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Geomagnetic Variability and Climate Change: Is there a link?

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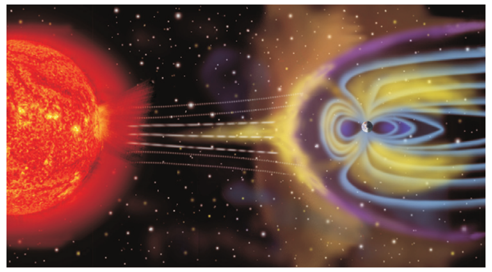
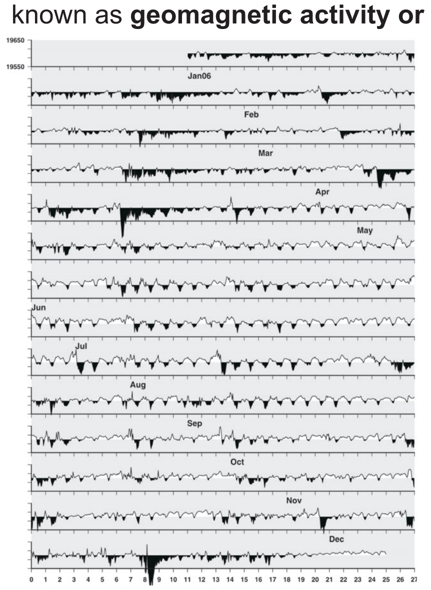
Introduction

The Earth's magnetic field varies over many time scales. Whilst the slow secular variation of the strength and direction of the field over years to centuries is governed by processes in the fluid outer core of the Earth, the shorter variations, on time scales of seconds to years, are driven by the Sun. These external field variations are classified as irregular or regular. The larger irregular variations, commonly known as **geomagnetic activity or storms**, occur as a consequence of extreme events on the Sun such as coronal mass ejections or (usually with less intensity) as a result of regions of increased solar wind speed from coronal holes. The (relatively) regular **diurnal variation** is due to currents flowing in the ionosphere where the atmosphere is ionised by the Sun's UV radiation. In this paper we discuss whether long-term changes in **these two phenomena** can be useful proxies for changes in solar radiation.



Artists impression of the Sun, the Earth and the interaction between the solar wind and the Earths' magnetic field, to form the magnetosphere. Credit: SOHO (NASA and ESA)



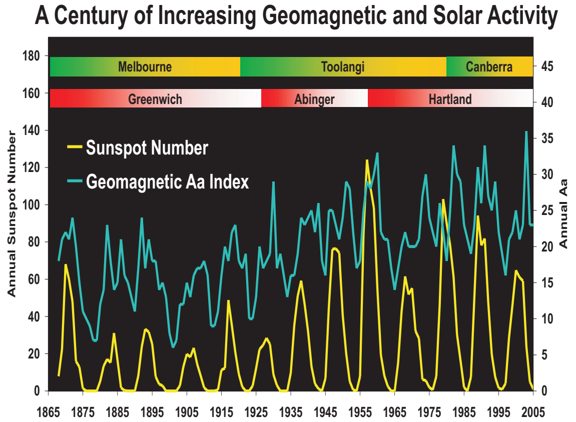
Hourly mean values of Horizontal Intensity (nT), plotted by days of solar rotation, at Hartland observatory during 2006. This shows the regular diurnal variation (*Sq*) during magnetically 'quiet' periods, which is more pronounced during summer.

The Sun's significance for climate change appears to be clear, since its radiation is the Earth's source of external energy. However, there is controversy over what levels of solar variability are required to generate significant climate change and what the mechanisms are.

Hartland magnetic observatory, North Devon

Indices are often used to characterise geomagnetic activity and are well correlated with indices characterising solar activity. The *aa* index is derived from measurements made at near-antipodal magnetic observatories: one in the south of England, currently Hartland magnetic observatory, operated by BGS, and the other in Australia, currently Canberra magnetic observatory, operated by Geoscience Australia. The *aa* data set extends back to 1868, one of the longest geophysical time series, and is evidently related to solar activity, parameterised by the sunspot number, throughout the period (left). In particular during the minimum phase of the Sun's 11-year cycle there has been a steady increase in geomagnetic activity.

A Century of Increasing Geomagnetic and Solar Activity



Long-term change in geomagnetic activity

The trend in magnetic activity over the last century has been reported by many researchers and characterised by various indices and although debate continues over the detail, the upward trend is not in doubt. Clilverd *et al* (1998, 2002) have shown that the long-term trend in the *aa* index is linked to the Sun and not to instrumental discontinuities or ionospheric changes. The *aa* index has also been used quantitatively to derive the solar magnetic flux (right) and infer that it has doubled since 1901 (Lockwood *et al,* 1999). The effect of this on the total output or radiation from the Sun is not yet fully understood, but long-term changes in solar radiation could be a natural component of climate change.

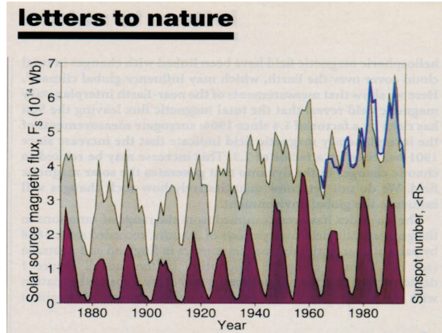
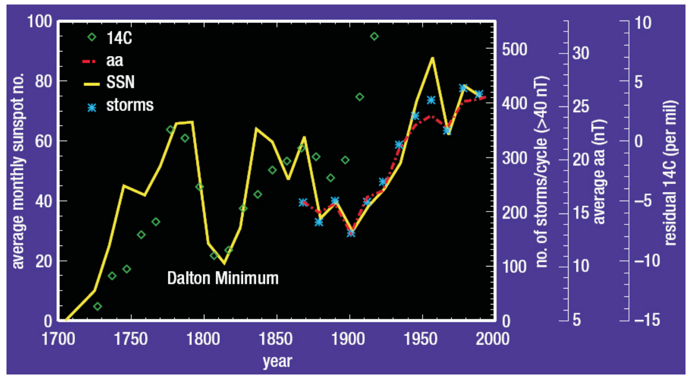

letters to nature

Figure 3 The total solar magnetic flux emanating through the coronal source sphere[12], F_s. Shown are the values derived from the geomagnetic *aa* data for 1868–1996 (black line bounding grey shading) and the values from the interplanetary observations for 1964–96 (thick blue line). The variation of the annual means of the sunspot number ⟨*R*⟩ is shown by the area shaded purple and varies between 0 and a peak of 190 for solar cycle 19.

Three different proxies of solar activity over 300 years have been combined by Clilverd *et al* (2003): the sunspot number; the *aa* index; and the variation of atmospheric radio carbon $\Delta^{14}C$, representing solar irradiation, which extends much further back in time, but is anthropogenically contaminated in recent decades.



The residue $\Delta^{14}C$ (diamonds) and sunspot number (solid line) since the Maunder Minimum of around 1700 and the total number of magnetic storms with *aa* > 40nT (asterisks) per solar cycle and the mean *aa* value (dotted line). Both the Maunder Minimum and the Dalton Minimum (shown) also coincide with unusually cold periods reported for the northern hemisphere.

This enabled an analysis of likely solar activity over a much longer period and the conclusion that over the next 100 years or so, solar and geomagnetic activity levels are likely to decrease back to 1900 levels. Although speculative, this work has further highlighted the importance of geomagnetic activity indices for long-term studies and the result may well have consequences for the debate on the link between Sun and climate.

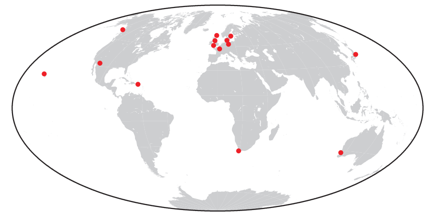
Conclusions

The importance of long-term monitoring of the geomagnetic field for the climate change debate is demonstrated.

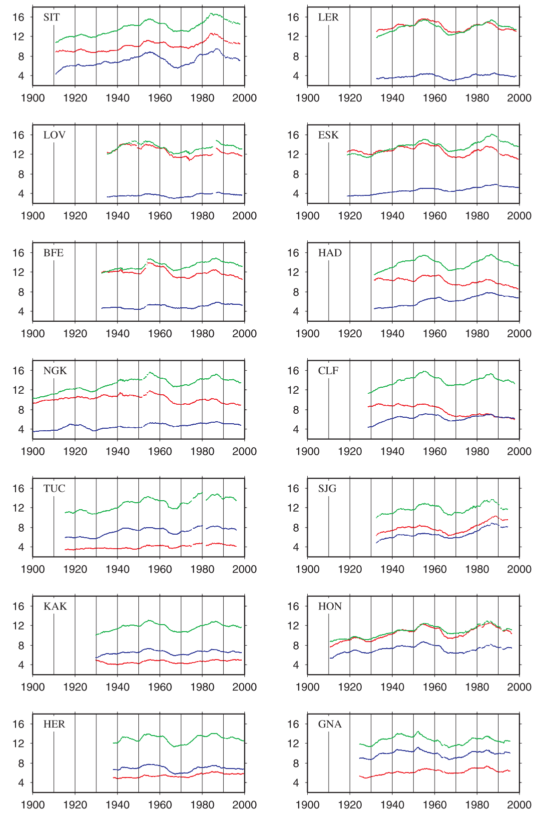
Geomagnetic observatory data can provide Earth-based proxies of solar variability that are suitable for studies into solar forcing of climate change and may have a role in helping to determine the mechanisms involved.

Long-term change in daily variation

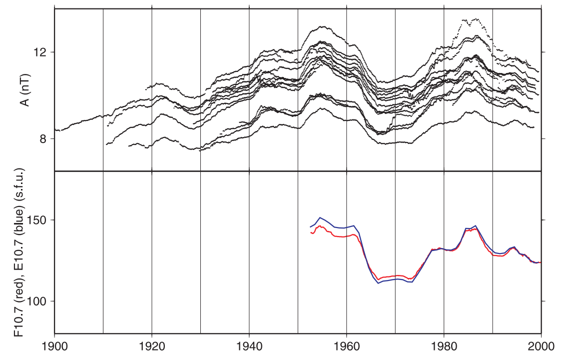
The regular diurnal variation of the geomagnetic field, *Sq*, which is generated by currents flowing in the ionosphere, 100-150 km from the Earth's surface, is determined from the average of several days with minimal levels of geomagnetic activity. Its variation with solar radiation and sunspot number has been known for some time but what is less well understood are the variations at periods longer than the 11-year solar cycle. Using long series of geomagnetic hourly mean data from a number of locations around the world including the 3 UK observatories operated by BGS, we determine 11-year average amplitudes of the daily variation at monthly intervals (left).



The locations of 14 observatories, with time series exceeding 70 years, used in this study.

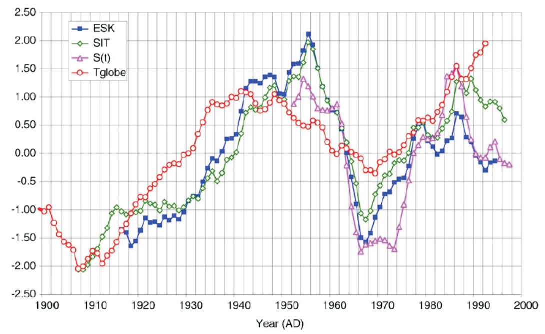


11-year running averages of estimates of amplitudes (nT) of geomagnetic daily variations(*Sq*) in North (red), East (green) and Vertical (blue) components at the 14 observatories.



The root mean square amplitudes of filtered *Sq* at the 14 selected observatories (upper panel) and solar irradiance proxies (EUV band), *F10.7* radio flux and *E10.7* (lower panel) in solar flux units.

The main cause for the patterns in the long-term diurnal variation is thought to be related to changes in the solar irradiance spectrum in the EUV band. This is demonstrated in the plot above right where it is clear that the extrema in the different time series coincide. Although the cause of the observed longer term upward trend in *Sq* amplitude is not certain, interestingly it does agree with the upward trend in geomagnetic activity as shown by *aa* and with the analysis presented by Le Mouël *et al* (2005). In a recent review Courtillot *et al* (2006) regard these similarities as evidence of solar origin for long-term *Sq* variation as well as the long-term magnetic storm increase.



11-year running averages of magnetic range indices, derived from both quiet and disturbed periods, at 2 observatories (Eskdalemuir and Sitka) compared to solar irradiance *S(t)* and global mean temperature *T*globe. (From Le Mouël *et al,* 2005, Courtillot *et al* , 2006 and references therein.) The data have been normalised so that the vertical axis is dimensionless and the curves directly comparable.

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