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Geomagnetic and Solar Variability and Natural Climate Change

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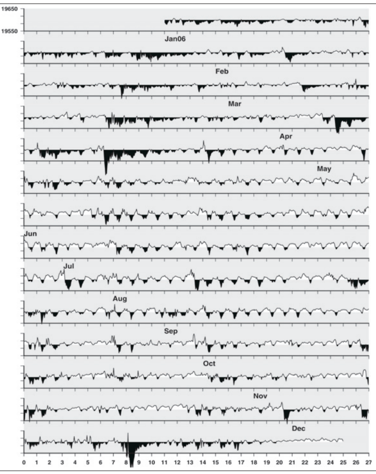
Introduction

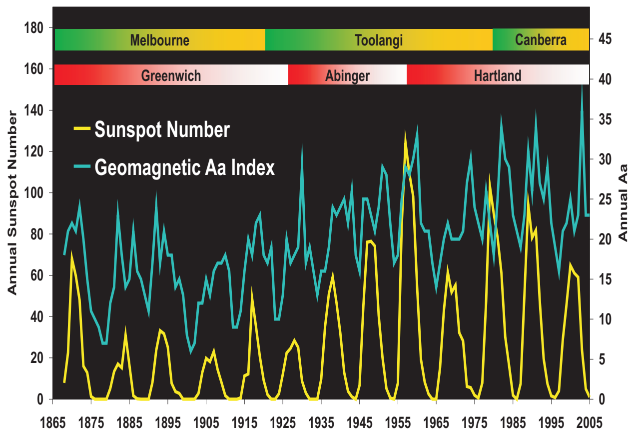
The Earth's magnetic field varies over many time scales. Whilst the slow secular variation of the strength and direction of the field over years to centuries is governed by processes in the fluid outer core of the Earth, the shorter variations, on time scales of seconds to years, are driven by the Sun. 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 and X radiation.

Controversy remains over what levels of solar variability are required to generate significant climate change and what the mechanisms are. We discuss here whether long-term changes in **the two phenomena mentioned above** can be useful proxies for changes in solar radiation, and thus be useful for studies attempting to answer these questions.

Above: A birdseye view of Hartland Magnetic Observatory, North Devon, which celebrated it's 50th anniversary in 2007, and provides data sets useful for long term studies.



Right: 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.



Above: Annual mean values of *aa* and sunspot number from 1868. Coloured time lines are also shown to indicate the observatories, in both hemispheres, that were used for the derivation of aa.

Long-term change in geomagnetic activity

Indices are often used to characterise geomagnetic activity and correlate well with solar activity indices. 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. *aa* extends back to 1868, one of the longest geophysical time series, and is clearly related to solar activity, parameterised here by the sunspot number (left). In particular during the minimum phase of the Sun's 11-year cycle there has been a steady increase in geomagnetic activity as characterised by *aa*.

The upward trend in magnetic activity over the last 80 years of the 20th century has been reported by many researchers and characterised by various indices and although debate continues over the detail, the trend is not in doubt. Clilverd *et al* (1998, 2002) have shown that the long-term trend in the *aa* index is of solar origin and not caused by instrumental, location or ionospheric changes. The *aa* index has been used quantitatively to derive the solar magnetic flux (right) and thus to infer that the solar coronal magnetic field increased significantly over the last century (Lockwood *et al,* 1999). This work coupled with the, as yet unexplained, correlation between geomagnetic activity indices, proxies for solar irradiance and global temperature until the mid-1980s, has triggered much debate on how much (and how) these natural changes affect Earth's climate.

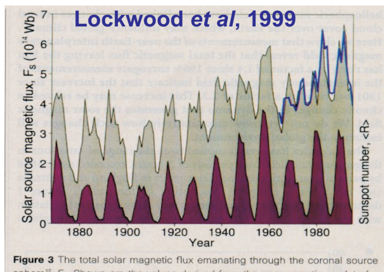
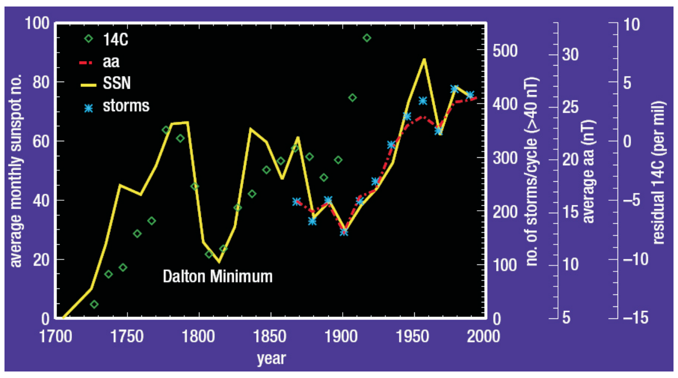


Figure 3 The total solar magnetic flux emanating through the coronal source sphere[12], F_S. Shown are the values derived from the geomagnetic *aa* data for 1868–1996 (black line bounding grey shading) and the values from the interplanetary observations for 1964–96 (thick blue line). The variation of 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.

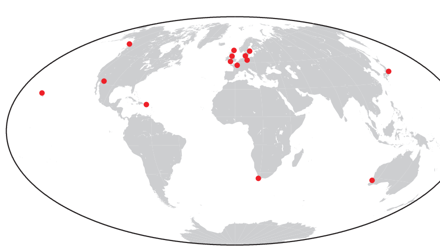
Three different proxies for solar variations over 300 years have been combined by Clilverd *et al* (2003): the sunspot number; the *aa* index, representing energy from the solar wind; and the variation of atmospheric radio carbon Δ^{14}C, representing solar irradiation, which extends much further back in time, but is anthropogenically contaminated in recent decades. The combined data were used in a superposed epoch analysis to speculatively predict a decrease in solar activity over the next century and thus conclude that any climatic changes due to solar forcing will not continue in the same way as in the previous century.



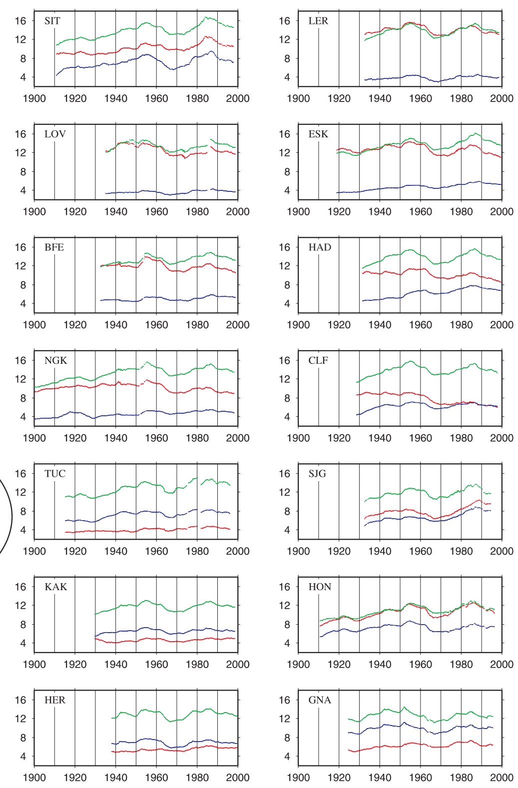
Right: The residual Δ^{14}C (diamonds) and sunspot number (solid line) since the Maunder Minimum of around 1700 and the total number of magnetic storms with *aa* > 40nT (asterisks) per solar cycle and the mean *aa* value (dotted line). Both the Maunder Minimum and the Dalton Minimum (shown) coincide with unusually cold periods reported for the northern hemisphere. (from Clilverd et al, 2003)

Long-term change in diurnal variation

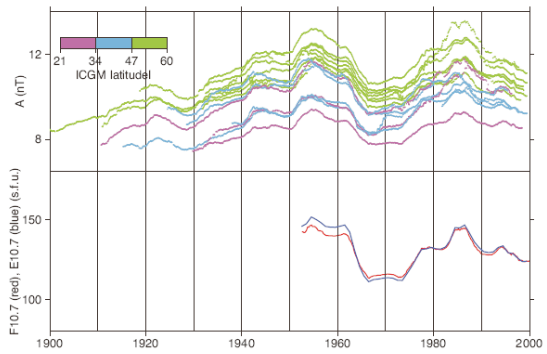
The regular diurnal variation of the geomagnetic field, *Sq*, which is generated by currents flowing in the ionosphere, is determined from the average of several days with minimal levels of geomagnetic activity. Its variation with solar radiation has been known for some time but what is less well understood 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, Macmillan and Droujinina (2007) determine 11-year average amplitudes of the daily variation at monthly intervals.



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



Right: 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.

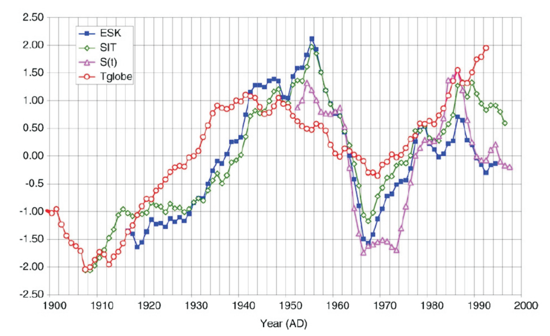


The root mean square amplitudes of filtered *Sq* at the 14 selected observatories, coloured by corrected geomagnetic latitude (upper panel) and solar irradiance proxies (EUV band), *F10.7* radio flux and *E10.7* (lower panel) in solar flux units.

The cause for the patterns in the long-term diurnal variation is related to changes in the solar irradiance spectrum in the EUV band. This is demonstrated in the plot above 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 irregular geomagnetic activity levels as indicated earlier using *aa* and with simple range indices using hourly mean values from single observatories in an analysis presented by Le Mouël *et al* (2005).

In a recent review, Courtillot *et al* (2007) regard these similarities as evidence of solar origin for long-term *Sq* variation as well as the long-term magnetic storm increase. They go on to show that these indices correlate with mean global temperature (until the end of 1980s) suggesting that there is solar forcing of both the Earth's magnetic field and the Earth's climate. Others (Bard and Delaygue, 2007) have declared this evidence as inconclusive, questioning whether it is correct to use terrestrial proxies for open solar magnetic flux to quantify total solar irradiance.



Above: 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 *Tglobe*. (From Le Mouël *et al*, 2005, Courtillot *et al* , 2007 and references therein.) The data have been normalised so that the vertical axis is dimensionless and the curves directly comparable.

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.

References

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