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PEREGEE-SYZYGY TIDES IN ATMOSPHERE

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ABSTRACT. It is shown that in 2016/17 the smoothed anomalies of air temperature in The European Territory of Russia repeated the course of the perigee distance, which varies along the sinusoid with a period of 206 days. Discovered the basic pattern perigee-syzygy tides: 206 daily beating pressure anomalies for the new moons and full moons. Pressure anomalies in the full moon and new moon can be approximated by sinusoids with periods of envelope beating about 412 days and opposite phases. The range of oscillations in the antinodes reaches 40 MB, which in order of magnitude is quite comparable to the real SYNOPTIC fluctuations in atmospheric pressure.

Keywords: lunisolar tides, lunar cycles, weather forecast, climate changes.

АНОТАЦІЯ. Стаття присвячена перігейно-сізігійний приливам в атмосфері Землі, які яскраво проявилися в незвичайному розвитку погодних процесів на Європейській території Росії (ЄТР) в останні три роки. У 2017 році ми вперше помітили, що згладжені аномалії температури повітря на ЄТР повторювали хід перігейної відстані Місяця. Показано, що додавання частот місячних аномалістичних і синодичних півмісяців породжують биття припливної сили з періодом 206 діб. Цей приливний цикл впливає на розвиток синоптичних процесів, на коливання атмосферного тиску, температури і погоди на ЄТР. 206-добовий цикл порушує правильний сезонний хід погоди, приводячи до значних аномалій метеорологічних характеристик. Встановлено співпадіння випадків з рекордною максимальною температурою з максимумом перігейної відстані Місяця, а випадків мінімальної температури – з його мінімумом. Знайдена основна закономірність перігейно-сізігійних припливів: биття аномалій тиску для молодого та повного Місяця. Аномалії тиску в молодого і повного Місяця можна апроксимувати синусоїдами, які огинають биття, з періодами близько 412 діб і протилежними фазами. Розмах коливань в пучностях досягає 40 мб, цю величину цілком можна порівняти з реальними синоптичними коливаннями атмосферного тиску. Показано, що кореляція перігейної відстані Місяця з аномаліями температури порушується внаслідок того, що Місяць буває в перигелії частіше, ніж відбуваються зміни її однойменних фаз. 15 аномалістичних місяців (413,31 доби) тривають стільки ж, скільки 14 синодичних місяців (413,42 доби). За 15 аномалістічних місяців спостерігаються дві зміни перігейної відстані – від 356 500 до 370000 км. Одна зміна здійснюється за 7 аномалістічних місяців (192,8 діб), а друга – за 8 місяців (220,4 діб). Така частотна модуляція зміни перігейної відстані сильно ускладнює синхронізацію атмосферних процесів з місячно-сонячними приливами.

Ключові слова: місячно-сонячні припливи, місячні цикли, прогноз погоди, зміни клімату.

1. Introduction

It is widely believed that global scale periodic oscillations of the Earth’s atmosphere are dominated by thermal tides, which are caused, first, by heating the atmosphere from the land and water surfaces directly absorbing solar radiation and, second, by absorbing solar radiation in the stratospheric ozone layer. Naturally, thermal tides have the solar daily frequency and its subharmonics (12, 8 hours, etc.). Gravitational tides caused by the attraction of the Moon and the Sun are generally thought of as negligible and having no effect on synoptic processes in the atmosphere (Chapman, Lindzen, 1972*;* Volland, 1988). However, a monitoring of lunisolar tidal oscillations of the Earth's rotation rate has revealed that atmospheric processes tend to vary simultaneously with extrema of tidal oscillations of the Earth's rotation rate (Sidorenkov, 2015). Additionally, Sidorenkov (2009) has found that the spectrum of the angular momentum of the global atmosphere has lunar components with periods of a lunar year (355 days), half a lunar month (13.6 days), and a quarter of a lunar month (7 days). This is confirmed by a spectral analysis of long-term series of air temperature anomalies in Moscow that reveal lunar components with periods of 355, 206, 87, and 27 days (Sidorenkov, 2009).

The 206-day lunar cycle in the evolution of weather processes over European Russia was first noted by the author in 2017. The spring of 2017 demonstrated an unusual dynamic for the weather processes over European Russia. More specifically, from the second week of February, the daytime air temperatures rose to thawing and, in the third week of February, the daily mean temperature became positive. On March 1, the absolute temperature maxima were broken in many cities of

European Russia. The temperature reached values typical for the middle of April and the existing snow cover thawed quickly. The ice on the Don, Oka, Dnieper, Western Dvina, and Volga rivers was broken extremely early. In the second week of April, the increase in temperature ceased and negative temperature anomalies persisted until the last days of April. Then a four-day summer-like heat wave was observed, which was followed (starting from May 4) by a temperature decrease to April values. In the third week of May, the temperature began to return to normal values. However, a cold wave of Arctic air swept the region on the first days of June. As a result, the temperature reduced to extremely low values. Night frosts were still observed in many areas of European Russia in June (i.e., extremely late in the season).

2. Observations and their analysis

The Hydrometeorological Center of the Russian Federation supports the MIDL database which stores the anomalies of daily mean temperature of about 2700 Northern Hemisphere weather stations. These anomalies are computed according to Bagrov's technique (Bagrov, Loktionova, 1994). The daily mean temperature anomalies for each station were determined by applying a piecewise parabolic approximation (*Gordin*, 1994), that used the monthly means. Data from MIDL for several stations in European Russia were used in the present study.

Figure 1 displays the anomalies of daily mean temperature in Moscow for 2016/2017. It shows that they exhibit large day-to-day fluctuations. Sidorenkov (2015) and Sidorenkov (2009 and 2016) show that intra-monthly (i.e. semi-monthly and quasi-weekly) temperature variations can linked to the lunisolar tides. Accordingly, daily temperature anomalies are smoothed by computing their 27-day moving averages. The smoothed data is displayed in Fig. 1 using a thick curve which mimics a sinusoidal wave with minima in November 2016, and May–June 2017, and maxima in March and September 2017.

The observed range in the temperature anomaly oscillations reaches 10° C, while the period (time interval between similar extrema) is about 204 days. This period is very close to the 206-day period obtained by Sidorenkov (2015) and Sidorenkov (2009 and 2016) from a computed periodogram of a 43-year time-series of temperature anomalies for Moscow.

Experience shows that the correlation length of the temperature anomalies for European Russia is more than 1000 km. Therefore, the plotted temperature anomalies for Moscow, well characterize the smoothed variations in temperature anomalies over the entirety of European Russia. In addition, plots like Fig. 1 were constructed for Krasnodar, Rostov-on-Don, Kazan, and Samara weather stations. These plots showed similar variations in their 27-day moving average temperature anomalies, differing only in the values and times of their daily fluctuations (Fig. 2). Finally, the temperature anomalies for all the stations cited follow the variations in the lunar perigee distance.

2.1. Origin of the 206-day lunar cycle

New and full moons are also known as syzygies. At times of syzygy, the Sun, Earth, and Moon are in a straight line. Accordingly, their tidal forces act to reinforce one another, so that the spring tides peak in strength. At times

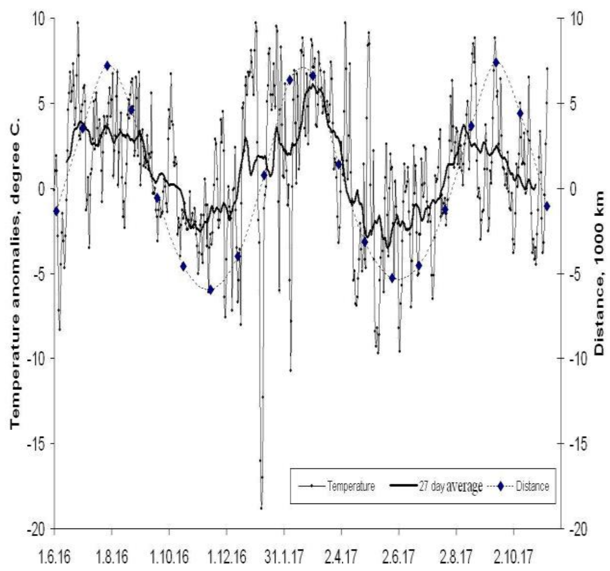

Figure 1: Deviation of the lunar perigee distance from 362464 km (diamonds) and the anomalies of daily mean air temperature in Moscow over 2016/2017 (the thin curve depicts daily mean values, and the thick curve shows 27-day moving averages).

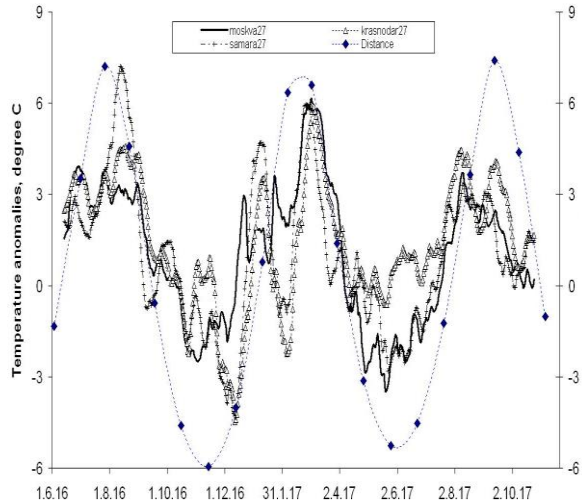

Figure 2: The 27-day moving averages of temperature anomalies in Moscow (solid), Krasnodar (triangles), and Samara (crosses) in comparison with the lunar perigee distance (diamonds connected by the dashed curve).

of quadrature (the first or third quarter phases), when the angle between the Moon and the Sun is 90°, the tides are at minimum strength (i.e. neap tides). If the lunar orbit were a circle, the strength of the spring and neap tides would not change over time. However, the lunar orbit is elliptical. The point of the Moon's orbit closest to the Earth is the perigee, while the farthest point is the apogee. A line drawn through the perigee and apogee is called the line of apsides (line-of-apse). Naturally, the tidal force of the Moon experienced by the Earth is a maximum at perigee and a minimum at apogee.

The perigee end of the line-of-apse of the lunar orbit continuously moves from west to east over the celestial sphere, returning to nearly the same position relative to the stars every 8.85 years. The Sun makes a revolution relative to the stars in the same direction in 1 year. Therefore, if the perigee end of the line-of-apse starts at a time when it points directly at the Sun, then another 411.78 days or 1.127 years are required for it to return to the original configuration (i.e. the Sun catches up with the perigee). This is true because the frequencies of two considered revolutions are subtracted: $\frac{1}{1}-\frac{1}{8.85}=\frac{1}{1.127}$.

The 411.78-day period is called the Full Moon Cycle (FMC). Clearly, it takes roughly 206 days before the perigee end of the lunar orbit makes half a revolution. The 206-day cycle is known in astronomy as half of the FMC. From a physics point of view, the 412-day cycle is the period of beats produced by interfering the close frequencies of anomalistic (27.55 days) and synodic (29.53 days) months (Sidorenkov, 2015; Sidorenkov, 2009; 2016, Wilson, 2012) or the synodic month and the evection period in the lunar longitude (31.81 days). The important point to note is that the 206-day cycle is equal to the half-difference between the frequencies of the interfering oscillations as well as being a whole multiple of the synodic month (since 7 x 29.53 days = 206.7 days).

2.2. Manifestation in terrestrial processes

The re-alignment of the anomalistic and synodic orbital periods cited above influences lunar tidal and terrestrial atmospheric processes. For example, the distance between the Earth and the Moon at the perigee ranges from 370000 to 356000 km, with a long-term average period of about 206 days. This effect of lunar distance is illustrated in Figs. 1 and 2, where the deviation of perigean distance from its average value of 362464 km, is depicted by diamonds connected by a dashed curve. The length of the lunar anomalistic month (i.e., the time interval between two consecutive passages of the Moon through the perigee) ranges from 28.5 to 24.8 days, while its long-term average is equal to 27.554545 days.

It is important to note that the Earth's motion around the barycenter of the Earth–Moon system reflects all motions of the Moon at a scale of 1:81. Therefore, the Earth has similar variations in its pericentric distance and in its angular velocity of monthly rotation around the barycenter with a period of 206 days (Sidorenkov, 2015; Sidorenkov, 2009; 2016). However, since we are on the Earth, we cannot see or experience its motion and must use the Moon to study the motions of the Earth.

2.3. Spring tides

The 206-day cyclicity of the Earth's pericentric distance and, hence, its angular velocity of monthly rotation about the Earth-Moon barycenter, must influence processes in the Earth's spheres, primarily, in those of the atmosphere and hydrosphere. For example, Fig. 3 presents the maximum sea level heights at full and new moons in various ports around the globe (see Avsuk, Maslov, 2011).

Inspection of Fig. 3 shows that all tidal curves, for a given lunar phase (i.e. new or full), are well approximated by an enveloping sine function with a period of about 412 days and an amplitude of about 60 cm. For perigean spring curves, the period of the beats (the time interval between neighboring nodes or antinodes) is equal to 206 days.

Figure 3 provides key information for understanding the formation mechanism of 206-day oscillations of temperature anomalies in the atmosphere. It suggests that the atmosphere must exhibit pressure oscillations like the perigean spring tides in the ocean, which can lead to the formation of 206-day oscillations of air temperature. Specifically, Fig. 3 shows that the spring tides at full and new moons have opposite heights at antinodes and are nearly identical at nodes. With regards to atmospheric pressure, such behavior means that alternating semimonthly cyclonic and anticyclonic processes prevail at antinodes, but they die out at nodes. Such dynamics of atmospheric processes can lead to considerable differences between the air temperature conditions at antinodes and nodes. The period of these differences is 206 days.

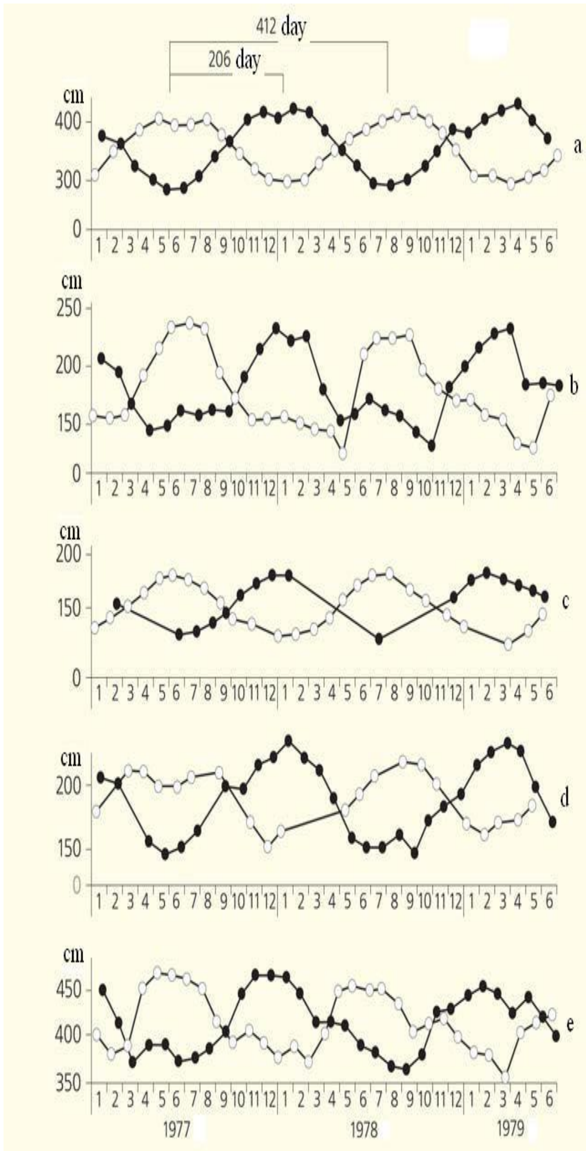

Figure 3: Highest spring tide at full moons (○) and new moons (●) in (a) Murmansk, (b) Puerto Williams (Chile), (c) Suva (Fiji), (d) Lerwick (Scotland), and (e) Magadan (Avsuk, Maslov, 2011).

The main feature of perigean spring tides is that the curve for each syzygy (i.e. new or full moon) is well approximated by a sine function (beat envelope) with a period of 412 days and a phase difference of 180° (Fig. 3). Therefore, for any tidal characteristic, each positive anomaly in one syzygy is associated with a negative anomaly in the nearest other-type syzygy. The root cause is that the lunar orbit is elliptical. If the Moon passes through perigee at full moon, then the distance to the Earth reduces to a minimum and the tidal force is maximum (positive anomalies). Roughly half a month later, at new moon, the Moon is in the opposite part of the orbit at the maximum distance (near apogee) and the tidal force becomes minimum (negative anomalies).

In 27.55 days, the Moon returns to the perigee, but this time two days ahead of full moon (29.53 – 27.55≈2); next time, it returns four days ahead of full moon, and so on. With each revolution, the tidal force decreases at full moon and increases at new moon. About 3.5 synodic months later, the spring tides become of equal strength (at a beat node) and, then, the tidal force at new moon begins to prevail over that at full moon, reaching a maximum range (at an antinode) after about 7 syzygies. Next, the tidal range decreases over 3.5 months until the next node is reached and so on. Changes in the sign of anomalies from full to new moons and back always occur at beat nodes at intervals of about 206 days.

2.4. Spring tides in the atmosphere

The appearance of a 206-day cycle in the 2017 weather prompted our study of atmospheric spring tides, which are expected to manifest themselves in atmospheric pressure oscillations in a similar manner to the see-level spring tides in Fig. 3 (Avsuk, Maslov, 2011). Specifically, a series of three-hour ground-surface pressure measured at the VDNKh weather station in Moscow over the last two years was used to calculate daily mean pressure values and their anomalies. The daily pressures at the Moscow State University meteorological observatory averaged over 1966–2010 were used as normals reference (Sidorenkov et al., 2008).

Next, for each full moon day, we chose the daily mean pressure anomaly over for this day. A series of atmospheric pressure anomalies for all new moons was separately generated in a similar manner. With the help of Excel, the atmospheric pressure anomalies at the VDNKh weather station were plotted for full moons (open circles on the broken curve) and for new moons (solid circles on the solid curve) over 2016–2017 (Fig. 4).

The spring tides in Kazan were additionally analyzed. With the help of Excel, the anomaly atmospheric pressure at the Kazan University weather station were plotted for full moons (open circles on the broken curve) and for new moons (solid circles on the solid curve) over 2016–2017 (Fig. 5).

Figures 4 and 5 show that the spring oscillations of atmospheric pressure are very noisy. Nevertheless, the basic features of spring tides, namely, nodes (in the summer of 2016 and May of 2017) and antinodes (in February–March and September–October of 2017) can be observed. It can clearly be seen that the pressure anomalies at new and full moons are of different signs. The pressure anomalies at full and new moons can be approximated by sinusoids with beat envelope periods of about 412 days and opposite phases. The range of oscillations at antinodes reaches 40 mb, which is comparable in order of magnitude with actual synoptic oscillations of atmospheric pressure and close to spring tides in the ocean (Avsuk, Maslov, 2011) since a 1-cm sea level elevation is equivalent to atmospheric pressure of 1 hPa (mb).

Thus, Figs. 4 and 5 suggest that the geodynamical forces in 2016/2017 were able to overcome the stochastic thermodynamics of the atmosphere and imposed their celestial-mechanical tidal cyclicity on the weather evolution over European Russia. It is these cases of forced synchronization of atmospheric dynamics and tides that give rise to lunar components in the spectra of anomalies of meteorological characteristics (Sidorenkov, 2009; 2015; 2016) connected with atmospheric spring tides. The 206-day cycle of spring tides violated the correct seasonal variations in meteorological characteristics. Many local record extremes of daily meteorological characteristics observed across European Russia in 2016/2017 were associated with this cycle.

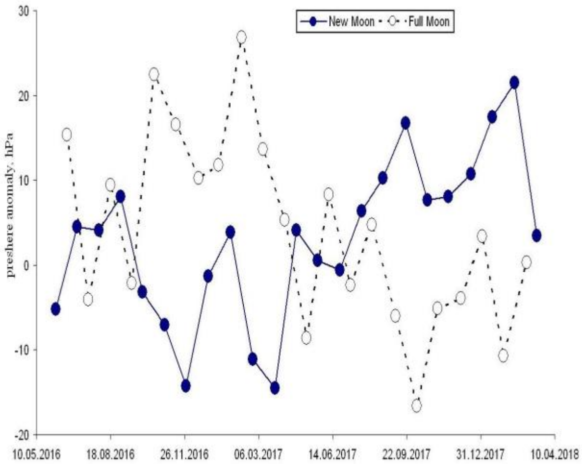

Figure 4: Spring oscillations of atmospheric pressure at the VDNKh (Moscow) weather station over 2016/2017.

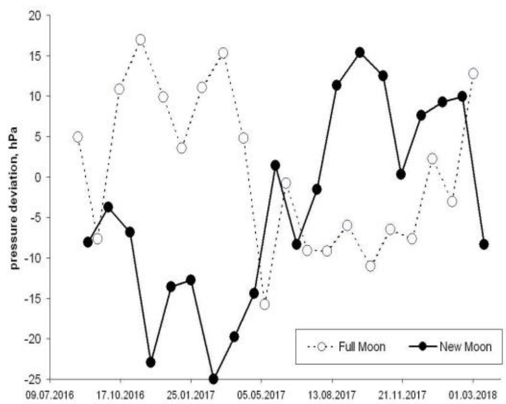

Figure 5: Spring oscillations of atmospheric pressure at Kazan weather station over 2016/2017

The 206-day cycle of temperature anomalies leads to violations of seasonal temperature variations. For example, due to its contribution, the 2016 winter over European Russia began nearly one month earlier, while the 2017 summer set in one month later than its usual time. These phenomena were followed by a shift in summer to August and a delay in fall. In January of 2018, the phases of 206-day lunar and annual solar cycles coincided, and winter came, though mild with little snow at the beginning, but frosty with much snow at the end.

Over the time interval considered, two extrema (maxima or minima) of the perigee distance and the temperature over European Russia were observed at the same time. This suggests an interesting dependence: record maximum temperatures tend to occur simultaneously with perigee distance maxima, while the cases of minimum temperature, with perigee distance minima.

For example, according to daily data from the Hydrometeorological Bulletin of the Hydrometeorological Center of Russia, near the maximum of the perigee distance on March 1, 2017, the absolute temperature maximum was exceeded in Moscow, St. Petersburg, Bryansk, Rostov-on-Don, Kirov, and some other cities. Near the next maximum of the perigee distance (on September 13), the temperature maximum for September 12 was exceeded in Velikiye Luki, Smolensk, Tver, Rybinsk, Simferopol, Anapa, Krasnodar, etc. However, absolute temperature minima are observed much less frequently, possibly due to the global warming of the climate. Near the distance minimum of May 26 to June 20, 2017, frosts were observed over European Russia and the minimum temperature extremes were exceeded in Arkhangelsk, Lipetsk, Pskov, Tambov, Ufa, etc.

The correlation presented in Figs. 1 and 2, however, between the lunar perigee distance R and the anomalies of temperature T cannot persist permanently. This is true since is that the Moon passes through ~~the~~ perigee more frequently than it passes through the same phase i.e. there is a slow drift between the Synodic and Anomalistic month so that 15 anomalistic months (413.3182 days) is roughly equivalent to 14 synodic months (413.4282 days). Thus, over 15 anomalistic months, the perigee distance varies twice from 356500 to 370000 km, with one variation lasts for seven anomalistic months (192.8 days), and the other, for eight months (220.4 days). This leads to a kind of frequency modulation being imposed on the perigee distance variations that complicate the synchronization of atmospheric processes with lunisolar tides.

An analysis of long-term temperature anomalies has shown that the situation described above is a rather rare event, where there is a synchronization of oscillations in the atmospheric circulation with oscillations of geodynamic forces in the Earth–Moon–Sun system. An analysis of atmospheric pressure in Moscow starting from 1966 reveals that cases like the above-considered synchronization of pressure oscillations with perigean spring tides were observed in 1978, 1980, 1982, and 1983. Some examples of synchronization of atmospheric processes with geodynamic forces can be found in (Sidorenkov, 2016; Sidorenkov, 2009; 2016, 2017).

All meteorological features discussed previously appear because of the effects produced by perigean spring tides on the atmosphere. Clearly, the possibility of synchronization depends on the season of the year. The 206-day cycle and four years are in the ratio of 1:7. So after four years, the phase of the 206-day cycle re-synchronizes with the seasons of the year. Hence, you would expect that the maximum correlation of the temperature anomalies T with R should have a four-year period. However, this study shows that it tends to have an eight-year period, since, in four years, the lunar phases reverse (i.e. full moons are observed instead of new moons). (Recall that the Moon is between the Sun and the Earth at new moon, while the Earth is between the Sun and the Moon at full moon, so the configuration of the gravitational forces is entirely different in these cases). Thus, the same lunar phase occurs at the same time in the seasonal cycle once every eight years, i.e., the 206-day cycle in temperature anomalies and weather features is manifested primarily when certain mutual configurations of the Earth, Moon, and Sun are repeated.

A good example of eight-year cyclicity is the still widely remembered unusually dry and warm fall observed over European Russia in 2018. Earlier similar weather anomalies in fall occurred in 2010, 2002, and 1994. Even earlier similar dry anomalies in fall were observed in 1954, 1946, and 1938.

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