THEORETICAL STUDY AND PREDICTION OF SECULAR GEOCENTER AND GRAVITY VARIATIONS

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Abstract. A semi-empirical model of the secular relative displacements of the Earth's mantle and core is developed. Known data about non-tidal acceleration of diurnal Earth rotation, about secular pole drift and about variation of geopotential coefficient of second zonal harmonic are used for construction of a mentioned model. It was shown that secular changes of Earth rotation, of gravity, of geopotential, of geocenter position, of Earth figure and some from observed natural planetary processes (variations of volcanism activity, seismic activity, sea level change and others) can be interpreted as variations which are dictated and controlled by mechanism of secular relative displacement of the mantle and core.

Introduction. Analysis of secular variations of activity of many geodynamical and geophysical processes, analysis of the secular variations of geopotential and Earth rotation unambiguously point to existence of the effective planetary mechanism of mass redistribution along definite inclined radial directions (Barkin, 2001 b, 2002). This redistribution can be considered in first approximation as axysimmetrical. These phenomena we connect with slow tendentious relative displacements of core and mantle of the Earth in the last century.

In general case, in accordance with our approach, an intensity of the mentioned process and orientation of the axis of symmetry are changed in the different time-scales with periods from a few minutes to many million of years. In present epoch some decade cycles and slow secular changes of activity of the different geodynamical and geophysical processes are observed.

This mechanism has a celestial-mechanical nature. It is dictated by the relative motion of the Earth shells, which are non-homogeneous, non-spherical and occupy definite eccentric relative positions. Due to these properties the shells are actively perturbed by the gravitational attraction of the Moon, the Sun and planets. These actions are effected on the background of their mutual interaction in conditions of the rotating and precessing Earth. This mechanism leads to big forces and torque's acting to the shells and generates their small relative motions: displacements of the centers of mass from their eccentric positions and slow relative rotations. Translational relative oscillations of the shells (lower and upper shells with boundary at 670 km, liquid core, rigid core, lithosphere and plates, ocean and oth.) and their slow rotations cause a forced mass redistribution in the upper layers of the Earth and variations of the many geodynamical and geophysical processes. The well known processes of the ice-water transformation (post glacial rebound and oth.) can be considered as surface processes, which are controlled by the main mechanism of the shell dynamics.

1 Mechanism of mass redistribution and its models

Pariisky N.N. has shown that observed secular and decade variations of the Earth rotation can not be explained by any surface processes of the planet and these variations are caused by an inner mechanism of the Earth mass redistribution (Pariisky, 2000). The possible inner reasons of observed effects in the Earth rotation and in its physical fields were studied by many authors (Avsjuk 1996; Greiner-Mai et al., 1999 and others), including the studies of the role of rigid core influence.

The models of the Earth mass redistribution for given intervals of time are developed here on the base of conception of the translational relative oscillations of the shells (Barkin, 2001 a,b; 2002). Semi-empirical method is used here. From observed data it follows, that for define intervals of time the mass redistribution of the planet has radial character and can be considered as axisymmetrical with respect to the definite inclined axis. This mechanism combines elastic deformations of the mantle layers (due to a perturbing inner tide potential) and redistribution of fluids. Intensity of these processes is defined by the momentum of the relative displacement of the inner shell $m_i\dot{r}_i$ (m_i and $\dot{r}_i$ is a mass and velocity of the shell). Moveable shell (core) directly leads to observed variations of gravity and to geocenter displacements. Variations of the geopotential coefficients (second and higher harmonics) and Earth rotation are caused in first by mass redistribution which is generated by translational motion of the shell with definite properties. On the base last fundamental conclusion the concrete evaluations of the secular and interannual variations of Earth rotation, geopotential, force of gravity, geocenter position were fulfilled in the paper (see Tables 1-5).

The simplest model of the mass redistribution is used here. It is presented by the material point with variable mass $m = \dot{m}t$ (t is the time and $\dot{m}$ is a constant velocity of mass change) situated on the axis of the radial displacement of the shell. For main models this point is situated on the Earth surface. In this report we consider mathematical aspects of model. But we can suggest also that this model reflects define processes of the fluid's concentrations (formation of fluid bulge) due to the tension changes in the interacting shells by their relative displacements (Barkin, 2001 a, b).

Total displacements of the shells (as alone generating mechanism) produce wide spectrum of the geodynamical and geophysical changes of the Earth with definite properties. All these mechanical changes and variations of different processes are mutually coupled. Rhythms, cycles, intensities of these changes in significant role are controlled and dictated by a mechanism of the shell translational motion. The formulae of these couples were obtained and have used for construction of the concrete models of the Earth mass redistribution on the base of observed data and for explanation and predictions of the geodynamical processes variations in the different time-scales. The main considered models are characterized by the three parameters: $\dot{C}_{20}^{\zeta}$ is a measure of the intensity of the mass redistribution (for point- model we have: $\dot{C}_{20}^{\zeta} = \dot{m}/m_{\oplus}$, $m_{\oplus}$ is a Earth mass); φ, λ are a latitude and longitude of the inclined axis of axisymmetrical mass redistribution.

Developed method let us to define the model parameters on the base of the average values of three components of the angular acceleration of the Earth rotation $\dot{p}/\omega$, $\dot{q}/\omega$ and $\dot{\omega}/\omega$ ($\dot{p}$, $\dot{q}$ are equatorial components and $\dot{\omega}$ is polar component normalized on the angular velocity of the Earth ω). Parameters of the models are defined in dependence from considered period of time (century, space geodesy period, interannual intervals). Results on the evaluations of the geodynamical variations are presented in Tables 1-5.

2 Secular variations of geodynamical parameters

2.1. Models of mass redistribution. The main result is a prediction of axisymmetrical redistribution of the Earth mass along inclined geocentric axis directed to the geographic point: $\varphi = 70^0 0\, N$, $\lambda = 116^0 5\, E$ (to peninsula Taimyr). Intensity parameter for corresponding point-model is $\dot{C}_{20}^{\zeta} = \dot{m}/m_{\oplus} = 3.808 \cdot 10^{-9}\, 1/cy$. This model explains the following fundamental geodynamical phenomena: non-tidal acceleration of the Earth diurnal rotation (Pariisky, 2000; Stephenson, Morrison, 1995); pole drift in the last century (Vondrak, 1985); observed variations of the coefficients of the zonal harmonics of geopotential: $\dot{J}_2, \dot{J}_3, \dot{J}_4, \dot{J}_6, \dot{J}_8$ (Cheng et al., 1997).

Some new phenomena have been predicted. In first the variations of the tesseral coefficients of the geopotential (harmonics 1, 2, 3, 4) were evaluated. $\dot{C}_{22}$, $\dot{S}_{22}$ variations fully coincide with their predicted values obtained in the paper Marchenko and Abrikosov (2001). The secular drift of geocenter with velocity $3-5\, cm/cy$ in direction to peninsula Taimyr and secular variation of gravity in this region about 18 $\mu gal/cy$ also were predicted. Developed semi-inverse method of geodynamical analysis (in its segment variant) has obtained important confirmations by analysis of the variations of gravity at Potsdam, Ledovo and Novosibirsk (see Tables 4,5).

Variations of geopotential coefficients were obtained for a few models of the mass redistribution. Here we consider the more interesting from them. In the Tables 1, 2 variations of the geopotential coefficients are presented for two point model (M) of mass redistribution: I and II. Parameters of the first model ($\varphi = 70^0 0\ N$, $\lambda = 104^0 3\ E$, $\dot{C}^{\zeta}_{20} = 3.8080 \cdot 10^{-9}\ 1/cy$) were calculated on the base of the following average values of the components of the angular acceleration in last century: $\dot{\omega}/\omega = 6.33 \cdot 10^{-9}\ 1/cy$, $\dot{p}/\omega = 394.5 \cdot 10^{-9}\ 1/cy$, $\dot{q}/\omega = -1547.5 \cdot 10^{-9}\ 1/cy$. Parameters of the second model ($\varphi = 57^0 06\ N$, $\lambda = 101^0 17\ E$, $\dot{C}^{\zeta}_{n0} = 4.671683 \cdot 10^{-9}\ 1/cy$) were calculated on the base of the variations of the geopotential coefficients of the model of the Earth gravitational field EGM96: $\dot{C}_{20} = 2.600 \cdot 10^{-9}\ 1/cy$, $\dot{C}_{21} = -0.4131 \cdot 10^{-9}\ 1/cy$, $\dot{S}_{21} = 2.0914 \cdot 10^{-9}\ 1/cy$. For both model the point with variable mass $\dot{m}/m_{\oplus} = \dot{C}^{\zeta}_{20}$ is situated on the Earth surface in the pole of the inclined axis which is characterized direction of the modulated mass redistribution.

2.2. Variations of the zonal coefficients of geopotential. They were calculated on the base of the following formula of method (P_n is a Legendre's polynomials):

$$\dot{C}_{n0} = P_n(\sin\varphi)\dot{C}^{\zeta}_{n0}, \qquad \dot{C}^{\zeta}_{n0} = \dot{m}r^n / m_{\oplus} r^n_{\oplus} .$$

Table 1. Variations of the coefficients of the zonal harmonics of geopotential $\dot{J}_{\sigma}$.

M	$\dot{J}_1$	$\dot{J}_2$	$\dot{J}_3$	$\dot{J}_4$	$\dot{J}_5$	$\dot{J}_6$	$\dot{J}_7$	$\dot{J}_8$	$\dot{J}_9$	$\dot{J}_{10}$	$\dot{J}_{11}$
I	**-3.58**	**-3.14**	**-2.53**	**-1.81**	**-1.03**	**-0.27**	**0.41**	**0.96**	**1.34**	**1.53**	**1.52**
II	**-3.92**	**-2.60**	**-1.02**	**0.45**	**1.50**	**1.93**	**1.72**	**1.02**	**0.09**	**-0.77**	**-1.32**
OB	**-----**	**-2.7 ±0.4**	**-1.3 ±0.5**	**-1.4 ±1.0**	**2.1 ±0.6**	**0.3 ±0.7**	**-2.4 ±1.4**	**1.1 ±0.8**	**-----**	**-----**	**-----**

2.3. Variations of tesseral coefficients of geopotential. They were calculated on the base of the following analytical formulae:

$$\dot{C}_{nk} = \dot{C}^{\zeta}_{n0} k_{nk} P^{(k)}_n(\sin\varphi)\cos k\lambda, \qquad \dot{S}_{nk} = \dot{S}^{\zeta}_{n0} k_{nk} P^{(k)}_n(\sin\varphi)\cos k\lambda ,$$

where $(n = 1,2,3,4;\ k = 0,1,...,n)$, $k_{nk} = 2(n-k)!/(n+k)!, P^{(k)}_n(\sin\varphi)$ are associated Legendre's functions. Variations of geopotential coefficients evaluated for models I and II are presented in the Tables 1, 2 $(1\ unit = 10^{-9}\ 1/cy)$. The comparison of the obtained results with observational data (OB) of space geodesy (Cheng K. et al., 1997) is given in the Table 1.

Table 2. Variations of the coefficients of the tesseral harmonics of geopotential $\dot{C}_{nk}, \dot{S}_{nk}$ $(n = 1,2,3,4)$ $(1\ unit = 10^{-9}\ 1/cy)$.

M	$\dot{C}_{11}$	$\dot{C}_{21}$	$\dot{C}_{22}$	$\dot{C}_{31}$	$\dot{C}_{32}$	$\dot{C}_{33}$	$\dot{C}_{41}$	$\dot{C}_{42}$	$\dot{C}_{43}$	$\dot{C}_{44}$
I	**-0.32**	**-0.30**	**-0.10**	**-0.28**	**-0.09**	**0.00**	**-0.24**	**-0.08**	**0.00**	**0.00**
II	**-0.49**	**-0.413**	**-0.319**	**-0.31**	**-0.27**	**0.02**	**-0.20**	**-0.21**	**0.02**	**0.00**
M	$\dot{S}_{11}$	$\dot{S}_{21}$	$\dot{S}_{22}$	$\dot{S}_{31}$	$\dot{S}_{32}$	$\dot{S}_{33}$	$\dot{S}_{41}$	$\dot{S}_{42}$	$\dot{S}_{43}$	$\dot{S}_{44}$
I	**1.26**	**1.19**	**-0.05**	**1.09**	**-0.05**	**-0.01**	**0.94**	**-0.05**	**0.00**	**0.00**
II	**2.49**	**2.091**	**-0.131**	**1.57**	**-0.11**	**-0.03**	**1.01**	**-0.09**	**-0.02**	**0.00**

2.4. Explanation of the geocenter trend in the last decade. Theoretical parameters of the geocenter trend were obtained on the base point-model of the mass redistribution. Geocenter drift with velocity $v_G = \dot{m}(1+k)/m_{\oplus}$ is executed along axis of the axisymmetrical mass redistribution (to the point with variable mass by $\dot{m} > 0$, and in opposite direction by $\dot{m} < 0$). φ_G and λ_G are a latitude and longitude of the direction of geocenter trend. A parameter k takes into account elastic deformation of the Earth surface due to inner tide from the moveable lower shell. Empirical evaluation of the parameter is $k = 0.49$ (Barkin, 2001 b). In the Table 3 a comparison of the theoretical parameters of the geocenter motion and their values obtained from satellite observations are given for two periods of time: a) 1991.4-1994.8 (Montag et.al., 1995) and b) 1995.4-1996.7 (Zhu et. al., 1999).

Таблица 3 a, b. Theoretical and observed values of parameters of geocenter motion: a) period of 1991.4-1994.8 , b) period of 1995.4-1996.7 .

Parameters a)	Theory	Observations	Parameters b)	Theory	Observations
v_G **(mm/y)**	**2.12**	**5.7 $\pm$ 4.5**	v_G **(cm/y)**	**2.85**	**2.85 $\pm$ 0.19**
φ_G	**73^{0}5 S**	**64^{0}6 S**	φ_G	**0^{0}7 S**	**2.85 $\pm$ 0.19 S**
λ_G	**92^{0}0 E**	**97^{0}1 E**	λ_G	**116^{0}5 W**	**116^{0}9 W**

2.5. Interpretation of gravity non-tidal variations at Ledovo, Potsdam, Novosibirsk. Theoretical evaluations of variations of gravity were obtained on the base of formulae:

$$\dot{g} = 2gm_i\dot{r}_i(1 + h_{-2} - 0.5k_{-2})\cos\varphi_0 /(m_{\oplus} r_{\oplus}), \qquad \dot{g} = g\{5.24 \cdot \dot{C}_{20}^{\zeta}\}\cos\varphi_0 ,$$

applied for definite segments of time.

Their comparison with observed data (Arnautov, 1986; Potsdam data and another) is presented in the Tables 4 and 5. Here m_i and $\dot{r}_i$ is a mass and velocity of the relative motion of the lower shell, k_{-2}, h_{-2} are the Love numbers of the new (inner) tide in the mantle of the order (-2). Last elastic characteristic are unknown now and here we have used Potsdam gravimetry data for their semi-empirical evaluation (see second formula for $\dot{g}$), using also additional assumption $m_i\dot{r}_i \sim \dot{C}_{20}^{\zeta}$. φ_0 is an angle between the geocentric direction to a gravity station and direction of lower shell drift.

Obtained here results can be considered as a confirmation of a reality of radial redistribution of the Earth mass along mentioned inclined geocentric axis. In this connection the study of set of mechanical problems about relative translational displacements of elastic shells of celestial bodies perturbed by others external bodies is very actual.

Table 4. Theoretical $\dot{g}(1)$ and observed $\dot{g}(2)$ gravity variations (1 $unit = \mu gal/y$).

N	Segments of time (years)	$\dot{\omega}/\omega$	v_P	λ_P	$\dot{C}_{20}^{\zeta}$	φ	λ	φ_0	$\dot{g}(1)$	$\dot{g}(2)$
1	**00-97, Ledovo**	**6.33**	**1597**	**-75^{0}7**	**3.808**	**70^{0}0**	**104^{0}3**	**31^{0}5**	**0.17**	**-----**
2	**00-97, Potsdam**	**6.33**	**1597**	**-75^{0}7**	**3.808**	**70^{0}0**	**104^{0}3**	**42^{0}3**	**0.15**	**-----**
3	**00-97, Novosibirsk**	**6.33**	**1597**	**-75^{0}7**	**3.808**	**70^{0}0**	**104^{0}3**	**17^{0}7**	**0.19**	**-----**
4	**76-90, Ledovo**	**110.9**	**2272**	**-68^{0}9**	**55.1**	**88^{0}2**	**68^{0}9**	**34^{0}8**	**-2.4**	**-2**
5	**80.7-83.9, Potsdam**	**-468**	**3054**	**153^{0}5**	**-464.5**	**0^{0}29**	**-26^{0}5**	**117^{0}8**	**11.4**	**10.6**
6	**80.7-83.9, Ledovo**	**-468**	**3054**	**153^{0}5**	**-464.5**	**0^{0}29**	**-26^{0}5**	**120^{0}1**	**12.2**	**12.8**

7	**80.7-83.9,Novosibirsk**	**-468**	**3054**	**$153^{0}5$**	**-464.5**	**$0^{0}29$**	**$-26^{0}5$**	**$122^{0}4$**	**13.0**	**14.1**

Table 5. Variations of gravity at Potsdam in 1976.6-1994.6.

N	Segments (years)	$\dot{\omega}/\omega$	v_P	λ_P	$\dot{C}_{20}^{\zeta}$	φ	λ	φ_0	$\dot{g}_r(1)$	$\dot{g}_r(3)$
1	**76.6-78.8**	**-268.8**	**3054**	**$-116^{0}5$**	**284.6**	**$0^{0}47$**	**$63^{0}5$**	**$113^{0}3$**	**-5.9**	**-10.7**
2	**78.8-80.7**	**600.7**	**4121**	**$-116^{0}5$**	**-596.0**	**$0^{0}30$**	**$-116^{0}5$**	**$112^{0}6$**	**12.0**	**14.5**
3	**80.7-83.9**	**-468.2**	**3054**	**$153^{0}5$**	**-464.5**	**$0^{0}29$**	**$-26^{0}5$**	**$117^{0}8$**	**11.4**	**10.6**
4	**83.9-86.4**	**316.6**	**3054**	**$-26^{0}5$**	**157.1**	**$89^{0}1$**	**$153^{0}5$**	**$38^{0}3$**	**-6.5**	**-6.7**
5	**86.4-88.0**	**-514.4**	**3054**	**$-116^{0}5$**	**510.3**	**$0^{0}26$**	**$63^{0}5$**	**$113^{0}1$**	**-10.5**	**-18.8**
6	**88.0-90.0**	**259.0**	**3054**	**$-116^{0}5$**	**128.5**	**$-89^{0}0$**	**$-116^{0}5$**	**$142^{0}6$**	**-5.4**	**-5.6**
7	**91.4-94.7**	**-39.5**	**5968**	**$-21^{0}6$**	**-21.2**	**$77^{0}2$**	**$-21^{0}6$**	**$141^{0}4$**	**0.87**	**0.69**

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