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Lunar semimonthly signal in cloudiness: lunar-phase or lunar-declination effect?

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Abstract

The cloud amount summer nighttime data obtained from the 1994-2007 NASA satellite infrared and visible range measurements taken within the framework of the International Satellite Cloud Climatology Project (ISCCP) were analyzed, and the contribution by lunar signal to the cloud amount was extracted. Although the fact of lunar influence on cloudiness is known, this investigation has made it possible to separate the lunar-phase and lunar-declination effects on cloudiness. The relative cloud amount tends to grow with a change in lunar phase from a quadrature to the New Moon or Full Moon and with an increase in lunar declination by absolute value. Both the effects are statistically significant, the lunar-declination effect is a little stronger. The obtained results do not seem to contradict the theory of lunar tides.

Keywords: Gravitational lunar tides; tropospheric clouds; tropospheric dynamics

Introduction

Lunar semimonthly variations were found in precipitation (Howard, 1820) and cloudiness (Rodés, 1937), sunshine duration (Lund, 1965), and ice-nucleus concentration in the troposphere (Bigg, 1963). Some more recent statistical results on this topic were mentioned by Pasichnyk (2002). The global temperature of the lower troposphere, probably interrelated to cloudiness, also provides the lunar synodical monthly and semimonthly peaks in its spectrum (Balling and Cerveny, 1995). The lunar synodical monthly and semimonthly periodicities were also observed in noctilucent clouds (Kropotkina and Shefov, 1976). Thus, both tropospheric and mesospheric clouds are involved in some processes or process connected with synodical semimonthly oscillations, at least, in restricted geographic regions in definite seasons of a year.

Rodés (1937) studied the contributions made by different variables describing the Moon's position (declination, phase, distance from the Earth and lunar time i.e. passage time of a given meridian under the Moon) to meteorological data (precipitation, cloud amount, wind velocity, etc.). For precipitation and cloud amount, the strongest effect was due to lunar declination. To amplify the lunar signal, Rodés selected the dates with positive declinations and shorter distances and, vice versa, negative declinations and longer distances and, thus, obtained the strongest effect. In fact, it was the first step to a multidimensional analysis in the studies of lunar influence. A similar approach to the US precipitation data was used by Brier (1965). He sampled the synodical month with a syzygy (New Moon or Full Moon) which were close to the lunar perigee and simultaneously to the ecliptic plane. In this case, the lunar semimonthly variations were significantly stronger than average ones within all the synodical months. However, most of relevant papers~~,~~ devoted to the lunar effect in cloudiness and precipitation used a one-dimensional analysis only, i.e. the effects of lunar phase and declination or other variables were studied separately. In the paper by Dalin et al. (2006), attention has been focused on the mutual statistical relationship between lunar phase and lunar declination. This mutual dependence is especially strong within a short seasonal segment (of many years), and must be taken into account in a statistical analysis, when dealing with clouds within definite seasonal segments. In the study by Pertsev et al. (2007) (below, we shall refer to it as PDR07), an attempt was made to distinguish between the lunar-phase and lunar-declination effects on tropospheric nighttime summer clouds and noctilucent clouds over the Moscow region (Russia) for both monthly and semimonthly periods, which led us to the conclusion that the declination effect was significantly stronger for semimonthly lunar signal in the both types of clouds, whiles the lunar-phase effect may occur artificially due to statistical relationship between lunar phase and lunar declination. The insufficient data volume on both tropospheric and noctilucent clouds, which was used in PDR07, did not allow us to obtain a more precise result in that paper. The rough estimates of the relative sky area covered by tropospheric clouds, which were obtained visually by observers of noctilucent clouds during summer nights over a period of many years, were used in PDR07 as an index of tropospheric cloudiness. The main aim of the present paper is to verify the results of PDR07 with a more complete and reliable database on cloudiness and to formulate a more precise conclusion about the influence of lunar phase and lunar declination on the development of cloudiness.

1. Theoretical background

Although lunar oscillations in the atmosphere may occur due to various physical mechanisms (Rodés, 1937; Adderley and Bowen, 1962; Markson, 1971; Herman and Goldberg, 1978), a gravitational tide is usually recognized as the most realistic or powerful mechanism. Several models were used to investigate the effects of lunar tides in the atmosphere (e.g. Chapman and Lindzen, 1970; Forbes, 1982). The lunar tidal force is described by a gravitational potential:

$$\Pi_L \approx -\frac{3}{2}\frac{gMr^2}{D^3}P_2(\cos\theta) \qquad (1)$$

where g is the gravitational constant, M is the mass of the Moon, r is the distance from the Earth's center to a probe point on the Earth's surface or in the atmosphere, D is the varying distance between the Moon and the Earth, θ is the polar angle between the Moon's center and a probe point, and $P_2(\cos\theta)$ is the zonal harmonic of degree 2 which is expressed as follows:

$$P_2(\cos\theta) = \frac{1}{2}[3(\sin^2\phi - 1/3)(\sin^2\delta - 1/3) - \sin 2\phi \sin 2\delta \cos(t-\nu) + \cos^2\phi \cos^2\delta \cos 2(t-\nu)] \qquad (2)$$

where ϕ is the latitude of a probe point, δ is the lunar declination to the equator, t is the mean solar local time in angular units and ν is the lunar phase angle which is equal to the difference between the longitudes (i.e. difference in right ascensions in angular units) of the mean Moon and the mean Sun. Although Eq. (1) contains oscillations with different periods, in this paper we consider mainly semimonthly ones (~14 days). Such variations are described by the two components in Eq. (1). The first one, proportional to $\sin^2\delta$, is governed by lunar declination and has an average period of 13.66 days. The term $\sin^2\delta - 1/3$ in Eq. (2) varies from -0.333 up to -0.106 and has an average value of -0.244, thus, this oscillation has an amplitude up to 67% of an average value of the right-hand part of Eq. (1) at the given latitude ϕ. The other semimonthly component is a product of the time-independent part of Eq. (2) and the second harmonic of periodically (27.55 days) changing D^{-3}. The Fourier decomposition of D^{-3} shows that the amplitude of the second harmonic is as small as 1% of an average value of the right-hand part of Eq. (1). The expressions similar to Eqs. (1 and 2) can be written for the solar tidal gravitational potential, and both the lunar and solar effects are linearly superposed in the joint tidal gravitational potential. However, since this paper is devoted to semimonthly variations, we do not consider solar tides.

This simple theoretical description of semimonthly variations in the lunar tidal potential must be accompanied by the two important sophistications in studying of lunar semimonthly variations in geophysical data. The first one concerns a special data sampling: if the geophysical data under analysis are taken for same constant local solar time, the variations proportional to $\cos 2(t-\nu)$ with a semidiurnal (12 h 25 m) period look like a process determined by the double lunar phase 2ν with a semimonthly period of 14.77 days (Chapman and Lindzen, 1970). The other sophistication arises from the statistical relationship of lunar declination and lunar phase (Dalin et al., 2006), that exists contrary to the difference in average periods (27.32 and 29.55 days) of these variables.

2. The used data on tropospheric clouds and lunar position

In this paper the cloud amount D1 data (Rossow et al., 1999) of International Satellite Cloud Climatology Project (ISCCP) is used. The cloud estimations are based on radiance measurements from the satellites GMS-3, 4, GOES-6, 7, METEOSAT-2-5, and NOAA-9-12 in the visible and/or infrared range. Of a very large body of the ISCCP-D1 database, we use its rather small portion which could be comparable to the database used in PDR07. Only the relative cloud amount (RCA), i.e. the ratio of the number of cloudy pixels to the total number of pixels in a given grid cell, is used as most appropriate index describing a cloud amount. The summer data (from May 16 to August 16)[1] of 14 years (1994-2007) for UTC=21±1.5 h and from only the three grid cells (6010-6012) with latitude 56.25°±1.25°N and longitudes varying from 40.5° to 54°E is analyzed in this paper. Each of those cells has an area of $7.7\cdot10^4$ km^2 and is located deep inside the continent to the east of Moscow (central Russia). The local solar time (LT) corresponding to the selected UTC and the grid cells can vary between 21:36 and 02:12. A slight shift in the selected grid cells to the east of Moscow is caused by a rather large time sampling interval (3h) in the ISCCP-D1 data: if the previous (to the west) grid cell is added to the analysis, it will go out of the summer nighttime segment of LTs (21:30÷02:30) at any possible UTCs.

The orbital elements of the Moon's motion (phase angle and declination to the equator) have been calculated on the basis of laws of the celestial mechanics (Montenbruck and Pfleger, 2000).

3. Statistics for cloud amount versus lunar position

The two dependencies found in PDR07 for lunar semimonthly oscillations in cloudiness, namely, the dependence on lunar phase (cloudiness vs. cos 2ν) and dependence on the absolute value of lunar declination, are also manifested in the ISCCP-D1 database These dependences are shown by the linear regression curves in Figs. 1 and 2. Instead of the non-uniformly distributed variable cos 2ν, we use the lunar-phase definition:

$$\Phi = \frac{1}{2}\arccos(\cos 2\nu) \qquad (3)$$

which does not distinguish between the lunar and anti-lunar points of the sky, so that the lunar phase is allowed to vary from 0 (New Moon or Full Moon) to 90° (First or Last Quarter). The 95% confidence intervals also given in Figs. 1 and 2 demonstrate that both the regression lines are significant with more than 95% probability. The alternative semimonthly synodical harmonic $\left(\sim \arccos(\sin 2\nu)\right)$ is also allowed to be extracted from RCA, however, as in PDR07, the latter dependence appeared to be weak and not significant for any acceptable probability. It should be noted that there is a difference compared to the results of PDR07: in PDR07, the declination effect is substantially stronger than the lunar-phase effect, whereas, in the present paper, the declination effect is only slightly stronger and provides ~8% contribution to the standard deviation of RCA vs. ~7% contribution by lunar-phase effect.

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[1] For 2007 the data were available up to July, 1.

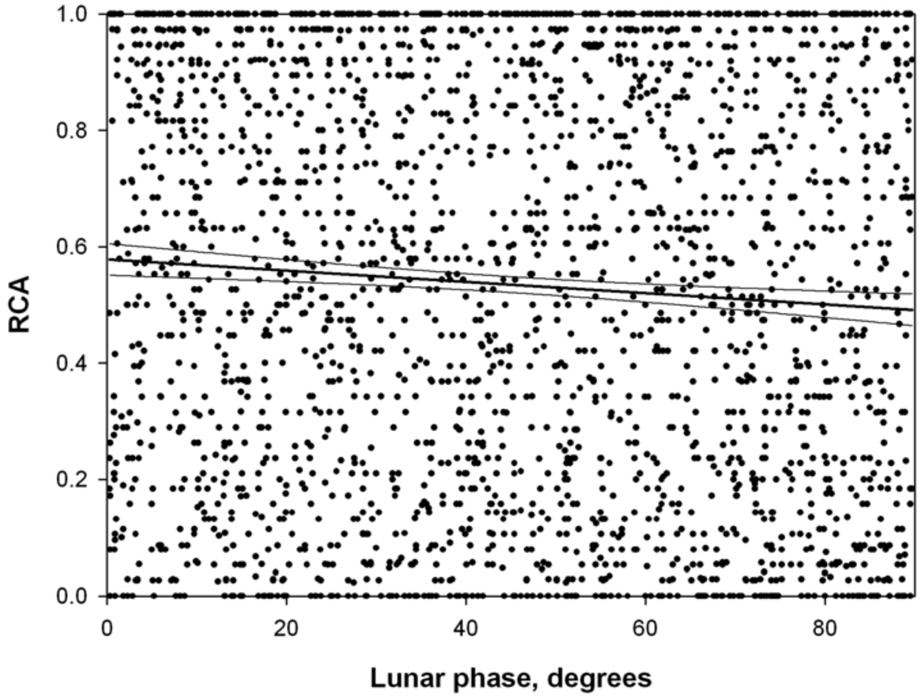

Figure 1. Lunar phases (defined by (3)) vs. RCA index. Each date (UTC=21 h) is represented by the three dots, corresponding to the three longitudinal cells (see the text). The linear regression dependence is marked by the thick line and its 95% confidence limits are shown by thin lines.

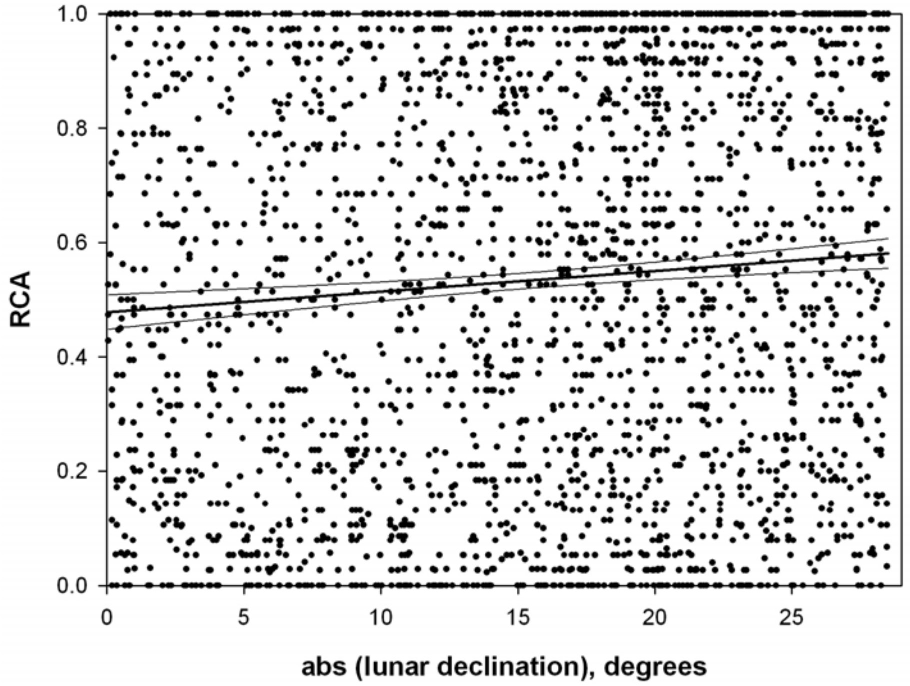

Figure 2. Same as in Fig. 1, but for absolute values of the lunar declination vs. RCA index.

The statistical relationship between the lunar phase and lunar declination (Dalin et al., 2006) must be further taken into account (plotted in Fig. 3 for the considered dates). The statistics in the previous studies (Dalin et al., 2006; PDR07) did not allow us to consider separately the effects of lunar declination and lunar phase. The number of samples in the present statistics is large enough (2592) to separate the two effects by using bilinear least-square fitting:

$$RCA = const + \beta_1 \cdot \Phi + \beta_2 \cdot |\delta| \tag{4}$$

More definite (less scattered) is the relationship between the two arguments, the larger are the errors of the regression coefficients β_1 and β_2. If there is a substantially less-scattered relationship between lunar phase and the absolute value of lunar declination, the separation of the two effects would not be possible. Fortunately, the scattering of the two arguments around their mutual regression line in Fig. 3 appears to be large enough to come to not too large errors in the regression coefficients. In the aftermath, the regression coefficients are found to be as follows: β_1=(-5±3)·10^{-4} degrees^{-1}, β_2=(2.6±1.1)·10^{-3} degrees^{-1}. Relative contributions of the two dependencies to the RCA standard deviation are as large as 3.5% for lunar phase, 6% for lunar declination, and 8.5% for both of them. Therefore, we confirm the previous finding (PDR07) on lunar signal in RCA: the lunar-declination effect in summer nighttime cloudiness is stronger than the lunar-phase effect, but now we provide the more precise conclusion that both of them are statistically justified and yield their own contributions to cloud variability.

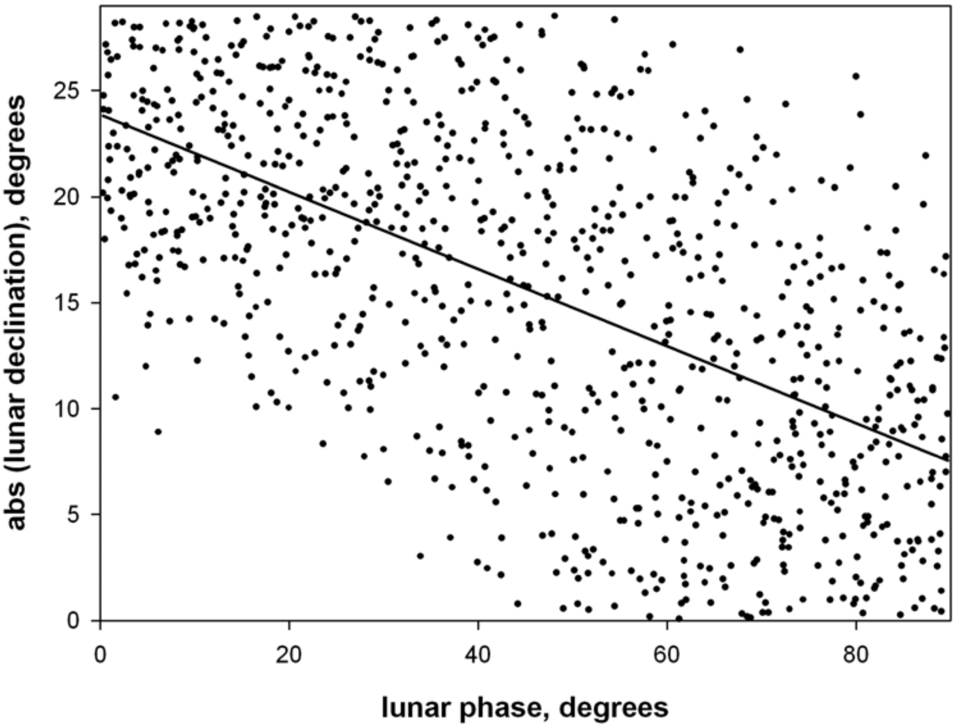

Figure 3. Statistical relationship of the lunar phase and lunar declination. The linear regression is shown by the solid line.

As was mentioned above, in order to find an odd lunar-phase effect on cloudiness, we complicated Eq. (4) by introducing an extra variable, which describes a delay of cloudiness response behind the New or Full Moon. In this case, the regression coefficients β_1 and β_2 change slightly only, and the cloudiness delay in lunar phase behind the New or Full Moon is found to be within the range of 10±30º, which implies that this effect has no statistical significance.

4. Discussion and conclusion

The relatively weak but significant lunar signal obtained in the present study reveals itself in spite of superiority of stronger processes of different scales; these processes determine mainly the cloud distribution over the pixels (areas) processed. A physical explanation of the similar situation was outlined by Brier (1965): from the viewpoint of other processes, the presence of the lunar additive term results in a positive or negative initial condition helping or complicating them to satisfy critical condition for cloud formation.

The first question to be discussed is the separation of lunar semidiurnal oscillations from lunar semimonthly oscillations in spite of their aliasing mentioned in Sect. 2. Since the cloudiness data are taken for LT close to midnight, then $t \approx 0+2\pi n$, the semidiurnal oscillation ~ $\cos 2(t-v)$ reveals itself as semimonthly ~ $\cos 2v$ for such data sampling. But the gravitational potential (Eq. (1)) contains no semimonthly terms governed by the lunar phase v. That is why we assume that the found lunar-phase effect describes lunar *semidiurnal* oscillations. The insignificance of odd effects in the lunar phase (~ $\sin 2v$) confirms such an assumption. Just this situation is bound to occur according to Eqs. (1 and 2). However, we do not deny a possible time shift between cloudiness and gravitational tide, which is to be expected similarly to the lunar effect found in precipitation (Adderley and Bowen, 1962; Bradley et al., 1962) and in sunshine duration (Lund, 1965); however the present statistical study fails to reveal such a delay.

As to the declination effect, it must be a semimonthly tide, because it corresponds to the only term in Eq. (2), which is governed by variations in δ and which is separated from v. In addition to the retrieved signal proportional to $|\delta|$, there have been extracted other semimonthly changing variables, such as $\delta^2, \sin^2\delta, \frac{\sin^2\delta}{D^3}$. The fitting quality difference determined from the standard deviation of residual series appeared to be negligibly small among all of those variables. Thus, the found dependence of RCA on $|\delta|$ most probably describes the ~ $\frac{\sin^2\delta}{D^3}$ semimonthly term of the gravitational potential (Eq. (1)).

The results described in this paper are obtained under both spatial and temporal restrictions on the data under analysis (very narrow ranges of LT, latitudes, longitudes and limited season). On the one hand, this allows us to avoid an additional statistical noise caused by diurnal, seasonal and geographical variations in cloud formation and latitudinal variations in lunar perturbations (it is not clear whether the lunar effect will show up the similar dependences in different types of clouds in different seasons and geographical locations). On the other hand, it is important at the first stage to prove the existence of a distinct lunar declination signal in the cloudiness for the more detailed studies of lunar perturbations in clouds in future. A more complicated analysis should be performed, which will take into account different latitudes, longitudes, LTs, seasons, continents/oceans and will allow the even symmetry both in lunar phase and in declination to be broken (for other LTs, the $\sim\sin 2\nu$ term in Eq. (2) would appear, and in other seasons the statistical relationship between lunar phase and declination becomes more complicated).

Returning to the results by Rodés (1937), it should be noted that they also contain a distinct declination effect (general growth for the number of rainy days and precipitated water with $|\delta|$) that is similar to our result. The lunar-phase effect was also obtained by Rodés, but it appeared to be monthly rather than semimonthly. However, there is little point in comparing the results by Rodés with ours, because his results were not discriminated by seasons, while ours refer only to summer time. As to other old papers devoted to the lunar synodical effect on the variables closely related to precipitations and tropospheric cloudiness (Adderley and Bowen, 1962; Bradley et al., 1962; Bigg, 1963; Lund, 1965), one can find that their results are hardly comparable to those described in the present paper, because they did not consider lunar declination, besides, their data were not related to certain LT or were not uniform in LT, e.g. Bigg (1963) considered daily mean ice nucleus concentrations and total daily rainfall (with unknown LT-distribution). This does not permit to discriminate between the lunar semidiurnal oscillation and lunar semimonthly one~~s~~.

The lunar modulation of meteoric dust (Adderley and Bowen, 1962) and atmospheric tides (Brier and Bradley, 1964) were considered as possible conductors of lunar influence on precipitation. Markson (1971) drew attention to cosmic rays as a possible participant of the lunar influence on precipitation. He supported his assumption by the results of Brier and Bradley (1964) concerning an increase in lunar effects on precipitation data during the years of solar minimum (when the flux of galactic cosmic rays was larger). We consider lunar tides in the atmosphere as the most probable cause of lunar semimonthly variations, and our results do not contradict the theory of lunar tides (Chapman and Lindzen, 1970) outlined in Sect. 2. Besides, as will be argued below, variations in cosmic rays may be partially caused by atmospheric tides. However, one important question has not been studied yet - what physical mechanism of atmospheric tides is responsible for enhancement or destruction of clouds. The two possible solutions of this problem, dynamic and electro-dynamic, should be regarded. In the dynamical mechanism, the gradient of tidal potential (Eq. (1)) in semimonthly variations creates vertical and meridional forces comparable in magnitude. The vertical forces are equilibrated by the vertical gradient of redistributed pressure. On the contrary, the meridional tidal force, according to Eqs. (1 and 2), does not vary along a latitude circle and, hence, leads to acceleration in a meridional plane. Thus, the semimonthly tides can periodically modulate the atmospheric prevailing circulation in the meridional plane and the latter is of importance for the formation and destruction of clouds under certain conditions.

When considering electro-dynamic mechanism, the periodic changes in the gravitational potential (mainly in the solid Earth) must lead to periodic variations in the Earth's electric and magnetic fields (Grigor'ev et al., 2005). In turn, this can affect the influx of cosmic rays to the atmosphere, and, at last, it may modify the number of condensation nuclei that are necessary for cloud formation. The statistical relation between cloud amount and cosmic rays has repeatedly been obtained (Svensmark and Friis-Christensen, 1997; Marsh and Svensmark, 2000; Svensmark et al., 2009).

Considering the possible conductors of lunar influence on cloudiness, it is necessary to mention a special type of condensation nuclei – atmospheric micro-organisms which may be affected by a large variety of atmospheric and electromagnetic parameters and which can contribute substantially to cloud formation (e.g., Möller et al., 2007). The lunar effect may be manifested in cloudiness in a rather sophisticated way due to this mechanism. All these mechanisms require an independent statistical verification and should be studied in detail in the future.

The variations in lunar declination lead to a long-term semi-monthly tide with a period of 13.66 days. On the Earth's surface, this tide is explained by the zonal spherical function. A lunar gravitational tide propagating throughout the atmosphere causes variations in atmospheric parameters (pressure, temperature, and wind speed), which, in turn, result, to some extent, in different physical conditions for cloud formation. Our findings demonstrate that changing lunar gravitational semimonthly tides indeed lead to variations in tropospheric cloudiness. The cloud formation increases with an increase in lunar declination and when the Moon tends to be along the Sun-Earth line.

Our conclusions are as follows:

1. For the first time, lunar signals in cloudiness have been extracted from a reliable database.

2. These lunar signals contain a semimonthly tide governed by variations in lunar declination and a semidiurnal tide governed by the variations in lunar phase (under the condition of fixed solar local time). Relative contributions of the two dependencies to the RCA standard deviation amount to 3.5% for the lunar phase, 6% for the lunar declination, and 8.5% for both of them.

3. The extracted lunar signals seem to fit the theory of lunar gravitational tide.

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References

Adderley, E.E., and Bowen, E.G., 1962. Lunar component in precipitation data. Science 137, 749-750.

Balling Jr., R.C., and Cerveny, R.S., 1995. Influence of lunar phase on daily global temperature. Science 267, 1481-1483.

Bigg, E.K., 1963. A lunar influence on ice nucleus concentrations. Nature 197, 172-173.

Bradley, D.A, Woodbury, M.A., and Brier, G.W., 1962. Lunar Synodical Period and Widespread Precipitation. Science 137, 748-749.

Brier, G.W., and Bradley, D.A., 1964. The lunar synodical period and precipitation in the United States. Journal of the Atmospheric Sciences 21, 386-395.

Brier, G.W., 1965. Diurnal and semidiurnal atmospheric tides in relation to precipitation variations. Monthly Weather Review 93, 93-100.

Chapman, S., and Lindzen, R.S., 1970. Atmospheric tides: thermal and gravitational. D. Reidel publishing company, Dordrecht-Holland, 200 pp.

Dalin, P., Pertsev, N., and Romejko, V., 2006. Significance of lunar impact on noctilucent clouds. Journal of Atmospheric and Solar-Terrestrial Physics 68, 1653-1663.

Forbes, J. M., 1982. Atmospheric tides. 2, The solar and lunar semi-diurnal components. Journal of Geophysical Research – Space 87, 5241-5252.

Grigor'ev, V.I., Grigor'eva, E.V., Pisanko, Y.V., and Rostovsky, V.S., 2005. Baro-electric effect & celestial magnetism. Moscow, KomKniga, 128 pp.

Herman, J.R., and Goldberg, R.A., 1978. Sun, weather and climate. NASA SP-426, Washington, D.C., 333 pp.

Howard L., 1820. The climate of London, deduced from Meteorological observations, made at different places in the neighbourhood of the metropolis. Vol. 2. Harvey and Darton, London, 163 pp.

Kropotkina, Ye.P., and Shefov, N.N., 1976. Influence of lunar tides on the probability of appearance of noctilucent clouds. Russian Academy of Sciences, Izvestiya Atmospheric and Oceanic Physics 11, 741-742.

Lund, I.A., 1965. Indications of lunar synodical period in United States observations of sunshine. Journal of the Atmospheric Sciences 22, 24-39.

Markson, R., 1971. Consideration regarding solar and lunar modulation of geophysical parameters, atmospheric electricity and thunderstorms. Pure Applied Geophysics 84, 161-200.

Marsh, N., and Svensmark, H., 2000. Cosmic rays, clouds and climate. Space Science Reviews 94, 215-230.

Möhler, O., DeMott, P.J., Vali, G., and Levin, Z., 2007. Microbiology and atmospheric processes: the role of biological particles in cloud physics. Biogeosciences 4, 1059–1071.

Montenbruck, O., and Pfleger, T., 2000. Astronomy on the personal computer. Springer-Verlag, Berlin, Heidelberg, 300 pp.

Pasichnyk, R.M., 2002. The Vital Vastness, 2. Writer's Showcase Press, New York, 583 pp.

Pertsev, N., Dalin, P., and Romejko, V., 2007. A lunar signal in summer nighttime tropospheric cloudiness and in noctilucent clouds. Proceedings of the 18th ESA Symposium on European Rocket and Balloon Programmes and Related Research, Visby, Sweden, ESA SP-647, 589-592.

Rodés, L., 1937. ¿ Influye la Luna en el tiempo? Estudio estadístico. Memorias del Observatorio del Ebro 7, Tortosa: Imprenta Moderna de Algueró y Baiges, 35 pp.

Rossow, W.B., and Schiffer, R.A., 1999. Advances in understanding clouds from ISCCP. Bulletin of the American .Meteorological Society 80, 2261-2287.

Svensmark, H., and Friis-Christensen, E., 1997. Variation of cosmic ray flux and global cloud coverage – a missing link in solar-climate relationships. Journal of Atmospheric and Solar-Terrestrial Physics 59, 1225-1232.

Svensmark, H., Bondo, T., and Svensmark J., 2009. Cosmic rays decreases affect atmospheric aerosols and clouds. Geophysical Research Letters 36, L15101, doi:10.1029/2009GL038429.