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Evidence of the solar Gleissberg cycle in the nitrate concentration in polar ice

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ABSTRACT

Two sets of nitrate (NO_3^-) concentration data, obtained from Central Greenland and East Antarctic (Dronning Maud Land) ice cores, were analyzed statistically. Distinct century-scale (50–150 yr) variability was revealed in both data sets during AD 1576–1990. It was found that century-type variation in Greenland and Antarctic nitrate correlates fairly significantly with the corresponding Gleissberg cycle: (a) in sunspot number over 1700–1970 AD; (b) in ^{10}Be concentration in Central and South Greenland over 1576–1970 AD. Thus, presence of century-scale relationship between polar nitrate and solar activity was confirmed over the last 4 centuries. That proves that NO_3^- concentration in polar ice caps could serve as indicator of long-term solar variability.

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1. Introduction

1.1. Nitrate concentration in polar ice

The polar glaciers, where no summer melting happens, serve as natural archives which keep information about physical-chemical conditions of the polar atmosphere that took place in the past. Concentration of nitrate – NO_3^- ions – has been under investigation for few decades in ice of both Antarctica and Greenland. The nitrate record in polar ice cores is expected to contain information about past atmospheric concentrations of the various odd nitrogen chemical species NO_y (N, NO, NO_2, NO_3, HN_2O_5, N_2O_5, HO_2NO_2, $ClONO_2$, $BrONO_2$) due to the close link of NO_3^- and NO*y*. The most important properties of nitrate record in ice are connected with its mechanism of generation. According to Legrand and Kirchner (1990), Mayewski et al. (1990), Jackman et al. (1990), Vitt et al. (2000), in polar regions nitrate "precursors" NO*y* are generated at different altitudes of the atmosphere:

(a) in the troposphere (from lighting, industrial activity, biomass burning, soil exhalation and galactic cosmic rays).
(b) in the stratosphere and higher (from biogenic N_2O oxidation, galactic cosmic rays (GCR), solar cosmic rays (SCR), solar UV radiation and relativistic electron precipitation).

Thus, concentration of nitrate ions in well-dated ice cores might contain important information about ionization of middle atmosphere and, hence, about fluxes of ionizing cosmic radiations.

1.2. Polar ice nitrate and solar-cosmic factors

Examination of the experimental nitrate sequences has given ambiguous results. The main conflict is connected with the possible relation between impulsive nitrate events and fluxes of solar cosmic rays. Zeller et al. (1986), Dreschhoff and Zeller (1990), Dreschhoff and Zeller (1998), Mc Cracken et al. (2001), Kepko et al. (2009) reported the distinct association between solar proton events (SPE) and short but prominent peaks in NO_3^- concentration observed in polar ice of both Antarctica and Greenland.

Motizuki et al. (2009) revealed two highly significant NO_3^- spikes coincident with supernovae of AD 1006 and AD 1054 (the Crab Nebula). However, other investigators (Legrand and Delmas, 1986; Legrand and Kirchner, 1990; Wolff et al., 2012) have found no link between short-term pulses of cosmic ray intensity and nitrate. Some authors proposed a weak contribution to the polar ice nitrate record from the middle atmosphere in relation to tropospheric sources (Legrand and Delmas, 1986; Legrand and Kirchner, 1990). It has been also noted that solar proton event (SPE) fingerprints can be masked by local meteorological or anthropogenic events (Wolff et al., 2012). Thus a possibility of nitrate record to reflect the short-term SCR fluctuations is still debated.

On the other hand, evidence for a century-scale (Gleissberg) solar variation in the polar ice nitrate is accumulating. Particularly, Mayewski et al. (1993), Kocharov et al. (2000) and Ogurtsov et al. (2004) have reported presence of century-long cycle in the concentration of NO_3^- ions in Greenland ice. Ogurtsov et al. (2004),

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who analyzed nitrate concentration in the two closely situated Central Greenland cores, found a significant correlation between the sunspot and nitrate records, wavelet filtered in the century-scale cycle band (55–147 yr), through 1700–1980 AD. Recently, the same relationship has been established in Antarctica by Laluraj et al. (2011), who reported a good similarity in long-term variations in nitrate data, measured in a shallow East Antarctic ice core (IND-22/B4) and South Pole ^{10}Be for the last 450 yr. Traversi et al. (2012) revealed significant wavelet coherency between reconstructed cosmic ray intensity and nitrate, measured in Talos Dome core (72°49′S, 159°11′E, altitude 2315 m), in the Gleissberg cycle band (50–100 yr) during 1713–1913 AD. Since meteorological conditions of the Dronning Maud Land (IND-22/B4 core) and the edge of the East Antarctic plateau (Talos Dome) area are very different from that in Central Greenland, results of Laluraj et al. (2011) and Traversi et al. (2012) corroborates that the century-type periodicity is a robust feature of nitrate variability related to the solar Gleissberg cycle, not to climatic changes. That, in turn, testifies that ice core nitrate is a perspective tool for further research in solar paleoastrophysics. In present work we performed a thorough examination of a century-scale link between nitrate in polar ice and solar activity using:

(a) nitrate records, obtained from both Greenland and Antarctic cores;
(b) beryllium records, obtained from Greenland cores.

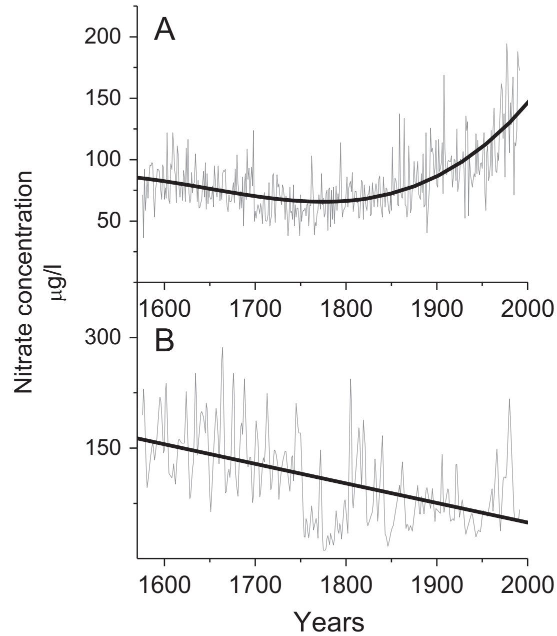

Fig. 1. (A) Thin curve—nitrate concentration in Greenland ice (GISP2-H core), obtained from original data of Dreschoff and Zeller (1994) by Ogurtsov et al. (2004), thick curve—polynomial trend of 3rd order.; (B) thin curve—nitrate concentration in Antarctic ice, thick curve—linear trend. Data were electronically scanned from Laluraj et al. (2011) and digitized.

2. Data records

The nitrate record of Kansas University was obtained from a GISP2 H core drilled in the central part of the Greenland Ice Sheet (73°N, 38°W, altitude 3230 m). This core was divided into 7776 segments, 1.5 cm in thickness each, producing the record of nitrate concentration covering the interval A.D. 1576–1991, with a time resolution sometimes down to just a few weeks (Dreschoff and Zeller, 1994,1998). Ogurtsov et al. (2004) converted the original set of 7776 individual samples, into a 415 yr long annual series, which is much more suitable for the investigation of nitrate variations at time scales larger than 1 yr. The dating was based on distinct seasonal variations in nitrate signal and electrical conductivity depth profile, measured by Dreschoff and Zeller (1994) in the same core, which includes a number of volcanic markers (peaks of conductivity corresponding to known volcanic eruptions). This annually resolved record is shown in Fig. 1A.

A nitrate sequence was measured in an ice core IND-22/B4, drilled by 22nd Indian Antarctic Expedition in the coastal part of Dronning Maud Land (70°51.3′S, 11°32.2′E, altitude 680 m, snow accumulation rate 170 $kg \times m^{-2} \times yr^{-1}$). The data were electronically scanned from Laluraj et al. (2011) and digitized. This record is plotted in Fig. 1B. It is seen from Fig. 1, that secular tendencies in both series are quite dissimilar. Most likely it is a result of difference in meteorological climatic and glaciologic conditions between Central Greenland and East Antarctica-regions, which are situated close to poles of different hemispheres. Moreover central part of Greenland ice sheet is an area of continental climate while IND-22/B4 site is located close to ocean and thus its climate is appreciably influenced by cyclonic activity. On the other hand, Antarctica is situated very far from the sources of NO_y anthropogenic pollution. It should be noted that meteorological conditions of IND-22/B4 site also differ from that of Talos Dome, because weather of Dronning Maud Land is influenced by katabatic winds in a more extent than Talos Dome area—see Fig. 4.6 after King and Turner (1997).

Apparently, substantial meteorological fluctuations and strong winds, which cause effects of wind-driven deposition, make the IND-22/B4 core site a zone not suitable for research of high-frequency nitrate pulses. Analysis of long-term variability of this nitrate record thus gets a particular interest.

Cosmogenic isotope ^{10}Be preserved in polar ice is known as a reliable indicator of the historical cosmic ray and solar activity variations (Beer et al., 1988, 1994; Bard et al., 1997; Mc Cracken, 2004). It is generated in the stratosphere and troposphere due to high-energy (500 MeV–50 GeV) charged cosmic particles, incorporated in a number of geophysical and geochemical processes and finally fixed in polar ice and bottom sediments. The main part of the cosmogenic ^{10}Be is produced by GCR, although SCR may contribute to this process. The rate at which cosmogenic beryllium is generated, is inversely dependent upon the strength of the magnetic field in the Sun's heliosphere and, hence, on the sunspot number. The use of proxy ^{10}Be records, which can cover time intervals of many millennia, allows substantial increase in our knowledge about past solar activity. In present work we used the annual flux of ^{10}Be in an ice core, which is determined by formula:

$$F_{10_{Be}}(\text{atoms} \times \text{cm}^{-2} \times \text{yr}^{-1}) = \rho \times a \times [^{10}\text{Be}], \quad (1)$$

where [^{10}Be] in atoms $\times$ g^{-1}, ρ is the density of ice (0.92 g $\times$ cm^{-3}), a is the ice accumulation rate in cm $\times$ yr^{-1}.

Two annually resolved beryllium time series were analyzed:

(a) ^{10}Be record after Beer et al. (1990), (2006) measured from an ice core from Dye-3 site in South Greenland (65.18°N, 43.83°W, altitude 2870 m), which covers the time interval AD 1424–1985.
(b) A new ^{10}Be series spanning the period AD 1389–1994, which has been measured from an ice core from NGRIP site in Central Greenland (75.10°N, 42.32°W, 2917 m) (Berggren et al., 2009). Using these two beryllium data sets (Fig. 2), obtained at different geographic locations, we can reduce possible effects due to local climatic variability and core uncertainty, which

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