NORMAL DENSITY EARTH MODELS

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Resume: Выведены модели распределения плотности близкие модели PREM (т. наз. нормальные модели плотности), внешнее гравитационное поле которых идентично совпадает с нормальными гравитационным полем Земли. Поверхность Земли аппроксимируется в работе эллипсоидом вращения. Динамическое сжатие нормальных моделей составляет \( H = 0.003\, 273\, 994 \). Из множества выведенных нормальных моделей рекомендуется модель HME2. В качестве априорной оценки нормальных моделей плотности была использована средняя радиально симметрическая модель PREM. Предлагается модификация этой модели под названием PREM-E2.

Summary: Models of the Earth's density, close to the PREM model, have been derived, they reproduce the external normal gravitational field of the Earth and its dynamic flattening, and are referred to as normal density models. The Earth's surface is approximated by an ellipsoid of the order of the flattening, or of its square. Of the group of normal models satisfying the solution of the inverse problem, the normal density model HME2 is recommended. The spherically symmetric density model PREM, which was corrected in the course of solving the inverse problem, thus creating the modified PREM-E2 model, was used as the a priori information.

1. INTRODUCTION

The knowledge of the density distribution within the Earth is of fundamental importance in many geophysical disciplines. The density distribution appears in the equations expressing the kinematics and dynamics of seismic wave propagation, the free oscillations of the Earth, in equations of the Earth tides and of the convective flow in the Earth's mantle and core. The density also affects the dynamics of the Earth's rotation. It represents the distribution of the sources of the internal and external gravity fields. Moreover it is one of the state parameters controlling the thermodynamics of the Earth's interior. Consequently, the density distribution may be derived from different geophysical, geodetical and astronomical observations, i.e. from combined travel-time and surface wave dispersion data, as well as from the analysis of free oscillations and from the coefficients of the gravity potential. The density distribution must conform to the results related to the behaviour of the minerals constituting the Earth's mantle under high pressure and corresponding temperature.

It is important that the external gravity field be known with an accuracy higher than any other geophysical parameter pertaining to radial and lateral variations [16]. The use of satellite tracking data has made it possible to describe the external gravity field by coefficients up to the 180th order, i.e. with a spatial resolution of approximately one degree. The external gravity field reflects the details in the density distribution within the Earth and, therefore, represents a useful source of information on the radial and lateral density variations. On the other hand, the fact that the density is involved in many geophysical, geodetical and astronomical problems yields a system of

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important constraints on the density distribution. The correct density distribution must take into account all the stipulations originated in the Earth and space sciences mentioned in order to be self-consistent. The constraints are a powerful tool for determining the fine density distribution, involving both radial and angular variations.

The problem of the Earth's reference density model has been tackled by many investigators from several points of view. Dziewonski and Anderson [8] considered this problem from the seismological aspect. They derived a preliminary reference Earth model, called PREM. It is related to a spherically symmetric Earth and concerns the velocities of seismic P and S waves, the density and coefficient of seismic anisotropy. It is based on a large amount of normal modes, seismic travel-time and long-period surface wave observations. The following basic astronomical and geodetic data were incorporated in the model: the Earth's radius \( R = 6371 \) km, mass \( M = 5.974 \times 10^{24} \) kg and moment of inertia \( I = 0.3308MR^2 \). The Earth's body was divided into the following principal regions: (1) Ocean layer, (2) Upper and lower crust, (3) the region above the low-velocity zone (LID), (4) the low-velocity zone (LVZ), (5) the region between the low-velocity zone and the 400 km discontinuity, (6) the transition zone spanning the region between the 400 km and 670 km discontinuities, (7) the lower mantle subdivided into three parts connected by second-order discontinuities, (8) the outer core, (9) the inner core. In constructing the PREM model, the initial density distribution was determined using the method proposed by Birch [4]. It was assumed that the Adams-Williamson equation was satisfied in every subregion from the centre up to the 670 km discontinuity. The relation between the density and P-wave velocity was considered to be linear. The initial model was subject to parameter variation. The final density in each layer is represented by a polynomial in terms of the normalized radius \( x = r/R \) up to the third degree. The coefficients can be found in Tab. 1 of [8] and also in Tab. 4 of this paper.

The stipulation that the density produces the same external gravity field as the observed was not applied. However, some models constructed on the basis of the theory of stratified heterogeneous spheroids include this stipulation. Under the additional assumption of hydrostatic equilibrium, this approach was applied by Moritz [18], Kartvelishvili [13], Nakiboglu [19], James and Kopal [12], and Kopal and Lanzano [15]. An indirect approach, based on the properties of the covariance function of the gravity field was suggested by Tscherning [27]. However, it must be borne in mind that no density distribution can satisfy all the geodetical and astronomical observation conditions under assumption of hydrostatic equilibrium [14]. In the above mentioned cases, the density model must be considered the optimum model which fits the observational data best.

To determine the 3-D distribution of the Earth's parameters has become an important task of geophysical research in the last decade. Progress has been made in determining the large-scale inhomogeneities in the Earth's mantle [9, 29]. Seismological data have mostly been used and special methods such as tomographic imaging have been developed.

The objective of the present study is to develop Earth density models which would fit not only seismic observations, but also the external gravity field represented by the normal gravity formula. This formula has been widely used in interpreting regional and global gravity data. As suggested by Kartvelishvili [13], it seems to be useful to look for a normal density distribution related to the normal gravity formula. A normal density model which would fit seismological, geodetical and astronomical data, and which would reproduce the coefficients \( J_{20} \) and \( J_{40} \) of the external gravity field as well, would certainly be welcomed by geophysicists, namely by researchers concerned with large-scale gravity anomalies.