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New results on the Earth insolation and their correlation with the Late Pleistocene paleoclimate of West Siberia

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Abstract

The three problems composing the astronomical theory of paleoclimate have been solved in a new way. Two of them (changes in the orbital motion of the Earth and its insolation) have confirmed the results of previous research. In the third problem (a change in the rotational motion of the Earth), the obtained oscillations of the Earth's rotation axis have an amplitude seven–eight times higher than the earlier estimated one. They lead to changes in insolation, which explain the paleoclimatic fluctuation. The changes in insolation and its structure for 200 kyr are considered. It is shown that the Late Pleistocene key events in West Siberia, for example, the last glaciations and warming between them, coincide with the extremes of insolation. The insolation periods of paleoclimatic changes and their characteristics are given.

Keywords: obliquity; insolation; paleoclimate; Pleistocene; West Siberia

Introduction

In the first half of the 20th century, M. Milanković (1939) developed the astronomical theory of climate change. In this theory, the Earth's insolation is calculated in different latitudes with the use of three parameters: eccentricity (e) of the Earth's orbit, the angular position of the perihelion ($\varphi_{p\gamma}$), and obliquity (ε). The astronomical theory of the Earth's climate includes the problems of orbital motion of bodies, of the Earth's rotational motion, and of its insolation as a function of the parameters of orbital and rotational motion.

Several generations of researchers (Berger and Loutre, 1991; Edvardsson et al., 2002; Laskar et al., 2004; Sharaf and Budnikova, 1969; Van Woerkom, 1953) consistently repeated Milanković's solutions. Still, they all followed the same path that had been developed in Celestial mechanics over centuries. Equations of orbital and rotational movement, starting from their derivation, were adjusted to solution by approximate analytical methods. We take a different path. First, instead of copying equations by our predecessors, we derive them based on fundamental principles (Smulsky and Smulsky, 2012). Second, we seek to employ minimum simplification in our derivation (Smulsky, 2011, 2012a). Third, we solve problems using numerical procedures, aiming to employ their most accurate versions (Smulsky, 2014; Smulsky and Krotov, 2014) or create new ones (Smulsky, 2012b). Our independent studies of the first two problems confirm the earlier conclusions (Mel'nikov and Smulsky, 2009; Smulsky and Krotov, 2014), while the results of the rotational motion study are different. The oscillation amplitude of obliquity ε is seven–eight times larger (Smul'skii, 2013; Smulsky, 2014) than the value determined in the previous theories. These oscillations result in such fluctuations of insolation that can explain the past climate changes. We first consider changes in insolation over time at 65° N and then in other latitudes.

Evolution of obliquity and insolation at 65° N

The evolution of obliquity over the last 200 kyr is shown by line *1* (Fig. 1). At first, changes in angle e in our solutions coincide with the approximation of observation data and, till 2 ka, with the results obtained by other authors (Laskar et al., 2004; Sharaf and Budnikova, 1969). Afterward, the obliquity value calculated by us differs from the results in (Laskar et al., 2004; Sharaf and Budnikova, 1969). The oscillation amplitudes in our solutions are seven–eight times as large as those calculated according to earlier theories (line *2*). Initially, several thousand years ago, starting from $T = 0$, obliquity *1* increased, like obliquity *2*. Afterward, it decreased to a minimum, while obliquity *2* was at a maximum, according to

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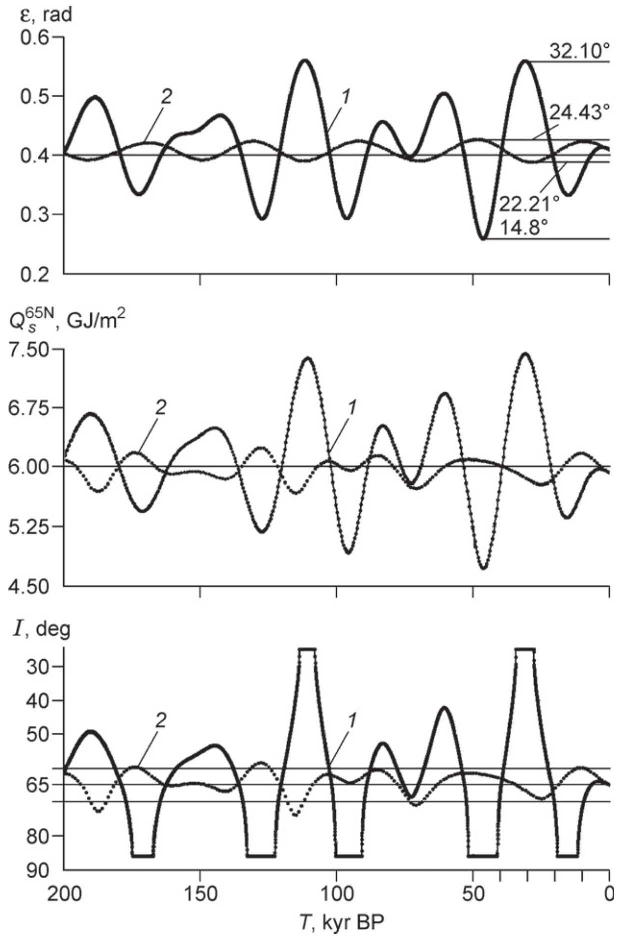

Fig. 1. Evolution of obliquity ε and summer insolations Q_s^{65N} and I over the last 200 kyr. Comparison between new results (*1*) and the results of previous research (*2*) by the example of (Laskar et al., 2004): ε, obliquity; Q_s^{65N}, insolation for the summer caloric half-year at 65º N; I, insolation in the equivalent latitudes for the summer caloric half-year at 65º N. The maximum and minimum values of angle ε are given in degrees. T, Time (ka) from 30 December 1949.

the earlier theories. For the rest of the time interval, the maxima and minima of oscillations in obliquities *1* and *2* also differ. However, the values of these extremes are more important. In the earlier theories, obliquity within the interval changes from 22.21º to 24.43º. On the other hand, obliquity in our solutions changes from 14.8º to 32.1º. An approximately the same range of changes in angle ε was obtained when solving the problem for the future 200 kyr (Smul'skii, 2013).

The average oscillation period of obliquity in the earlier theories is 41.1 kyr. Insolation Q_s^{65N} is characterized by the same oscillation period (line *2*). The new dependence for obliquity (line *1*) shows that the characteristic oscillation period is shorter by a factor of 1.5–2.0.

Insolation is considered in astronomical theories of paleoclimate for equal caloric rather than astronomical half-years. The beginning and end of the summer caloric half-year is determined so that insolation for each day is more intense than that for any day of the winter half-year. Next, we will consider insolation at 65° N. Change in Q_s^{65N} over the last 200 kyr was calculated using both the parameters determined by us (e, ε, and $\varphi_{p\gamma}$) (line *1*, Fig. 1) and those determined by J. Laskar et al. (2004) (line *2*). The plots show that insolation for the summer caloric half-year at 65º N (Q_s^{65N}) in our solutions also varies within a seven–eight times wider range than before. Besides that, moments of warming and cooling in our calculations (*1*) and according to the previous theories (*2*) differ. Starting from T = 0, as shown by Q_s^{65N} (Fig. 1), summer insolation increases for 4–5 kyr and then decreases to a minimum at 16 ka. This minimum is followed by warming, which ends with a large maximum of insolation at 31 ka.

So, insolation in our solutions fluctuates within a seven–eight times wider range. How significant is the fluctuation? This question can be answered by representing insolation in equivalent latitudes I, which is calculated as follows. If summer insolation in latitude φ during period T was like that in latitude φ_0 today, then insolation in equivalent latitudes is $I = \varphi_0$. Insolation I in equivalent latitudes, calculated for 65° N, both according to our data (line *1*) and according to Laskar et al. (2004) (line *2*), is shown in Fig. 1. Starting from T = 0, insolation I, according to our data (*1*), decreases by several degrees from 65° N; i.e., it becomes warmer at 65° N. Next, the I value increases to latitudes of 80° and 90° N. At 15.88 ka, summer insolation at 65° N is less intense than the present summer insolation at the poles; hence the horizontal line on the plot of the I value. Thus, the horizontal line at 12–19 ka means that insolation at 65° N was less intense than today's polar insolation. Such a small quantity of heat might have caused glaciation at 65° N.

As time passes to reach 30 ka, summer insolation I in equivalent latitudes reaches 50°, 40°, and 30° N; i.e., there is considerably more solar heat at 65° N. The horizontal line at 28–34 ka means that there was more heat at 65° N than now at the Equator.

Line *2* shows insolation I in equivalent latitudes, according to the previous theories. Summer insolation I at 65º N within the considered time interval of 50 kyr varies from 60º to 70º. The change in the quantity of heat at 65º N to the values observed now at 60º and 70º N can hardly cause substantial climate warming or cooling. These insignificant changes in insolation have always been doubtful (Bol'shakov and Kapitsa, 2011).

The fluctuations in insolation calculated by us might have led to the observed climate changes. The decrease in summer insolation I at 19–12 ka to lower values than those at the poles (line *1*, Fig. 1) might have caused glaciation. On the other hand, it is possible that the increase in summer insolation I to higher values than those at the Equator, which took place at 34–28 ka, favored the existence of mammoth fauna.

Latitudinal change in insolation

Change in insolation over time at 65° N was considered above. Now, let us look at latitudinal change in insolation at individual moments. Change in summer (Q_s), winter (Q_w), and halved annual insolation (Q_T) over latitude φ for 31.28 ka is