On the possibility of disturbance of the Earth's dynamic balance by the technogenic impact

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Abstract. The article describes the possible disturbance of the Earth's dynamic balance due to climate changes throughout the last 150 years and technogenic impact. An accident occurred on an oil platform in the Gulf of Mexico on April 20, 2010 is taken as an example of such impact. It is assumed that the accident may have accelerated the slowdown of the Gulf Stream and changed its path, which led to a change in temperature, salinity and density of significant ocean masses. Variations of ocean mass density in some areas could cause a shift of the Earth's center of mass by 10^{-5} m and a deviation of its rotation axis by $2.9{\cdot}10^{-6}$ arcsec. It is shown that the process of disturbance of the Earth's dynamic balance can be accompanied by an increase in the number of relatively weak earthquakes (in a range of magnitudes 4.2–4.8 by 41.5%) and the intensity of seismic noise (tremor), as shown by broadband seismic networks and satellite GPS navigation data.

1 Introduction

The occurrence of deformation processes caused by subtle changes in the stress-strain state of the Earth's crust may be viewed through the hypothesis of the disturbance of the dynamic balance of the rotating Earth. The hypothesis is based on the postulate that interaction mechanisms of various physical fields are bound to change due to random micro effects. These micro fluctuations may be caused by the variations of global factors, such as climate change, shifts of the Earth's rotation parameters, earth and ocean tides, regular changes of moonphases etc., as well as anthropogenic factors such as large-scale blasts, industry-caused climate changes, or redistribution of the ocean currents, as shown in this article. The changing number of minor earthquakes in the Earth's lithosphere may be indicative of the shifts in the dynamic balance.

We justify the working assumption that variations in the Earth's dynamic balance may be related to a random technogenic impact. Verification technique comprises the actual data analysis, building of the numerical model and performing the corresponding calculations.

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According to the satellite data, oil spill in the Gulf of Mexico and wide use of dispersants altered the rate and direction of the Gulf Stream (Fig.1). The Gulf Stream is an intense warm ocean current in the western part of Atlantic ocean along the eastern coast of North America. It splits into two sub-currents - Northern or North Atlantic current, which crosses the Atlantic ocean in the direction towards the Northern Europe, and Southern or Canaries current, recirculating from the shores of West Africa [1]. The current is 100 km wide and about 800 - 1200 m deep, with a volume of water per second from 20 to 40 Sv (1 Sv = 10^6 m^3), exceeding the overall flow of all the rivers in the world combined. Closer to the eastern border of North America the warm Gulf Stream meets the cold waters of the Labrador Curren. The temperature of the Labrador current is below 0°C, the average salt content is about 30 - 34 $^{o}/_{oo}$. It borders with the continental shelf and flows at the depth up to 600 m. It moves about 3.5- 5.4 Sv of water per second [2].

Fig. 1. Currents of the Atlantic ocean [3]

As stated in [4-6], the convection of the Labrador and the Gulf Stream currents have been anomalously weak over the past 150 years. According to the satellite data, this weakening can be traced by changes in the subsurface water temperatures of the subpolar regions of the Atlantic ocean and within the Gulf Stream current. From 2006 the decrease of the Gulf Stream's speed has been the result of natural desalting of the Labrador current.

In the Deepwater Horizon oil spill on April 20, 2010 in the Gulf of Mexico can be regarded as an example of catastrophic technological environmental impact that caused an increased reduction of the Gulf Stream's velocity. The wellbore was damaged at the depth of about 1522 m allowing an uncontrolled oil leakage for 152 days [7]. The volume of oil leaving the damaged well reached 62200 barrels per day. The total volume of spilled oil was more 4.9 million barrels first 89 days [8]. The oil spill covered the area of 3200 km^2 around the well and makes up from 4 to 31% of the heavy oil. [9].

The first mentioning of the Gulf Stream's speed decrease can be found in [11], where the authors indicate the decrease in average temperature of the current by 10 ^{o}C compared to the value of 2009 before the accident occurred. Moreover, the current moved up to 800 miles (1481 km) to the east. Results of the scientific research of Protonics Chemical Corporation and Department of Aerospace Engineering Sciences of the University of Colorado (USA) also confirm the change in the trajectory of the current.

The deviation of the Gulf Stream's trajectory took place alongside its temperature regime, salinity and density of considerable volumes of ocean masses (Fig. 2).

The process was relatively slow and the "post-accident" change of the temperature regime was forming for almost two years starting from 2011. Thus, we can assume that redistribution of the ocean masses of the Gulf Stream could the disturbance of the dynamic balance of the rotating Earth, shift of the Earth center and poles.

2 Problem definition and solution

Motion of the Earth's center is a mechanical attractor that defines all the inner and outer criteria of the final state of the evolution of the system. Let's consider the disturbance of the steady state of the Earth's center caused by non-homogeneous distribution of the mass on its surface. A simplified model of the changing part of the currents can be assumed as two equally sized round areas with the radius of 500 km (R_G), thickness of 800m (H_G) and and with a changed water density p_G with the center at N40° W60° (area I – temperature increase) and N60° W35° (area II – temperature decrease) (Fig.2).

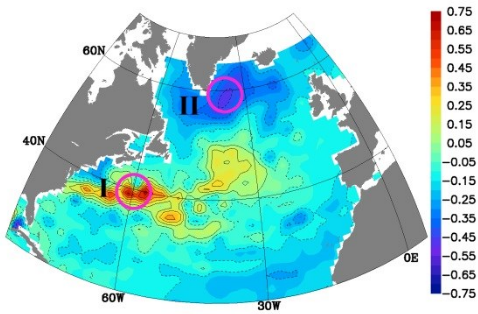

Fig. 2. Map view of rates of subpolar gyre currents [6]. I and II indicate computed rates of changes of the temperature regime.

The center of the Earth's mass is defined as a geometric point describing the movement of the system of particles of a single body. In Newtonian mechanics the locus equation as a system of material points with continuous distribution of mass is defined as follows [11]:

$$\overline{r_c} = \frac{1}{M}\int_V \rho(\bar{r})\,\bar{r}\,dV \tag{1}$$

where r_c – radius of the center of mass, M – total mass of the system, V stands for volume, and ρ denotes density.

Let index 1 denote the state of the system "before" the disturbance of the motion regime and index 2 - "after". Considering the coordinates of the mass' center the Equation (1) can be defined as;

$$x_1 = \frac{1}{M}\int_V \rho(\bar{r})\,x\,dV \tag{2}$$

$$y_1 = \frac{1}{M}\int_V \rho(\bar{r})\,y\,dV \tag{3}$$

$$z_1 = \frac{1}{M}\int_V \rho(\bar{r})\,z\,dV \tag{4}$$

Then we define the volumes of heterogeneous areas redistribution as "before" V_1 and "after" V_2, when $|V_2| = |V_1|$. Thus, the volume of the the constant part will be defined as $V_o = V-(V_1+V_2)$.

If ρ_1 denotes the density "before" and ρ_2 - "after", then the Equation (2) can be as follows:

$$x_{before} = \frac{1}{M}\int_{V_1}\rho(\bar{r})\,x\,dV + \frac{1}{M}\int_{V_2}\rho(\bar{r})\,x\,dV + \frac{1}{M}\int_{V_0}\rho(\bar{r})\,x\,dV = \frac{1}{M}\rho_1 X_1 V_1 + \frac{1}{M}\rho_2 X_2 V_2 + \frac{1}{M}\int_{V_0}\rho(\bar{r})\,x\,dV \tag{5}$$

where X_1 и X_2 denote the coordinate of the center of points I and II.

In a similar way we define:

$$x_{after} = \frac{1}{M}\rho_2 X_1 V_1 + \frac{1}{M}\rho_1 X_2 V_2 + \frac{1}{M}\int_{V_0}\rho(\bar{r})\,x\,dV \tag{6}$$

Substracting (5) from (6) we derive the following:

$$dX = \frac{1}{M}(\rho_2 - \rho_1)(X_1 - X_2)|V| \tag{7}$$

Similar to the above mentioned, substracting (3) from (4) the following is derived:

$$dY = \frac{1}{M}(\rho_2 - \rho_1)(Y_1 - Y_2)|V| \tag{8}$$

$$dZ = \frac{1}{M}(\rho_2 - \rho_1)(Z_1 - Z_2)|V| \tag{9}$$

where *dX, dY, dZ* denote the deviations of the geometric point of the Earth's mass center from its initial stable state.

Now, let's analyze the possible deviation of poles of the Earth's rotation axis caused by the shift of mass center. In order to make the problem mathematically coherent we assume that *the new rotation axis minimizes the total shift of the poles*. With that the new rotation axis lies within the plane that crosses the old poles and the new mass center (Fig. 3)

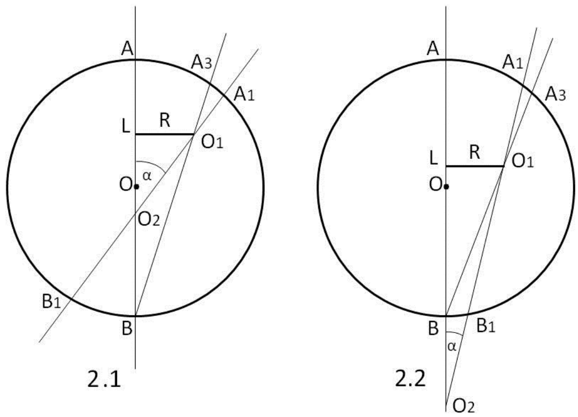

Fig. 3. O – mass center "before", O_1 – mass center "after", AB – rotation axis "before", A_1B_1 – rotation axis "after", O_2 – point where the rotation axes cross, α – angle between the rotation axes, (2.1 – O_2 inside the Earth; 2.2 – O_2 outside the Earth),

$$\begin{aligned} &R = \sqrt{dX^2 + dY^2} \\ &dX = |X_1 - X_2| \\ &dY = |Y_1 - Y_2| \\ &dZ = L = R_{Earth}\left(\sin(X_1) - \sin(X_2)\right) \end{aligned} \tag{10}$$

Deviation of the angle α overlap the nutation of the Earth's axis fluctuations at the time of precessional motion. Nutation alters the spatial orientation of the Earth axis rotation alone and does not affect its position within the Earth body.

Let us consider the following possibilities: Figure 2.1 - point O_2 lies within the Earth or on its surface. Angle α is defined as half-sum of the curves AA_1 and BB_1 , thus defining the total shift of the poles. The minimum value of the poles shift can be achieved by aligning B_1 with B:

$$2\alpha = \arctan\left(\frac{r}{R+L}\right) \tag{11}$$

Fig.2.2 - point O_2 lies outside the Earth. In this case the angle α can be defined as a half sum of AA_1 and BB_1. Since O_1 lies above O, the curve BB_1 is bigger than A_1A_3, and the minimum value of the poles shift can be achieved when B_1 and B coincide (Equation 11).

Thus, the Equations (7-11) describe the finite state of the dynamic evolution of the attractor – the center of the Earth mass.

3 Input data

Let us consider the sea water as a two-component system - water (dissolving medium) + sea salt (dissolved substance) the main properties of which are characterized by the internal parameters such as temperature, salinity and pressure. They define the value of the sea water density. Density values, characteristic of the sea (ocean) surface and dependable on the temperature, lie within a range from 0,9960 to 1,0283 kg/m^3 [12].

In this article we use empirical dependence to calculate the density of the sea water with regard to its temperature and salinity (Fig. 4). According to the satellite data [13] the salinity level of some parts of the Atlantic ocean did not change drastically within the period described (2009 - 2012), both at depth 459 m (not more than $\pm 0.01^o/_{oo}$) and 747 m (not more than $\pm 0.005^o/_{oo}$), thus it may be considered constant 35.52 $^o/_{oo}$ (Fig. 5).

Assume that the average deviation in ocean water temperature between the modeled areas for the periods 2009 - 2010 and 2011 - 2012 characterized by the values: +0.5 ^{o}C heating of region I and - 0.5 ^{o}C cooling of region II, i.e. $\Delta T = 1^o C$ (Fig. 6). According to empirical dependance this shift in sea water temperature, providing the salinity is constant, may correspond to a relative variation of density by 0,25 kg/m^3 (p_G).

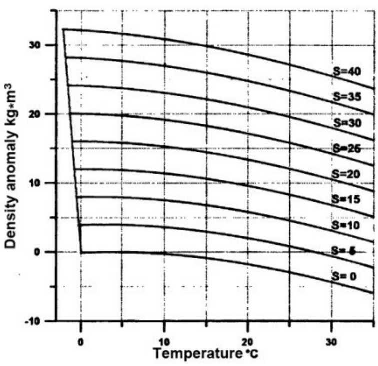

Fig. 4. Sea water density with respect to its temperature and salinity at atmospheric pressure [14].

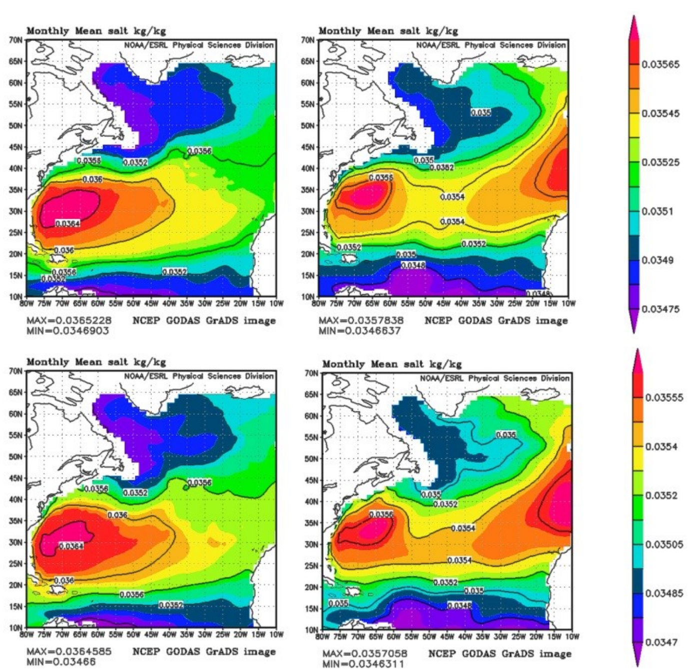

Fig. 5. Monthly average values of sea water salinity at depths 459 m and 757 m (left to right) for the period 2009-2010 (top) and 2011-2012 (bottom) [13]

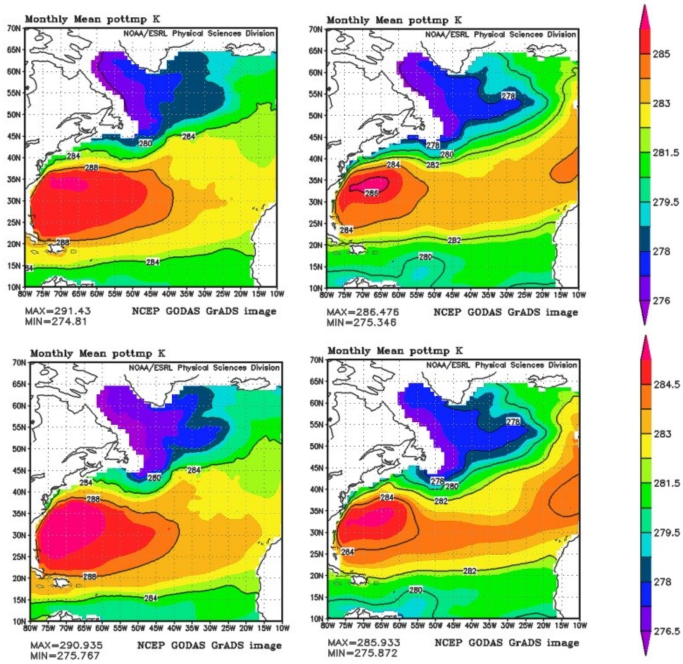

Fig. 6. Monthly average values of sea water temperature at depths 459 m and 757 m (left to right) for the period 2009 – 2010 (top) and 2011 – 2012 (bottom) [13].

Based on the assumptions discussed above (Table 1) and derived analytical equations (7-11) we can conclude, that disturbance of the dynamic balance of the Earth caused by redistribution of temperatures and ocean mass density within the Gulf Stream and the Labrador currents may lead to the deviation of the Earth's mass center by 10^{-5} m and the deviation of the Earth's rotation axis at the North Pole may be as high as $2.9 \cdot 10^{-6}$ arcsec, which corresponds to 0.0007% of the amplitude of the maximum pole nutation.

Table 1. Input data for the calculations

Parameter	Value	SI
Mass of the Earth (kg)		5.972E+24
Radius of the Earth (m)		6378000
Latitudal deviation of points I-II (X_1-X_2) *(degrees)*	22	2222680 m
Longitudal deviation of points I-II (Y_1-Y_2) *(degrees)*	10	1964590 m
Deviation of points along the axis of rotation I-II (Z_1-Z_2)	dZ	1865239 m
Volume of changeable part of the current (m^3)	$\pi R_G^2 H_G$	7.854E+14
Deviation of p_G (kg/m^3)		0.25

4 Discussion

The results we received support the hypothesis of the possible disturbance of the dynamic balance of the Earth due to a weakening convection of the Gulf Stream and subsequent redistribution of mass within the system of North Atlantic currents. This process has been relatively weak throughout the last 150 years [4,5] and gained full strength after the anthropogenic accident in the Gulf of Mexico on April, 20, 2010. At the present time its activity is reducing again and the ocean currents are gradually returning to their “before accident” regime. Increase of seismic activity combined with GPS methods may be viewed as an indicator of dynamic balance disturbance.

Variations of global seismic noise were first analyzed and published in [15]. Measurements of 229 broadband stations of GSN, GEOSCOPE and GEOFON systems were analyzed for the 16-year period from 1997 to 2012. The four coherent parameters characteristic of the global low frequency seismic noise within the time window of 2 up to 500 mins were discussed. These parameters included logarithmic dispersion, kurtosis, spectral width of singularity and minimal entropy of continuous seismic wavelet coefficients. The results of the analysis [15] show an increased synchronization of global seismic noise parameters throughout the whole research interval from 1997. “The synchronization increases up to the end of the research (2012) and may be interpreted as a possible indicator of further increase of global seismic activity”.

Increase of the global seismic noise by the end of 2012 may be associated with a gradual weakening of the Gulf Stream throughout the last 150 years.

The project described in [16, 17] confirms the abrupt acceleration of the process under discussion after the anthropogenic accident. The survey deals with the statistical parameters of the deviations of GPS stations which correspond to the surface fluctuations of the stress-strain state of the Earth’s crust (Fig.7).

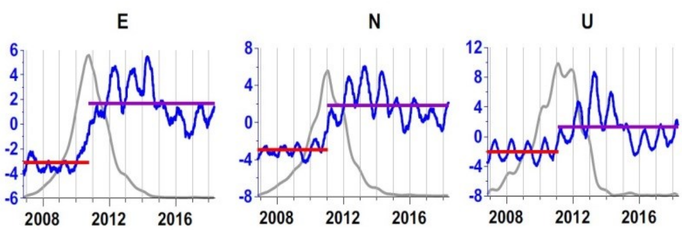

Fig. 7. Diagrams of the first main components of average correlations of GPS time series deviations (blue); red and purple horizontal lines denote mean values; gray lines – variation of Fisher coefficient [16].

Complex processing of the global day-to-day continuous GPS data [16] allowed to detect the synchronization effect of low frequency inner noise of the Earth, being registered from October 23, 2010 to February 17, 2011.

The significant increase of the mean coherent value (level of correlation) of daily noise, measured by 1097 GPS stations in nine regions (East, West and Central America, South America, Europe, Japan, Alaska, Australia, New Zealand) was also registered. In some of these regions the mean level of coherency stays relatively high and doesn’t drop back to the previous values (Fig. 7). Some of the authors [16,17] consider the increase of seismic noise to be the trigger of a catastrophic earthquake on March 11, 2011, M=9.1 in Japan (Tohoku).

Moreover, besides from analyzing seismic variations of the dynamic balance of the Earth, we have discussed the statistical aspects of relatively weak earthquakes, referring to global seismic events of different magnitudes registered within two equally long periods from 2009 – 2010 and 2011 – 2012 and listed in a global earthquake catalog [18]. Table 2 and Figure 8 describe the distribution of earthquakes and seismic energy E (in J) within two time intervals.

Table 2. Number of earthquakes and log10 of the resulting seismic energy in 2009 – 2012.

Magnitudes	2009.01.01 - 2010.12.31		2011.01.01 - 2012.12.31	
	Number of events	Energy (log10)	Number of events	Energy (log10)
6.9-9.0	51	18,168	43	17,960
6.2-6.8	151	16,686	152	16,684
5.6-6.1	649	16,362	733	16,418
4.9-5.5	4902	16,212	5069	16,203
4.2-4.8	13146	15,743	18614	15,903
3.6-4.1	3744	14,373	4768	14,478

The number of earthquakes of magnitudes M≤6.8, registered “after the accident” has increased, especially in respect to relatively weak events with M=4.2-4.8: from 13146 up to 18614, i.e. by 41.6%. This include all the events and their aftershocks for more complex definition of global tectonic stress weakening.Note that the deviation of the law of frequency of earthquakes (Gutenberg – Richter) with magnitudes M=3.6-4.1 listed in Table 2 and Figure 8 is due to the sparse network of seismic stations throughout the world. However, even within this range of magnitudes we can see an increased number of earthquakes “after the accident” (2011-2012).

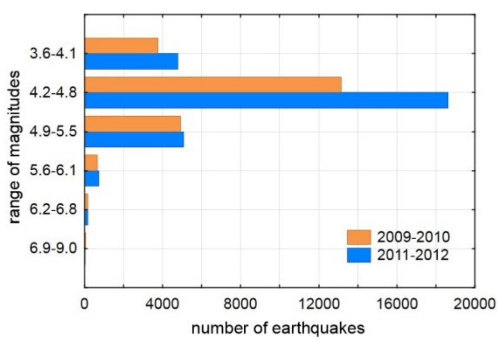

Fig. 8. Bar graph showing the distribution of earthquakes from 2009 to 2012.

At the same time there is no considerable differentiation in seismic energy released during these time periods. Thus we can assume that disturbance of the dynamic balance of the Earth provoke only an increase of seismic noise (tremor) while maintaining the mean level of the seismic energy being released.

5 Conclusion

The simplified model obtained describe the weakening of the ocean current Gulf Stream and local redistribution of temperatures and density of ocean mass, caused by both climate changes throughout the last 150 years and the anthropogenic accident, can go along with disturbance of the dynamic balance of the Earth.

According to the measurements, the possible shift of the Earth’s mass center by 10^{-5} m and deviation of its rotation axis by $2.9 \cdot 10^{-6}$ arcsec within two years after the accident in the

Gulf of Mexico may have provoked an increase of weak earthquakes with magnitudes 4.2 - 4.8 by 41.5% and more intense seismic noise (tremor) registered by broadband seismic and GPS stations. At the same time the total amount of seismic energy remained almost constant. This speaks of a relative stability of the Earth dynamic balance in terms of years - decades - number of centuries. Note that the system described is characterized by some fluctuations and not always returns to its prior state, staying just ultimately close.

Thus, the hypothesis of possible disturbance of the Earth's dynamic balance caused by anthropogenic factor has been proved by empirical data and measurements described within the numerical model.

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