Frequency Dependency of Earth's Q-value in tidal band inferred from the superconducting gravimeter

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1. Data and tidal analysis

The data used here were obtained from a superconducting gravimeter (SG) at Canberra, Australia for the period from January 27, 1997 to August 31, 2000 (about 3.7 years in length). The data were analyzed by means of a tidal analysis program called 'BAYTAP-G' (Tamura et al., 1991). In order to separate the effect of air pressure changes on the observed gravity signals, the air pressure data obtained at the observation site were taken into account by means of a response term to be estimated.

The scale factor of the SG has been calibrated three times during the above observation period by an Australian group and a French group by comparing with absolute gravimeters. The average of the three calibration values is -75.878+/-0.149 microGal/Volt (1 microGal = 1E-8 in MKS unit). The formal error suggests that the scale factor is determined at the accuracy better than 0.2% and/or the scale factor has been in stable at its level during the observation period. For the main waves whose amplitudes are larger than 20 microGal, the formal 1-sigma errors of the obtained gravimetric tidal factor (δ-factor) and phase are 0.0002 to 0.00002 and 0.009 deg to 0.001 deg, respectively.

In order to compare the theoretical values, we applied here the following three corrections to the observed values; (1) for the phase delaying due to the analog filter, (2) for the effect of an additional acceleration on the gravimeter due to the up-down ground motion caused by tides (i.e. so called 'inertial correction') and (3) for the ocean tides.

2. Comparison with the theory

The four ocean models were used for the comparison; (1) NAO99 model by Matsumoto et al. (2000) that was assimilated with TOPEX/Poseidon data, (2) another version of this model that was modified it by taking into account the local tides observed in the east coast of Australia, (3) Shwiderski's model (1987), and (4) Desei and Wahr model (1995). The effects of the ocean tides were computed by using the Green's function for the 1066A earth model (Gibert and Dziewonski, 1975).

The theoretical δ-factors for the elastic earth were estimated based on the theories of Wahr(1981) and Dehant Ducarme(1987). On the other hand, those for the inelastic earth were estimated based on the theories of Wahr and Bergen (1987) and Dehant and Zschau(1988). The former two give the Love numbers for the 1066A earth model, and the latter two gives the inelastic Love numbers for several earth models including the PREM model (Dziwonski and Anderson, 1981).

Figure 1 shows the comparison between the observed δ-factor and phase lag and theoretical ones for the two waves of M2 and O1. We restrict here our discussions to these two waves, because (1) the amplitudes of the O1 and M2 waves are large (34 microGal and 59 microGal, respectively) and (2) we can also expect that both the possible remaining air pressure effect and the effect of the free core resonance are to be small for these waves. As shown in Fig.1, due to the difference in the ocean models used for the correction, the corrected δ-factor and phase lag are scattered within the ranges of 0.002 to 0.004 and 0.09 deg to 0.17 deg, respectively. We use here their mean values shown with the mark * in the figure for the following discussions.

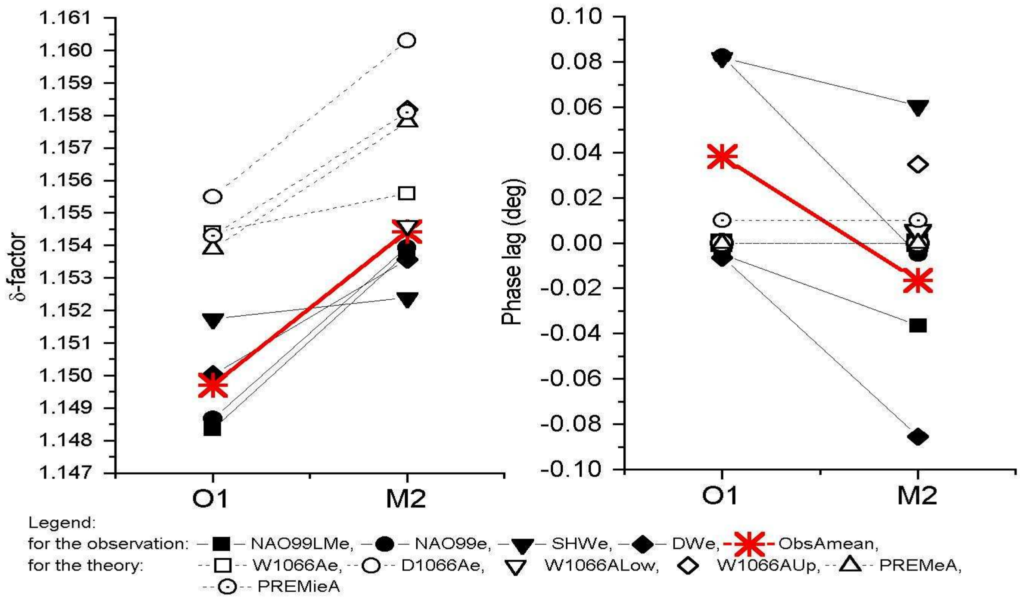

Fig.1. Comparison between the observed δ-factor and phase lag and the theoretical ones. Filled marks stand for the observation, and NAO99LM, NAO99, SHW and DW show the ocean models used for the correction to the observed values (se text). D and W stand for the theories by Wahr (1981) and Dehant and Decarme (1987). W1066ALow and W1066AUp show the lower and upper bounds of the inelastic effect, which were estimated based on the theory by Wahr and Bergen (1986). PREMeA and PREMieA are results for the PREM earth model based on the theory by Dehant and Zschau(1987).

3. Discussions

3.1. Latitude dependency of the tidal factor

A characteristics of tides on an elliptical rotating earth is a latitude dependency of the δ-factors, which does not appear the tides on a spherical non-rotating earth. The difference in magnitude of the δ-factors estimated from the two theories of Wahr(1981) and Dehant and Ducarme(1987) is mainly due to this effect (see the difference between the M2 and O1 waves shown in Fig.1. The former computed the tidal force on the earth toward the geo-center, but the latter computed the force along the vertical (i.e. in the direction of the ellipsoidal normal) to be compared with the observation.

Our results clearly prefer the theory by Dehant and Ducarme(1987) rather than that by Wahr(1981).

3.2. Effect of the inelasticity

As suggested from the theories, the expected phase lag due to the inelastic structure of the earth is very small. Dehant and Zchau (1988) estimate a value of 0.005 deg as the phase lag due to the inelastic effect. If we take the mean of the averaged M2 and O1 waves, we obtained a value of +0.022 deg. This close to a value in-between the lower and upper bounds inferred from the theory by Wahr and Bergen (1987). However, from the present observation results, it is difficult to draw a definitive conclusion related to the Q-value of the short-period tides. This is due to the discrepancy in the ocean models used for the correction. Although it is desired to improve the accuracy of the both the gravity observation and the ocean models to tightly constrain the inelastic property of the earth from the observation, it is worth to note that the observed values corrected by using the recent ocean models, which were derived from the TOPEX/Poseidon data, show very consistent results for both the δ-factor and phase lag. Our results also suggest that the discrepancy in the M2 wave is larger than that for the O1. This may be due to the complexity in the spatial distribution of the M2 wave compared with the O1 wave.

3.3. Density of the fluid core

As described in the previous sub-section, our observation clearly shows the latitude dependency in the δ-factors as expected from he theory, but the observed δ-factors are systematically small by about 0.3% to 0.5% for both the M2 and O1 waves compared with the theoretical ones. The similar tendency is also observed for other main waves, for example, the P1, K1 and S2 waves. Compared with the accuracy of calibration of SG and the ranges of the distribution of the corrected δ-factors, this difference is considered to be significant.

Okubu (1987) discussed a possible significant effect of the density change at the core mantle boundary (CMB) on the theoretically estimated Love numbers and the load Love numbers, and he pointed out that 1% uncertainty in the liquid core density makes 0.1-1% uncertainty in the estimation of Green's function used for the ocean tide correction. We do not attribute all of discrepancy in δ-factors shown here to the uncertainty in the core density, but our results suggest a possibility to use the tidal observation to constraint the magnitude of the density change at CMB.

4. Conclusions

An important conclusion obtained here is that we have a chance to constrain the core density from the tidal observations with the SG. The data obtained from a global SG network such as OHP network are useful to discuss this problem. For this purpose and to improve the estimation of the tidal parameters, it is important to calibrate regularly the SGs of the network, for example, at the frequency once or twice a year.

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