Long-term trends in geomagnetic daily variation

Susan Macmillan[1], Anna Droujinina[1] and Emma Woodfield[2]
[1] British Geological Survey, [2] Liverpool University

GEOSPACE meeting
5-6 January 2006
Leeds University

SUMMARY

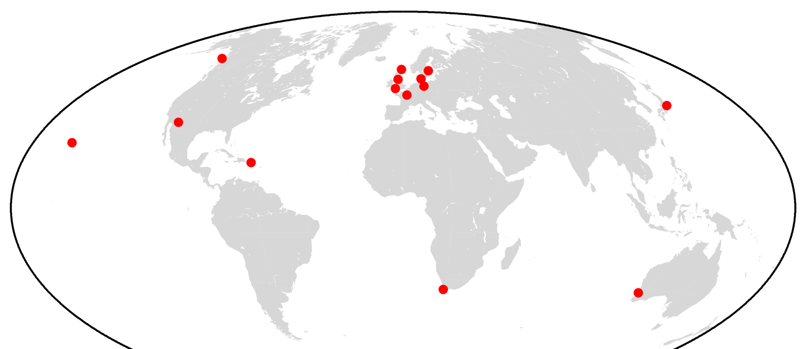
Long-term changes in the magnetic environment of the Earth are of interest to those studying climate change. To this end we examine long-term changes in daily variation as derived from hourly mean values from 14 geomagnetic observatories around the world. Their time series date back to the beginning of the 20th century. We find that there are similar features in all the records, with extrema in the amplitudes of the daily variation occurring in the 1950s, 1960s and 1980s, and a small upward trend of about 7% since the start of the century. The extrema coincide with those seen in proxy solar irradiance data, in particular the F10.7 flux density dataset. The most likely cause of the long-term increase is also related to the Sun but the possibility of processes inside the Earth contributing to this observation cannot be discounted. This work demonstrates the possibility of using long-term geomagnetic data as a proxy for processes in the upper atmosphere.

MOTIVATION

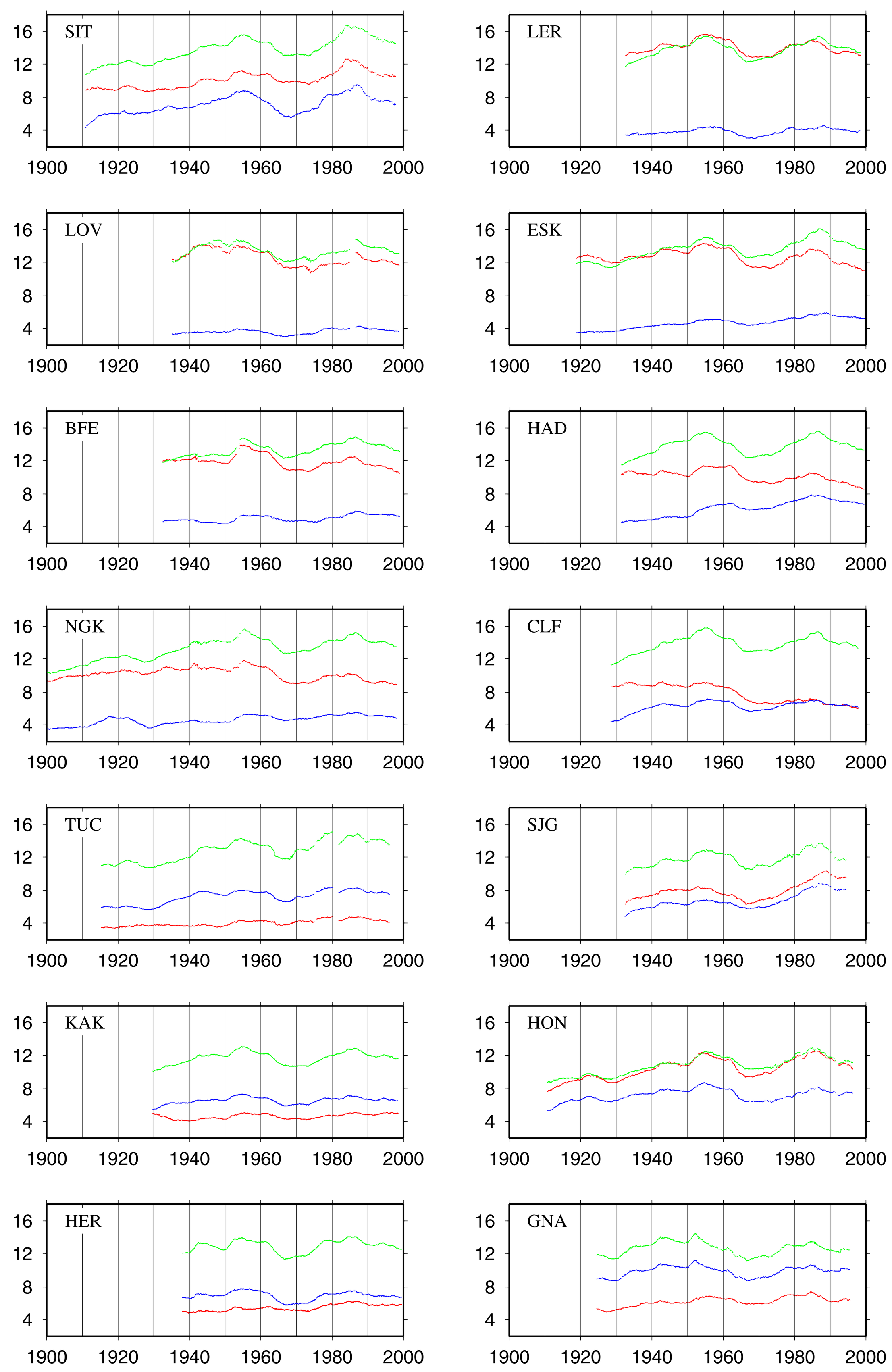
Long-term trends in magnetic activity levels as characterised by, for example, the *aa* index (Clilverd *et al*, 1998), inter-hourly variations (Svalgaard *et al*, 2004) and daily ranges of hourly mean values (Le Mouël *et al*, 2005) all contribute to understanding long-term changes in the Sun and near-Earth environment. These changes may have important impacts on climate studies. Here we concentrate on the regular magnetic daily variation, Sq, generated in the ionospheric dynamo, a region only 100-150 km from the Earth's surface.

METHOD

Fourier series (with periods 24, 12 and 8 hours) are fitted to hourly mean values from 5 quiet days per month at 14 observatories at mid and low latitudes with time series exceeding 70 years. Their locations are shown to the right.

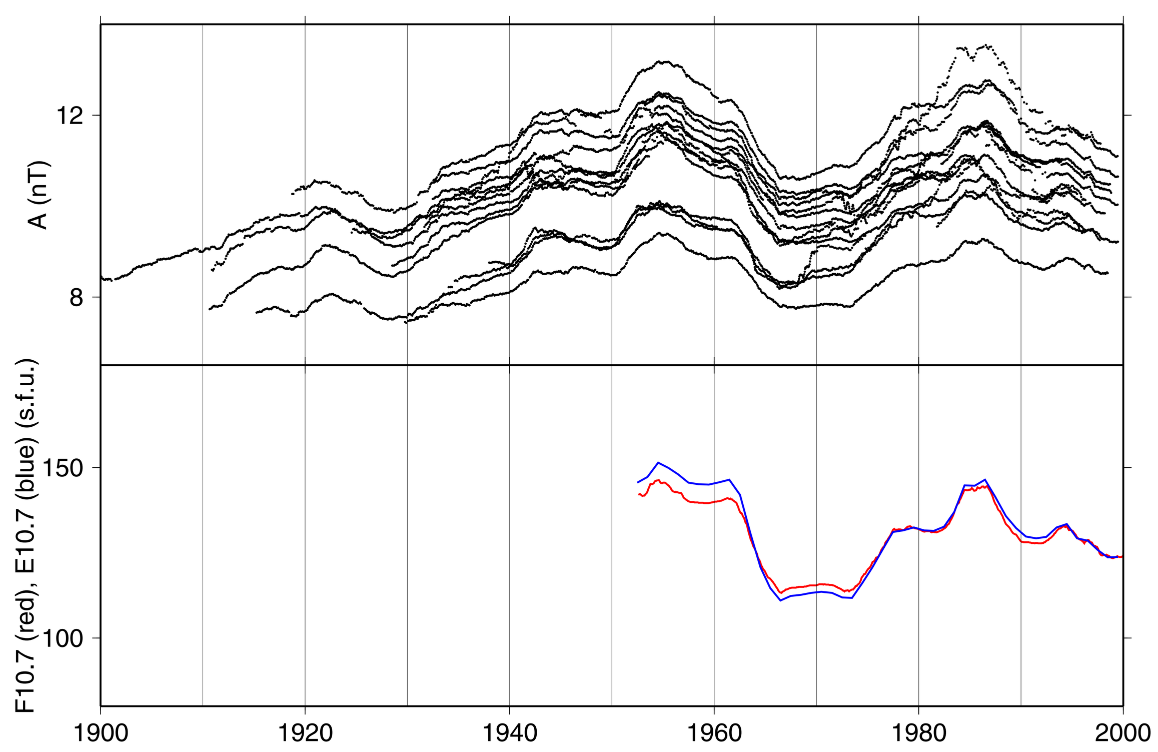


The semi-annual, annual and solar cycle signals are filtered out in the resulting series of estimates of the 24-hour amplitudes and phases by applying 11-year running means. Shown below are the filtered monthly estimates of amplitudes (nT) of geomagnetic daily variations in *X* (red), *Y* (green) and *Z* (blue) at the selected geomagnetic observatories ordered by corrected geomagnetic latitude from left to right, top to bottom.



The root mean squares of the smoothed *X*, *Y* and *Z* amplitudes are computed and compared with the F10.7 radio flux dataset which starts in 1947. This is the longest continuous dataset of energy output by the Sun and whilst it is only a proxy for part of the spectrum, it is the part that affects the ionosphere where Sq originates. We also use E10.7, a new proxy for the Extreme Ultra-Violet (EUV) irradiance output by the Sun from a self-consistent model of the solar spectrum, SOLAR2000 (Tobiska *et al*, 2000). This dataset may be a better characterization of the actual solar irradiance that deposits energy in the upper atmosphere, the main source region for Sq. As with the amplitudes, 11-year running means are applied to both F10.7 and E10.7 data series.

Shown below are the root mean square amplitudes of filtered Sq at the 14 selected observatories (upper panel) and solar irradiance datasets F10.7 and E10.7 in solar flux units (lower panel).



RESULTS

- *Y* component amplitudes > *X* or *Z* amplitudes
- No obvious dependence on latitude
- Extrema occur in the 1950s, 1960s and 1980s at all observatories
- The extrema in Sq amplitudes correlate very well with extrema in the irradiance datasets
- There is an increase of about 7% in the Sq amplitude from 1900 to 2000

INTERPRETATION

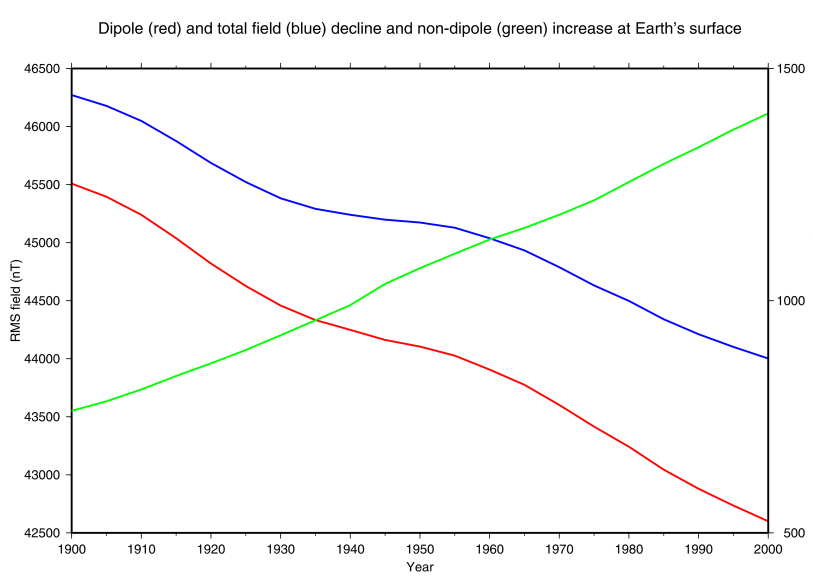
External causes

The main cause for the patterns in the magnetic data appears to be related to changes in the solar irradiance spectrum in the EUV band.

The upward trend agrees with that in the Sun's coronal magnetic field strength found by Lockwood *et al* (1999) from the *aa* index. This index has the daily variation accounted for in its derivation so it therefore characterizes the irregular activity which is a consequence of particle radiation from the Sun. An increase in the numbers, and energies, of charged particles from the Sun is likely to energize current systems inside the magnetosphere and the ionospheric dynamo at mid-latitudes may be strengthened.

Internal causes

During the 20th century there has been a decrease in the internal field, in both the dipolar and whole magnetic field as modelled at the surface of the Earth. This is shown to the right.



There are two important properties of the ionospheric dynamo layer that are affected by changes in the magnetic field strength, namely the magnitude of the conductivity perpendicular to the magnetic field and the mean height of the ionospheric dynamo layer. The conductivity perpendicular to the magnetic field is split into two components, Pedersen conductivity (parallel to the electric field) and Hall conductivity (perpendicular to the electric field). These are given by the following equations:

$$\sigma_P = (Ne/B)[f_P(\omega_e/\nu_e) + f_P(\omega_i/\nu_i)] \qquad \sigma_H = (Ne/B)[f_H(\omega_e/\nu_e) - f_H(\omega_i/\nu_i)]$$

where f_P and f_H are dimensionless functions of the ratio of the gyrofrequency to the collision frequency and
N is the electron density (assumed equal to the ion density)
e is the electron charge
B is the magnetic field strength
w_e is the electron gyrofrequency (=eB/m_e)
v_e is the collision frequency between electrons and neutrals
w_i is the ion gyrofrequency (=eB/m_i)
v_i is the collision frequency between ions and neutrals

Decreasing B will have two effects:

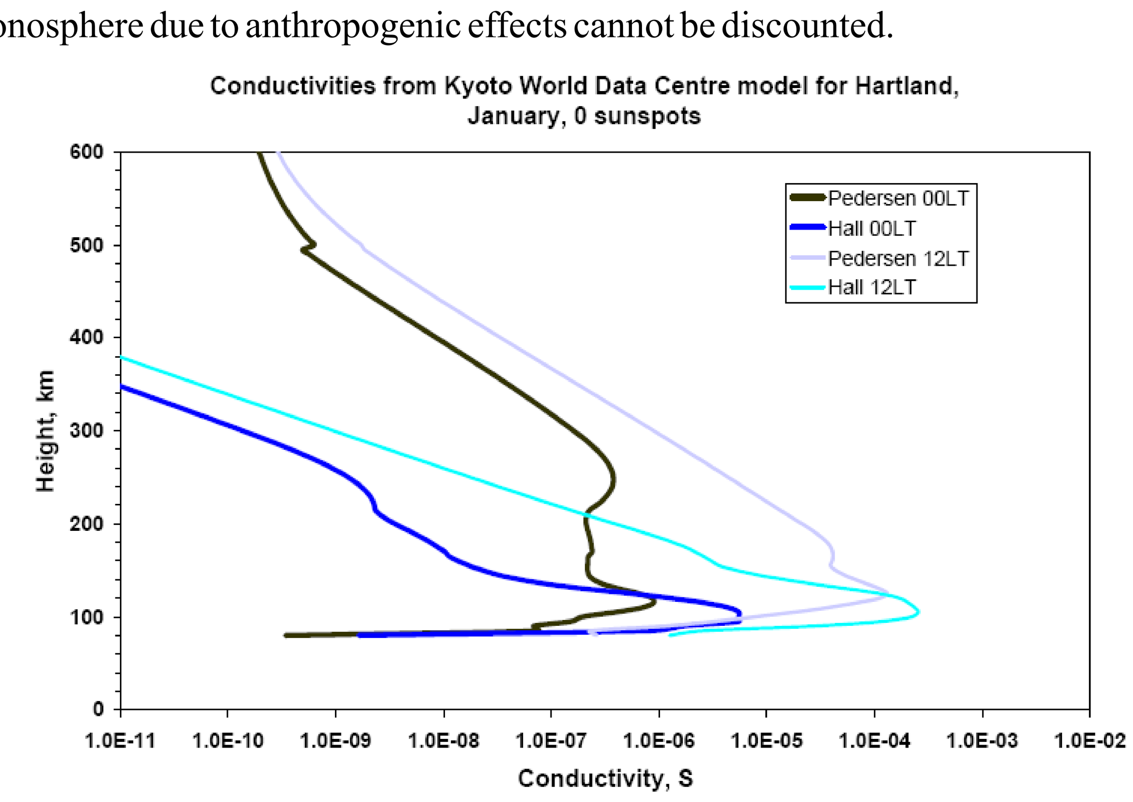
- an increase in both Hall and Pedersen conductivities - because of the multiplying factor (Ne/B)
- the height profiles for the conductivities will move upwards - because of the increase in the ratio of gyrofrequency to collision frequency

The first of these should increase the magnitude of the Sq current as seen from the ground and the second should decrease it. Typical height profiles of these conductivities are shown below.

It is also likely that the coupling of solar energy into a dipolar magnetosphere would be reduced with a decrease in the dipole but that the increase in its variability (i.e. becoming more quadrupolar, shown above) may increase the occurrence of conditions which favour reconnection with the interplanetary magnetic field (Vogt *et al*, 2004).

Other causes

Changes in the ionosphere due to anthropogenic effects cannot be discounted.



ACKNOWLEDGEMENTS AND REFERENCES

We thank the staff at the institutes involved in operating the observatories whose data were used in this study, the World Data Centres who collate and distribute them and the producers of the F10.7 and E10.7 datasets.

Clilverd, M. A., T. D. G. Clark, E. Clarke and H. Rishbeth, 1998. Increased magnetic storm activity from 1868 to 1995, *J. Atmos. Solar-Terr. Phys.*, **60**, 10, 1047-1056.

Le Mouël, J.-L., Kossobokov, V. and Courtillot, V., 2005. On long-term variations of simple geomagnetic indices and slow changes in magnetospheric currents: The emergence of anthropogenic global warming after 1990? *Earth Planet. Sci. Lett.*, **232**, 273-286.

Lockwood, M, Stamper, R. and Wild, M. N., 1999. A doubling of the Sun's coronal magnetic field during the past 100 years. *Nature*, **399**, 437-439.

Svalgaard, L., Cliver, E. W. And Le Sager, P., 2004. IHV: A new long-term geomagnetic index. *Adv. Space Sci.*, **34**, 436-439.

Tobiska, W. K.; Woods, T.; Eparvier, F.; Viereck, R.; Floyd, L.; Bouwer, D.; Rottman, G.; White, O. R.,2000. The SOLAR2000 empirical solar irradiance model and forecast tool. *J. Atmos. Solar-Terr. Phys.*, **62**, 14, 1233-1250.

Vogt, J., B. Zieger, A. Stadelmann, K.-H. Glassmeier, T. I. Gombosi, K. C. Hansen, and A. J. Ridley, 2004. MHD simulations of quadrupolar paleomagnetospheres, *J. Geophys. Res.*, **109**, A12221, doi:10.1029/2003JA010273.