Moscow University
Physics Bulletin
Vol. 53, No. 1, pp. 53–56, 1998

Vestnik Moskovskogo
Universiteta. Fizika
UDC 551.24

GEOPHYSICS

SECULAR VARIATION OF THE EARTH'S MEAN RADIUS

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It is shown that the mechanism of subduction and accumulation of the masses of oceanic platforms leads to a slow decrease of the Earth's mean radius at a rate of ~0.35 mm/year.

The problem of secular variation of the Earth's radius has been standing for more than a century. The idea of the Earth's expansion from its rudiments to the present state is exposed in detail in [1]. Therefore, we shall only mention the publications directly relevant to our present investigation.

According to present views, almost 95% of the Earth's surface is in the state of compressive strain. This may be regarded as a direct indication of the Earth's radius contraction [2]. The geodynamic model advanced by Kropotkin [2] leans upon the platform motion theory and Obruchev's pulsation hypothesis. According to [2], the variation of the Earth's surface area is alternating, has a decade and irregular character, and correlates with variations in the Earth's rotation velocity. In other words, the periods of the Earth expansion alternate with periods of its contraction. It is pointed out in [2] that the observed contraction of the Earth's crust might result from the Earth's radius contraction during the last 10 million years at the neotectonic stage of Earth's development.

Thoroughly analyzing the integrals of the Earth–Moon system kinetic moments with the use of present-day data on tidal variations of this system parameter, secular variation of the geopotential coefficient J_2, and angular acceleration of the Earth's rotation, Bursa [3, 4] came to a similar conclusion on the Earth's radius decrease in the Recent epoch.

In recent years, investigations have been published [5, 6] where attempts are made to determine the rate $\dot{R}$ of the Earth's radius variation, proceeding from the data of high-precision laser observations of Lageos satellites. The authors hold opposite viewpoints on the problem, and their data on $\dot{R}$ are contradictory (for instance, the values of $\dot{R}$ found by them vary within a wide range, from 16 to -20 mm/year).

The problem of mechanisms generating variations of the Earth's mean radius is still more intricate. For instance, the reasoning of W. Carey, a well-known proponent of the hypothesis of the expanding Earth [1], is based on the idea of ether absorption by the Earth, entertained by the Russian engineer Yarkovskii, and also on Hubble's law of expanding Universe. To estimate possible geodynamic effects, other physical theories are also recruited, for example, those allowing for time variations of the gravitational constant [7].

In this work we obtained estimates for the rate of variation of the Earth's mean radius basically assuming the existence of mass accumulation mechanism along comparatively narrow precincts of subduction zones [8].

According to this hypothesis, asthenospheric masses coming to rift zones and accreting on the soles of oceanic platforms, are transported due to global motion of the platforms to the subduction zones and become accumulated in their vicinity. That is, in the given geological epoch the asthenospheric layer, as it were, loses its mass, becomes thinner, and, as a result of this planetary process, the Earth's mean radius decreases. In other words, the masses of oceanic platforms coming to the asthenosphere, according to our assumption, do not replenish "instantaneously" the losses of "stock masses" of the asthenospheric layer, but are concentrated along comparatively narrow belts on the Earth's surface. "Leveling" of the asthenospheric layer, "dispersal" and "towage" of the masses accumulated along the subduction zones occur only within geologic time intervals and upon substantial changes in the intensities of subduction and spreading processes. Global rotation of the lithosphere plays an essential role in the said processes [9].

Therefore, in the zones of mass concentration of subsiding oceanic platforms there should be observed an inverse effect of the Earth's mean radius increase. This is confirmed, e.g., by the uplift of the Tibet plateau, etc. Actually, formation of such "seams" should result in slow reduction of the Earth's mean radius (calculated for the Earth's entire surface, except for the above-mentioned narrow belts of the subduction zones).

The proposed scheme of redistribution of land masses lends itself to simple analytical description from different standpoints. In what follows, we shall derive fairly consistent $\dot{R}$ values by three agreeable methods.

The first method is based on the mass balance relation: a decrease of the asthenospheric layer mass per unit of time is equal to the sum of masses accumulated along subduction zones and those coming to the mid-oceanic ridges per the same unit of time. In this case, the rate of variation of the asthenospheric layer radius is

$$\dot{R} = -R(\dot{m}_s + \dot{m}_c)\rho/(3m\rho_a) = -R \times 0.5727\frac{(\dot{m}_s + \dot{m}_c)}{m}, \tag{1}$$

where $R = 6371$ km is the Earth's mean radius; m is the Earth's mass; $\rho_a = 3.21$ g/cm^3 and $\rho = 5.515$ g/cm^3 are the asthenospheric layer density and the Earth's mean density; $\dot{m}_s$ and $\dot{m}_c$ are two fundamental parameters of the global tectonic process, $\dot{m}_s$ is the rate of arrival of oceanic platform masses to all subduction zones, $\dot{m}_c$ is the rate of arrival of asthenospheric masses to all the rift zones (along mid-oceanic ridges). With a prescribed kinematics of the platforms, the said characteristics are defined by simple curvilinear integrals on the Earth's surface along the subduction zones and rift zones and can be calculated rather easily by approximation methods.

For calculating $\dot{m}_c$, we also used the well-known value of the ocean bed spreading rate $\dot{S}_c$ = 3.1 km^2/year [2] and the platforms thickness in zones of their origination $H = 2$ km [10]. When calculating the value $\dot{m}_s$, we used the Ushakov–Galushkin theory of relative movement of lithospheric platforms [11]. The mean thickness of submerging blocks of platforms was assumed to be $H = 80$ km, their density $\rho = 3.3$ g/cm^3.

For the found values of parameters,

$$\dot{m}_s/m = 9.12 \times 10^{-9}\ \text{epoch}^{-1}, \quad \dot{m}_c/m = 0.34 \times 10^{-9}\ \text{epoch}^{-1}.$$

The rate of variation of the Earth's mean radius (1) was $\dot{R} = -0.345$ mm/year ($\dot{R}/R = -5.42 \times 10^{-9}$ epoch^{-1}).

In the second method, an invariant of the tectonic process is used: the sum of axial moments of inertia of tectonic masses upon any redistribution of the masses in a thin near-surface spherical layer remains invariable.

Hence, an equation for the rate of variation of the Earth's radius is

$$\frac{\dot{R}}{R} = -\frac{\rho I}{6\rho_a}\frac{(\dot{A} + \dot{B} + \dot{C})_s}{C} = -0.0947\frac{(\dot{A} + \dot{B} + \dot{C})_s}{C}, \tag{2}$$

where $I = C/mR^2 = 0.33068$ is the dimensionless moment of inertia of the Earth; $(\dot{A})_s$, $(\dot{B})_s$, and $(\dot{C})_s$ are the rates of variation of the Earth's axial moments of inertia induced by subduction and accumulation of the masses of oceanic platforms. Their values (see (5)) were determined by an approximate calculation of corresponding volume integrals [8].

For these values, we find by formula (2): $\dot{R}/R == -5.025 \times 10^{-9}$ epoch^{-1}, $\dot{R} = -0.320$ mm/year.

The third method employs the value of nontidal acceleration of the Earth's rotation [12] caused by variation of the Earth's dynamic structure (to be more precise, of its polar moment of inertia C),

$$\dot{\omega}_{nt}/\omega = -\dot{C}/C = (6.92 \pm 1.73) \times 10^{-8}\ \text{epoch}^{-1}. \tag{3}$$

The latter equality can be rewritten in more detail,

$$\frac{\dot{R}}{R} = -\frac{\rho I}{2\rho_a}\left[\frac{\dot{\omega}_{nt}}{\omega} + \left(\frac{\dot{C}}{C}\right)_O + \left(\frac{\dot{C}}{C}\right)_A + \left(\frac{\dot{C}}{C}\right)_G + \left(\frac{\dot{C}}{C}\right)_{WI} + \left(\frac{\dot{C}}{C}\right)_S\right]. \tag{4}$$

The expressions in square brackets represent variations of the Earth's moment of inertia, caused by changes in the World Ocean level (O), accretion of ice in Antarctica (A) and Greenland (G), and subduction of platforms (S). The variation $(\dot{C})_{WI}$ is caused by other processes of ice–water–ice transformation in the Earth's near-surface layers.

All these variations were calculated for simple models of the above-stated geodynamic processes by the procedure used, e.g., in [8]. The rates of secular variations of the World Ocean level and of the Greenland and Antarctica ice cover were assumed 1.38 and 20 mm/year, respectively [13]. The mean effective thickness of submerging lithospheric platforms was assumed 80 km [10].

Omitting the procedure of calculating variations of the Earth's polar moment of inertia in (4), which reduces to approximate calculation of corresponding surface integrals by the method of trapezoids, we present the values of these variations:

$$\begin{aligned}
\left(\dot{A}\right)_0/C &= 13.29 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{A}\right)_A/C &= 9.83 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{A}\right)_G/C &= 1.70 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{A}\right)_S/C &= 17.17 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{B}\right)_0/C &= 13.80 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{B}\right)_A/C &= 9.61 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{B}\right)_G/C &= 1.73 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{B}\right)_S/C &= 14.13 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{C}\right)_0/C &= 14.12 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{C}\right)_A/C &= 0.64 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{C}\right)_G/C &= 0.17 \times 10^{-9}\ \text{epoch}^{-1},\\
\left(\dot{C}\right)_S/C &= 21.77 \times 10^{-9}\ \text{epoch}^{-1}.
\end{aligned} \tag{5}$$

The variation $(\dot{C})_{WI}$ can approximately be estimated on the basis of a similar invariant for water–ice masses: the sum of their axial moments of inertia is a constant value. Under this assumption, from the data of (5) we find

$$(\dot{C})_{WI}/C = -(1/3)(\dot{A} + \dot{B} + \dot{C})_{O,A,G}/C = -21.62 \times 10^{-9}\,\text{epoch}^{-1}.$$

Here $(\dot{A} + \dot{B} + \dot{C})_{O,A,G}$ is the variation of the sum of the Earth's axial moments due to three processes (O, A, G).

For the value of nontidal acceleration (3) we find from formula (4) $\dot{R} = -0.273 \pm 0.031$ mm/year.

CONCLUSION

All the three methods proposed above give close values for the rate of contraction of the Earth's radius in the Recent epoch, $\dot{R} = -(0.27–0.35)$ mm/year. Different initial data were used in the calculations: variations of tectonic masses and of the Earth's axial moments of inertia as well as the nontidal acceleration of the Earth's rotation. The obtained results give some grounds to assign the fine geodynamic phenomenon under study to actually occurring phenomena. In contrast to the investigations carried out by other authors, in this work we indicate and estimate quantitatively a particular mechanism of variations in the geometry of the Earth's masses and radius. The value $\dot{R}$ found here is the upper estimate of this parameter. An additional analysis of the tectonic mass accumulation mechanism shows that the actual value $\dot{R}$ may amount to as little as 0.10 mm/year.

This work was supported by the Russian Foundation for Basic Research (Grant 96-05-65015).

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23 May 1997

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