POLE DRIFT, NON-TIDAL ACCELERATION AND INVERSION REORGANIZATION OF THE EARTH

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ABSTRACT. New mechanism of the Earth mass reorganization caused by the forced relative translatory-rotary oscillations of the core and mantle due to a gravitational attraction of external celestial bodies is studied and fundamental geodynamical consequences are discussed.

1. INTRODUCTION

All celestial bodies: planets, large satellites, stars and others objects are the define systems of the shells. Only in the first approximation the shells of these objects can be presented as concentric and with definite concentric distribution of densities. All shells are characterised by definite physical properties, sizes and mass distribution. They can have different physical states (rigid, elastic, non-elastic, liquid, gaseous and other). Shells are mutually interacting (including their gravitational interaction) and interact with external celestial bodies. In more detailed consideration the density of distributions of the shells are quasi-concentric and in general case the shells are non-homogeneous and non-spherical and with changing physical properties. From a mechanical point of view it means that shells are exposed by differential gravitational influence from the external celestial bodies. As result the small relative forced oscillations of the shells as celestial bodies must be observed. The centres of mass of the shells are displaced in definite rhythms including long-periodic (and secular) components. And all shells make relative rotational oscillations (small turns) with frequencies defined by the configuration of external celestial bodies and in different time-scales (Barkin, 2002). To the order by the forced oscillations should be shown and own (free) oscillations of the planet shells as celestial bodies. The main planet shells are the core and the mantle. Therefore our research on dynamics of shells have begun with two-shells models of a planet in its various treatments: a rigid core and an elastic mantle (Barkin, Shatina, 2004), a liquid core and an elastic mantle (Barkin, 2005), a rigid core and a rigid mantle separated by a visco-elastic layer (Barkin, 2001, 2002; Barkin, Vilke, 2004).

2. OSCILLATIONS OF THE EARTH CORE-MANTLE SYSTEM

The Earth, as well as many other celestial bodies, represents a system of celestial gravitating bodies - system of shells, with basic components the mantle and the core. Shells are non-spherical unbalanced bodies and, hence, are exposed to different gravitational influences on the part of external celestial bodies (the Moon, the Sun and others). In result they are forced to make small relative displacements and turns with frequencies characteristic for external actions. In result, the free oscillations and forced oscillations of the specified system are generated. The periods of

free oscillations of dynamic system "the elastic mantle - the rigid core of the Earth" have been established (Barkin, 2005): 3.47, 4.06 and 4.89 hours. Variations with the specified periods and their derivatives are observed in many geodynamic, geophysical, biological and physical processes. That specifies existence of the effective mechanism of excitation of the observed oscillations. By the study of forced relative oscillations of the core-mantle system both shells are considered as unchangeable spheroids which are subject to differential gravitational influence on the part of the Moon and the Sun and mutually interacting gravitationally and with certain elastic force and moments (Barkin, 2001, 2002; Barkin, Vilke, 2004). In this paper the mutual interaction was modeled with the help of thin elastic layer between the core and the mantle (an analog of D" layer). Here we take into account gravitational interaction of the core with the fully elastic mantle. Forced oscillations have been studied on the basis of a model problem about relative motions of a non-spherical elastic mantle and non-spherical rigid core under gravitational perturbation of the Moon and the Sun. On the basis of dynamical analytical studies of the problem (Barkin, 2002; Barkin, Vilke, 2004) we have shown that in case of the unperturbed circular orbit of the Moon, its gravitational action on the non-spherical core and mantle produces relative oscillations of their centers of mass along polar axis of the Earth according to the law

$$z = -1.519 + 0.966\cos 2M - 4.676\sin M \quad \text{(cm)} \tag{1}$$

Formula (1) describes the core oscillations with periods 13.9 days (with amplitude 0.966 cm) and with synodic period 27.8 days with amplitude 4.676 cm. Here is the mean anomaly of the circular Moon orbit. That will be coordinated to the data of precision satellite observations of the geocenter motion (Barkin, Vilke, 2004).

The angle between the polar axes of inertia of the core and mantle also oscillates with significant amplitude (Barkin, Vilke, 2004)

$$\theta_2 - \theta_1 = -0''36 \cdot 10^{-5} - 9''076\cos 2g\,. \tag{2}$$

From the formula (2) it follows, that pole of axis of symmetry of the core is displaced periodically (with period equal to a half of Moon orbital period) with amplitude about 152 m at the mantle bottom. It means, that the core "is periodically turned" relatively mantle on mentioned distance.

3. SECULAR DRIFT OF THE CORE TO THE NORTH POLE

3.1. Secular drift of center of mass

Alongside with a wide spectrum of periodic variations of position of the centre of mass of the Earth the phenomenon of its slow (secular) drift is observed. An original method (Barkin, 1995a) made us possible for the first time to evaluate a velocity of the centre of mass motion. Formally, this motion was referred to special reference system in which the coefficient of geopotential J_3 is equal zero. And effect of the center of mass motion has been interpreted as result of the change of the Earth pear-shaped form which is characterized by the known secular variations of the geopotential zonal coefficients $\dot{J}_2$ and $\dot{J}_3$. It was shown that in the given epoch the mass centre of the Earth moves to the North Pole with velocity about $1.0 \div 2.0$ cm/year. In the last years the space geodesy investigations have confirmed this phenomenon. In particular, for velocity of the center of mass drift were obtained values: 6.9 ± 3.5 mm/yr, 9.6 mm/yr (Tatevian, Kuzin, Kaftan, 2004: GPS data, 1993-2003) and others.

3.2. Core drift to North pole

For explanation of the geocenter drift (and its oscillations), the mechanism of relative translational displacements of the core and mantle of the Earth has been suggested as the main mechanism of the Earth mass redistribution (Barkin, 1995a).

For description of the geocenter drift we have used model of the homogeneous mantle and the core and on the base of PREM model we have determined superfluous mass of the core as 0.1932 of the Earth mass. The drift of this mass with theoretical velocity 4.975 cm/yr generates the center of mass drift to the North Pole with velocity 0.875 cm/yr. Relative displacements of the core and the mantle are accompanied by elastic mantle deformations. That also gives systematic component of a geocenter drift. In final solution of the problem of elasticity, the displacement vector was determined in an analytical form and additional component of the geocenter drift was evaluated as 0.25 cm/yr in direction to the North Pole also. For evaluation of the core velocity the modern data about lengthening of parallels in Southern hemisphere of the Earth have been used. In result of fulfilled studies, the following statements can be formulated (Barkin, 2005).

The main mechanism of the center of mass drift. The secular drift of the Earth center of mass is mainly a reflection of the slow drift of the mass center of the core relatively to the mass center of the mantle which occurs in the same direction as that of the mass center of the Earth.

Hypothesis about origin of the pear-shaped form of celestial bodies. The pear-shaped form of the Earth is a result of the slow redistribution of the mass (mantle deformations) caused by the core - mantle relative displacements along polar axis under the gravitation action of the external gravitating bodies (the Moon, the Sun and planets). This phenomenon is probably general for many others planets and satellites.

4. LENGTHENING (SHORTENING) OF PARALLELS IN SOUTHERN (NORTHERN) HEMISPHERE OF THE EARTH

The phenomenon of the core drift discussed here, has obtained very important confirmations on the base of the observational data: in measurements of the superconducting gravimeters and in space geodesy and VLBI data. The more important from them is a discovery of inversion geodesy phenomenon of the lengthening of the parallels of the Earth in Southern hemisphere and shortening parallels in northern hemisphere (Shuanggen Jin, Zhu Wenyao, 2002). This phenomenon has been described in an analytical form as result of solution of the problem of elasticity about mantle deformations by the secular drift of the liquid core (Barkin, Shatina, 2004; Barkin, 2005). In accordance with the last solution, the velocity $\dot{L}_p$ of lengthening of parallel φ is connected with the relative velocity of the core drift $\dot{\rho}$ by the simple relation:

$$\dot{L}_p = 2\pi 0.108021 \dot{\rho} \sin\varphi \cos\varphi = 1.5765 \sin(2\varphi) \ \ (\text{cm/yr}) \tag{3}$$

Based on results of Chinese authors on space geodesy determination of the changes of the parallel lengths we adopt $\dot{L}_p = 16.901 \pm 2.535$ mm/year for the latitude $\varphi = 45^\circ$ with formal error about 15%. By this assumption on the base of observational data, we obtain for velocity of the core trend the following evaluation:

$$\dot{\rho} = \dot{\rho}_0 = 4.6455 \pm 0.697 \ \ (\text{cm/yr})\,. \tag{4}$$

The phenomenon of the lengthening (shortening) of parallels in southern (northern) hemispheres, discovered in the Chinese works, is fully explained by the gravitational influence of the drifting core on the elastic mantle of the Earth.

5. GRAVITY CONFIRMATIONS OF THE CORE DRIFT

5.1. Love numbers of order (-2)

If the core drift is real phenomenon so many others related inversion planetary geodynamical and geophysical phenomena must be observed in the case of the Earth, it means: in gravity

measurements, in secular variations geodesic heights, in ocean and atmospheric secular mass redistributions and in many natural processes. The gravity variation in given place on the Earth surface is determined indirectly by displacement of superfluous mass of the core. The additional gravitational potential caused by the mantle deformation and height variations of gravimeters also gives contributions to gravity variation. Last two components are described with the help of the Love numbers of the order of (-2). For accepted models of the core and mantle the values of the Love numbers have been determined: $k_{-2} = -0.1423$ and $h_{-2} = 0.1419$.

5.2. Secular trend of gravity

The secular variation of gravity at the point with latitude φ is determined by formula $\dot{g} = 2g\Delta m_c\dot{\rho}(1 - h_{-2} - 0.5k_{-2})\sin\varphi/(m_\oplus r)$, where $\Delta m_c = 0.1932m_\oplus$ is the superfluous mass of the core in units of the Earth mass and r is the mean radius of the Earth. Taking into account values of parameters of problem the final expression of secular gravity variation we present in the form: $\dot{g} = 2.6182\sin\varphi$ μgal/yr.

5.3. Comparison of the theory and observations

The predicted variation of gravity at station Medsina (Zerbini et al., 2001) makes 1.82 ± 0.27 gal/yr that will well be coordinated with marked by observations secular trend in this region 1.7 ± 0.1 μgal/yr. Theoretical value of a variation of a gravity at Antarctic station Syowa -2.45 ± 0.37 μgal/yr precisely corresponds to observable here trend in 1997-2000 in -2 to -3 μgal/yr. In Potsdam for the period of 1972-1982 the variation has made about 2 to 2.5 μgal/yr that also will be coordinated to theoretical value 2.0 ± 0.3 μgal/yr.

6. HEIGHT CONFIRMATIONS OF THE CORE DRIFT

6.1. Secular height variations

A secular height variation at Earth surface on the latitude φ due to a secular trend in the relative motion of the core and the mantle is described by formula: $\delta h = -9.0487\sin\varphi$ mm/year.

6.2. Comparison of the theory and observations

As an confirmation of this result we point that the GPS height daily solutions for period July 1996 - June 2000 gives the negative linear trend of the height at a Medicine station about -7.0 ± 0.2 mm/year (Zerbini et al., 2001), that is close to a theoretical value of height trend in this region -5.4 ± 0.8 mm/year (Barkin, 2005).

7. REFLECTION OF THE CORE DRIFT IN OCEAN MASS REDISTRIBUTION

Inversion ocean tide. The luni-solar tides caused by an attraction of the Moon and the Sun, have been investigated in details. Alongside with these classical tides we ascertain existence of a new class of the tides caused by the gravitational attraction of oceanic shell by the displaced core. Obviously the gravitational attraction of the core superfluous mass moving to the North Pole must leads to formation of the special polar tide in ocean. This tide is asymmetrical. In northern hemisphere the sea level increases and in southern hemisphere it has an opposite tendency. The preliminary studies show that velocity of the sea level change (with respect to the crust) is described by the law: $\dot{\zeta} = 6.43\sin\varphi + 0.67$ mm/yr (Barkin, 2005). If the discussed fundamental phenomena of the expansion of the southern and contraction of northern hemispheres of the Earth in reality are characterized by found amplitudes (Shuanggen Jin, Zhu Wenyao, 2002) it means that the core drifts with velocity (4) and inevitably the asymmetric secular tide at global ocean should be observed on the background of many others tides of the sea. It is worth to remark that this result was obtained on the base of the classical static theory of tides and has

restricted character. In reality the formation of this inversion tide can be connected with the organization and with inversion activation of the ocean flows.

8. TO EXPLANATION OF THE NON-TIDAL ACCELERATION OF THE EARTH ROTATION

Preliminary evaluations show, that mentioned in section 7 tide (and similar cyclic inversion tides with annual and semiannual periods) causes significant secular (cyclic) variations of the moments of inertia of the Earth, geopotential coefficients and play important role for understanding of observed geodynamical phenomena. On our preliminary evaluation the described tide gives the contribution to variation of coefficient of second zonal harmonic $\dot{J}_2$ equal to 0.43. This value and all values below are given in units 10^{-9} 1/cy. The tectonic process of the plate subduction in accordance with author paper (Barkin, 1995b) gives contribution 2.00; in postglacial rebound process, Antarctica and Greenland in accordance with the model ICE1A give contributions: -8.9, 3.18 and 0.48, respectively. Others geophysical factors give the following contributions: atmosphere (0.7, 0.17), ground water (0.2), mountain glacier (0.34), reservoirs (-0.08), earthquakes (-0.022), core rotation (-0.04) and pressure at CMB (-1.3) (Cheng, 2000). So, summary effect in variation $\dot{J}_2$ is evaluated as -2.17. This variation determines secular acceleration of the Earth diurnal rotation of 4.4×10^{-9} (1/cy).

9. TO EXPLANATION OF THE POLE DRIFT

According to modern estimations the pole moves with velocity 0.351"$\pm$0.003" 1/cy in direction of meridian 79.2° W (Gross, Vondrak, 1999). Similar approach (see p. 8) can be used for explanation of this phenomenon. To describe pole drift we must determine first secular variations of geopotential coefficients caused by the all known reasons (they are mentioned in section 8). Then velocities of changes of the pole coordinates $\dot{C}_{21}$ and $\dot{S}_{21}$ can be evaluated on formulas:

$$\frac{\dot{p}}{\omega} = \left(1 - \frac{T_{CH}}{T}\right) \frac{\dot{C}_{21}}{I}, \quad \frac{\dot{q}}{\omega} = \left(1 - \frac{T_{CH}}{T}\right) \frac{\dot{S}_{21}}{I}$$

(T_{CH} is Chandler period, T is the period of the Earth rotation).

In particular we have shown that tectonic mechanism and mechanism of inversion tide give remarkable contributions to both components $\dot{p}/\omega$ and $\dot{q}/\omega$. The mechanism of plate subduction and mass accumulation give 0"139 1/cy and $-$0"153 1/cy respectively (Barkin, 1995b) and the mechanism of inversion tide gives 0"041 and 0"059 respectively.

REFERENCES

Barkin Yu.V. (1995a) About motion of the Earth center of mass, caused by global change of dynamical structure and by tidal deformations. Vestnik Moskovskogo Universiteta, Ser. 3, Physika, astronimia, Ser. 3, v.36, N5, pp.99-101. In Russian.

Barkin Yu.V. (1995b) Lithosphere Plate Motion as Mechanism of the Secular Variations of the Geopotential and Earth Rotation. Vestnik MGU. Ser.3. Fiz., Astron. 1995, T.36, No.6, p.89-94. In Russian.

Barkin, Yu.V.(2001) Dynamics of the Earth's shells and fundamental problems of celestial mechanics, astrometry, gravimetry and geodynamics. Proceedings of international conference "AstroKazan-2001". Astronomy and geodesy in new millennium (24-29 September 2001), Kazan State University: Publisher "DAS", p.59-65.

Barkin Yu.V. (2002) Explanation of endogenous activity of planets and satellites and its cyclicity. Izvestia cekzii nauk o Zemle. Rus. Acad. of Nat. Scien., Issue 9, December 2002, M.: VINITI, pp. 45-97. In Russian.

Barkin Yu.V. and V.G. Vilke (2004) Celestial mechanics of the planet shells. Astronomical and astrophysical transactions, v. 23, Issue 6 (December 2004), pp. 533-554.

Barkin Y. V. and Schatina A.V. (2004) Deformations of the mantle by moving core and geocenter motion. Abstracts of 9th Symposium on Study of the Earth's Deep Interior (SEDI 2004, July 4-9, Garmisch-Partenkirchen, Germany). P. 61.

Barkin Yu.V. (2005) Celestial geodynamics and solution of fundamental problems of geodesy, gravimetry, astrometry and geophysics. In: Metamorphism, cosmic, experimental and general issues of petrology. (Eds. Mitropfanov F.P., Fedotov Zh. A.) Proceedings of International (X All-Russian) Petrographic Conference (June 20-22, 2005, Apatity). Volume 4. - Apatity: Print. Kola Science Centre RAS, pp. 48 - 50. In Russian.

Cheng M.K. (2000) Observed and measured zonal rates. Private communication. XXV General Assembly of EGS (Nice, April 25-29, 2000).

Gross R.S. and Vondrak J. (1999) Astrometric and space-geodetic observations of polar wander. Geophysical res. Ltrs/ 1999GL900422, Vol. 26, No. 14, p. 2085.

Shuanggen Jin, Zhu Wenyao (2002) Quantitative analysis of the slowing expansion of the South hemisphere. Proceedings of colloquium "APSG-Irkutsk, 2002, Moscow, GEOS, pp. 154-162.

Tatevian S.K., Kuzin S.P., Kaftan V.I. (2004) Comparison of geocenter variations derived from GPS and DORIS data. Report of EGU (25-30 April 2004, Nice, France).

Zerbini S., Richter B. et al. (2001) Height and gravity variations by continuous GPS, gravity and environmental parameter observations in the southern Po Plain, near Bologna, Italy. Earth and planetary Science Letters, 192, pp. 267-279.