Experimental Earth Tidal Models of the Core Resonance Obtained by Stacking Tidal Gravity Observations from GGP Stations

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Abstract

By stacking tidal gravity observations obtained by superconducting gravimeters in 20 GGP stations, the resonant parameters of the free core nutation are determined and 3 experimental tidal gravity models in diurnal band are constructed. It is found that our experimental models are in good agreement with those obtained in previous studies (Dehant et al 1999) and (Mathews et al, 2002).

1 Introduction

In recent years, many studies are developed in theoretical modelling and practical detection on the free core nutation (FCN) phenomena of the Earth. Based on the angular momentum equations, the eigenperiod can be theoretically computed by using analytical or numerical integration techniques, it is in the range from 455.8 to 467.4 sidereal days (sd) depending on Earth's model adopted (Wahr, 1981, Wahr and Bergen, 1986, Mathews et al 1991). The researches show that ground based observations as gravity, tilt, strain, water tube and VLBI, can be influenced by the FCN. In the diurnal tidal observations, the amplitudes of the P1, K1, y1 and j1 wave, are enhanced due to the core resonance. By using ground based high precision tidal gravity observations recorded with superconducting gravimeters (SGs) at the GGP network, the tidal parameters will be determined with considering pressure and ocean loading corrections. Then the resonant parameters of the Earth will be determined. The experimental tidal gravity models will be constructed when rejecting some bad tidal parameters due to the high noise level in this paper.

2 Data preparation

In our researches, 28 series of the tidal gravity observations recorded from SGs at 20 stations in total 92.086 years are used. The minute samplings are pre-processed using a Tsoft technique (Vauterin, 1998) at the International Centre for Earth Tides (ICET). The hourly sampling are obtained by using a remove restore technique and then processed by using Eterna technique. The details of the data length, atmospheric pressure admittances and the standard deviations can be found in Sun (Sun et al, 2002). As the selected data length for all stations is longer than one year, it is possible to separate accurately 13 wave groups in the diurnal wave band including some small waves as y_1 and j_1 in which their frequency are close to the resonant one of the Earth's liquid core. In order to check against the values predicted by recent models of the response of the Earth to the tidal forces, it is necessary for us to remove for the first step the influence of the atmospheric pressure and oceanic tides.

The influence of the atmospheric pressure is corrected by using the regression coefficients between gravity residual and change in station pressure. The global ocean models used in this study include the old Scw80, and the most recent ones developed by the analysis of the precise measurements from the Topex/Poseidon altimeters, and those result from parallel developments in numerical tidal modelling and data assimilation, such as the Csr3.0 (Eanes), Fes95.2 (Grenoble), TPXO2 (Egbert), CSR4.0 and Ori96 (Matsumoto) models.

Based on the global ocean models and model Earth Green's functions (Farrell 1972), the loading vectors are computed using a standard procedure (Agnew 1997, Sun 1992). Since the tidal load vectors are directly proportional to the wave amplitude in the exciting tidal potential and the phase change exhibits a regular behaviour with respect to the frequency shift, it is easy to interpolate the load vectors for weak components as y1 and j1. However, during the interpolation process, it is necessary for us to take into account the influence of the core resonance phenomena on oceanic tides (Wahr and Sasao, 1981, Matheow 2001). The loading vectors for 9 additional small components as s1, r1, NO1, p1, y1, j1, q1, J1 and OO1 in diurnal wave band are obtained. The efficiency of the loading correction for both principal and small tidal components is confirmed (Sun et al, 2002).

3 Calculation techniques

The complex amplitude factor of a diurnal tidal wave with frequency *s* can be theoretically computed as (Defraigne et al 1994)

$$\delta_{th}(\sigma) = \delta_0 + \overline{A}/(\sigma - \overline{\sigma}_{FCN}), \qquad (1)$$

with

$$\delta_0 = 1 + h_0 - \tfrac{3}{2}k_0, \qquad \overline{A} = -(A/A_m)(h_1 - \tfrac{3}{2}k_1)(\alpha - q_0 h^c/2)\Omega, \qquad (2)$$

where d_0 is the amplitude factor combined from the classical Love numbers h_0 and k_0, the $\overline{\sigma}_{FCN}$ is the eigenfrequency of the FCN, $\overline{A}$ is the resonance strength related to the geometric shape of the Earth and the rheology properties of the Earth's mantle. h_1 and k_1 are the internal pressure Love numbers, h^c is the secular Love number. A and A_m are the equatorial moments of inertia of the entire Earth and the solid mantle, a is the dynamic ellipticity of the Earth, q_0 ratio of the centrifugal force to gravity on the equator and W is the sidereal frequency of the Earth's rotation. For an inelastic Earth model, $\overline{A}$ and $\overline{\sigma}_{FCN}$ should be described as a complex

$$\overline{A} = A_r + iA_i, \qquad \overline{\sigma}_{FCN} = \sigma_r + i\sigma_i. \qquad (3)$$

The eigenperiod of the FCN is then $T_{FCN} = \Omega/(\sigma_r + \Omega)$ and the quality factor is $Q = \sigma_r/(2\sigma_i)$. Considering the frequency of the wave O_1 is far away from the one of the FCN, it can be referred as a reference. The similar treatment in determination of the FCN parameters as in the previous studies is used (Neuberg et al,1987, Defraigne et al, 1994 and Xu et al, 1999). The data from various stations are stacked in order to reduce the systematic discrepancy and local environmental disturbance. When removing the signals of wave O_1, the fitting equations can be deduced by modelling the observed parameters to theoretical ones in expression (1)

$$\delta(\sigma, j) - \delta(O_1, j) = \frac{A_r + iA_i}{\sigma - (\sigma_r + i\sigma_i)} - \frac{A_r + iA_i}{\sigma(O_1) - (\sigma_r + i\sigma_i)} \qquad (4)$$

where *j* stands for the station series number. To solve the above equation, Marquadt's algorithm of linearized iteration and modification is used (Xu et al, 2001).

4 Numerical results and discussions

The tidal gravity parameters are corrected by using loading vectors averaged from 6 different global ocean models for waves O1, P1, K1, y1 and j1. In order to check globally the core resonance phenomena, by stacking all tidal gravity observations from the GGP network, the eigenperiods of the core resonance T_{FCN} are obtained for three different cases, they are (1) 429.9 sd with error range (427.2, 432.7 sd) when staking tidal gravity observations obtained at 19 GGP stations with rejecting the stations BA and CB since the high noise level (the abridge of the station name can be found in Sun (Sun et al 2002); (2) 429.1 sd with error range (428.0, 430.3) when staking tidal gravity observations obtained at 22 series from 20 GGP stations (two series from stations ST and WE, with rejecting some special bad waves as K1 (SY), O1 (SY, WE), P1 (SY), y1 (BA, BR, KY, MA, PC, SU), j1 (BA, BO, KY); and (3) 429.7 sd with error range (426.8, 432.6) when using the procedure same as (2) with taking into account the signal to noise ratio by normalizing the standard deviations of the waves using the theoretical amplitudes of the corresponding waves.

It is found our results to be in good agreement with those deduced from the VLBI as 429.5 sd (Dehant et al 1999) and 430.04 sd (Mathews et al, 2002), the discrepancy is about 0.4%. They correspond also to those in previous experimental researches (Herring et al 1986, Neuberg 1987, Defraigne et al 1994 and Xu et al 2001). However, they are much less than the one in theoretical calculation as of about 460 sd (Wahr and Sasao, 1981). The unique convinced explanation to the T_{FCN} discrepancy of 30 sd is the dynamic ellipticity of the fluid core may to be about 4.8% larger than the hydrostatic one (Sun et al 2002).

Based on above three cases, three experimental Earth tidal models of the core resonance (SXD1, SXD2 and SXD3) are constructed based on formula (1). It is found that the largest discrepancy among the models of SXD1, SXD2 and SXD3 is less than 0.1% (table 1 and figure 1). The comparison of our results with those given by Mathews is also made (figure 2). It is found that the discrepancy is about 0.56% between MATH and SXD1, 0.25% between MATH and SXD2 and 0.33% between MATH and SXD3. The DDW tidal gravity models are also listed in table 1 in order to compare easily. The results in table1 and figures 1 and 2 demonstrate our 3 experimental models are in same level, they are close to the theoretical ones. It seems that the best fitting model is the one of SXD2 since the effectiveness of rejecting some bad waves, and comparing to the Mathew's model, the discrepancy is lowest one.

5 Conclusions

Based on the numerical results, we conclude the high quality observations are important in the determination of the FCN parameters, Our experimental models are in good agreement with those obtained in theoretical computations (Dehant et al 1999) and (Mathews et al, 2002).

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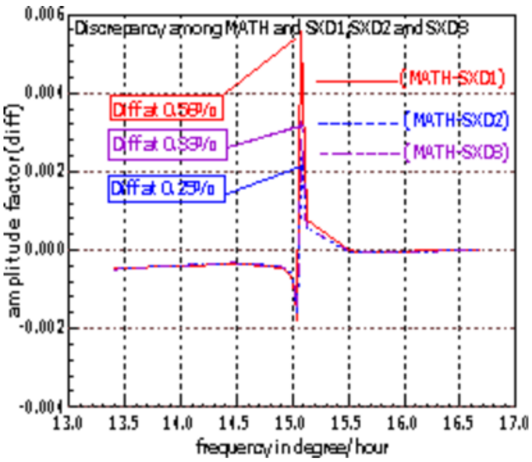

Figure 1 Comparison among the SXD models

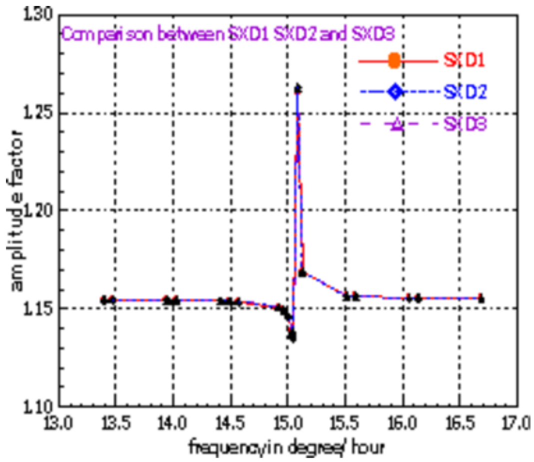

Figure 2 Comparison of SXD models with the Mathew's one

Table 1 Comparison of the tidal gravity models in the diurnal wave band

Wave argument		Frequency	name	DDW1	DDW2	MATH	SXD1	SXD2	SXD3
1-4 0 3 0 0	115.855	12.30991148	308	1.15254	1.15400		1.15473	1.15474	1.15474
1-4 2 1 0 0	117.655	12.38276513	SGQ1	1.15256	1.15402	1.15403	1.15473	1.15473	1.15473
1-3 0 1 0 0	125.655	12.84964437	noname	1.15269	1.15415		1.15468	1.15468	1.15468
1-3 0 2-1 0	125.745	12.85207978	2Q1x	1.15269	1.15415		1.15468	1.15468	1.15468
1-3 0 2 0 0	125.755	12.85428619	2Q1	1.15269	1.15415	1.15409	1.15468	1.15468	1.15468
1-3 2 0-1 0	127.545	12.92493343	SG1x	1.15271	1.15417		1.15467	1.15467	1.15467
1-3 2 0 0 0	127.555	12.92713984	SIG1	1.15271	1.15417	1.15410	1.15467	1.15467	1.15467
1-2 0 0-1 0	135.545	13.39181267	noname	1.15279	1.15425		1.15459	1.15459	1.15459
1-2 0 0 0 0	135.555	13.39401908	noname	1.15279	1.15425		1.15458	1.15459	1.15459
1-2 0 1-1 0	135.645	13.39645449	Q1x	1.15279	1.15425	1.15410	1.15458	1.15459	1.15459
1-2 0 1 0 0	135.655	13.39866089	Q1	1.15280	1.15425	1.15410	1.15458	1.15459	1.15459
1-2 2-1 0 0	137.455	13.47151455	RHO1	1.15280	1.15426	1.15410	1.15457	1.15457	1.15457
1-1 0 0-1 0	145.545	13.94082919	O1x	1.15279	1.15424	1.15401	1.15440	1.15440	1.15440
1-1 0 0 0 0	145.555	13.94303560	O1	1.15279	1.15424	1.15401	1.15440	1.15440	1.15440
1-1 0 1 0 0	135.655	13.94767741	noname	1.15279	1.15424		1.15440	1.15440	1.15440
1-1 0 2 0 0	145.755	13.95231923	2NO1	1.15279	1.15424		1.15440	1.15440	1.15440
1-1 2 0 0 0	147.555	14.02517288	TAU1	1.15278	1.15422	1.15397	1.15436	1.15436	1.15436
1 0-2 1 0 0	153.655	14.41455665	NTAU	1.15252	1.15396	1.15366	1.15400	1.15399	1.15399
1 0 0-1-1 0	155.445	14.48520390	LK1x	1.15242	1.15386		1.15388	1.15387	1.15387
1 0 0-1 0 0	155.455	14.48741031	LK1	1.15242	1.15385	1.15354	1.15388	1.15387	1.15387
1 0 0 0-1 0	155.545	14.48984571	noname	1.15242	1.15385		1.15387	1.15386	1.15386
1 0 0 0 0 0	155.555	14.49205212	noname	1.15241	1.15385		1.15387	1.15386	1.15386
1 0 0 0 1 0	155.565	14.49425853	noname	1.15241	1.15384		1.15386	1.15386	1.15386
1 0 0 1 0 0	155.655	14.49669393	NO1	1.15240	1.15384	1.15351	1.15386	1.15385	1.15385
1 0 0 1 1 0	155.665	14.49890034	NO1x	1.15240	1.15383	1.15351	1.15386	1.15385	1.15385
1 0 2-1 0 0	157.455	14.56954759	CHI1	1.15226	1.15369	1.15336	1.15370	1.15369	1.15369
1 1-3 0 0 1	162.556	14.91786468	PI1	1.14933	1.15072	1.15043	1.15091	1.15087	1.15087
1 1-2 0-1 0	163.545	14.95672495	P1x	1.14788	1.14927	1.14903	1.14959	1.14953	1.14953
1 1-2 0 0 0	163.555	14.95893136	P1	1.14777	1.14916	1.14892	1.14949	1.14943	1.14942
1 1-1 0 0 1	164.556	15.00000196	S1	1.14446	1.14589	1.14578	1.14654	1.14643	1.14643
1 1 0-1 0 0	165.455	15.03642683	noname	1.13543	1.13728		1.13879	1.13860	1.13858
1 1 0 0-1 0	165.545	15.03886223	K1x-	1.13416	1.13610	1.13610	1.13773	1.13753	1.13751
1 1 0 0 0 0	165.555	15.04106864	K1	1.13284	1.13489	1.13494	1.13664	1.13643	1.13641
1 1 0 0 1 0	165.565	15.04327505	K1x+	1.13133	1.13352	1.13361	1.13541	1.13518	1.13516
1 1 1 0 0-1	166.554	15.08213532	PSI1	1.23736	1.26978	1.26548	1.25993	1.26302	1.26217
1 1 2 0 0 0	167.555	15.12320592	PHI1	1.16776	1.17029	1.16932	1.16856	1.16878	1.16876
1 2-2 1 0 0	173.655	15.51258969	TET1	1.15551	1.15703	1.15641	1.15643	1.15646	1.15646
1 2 0-1 0 0	175.455	15.58544335	J1	1.15531	1.15682	1.15619	1.15622	1.15625	1.15625
1 2 0-1 1 0	175.465	15.58764975	J1x	1.15530	1.15682	1.15618	1.15622	1.15624	1.15624
1 2 0 0 0 0	175.555	15.59008516	noname	1.15530	1.15681		1.15621	1.15624	1.15624
1 2 0 0 1 0	175.565	15.59229157	noname	1.15529	1.15681		1.15621	1.15623	1.15623
1 3-2 0 0 0	183.555	16.05696440	SO1	1.15482	1.15631	1.15559	1.15562	1.15564	1.15564
1 3 0-2 0 0	185.355	16.12981805	2J1	1.15479	1.15628		1.15557	1.15559	1.15559
1 3 0-1 0 0	185.455	16.13445987	noname	1.15479	1.15628		1.15557	1.15559	1.15559
1 3 0 0 0 0	185.555	16.13910168	OO1	1.15479	1.15628	1.15555	1.15557	1.15559	1.15559
1 3 0 0 1 0	185.565	16.14130809	OO1x	1.15479	1.15628	1.15555	1.15557	1.15558	1.15558
1 4 0-1 0 0	195.455	16.68347639	NU1	1.15474	1.15623	1.15538	1.15536	1.15538	1.15538
1 4 0-1 1 0	195.465	16.68568279	NU1x	1.15474	1.15623		1.15536	1.15538	1.15538

Note: DDW1: tidal model in hydro static Earth hypotheses given by Dehant-Defraign-Wahr (1999);
DDW2: tidal static in non-hydro static Earth hypotheses given by Dehant-Defraign-Wahr (1999);
MATH: tidal model obtained by Mathews (2001);
SXD1: experimental tidal models given by Sun-Xu-Ducarme in this paper (2002);
SXD2: experimental tidal models given by Sun-Xu-Ducarme in this paper (2002);
SXD3: experimental tidal models given by Sun-Xu-Ducarme in this paper (2002);