Polar compression of planets of solar system and ways of development of geophysical processes

B W Levin\(^1,2\) and E V Sasorova\(^2\)
\(^1\)Institute of Marine Geology and Geophysics, Yuzhno-Sakhalinsk, Russia
\(^2\)Shirshov Institute of Oceanology, Moscow, Russia

E-mail: levinbw@mail.ru, sasorova_lena@mail.ru

Abstract. The global parameters of the planets of the solar system are considered taking into account periodic variations of the main parameters, and it is shown that the cyclic variation of the polar compression for some planets should lead to pulsations in the shape of the planets and the intensification / weakening of the intensity of geophysical processes.

The planets of the solar system in the first approximation are an ellipsoid of revolution, which on the velocity of rotation determines the magnitude of the polar compression (\(\varepsilon\)) of the celestial body. This parameter is defined as \((R-H) / R\), i.e. - the difference between the equatorial (R) and the polar radius (H) of the body, referred to the magnitude of the equatorial radius.

Table 1. Characteristics of the planets needed to calculate the centrifugal and gravitational forces. The flatness column indicates the observed and calculated values.

| Planets | Mean radius, m | Mass, kg | Rotation period, s | Angular velocity, sec\(^{-1}\) | The flatness, (compression) | Distance to the Sun, million km |
|---------|----------------|----------|--------------------|-------------------------------|-----------------------------|--------------------------------|
| Venus   | 6.05*10\(^6\)  | 5.72*10\(^{24}\) | 243 days | 3 * 10\(^{-4}\) | 5.20*10\(^{-8}\) | 108 |
| Mercury | 2.43*10\(^6\)  | 3.30*10\(^{23}\) | 58.65 days | 1.24*10\(^{-6}\) | 0.999*10\(^{-6}\) | 58 |
| Moon    | 1.737*10\(^6\) | 7.35*10\(^{22}\) | 29.5 days | 2.47*10\(^{-6}\) | 6.51*10\(^{-6}\) | 146 |
| Earth   | 6.37*10\(^6\)  | 6*10\(^{24}\) | 24 h | 7.3*10\(^{-5}\) | 3.36*10\(^{-3}\) | |
| Mars    | 3.4*10\(^6\)   | 6.4*10\(^{23}\) | 24h 37min 22.7 sec 9h 55 min | 7.1*10\(^{-5}\) | 4.61*10\(^{-3}\) | |
| Jupiter | 69.2*10\(^6\)  | 1.9*10\(^{27}\) | 10h14min on equator | 1.76*10\(^{-4}\) | 8.1*10\(^{-2}\) | |
| Saturn  | 57.3*10\(^6\)  | 5.7*10\(^{26}\) | | 1.7*10\(^{-4}\) | | |

It should be noted that the polar compression of the planets is one of the most important parameters of the planet, characterizing its movements. A number of global parameters of the planets of the solar system in the first approximation are an ellipsoid of revolution, which on the velocity of rotation determines the magnitude of the polar compression (\(\varepsilon\)) of the celestial body. This parameter is defined as \((R-H) / R\), i.e. - the difference between the equatorial (R) and the polar radius (H) of the body, referred to the magnitude of the equatorial radius.
system, such as: the mean radius, the mass of the body, rotation period around the axis, the compression or flattening of the planet and the distance to the Sun are given in table 1.

Theoretically, the compression of planets can be calculated from the expression \( \varepsilon = \frac{\omega^2 R^3}{GM} \), where \( \omega \) is the angular velocity of rotation of the planet around the axis, \( R \) is the mean radius of the body, \( M \) is the planet mass, \( G \) is the gravitational constant \( (G = 6.673 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ sec}^{-2}) \). In addition to computational methods, the value of \( \varepsilon \) can be determined by observational methods, by measuring the equatorial and polar radii. Figure 1 shows a scatter diagram for the angular velocity of rotation of planets and the degree of their flatness.

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Scatter diagram for the angular velocity of rotation of planets and the degree of their flatness (along the X axis - the decimal logarithm of the flatness value, and along the Y axis - the decimal logarithm from the value of the angular velocity of rotation of the planets).

A comparative analysis of the global parameters of the planets and the scattering diagram shows the existence of a group of slow-moving planets (Venus, Mercury) with weak polar compression. For example, the period of revolution of Venus around the axis of rotation is 243 terrestrial days, and the period of its rotation around the Sun is 224 days. Paraphrasing the words of the famous Russian poet, we can say: “longer than a year, lasts a day”. For Mercury, the period of revolution around the rotation axis is 58.65 earth days and the period of its revolution around the Sun is 88 days. The compression ratio of these planets is insignificant: \( 5.20 \times 10^{-8} \) for Venus and \( 0.999 \times 10^{-6} \) for Mercury. This group of planets is located relatively close to the Sun.

The second group includes planets: Earth, Mars, and the Moon. For these celestial bodies the velocity of rotation and associated with it centrifugal forces are quite significant. This is manifested in the appearance of lunar seismicity, which was recorded in the experiments of 1969-1977. And it is described in a number of papers on the geophysics of the Moon. Unfortunately, on other planets, experiments on observational seismology were not performed. The compression of the Earth and Mars is approximately 1/300 and 1/217, respectively.

The third group consists of the planets Jupiter and Saturn, distant from the Sun, whose period of rotation around the axis is almost 2.5 times smaller than that of the Earth (about 10 hours). In connection with this, the polar compression of the planets is 1/10 and 1/15, which strongly distinguishes them from other planets. It is known that the satellites of the giant planets are characterized by high activity of their subsoil. Numerous craters are located on the surface of the satellites; the ejections of liquid heated jets to a large height have been repeatedly recorded.
The second and third groups of planets are located much further from the Sun than the first group. It is interesting to note that as the distance from the Sun increases, the angular velocity of rotation of the planets around the axis increases.

Observations show that the angular velocity of rotation of the planets does not remain constant, that it varies with time. For the Earth, the duration of observations of variations in the velocity of rotation (or the period of the earth’s day) is more than 300 years. The long-period variations lasting several years, or several ten years and medium-period variations associated with the moving of the planet around the Sun, are noted. Regular changes in the velocity of rotation of the planet cause regular changes in the degree of its compression and shape (pulsation). If the planets would rotate at a constant velocity the values of ε, R and H remain constant.

However, when the rotational velocity changes, the degree of its compression and the surface area of the planet change. As the velocity of rotation increases, its equatorial radius increases, and the polar radius decreases, as the velocity of rotation decreases, the equatorial radius decreases and the polar radius increases. That is, in response to changes in the velocity of rotation, there is a pulsation of the Earth’s shape, a change in its surface while maintaining and retaining the volume. The scheme of such pulsations is shown in figure 2.

Figure 2. Diagram of the pulsation of the ellipsoid surface as a function of variations in the angular velocity of rotation - dω. The compression ratio is ε, H and R are the polar and equatorial radii, R₀ is the radius of the sphere that is equal in volume to the ellipsoid, 1) dω₁ = 0 (H₁, R₁) is the sphere, ε₁ = 0; 2) dω₂ > 0, (H₂, R₂), ε₂ > 0; 3) dω₃ > dω₂, (H₃, R₃), ε₃ > ε₂.

Consider the effect of variations in the value of the angular velocity of rotation of the planet on the total energy of the rotating body, which is described as the product of the moment of inertia (I) by the square of the angular velocity υ. The energy of the body as a result of the instability of rotation should increase as a result of adding the angular velocity and the value of the moment of inertia of the body:

\[
\frac{dE}{E} = 2 * \frac{d\nu}{\nu} + \frac{1}{2} * \frac{dI}{I}
\]

The relative value of the variations in the angular velocity of rotation for the Earth is estimated from the observations of [1] as \(d\nu/\nu \approx 10^{-8}\) . According to the estimates given in [2, 3] for the Earth, the value of dE is equal to \(10^{21}\) J. This value exceeds by two orders of magnitude the annually allocated energy from earthquakes on the whole Earth. Even a seemingly small change in the velocity of rotation causes a significant energy release due to the huge mass of the planet. Such variations in the rotational velocity can generate amplification or attenuation of a whole series of catastrophic geophysical phenomena. In recent years, scientific literature has published papers showing the
relationship between the variations in the angular velocity of the Earth's rotation and the increase in seismic and volcanic activity [3-6].

In the works cited above, based on a joint analysis of time series of seismic event density and variations of the Earth's rotation velocity of about 300 years, it is shown that the maxima of seismic activity (SA) correspond to the final stages of the angular rotation velocity reduction (i.e., deceleration stages). Intervals of time with a minimum CA correspond to the final stages of the stage of increasing the angular velocity. The local minima of the angular velocity increments ΔVn / Δt practically coincide in time with the maxima of the SA. Thus the maximum increase of the CA occurs at the maximum of braking stage. A comparative analysis of earthquake density in five-year intervals for the period from 1895 to 2016 and variations in the Earth's rotation velocity is shown in figure 3.

![Figure 3](image)

Figure 3. Comparative analysis for the period 1895 -2016. Fragments:
- a) - is the increment of the angular velocity;
- b) density distribution of strong earthquakes (with M≥7.5) over five-year intervals, along the vertical axis - the number of earthquakes in each five-year interval. On the horizontal axes - the upper boundaries of the five-year intervals (year).

Unfortunately, at the present time we have practically no observational material for seismic, volcanic activity and other geophysical manifestations on other celestial bodies, except the Earth and the Moon.

However, in recent years works have appeared in the scientific literature showing the relationship between the variations in the angular velocity of the Earth's rotation and the increase in seismic and volcanic activity. In the work [7] considers the relationship between variations in angular velocity and volcanic activity of the Earth. Decreasing of the angular velocity of rotation of the planet (the braking stage) leads to an increase in volcanic activity, and vice versa, an increase in the rotation velocity of the Earth leads to a decrease in it (figure 4).

The presence of a negative correlation between volcanic activity and the relative angular velocity of the Earth's rotation is shown. All catastrophic eruptions with the volcanic explosivity index (VEI)> 5 and 88% of large eruptions (with VEI> = 5) begin during the braking period.
Figure 4. Time series of values of relative angular velocity ($\nu$, thin red line) and its low-frequency component ($V_n$, thick blue line) - for the period 1720 - 2017. Black vertical lines with arrows - the initial stages of the strongest eruptions in the last 300 years (1 - the volcano Tambora (1812), 2 - Krakatau (1883), 3 - Santa Maria (1902), 4 - Novarupta (1912), 5 - Pinatubo 1991)). On the horizontal axis - time (year), along the vertical axis the values of $\nu \times 10^8$ and $V_n \times 10^8$.

At present, the Earth enters the initial phase of the new braking process, which has already led to an increase in global seismic and volcanic activity in recent years. Unfortunately, now we practically have no observational material behind seismic, volcanic activity and other geophysical manifestations on other celestial bodies, except the Earth and the Moon. A comparative analysis of lunar and terrestrial seismicity was carried out in [8].

All planets of the solar system move along elliptical orbits around the Sun and periodically experience acceleration in the region of perihelion and braking in the aphelion region. At the same time, the planets rotate around their own rotation axes. Variations in the angular velocity of rotation cause constant periodic changes in the degree of polar compression (oblateness) and, accordingly, the pulsation of the shape of the planets.

Until now, the assumptions about the pulsation of the Earth's shape have been based only on theoretical positions. At present, 814 GPS observation stations are located on the Earth's surface, and we have geodetic observations of changes in the vertical strain components at the observation points [9]. The duration of these observations is from 6.5 to 10 years. Now we have observational data on the changes in the vertical components of the GPS station coordinates, which confirm our theoretical proposals about the periodic pulsations of the Earth's shape. The amplitudes of these pulsations (about 20 mm) depend on the latitudinal locations of GPS stations and the characteristic periods of a year or sometimes a year and a half a year. This confirms the medium-period pulsations of the Earth's shape [10].

At present, the duration of the GPS observation period is not sufficient to confirm the changes in the vertical components of the Earth's surface deformation in the low-frequency range.

Acknowledgments
The work was performed within a state task No. 0149-2018-0015 (IORAN) and No. 0285-2018-0014 (IMGiG of the FEB RAS) Russia. The work is partially supported by RFBR grants 16-05-00089.

References
[1] Sidorenkov N S 2002 Physics of the Earth's Rotation Instabilities (Moscow: Nauka)
[2] Levin B W et al 2014 Adv. Geosci. 35 137-44
[3] Sasorova E V and Levin B W 2018 Geography and Geology 10 43-55
[4] Levin B W and Sasorova E V 2015 *Doklady Earth Sciences* **461** 254-9
[5] Levin B W and Sasorova E V 2015 *Doklady Earth Sciences* **464** 351-5
[6] Bendick R and Bilham R 2017 *Geophys. Res. Lett.* **44** 8320-7
[7] Levin B et al 2018 *Geophysical Research Abstracts. EGU General Assembly 2018* **20** p 3814
[8] Levin B W and Sasorova E V 2010 *Doklady Earth Sciences* **434** 1249-52
[9] Scripps Orbit and Permanent Array Center, http://sopac.ucsd.edu/
[10] Levin B W et al 2017 *Geodesy and Geodynamics* **8** 206-12