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THE DECADE-LONG INSTABILITIES IN EARTH'S ROTATION AS EVIDENCE OF LITHOSPHERIC DRIFT OVER THE ASTENOSPHERE

N. S. Sidorenkov

Hydrometcenter of the Russia, Moscow, *sidorenkov@mecom.ru*

ABSTRACT. The decade instabilities in Earth's rotation (DIER) are usually explained by the interactions of the Earth's core and mantle. This hypothesis explains well a close correlation between DIER and the variations in the rate of the westward drift of the geomagnetic eccentric dipole; it corresponds quite reasonably to the possible redistribution of the angular momentum between the fluid core and the mantle of the Earth. however, the hypothesis can not explain the close correlations of DIER with the observable variations in the masses of the Antarctic and Greenland ice sheets, with the decade oscillations of the types of synoptic processes (the epochs of the atmospheric circulation), with the anomalies of the global temperature, regional anomalies of the cloudiness, precipitation, and other climatic characteristics.

It is supposed that the DIER are the fluctuations of the velocity of the lithosphere driftage along the asthenosphere. The sliding of the lithosphere over the asthenosphere is possible due to of the vibratory displacement mechanism by tidal forces. The consequences following from this hypothesis are discussed.

Keywords: Decade fluctuation in Earth's rotation, drift of lithosphere, plate tectonics.

1. Hypothesis

It is well known that seasonal variations in the Earth's rotation are determined by the redistribution of the angular momentum between the atmosphere and the Earth. When the moment of the atmosphere is increasing then the moment of the Earth is decreasing and vice versa. This regularity is well seen on Figure 7.10 (Sidorenkov, 2009) where the time series of the angular momentum of the atmosphere is compared with the time series of the angular momentum of the Earth taken with the opposite sign. Thus, the no tidal irregularities of the Earth rotation are mainly due to the exchange between the angular momentum of the solid lithosphere and its fluid environment – the atmosphere and the hydrosphere. This exchange occurs due to the moments of the frictional forces and pressure forces pushing on mountain ranges.

Special Bureau for the Atmosphere carries out the monitoring of the exchange of the angular momentum by both the momentum approach (that is, by the evaluation of the effective functions of the atmospheric and oceanic angular momentum), and the torque approach (that is, the evaluations of the torque resulting from the wind and current stresses and pressures).

Calculations of the friction and pressure momentum forces are performed for the entire Earth surface as a whole. However, the lithosphere is cracked on a set of the lithosphere plates. The atmosphere and ocean are acting on the lithosphere plates, and only then is this action transmitted to the Earth. What is the result of the atmospheric action on the lithosphere plates? Let us recall that under the lithosphere, there is a layer of the lower viscosity – the asthenosphere in which the lithosphere plates are capable to float. Continents are frozen into the oceanic plates, and they may passively move with them (Trubitsyn and Rykov, 1998; Trubitsyn, 2000). The lithosphere plates float in the asthenospherical substratum. On the decade time scale, the lithosphere plates can move in the horizontal direction under the effect the friction and pressure (acting on mountain ranges) forces. The plates are in motion under the action of the friction stresses and pressure, which the atmosphere and ocean produce on the exterior surface of the plate. The viscous cohesive force with the asthenosphere on the soles and faces of the plates decelerates their movement, but the exterior forces overcome this resistance. Therefore, when calculating the torque, it is necessary to carry out the integration not only for the entire Earth surface but also separately for every lithosphere plate. The moment of forces affecting on an individual plate determines the vector of the movement of the plate (Sidorenkov, 2009).

2. Evidence

A good example of this is the situation in the Drake Passage. Strong westerly winds dominate in the 40_S – 50_S. They generate the powerful Antarctic Circumpolar Current (ACC) in the Southern Ocean. The South America, the Antarctic Peninsula, and the underwater lithosphere present a barrier for ACC. Westerly atmospheric winds and oceanic currents have replaced this barrier downstream and have shifted this lithosphere bridge to the east by 1500 km. This process resulted in the formation of the Scotia Sea (the South-Antilles hollow). It is bordered along the perimeter by the remains of the lithosphere bridge in the form of the South-Antilles ridge and numerous islands, the arc of the South Sandwich Islands being the principal of them. This ridge, at the drifting in the eastward stream, has crumpled the oceanic lithosphere and has formed the deep South-Sandwich trench.

Let us present one more piece of evidence for the benefit of our hypothesis. The atmospheric circulation has a remarkable feature: at the latitudes of 35_N and 35_S, the wind direction alters to the opposite one. Easterly winds predominate in the tropical belt between these latitudes, and westerly winds in the moderate and high latitudes. According to this, the stresses of friction on the surface of the lithosphere are directed to the opposite sides. Therefore, the maximum stress in the lithosphere should concentrate near the latitudes of 35_N and 35_S. These bands should exhibit an increased seismic and tectonic activity. Really, in the Northern Hemisphere, in this band, continuous mountain ranges are extending through the Mediterranean Sea, Middle East, Iran, Pamir, Tibet, Japan and USA. Here, Earthquakes and eruptions of volcanoes occur most frequently. In the Southern Hemisphere, the band of the sign change in wind direction is located over the World Ocean. Therefore, the seismic and tectonic processes do not manifest themselves.

3. Estimations

Now let us estimate the order of magnitudes of the atmospheric and oceanic forces effecting on a separate plate and of the stresses of the interaction between plates.

At the common wind velocity (u=10 m/s) the friction stress τ on the surface of the plate is $\tau = c\rho u^2 = 0.004\times1.27$ kg/m^3 (10 m/s)^2 = 0.5N/m2, the area of the plate is $\approx2\times10^{13}$ m^2; therefore, the total atmospheric force effecting on a separate plate, is $\approx10^{13}$ N. Under the effect of this force the plate interacts with the circumjacent plates through the frontal contacts. The interaction takes place only at the sites of adhesion of plates, and the area of contacts may be small. The total atmospheric force concentrates on this small area. Therefore, the stresses may reach such high values (10^6–10^7 N/m^2), at which the discontinuity and displacement of plates from each other occur. The discontinuity triggers the seismic waves. Thus, the mechanical action of the atmosphere and ocean on the lithosphere plates controls the relative movements of the lithosphere plates and can cause the earthquakes and volcanic activity.

There is a substantial body of publications in which strong correlations between the seismicity and the variations in the atmospheric indices, as well as between the seismicity and the fluctuations in the Earth's rotation (Zharov, Konov, and Smirnov, 1991; Gorkavyi et al., 1994a; Gorkaviy, Trapeznikov, and Fridman, 1994b; Barsukov, 2002) are found. Our hypothesis explains these correlations. The atmospheric and oceanic circulation is the initial cause of both the whole class of earthquakes and the variations in the Earth rotation. Note that the variations in the Earth rotation are very small ($(\delta\omega/\omega)\approx10^{-8}$) and do not affect the geophysical processes (Sidorenkov, 1961, 2002).

4. Variations in the ice sheet masses

Redistribution of water between the world's oceans and the ice sheets was accompanied by changes in the moment of inertia of the Earth and must have led to its irregular rotation and secular polar motion. On this basis, combined algebraic equations can be set up to relate the value of the Earth's rotational speed and the polar coordinates to the masses of ice in Antarctica and Greenland and water in the world's oceans (Sidorenkov, 2009). These equations allow one to calculate the rotational characteristics of the Earth: the polar coordinates and the rotational speed of the Earth. If the masses of ice are unknown but data on the instability of the Earth's rotation are available, it is possible to solve the inverse problem: to compute the annual values of ice masses in Antarctica and Greenland and of water in the world's oceans from the polar coordinates and the rotational speed.

It was found by Sidorenkov (2002, 2009) that the variations observed in the Antarctic ice sheet mass agreed with the mass's variations required for the explanation of the decade (5–100 year) fluctuations of the Earth's rotation rate and the secular polar motion (Fig. 1). However, this agreement proved to be only the qualitative one. As to the quantitative agreement, the variations observed in the ice masses proved to be 28 times less than the required variations.

These contradictory results indicate that the observed decades-long fluctuations in the Earth's rotation rate are not due to the rotation and polar motion of the whole Earth but rather to changes in the speed of drift of the

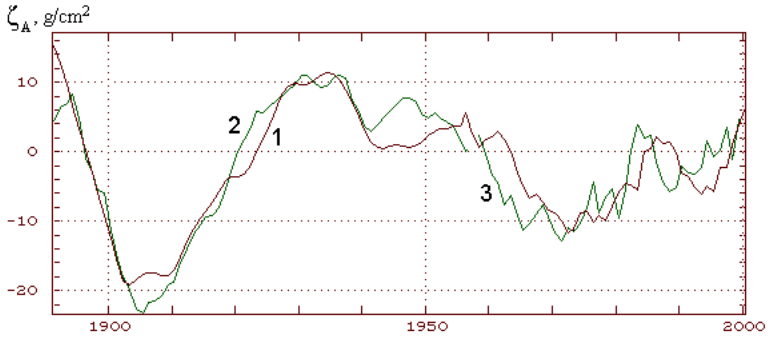

Figure 1: Temporal variations in the specific ice masses for Antarctica: 2 and 3 – data of the glaciological observations; 1 – volume required for the explanation of the decade fluctuations of the Earth's rotation velocity and the secular polar motion.

lithosphere over the asthenosphere. Indeed, the moments of the like-sign forces arising in the process of fluctuation in the global water exchange operate for decades. It is possible that, with such long-term impacts, the matter of the asthenosphere underlying the lithosphere does not behave like a solid body but rather flows like a viscous fluid. Then, the decades-long global water exchange can result in the lithosphere's sliding over the asthenosphere without having a noticeable effect on the Earth's deeper layers. In astronomical observations, changes in the lithosphere's drift rate are recorded as the irregularities in the Earth's rotation and polar motion. However, such apparent irregularities and motions require the redistribution of water masses that are 28 times lower than in the case of rotation of the whole Earth.

5. The lithosphere drifts over the asthenosphere

The Earth's layers that are deeper than the asthenosphere don't take part in the formation of the observed decade fluctuations. The lithosphere's moments of inertia are 28 times less than the moment of inertia of the whole Earth and therefore the variations in the Antarctic ice mass exactly correspond to the mass's variations required for the explanation of the decade fluctuations in the lithosphere's angular rotation rate.

The sliding of the lithosphere over the asthenosphere is possible in the case when the action duration T is many times longer than the characteristic relaxation time t within the asthenosphere. It is known that the relaxation time t is determined from the relationship $t=\mu/\eta$, where μ is the viscous coefficient and η is the rigidity. For the asthenosphere, $\mu \approx 10^{18} - 10^{23}$ Poise and $\eta \approx 10^{12}$ dyn cm^{-2}. As a result, $t=\mu/\eta=10^{6} - 10^{11}$ s or 0.03–3000 years. Clearly, the above-mentioned hypothesis could be accepted if we take a lower limit to the permissible values of μ. At the upper limit of viscosity, the drift of the lithosphere is hardly probable.

However, this classical estimate does not take into account the effects of vibrational lithospheric displacements. Indeed, the lithospheric plates constantly vibrate in the vertical direction under the action of lunisolar tides. On the other hand, the lithospheric plates are constantly affected in the horizontal direction by shear stresses caused by friction of wind, and ocean currents. As a result, the lithospheric plates must exhibit vibrational displacements over the asthenosphere in the direction of acting tangential forces. There is abundant evidence supporting this plate drift.

Now Global Positioning System (GPS) is used to study moving of the Earth's tectonic plates (Fig. 2). Plates move as slow as a few centimeters in a year.

The differential rotation of the lithosphere and mantle is considered in many papers devoted to the tectonics of plates (Scoppola B., Boccaletti D., Bevis M. et al., 2006; Chuikova & Maksimova, 2005) have found the uncompensated masses and stresses at the crust and uppermantle. They supposed the crust's movements caused by the crust pressing on the mantle for both the isostatic and gravity nonequilibrium.

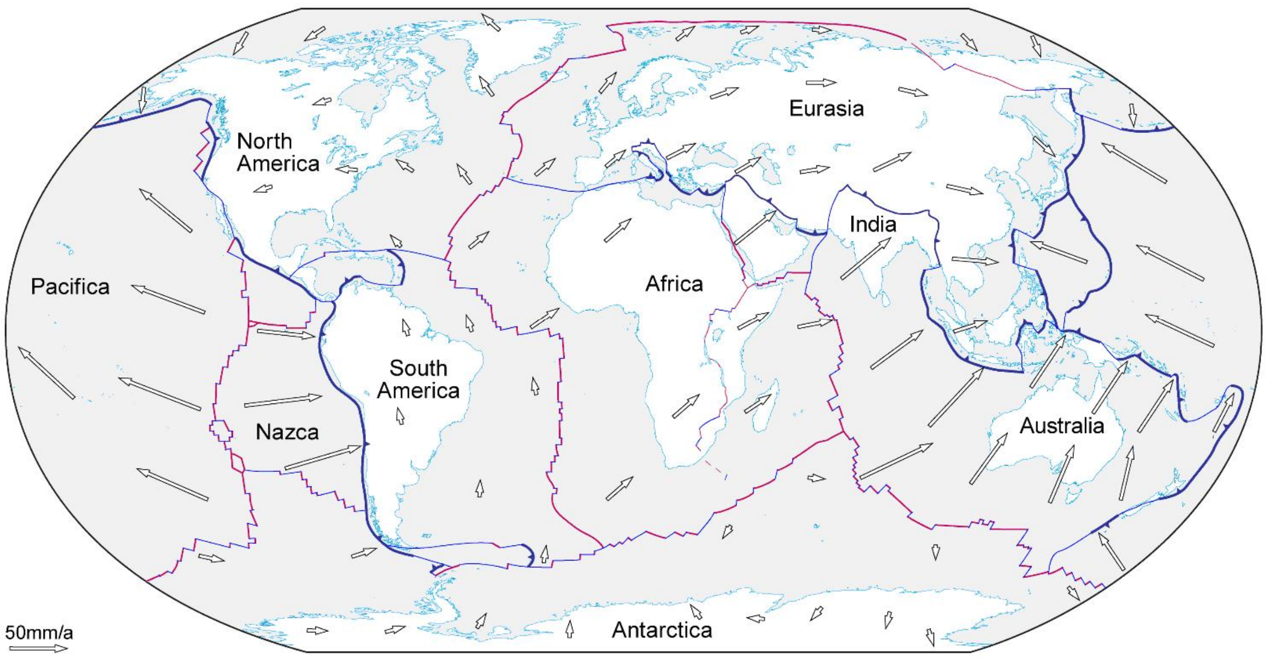

Figure 2: Current absolute plate motion from GPS information (world Robinson projection). Length of arrows indicates rate of movement of that part of the plate
http://www.files.ethz.ch/structuralgeology/jpb/files/english/1Introtecto.pdf

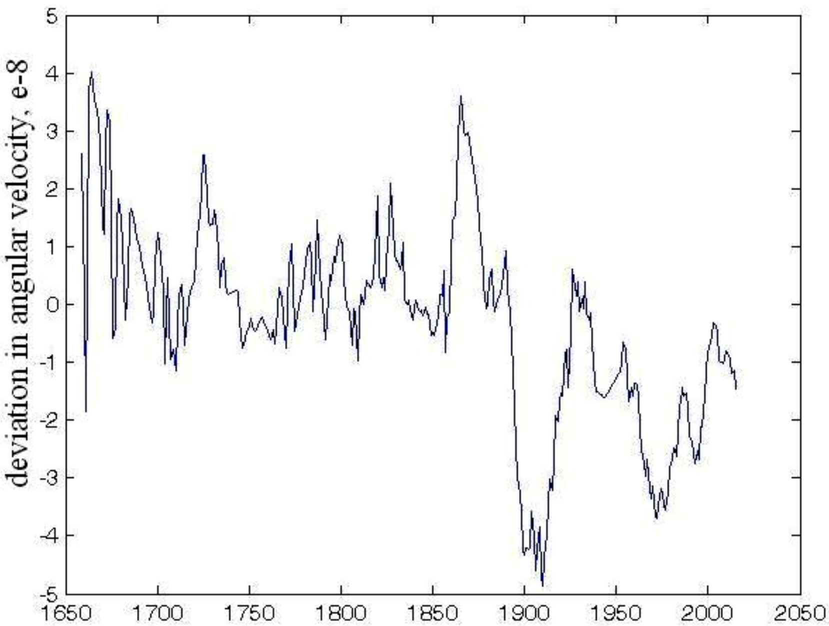

Figure 3: Fluctuations of the angular velocity of lithospheric drift over the asthenosphere in 1660-2015

Thus, the research results and observations confirm the hypothesis about the movement of the lithosphere plates under the impact of the atmospheric and oceanic circulation on the decade time scale. The total effect of the movement of all lithosphere plates is interpreted by geophysics as the decadal fluctuations of the Earth's rotation.

It can be stated that the lunisolar tidal ocilations cause the vibration displacement of continental plate. Observed by astronomers, decade variations in the Earth's angular velocity are actually variations in the angular velocity of lithospheric drift over the asthenosphere. Figure 3 demonstrates these variations over the last 350 years.

The hypothesis on the drift of the lithosphere over the asthenosphere is based not only on the analysis of the effect of redistribution of water between the ocean and the ice sheets in Antarctica and Greenland but also on a review of the mechanism of the angular momentum interchange between the atmosphere and the Earth (Section 1). The frictional forces and the pressures of the atmosphere and oceans on the lithosphere plates cause their drift over the asthenosphere. This hypothesis also agrees with the fact that there is a significant correlation between the seismic activity and the irregularities of the Earth's rotation.

The lunisolar tides affect the atmospheric and oceanic processes. On the one hand, they generate the vibrational displacement of plates and, on the other hand, influence the atmospheric and oceanic processes. That is why there are numerous relationships between the dynamics of seismicity and the peculiarities of variations of atmospheric circulation.

The state of the ice sheets in the Antarctic and Greenland depends on the climatic variations. Therefore, the decadal fluctuations in the Earth's rotation may also correlate with the fluctuations in the climatic characteristics and indices. This relationship has been found in (Lambeck, 1980; Sidorenkov, 2002; 2009). There is a close correlation between the Earth's rotation fluctuations and the frequencies of the atmospheric circulation forms, the anomalies of the hemisphere-averaged air temperature, and many another climate characteristics (Sidorenkov, 2009). These relationships are explained given the assumption that the lithosphere drifts along the asthenosphere.

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