DIURNAL AND SEMIDIURNAL VARIATIONS IN EARTH ORIENTATION DETERMINED FROM LAGEOS LASER RANGING AND GPS

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ABSTRACT. Two analyses of high frequency Earth orientation were performed. In the first study, variations in universal time and polar motion due to ocean tides at nearly diurnal and nearly semidiurnal frequencies were determined from analysis of laser ranging to the Lageos satellite over the period from 1987 to 1992. The adjusted diurnal tides were K_1, S_1, P_1, O_1 and Q_1, while the semidiurnal tides were K_2, S_2, M_2, and N_2. In the second study, daily estimates of diurnal and semidiurnal UT1 variations were determined for a 49-day interval during the summer 1992 IGS campaign using doubly differenced GPS phase data. The results were then compared to the tidal variations observed from Lageos. For both studies, formulations were used that explicitly separated prograde and retrograde terms in the polar motion in order to eliminate aliasing from the singularity of retrograde wobble with long period orbit error and nutation. The results of the EOP variations at tidal frequencies obtained in this study agree well with those from the VLBI studies, typically at the 2–3 μs level in universal time and 30–50 μas level in polar motion. The results from the GPS analysis indicated independent daily determination of diurnal and semidiurnal variations of UT1 with accuracies at the 20–30 μs level.

1. Procedure

The solution for the tidal variations, described in detail in Watkins and Eanes [1993], was performed using the exact alias frequency of the tides in question as shown below, and adjusting a single amplitude and phase for each tidal frequency.

$$m = \sum_{s=1}^{N} [m_p^{s+} \exp(i\,\theta_s) + m_p^{s-} \exp(-i\,\theta_s)] = x - iy$$

where θ_s is the instantaneous phase of the particular tide in question, and m_p^{s+} and m_p^{s-} are complex prograde and retrograde subdiurnal polar motions modulated by the tidal frequency. We define the real and imaginary parts of m_p^{s+} and m_p^{s-} in terms of the usual x_p and y_p components as:

$$m_p^{s+} = x_p^{s+} - iy_p^{s+}$$

$$m_p^{s-} = x_p^{s-} - iy_p^{s-}$$

where x_p^{s+}, x_p^{s-}, y_p^{s+}, and y_p^{s-} were the real variables estimated using the SLR data. The singularity between retrograde nearly diurnal polar motion and the satellite orbit is avoided by removal (nonestimation) of the retrograde quantities for diurnal tides.

High frequency variations in UT were modeled as.

$$\delta \mathrm{UT1} = \sum_{s=1}^{N} [u^{sc} \cos(\theta_s) + u^{ss} \sin(\theta_s)]$$

where u^{sc} and u^{ss} were the real parameters estimated. For both wobble and UT1, the index s varied over 9 total ocean tide frequencies listed above. The preliminary solution described above was performed using 6 years of Lageos data spanning the period 1987–1992, the period of highest quality Lageos data. Approximately 400,000 two-minute normal points from 70 tracking sites formed this data set. The models used in the data analysis adhered generally to the IERS standards with several notable exceptions. The static geopotential model was JGM-1, and changes in the geopotential due to ocean tides were modelled using an enhanced model which included all terms, chosen from a degree and order 20 spherical harmonic expansion, with perturbations that exceeded 1 mm in either the radial, normal, or transverse components of the orbit, respectively. The nominal coefficients were from the model of Schwiderski [1980], with a subset of terms adjusted at the UTCSR from a multisatellite solution. The perturbations were determined from an analytic approach due to Casotto [1989]. The tidal amplitudes at frequencies not included in the original Schwiderski model were extrapolated using an assumption of admittances which vary linearly with frequency.

The solid tide model was expanded to include geopotential variations due to third degree terms, assuming the Love number, k_3 of 0.093 [Wahr, 1981]. Finally, the free core nutation period was changed from 460 to 430 days.

The reference frame was fixed to the CSR93L01 system of Eanes and Watkins [1993] which was determined from analyses of the entire Lageos mission, adjusting positions for over 110 sites and horizontal velocities for 47 sites. Sites with unadjusted velocities were assumed to have the velocities predicted by the NUVEL-1NNR model of Argus and Gordon [1991]. Site-dependent nuisance parameters such as range or clock biases were adjusted where necessary.

In the estimation process, mean orbital elements (excluding the nodal longitude), x_p, y_p, and UT1 were adjusted every 3 days, along with the diurnal and semidiurnal prograde and retrograde wobbles and UT1 variations. Using the above modelling and parametrization, the postfit range residual rms was 22 millimeters. The results of the adjustment are presented in the following table, along with conservative estimates of the uncertainties. The uncertainties included in the table are scaled formal uncertainties. The scale factor has been derived through comparison of Earth orientation and site positions with external solutions, such as those derived from VLBI, in order to make the formal uncertainties consistent with the inferred accuracy. Error analyses described in Watkins and Eanes [1993] support these uncertainties.

For the second study, the analysis of 49 days of GPS data, variations in universal time at exactly once and twice per sidereal day were adjusted for each day, along with initial conditions for each

Observed Tidal Variations in UT1 and Polar Motion

Tide	X_p^+, μas	Y_p^+, μas	X_p^-, μas	Y_p^-, μas	$UT1_c$, μs	$UT1_s$, μs
K_1	158±30	5±30	–	–	4.8±3	14.7±3
K_1^*	–	–	–	–	5.7±3	13.1±3
S_1	−51±30	−38±30	–	–	1.3±3	4.4±3
P_1	−25±30	19±30	–	–	−2.0±3	−1.1±3
Q_1	−41±20	−5±20	–	–	−4.0±2	−7.9±2
O_1	−131±20	9±20	–	–	−20.8±2	−17.3±2
O_1^*	–	–	–	–	−17.0±2	17.2±2
K_2	0±20	−23±20	20±30	−5±30	1.4±3	0.6±3
S_2	7±20	−81±20	−56±30	127±30	3.0±3	7.8±3
M_2	51±20	−114±20	25±20	195±20	−7.6±2	15.1±2
N_2	2±20	−21±20	2±20	18±20	−2.8±2	3.8±2

* corrected for 18.6-year sideband effects

GPS satellite, site dependent zenith delays every 2.5 hours, and phase ambiguities where necessary. The model for EOP variations was:

$$\delta UT1 = \sum_{n=1}^{N} [u^{nc} \cos(n\theta_g) + u^{ns} \sin(n\theta_g)]$$

where θ_g is the Greenwich sidereal time, and u^{nc} and u^{ns} are the real parameters estimated with the GPS data. The models used in the analysis generally adhered to the IERS Standards or appropriate International GPS Service recommendations, as above, with the exception of the use of the University of Texas TEG-2 gravity field.

In order to compare these results to the EOP variations at the tidal frequencies derived above, we reconstructed the equivalent variations at exactly once and twice per sidereal day from the sum of the 5 diurnal and 4 semidiurnal tides, respectively. These variations were then compared with the variations observed with GPS. The results, discussed in Sonntag and Watkins [1993], indicated 20 to 30 microsecond agreement between the two series, with slightly better agreement for the semidiurnal terms. The formal uncertainties on the daily GPS estimates were on the order of 15 to 20 microseconds.

2. References

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