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GEOPHYSICS

Interannual Variations in the Duration of the Tropical Year

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The tropical year is the time interval between two sequential passes of the Sun's true center through the point of the spring equinox. The duration of the tropical year defined from the astronomical observations is 365 days 5 h 48 min 46 s or 365.2422 days. Were the motion of the Earth not perturbed (Kepler motion), the duration of the tropical year would be constant in time. However, the real orbital motion of the Earth is perturbed [1, 4–6]. The differences in the annual transport of solar radiation to the Earth result from the perturbed motion of the Earth and related variations in the duration of the tropical year. Thus, the variability in the duration of the tropical year is one of the many causes of long-term variations in the solar energy transported to the Earth; hence, variations in the radiation and heat balance of the Earth exist that have not yet been studied in detail.

The moment when the Earth passes the points of the summer equinox (0° Aries) in the time interval from 1900 to 2050 [11, 12] was determined from the ephemerides data (JPL Planetary and Lunar Ephemerides, De–406). The time accuracy of ephemerides is 1 s or 0.0000115 days. These data were used to calculate the time between sequential positions of the Earth at the points of the spring equinox. Thus, we obtained the durations of the tropical year for the period from 1900 to 2050. After sequential subtraction of these values, we calculated the values of the interannual variability of the duration of the tropical year. As a result of the analysis of the interannual variability of the duration of the tropical year, we obtained new amplitude periodical characteristics of the variations in the duration of the tropical year related to the perturbed orbital motion of the Earth.

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The values of the duration of the tropical year determined from the ephemerides for the period 1900–2050 are shown in Fig. 1.

The authors of [10] compared the data with the results of measurements of the tropical year in five sequential years from 1985 to 1989 and found that the differences were equal, on average, to 17.37 s for a tropical year. We determined the mean amplitude of the interannual variations in the duration of the tropical year as 0.004761 days or 6 min 51 s (Fig. 2); hence, the differences are insignificant (on average, they are equal to 0.042 of the mean value of the amplitude of interannual variability).

A three-year cycle is seen in the interannual variability of the duration of the tropical year, which alternates in 8 and 11 years with a two-year cycle, while the spectral density maximum falls on a period of 2.7 yr (Fig. 2, table).

Owing to the fact that periodicity is not concealed, we used a simple method to determine its structure (table), which consisted of the following stages:

Determination of the years with the maximum positive values of the interannual variability of the duration of the tropical year (columns 1 and 2); these values are highlighted with bold face;

Determination of the duration between the highlighted neighboring years according to the previous paragraph; this was the method to determine the main two-year and three-year cycles;

Sequential calculation of the duration from the year of the first two-year cycle to the next one, etc.; thus, we determined the additional 8-year and 11-year cycles (column 4).

It follows from the method of cyclicity separation that the main two-year and three-year cycles reflect the periodicity in the interannual variability of the duration of the tropical year. The additional 8-year and 11-year cycles reflect the periodicity resulting from the alteration of two-year and three-year cycles

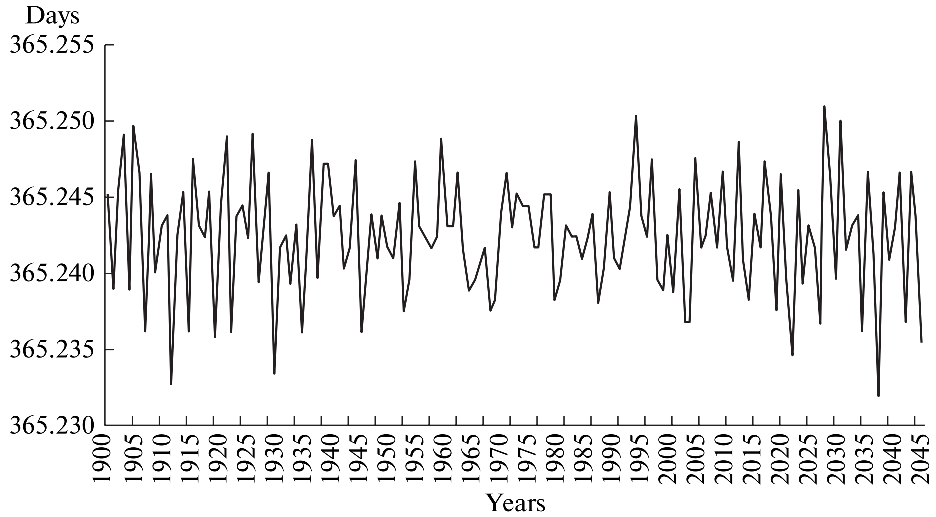

Fig. 1. Duration of the tropical year over the period from 1900 to 2050. Note: The calendar year corresponds to the beginning of the tropical year.

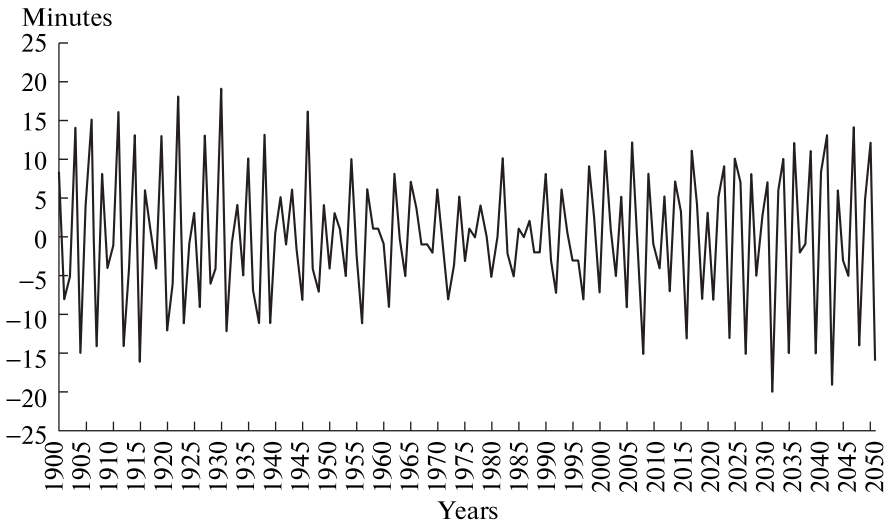

Fig. 2. Interannual variations in the duration of the tropical year.

in time. The 11-year cycle consists of three three-year and one two-year cycles, while the 8-year cycle consists of two three-year cycles and one two-year cycle (Fig. 2, table). Earlier, similar periodical characteristics were obtained in the interannual variations in the distance between the Earth and the Sun and the solar constant [8, 9].

The amplitude of interannual variability of the duration of the tropical year is on average 0.004761 days (or 6 min 51 s). The mean amplitude was determined by the transformation of the time series of the interannual variability with alternating sign to a time series of the absolute values of this time series and further calculation of the mean value for it. The maximum amplitude is 0.013888 days (20 min 00 s). The mean amplitude of the three-year cycle based on our calculations is 0.006659 days or 9 min 35 s, and the mean amplitude of the two-year cycle is 0.004676 days or 6 min 44 s.

A decrease in the amplitude of the interannual variability and distortions in the strict order of two-year and three-year cycles is observed in the interval from 1960 to 2000 (Fig. 2). The mean amplitude in the interval from 1960 to 2000 is 0.002642 days, while the mean amplitude in the intervals from 1900 to 1960 and from 2001 to 2050 is 0.005543 days, i.e., 2.098 times greater.

Cyclic structure of the interannual variations in the of the tropical year (the example of the fragment from 1916 to 1951)

Year	Interannual variability of the tropical year duration	Time between maxima, years	Time between two-year cycles, years
1916	**0.004167**		
1917	0.000685		
1918	–0.002778		
1919	**0.009028**	3	
1920	–0.008334		
1921	–0.004167		
1922	**0.012501**	3	
1923	–0.007639		
1924	–0.000695		
1925	**0.002083**	3	
1926	–0.006250		
1927	**0.009028**	2	11
1928	–0.004166		
1929	–0.002777		
1930	**0.013194**	3	
1931	–0.008334		
1932	–0.000695		
1933	**0.002779**	3	
1934	–0.003473		
1935	**0.006945**	2	8
1936	–0.004861		
1937	–0.007639		
1938	**0.009028**	3	
1939	–0.007639		
1940	0.000000		
1941	**0.003472**	3	
1942	–0.000694		
1943	**0.004166**	2	8
1944	–0.001388		
1945	–0.005556		
1946	**0.011110**	3	
1947	–0.002776		
1948	–0.004863		
1949	**0.002780**	3	
1950	–0.002780		
1951	**0.002085**	2	8

It is known that a number of specific relations exist in the parameters of the motions of planets and their satellites due to the existence of commensurabilities and resonances [3]. The resonance conditions are determined by the equalities of the frequencies of the forced (under the influence of external force) and natural oscillations. For example, the sidereal period of Venus is 224.701 days (0.61521 tropical years), the period of Mars is 686.980 days (1.88089 tropical years), and the period of the Earth (sidereal year) is 365.526 days (1.00004 tropical years). The rotational frequencies of the planets $\left(\omega = \dfrac{2\pi}{T}\right)$ are the following: for Venus 0.0279624 days^{-1}; for Mars 0.0091460 days^{-1}; for the Earth 0.0171894 days^{-1}. It follows from this that

$$2\omega_{\text{Mars}}\,(0.0182920\ \text{days}^{-1}) - \omega_{\text{Earth}}\,(0.0171894\ \text{days}^{-1}) = 0.0011026\ \text{days}^{-1},$$

$$3\omega_{\text{Venus}}\,(0.0838872\ \text{days}^{-1}) - 5\omega_{\text{Earth}}\,(0.085947\ \text{days}^{-1}) = -0.0020598.$$

This provides evidence that every two years the relative positions of the Earth and Mars and every three years the positions of the Earth and Venus repeat determined periodical resonance perturbations of the orbital motion of the Earth and, hence, variations in the duration of the tropical year and transport of solar energy to the Earth during the tropical year.

The total amount of solar energy reaching the Earth (at the upper boundary of the atmosphere) during a tropical year was calculated with account for the found small-amplitude variations in the interannual duration of the tropical year. One maximum of the spectral density near a period of 2.7 years, which reflects the ratio of the two-year and three-year oscillations, is found in the spectrum of the time series of the interannual variations in the solar energy transported to the Earth. The interannual variability of the solar energy has a high correlation (0.794 at a probability of 99%) with the interannual variability of the duration of the tropical year. The amplitude of the solar energy that reaches the Earth is on average 6.78124×10^{19} J or approximately 0.00123% of the mean value of the transported energy over a year (55.50212×10^{24} J). If the amplitude values are close to the maxima, this ratio is approximately equal to 0.00230%.

The energy that is transported from the Earth's interior to the surface is determined by an approximate value of 8.4×10^{20} J [6]. The mean value of the amplitude of the interannual variation in the solar energy that reaches the Earth is 8.07% of the energy transported from the interior. For the values close to the maxima, this relation is 14.80%.

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