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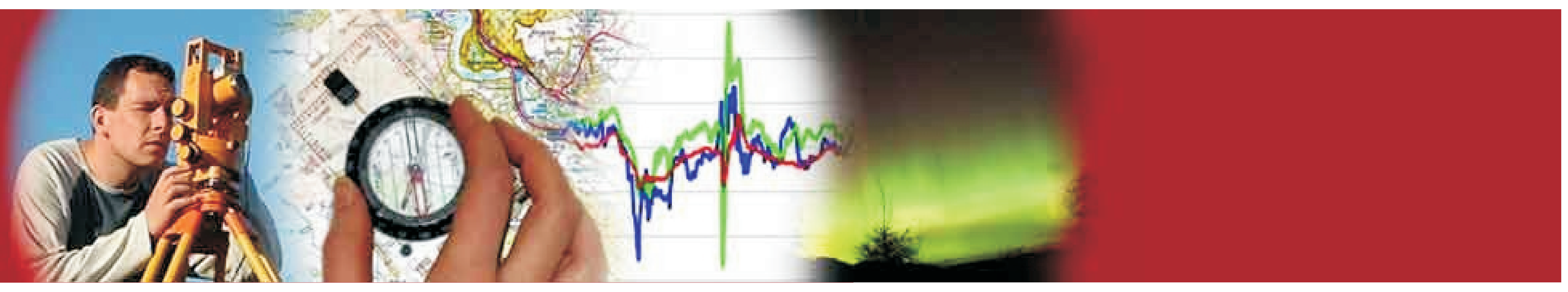

Long-term trends in geomagnetic daily variations

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SUMMARY

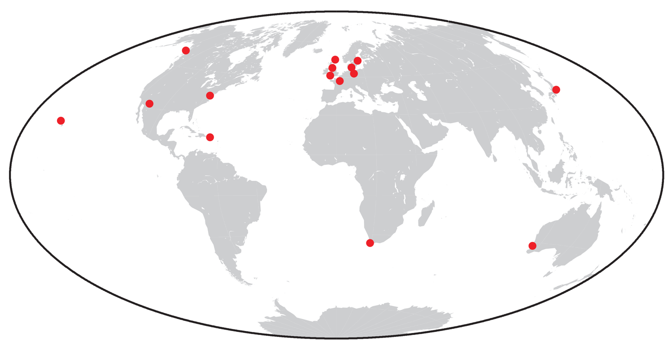
Long-term changes in the magnetic environment of the Earth are of interest to those studying space weather and climate change. To this end we examine changes in daily variation as derived from hourly mean values from 15 geomagnetic observatories around the world with records extending back to 1900. For the period after 1947 we, not surprisingly, find correlations with the F10.7 flux density, a solar irradiance proxy. We here examine a more robust technique of removing the solar cycle signal than simply applying 11-year running means. This involves a procedure developed by Lockwood and Fröhlich (2007) to account for the variations in the solar cycle length. We find a long-term increase in the amplitude of the daily variation since 1900, confirming earlier results using fewer data from fewer observatories and 11-year running means (Macmillan and Droujinina, 2007). 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.

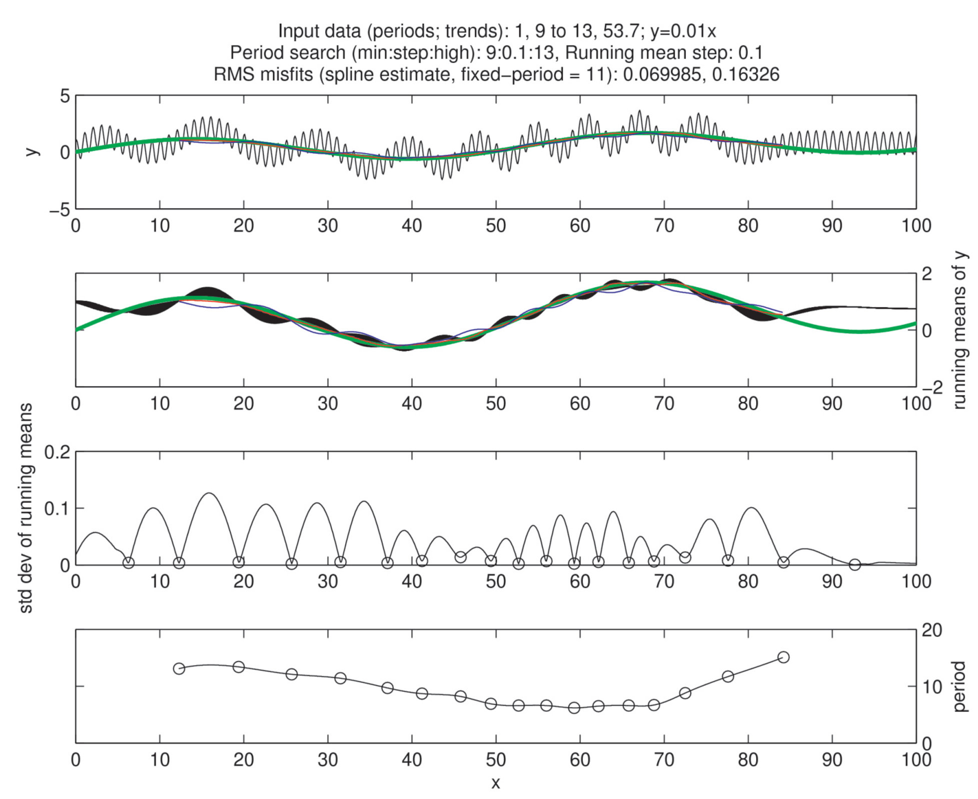
METHOD

Fourier series (with periods 24, 12 and 8 hours) are fitted to hourly mean values from 5 quiet days per month at 15 observatories at mid and low latitudes with time series exceeding 70 years. Their locations are shown to the right.

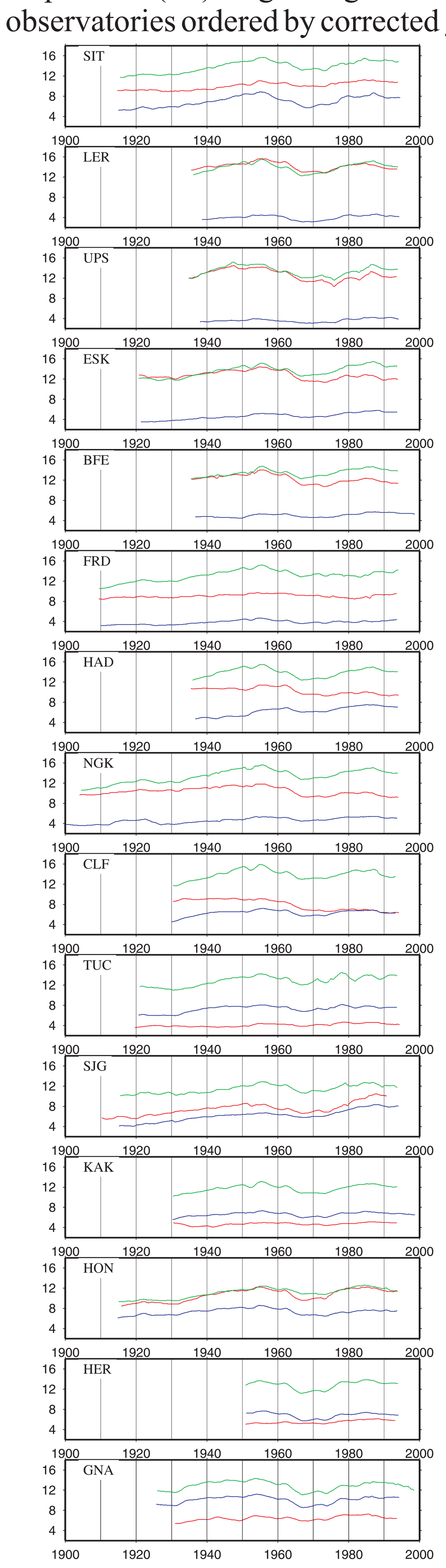


The semi-annual, annual and solar cycle signals are filtered out in the series of estimates of the 24-hour amplitudes following the method of Lockwood & Fröhlich (2007) - henceforth referred to as LF. Figure below shows comparison of this method to a fixed 11-year running mean on synthetic data (black curve, top panel) consisting of: annual and long (> solar cycle) signals as well as linear trend plus a signal of variable period between 9 and 13 years. The desired filtered signal is the long period plus linear trend (green curve, 1st and 2nd panel). The steps are:

- Apply 1-year running mean to data to remove known periodicities (annual/semi-annual)
- Compute running means between 9 and 13 years in steps of 0.1 year at 0.1 year intervals (black curve 2nd panel)
- Determine standard deviations of running means at each time step (black curve 3rd panel)
- Find minima in standard deviations (circles, 3rd panel). These minima correspond to points in the time series that are least sensitive to the running mean period
- Derive estimate of time period at each minimum from the time between minima before and after (circles 4th panel)
- Fit cubic spline to these periods to form smooth profile over time series (black curve, 4th panel)
- Recompute running means at each time step using periods derived from cubic spline (red curve, 1st and 2nd panels)



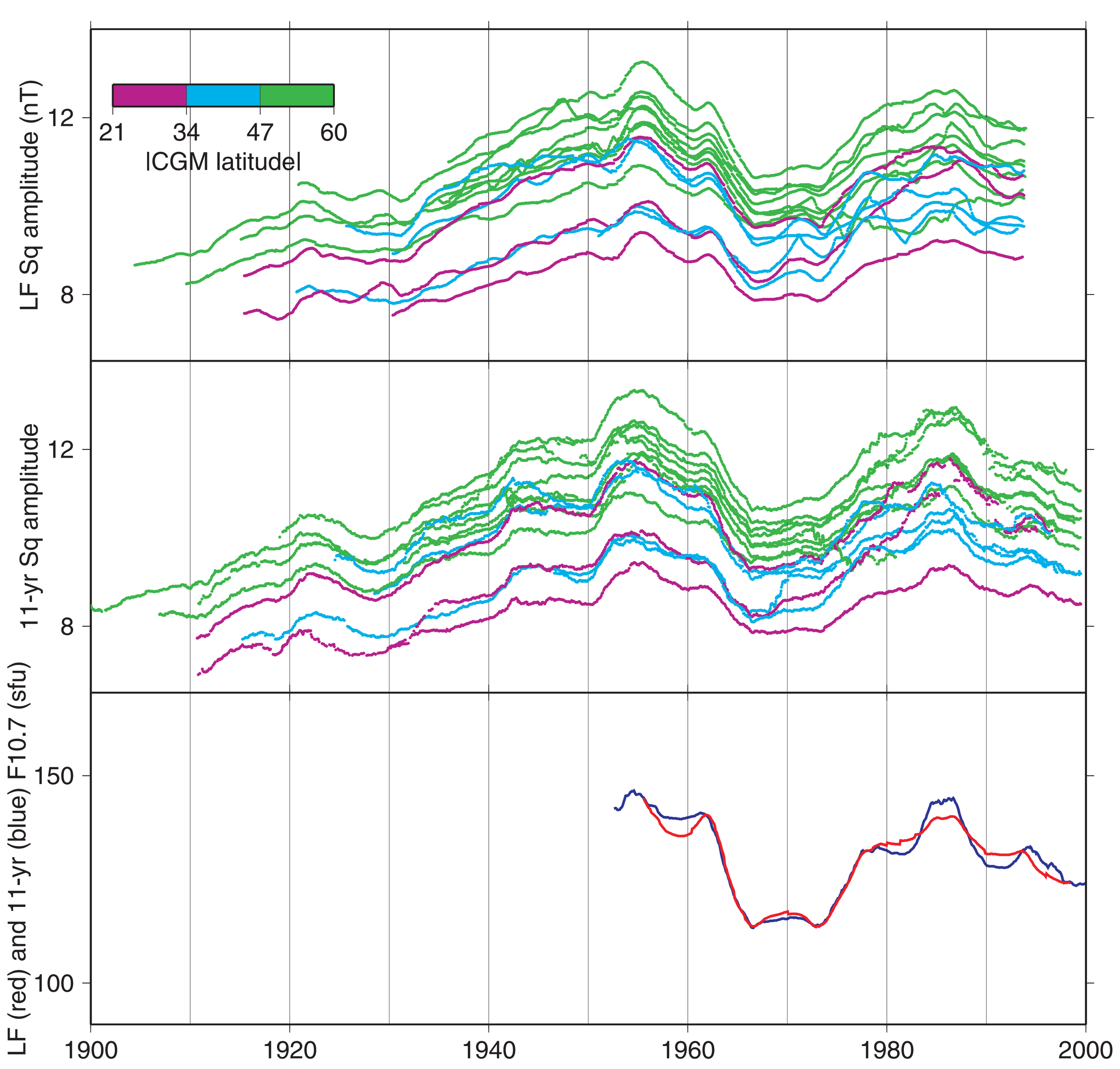
With this synthetic data test the RMS misfit between desired signal and LF filtered data is ~50% lower than 11-year running mean method (blue curve, 1st and 2nd panels). Shown below are the filtered monthly estimates of amplitudes (nT) of geomagnetic daily variations in *X* (red), *Y* (green) and *Z* (blue) at the selected geomagnetic observatories ordered by corrected geomagnetic latitude.



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.

Shown below are the amplitudes of LF filtered Sq at the 15 selected observatories colour-coded according to corrected geomagnetic latitude (upper panel), the amplitudes of 11-year box-car filtered Sq (middle panel) and the LF filtered F10.7 series (lower panel).

One disadvantage of the LF procedure is the difficulty in determining the minima in the standard deviations and this is the reason why the resulting filtered data series are shorter than those when an 11-year box-car filter has been applied.



RESULTS

Differences between data filtered using Lockwood and Frölich procedure and 11-year running means are < 0.5 nT

Y component amplitudes > *X* and *Z* components (geometry of the main field)

Maxima in the 1950s and 1980s occur in all datasets

Amplitudes increase with corrected geomagnetic latitude

~10% increase in amplitudes over 100 years

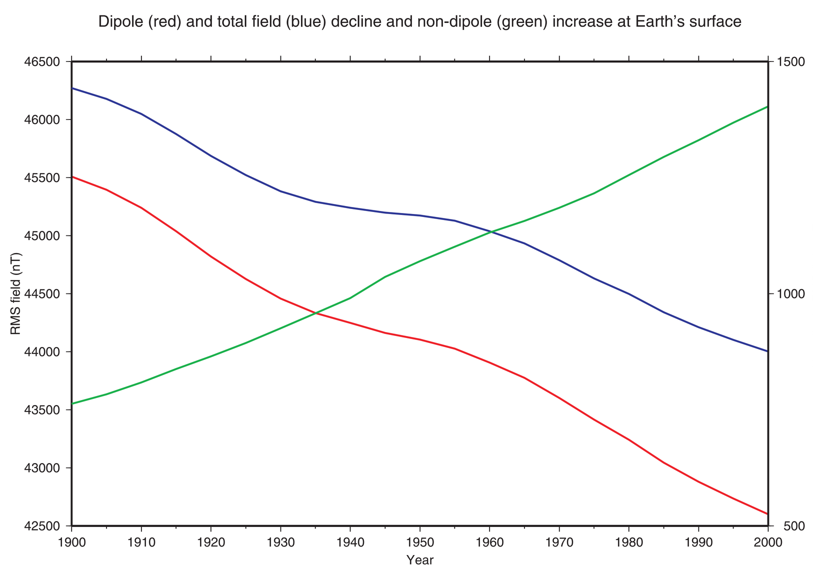
INTERPRETATION

External causes - changes in solar irradiance spectrum

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.

Internal causes - effects of changes in core-generated field on ionosphere

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.



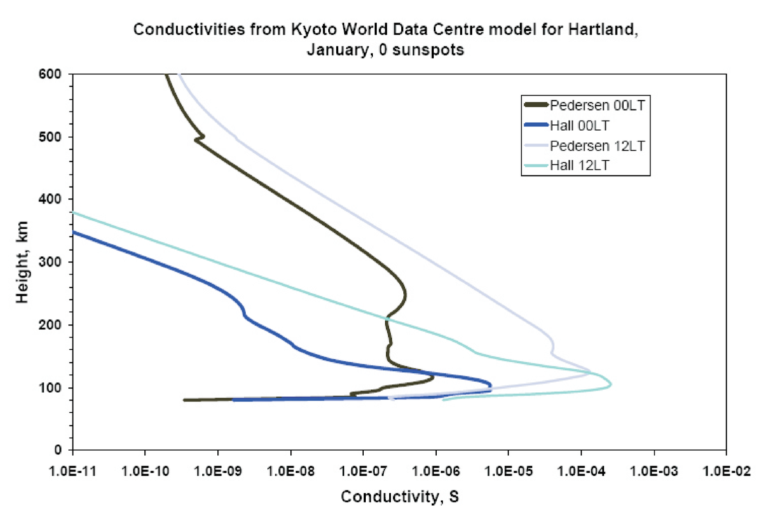
There are two important properties of the ionospheric dynamo layer that are affected by changes in the magnetic field strength, namely the magnitude of the conductivity perpendicular to the magnetic field and the mean height of the ionospheric dynamo layer. The conductivity perpendicular to the magnetic 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 the altitude of largest conductivities are found where $w_e = v_e$ (Clilverd et al., 1998). As the gyro-frequency decreases with B this point will move to higher altitudes.

The first of these should increase the magnitude of the Sq current as seen from the ground. The second effect is similar to that shown in the conductivity height profile plot below; the impact on the Sq amplitude at ground level is likely to also be an increase. 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).



ACKNOWLEDGEMENTS AND REFERENCES

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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. and Fröhlich, C. , 2007. Recent oppositely directed trends in solar climate forcings and the global mean surface air temperature, *Proceedings of The Royal Society A,* **463**, 2447-2460.

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.

Macmillan, S and A. Droujinina, 2007. Long-term trends in geomagnetic daily variation. *Earth, Planets and Space*, **59**, 391-395.

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

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.