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Interannual Variability of the Solar Constant

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Abstract—It can be concluded from the calculations performed of interannual variations of the distance between the Sun and the Earth in the moments of the Earth's position in the equinoctial and solstitial points that the mean amplitude (approximately the same for all the equinoctial and solstitial points) is determined to be equal to 5700 km (at the maximum values being approximately equal to 15000 km). The values of the solar constant have been calculated on the basis of the data of varying distances, and the values of its interannual variability (for the period from 1900 up to 2050) have determined. Based on the analysis of the series, new periodic characteristics of a long-term variation of the solar constant, related to the celestial-mechanical process, namely, to the perturbed orbital motion of the Earth, are obtained. A three-year cycle is distinguished in the interannual variability of the solar constant, which alternates with a two-year cycle every eight and eleven years. The amplitude of the interannual variability in the series of equinoctial and solstitial points is on average about 0.1 W/m^2 (about 0.008% of the solar constant value). This is comparable to the interannual variability of the solar constant in the eleven-year cycle of the solar activity. The series obtained can be represented by alternation of eleven-year and eight-year cycles. The eleven-year cycle is composed of three three-year cycles and one two-year cycle, and the eight-year cycle is composed of two three-year cycles and one two-year cycle.

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INTRODUCTION

The solar constant is the total solar radiant flux that passes through the unit area, oriented perpendicular to the flux at a distance of one astronomical unit (AU) from the Sun outside the Earth's atmosphere, per unit time (Eygenson, 1963; Kondratyev, 1965). According to the data of extraterrestrial measurements, the solar constant equals 1367 W/m^2 (Kislov, 2001). The solar constant varies with time. Its variations are conventionally related to the solar activity variation, i.e., to the physical processes on the Sun. Attention is paid to the fact that the variations of the solar constant are caused by the variation of the radiant flux with the variation of the number and total area of sunspots, with the relative variations of the radiant flux occurring most intensively in the X-ray and radio regions (Eygenson, 1963; Vitinskiy, 1983; Abdusamatov, 2009). The roles of facular regions and magnetic fields are also noticed as important factors. They contribute to the cyclic variations of the radiant flux (Foukal et al., 2006). The period of direct measurements of the solar constant is short (since 1978), and the amplitude of variation of the solar constant during the eleven-year cycle of the solar activity (Schwabe–Wolf cycle) for the period of measurements is about 1 W/m^2 (or approximately 0.07% of the solar constant (http://www.pmodwrc.ch)). The data for direct measurements of the estimation of the solar constant variation for longer solar cycles (Hale cycle, Gleisberg cycle, etc.) are absent (Makarova et al., 1991).

The long-term variations of the solar constant are related not only to the variation of solar activity (a great number of publications and monographs are devoted to the investigation of solar activity), but also to the celestial-mechanical processes that change the distance between the Sun and the Earth. During the unperturbed (keplerian) motion of the Earth, the solar constant varies within an annual orbital motion of the Earth around the Sun with regular annual variation (the maximum is at perigee, the minimum is at aphelion). However, the real orbital motion of the Earth is a perturbed motion (Marov, 1981; Fedorov, 2000; 2002). In this connection, the Earth is from year to year at a different distance from the Sun, for example, while passing through the equinoctial and solstitial points. This is one more reason for the long-term variations in the solar constant, which has not been studied yet. The purpose of this work is to estimate the influence of this factor on the long-tem variations of the solar constant.

In the last century, M. Milankovich carried out the calculations for solar radiation allowing for variations in the earth's orbit due to factors such as inclination of the axis, eccentricity, and longitude of perihelion. the periodicity of variation of these factors is tens of thousands of years (Milankovich, 1939). In our calculations one astronomic parameter, namely, the distance from the Earth to the Sun, is used; and the variation of the solar constant is considered in other time scales (years, tens of years) that are comparable to the topical problems of modern civilization.

TECHNIQUE OF THE INVESTIGATIONS

The distances between the Earth and the Sun in the moments of the Earth's position in the equinoctial and solstitial points within the time interval from 1900 up to 2050 (http://www.ssd.jpl.nasa.gov; http://www.willbell.com) are determined according to the ephemerides data (JPL Planetary and Lunar Ephemerides (DE-406)). The accuracy of ephemerides in distance is 10^{-9} AU or 0.1496 km. The value of the solar constant at a distance between the Earth and the Sun of 1 AU equals $J_0 = 1367$ W/m^2. It is known that if a is the average distance between the Sun and the Earth, which is equal to the major semiaxis of the ellipse of Earth's orbit (1 AU), then at distance l we have:

$$J_l = J_0\left(\frac{a}{l}\right)^2. \quad (1)$$

The values of solar constant in the moments of the Earth's position in the equinoctial and solstitial points for each year within the time interval from 1900 up to 2050 have been calculated by Eq. (1). The series of values of the interannual variability of solar constant for the cardinal points of earth orbit (equinoctial and solstitial points) are obtained through successive subtraction. As a result of the analysis of the calculated series, new periodical characteristics of the long-term variation of solar constant, which are related to the perturbed orbital motion of the Earth, have been obtained.

RESULTS AND DISCUSSION

The distances between the Earth and the Sun in the moments of the Earth's position in the equinoctial and solstitial points within the time interval from 1900 up to 2050, obtained through the ephemerides, are presented in Fig. 1.

The values of the interannual variability of the distance for the equinoctial and solstitial points have been calculated on the basis of the values of distance between the Sun and the Earth (it was performed by successive subtraction; therefore, the influence of the trend related to the precession was eliminated from further calculations and results). The average amplitude of the interannual variations of the distance between the Earth and the Sun in the moments of the Earth's position in the equinoctial and solstitial points (which is approximately the same for all the equinoctial and solstitial points) is determined to be equal to 5738 km (at the maximum values being on average equal to 15042 km). The three-year and two-year periodicities are observed in the distance variability (the maximum of spectral density occurs in a period of 2.7 years). The corresponding values of the solar constant have been calculated on the basis of the values obtained for the distance between the Earth and the Sun. It may be seen from the graphs (Fig. 2) that the interannual variability of the solar constant for the equinoctial and solstitial points is periodical.

A three-year cycle is distinguished in the interannual variability of the solar constant, which alternates with a two-year cycle in eight and eleven years. The amplitude of the interannual variability in the series of the equinoctial and solstitial points is on average about 0.1 W/m^2 (0.008% of the solar constant value). For a series of the interannual variability values, averaged over these four points, the amplitude decreases by 0.06 W/m^2. The investigated period contains 38 complete three-year cycles and 16 complete two-year cycles. In other words, the series are represented by alternating eleven-year and eight-year cycles. The eleven-year cycle is composed of three three-year cycles and one two-year cycle, and the eight-year cycle is composed of two three-year cycles and one two-year cycle (Figs. 3, 4). These characteristics are still beyond the limits of measurement accuracy of the solar constant that are ±0.3–0.7 W/m^2 or 0.02–0.05% of the solar constant value (Makarova et al., 1991).

According to the data of the spectrum analysis, the increase in the spectral density within the approximate range from 2.3 up to 3 years, with the maximum being equal to a period of 2.7 years, is observed for all the series (Fig. 5).

According to the data of the direct observations (Willson, 1997; Willson and Mordvinov, 2003; Abdusamatov, 2009; http://www.pmodwrc.ch; http://www.acrim.com) the amplitudes of the eleven-year cycles of the solar constant are 0.955 W/m^2 in the 21st cycle, 0.919 W/m^2 in the 22nd cycle, 1.039 W/m^2 in the 23rd cycle. The data of the direct measurements of the solar radiant flux, corrected with respect to the Sun–Earth distance, reflect the physical processes that take place on the Sun. With allowance for the duration of these cycles (10.25, 9.75, and 12.50 years, respectively), the interannual variability is on average 0.415, 0.427, and 0.332 W/m^2, respectively. These values are approximately 3–4 times greater than the values of the average interannual variability of the solar constant for the equinoctial and solstitial points (0.105 W/m^2 and 0.008% of the solar constant), obtained in the work, that are related to the variation in the Sun–Earth distance. Thus, the solar constant interannual variations of a different physical nature have rather similar amplitude characteristics. However, an additional analysis of the results is required for the determination

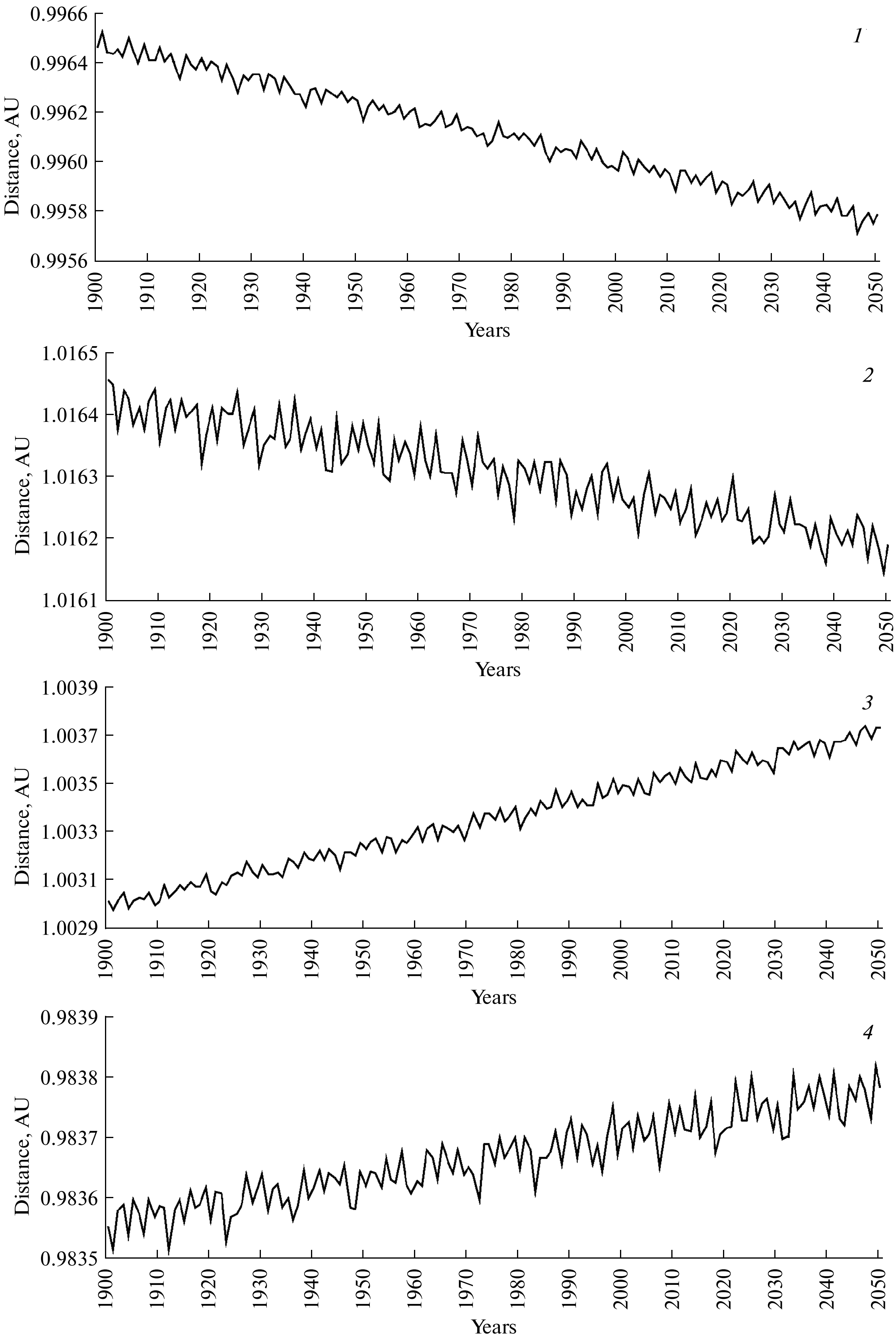

Fig. 1. Variability of the Earth–Sun distance for the period from 1900 up to 2050 at the Earth's position in the following points: *1*, the vernal equinox, *2*, the June solstice, *3*, the autumnal equinox, *4*, the winter solstice.

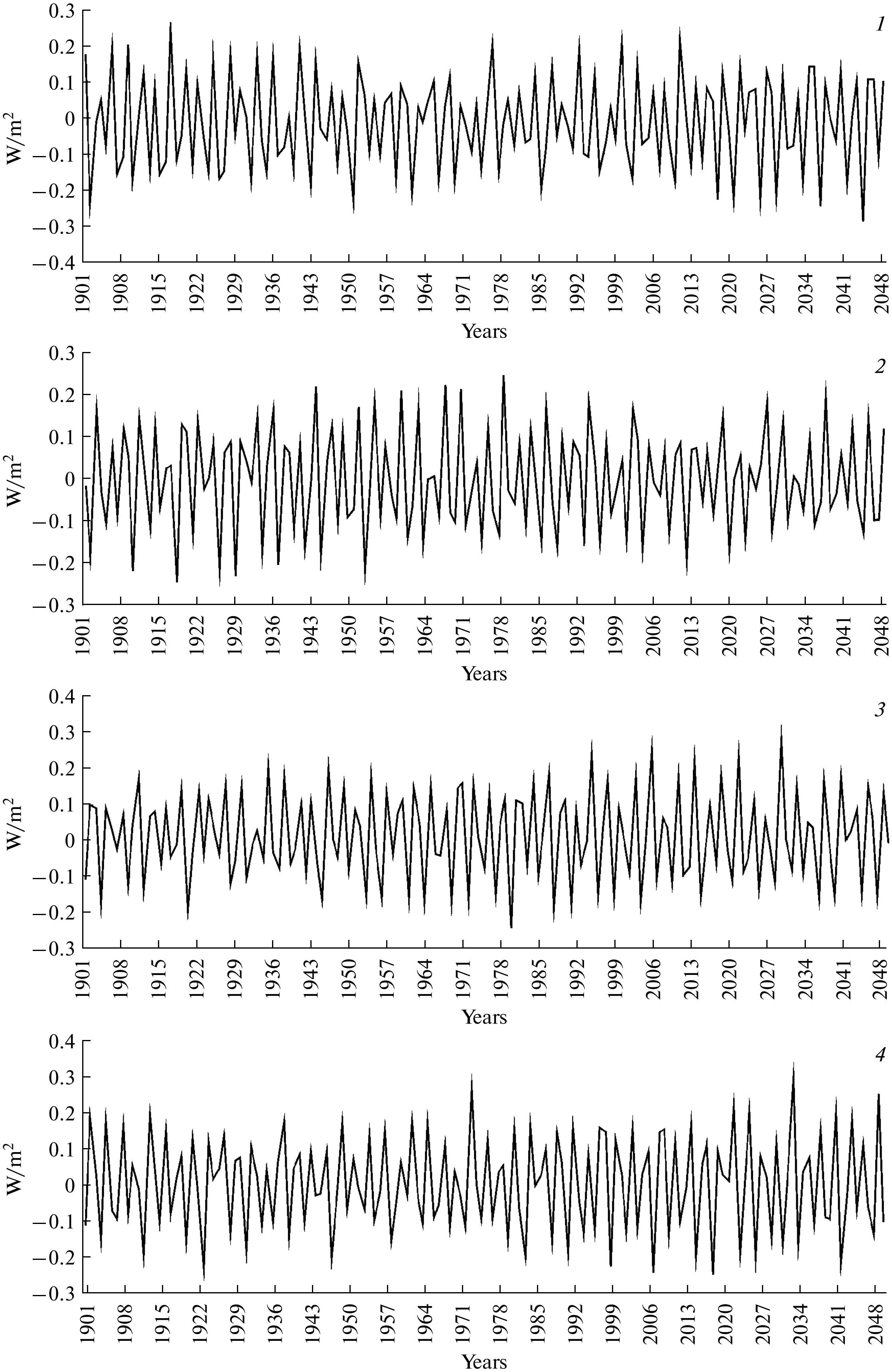

Fig. 2. Interannual variability of the solar constant for a period from 1900 to 2050 at the Earth's position ay the following points: *1*, the vernal equinox, *2*, the June solstice, *3*, the autumnal equinox, *4*, the winter solstice.

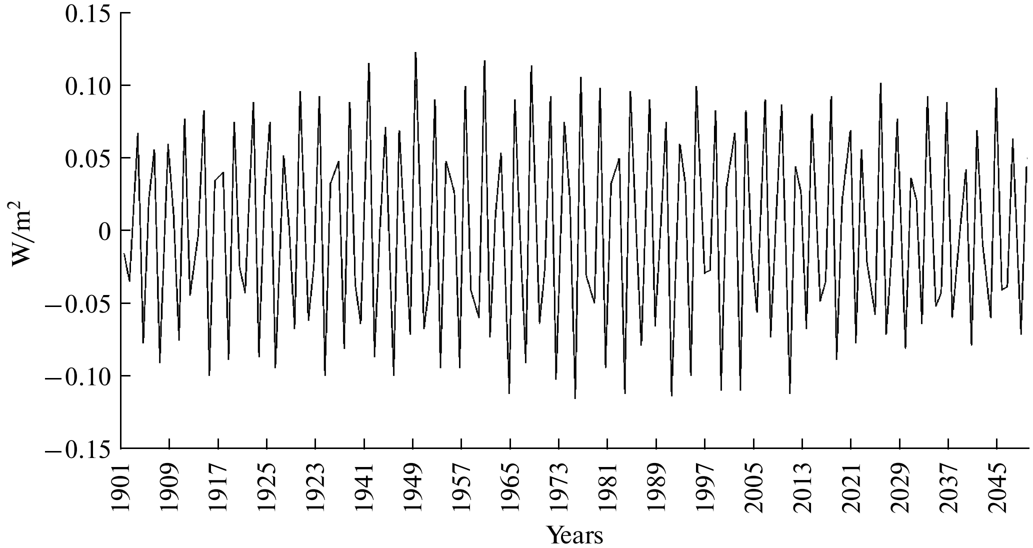

Fig. 3. Dynamics of the average (over four points, equinoxes and solstices) values of the interannual variability of the solar constant for a period from 1900 to 2050.

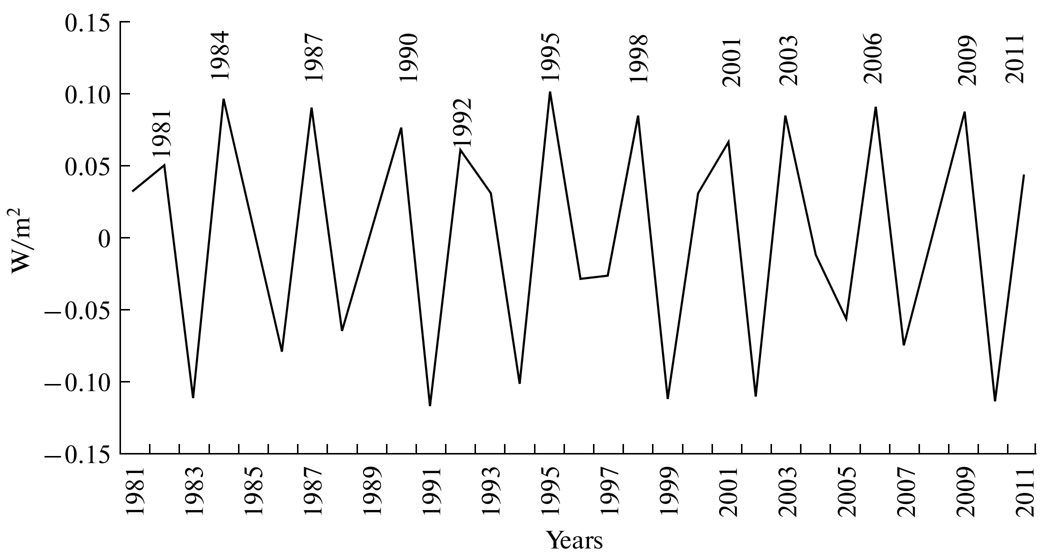

Fig. 4. Fragment of the dynamics of the average (over four points, equinoxes and solstices) values of the interannual variability of the solar constant for a period from 1981 to 2011.

of the correlation of the two-year and three-year orbital cycles with the solar activity cycles (Schwabe–Wolf eleven-year cycle) in the instrumentally obtained variations of the solar constant (satellite measurements since 1978).

In addition, the studies on the determination of the influence of the demonstrated cycles of long-term variation of the solar constant on climate variations are necessary. The two-year cycles and three-year cycles are multiple of the Earth's period of oscillation (one year) and are close to it (closer in value than the Schwabe–Wolf eleven-year cycle); therefore, such investigations seem to be perspective due to a probable resonant response of the Earth climate system to the

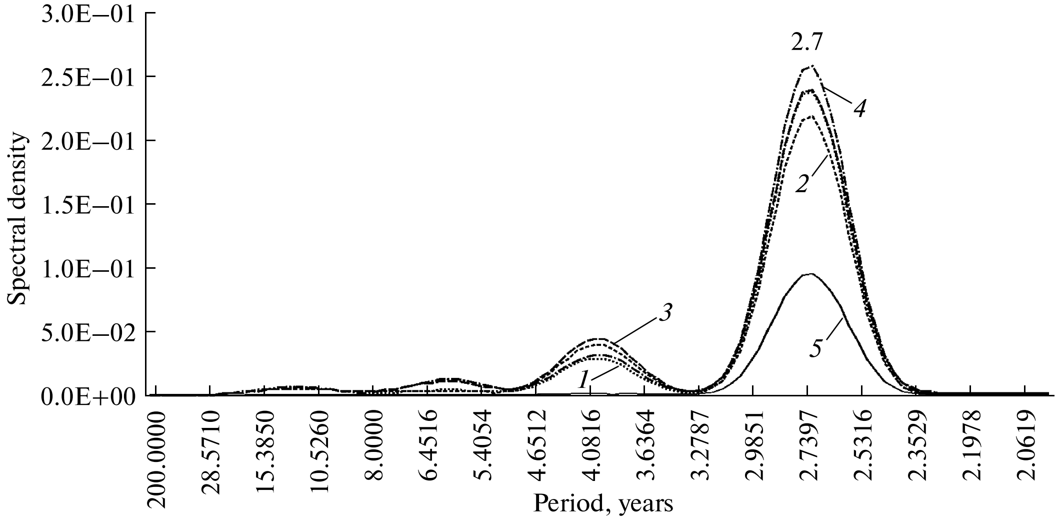

Fig. 5. Spectra of the interannual variability of the solar constant for the following points: *1*, the vernal equinox, *2*, the June solstice, *3*, the autumnal equinox, *4*, the winter solstice, *5*, the spectrum of the interannual variability of the solar constant averaged over the four points of equinox and solstice.

revealed characteristics of the solar constant variation. A distinct expression of the observed two-year and three-year cycles in contrast to the eleven-year cycle of solar activity with less stable duration also points to this fact. From about the mid-18th century, the duration of separate cycles of solar activity, determined by the maxima of the number of sunspots, was within 7–17 years, and the same duration, determined by the minima of the number of sunspots was within 9–14 years (Makarova et al., 1991). In addition, the three-year periodicity is observed in a number of geophysical and hydrometeorological processes (Eigenson, 1963).

CONCLUSIONS

New orbital characteristics, related to the processes of celestial mechanics, namely, to the periodic variation in the distance between the Sun and the Earth, were found in the long-term variation of the solar constant for the equinoctial and solstitial points. The characteristics found are probably also related to other points of earth orbit. A dominant factor associated with a marked long-term variation in the solar constant is a well-defined three-year cycle with an amplitude approximately equal to 0.1 W/m^2. This cycle alternates, as a rule, every 8 or 11 years with the two-year cycle. The value of the interannual variability of the solar constant in the three-year cycle is comparable (is three-four times less) with the interannual variability of the solar constant in the eleven-year cycle of solar activity.

The data obtained are important for both understanding the nature of the solar constant variability and the clarification of ideas about solar activity variations and the solar climate of the Earth.

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REFERENCES

Abdusamatov, Kh.I., *Solntse diktuet klimat Zemli* (The Sun Dictates the Earth's Climate), St. Petersburg: Logos, 2009.

Eigenson, M.S., *Solntse, pogoda i klimat Zemli* (Sun, Weather and the Earth's Climate), Leningrad: Gidrometeoizdat, 1963.

Fedorov, V.M., *Gravitatsionnye factory i astronomicheskaya khronologiya geosfernykh protsessov* (Gravitation Factors and Astronomical Chronology of Geosphere Processes), Moscow: MGU, 2000.

Fedorov, V.M., *Astronomicheskaya klimatologiya* (Astronomical Climatology), Moscow: MGU, 2002.

Foukal, P., Fröhlich, C., Spruit, H., and Wigley, T.M.L., Variations in Solar Luminosity and Their Effect on the Earth's Climate, *Nature,* 2006, vol. 443 (7108), pp. 161–166.

Kislov, A.V., *Klimat v proshlom, nastoyashchem i budushchem* (Climate in the Past, Present and Future), Moscow: Nauka, 2001.

Kondrat'ev, K.Ya., *Aktinometriya* (Actinometry), Leningrad: Gidrometeoizdat, 1965.

Makarova, E.A., Kharitonov, A.V., and Kazachevskaya, T.V., *Potok solnechnogo izlucheniya* (Solar Radiation Flux), Moscow: Nauka, 1991.

Marov, M.Ya., *Planety solnechnoi sistemy* (Solar System Planets), Moscow: Nauka, 1981.

Milanovich, M., *Matematicheskaya klimatologiya i astronomicheskaya teoriya kolebaniya klimata* (Mathematical Climatology and Astronomical Theory of Climate Variation), Moscow–Leningrad: GONTI, 1939.

Vitinskii, Yu.I., *Solnechnaya aktivnost'* (Solar Activity), Moscow: Nauka, 1983.

Willson, R.C., Total Solar Irradiance Trend during Solar Cycles 21 and 22, *Science*, 1997, vol. 277, no. 5334, pp. 1963–1965.

Willson, R.C. and Mordvinov, A.V., Secular Total Solar Irradiance Trend during Solar Cycles 21–23, *Geophys. Res. Lett.*, 2003, vol. 30, no. 5, pp. 1199–1202.

http://www.acrim.com

http://www.ssd.jpl.nasa.gov

http://www.pmodwrc.ch

http://www.willbell.com