UPDATED MODEL OF SHORT-PERIOD TIDAL VARIATIONS IN EARTH ROTATION

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INTRODUCTION

The ocean tides are the dominant cause of short-period (daily and subdaily) variations in the Earth's rotation rate and polar motion (Chao et al., 1996). The tides directly perturb the Earth's inertia tensor as well as exchange angular momentum with the solid mantle. Both mechanisms are important for understanding the rotation variations, which are well observed by modern methods of space geodesy (Brosche et al., 1991; Herring and Dong, 1994; among others).

Over the past decade there have been a number of estimates of tidally driven Earth-rotation variations based on various kinds of ocean tide models. The most accurate of these are models constrained by direct oceanic measurements, usually either tide gauges (Ray et al., 1994) or satellite altimetry (Chao et al., 1996). Models based upon strictly numerical hydrodynamic methods (i.e., those that use only bathymetry data and the known astronomical potential) have been less successful. The reason for this is the difficulty of accurately modeling the ocean's barotropic response to very short-period forcing. When the basic mechanisms of tidal energy dissipation are still unresolved (Munk, 1997), it is not surprising that strictly numerical models are found wanting. By far the most accurate models of ocean tides are nowadays those based on direct tidal estimates from the Topex/Poseidon satellite altimeter. Hydrodynamic theories are still required for deducing current velocities, and also for modeling tides in polar seas, but the direct estimates from T/P have been a great boon to tidal accuracies.

Chao et al. (1996) published tidal Earth-rotation predictions based on three models constrained by T/P observations. All these models were based on 3 or fewer years of T/P measurements. As of this writing the T/P satellite has accumulated slightly more than 7 years of measurements, and updated (second generation) tidal models are now appearing. Moreover, methods of analysis have been improving, as have methods of deducing barotropic tidal currents from the measured elevations. This report tabulates updated predictions of tidal rotation variations from one such new model.

IMPROVED ESTIMATES OF TIDAL HEIGHTS AND CURRENTS

Goddard Ocean Tide model GOT99.2 is based on 232 10-day cycles of Topex/Poseidon altimeter measurements, processed as a correction to a prior tide model consisting of several hydrodynamic models, primarily FES94.1 of Le Provost et al. (1994) plus several regional models for various shallow and inland seas. (All polar seas above the T/P inclination of 66° rely on the FES model.) The Earth's body tide and load (radial displacement) tide were removed from the altimeter data by use of (strictly real) Love and loading numbers h_2 and h_n'. For further details of this tidal height model, including data processing steps, adopted geophysical constants, and final global cotidal charts, see Ray (1999).

The GOT99.2 elevations are clearly superior to the models used by Chao et al. (1996). This is especially evident in some shallow sea areas, such as the Gulf of Maine and the South and East China Seas. The model is also marginally better in the deep ocean. For example, in a comparison with 102 deep-sea tide gauges and bottom-pressure recorders, the new model has an rms discrepancy in M_2 of 1.47 cm, compared with 1.64 cm for CSR3.0 and 1.55 cm for CSR4.0 (which are two widely used models based on T/P).

Barotropic (depth-averaged) tidal currents were computed from the GOT99.2 elevations by a least-squares procedure that fits both the hydrodynamic equations of momentum and continuity. The momentum equations included terms for self-attraction and loading and a linearized bottom frictional stress for dissipation (with frictional coefficient $r = 0.01$ m/s). The resulting currents are clearly superior to two of the three models used by Chao et al. and are comparable to the third (their "Model C"—the TPXO.2 model of Egbert et al., 1994). Comparisons with 77 deep-ocean moored current meters and with two deep-ocean acoustic tomography arrays suggest that the new currents are comparable to TPXO.2 and slightly less accurate than TPXO.3 (although the elevations are more accurate). Further details of the methodolgy used for deriving the currents are described in Ray (2000).

IMPLIED TIDAL VARIATIONS IN EARTH ROTATION

The new model of tidal heights and currents has been used to compute ocean tidal angular momentum (Table 1) and the implied variations in UT1 and polar motion (Table 2). The procedure followed is precisely the same as that used by Chao et al. (1996). Note that the Z component of angular momentum is computed directly from the Y_2^0 spherical harmonic component of the model; this avoids a small inaccuracy stemming from a slight nonconservation of mass (see discussion in Ray et al., 1997). The conversion from angular momentum to UT1 and polar motion follows Gross (1993), including his adopted values for Love numbers and FCN and Chandler Wobble frequencies. The phase convention used in Tables 1 and 2 is consistent with that used by both Gross (1993) and Chao et al. (1996); the phases used for angular momentum and for UT1 are phase lags and are consistent with the Doodson convention for Greenwich phase lags used by most oceanographers.

While the GOT99.2 tidal heights and currents are certainly improved over the models used by Chao et al. (1996), as noted by *in situ* comparisons of oceanic heights and currents, there is no comparable way to assess the accuracy in the extremely long wavelength band (e.g., the degree-2 heights) which affects Earth rotation. Yet it seems likely that these components must also be improved. Comparisons with space-geodetic Earth orientation measurements are probably the most direct test. No such detailed tests have yet been performed, but cursory comparisons (e.g., UT1 comparisons for M_2, O_1, and K_1 with the VLBI estimates of Gipson [1996]) do suggest marginal improvement in model estimates.

The ΔUT1 phasor diagram for the M_2 tide is of special interest because of the possible detection of Earth libration, which results from tidal forcing of the triaxial solid Earth and is estimated to contribute approximately 1.9 μs (Chao et al., 1991) to UT1 (based on the Earth's C_{22} and S_{22} Stokes coefficients). Figure 1 shows the components of tidal heights, currents, and libration contributing to ΔUT1, plus the VLBI estimate of Gipson (1996). (Other published VLBI estimates are similar to Gipson's but with larger error circles; published estimates based on GPS and SLR observations, however, are not consistent with the VLBI; see Chao et al., 1996.) The total of tides plus libration falls almost within 2σ of the VLBI measurement of UT1, which is a small improvement to the results shown in Chao et al. (1996). The error circle for the tidal estimates is unknown but is surely as large (more likely, larger) than the VLBI estimate (preliminary calculations by G. Egbert based on inverse methods of tidal analysis suggest an error circle 50% larger than Gipson's).

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Table 1. Oceanic tidal angular momentum (OTAM) Amplitudes and phase lags.

		X	Y	Z
Q1	heights	1.1, 342°	2.6, 216°	0.7, 134°
	currents	0.7, 296°	0.7, 206°	1.3, 109°
O1	heights	4.7, 328°	11.7, 221°	2.0, 151°
	currents	2.9, 318°	3.9, 214°	5.9, 118°
P1	heights	1.6, 309°	4.6, 223°	0.4, 40°
	currents	1.7, 284°	2.5, 190°	2.5, 129°
K1	heights	4.6, 307°	13.8, 223°	1.4, 31°
	currents	5.2, 288°	7.5, 192°	7.7, 130°
N2	heights	1.2, 347°	0.4, 232°	0.5, 78°
	currents	1.1, 247°	2.3, 157°	3.0, 328°
M2	heights	5.1, 12°	3.6, 305°	6.0, 86°
	currents	9.8, 258°	17.5, 164°	16.0, 321°
S2	heights	1.1, 40°	2.7, 7°	2.4, 133°
	currents	5.2, 301°	9.4, 202°	7.1, 342°
K2	heights	0.4, 40°	0.9, 0°	0.7, 120°
	currents	1.4, 298°	2.6, 198°	2.2, 342°

Amplitudes in 10^{24} kg m^2/s; Greenwich phase lags in degrees.

Table 2. Tidal variations in UT1 and Prograde and Retrograde Polar Motion.

	ΔUT1	Progr. PM	Retr. PM
Q1	4.7, 26.2°	29, 76°	44, 302°
O1	20.5, 34.6°	139, 65°	102, 307°
P1	6.7, 31.9°	57, 57°	880, 134°
K1	19.8, 31.9°	169, 56°	9840, 132°
N2	4.0, 244.3°	15, 136°	37, 269°
M2	18.9, 246.1°	82, 125°	245, 269°
S2	7.4, 261.8°	29, 92°	122, 303°
K2	2.3, 263.3°	7, 92°	32, 301°

Amplitudes of ΔUT1 are μs.

Amplitudes of polar motion are μas.

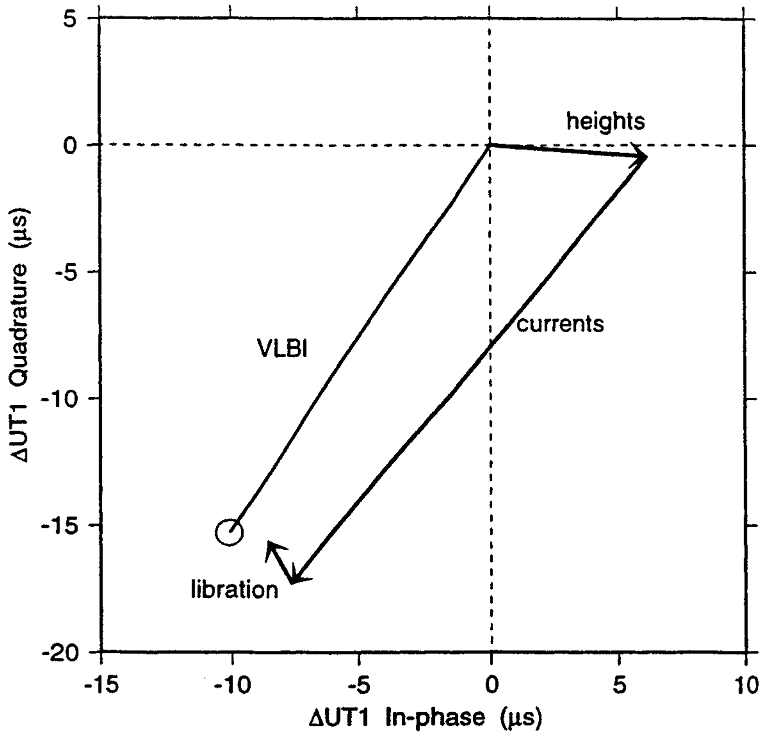

Figure 1. ΔUT1 phasor diagram for M_2, in microseconds. Tidal heights and currents correspond to model GOT99.2. Libration is 1.9 μs, with phase lag 120°. VLBI is "constrained" solution of Gipson (1996).