An interhemispheric comparison of the geomagnetic activity signature in the lower atmosphere

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The geomagnetic activity signature in the southern hemisphere atmospheric circulation is examined and the results are compared to those of Palamara and Bryant (2004) and other researchers for the northern hemisphere. Sliding correlations are used with monthly data to identify temporal and seasonal aspects of a potential relationship between solar modulated geomagnetic activity and the southern annular mode, while the geomagnetic activity signature in both hemispheres is compared in zonal-mean zonal wind data. The results reveal that apart from a suggestive, but inconclusive, relationship between the geomagnetic AA index and an index of the southern annular mode in March, there is no evidence for a geomagnetic activity signature in the southern hemisphere troposphere.
Key words: Meterology and atmospheric dynamics (general circulation, climatology).

1. Introduction

Numerous studies have identified a link between solar-modulated geomagnetic activity and atmospheric circulation in the northern hemisphere lower atmosphere (see, for instance, Bucha and Bucha, 1998; Boberg and Lundstedt, 2002; Thejll *et al.*, 2003; Palamara and Bryant, 2004). By using either the North Atlantic Oscillation (NAO) index or an index of the Northern Annular Mode (also known as the Arctic Oscillation) as a measure of atmospheric circulation in the northern hemisphere, it has been demonstrated that:

1. Geomagnetic activity is positively correlated to indices of atmospheric circulation in the northern hemisphere, though this relationship is temporally constrained. Palamara and Bryant (2004), using sliding correlations, found that the onset of the correlations occurs around 1965. Other researchers (Bucha and Bucha, 1998; Thejll *et al.*, 2003) found a slightly later onset for the correlations, due largely to differences in methodology.
2. The relationship occurs only in boreal winter months. Thejll *et al.* (2003) demonstrated this using seasonal (three monthly) data, while Palamara and Bryant (2004) used monthly indices to reveal that the influence of geomagnetic activity is restricted to the stratosphere in December and evident in the troposphere only in January.
3. The geomagnetic forcing of the northern hemisphere lower atmosphere circulation occurs via the stratosphere, as shown by Thejll *et al.* (2003) in 20 hPa geopotential height data and Palamara and Bryant (2004) in zonal-mean zonal wind and temperature data extending from the surface to 10 hPa. Furthermore, Palamara and Bryant (2004) have shown that the relationship is dependent on the phase of the quasi-biennial oscillation (QBO); a strong relationship ($r = 0.85$) between the geomagnetic AA index and the NAM index is evident only when the QBO is in an easterly phase.

Given the uncertainties pertaining to the origin and nature of variations in the NAM/NAO, the relationship described thus far has important implications for the understanding of recent climate change (Palamara and Bryant, 2004). However, before this transient relationship can be both generally accepted and put to practical use, the temporal inconsistency in the correlations must be explained and a suitable mechanism must be demonstrated that couples solar-modulated geomagnetic activity to the lower atmosphere. In fact, the lack of a plausible mechanism has hindered the acceptance of solar-climate relationships since Herschel (1801) first suggested that climate might be linked to sunspots. It is therefore worthwhile examining the possible role of geomagnetic activity in the southern hemisphere atmospheric circulation, not only because the interhemispheric comparison of the geomagnetic activity signature in the lower atmosphere may help constrain potential mechanisms, but also because it is not known if solar-modulated geomagnetic activity is relevant to the southern annular mode. The *a priori* reason for expecting a correlation, however, is the strength of the corresponding northern hemisphere correlations described by Bucha and Bucha (1998), Thejll *et al.* (2003), and Palamara and Bryant (2004).

2. Data and Methods

Atmospheric circulation was parameterised by the Southern Annular Mode (SAM) index (also known as the Antarctic Oscillation index), which is provided online by Todd Mitchell (http://www.jisao.washington.edu/aao/) and extends from 1948 to 2002. All other data used in this study is the same as that employed by Palamara and Bryant (2004) to examine the geomagnetic activity forcing of the Northern Annular Mode. Specifically, Mayaud's (1972) geomagnetic AA index was obtained from the NOAA NGDC Solar Terrestrial Physics Division website (ftp://ftp.

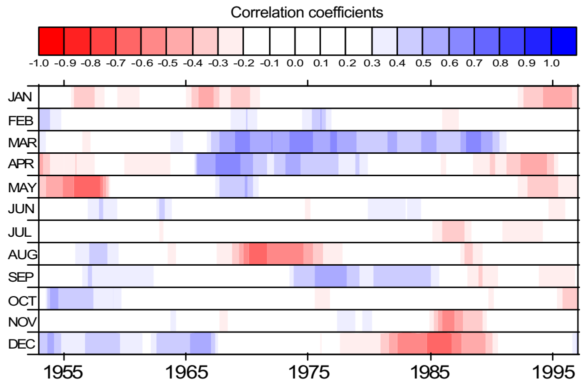

Fig. 1. Sliding correlations between the geomagnetic AA and SAM indices. The sliding correlation window width is 11-years, with a one-year increment. Correlation coefficients below 0.30 are unshaded. There is an overall lack of consistent, strong correlations for all months except March, indicating that solar-modulated geomagnetic activity is not a strong forcing mechanism for atmospheric circulation in the southern hemisphere. For March there is an interval between 1966 and ∼1990, for which the AA and SAM indices are mildly correlated ($r = 0.50$).

ngdc.noaa.gov/STP/SOLAR_DATA/RELATED_INDICES/), the NCER/NCAR reanalysis zonal wind data (Kalnay *et al.*, 1996) from the NOAA-CIRES Climate Diagnostics Center website (http://www.cdc.noaa.gov/cdc/reanalysis), and the quasi-biennial oscillation index, provided by Barbara Naujokat of the Freie Universität Berlin, from the Joint Institute for the Study of the Atmosphere and Ocean website (http://tao.atmos.washington.edu/data_sets/qbo/).

In the first phase of the analyses, the temporal and seasonal aspects of the relationship were examined using sliding correlations, with an 11-year window, between the geomagnetic AA index and the SAM index. The use of the 11-year sliding correlations results in the loss of five years of data from the analyses, limiting the results to the interval 1953 to 1997. In the next phase of the analyses the original unfiltered geomagnetic AA index was correlated to zonal-mean zonal wind data. The seasonal aspect of the potential relationship is examined by presenting correlations for each month separately. The results for all months are shown so as not to overlook a possible geomagnetic activity signature in zonal wind that is not reflected in indices of the annular modes. The zonal wind data are from the NCEP/NCAR reanalysis data set; consequently they should be interpreted with caution due to quality issues with the data in the southern hemisphere prior to 1979 (see, for example, Tennant, 2004).

3. Results

Figure 1 shows the results of the sliding correlations between the AA and SAM indices. The correlations are gener-

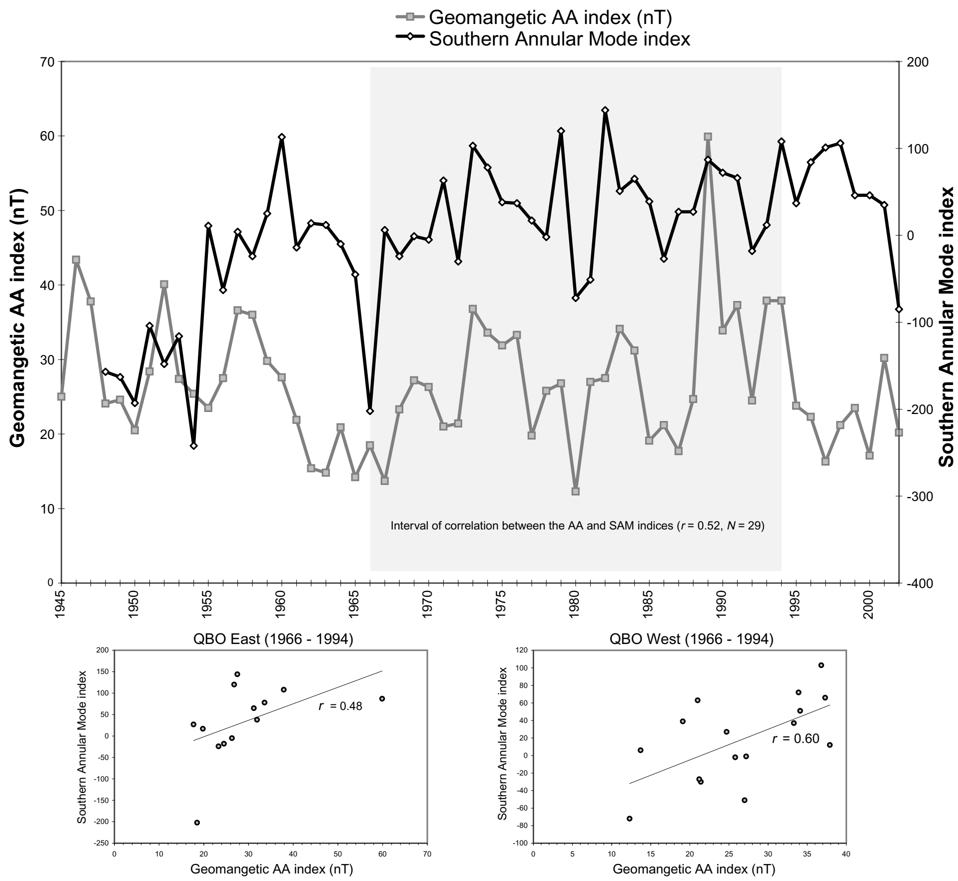

Fig. 2. The March AA and SAM indices. The interval for which the two time series show similarity, 1960–1994, is highlighted. The correlation coefficient between the two series for this interval is 0.52, which is statistically significant at the 95% confidence level ($N_{eff} = 29$). Also shown are scatterplots for the March AA and SAM data for both phases of the QBO. For the QBO east data, from 1966 to 1994, the AA and SAM indices are not well correlated ($r = 0.48$, $N = 13$). For the QBO west data there is some strengthening of the correlation ($r = 0.60$), though this may be the result of the reduced sample size ($N = 16$).

ally very low or non-existent, indicating that solar-modulated geomagnetic activity is not a dominant forcing mechanism for atmospheric circulation in the southern hemisphere. The absence of strong, consistent correlations for the month of January are of particular interest, because this indicates that the geomagnetic activity signature prevalent in the northern hemisphere during this month does not occur simultaneously in the southern hemisphere. The seasonality of the geomagnetic activity signature in the northern hemisphere, wherein it is evident during December and January only, cannot therefore be attributed to the peak in insolation during January. The lack of correlations in and around June and July indicate that geomagnetic activity is not evident in the austral winter troposphere in the same manner as it is in the boreal winter troposphere, and the geomagnetic influence on climate, if real, cannot therefore be considered to be specifically a ‘winter’ phenomenon.

Overall, there is a general absence of strong, consistent correlations for all months except March, which displays a consistent period of moderate correlations from ∼1966 to 1990. The similarity between the AA and SAM indices during March actually continues until 1994; the similarity for the last for years is not evident from the sliding correlations due to the width of the correlation window but can be seen in Fig. 2, which shows the time series of the March AA and SAM indices. The correlation coefficient between the AA and SAM indices for this period is 0.52, which is statistically significant at the 95% confidence level using the actual number of observations ($N = 29$). The effective number of observations due to autocorrelation, calculated using the formula of Slonosky *et al.* (2000), is in this case is the same as the actual number of observations ($N_{eff} = 29$). When the correlations are restricted to March data for which the corresponding QBO index is westerly (see scatter plot in Fig. 2) there is a slight improvement in the correlations ($r = 0.60$), which although statistically significant at the 95% confidence level may be simply the result of the reduced sample size ($N = 16$). The correlation for QBO east years is not statistically significant ($r = 0.48$, $N = 13$).

Figure 3 shows the spatial signature of the geomagnetic activity index in zonal-mean zonal wind for each month of the period 1965 to 1997. This interval matches that used in Palamara and Bryant (2004) and allows a direct comparison of the geomagnetic activity signature already described for the northern hemisphere to a possible signature in the southern hemisphere. It also coincides roughly with the interval of correlations between the March AA and SAM indices identified thus far (1966–1994), thereby allowing this suggestive relationship to be verified or disproved using its spatial signature in the zonal wind data, which is discussed in the following paragraphs. In all cases, $N = 33$, requiring an approximate correlation coefficient of 0.35 for statistical significance at the 95% confidence level. The effective number of observations is not considered because the data have not been smoothed and the zonal wind time series are not strongly serially correlated.

The strong correlations in the northern hemisphere stratosphere in December and troposphere in January are clearly evident in Fig. 3, and form a dipole centred on ∼45°N. For March, a similar, though weaker, configuration is evident

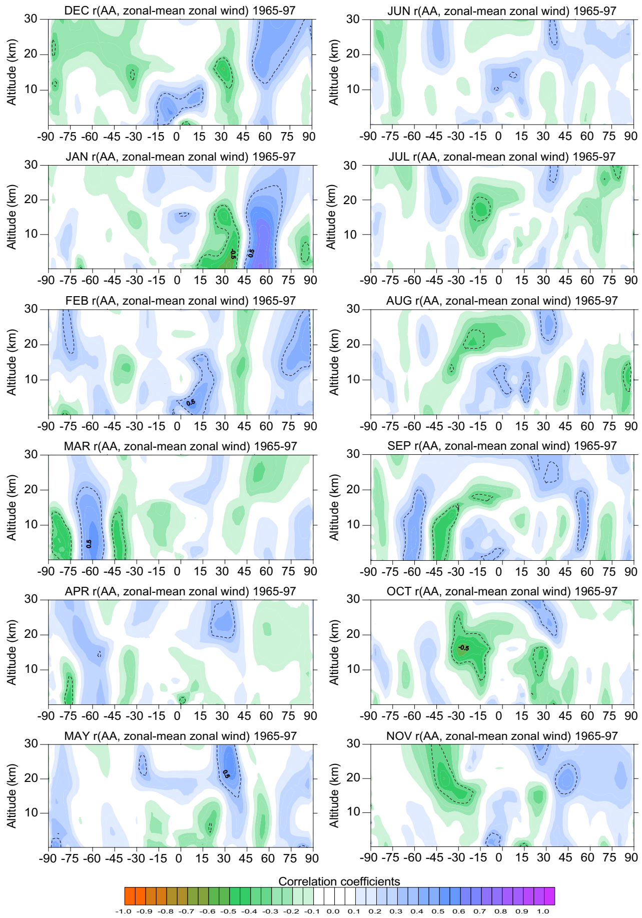

Fig. 3. Correlations between the geomagnetic AA index and NCEP/NCAR reanalysis zonal-mean zonal wind data, from 1965–1997, for each month. The zonal wind data consist of 17 geopotential height layers ranging from 10 hPa to 1000 hPa. The approximate threshold of statistical significance at the 95% confidence level is marked by a stippled line. The results clearly show the strong relationship between geomagnetic activity and atmospheric circulation evident in the northern hemisphere stratosphere in December and troposphere in January, as described by Palamara and Bryant (2004). The suggestive relationship between the March AA and SAM indices is also evident in the southern hemisphere as a dipole of relatively strong correlations centred on ∼45°S, but it is evident that there is no stratospheric precursor to this feature in the preceding months. There is no evidence for a strong geomagnetic activity signature during any other month, either in the troposphere or the stratosphere.

with an area of positive correlations centred on 60°S extending from the surface to ∼20 km altitude, with a maximum value of $r = 0.54$ at 60°S at a geopotential height of 400 hPa, and a smaller area of negative correlations centred on ∼40°S. The maximum negative correlation occurs at 77.5°S at a geopotential height of 925 hPa. In this regard the geomagnetic activity signature in the southern hemisphere differs to that of the northern hemisphere in that the extent of the negative correlations in the polar area is larger and the correlations are stronger.

There is no stratospheric precursor to the March geomagnetic activity signature in the troposphere. The dipole pattern of correlations occurs mainly in the troposphere, and the lack of large-scale correlations in the stratosphere for February or even January indicates that, even if the March correlations represent a ‘real’ phenomenon, stratospheric forcing is not involved. For the March geomagnetic activity signature there

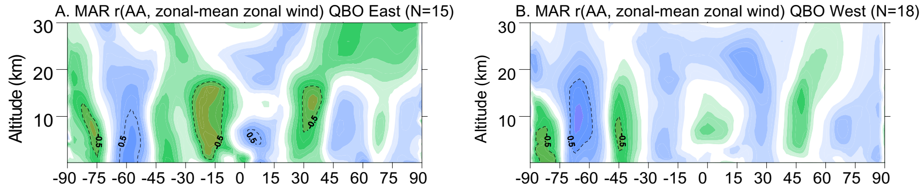

Fig. 4. Correlations between the March AA index and zonal-mean zonal wind data, from 1965–1997, for (A) QBO east years and (B) QBO west years. There is very little strengthening of the March geomagnetic activity signature in the zonal wind data when the data are separated according to the phase of the QBO.

is no strong improvement to the correlations when data are separated according to the QBO phase (Fig. 4). The mild strengthening of the correlations evident in Fig. 4 is due to the reduction in sample size, and when compared to the very strong signature associated with the January QBO east data presented in Palamara and Bryant (2004), the March results cannot be considered as anything more than suggestive. The fact that the QBO does not modulate the observed relationship further supports the conclusion that the stratosphere is not involved in the geomagnetic activity forcing of the March SAM.

A similar, troposphere-bound dipole-like geomagnetic activity signature is evident in the September data, though the magnitude of the correlations is smaller (the maximum correlation is 0.49 and occurs at the surface at 65.2°S). The coincidence of the March and September geomagnetic activity signatures is suggestive of an ‘equinoctial’ phenomenon, but since the September pattern is not represented in the sliding correlations presented earlier using indices of the SAM, it is very likely that it is the result of chance and does not warrant further investigation. There are no other strong correlations in any of the zonal-mean zonal wind data, even when the correlations are performed for separate QBO east and west phases (not shown).

4. Discussion and Conclusions

If the geomagnetic activity signature in the March SAM index for the interval 1966–1994 or the March zonal-mean zonal wind data is real, then the geomagnetic activity forcing of the southern hemisphere circulation operates in a distinctly different manner to that of the northern hemisphere. Unlike its northern hemisphere counterpart, the geomagnetic activity signature in the southern hemisphere does not involve the stratosphere, is not a winter phenomenon, and is not reliant on the QBO. It is interesting to observe, however, that the temporal pattern is very similar between hemispheres. Palamara and Bryant (2004) reported that the onset of the geomagnetic forcing of the NAM occurs in 1965, while the southern hemisphere March equivalent begins in 1966. At least for the northern hemisphere results, this temporal pattern may be related to the stratospheric regimes described in Christiansen (2003).

Despite this similarity, however, it is difficult to conclude that these results are anything more that a statistical coincidence. Unlike the corresponding northern hemisphere results, there is no underlying climatic variability mode in the southern hemisphere that matches the seasonal and temporal patterns of the results, and no suggestion of external forcing of the SAM during March for the interval noted here. In this light, the mechanism linking geomagnetic activity to the lower atmosphere must be able to accommodate the peculiarities of the northern hemisphere relationship, while explaining the lack of a geomagnetic activity signature in the southern hemisphere circulation.

It is therefore concluded that there is no strong evidence for a relationship between geomagnetic activity and atmospheric circulation in the southern hemisphere. Furthermore, because there is no geomagnetic activity signature in zonal wind data beyond that already identified in Palamara and Bryant (2004), the geomagnetic activity forcing of atmospheric circulation seems to be exclusively a northern hemisphere phenomenon.

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