The Seasonal Dependency of the NO(Y) Impulsive Precipitation Events in Arctic Polar Ice

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Abstract

Large fluence solar energetic particle events ($>\sim 10^9$ cm^{-2} omnidirectional fluence at energies > 30 MeV) result in characteristic impulsive NO(Y) enhancements in the polar ice. We currently have a ∼430-year record of these impulsive NO(Y) events. We find that these impulsive NO(Y) events correspond to known exceptional solar activity episodes. We find a distinct seasonal effect in the distribution of these impulsive NOY events with substantially more large events detected in the second half of the Arctic year. We also find a correspondence with the ∼160 year geomagnetic storm record with an apparent correspondence between the occurrence pattern of the smaller impulsive nitrate events (omnidirectional solar proton fluences between 0.5 and 1.0×10^9 cm^{-2}) and the geomagnetic storm equinoctial frequency of occurrence pattern.

1. Introduction — Nitrates in Polar Ice as "Markers" of Major Solar Proton Events

The work of McCracken et al. (2001a,b) has shown that large impulsive increases in nitrate concentration [NO(Y)] in polar ice represent major solar proton fluence events in the past. Using solar proton event measurements from 1950 to 1990, McCracken et al. (2001a) derived a relationship between the excess nitrates and the > 30 MeV omnidirectional solar proton fluence, and applied this relationship to the excess nitrate measurements from an Arctic ice core that was dated from 1561 to 1992. This paper concentrates on a sub-set of that data — the 62 nitrate events with a > 30 MeV omnidirection fluence above 5×10^8 from 1840–1950. These dates are consistent with a semi-homogeneous list of major geomagnetic storms for the same period. The intent of this study was to ascertain if there was a seasonal dependency in the nitrate enhancements and to see if there was any relationship between major geomagnetic disturbances and subsequent (i.e. within a few months) impulsive nitrate enhancements.

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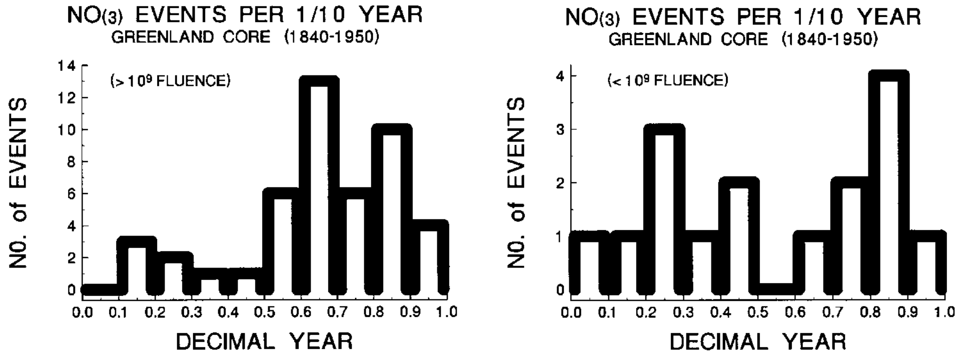

Fig. 1. Impulsive nitrate events (1850–1950) as a function of decimal year.

2. Seasonal Dependency

The 62 impulsive nitrate enhancements between 1840–1950 were divided into two groups: 46 events with a derived > 30 MeV omnidirectional solar proton fluence $> 10^9$ cm^{-2} and 16 events with a derived omnidirectional solar proton fluence between 5×10^8 cm^{-2} and 1×10^9 cm^{-2}. Figure 1 shows the distribution of these events as a function of decimal year. The distribution of the largest events, shown on the left side of Figure 1, has a pronounced increase in the number of events during July-October. This distribution is independent of the size of the event above the 10^9 cm^{-2} fluence threshold. At this point we do not have a physical explanation for the excessive nitrate enhancements occurring in the Northern Hemisphere late summer and early autumn time period. Nevertheless it is broadly consistent with the estimate in McCracken et al. (2001b) that the probability that a solar proton event would be detected in the NO(Y) record is 75%.

The impulsive nitrate enhancements with a total derived > 30 MeV omnidirectional fluence between 5×10^8 cm^{-2} and 1.0×10^9 cm^{-2} exhibited a different pattern with the maximum number of events around the periods of solar equinoxes as illustrated in the right side of Figure 1. This pattern is similar to the annual distribution of geomagnetic disturbances noted by Russell and McPherron (1973).

3. Geomagnetic Storms and Major Solar Proton Fluence Events

We know that of the eight major solar proton events (listed in Table 1) from 1955–1991 having a > 30 MeV omnidirectional solar proton fluence $> 10^9$ cm^{-2}, seven of the events were associated with a major geomagnetic storm within approximately 2 days from the onset of the proton event. The maximum value of the magnetic Kp index within 3 days from the solar proton event is also listed in Table 1. The eighth event, 29 September 1989, was the third largest ground-level

Table 1. Major Solar Proton Fluence Events ($> 10^9$ cm^{-2}), 1955–1991

Event	GLE	> 30 MeV Fluence	Maximum Kp Values
23 Feb 1956	Large	1.0×10^9	8+ (24 Feb)
10–17 Jul 1959	Small	2.4×10^9	9 (15 Jul); 9− (17 Jul)
11–21 Nov 1960	Large	9.7×10^9	9 (13 Nov); 8+ (15 Nov)
2–7 Aug 1972	Small	5.0×10^9	9 (4 Aug); 9− (5 Aug); 8+ (9 Aug)
12–18 Aug 1989	Mod.	1.4×10^9	7− (14 Aug); 7− (15 Aug)
29 Sep–2 Oct 1989	Large	1.4×10^9	—
19–30 Oct 1989	Large	4.2×10^9	8+ (20 Oct); 8+ (21 Oct)
22–26 Mar 1991	No	1.8×10^9	9− (24 Mar); 9− (25 Mar)

While most geomagnetic storms are not associated with major solar proton events Shea and Smart (1994) established that the majority of large solar proton fluence events measured at Earth are associated with major solar activity near the central meridian of the sun. Six of the events in Table 1 were associated with solar activity near the central meridian; the remaining two events (23 Feb and 29 Sept) were major high energy solar proton events, ranking No. 1 and No. 3 of the 64 ground-level events since 1942 (Smart and Shea, 1991). McCracken et al. (2001a) assumed that the nitrate deposition in polar ice begins approximately within 6–8 weeks after the occurrence of the proton event and may continue for another 6–8 weeks. Thus it seemed reasonable to assume that many of the impulsive nitrate events in the period 1840–1950 would be associated with geomagnetic activity a few weeks preceding the nitrate enhancement.

event (GLE) in recorded history (Smart and Shea, 1991) at which time protons with energies > 20 GeV were recorded (Swinson and Shea, 1990). While there are many geomagnetic storms and disturbances that are not associated with solar proton events at Earth, 88% of the > 30 MeV proton events in Table 1 are associated with a major geomagnetic storm.

To ascertain if a geomagnetic disturbance occurred prior to the identified impulsive nitrate enhancements, we inspected geomagnetic records (Royal Greenwich Observatory, 1955; Nevanlinna et al., 1993; Nevanlinna and Kataja, 1973) for significant activity for the three-month period prior to the nitrate enhancement. Additional information such as major sunspot groups near central meridian or sequences of geomagnetic activity over a short period of time was also identified if these records were available in the above publications or references therein.

Of the 62 impulsive nitrate enhancements with a derived > 30 MeV omnidirectional solar proton fluence above 5×10^8 cm^{-2} between 1840–1950, 52 of them (84%) appear to have some association with significant geomagnetic disturbances. When separating these events into the same categories as mentioned previously, the 46 larger fluence events have an 80% association while the 16 smaller fluence events have a 94% association. This 94% association is in agreement with the sea-

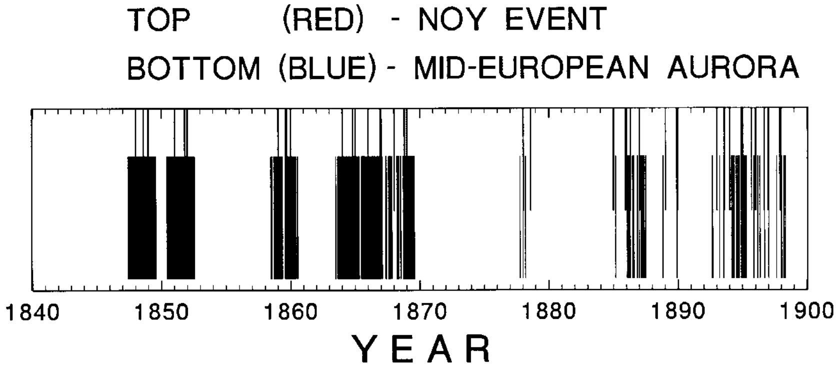

Fig. 2. Impulsive nitrate events (top) and mid-latitude aurorae (bottom)

sonal distribution of both the nitrate events shown in the right side of Figure 1 and the known seasonal distribution of geomagnetic disturbances. The statistical significance of these results are being evaluated.

4. Auroral Records

Mid-latitude aurorae are often sighted during major geomagnetic storms. Using the data from Křivský and Pejml (1988) Figure 2 illustrates the commonality between the impulsive nitrate events and mid-latitude aurorae from 1840–1900. This figure reflects that the nitrate events are frequently associated with mid-latitude aurorae sightings reflecting a common source.

5. Acknowledgments

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6. References

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