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Cosmogenic variations of nitrate abundance in polar ice

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Abstract. Time variations of the nitrate content in Greenland ice core for the last 400 years are analysed. An approximately 20-year cyclicity dominates the nitrate series during the Maunder minimum (1645-1715) due to similar variations of galactic cosmic ray intensity. During times of normal high solar activity level, the 4-6-year periodicity dominates the nitrate series. This is probably due to a superposition of fluxes of galactic and solar cosmic rays, and due to favourable conditions for the nitrate precipitation.

1 Introduction

Measurements of nitrate content in polar ice show that there is a strong dependence of the nitrate content on the solar activity level (Zeller and Parker, 1981; Dreschhoff et al., 1993). Nitrate content variations reflect long periods of both high and low (e.g., the Maunder minimum) solar activity. On top of that, an analysis of the high temporal resolution data on nitrate content in polar ice yields that there are significant peaks in the nitrate concentration which have been associated with strong solar flares such as in September 1859, July 1928, July 1946, August 1972, etc. (Dreschhoff and Zeller, 1990, 1998).

Nitrates are produced in the atmosphere as a result of various chemical reactions of active nitrogen oxides. There are two ways of nitrogen oxides coming in the atmosphere. The first one is a part of the natural nitrogen cycle, and it results in the permanent existence of nitrogen oxides in the atmosphere due to decomposition of nitrous oxide. The second way is production of nitrogen oxides as a result of the atmospheric ionisation. The relation between the level of atmospheric ionisation and nitrogen oxide production is very close Dalgarno (1967); Warnek (1972). Probably, ionisation of the atmosphere at stratoscpheric altitudes due to galactic and solar cosmic rays is the reason of the relationship between nitrate content in polar ice and the solar activity level. We note also that, during strong solar proton events, the physical-chemical conditions in the stratosphere assist nitrates in fast fall-out in polar regions (Gladysheva, 1996; Gladysheva and Dreschhoff, 1997).

In the present paper we study time characteristics of nitrate content in the ice core taken in Greenland (72,6^{o}N, 38,5^{o}W) during the times of high overall solar activity level as well as during the Maunder minimum (1645-1715). The original series of nitrate concentration in polar ice was obtained by the University of Kansas (USA). (One can see the details about the series and its dating in papers by Dreschhoff and Zeller (1994, 1998).) This series covers the period of 1576-1991 with the time resolution of about one month. Here we deal with the series of yearly values of nitrate concentration in Greenland ice.

2 Cyclicities in the nitrate data

We performed the moving periodogram analysis of the nitrate series using the FFT-method. First, we detrended the series removing the long-term 29-year running average trend from the original data. Next, a periodogram in the time window 61 years (30 years) was built using the detrended series. Then the time window was slided for one year and new periodogram was built. The resulting ”map” of power in dependence of the time and period is shown in Fig. 1. One can see that the time behaviour of the nitrate signal is significantly different during times of normal solar activity level (18-19 century) and during the Maunder minimum when solar activity was extremely weak. While approximately 20-year is the dominant periodicity during the Maunder minimum, the most prominent periodicity during normal solar activity times is 4-6-year periodicity. Individual periodograms are shown in Fig. 2 for the periods of the Maunder minimum (1650-1710) and for the equally long period of roughly constant high solar activity level (1820-1880). One can see that the two periodograms are very much different from each

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other.

It has been suggested, using radiocarbon data, that the cosmic ray intensity had the dominant approximately 22-year cyclicity during the Maunder minimum Kocharov et al. (1995); Peistykh and Damon (1998). Moreover, recent detailed analysis of the group sunspot number series showed that about 22-year cyclicity was dominant also in solar activity Usoskin et al. (2000). Under these circumstances it is possible that the ≈ 20-year periodicity in nitrate concentration during the Maunder minimum is related to the variations of the polar atmosphere ionisation by cosmic rays. This relation might be quite important because the total flux of cosmic rays was higher during the Maunder minimum due to the very quite heliospheric conditions and, hence, extremely weak solar modulation of galactic cosmic rays (see, e.g., (Mendoza, 1997; Cliver et al., 1998)). In order to verify this hypothesis we studied the cross-correlation between yearly nitrate content variations and relative abundance of radiocarbon in tree rings (Stuiver and Braziunas, 1993). The series were detrended as smoothed. We also took into account the fact that the residence time of nitrates in the atmosphere is few months while the radiocarbon signal is delayed for several years (see, e.g., (Stuiver and Braziunas, 1998)) due to exchange between huge reservoirs. The results of the calculated correlation are shown in Fig. 3. One can see that the significant correlation exists between the two series with the cross-correlation coefficient reaching the value of 0.34 at 2-4-year time delay of radiocarbon vs. nitrate data. Fig. 4 shows a good agreement between the nitrate concentration variations and 4-year shifted radiocarbon series.

The 4-6-year periodicity in nitrate concentration variations during the times of normal solar activity level was studied recently by (Kocharov et al., 1999). They suggested that this periodicity appears because strong solar proton events occur with the doubled frequency of solar cycle, namely in ascending and descending phases. However, an analysis of solar proton events during last 4 cycles does not support this idea. Strong solar proton events are distributed widely around the maximum of solar cycle without any notable double-peak structure Smart and Shea (1989); Shea and Smart (1999). In line of the idea, employed above for the Maunder minimum, that cosmic rays may play a significant role in the nitrate signal variations, we suggest a physical interpretation of the 4-6-year periodicity in the nitrate series during times of the normal solar activity level. While the maximum of atmospheric ionisation by galactic cosmic rays falls at minimum of solar activity, solar proton events are concentrated around maxima of solar activity. It is probable that both these factors are important for the atmospheric ionisation. Moreover, since galactic cosmic rays and solar cosmic rays cause ionisation at different altitudes, it may well be that the superposition of these two processes results in activation of the condensation processes and is conductive to precipitation processes which also plays a role in the nitrate record formation. This can explain the 4-6-year periodicity.

2.1 Conclusions

In the present paper, we connected observed variation of nitrate concentration in Greenland ice to the stratospheric ionisation by solar and galactic cosmic rays during times of normal solar activity as well as during the Maunder minimum. It is suggested that the ionisation of the atmosphere by galactic cosmic rays drives the nitrate signal during the Maunder minimum leading to the ≈ 22-year periodicity. During times of normal solar activity, a superposition of solar and galactic cosmic rays are suggested to be important in the formation of the nitrate series leading to the 4-6-periodicity. This conclusion has been made basing on the analysis of only one nitrate series. In order to verify these results and exclude local climatic factors, similar analysis of other nitrate series should be performed. A series of nitrate content from Antarctica seems to be the most suitable for this purpose since that continent is isolated from mid-latitudes, and factors related to the transport of nitrogen oxides are suppressed there.

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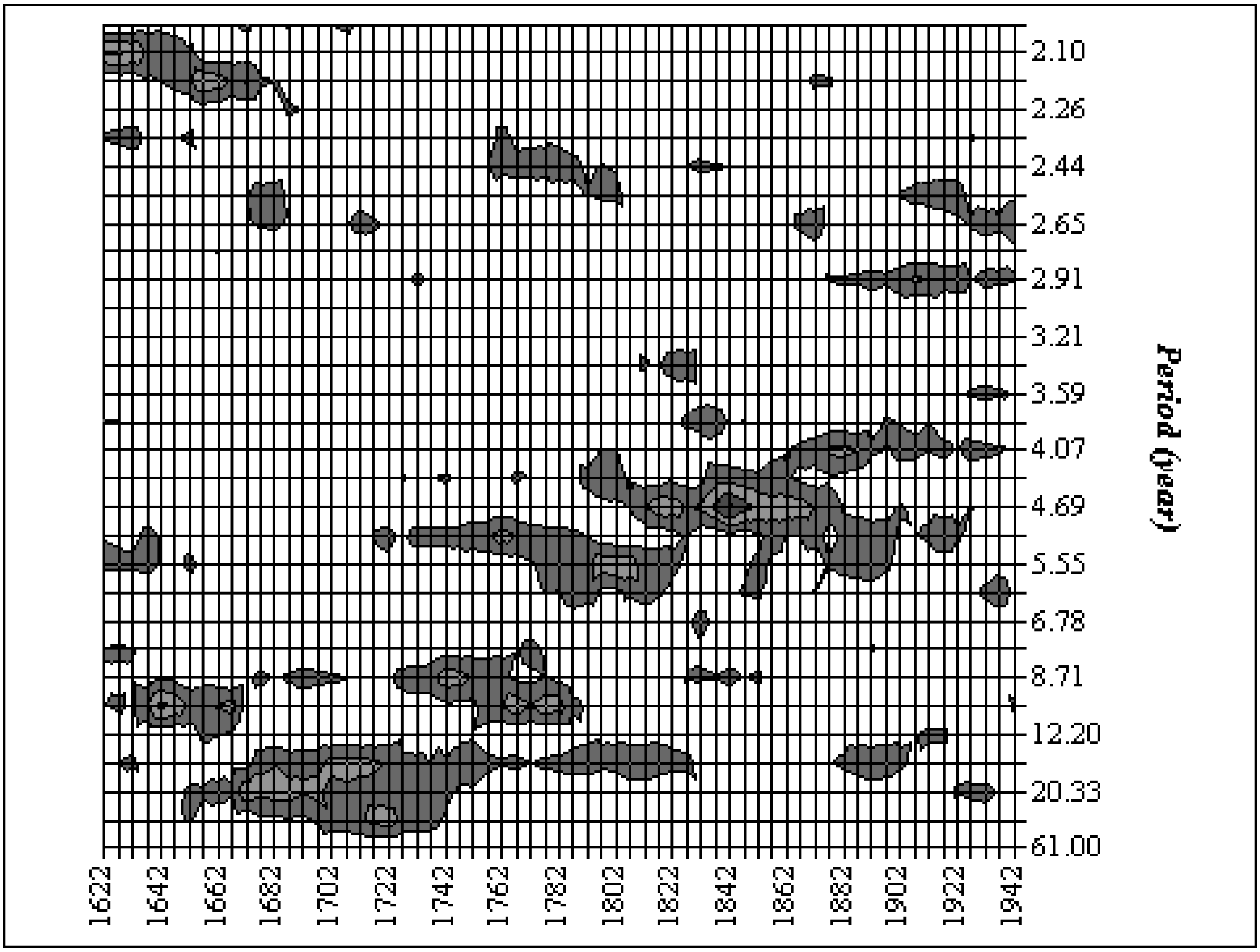

Fig. 1. Moving periodogram of the nitrate content in polar ice.

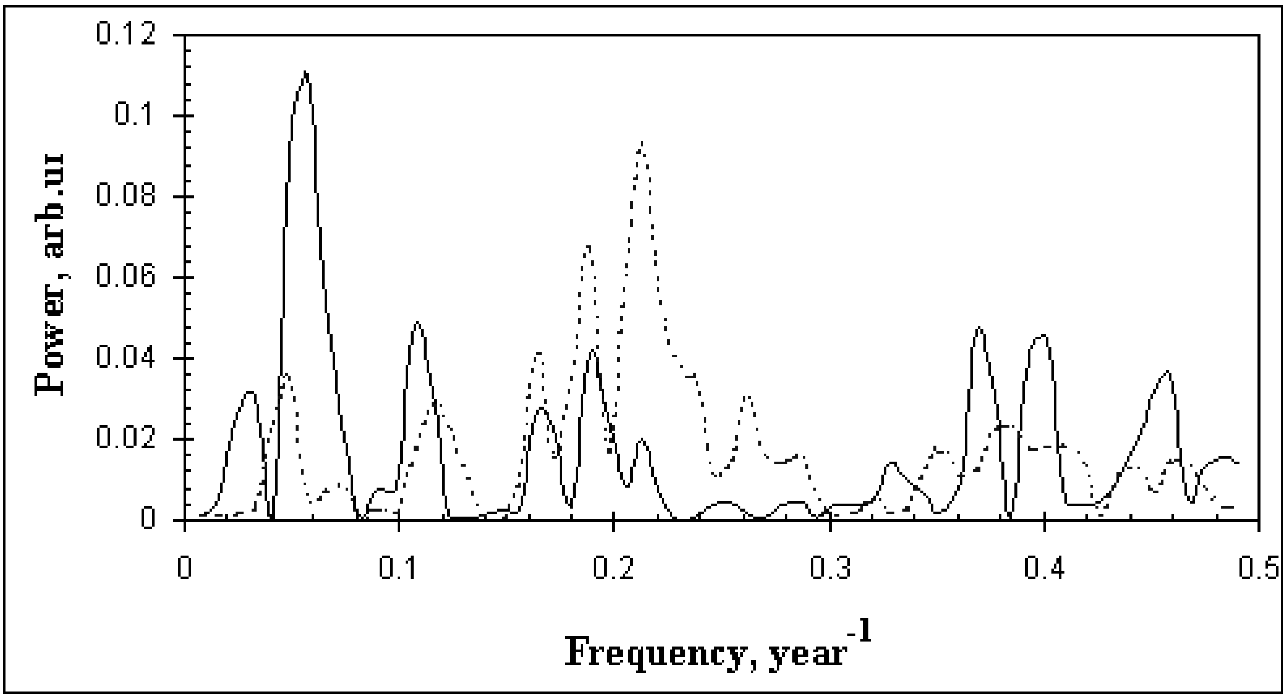

Fig. 2. Power spectrum of the nitrate series for the peirods of 1650-1710 (solid line) and 1820-1880 (dashed line).

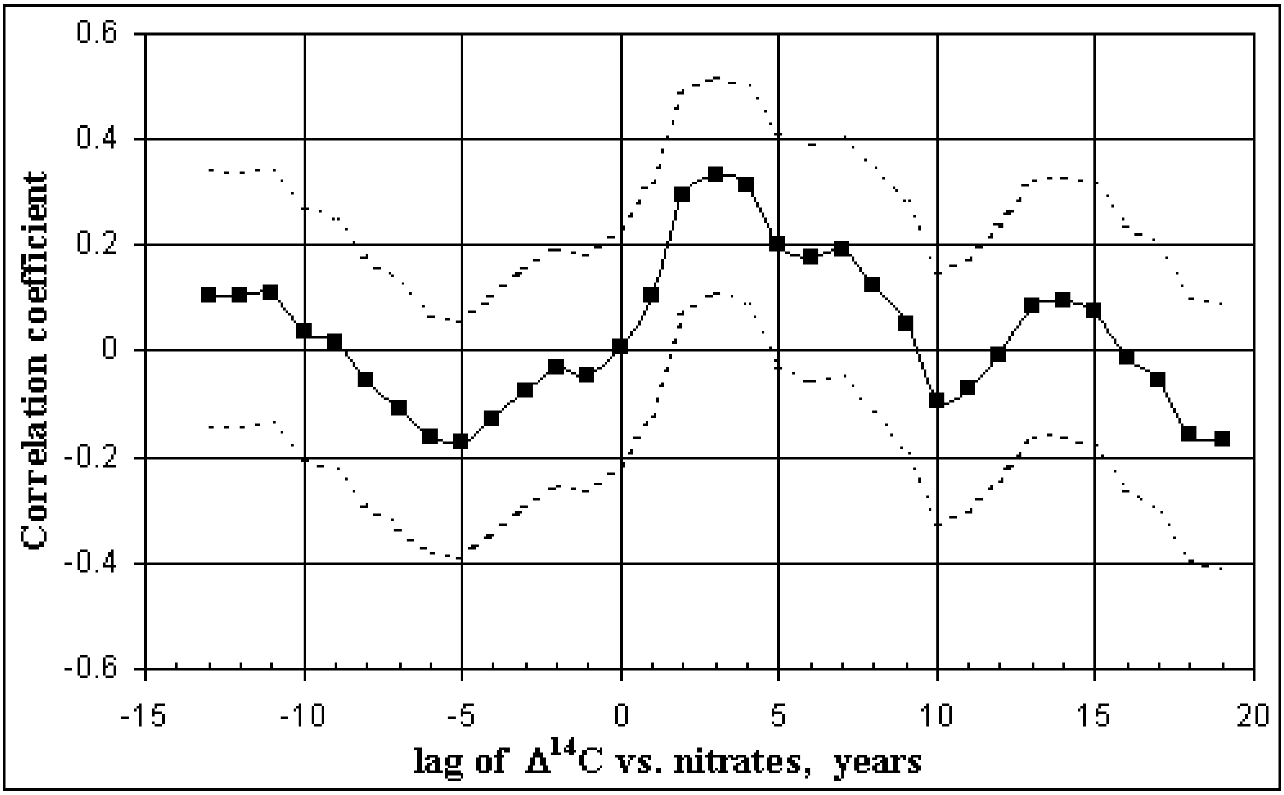

Fig. 3. Cross-correlation between the nitrates and shifted radiocarbon series. Dashed lines denote 95% confidence interval.

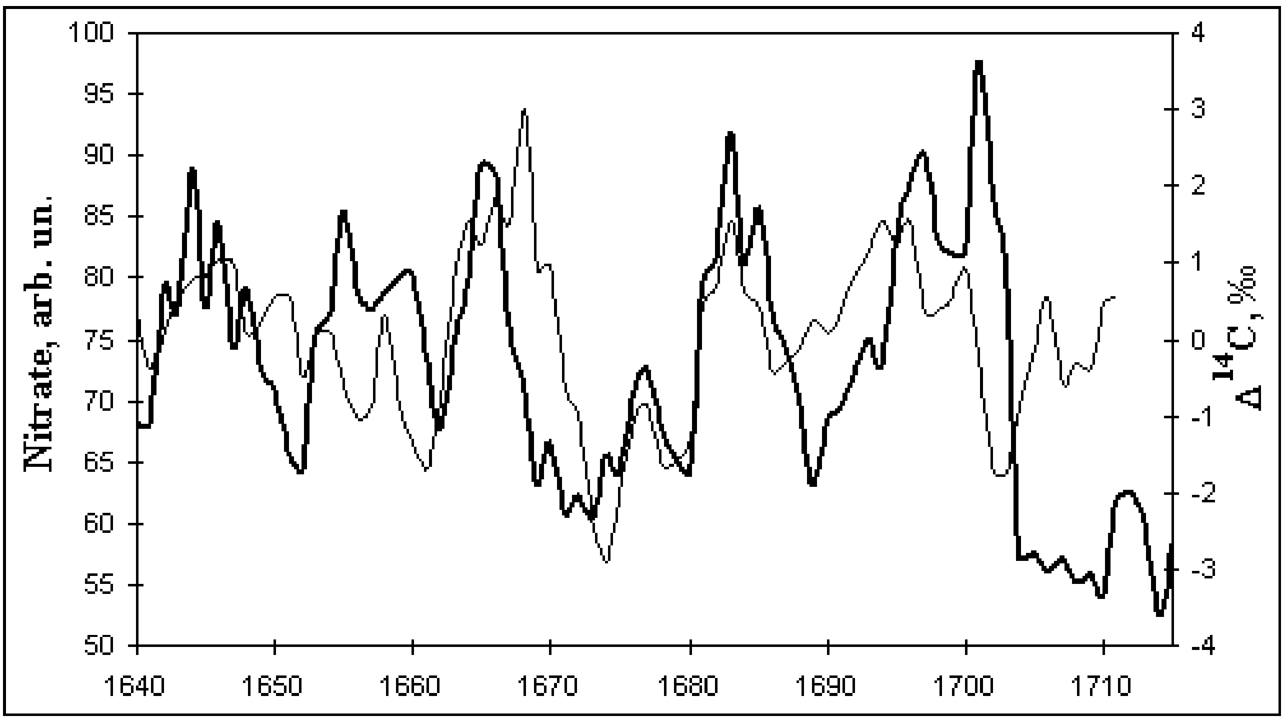

Fig. 4. Time profiles of nitrate (thick line, left axis) and radiocarbon (thin line, right axis) data during the Maunder minimum.