THE EARTH'S CLIMATE CHANGE IN THE 13TH-15TH MILLENNIA BC. POSSIBLE CAUSE

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Abstract. Data on the content of the cosmogenic isotope ^{14}C in the Earth's atmosphere make it possible to study variations in solar activity in past epochs. However, changes in the Earth's climate over time also lead to a distortion of information about solar activity. This paper examines the time interval from the end of the 17th to the beginning of the 10th millennium BC. During this time, as is known, there were several periods of climate change on Earth. There were several warming events (Mayendorf, Allered) and cooling events (the Oldest, Ancient, and Late Dryas). The reasons for these changes have not yet been determined. It is shown that a possible cause of the cooling during the Ancient Dryas could be a decrease in solar activity.

Keywords: *Solar activity, Earth's climate, cosmogenic isotopes*

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1. INTRODUCTION

The radionuclide method can reconstruct solar activity (SA) in the past and distant past [Solanki et al., 2004; Usoskin et al., 2006; Roth and Joos, 2013; Wu et al., 2018]. In this work, we compare specific periods of CA changes in our radionuclide reconstruction with known grand changes in terrestrial temperature on the time interval from the late 17th to early 10th millennium B.C. (A.D.).

As is known, the maximum of the last global glaciation took place about 19-27 thousand years ago, and the warm period of the Holocene occurred about 11700 years ago. Thus, the transition from global cooling to interglacial warming of the Holocene took 7-8 thousand years. During this transition period, the global temperature increase was not monotonous - there were alternating periods of warming and cooling. In particular, the Mayendorf and Alerød warming periods included warming periods. The Ancient, Ancient and Late Dryas belonged to the periods of cooling. In recent times, there has been evidence that the Late Dryas may have been associated with a decrease in solar activity. Using radiocarbon data, this article investigates whether the Ancient Dryas (14800-12800 B.C., Fig. 1) could also have been the result of reduced solar activity.

Figure 1.

Figure *1a* presents data on variations in the ^{18}O isotope content (i.e., δ^{18}O) in Greenland ice layers, which reflect the temperature of the ice layer during its formation [Svensson et al., 2008]. This figure shows that a cooling began ≈15000 B.C. and ended with a warming in ≈12800 B.C. This cooling coincides in time with the Ancient Dryas cooling (labeled Dr_1 in Fig. *1a*). This was followed by the Meiendorf (or Bölling) warming (M). The question arises as to the nature of these climatic changes. It should be noted here that, unlike Greenland temperatures, the global temperature data [Shakun et al., 2012; Marcott and Shakun, 2015] do not show a temperature decline in the **16-14** millennia (Fig. *1b*). In these data, the transition to the Meyendorff Warming is marked by a sharper temperature rise in **13050-12300** BCE. The temperature minimum of **10750-10650** BC falls in the Late Dryas (≈10700-9700 BC). In [Kudryavtsev and Dergachev, 2019; Kudryavtsev et al., 2022], it was shown that the Mayendorf warming could be the result of increased solar activity.

2. CONTENT OF ISOTOPE ^{14}C IN THE EARTH'S ATMOSPHERE AND HELIOSPHERIC MODULATION POTENTIAL

Let us consider how the content of isotope ^{14}C in the Earth's atmosphere changed during the time interval corresponding to the Meyendorff warming. For this purpose, we will use the data on the temporal variation of Δ^{14}C [Reimer et al., 2013] and carbon dioxide concentration in the Earth's atmosphere [Monnin at al., 2004] shown in Fig. *2a*, *b*, respectively. According to the definition of Δ^{14}C, the variations of the concentration of isotope ^{14}C in the atmosphere $N_a(t)$ (Fig. *2c*) can be expressed as (see, for example, [Kuleshova et al., 2015]):

$$\frac{N_a(t)}{N_a(t_o)} = \frac{\mathrm{CO}_2(t)}{\mathrm{CO}_2(t_o)}(1+\Delta^{14}\mathrm{C}(t)/100)/(1+\Delta^{14}\mathrm{C}(t_o)/100)\,, \quad (1)$$

where $\Delta^{14}C$ is the relative content of the ^{14}C isotope in the atmosphere in percent, t_o an arbitrary point in time.

Figure 2.

In [Kudryavtsev and Dergachev, 2019; Kudryavtsev et al., 2022], it was shown that the Mayendorf warming could be the result of increased solar activity. To answer the question about the possible nature of the cooling during the Ancient Dryas, we consider a reconstruction of the heliospheric modulation potential φ(*t*) (HMP), based on data on the relative content of the cosmogenic isotope^{14}C , (i.e., $\Delta^{14}C$) in the Earth's atmosphere [Reimer et al, 2013], discussed in detail in [Kudryavtsev and Dergachev, 2019; Kudryavtsev et al., 2022] (Fig. 3). The change in φ(*t*) can be used to judge the change in the Sun's activity.

Figure 3.

As can be seen in Fig. 3, from about 15150 B.C., solar activity began to decrease and reached a minimum around 13370 B.C., after which it began to increase. This decrease in solar activity coincides with the Ancient Dryas. With the subsequent increase, the SMG reaches a maximum around 12380 B.., and this peak corresponds to the Meyendorff Warming. Thus, the cooling during the Ancient Dryas could be caused by a decrease in SA, and the Mayendorff warming by an increase in SA.

Let us now consider the change in the atmospheric carbon dioxide content of the ^{14}C isotope (Fig. *2c*), which can be determined (see, e.g., [Kudryavtsev and Dergachev, 2019]), as noted above, based on measurements of the carbon dioxide content in the Earth's atmosphere [Monnin et al., 2004] and $\Delta^{14}C$ [Reimer et al., 2013]. It should be noted here that the content of the cosmogenic isotope ^{14}C in the Earth's atmosphere is determined by two factors: 1) changes in solar activity and 2) redistribution of carbon dioxide between natural reservoirs. The first factor leads to the fact that with increasing solar activity there is a decrease in the flux of galactic cosmic rays (CA) coming to the Earth's atmosphere, and, consequently, the rate of generation of isotope ^{14}C in the Earth's atmosphere decreases. When the SA decreases, the generation rate of $^{\text{the }(14)}C$ isotope increases. On the other hand, when the ocean cools, there is an increase in the rate of CO_2 transfer to the ocean from the atmosphere as a result of the temperature dependence of the solubility of CO_2 in water. These two factors act in opposite directions, which may break the correlation between φ(*t*) and the atmospheric content of isotope ^{14}C. Comparing Fig. *2c* and Fig. 3, we can see that the increase of the ^{14}C isotope content in the atmosphere over the time interval **14450-13130** occurs in the phase of the decline and minimum of φ(*t*). Consequently, we can conclude that this increase in the content of $^{\text{the }(14)}C$ isotope in the Earth's atmosphere is caused by an increase in the generation rate of this isotope as a result of the increase in the GCR intensity during the CA decline. At the same time, the increase in the rate of generation of ^{14}C compensates for the increase in the rate of CO_2 transfer from the atmosphere to the ocean at its cooling. The time delays can be related to the above-mentioned cause.

The subsequent decrease of the ^{14}C isotope content in the Earth's atmosphere (13130-12380 BC) may be due to a decrease in GCR intensity with increasing CA.

3. CONCLUSION

It is shown that a possible reason for the temperature decrease on the Earth during the Ancient Dryas (≈**15-12**.8 thousand years B.C.) may be a decrease in the activity of the Sun during this period of time.

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Figure captions

Fig. 1. Variation of the ^{18}O isotope content in the Greenland glacier (*a*) [Svensson et al., 2008] and global temperature (*b*) [Shakun et al., 2012].

Fig. 2. Relative change in the content of the cosmogenic isotope^{14}C in the Earth's atmosphere (*a*) [Reimer et al., 2013]; change in the CO_2 content in the atmosphere (b) and surface concentration of the ^{14}C isotope in the Earth's atmosphere as part of CO_2 (*c*).

Fig. 3. Reconstruction of the heliospheric modulation potential.

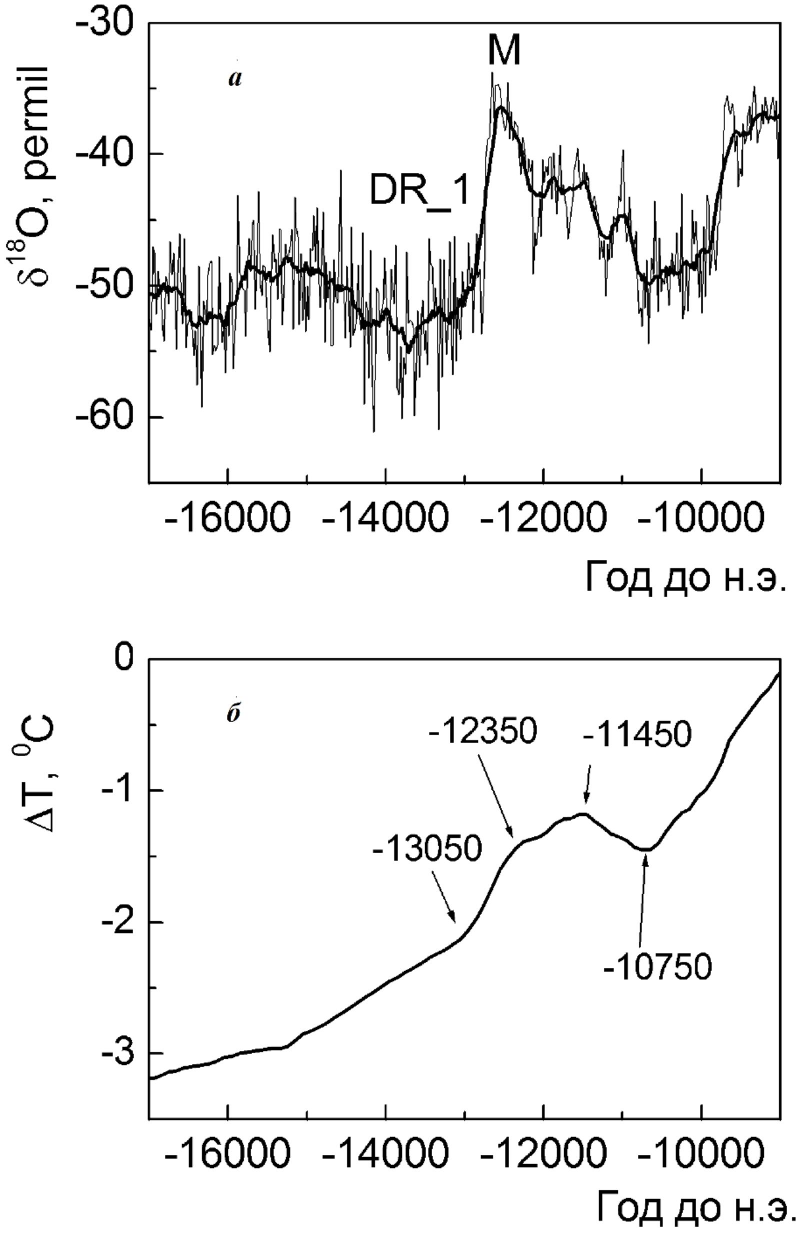
-30
-40
-50
-60
δ18O, permil
a
M
DR_1
-16000
-14000
-12000
-10000
Год до н.э.
0
-1
-2
-3
ΔT, 0C
б
-12350
-11450
-13050
-10750
-16000
-14000
-12000
-10000
Год до н.э.

Figure 1.

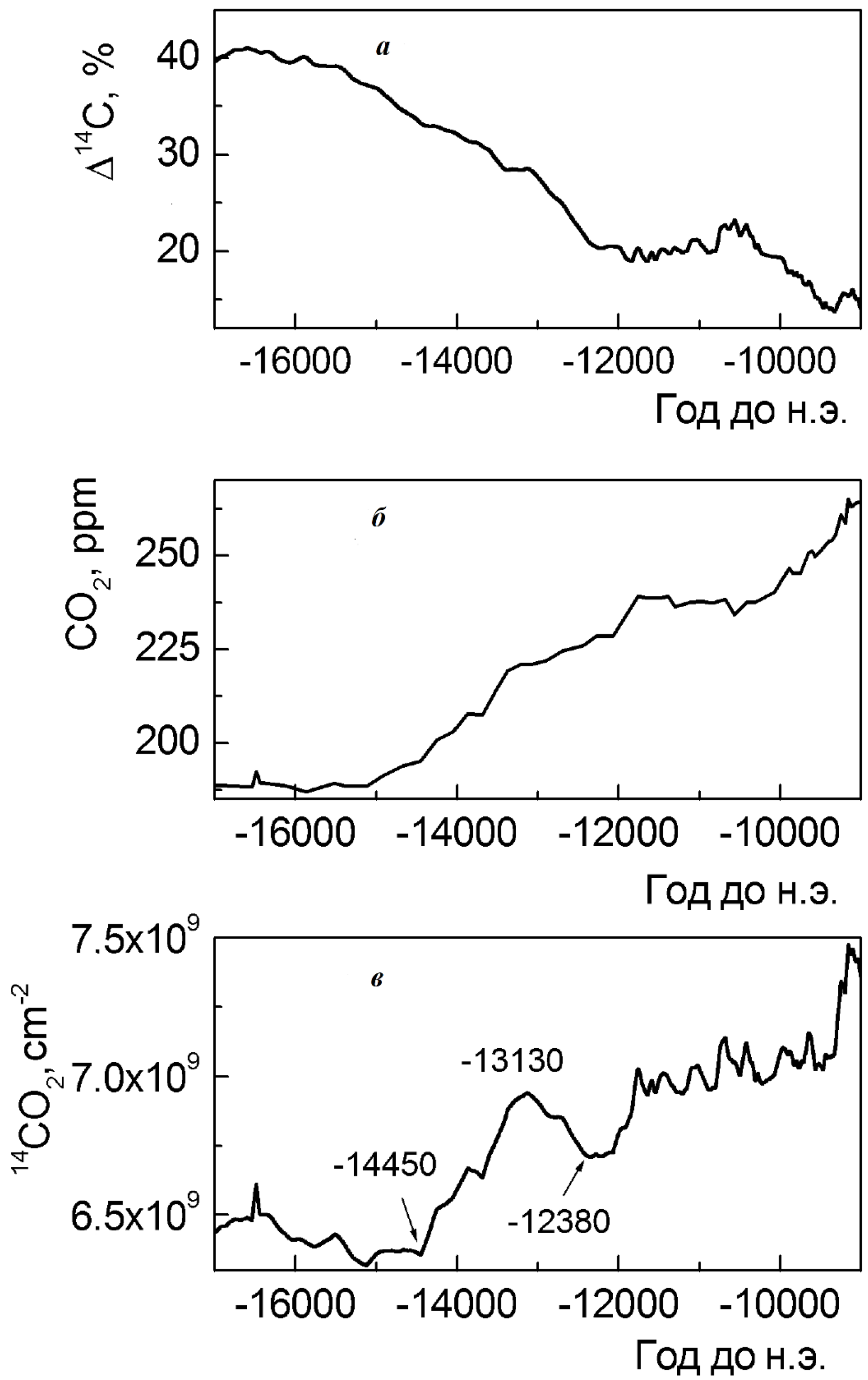
а
Δ14C, %
40
30
20
-16000
-14000
-12000
-10000
Год до н.э.
б
CO2, ppm
250
225
200
-16000
-14000
-12000
-10000
Год до н.э.
в
14CO2,cm-2
7.5x10^9
7.0x10^9
6.5x10^9
-13130
-14450
-12380
-16000
-14000
-12000
-10000
Год до н.э.

Figure 2.

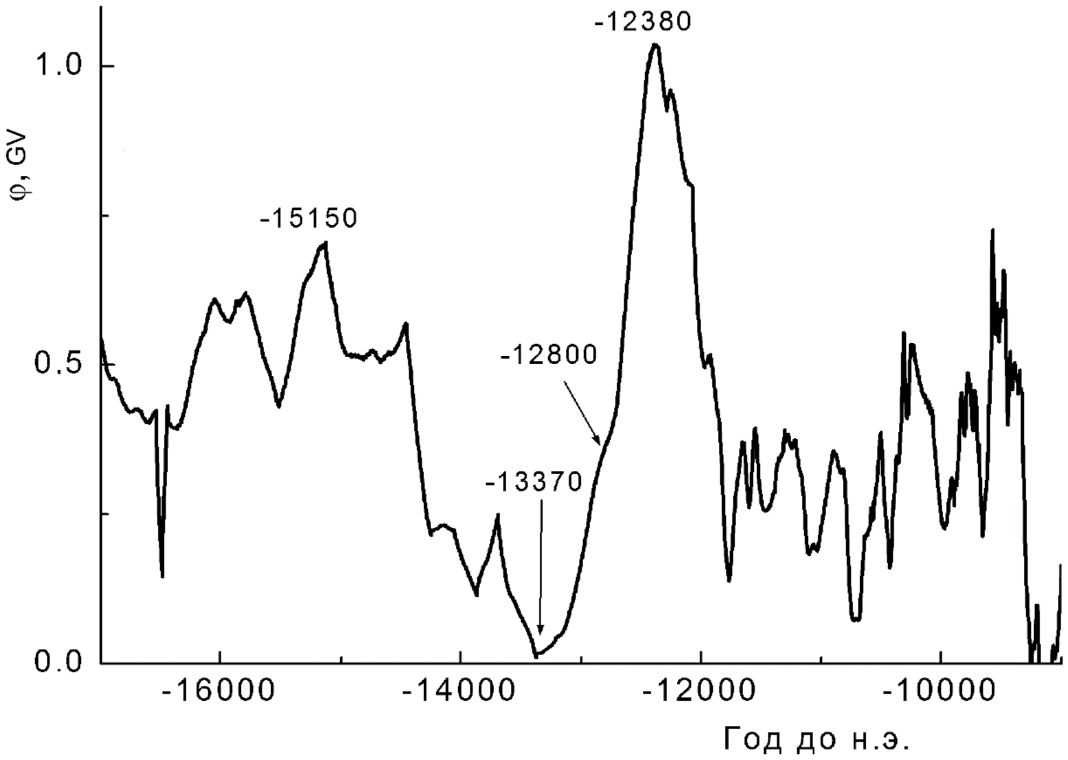
-12380
1.0
φ, GV
-15150
0.5
-12800
-13370
0.0
-16000
-14000
-12000
-10000
Год до н.э.

Figure 3.