INFLUENCE OF THE ATMOSPHERIC AND OCEANIC CIRCULATION ON THE PLATE TECTONICS

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ABSTRACT. The non-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 (i.e., by the evaluation of the effective functions of the atmospheric and oceanic angular momentum), and the torque approach (i.e., 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 lithosphere plates can move in the horizontal direction under the effect of the friction and pressure (acting on mountain ranges) forces. 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 estimations of the orders of magnitudes of the atmospheric and oceanic forces effecting on a separate plate and of the stresses of the interaction between plates are given in this paper. The mechanical action of the atmosphere and ocean on the lithosphere plates is likely to be an initial cause of earthquakes. The empirical facts which evidence for the benefit of this conclusion are given.

A mathematical model of the movement of the lithosphere plates under the effect of the frictional and pressure forces is formulated. Two equations describing the horizontal movement of the plate's center of gravity and one equation describing the rotation of the plate around the vertical axis are used. The algorithm of calculation of the movement of the lithosphere plates is constructed.

1. INTRODUCTION

It is well known that seasonal variations in the Earth 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 next graph where the time series of the angular momentum of the atmosphere is compared with the time series of the angular momentum of the Earth (Fig.1).

Thus, the non-tidal irregularities of the Earth rotation are mainly due to the exchange

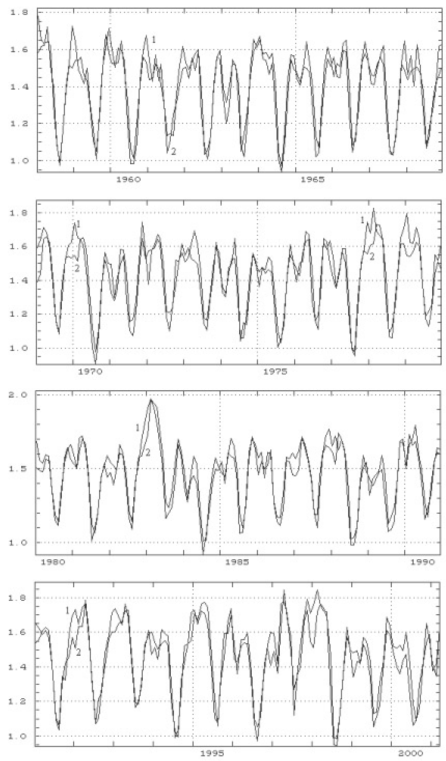

Figure 1: The angular momentum of the atmosphere (1) and the angular momentum of the Earth (2).

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 (i.e., by the evaluation of the effective functions of the atmospheric and oceanic angular momentum), and the torque approach (i.e., 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 this action is being transmitted to the Earth. What is the result of the atmospheric action on the lithosphere plates? Let's recollect, that under the lithosphere, there is a layer of the lower viscosity - an asthenosphere in which the lithosphere plates are capable to float. Continents are frozen in to 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 of the friction and pressure (acting on mountain ranges) forces. Plates 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 end faces of the plates decelerates their moving, 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 effecting on an individual plate, determines the vector of the movement of the plate.

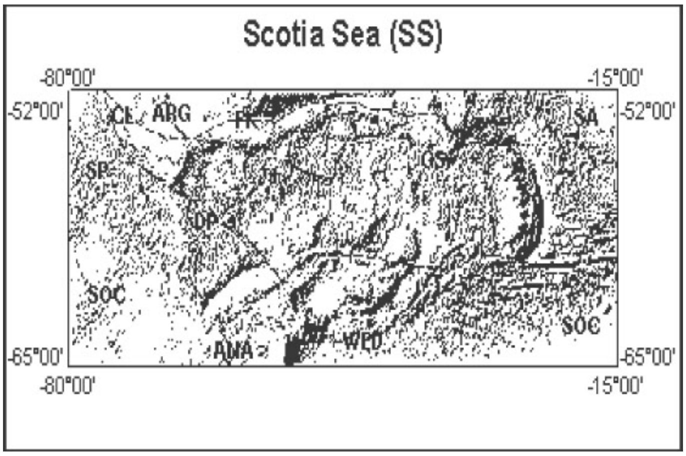

Figure 2: Westerly atmospheric winds and oceanic currents have broken down lithosphere bridge the South America – Antarctic Peninsula and have shifted its to the east by 1500 km. The color map can be looked on the site
http://walrus.wr.usgs.gov/infobank/gazette/html/regions/ss.html.

2. EVIDENCES

A good example of this is the situation in the Drake Passage (Fig.2). Strong westerly winds dominate in the 40°–50°th S. They generate the powerful Antarctic Circumpolar Current (ACC) in the Southern Ocean. The South America, 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 (South-Antilles hollow). It is bordered along 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 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 stress of friction on the surface of the lithosphere is directed in two 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 of the wind direction over the water surface of 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 $\tau = c\rho u^2 = 0.004 \times 1.27 kg \cdot m^{-3} \times (10 m \cdot s^{-1})^2 = 0.5$ N/m ^{2}, the area of the plate is $\approx 2 \cdot 10^{13}$ m ^{2}; therefore, the total atmospheric force effecting on a separate plate, is equal $\approx 1 \cdot 10^{13}$ 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 relative movements of the lithosphere plates and can cause the earthquakes and volcanic activity.

There is a substantial body of publications in which close correlations between seismicity and variations of the atmospheric indices (Sytinsky, 1985), seismicity and fluctuations in the Earth rotation (Zharov et al., 1991; Gorkavyi et al., 1994a, 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 ($\frac{\delta\omega}{\omega} \approx 10^{-8}$) and do not affect the geophysical processes (Sidorenkov, 2002).

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 geophysists as the decade fluctuations of the Earth rotation.

4. MODEL

Our hypothesis can be mathematically described similarly to the Trubitsyn's model of the mantle convection with floating continents (Trubitsyn, 2000).

It is known that the motion of a rigid body is defined by the motion of its center of masses and by the rotation with respect to the center of masses. To deduce the differential equations of the plate motion, we use the theorem of the movement of the center of masses of the plate:

$$m \frac{d\overrightarrow{V}_{0i}}{dt} = \overrightarrow{F}_i, \tag{1}$$

and the theorem of the angular momentum:

$$\frac{d\overrightarrow{H}_i}{dt} = \overrightarrow{L}_i, \tag{2}$$

where m is the mass of the plate; $\overrightarrow{V}_{0i}$ is the instantaneous velocity vector of the center of masses; $\overrightarrow{H}_i$ is the angular momentum of the plate; $\overrightarrow{F}_i$ is the external force; and $\overrightarrow{L}_i$ is the total force moment (torque), which is the sum of the moments q_i of forces σ_j applied to separate elements of the plate surface

$$q_k = \varepsilon_{ijk}(x_i - x_{i0})\sigma_j. \tag{3}$$

The angular momentum of the plate may be determined

$$H_i = I_{il}\omega_l. \tag{4}$$

Here I_{ik} is the moment of inertia tensor of the plate,

$$I_{ik} = \int \rho[(x_l - x_{l0})^2 \delta_{lj} - (x_i - x_{i0})(x_k - x_{k0})] dv. \tag{5}$$

Let us consider only the horizontal movement of the center of masses of the plate and its rotation around of the vertical axis. In this case, the equations (1-2) are reduced to the system of three equations:

$$m\frac{du_1}{dt} = \int\int(-p\delta_{1j} + \tau_{1j} + f_{1j})n_j ds; \tag{6}$$

$$m\frac{du_2}{dt} = \int\int(-p\delta_{2j} + \tau_{2j} + f_{2j})n_j ds; \tag{7}$$

$$I_{33}\frac{d\omega_3}{dt} = \int\int \varepsilon_{ij3}(x_i - x_{0i})(-p\delta_{jk} + \tau_{jk} + f_{jk})n_k ds. \tag{8}$$

Here, x_i are the coordinates of an arbitrary point of the continent; x_{i0} are the coordinates of the instantaneous center of masses of the plate; δ_{ij} is the Kronecker symbol (equal to 1 at $i = j$ and 0 at $i \neq j$); ε_{ijk} is the Levy-ЦCivita symbol, which is equal to 0 (if any two indexes coincide) or 1 (at an even transposition of indexes with respect to (1, 2, 3)) and -1 (if this transposition is uneven); p is pressure; τ_{jk} are the friction stresses of the atmosphere and ocean on the exterior surface of the plate; f_{jk} are viscous stresses of the asthenosphere on submerged surface of the plate; n_j is the unit vector of the outward normal to the surface of the plate; ds is absolute value of an elementary surface area of the solid continent.

Taking into account that:

$$\frac{dx_1}{dt} = u_1, \frac{dx_2}{dt} = u_2, \frac{d\varphi}{dt} = \omega_3, \tag{9}$$

we can, using the given magnitudes coordinates of the center of masses of the plate $x_1(t)$, $x_2(t)$, $\varphi(t)$ and values $p(t)$, $\tau_{ij}(t)$ end $f_{ij}(t)$, calculate the linear velocities $u_1(t)$, $u_2(t)$ of the translational motion and the angular velocity $\omega_3(t)$ of the rotation of a plate. Equations of motion (6-8) are necessary to write out for each plate.

The model allows us to calculate the linear velocities $u_1(t_1)$ and $u_2(t_1)$ of the translational horizontal motion of the plate's center of masses and the angular velocity $\omega(t_1)$ of the rotation of the plate around the vertical axis. This is made using the values of the frictional $\tau_{ij}(t_1)$ and the pressure $p(t_1)$ forces of the atmosphere and the ocean and the force $f_{ij}(t_1)$ of the interaction with the viscous asthenosphere, applied to the submerged surface of the plate, calculated for the moment t_1. Knowing these velocities and initial coordinates of the plate $x_1(t_1)$, $x_2(t_1)$, $\varphi(t_1)$ it is possible to find its position in the subsequent instant $t_2 = t_1 + \Delta t$: $x_1(t_2) = x_1(t_1) + u_1(t_1)\Delta t$, $x_2(t_2) = x_2(t_1) + u_2(t_1)\Delta t$, $\varphi(t_2) = \varphi(t_1) + \omega_3(t_1)\Delta t$. Then, using new values $\tau_{ij}(t_2)$, $p(t_2)$ and $f_{ij}(t_2)$, we calculate $u_1(t_2)$, $u_2(t_2)$ and $\omega_3(t_2)$, and determine the position of a plate for the following instant t_3. The calculations are performed up to the final moment of time. The time step depends on the discretization of calculations of the friction and pressure forces of the atmosphere and the ocean.

5. SUMMARY

Under the effect of the atmospheric and oceanic forces, the plates interact with the circumjacent plates through the frontal contacts. The stresses may reach such high values (10^6-10^7 N/m^2) at which the discontinuity and displacement of the plates from each other occur, that trigger the earthquakes. Relative movements of the lithosphere plates create the Earth's main earthquake and volcanic zones.

When calculating the moments of friction forces and pressure, the integration of the atmospheric and oceanic forces should be performed not only for the entire Earth surface but also separately for every lithosphere plate. The algorithm of calculation of the movement of lithosphere plates is developed.

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