.ac.at, johannes.boehm@tuwien.ac.at, harald.schuh@tuwien.ac.at

[2] Atmospheric and Environmental Research, Inc.
131, Hartwell Avenue, Lexington, MA 02421-3126, USA
e-mail: salstein@aer.com

ABSTRACT. Atmospheric excitation of Earth rotation at daily and sub-daily periods is routinely inferred from six-hourly atmospheric angular momentum (AAM) functions, which are derived from the operational analysis fields of Numerical Weather Models. The so-called *delayed cut-off stream*, recently introduced by the European Centre for Medium-Range Weather Forecasts (ECMWF), though, produces meteorological data with higher temporal resolution by incorporating short-term forecasts, and thus allows the estimation of three-hourly AAM functions. In detail, we determine six- and three-hourly AAM functions for a time span of five years. Comparisons of the two series reveal differences in amplitude and phase, but also highlight the counteraction of pressure and wind terms at short time scales. Moreover, the three-hourly AAM record represents an opportunity to resolve better the semi-diurnal band of atmosphere-induced variations in polar motion and LOD.

1. INTRODUCTION

By exchanging angular momentum with the solid part of the Earth, large-scale atmospheric processes account for major variations of all Earth Orientation Parameters (EOP), which are precession, nutation, polar motion and changes in length of day (LOD). The atmospheric influence on these parameters is usually studied by employing the angular momentum approach, requiring calculation of the so-called atmospheric angular momentum (AAM) functions from globally gridded meteorological data. The resulting excitation values agree well with the observed EOP variations on time scales of a few days or longer, e.g. Barnes et al. (1983) or Salstein et al. (1993). At daily and sub-daily periods, the AAM functions explain only a fraction of the measured changes in Earth rotation, see Brzeziński and Petrov (2000). However, these high-frequency effects, mainly originating from diurnal and semi-diurnal radiational tides in the atmosphere, are non-negligible, especially in the nutation band (Bizouard et al., 1998).

The aim of this study is to estimate and compare such high-frequency contributions of the atmosphere to EOP variations based on two different meteorological analyses of the European Centre for Medium-Range Weather Forecasts (ECMWF), see Section 2. Since a new, three-hourly AAM dataset is introduced, we seek to complement the recent estimates for atmospheric tides, which, up to now, have been all based on six-hourly analysis fields.

2. DATA DESCRIPTION

The AAM functions used in this study are inferred from two different sets of meteorological data, which are both provided by the ECMWF. The first set comprises data at six-hourly intervals (0, 6, 12, 18 UTC) and is retrieved from the standard analysis, available in the *Atmospheric model* archive. The second set stems from the re-organized ECMWF assimilation system, the so-called *Atmospheric model (delayed cut-off)* analysis, which became operational on 29 June 2004. The cut-off time represents the latest possible arrival time for meteorological observations to be included in an analysis cycle. By combining several analysis cycles and short-term forecasts, it is possible for the ECMWF to delay the cut-off time and achieve a higher temporal resolution of three hours. Both six- and three-hourly analysis

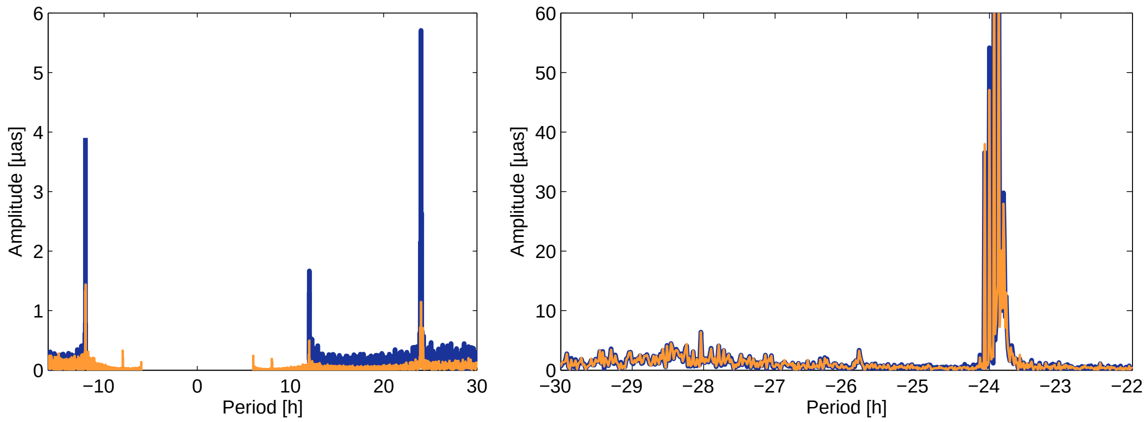

Figure 1: Amplitude spectra of atmosphere-induced variations of polar motion (left figure) and nutation (expressed as motion in the terrestrial reference frame, right figure) calculated from six-hourly AAM functions (*blue line*) and three-hourly AAM functions (*orange line*).

fields, given as 1° by 1° horizontal grids on 21 isobaric levels, are processed for the time span 1 July 2004 to 30 June 2009, yielding two sets of five-year AAM matter and motion time series.

3. ATMOSPHERIC EXCITATION OF EARTH ROTATION

The atmospheric contribution to precession, nutation, polar motion, and changes in LOD can be determined in a similar way for both AAM datasets. Dimensionless AAM functions are calculated from pressure and wind fields, and are subsequently convolved with the corresponding axial and equatorial transfer functions (Brzeziński et al., 2002). The equatorial transfer function comprises the Chandler Wobble and the Free Core Nutation resonance. The resulting amplitude spectra in Figures 1 (left part) and 2 illustrate the daily and sub-daily atmospheric effects in polar motion and LOD, showing that

- the six-hourly AAM functions do not allow resolution of bandwith with higher frequency than semi-diurnal,
- due to the prograde wind term, the six-hourly spectrum contains a lot of noise and
- the three-hourly amplitude estimates are of a significantly lower magnitude level than their six-hourly counterparts.

There is considerably better agreement in the nutation band, which is depicted in Figure 1 (right part).

For all three types of EOP it is of interest to distinguish the specific atmospheric tides in the excitation spectra. The set of $\{\Pi_1, P_1, S_1, K_1, \Psi_1, \Phi_1, T_2, S_2, R_2\}$ comprises the most prominent diurnal and semi-diurnal tides, which can be detected at their corresponding periods, for example in polar motion at $T = -12$ h or in nutation at $T = -24$ h (Figure 3). Naturally, the AAM series sampled at three-hourly intervals are superior in the semi-diurnal band, revealing S_2 plus its side-lobes. This detection is rather qualitative and can be replaced by a simple least squares adjustment of amplitude and phase at each tidal frequency. For this purpose, the axial excitation

$$l(t) = \sum_{j=1}^{9} a_j \cos(\omega_j t) + b_j \sin(\omega_j t) \quad (1)$$

is modeled as harmonic series containing the nine tides with unknown coefficients $\{a_j, b_j\}$ and the given frequencies ω_j with $j = 1, ..., 9$. The coefficients determine amplitude and phase of each tidal wave. Similar to Equation 1, $\{a_j, b_j\}$ are estimated separately for the real and imaginary parts of the equatorial excitation. This procedure yields real pro- and retrograde as well as imaginary pro- and retrograde amplitudes, which can be converted to pro- and retrograde phase and mean amplitude of every single tidal wave. The resulting mean amplitudes for the three-hourly AAM functions are summarized in Table 1.

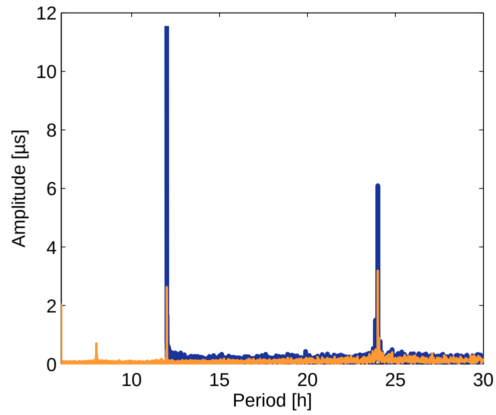

Figure 2: Amplitude spectrum of high-frequency LOD from six-hourly AAM functions (*blue line*) and three-hourly AAM functions (*orange line*).

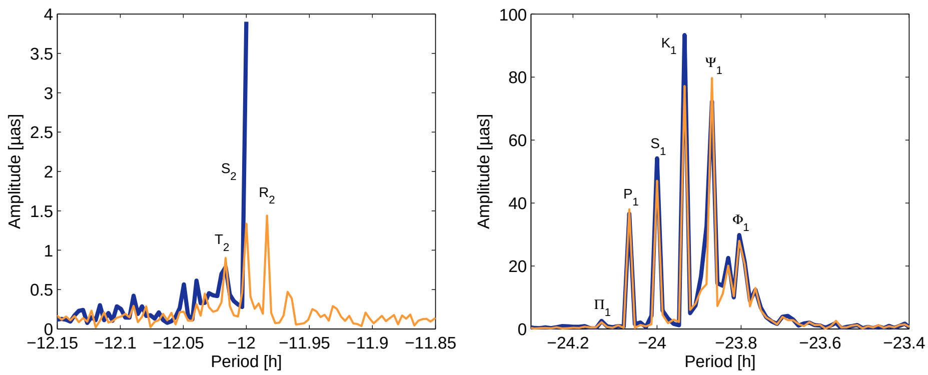

Figure 3: Amplitude spectra of polar motion (left figure) and nutation (right figure) calculated from six-hourly AAM functions (*blue line*) and three-hourly AAM functions (*orange line*).

As already indicated in Figures 1 and 2, the three-hourly amplitude estimates suggest very small atmospheric contributions to high-frequency EOP. The obtained values appear to be several times smaller compared to the results of Brzeziński and Petrov (2000) from six-hourly data from the U.S. National Centers for Environmental Prediction (NCEP) or to the six-hourly estimates of this study, which are 5.7 μas (S_1), 1.9 μas (S_2) for polar motion and 6.1 μs (S_1), 11.6 μs (S_2) for LOD. To a large extent, these discrepancies can be attributed to a distinct feature of the delayed cut-off series, which is a counteraction of pressure and wind terms. Both for the axial as well as the equatorial component, pressure and wind contributions to atmospheric excitation are of comparable size but likely to cancel out each other when their corresponding spectra are added. (This summation is carried out separately for real and imaginary parts.) Figure 4 gives a detailed look at the real prograde part of polar motion excitation, highlighting the phase shift of about 180° between pressure and wind signals.

4. CONCLUSIONS

Two sets of five-years AAM matter and motion terms with different temporal resolutions of three and six-hours, respectively, have been used to study the atmospheric contribution to daily and sub-daily EOP variations. The mean amplitudes and phases of the most important atmospheric tides, estimated by a simple least squares adjustment on both AAM datasets, differ significantly for polar motion and changes in LOD, but are in good agreement for the nutation band. The advantage of the three-hourly series is the ability to resolve the spectral structure in the semi-diurnal band. The small amplitudes of atmospheric effects calculated from this dataset can be ascribed to a counteraction of pressure and wind terms, which could originate from atmospheric circulation on short time scales. Detailed investigations concerning the time evolution and the physical reasoning of this phenomenon are in progress.

	Period [h]	**equatorial exc., prograde** [μas]	**equatorial exc., retrograde** [μas]	**axial exc.** [μs]
Π_1	24.13214	0.4	2.1	0.5
P_1	24.06589	0.4	37.9	0.9
$\boldsymbol{S_1}$	**24.00000**	**1.1**	**47.0**	**3.2**
K_1	23.93447	0.7	77.0	0.3
Ψ_1	23.86930	0.2	79.8	0.5
Φ_1	23.80448	0.0	27.9	0.2
T_2	12.01645	0.5	0.9	0.6
$\boldsymbol{S_2}$	**12.00000**	**0.2**	**1.3**	**2.6**
R_2	11.98360	0.3	1.4	0.5

Table 1: Atmospheric excitation: mean amplitudes of polar motion [μas] (prograde band and retrograde band at $T = -12$ h), nutation [μas] (retrograde band at $T = -24$ h) and LOD [μs], calculated from five-years AAM matter and motion terms with a temporal resolution of three hours.

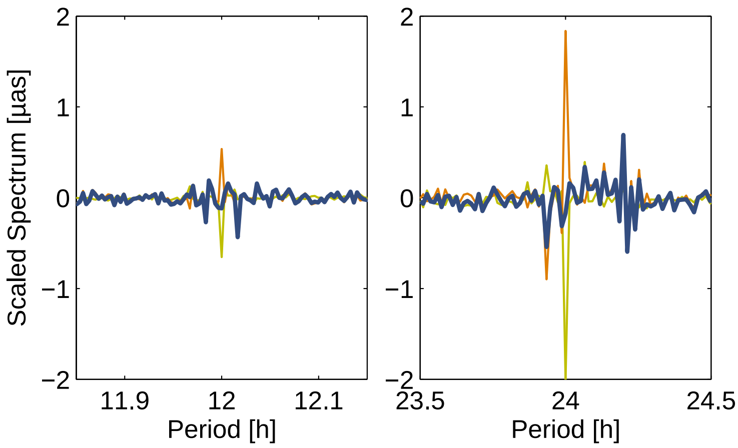

Figure 4: Real part of the discrete Fourier transform of polar motion from three-hourly AAM functions at $T = +12, +24$ h. *Bold blue line*: pressure plus wind terms, *olive line*: pressure term, *orange line*: wind term. The scale factor of the corresponding amplitude spectrum has been applied.

Acknowledgements. This study was carried out within project P20902-N10 of the Austrian Science Fund.

5. REFERENCES

Barnes, R., Hide, R., White, A., Wilson, C., 1983. Atmospheric angular momentum fluctuations, length-of-day changes and polar motion. Proc. R. Soc. Lond, A 387, 31-73.

Bizouard, C., Brzeziński, A., Petrov, S., 1998. Diurnal atmospheric forcing and temporal variations of the nutation amplitudes. J. Geod., 72, 561-577.

Brzeziński, A., Bizouard, C., Petrov, S.D., 2002. Influence of the atmosphere on Earth rotation: What new can be learned from the recent atmospheric angular momentum estimates? Surveys in Geophysics, 23, 33-69.

Brzeziński, A., Petrov, S., 2000. High frequency atmospheric excitation of Earth rotation. IERS Technical Note, 28, 53-60.

Salstein, D.A., Kann, D.M., Miller, A.J., Rosen, R.D, 1993. The sub-bureau for atmospheric angular momentum of the International Earth Rotation Service: A meteorological data center with geodetic applications. Bulletin American Meteorological Society, 74, 67-80.