An Empirical Model for the Effect of Long Period Ocean Tides on Polar Motion

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Abstract. Because the tide-raising potential is symmetric about the Earth's polar axis, it can excite polar motion only by acting upon non-axisymmetric features of the Earth like the oceans. In fact, after removing atmospheric and non-tidal oceanic effects, polar motion excitation observations show a strong fortnightly tidal signal. However, existing dynamical and empirical ocean tide models are unable to completely account for this observed signal. So a new empirical model for the effect of the termensual, fortnightly, and monthly tides on polar motion is derived here by fitting periodic terms at these tidal frequencies to polar motion excitation observations spanning 2 January 1980 through 8 September 2006. While this new empirical tide model can explain the observed fortnightly polar motion excitation signal, it is still desirable to have a more accurate dynamical model for the effect of long-period ocean tides on polar motion.

Motivation

None of the currently available dynamical or empirical ocean tide models are able to completely remove the observed polar motion excitation power at the prograde and retrograde fortnightly tidal frequencies.

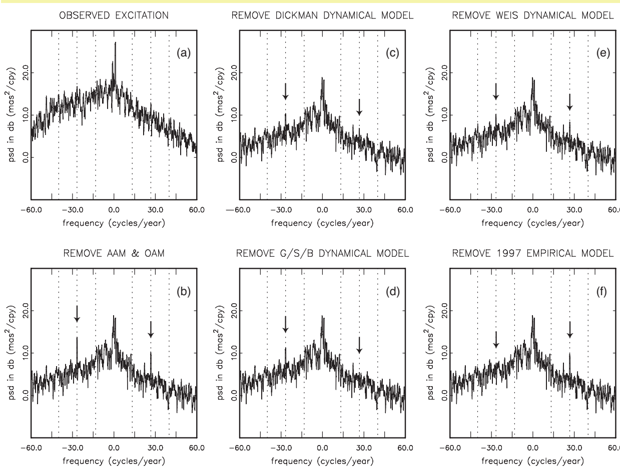


Figure 1. Power spectral density (psd) estimates in decibels (db) computed by the multitaper method from time series of polar motion excitation functions $\chi(t)$ spanning 2 January 1993 to 10 September 2006 of the: (a) observed COMB2006 polar motion excitation functions; (b) residual polar motion excitation functions formed by removing atmospheric and non-tidal oceanic effects from the observed functions; (c) residual excitation functions formed by additionally removing the Dickman (1993) tide model as reported by Gross et al. (1997); (d) residual excitation functions formed by additionally removing the Seiler (1991) tide model as reported by Gross (1993); (e) the residual excitation functions formed by additionally removing the Weis (2006) tide model; and (f) residual excitation functions formed by additionally removing the empirical model of Gross et al. (1997). Arrows indicate the retrograde and prograde fortnightly tidal terms.

Table 1 Ocean tidal variations in polar motion and polar motion excitation

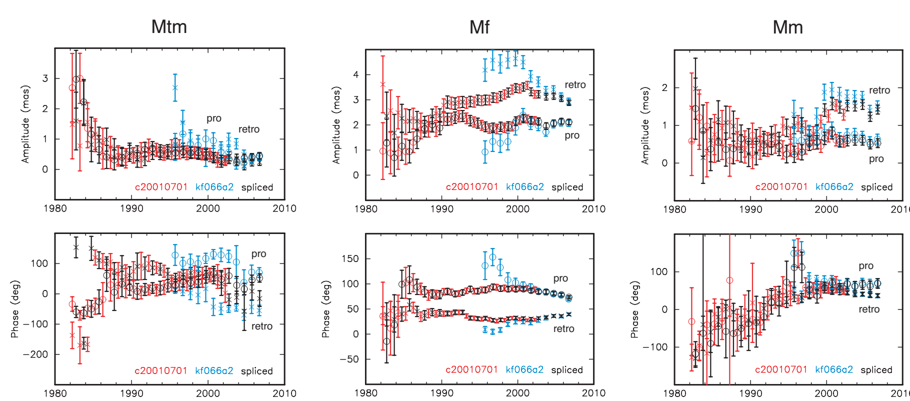
Tide Model							Polar Motion				Polar Motion Excitation			
							Prograde		Retrograde		Prograde		Retrograde	
	Argument					Period	amp	phase	amp	phase	amp	phase	amp	phase
	l	*l'*	*F*	*D*	Ω	(days)	(μas)	(degrees)	(μas)	(degrees)	(μas)	(degrees)	(μas)	(degrees)
mtm														
Dickman	1	0	2	0	1	9.12	2.81	–107.10	4.40	15.21	130.38	72.73	213.45	15.05
Weis	1	0	2	0	1	9.12	5.34	159.00	3.76	–137.00	248.17	–21.16	182.26	–137.16
1997 Emp	1	0	2	0	1	9.12	14.65	174.32	12.47	140.84	680.82	–5.84	604.66	140.69
This paper	1	0	2	0	1	9.12	3.88	–128.58	1.65	–26.83	180.15	51.26	80.18	–26.98
Mtm														
Dickman	1	0	2	0	2	9.13	6.79	–106.95	10.69	15.32	315.24	72.89	517.67	15.17
Weis	1	0	2	0	2	9.13	18.47	–144.00	11.07	103.00	857.20	35.84	535.91	102.84
1997 Emp	1	0	2	0	2	9.13	4.73	–161.12	6.84	–36.41	219.41	18.71	330.95	–36.57
This paper	1	0	2	0	2	9.13	9.36	–128.58	4.00	–26.83	434.55	51.26	193.41	–26.98
mf														
Dickman	0	0	2	0	1	13.63	16.95	–79.91	21.77	8.01	521.36	99.93	713.09	7.85
G/S/B	0	0	2	0	1	13.63	23.30	–125.00	18.00	72.00	716.71	54.83	589.68	71.84
Weis	0	0	2	0	1	13.63	28.85	–154.00	23.39	83.00	887.43	25.83	766.26	82.84
1997 Emp	0	0	2	0	1	13.63	44.42	–149.39	41.65	69.17	1366.47	30.44	1364.30	69.02
This paper	0	0	2	0	1	13.63	28.62	–105.95	36.81	39.42	880.22	73.88	1205.93	39.27
Mf														
Dickman	0	0	2	0	2	13.66	40.96	–79.76	52.49	7.97	1257.22	100.08	1716.11	7.82
G/S/B	0	0	2	0	2	13.66	56.10	–125.00	44.00	72.00	1722.07	54.83	1438.64	71.84
Weis	0	0	2	0	2	13.66	100.07	–132.00	95.03	71.00	3071.79	47.83	3107.14	70.84
1997 Emp	0	0	2	0	2	13.66	55.16	–64.07	79.01	31.48	1693.09	115.76	2583.21	31.32
This paper	0	0	2	0	2	13.66	69.18	–105.95	88.97	39.42	2123.44	73.88	2909.16	39.27
Mm														
Dickman	1	0	0	0	0	27.56	31.61	–43.97	16.98	–6.35	465.13	135.86	283.75	–6.50
G/S/B	1	0	0	0	0	27.56	53.00	–106.00	55.00	28.00	779.85	73.83	919.28	27.85
Weis	1	0	0	0	0	27.56	46.29	–77.00	50.17	9.00	681.12	102.83	838.55	8.85
1997 Emp	1	0	0	0	0	27.56	43.97	–85.01	58.62	–55.19	646.96	94.82	979.84	–55.34
This paper	1	0	0	0	0	27.56	38.56	–111.41	83.24	34.77	567.37	68.42	1391.36	34.62

l, *l'*, *F*, *D*, and Ω are the Delaunay arguments of the tidal constituent, expressions for which are given in Simon et al. (1994). The period, given in solar days, is the approximate period of the term as viewed in the terrestrial reference frame. The tabulated entries for the tide model labeled "Dickman" are from Dickman (1993) as reported by Gross et al. (1997); the entries labeled "G/S/B" are from Seiler (1991) as reported by Gross (1993); the entries labeled "Weis" are from Weis (2006); the entries labeled "1997 Emp" are from Gross et al. (1997); and the entries labeled "This paper" are from the preferred empirical tide model determined in this paper.

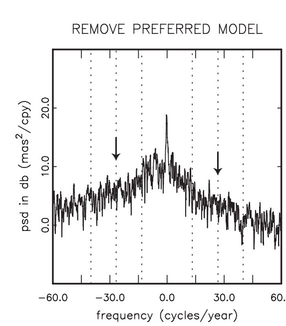
Constrained Least-Squares Fit

An empirical model for the effect of the termensual (Mtm and mtm), fortnightly (Mf and mf), and monthly (Mm) tides on polar motion is obtained by weighted least-squares fitting periodic terms at these tidal frequencies to residual polar motion excitation observations, that is, to observations from which atmospheric and non-tidal oceanic effects have been removed. A linear trend and periodic terms at the sermiannual (Ssa) and annual (Sa) tidal frequencies were also included in this fit. But the results for the Ssa and Sa tidal terms are not shown because they also include non-tidal effects caused by, for example, seasonal changes in water stored on land. During the fit, constraints are applied to tidal terms that have nearly the same frequency and that should therefore have the same relative response to the tide raising potential. This is done by setting the phases of the tidal terms to be equal to each other ($\phi_1 = \phi_2$) and by setting the ratio of the amplitudes of the tidal terms to be equal to the ratio of the amplitudes of the tide raising potential at the frequencies of those terms ($A_1/A_2 = f$). This constraint has been applied to the Mf and mf tidal terms and, separately, to the Mtm and mtm terms, since their frequencies differ by only 1/18.6 cycles per year (cpy). According to Cartwright and Edden (1973), the mf/Mf ratio f of the amplitudes of the tide raising potential is 0.4145, and the mtm/Mtm ratio is 0.4146.

New Empirical Ocean Tide Model



Has the new model converged? Maybe.



Does the new model remove the fortnightly tidal power that was observed during 2 January 1993 to 10 September 2006? Yes.

NB The new model was determined by fitting observations spanning 2 January 1980 to 10 September 2006.