EXTRACTING LONG-TERM TRENDS IN GEOMAGNETIC DAILY-VARIATIONS AND INDICES

Brian Hamilton (bham@bgs.ac.uk), Susan Macmillan
British Geological Survey, West Mains Road, Edinburgh EH9 3LA, United Kingdom

Abstract
Long-term changes in the Earth’s magnetic environment are of interest to those studying space weather and climate change and could act as proxies for processes in the upper atmosphere and the Sun-Earth environment. To this end we examine changes in the amplitudes of the geomagnetic daily variation and activity indices as derived from geomagnetic observatories around the world with records extending back to 1900. One obstacle to extracting long-term trends is the dominant role of the solar cycle in the behaviour of these quantities. Since the solar cycle length is variable, care must be taken when removing its effect to reveal longer-term trends. We compare two different techniques for removing the variable solar-cycle signal: a method developed by Lockwood and Fröhlich (2007) that uses a range of running mean periods; and a simple wavelet analysis. We also compare these techniques to a simple 11-year running mean and comment on the robustness of the results.

Motivation
Long-term trends in magnetic activity levels as characterised by, for example, the aa index (Clilverd et al., 1999), inter-hourly variations (Svalgaard et al. 2004) and daily ranges of hourly mean values (Le Mouël et al., 2002) 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
To generate the required time-series, we fit Fourier series (with periods 24, 12 and 8 hours) 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.

We then trial two methods of removing the quasi-periodic solar cycle variations from the time-series: Lockwood & Fröhlich (2007) (henceforth LF), and a simple wavelet analysis following Torrence & Compo (1998). Below we show an example of applying each method to Y component data from Hartland.

Wavenet method (right)
Top panel: take time series (black curve) and remove annual & semi-annual signals (giving blue curve).

2nd panel: compute running means between 9 and 13 years at each time step (black curve).

3rd panel: calculate standard deviations of running means at each time step then find minima in these standard deviations.

Bottom panel: derive estimate of solar cycle period from the time between minima in 3rd panel. Recompute running means at each time step using periods derived from cubic spline (red curve, 1st and 2nd panels).

Lockwood & Fröhlich method (left)
Top panel: Take time series (black curve) and remove annual & semi-annual signals (giving blue curve).

2nd panel: compute running means between 9 and 13 years at each time step (black curve).

3rd panel: calculate standard deviations of running means at each time step then find minima in these standard deviations.

Bottom panel: derive estimate of solar cycle period from the time between minima in 3rd panel. Recompute running means at each time step using periods derived from cubic spline (red curve, 1st and 2nd panels).

Results and Interpretation

Differences between trends using Lockwood and Fröhlich procedure, 11-year running mean, and wavenet method are ~< 0.01 nT/year, which holds for all indices and on general trends of the F-10.7 data. The trend in the component is either zero or positive at all observatories. For the Y component, the trend is positive with the exception of GNA. The X component is more variable with positive and negative trends at different observatories. There does not seem to be any obvious pattern in these trends in mid-latitude geomagnetic latitude, except perturbations in the X component, which is predominantly negative at high latitudes and positive at mid and low latitudes, although the sample is small.

The Ap and a index shows the same peaks in the 1950s and 1980s as the Sq amplitudes. The length of the aa time-series allows us to see another peak in the 1980s. The length of the Ap time-series is too short to derive a meaningful trend but the longer a index shows a trend of ~0.1/year.

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.

Decreasing B should increase both the Hall and Pedersen conductivities and so increase the magnitude of the Sq current as seen from the ground.

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 with favour reconnection with the interplanetary magnetic field (Vogt et al., 2004).

The different trends of the components of Sq could also be a result of the changes in the main field as the directions of the Hall and Pedersen conductivities are orientated by the electric and magnetic fields in the ionosphere. Changes in the main field could shift the pattern of conductivities affecting each component differently.

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