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Upper Mantle Structure and Global Earth Tides

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Abstract. Static earth tide characteristic numbers are calculated for seismic earth models differing with respect to upper mantle structure. The results confirm that global earth tides are rather insensitive to variations of upper mantle structure. The values of the static numbers obtained for a European continental structure are within the limits $h=0.611\pm0.002$, $k=0.301\pm0.001$, $l=0.0844\pm0.0006$, $\delta=1.161\pm0.002$, $\gamma=0.689\pm0.002$.

Key words: Earth tides – Upper mantle structure – Love numbers.

Introduction

Model calculations of the response of the earth to tidal accelerations have led to the conviction that the structure of the earth's upper mantle has only a minor influence on earth tides. Alsop and Kuo (1964) concluded from their calculations that different seismic velocities in the upper mantle do not significantly modify the earth tide parameters and that a change of the density distribution may cause a slight variation of the Love numbers. Kuo and Ewing (1966) obtained differences of 3% between the Love numbers h and k for a Gutenberg-Bullen A earth model with a low velocity channel centered at 140 km and a corresponding model with a structure of the New York-Pennsylvania area. Farrell (1972) calculated the M_2-tide Love numbers for a Gutenberg-Bullen A earth model and two corresponding models in which the top 1000 km were replaced by an oceanic and a continental shield mantle. The differences between the corresponding characteristic numbers were about 1%, and Farrell (1973) concluded that global earth tides are quite insensitive to the earth's structure. Calculations of Wilhelm (1976, 1978) contradicted these results as differences up to 10% between corresponding Love numbers appeared for some of the considered earth models. But, as Denis (1978) pointed out, it is physically quite unlikely that a change of properties in any part of the mantle could produce such large variations of the Love numbers. An examination of the referred calculations has confirmed this objection. As Denis supposed the differences are due to an inadequate computational procedure used for the numerical differentiation of the parameters for the model of Wang (1972) and the models

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UTD124A′ and UTD124B′ of Dziewonski and Gilbert (1972). In the upper mantle of these models there are second order discontinuities with high gradients where the numerical differentiation procedure introduced large errors. If these discontinuities are replaced by first order discontinuities with the corresponding boundary conditions the surprisingly large differences between the results (Wilhelm, 1976, 1978) disappear and a good agreement is obtained.

Results

The transformations used to obtain a set of six first order linear differential equations determining the tidal induced deformation and gravity disturbance differ from the corresponding transformations of Alterman et al. (1959). In order to solve the set of equations (9.38) of Wilhelm (1976) it is therefore necessary to compute the derivatives of density, gravity and Lamé's parameters. In the computation a rigidity of 1 kbar was assumed for the outer core. A diminuation of the rigidity generally yields only negligible changes of the results but according to Denis (1978), the calculated static Love numbers can be different according to whether the outer core is assumed to be fluid or not. In case of a nonvanishing rigidity in the outer core the Jeffreys-Vicente conjecture (Pekeris and Accad, 1972) holds whereas for a fluid outer core this conjecture may not be valid. However, if the Jeffreys-Vicente conjecture applies the static Love numbers calculated for core models with vanishing or small nonvanishing rigidity should agree. The determination of the static deformation of an earth model with a fluid core is still a matter of discussion (for references see (Denis, 1978)).

The tidal characteristic numbers were calculated for the model of Wang (1972), the models UTD124A′ and UTD124B′ of Dziewonski and Gilbert (1972), the models B497 and C198 of Gilbert et al. (1973) tabulated in (Dziewonski and Gilbert, 1973), the models 1066A and 1066B of Gilbert and Dziewonski (1975), the model B1 of Jordan and Anderson (1974), and the model C2 of Anderson and Hart (1976). The results are shown in Table 1. The model of Wang is slightly modified in the crust in order to avoid a negative Poisson's number. Model C2 has an ocean of 3 km depth, therefore the characteristic numbers refer to the ocean bottom. The values of h, k, δ-1 and γ agree to within about 2% and l to within 3% with each other. These calculations confirm the result that global earth tides are rather insensitive to the structure of the upper mantle and contrary assertions of Wilhelm (1976, 1978) are disproved.

Reference values of the earth tide parameters for European stations can be obtained by substituting a common upper mantle for the different upper mantles of the models of Table 1. Investigations of the dispersion of surface waves (Seidl, 1971; Seidl et al., 1971) have led to the model KA-100 for the upper mantle structure in western Europe. If the substitution is performed with this upper mantle model the characteristic numbers of Table 2 are obtained. Now there are only small differences in the third significant digit between corresponding values. The last two lines show the centered values and bounds for each column. They represent undisturbed static tidal parameters which can be expected for western Europe.

Table 1. Static characteristic numbers for the considered earth models

	h	k	l	δ	γ
WANG	0.612	0.302	0.0846	1.159	0.690
UTD124A′	0.609	0.301	0.0861	1.158	0.691
UTD124B′	0.609	0.301	0.0861	1.158	0.691
B497	0.610	0.301	0.0850	1.159	0.691
C198	0.610	0.301	0.0851	1.159	0.691
1066A	0.611	0.301	0.0845	1.159	0.690
1066B	0.611	0.301	0.0842	1.159	0.690
B1	0.608	0.301	0.0856	1.158	0.692
C2	0.618	0.303	0.0841	1.163	0.685

Table 2. Static characteristic numbers for the models of Table 1 with KA-100 upper mantle structure (cf. text)

	h	k	l	δ	γ
WANGKA	0.612	0.300	0.0840	1.162	0.688
124A′KA 124B′KA	0.610	0.300	0.0850	1.160	0.690
B497KA C198KA	0.612	0.301	0.0842	1.161	0.689
1066AKA	0.610	0.300	0.0844	1.160	0.690
1066BKA	0.611	0.301	0.0842	1.160	0.690
B1KA	0.611	0.301	0.0845	1.159	0.690
C2KA	0.613	0.301	0.0838	1.161	0.688
	0.611 ±0.002	0.301 ±0.001	0.0844 ±0.0006	1.161 ±0.002	0.689 ±0.002

Table 3. Static characteristic numbers for model B497 with upper mantle structure of W-, SW-, and SE-Europe (cf. text)

	h	k	l	δ	γ
B497KA	0.612	0.301	0.0842	1.161	0.689
B497SW	0.611	0.300	0.0834	1.160	0.690
B497SE	0.610	0.300	0.0835	1.160	0.690

For SE-Europe and for SW-Europe a slightly different structure of the upper mantle has to be assumed. The body wave velocities of these models were taken from (Mayer-Rosa, 1969) and (Mayer-Rosa and Müller, 1973), the density is tabulated in (Müller, 1971). In order to examine how much the differences of the upper mantle structure of W-Europe, SW-Europe and SE-Europe can affect the tidal parameters, the upper mantle of model B497 was replaced by the upper mantle models for SW- and SE-Europe. From the results shown in Table 3 it is evident that there are no significant variations of the values of h, k, δ-1, and γ for these models of the upper mantle in Europe.

Comparison With Earth Tide Measurements

A comparison with characteristic numbers resulting from earth tide measurements is only possible for the tide O_1 which in the European area is not so much disturbed by the indirect effect of ocean tides or by meteorological disturbances. From measurements over a period of altogether about 16,000 days at European stations Melchior (1974) obtains

$$\delta(O_1) = 1.164 \pm 0.001 \qquad \gamma(O_1) = 0.674 \pm 0.005 \tag{1}$$

from which follows

$$h(O_1) = 0.638 \pm 0.017 \qquad k(O_1) = 0.317 \pm 0.011. \tag{2}$$

$\delta(O_1)$ is somewhat greater and $\gamma(O_1)$ is distinctly smaller than the corresponding values of Table 2. The difference between the values of γ indicates that systematic disturbing influences are still affecting the mean value (1) of $\gamma(O_1)$. Since about 70% of the original data were obtained at earth tide stations in Belgium and Luxembourg (Melchior, 1973) a systematic disturbance may be caused by the indirect effect of ocean tides. A map of the regional distribution of $\delta(O_1)$ in Europe (Melchior et al., 1976) shows a continuous decrease of $\delta(O_1)$ from the Belgian coast (Ostende) via Bruxelles to Luxembourg (Walferdange). However, it is doubtful if the indirect effect is responsible for the deviation from the theoretically calculated values, as model calculations of the influence of the indirect effect on the M_2-tide lead to even greater discrepancies. On the other hand the recently published values (Melchior, 1978)

$$\delta(O_1) = 1.1608 \pm 0.0086 \qquad \gamma(O_1) = 0.6788 \pm 0.0056 \tag{3}$$

are approaching the corresponding values of Table 2.

Conclusions

The present investigation confirms that global earth tides are not significantly influenced by the structure of the upper mantle. The differences between the characteristic numbers calculated for earth models with various upper mantle structures are about 2%. Only the differences between the corresponding Shida numbers l attain 3%.

There are discrepancies left between the mean values of $\gamma(O_1)$ obtained from measurements at European stations and the corresponding static values calculated for a European continental structure. The reason for these discrepancies should be examined.

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