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Synchronization of terrestrial processes with frequencies of the Earth–Moon–Sun system

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It is proposed that the frequencies of the quasi-biennial oscillation (QBO) of atmospheric winds and the Chandler wobble (CW) of the Earth's poles are synchronized with each other and with the fundamental frequencies of the Earth–Moon–Sun system. The QBO and CW frequencies are resonance combinations of the frequencies of the Earth–Moon system's yearly rotation around the Sun, precessions of the lunar orbit, and the motion of its perigee. The QBO and CW frequencies are in a ratio of 1:2. The synchronizations between Mul'tanovskii's natural synoptic periods and tidal oscillations of the Earth's daily rotation rate, as well as between variations in climatic characteristics and long-time fluctuations of the Earth's rotation rate are described.

Keywords: Chandler wobble, quasi-biennial oscillations of winds, cosmic effects, weather forecast, climate change

1 Introduction

Three hundred and fifty years ago, Christian Huygens discovered the self-synchronization of a pendulum clock. By now it has been established that synchronization is, according to I.I. Blekhman (1988), the property of material objects of various nature to generate a unified rhythm of joint motion despite the difference in their individual rhythms and their sometimes rather weak coupling. Synchronization phenomena have been found in acoustic and electromechanical systems, electrical circuits, radio engineering, radio physical, mechanical, and engineering devices, and living systems.

The synchronization (comparability) of the orbital and spin frequencies of planets and moons in the solar system is widely known. By the synchronization, comparability, or resonance of a system in which the bodies rotate with orbital angular velocities ω_i, we mean linear expressions of the form

$$n_1\omega_1 + n_2\omega_2 + ... + n_k\omega_k = 0, \tag{1}$$

where the coefficients n_i are small integers.

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2 Orbital motion of planets

To date numerous comparability relations have been found for the orbital and spin angular velocities of bodies in the solar system. Following A.M. Molchanov (1973), for illustrative purposes, we present comparability relations between the mean orbital angular velocities of all planets in the solar system (Table 1). Here, the up-to-date orbital periods of the planets are presented in line 1 ; the coefficients n_i from expression (1) for each of the planets are given in lines 2–9; and the actual and theoretical ratios of the planets' angular velocities ω_i to Jupiter's ω_5, in lines 10 and 11, respectively. The last line (line 12) gives the relative deviations of the theoretical values ω_T (calculated using formula (1)) from the actual values ω_O. It can be seen that they are small. So, given the orbital angular velocity ω_k of one planet, we can fit the values of ω_i for the other seven planets of the solar system. For example, Venus' angular velocity ω_2 is equal to the sum of Saturn's velocity ω_6 and three times Mars' velocity ω_4. The relative error of the result is 0.2 %.

3 Earth's monthly motion

It is well known that the Earth and the Moon rotate around their center of mass (barycenter) with a sidereal period of 27.3 days. The orbit of the Earth's center of mass (geocenter) is geometrically similar to the Moon's orbit, but the orbit size is roughly 1/81 as large as that of the latter. The geocenter is, on average, 4671 km away from the barycenter. In the Earth's rotationless revolution around the barycenter, all its constituent particles trace the same nonconcentric orbits and undergo the same centrifugal accelerations as the orbit and acceleration of the geocenter (Murray and Dermott, 1999, Section 4.2). The Moon attracts different particles of the Earth with a different force. The difference between the attractive and centrifugal forces acting on a particle is called the tidal force. The generation of the lunar tidal force is a major geophysical effect of the Earth's monthly motion. The rotation of the Earth–Moon system around the Sun (Fig. 1) leads to solar tides. The total lunisolar tides vary with a period of 355 days (13 sidereal or 12 synodic months). This period is known as the lunar or tidal year.

The plane of the Earth and Moon's monthly orbit precesses with a period of 18.613 years. Therefore, the lunar nodes precess westward around the ecliptic, completing a revolution in 18.613 years. The lunar perigee moves eastward, completing a revolution in 8.847 years. Because of these opposite motions, a node meets a perigee in exactly in 6 years.

4 Polar wobble

It was indicated by Sidorenkov (2009) that the Chandler period is synchronized with the frequencies of the Earth–Moon–Sun system. The atmospheric forcing of the polar wobble with a solar year period of 365.24 days is modulated by the precession of the Earth's monthly orbit with a period of 18.613 years and by the motion of its perigee

Table 1 New SBS QSO candidates found by WISE colors.

Planet	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Orbital period	87.9693	224.7008	365.25636	686.9796	4332.8201	10755.699	30687.15	60190.03
n_1	1	0	0	0	0	0	0	0
n_2	–1	1	0	0	0	0	0	0
n_3	–2	0	1	0	0	0	0	0
n_4	–1	–3	–2	1	0	0	0	0
n_5	0	0	1	–6	2	–2	–1	0
n_6	0	–1	–1	0	-5	5	0	0
n_7	0	0	1	–2	0	0	7	-1
n_8	0	0	0	0	0	0	0	2
ω_O/ω_5 observed	49.2538	19.2826	11.8624	6.30706	1	0.40284	0.14119	0.07199
ω_T/ω_5 theory	49.2425	19.3240	11.758	6.2824	1	0.4000	0.14286	0.0706
$\frac{\omega_T - \omega_O}{\omega_O}$	0.0002	0.0021	0.0011	–0.0039	0	0.0071	0.0117	–0.019

Note: n_1 to n_8 are the coefficients in Eq. (1).

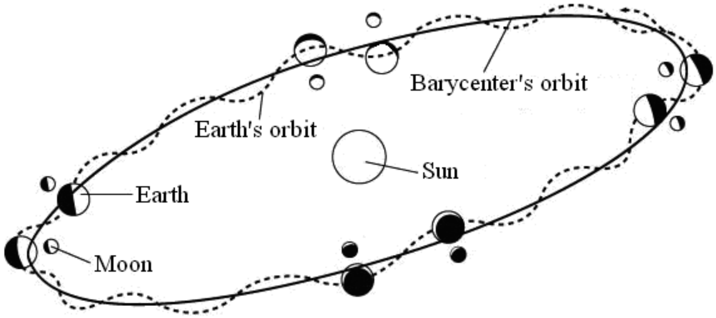

Figure 1 Revolution of the Earth–Moon system around the Sun.

with a period of 8.847 years. Finally, the resulting solar annual forcing generates polar wobble with a Chandler period of 1.20 year:

$$\frac{1}{1.000} - (\frac{1}{8.847} + \frac{1}{18.61}) = \frac{1}{1.200}. \tag{2}$$

The amplitude modulation of the Chandler wobble is clearly exhibited with a period about 40 years. It is known that the atmospheric and oceanic angular momentum functions are capable of accounting for about 90 % of the required Chandler wobble excitation. This excitation is believed to occur at the fundamental frequency of the climate system forcing with a period of 365.24 days. However, it was shown in the author's most recent works that, in addition to this basic forcing, the climate system experiences additional forcing caused by cloud amount variations with lunar year periods. Climatic characteristics and the equatorial component of the atmospheric angular momentum h_2 were found to oscillate with a period of 355 days (Sidorenkov, 2009; Sidorenkov, Sumerova, 2012). The wobble forcing with a lunar sidereal year period of 355 days (13 sidereal months) is modulated by the precession of the Earth's monthly orbit with a period of 18.61 years and by the motion of its perigee with a period of 8.847 years. Finally, the resulting "lunar sidereal" forcing generates polar wobble with a period of 1.161 year:

$$\frac{1}{355.18\,\mathrm{days}/365.24\,(\mathrm{days/yr})} - \left(\frac{1}{8.847} + \frac{1}{18.61}\right) = \frac{1}{1.161\,\mathrm{yr}}. \tag{3}$$

Interference of the 1.20-year Chandler oscillation and the 1.16-year oscillation leads to beats, i.e., to periodic variations in the polar wobble amplitude with a period of 35.3 years:

$$\frac{1}{1.16} - \frac{1}{1.20} = \frac{1}{35.3}.$$

Similarly, the lunar synodic year (12 synodic months) must excite polar wobble with a period of 1.157 year:

$$\frac{1}{354.37\,\mathrm{days}/365.24\,(\mathrm{days/yr})} - \left(\frac{1}{8.847} + \frac{1}{18.61}\right) = \frac{1}{1.157\,\mathrm{yr}}. \tag{4}$$

Interference of this excitation and CWP generates beats with a period of 32.6 years.

The "lunar" annual (13 anomalistic months) excitation can generate polar wobble with a period of 1.172 year:

$$\frac{1}{358.21\,\text{days}/365.24\,(\text{days/yr})} - \left(\frac{1}{8.847} + \frac{1}{18.61}\right) = \frac{1}{1.172\,\text{yr}}. \tag{5}$$

Interference of this wobble with CWP can generate beats with a period of 51.2 years:

$$\frac{1}{1.172} - \frac{1}{1.200} = \frac{1}{51.17}.$$

Thus, interference of the CW (1.20-year period) with these moon-caused oscillations gives rise to beats, i.e., to slow periodic variations in the CW amplitude with periods of 32 to 51 years. They are observed in reality.

Expressions (2–5) correspond to (1) with coefficients $|n_k| = 1$. They describe four-frequency synchronization or resonance. In this sense, we can say that the frequency of Chandler polar wobble is synchronized with the fundamental frequencies of the Earth–Moon–Sun system.

5 Quasi-biennial oscillation of zonal wind

The quasi-biennial oscillation (QBO) of the atmosphere was discovered in the early 1960s in the study of the equatorial stratospheric circulation. It was found that the direction of the equatorial zonal wind reverses with a period of about 26 months in the layer 18 to 35 km. A change from westerlies to easterlies in QBO does not happen simultaneously at all altitudes, but propagates downward at about 1 km per month. An instantaneous vertical profile of zonal wind in the layer 18–31 km has the form of a wave with easterlies following westerlies. This wave always propagates downward and disappears near the tropopause (at a height of ≈17 km) (Fig. 2).

At present, there is a 60-year monthly time series of mass-average zonal wind velocity $\bar{u}$ in the equatorial stratosphere (layer of 19–31 km) (Sidorenkov, 2009, Table D.2). Figure 3 shows power spectra of the pole coordinate x (top) and the QBO indices $\bar{u}$ (bottom). A surprising feature is that the spectrum of QBO indices $\bar{u}$ is similar with a factor of 2 to that of the pole's coordinates x and y. If the horizontal-axis scale in the spectrum of the pole's coordinates is doubled as shown in Fig. 3, then all the details in the spectrum of QBO indices $\bar{u}$ coincide with those in the polar motion spectrum; that is the oscillation in the polar motion is reflected as the doubled-period QBO in the atmosphere. In the equatorial stratosphere, the duration of all the Earth's polar motion cycles is doubled.

The QBO of the equatorial zonal wind is explained by the interaction of Kelvin waves and mixed Rossby-gravity waves with the zonal wind in the equatorial stratosphere (Lindzen, Holton, 1968). The nature of Kelvin and mixed Rossby-gravity waves is not clear. In the author's view, mixed Rossby-gravity waves are manifestations of the lunar tidal waves $2Q_1$ (6.86 days) and σ_1 (7.095 days) in the atmosphere (Sidorenkov, 2010). They account for an intense wide peak at a frequency of about 0.85 $(\text{day})^{-1}$ in the spectrum of the atmospheric angular momentum (Sidorenkov, 2009, see Section 6.5). It is believed that Kelvin waves propagate into the stratosphere, where they meet a westerly shear zone and are absorbed at the height where

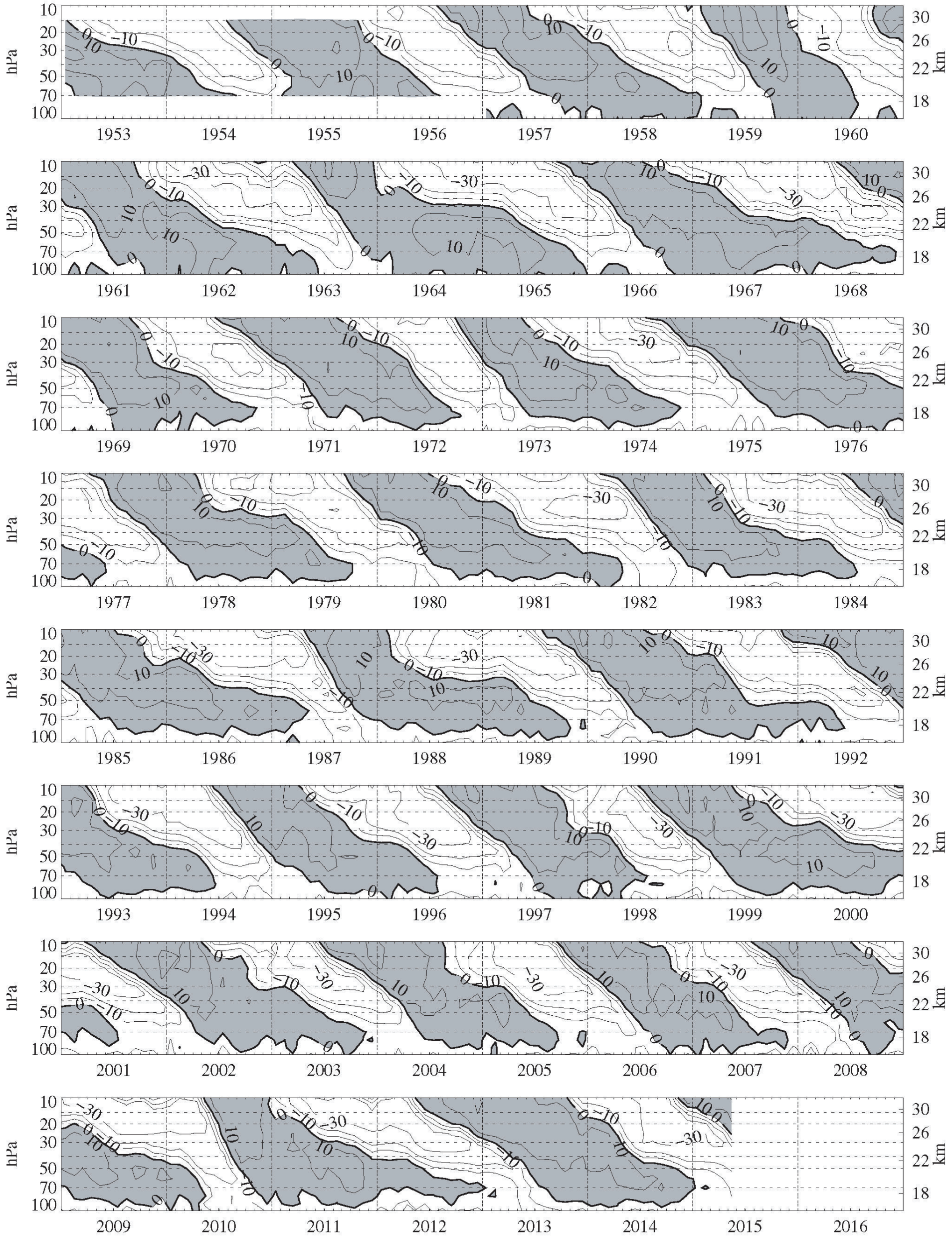

Figure 2 Time–height section of the zonal wind at the equator. Westerly winds are shaded. Isolines are at intervals of 10 m/s (from http://www.geo.fu-berlin.de/met/ag/strat/produkte/qbo/).

their phase velocity coincides with the wind velocity. As a result, the westerlies at this height strengthen, while the absorption of new waves is descended. Since wave absorption proceeds continuously, the westerly zone gradually sinks toward the tropopause

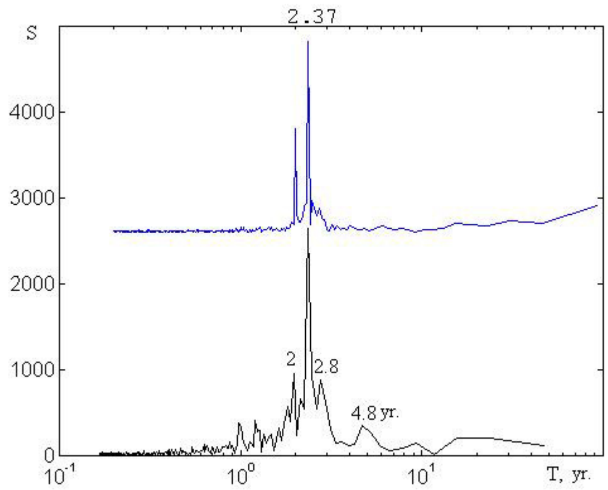

Figure 3 Power spectra of the pole coordinate (top) and the QBO indices (bottom). To demonstrate the curves' similarity, the pole's curve was transformed as follows: $T = 2T_0$ and, $S = 30S_0 + 2600$, where T_0 and S_0 are the actual values of the periods T and spectral densities S, respectively.

at a velocity of about 1 km/month. When the westerly zone stretches down to the tropopause, the Kelvin waves have low frequencies due to the Doppler shift, while the mixed Rossby-gravity waves have high frequencies. That is why the latter propagate upward. At the height of semiannual oscillations (≈35 km), they can meet an easterly shear zone, where they are absorbed. As a result, the easterly velocity increases and the easterly zone descends permanently from 35 km to the tropopause, where the cycle is completed. At the same time, Kelvin wave absorption begins at the height of semiannual oscillations and a new cycle starts. In this model, the QBO period for wind depends only on the intensity of atmospheric waves and on the distance between the equatorial tropopause and the height of semi-annual oscillations in the stratosphere.

A generalization of experimental and theoretical studies has revealed that the QBO period is a linear combination of the frequencies corresponding to the doubled periods of the tidal year (0.972 year), precession (18.61 years), and perigee (8.847 years) of the Earth monthly orbit:

$$\frac{1}{2}\left(\frac{1}{0.972} - \frac{1}{8.847} - \frac{1}{18.61}\right) = \frac{1}{2.32}. \qquad (6)$$

The tidal year frequency is taken in (6) because the mechanism of QBO excitation is associated with the absorption of Kelvin and mixed Rossby-gravity waves in the equatorial stratosphere. However our observations of variations in pressure, geopotential height, temperature, and cloudiness anomaly fields suggest that planetary atmospheric waves known as Rossby and Kelvin waves behave as lunar tidal waves and have the same characteristics (Sidorenkov, 2010).

The study of the equatorial angular momentum of atmospheric winds has also shown that their spectrum is dominated by semimonthly and quasi-weekly lunar waves, which are treated in meteorology as Yanai waves. In 1960 C. Eckart (p. 319) showed that Rossby waves are, in fact, oscillations described by Laplace's tidal equation. Taking into account all these findings, we believe that Rossby, Kelvin, and Yanai waves are visual manifestations of tidal waves in the atmosphere. From year to year, they repeat not with a tropical year period of 365.24 days, but with a period of 13 tropical months, which is equal to 355.16 days or 0.97 yr. It is called the tidal or lunar year.

In contrast to resonance expression (2), all the frequencies in (6) have doubled periods. This means that expression (6) corresponds not to the fundamental resonance, but rather to a resonance of the n-th kind, i.e., to a subharmonic oscillation (having a frequency that is a fraction of a fundamental frequency), whose existence follows from Mandelstam and Papaleksi's theory (Mandelstam, 1947). Thus, the quasi-biennial oscillation of zonal wind in the equatorial stratosphere is a combination oscillation driven by three periodic processes affecting the atmosphere: (a) lunar-solar tides, (b) the precession of the Earth's monthly orbit around the barycenter of the Earth–Moon system, and (c) the motion of the pericenter of this orbit. In the QBO case, synchronization occurs at the combination frequencies of the n-th kind.

6 Mul'tanovskii's natural synoptic periods

The lunar–solar tides deform the Earth's shape and change the Earth's moment of inertia. As a result, they have a noticeable effect on the velocity of the Earth's daily rotation. The tidal oscillations of the Earth's rotation rate over any time interval can be calculated theoretically (Sidorenkov, 2009). For illustration, Fig. 4 shows the tidal deviations of the Earth's daily angular velocity ν in 2016. The Earth's rotation velocity is characterized by the relative value (Sidorenkov, 2009)

$$\nu = \frac{\delta\omega}{\Omega} = \frac{\omega - \Omega}{\Omega} \approx -\frac{\Pi_E - T}{T},$$

where Π_E is the length of Earth's day; T is the length of the standard (atomic) day, which is equal to 86400 s; and $\omega = (2 \cdot \pi)/\Pi_E$ and $\Omega = (2 \cdot \pi)/86400$ rad/s are the angular velocities corresponding to the Earth's and standard days.

It can be seen that, during a tropical month, ν undergoes two semimonthly oscillations with maxima occurring at the maximum distance of the Moon from the celestial equator in both Northern and Southern hemispheres (i.e., at "stations of the Moon") and with minima occurring when the Moon intersects the equator (i.e., at "lunar equinoxes").

The monitoring of tidal oscillations of ν, the evolution of atmospheric synoptic processes, atmospheric circulation patterns, and time variations in hydrometeorological characteristics has shown that most types of atmospheric synoptic processes vary synchronously with the tidal oscillations of the Earth's angular velocity (Sidorenkov, 2009). Using retrospective data, we verified how frequently the extrema (minima or maxima) of ν coincide in time with changes in elementary synoptic processes (ESP) in terms of the Vangengeim classification. A statistical analysis showed that 76 % of the

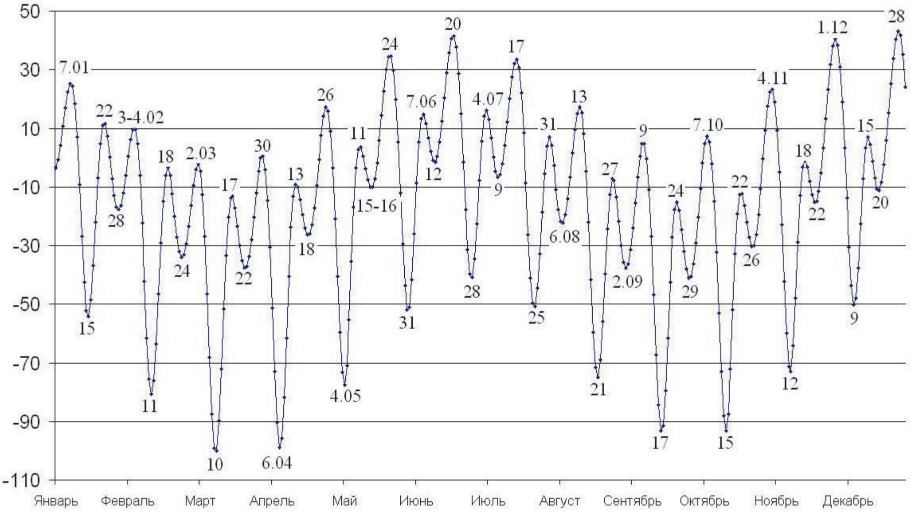

Figure 4 Tidal oscillations of the Earth's rotation velocity ν in 2016. The vertical axis represents the relative deviations of ν multiplied by 10^{10}. Numerals indicate the dates when maxima and minima occurred.

extrema of ν coincide in time (up to 1 day) with ESP changes. In the other 24 % of the cases, the extrema of ν are two and more days away from the nearest ESP change (Sidorenkov, 2009). The long-time comparative monitoring of tidal oscillations of ν and variations in meteorological characteristics in Moscow, Vladivostok, and other sites clearly suggests that variations in meteorological characteristics agree in time with quasi-weekly extrema of ν (http://geoastro.ru).

Variations in weather elements at other sites of the world have been monitored by S.P. Perov and L.V. Zotov. Their results also confirm that variations in meteorological characteristics are synchronized with oscillations of the Earth's angular velocity.

The tidal oscillations in the Earth's rotation velocity represent a perfect index for the features of the Earth's monthly rotation around the barycenter and time variations in the lunisolar tidal forces. They correlate with quasi-weekly and semimonthly variations in atmospheric processes and with local anomalies in the air temperature, pressure, cloudiness, and precipitation amounts depending on those variations.

Changes in weather patterns coincide with extrema of tidal oscillations of ν, which correspond to lunar solstices and lunar equinoxes. By analogy with three-month seasons of the year, which are associated with the Earth's rotation around the Sun, some kind of quasi-weekly weather "seasons" can be identified in weather patterns.

Quantized weather patterns were first described by B.P. Mul'tanovskii (1933) 100 years ago. He called them natural synoptic periods (NSPs). The above observations suggest that Mul'tanovskii's NSPs are possibly caused by the monthly rotation of Earth and Moon around their barycenter. Weather is synchronized with the times of lunar equinoxes and solstices. In contrast to solar seasons, the lunar NSPs are not constant: they vary from 4 to 9 days with a mean of 6.8 days. These variations are caused by the frequency modulation of the tidal force oscillations due to the motion of the lunar perigee. Plots of tidal oscillations of ν provide a kind of NSP timetable, demonstrating that variations in NSP lengths are not random. Unfortunately, there are still works appearing in which the dynamics of NSPs is erroneously treated in terms of Brownian motion.

Note that synchronization does not determine the formation mechanisms of thermobaric structures due to the baroclinic instability of the atmosphere, but rather imposes evolution rhythms close to tidal force oscillations (more precisely, to rhythms in the Earth–Moon–Sun system) on atmospheric processes.

7 Antarctic circumpolar wave

In the Southern Ocean, large-scale anomalies of the atmospheric sea level pressure, meridional wind stress, sea surface temperature, sea surface height, and ice edge extent propagate eastward around Antarctica, circling the globe every 8–10 years. This phenomenon was discovered by White and Peterson (1996) and Jacobs and Mitchell (1996) and was called the Antarctic Circumpolar Wave (ACW). Over the entire observation span, all anomalies appear quasi-periodic with a dominant 4-year period (see Fig. 1 by White and Peterson (1996) http://circulaciongeneral.at.fcen.uba.ar/material/White-Peterson.1996.pdf) and a 180° longitude wavelength.

Thus, the ACW appears as two anomalies on opposite sides of Antarctica, propagating eastward at about 10 cm/s. The ACW is generated by the ENSO (Turner, 2004). ACW revolutions with periods of 8 and 4 years suggest that the ACW is synchronized with the frequencies of the Earth–Moon system. Indeed, the Moon's rotation involves a Full Moon Cycle (FMC) of 412 days and its subharmonic with a period of 206 days (Sidorenkov et al., 2014). The 412-day period is one of beats generated by the frequencies of the synodic and anomalistic months:

$$\frac{1}{27.5546} - \frac{1}{29.5306} = \frac{1}{411.793}.$$

Three and a half FMCs take 4 years, while seven FMCs continue 8 years. Therefore, the interaction of 412- and 206-day cycles with the annual solar period (365.24 day) generates beats with periods of 4 and 8 years. Accordingly, tidal geophysical, meteorological, oceanological, and other terrestrial processes exhibit 4-year cycles. It is with these cycles of the Earth–Moon–Sun system that the ACW is synchronized.

8 Decadal climate changes

The synchronization of variations in meteorological characteristics with variations in the Earth's angular velocity ν and the motion of bodies in the Earth–Moon–Sun system can be observed not only on intramonthly time scales, but also on interannual and decadal scales.

Hot summers and cold winters over European Russia were observed in years close to 2002/2010, 1972, 1936/1938, and 1901 (Sidorenkov, Sumerova 2012). It is close to these years that we could observe changes in the Northern Hemisphere decadal temperature tendencies, atmospheric circulation epochs, the Indian monsoon intensity,

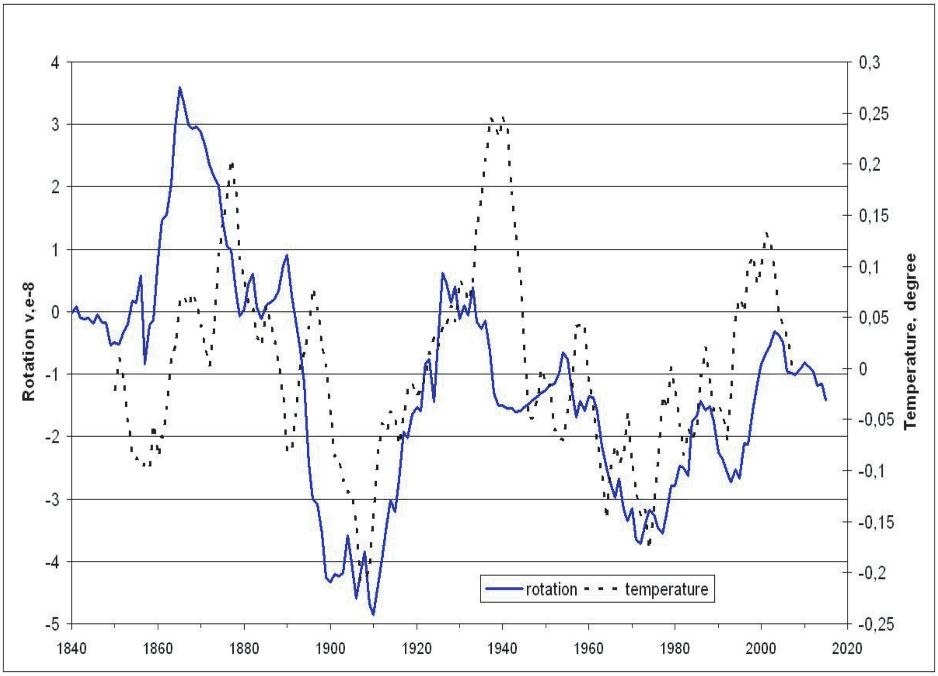

Figure 5 Synchronous changes in the Earth's rotation velocity $\nu \times 10^8$ (solid lines) and of five year running anomalies of the Northern Hemisphere's air temperature after elimination of parabolic trend (dashed lines). Original data from HadCRUT3.

the mass of the Antarctic and Greenland ice sheets, and Earth's rotation rate regimes (Fig. 11.5) (Sidorenkov, 2009).

The renewed results presented in Fig. 5 show that the temperature T grows when the Earth's rotation speeds up and decreases when the Earth's rotation slows down. The curve of ν correlates with variations in T with correlation coefficient $r = 0.67$.

Singular spectrum analysis (expansion in terms of empirical orthogonal functions of time) applied to series of the Earth's angular velocity and global air temperature and sea level anomalies suggests the presence of periods close to lunar periods of 18.6 and 8.85 years (Zotov et al., 2014).

According to observations, the values of ν and T reached their maxima in 2003. In 2004 a new epoch started in the atmospheric circulation, with Earth's rotation rate ν slowing down and T reducing.

A more detailed presentation can be found in Sidorenkov's publications (see http://geoastro.ru), where variations in meteorological elements are compared with extrema of ν over the years 2012–2015.

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