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Inferring convective responses to El Niño with atmospheric electricity measurements at Shetland

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Abstract

Pacific ocean temperature anomalies associated with the El Niño–Southern Oscillation (ENSO) modulate atmospheric convection and hence thunderstorm electrification. The generated current flows globally via the atmospheric electric circuit, which can be monitored anywhere on Earth. Atmospheric electricity measurements made at Shetland (in Scotland) display a mean global circuit response to ENSO that is characterized by strengthening during ‘El Niño’ conditions, and weakening during ‘La Niña’ conditions. Examining the hourly varying response indicates that a potential gradient (PG) increase around noon UT is likely to be associated with a change in atmospheric convection and resultant lightning activity over equatorial Africa and Eastern Asia. A secondary increase in PG just after midnight UT can be attributed to more shower clouds in the central Pacific ocean during an ‘El Niño’.

Keywords: ENSO, potential gradient, teleconnection, lightning

1. Introduction and data sources

The fair weather atmospheric electric field is sustained through the global atmospheric electrical circuit, which is the world-wide link between convective electrification during storms and the distant fair weather electrification [1]. Atmospheric electricity can hence provide a novel monitoring system for remotely sensing electrically active storms when surface data are sparse [2]. Lightning distribution changes have previously been inferred [3] during El Niño–Southern Oscillation (ENSO) phases using the lightning-excited Schumann radio frequency resonance within the earth-ionosphere cavity. By exploiting changes in current flow directly within the global circuit, atmospheric electricity measurements made at Lerwick Observatory in the UK’s Shetland Islands are used here to examine electrified storms’ response to ENSO.

The most commonly observed surface atmospheric electricity measurement is that of the vertical potential gradient—the difference in electric potential between a point 1 m above the surface and the surface—which, in fair weather conditions, can be closely linked to global circuit current

flow [4]. UK Met Office standardized potential gradient (PG) measurements began at Lerwick in 1926 [5], but the meteorologically quiescent ‘fair weather’ atmospheric electricity conditions necessary to reduce local weather effects were only explicitly identified in the data from 1957. Additionally, nuclear weapon tests contaminated the data record from the late 1950s, so usable Lerwick fair weather PG data only extend from 1968 until the 1984 cessation of measurements. Despite this, using December data to minimize the effect of local electrical variability, PG and global air temperature appear correlated [6]. This relationship motivates further investigation of the interaction between global climate variables (specifically ENSO) and the global atmospheric electrical circuit.

Several measures of ENSO are available extending back historically during the Lerwick PG measurements, but the Niño3.4 anomaly index [7] is employed here. This index is determined from the sea surface temperature (SST) in the Pacific ocean region bounded by 5°N–5°S and 120°–170°W, from which the climatological mean (for the period 1950–79) has been subtracted to obtain temperature anomalies. The Lerwick PG was originally tabulated hourly from a chart

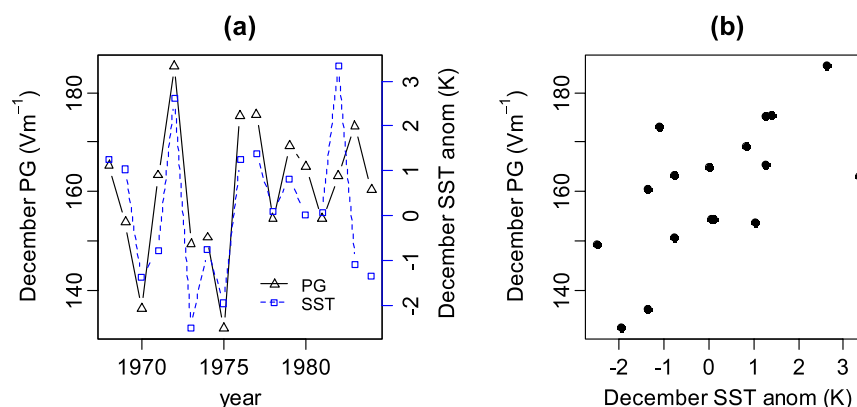


Figure 1. (a) Time series of mean fair weather potential gradient (PG), measured at Lerwick (December daily values only) and sea surface temperature (SST) anomaly from the Niño3.4 index for December. (b) PG plotted against SST anomaly, for the values in (a). (The gradient of a regression line fitted to the data is $(5.5 \pm 1.7)\% \text{ V m}^{-1} \text{ K}^{-1}$, where the uncertainty is one standard error. If the points are considered independent, the probability p that this arises by chance is 0.006.)

trace, with the hours marked if they met the conditions for ‘fair weather’ conditions (i.e. hours with no hydrometeors, no low stratus cloud, less than three-eighths cumuliform cloud and mean hourly wind speed was less than 8 m s^{-1}) [5]. A monthly average was calculated from all fair weather PG values; hourly averages by month were also found, from averaging all the values for the same hour in the month considered. Figure 1(a) shows the co-evolution of the December average PG at Lerwick in time with the December Niño3.4 index, illustrating how well these two quantities are correlated for a succession of years. The relationship is even more apparent from figure 1(b), which shows PG plotted against December Niño3.4 index; this implies that the global circuit strengthens as the Niño3.4 index becomes more positive (correlation coefficient $r = 0.64$), by $\sim 3.5\% \text{ K}^{-1}$ of SST anomaly.

2. Analysis

A well characterized aspect of the global circuit is its diurnal cycle, which is independent of the measurement location [8]. The robustness of this diurnal cycle permits further investigation of the underlying mechanism for the correlation in figure 1(a). This diurnal cycle in PG is known as the ‘Carnegie curve’ after the geophysical survey ship Carnegie of the 1920s which provided PG data demonstrating the diurnal cycle’s invariance with global position. The Carnegie curve shows a single oscillation, with a minimum at $\sim 3 \text{ UT}$ and a maximum at 19 UT . A close agreement between the Carnegie curve and the diurnal variation in global thunderstorm area was found [12], using areas obtained from analysis of thunderday statistics [13]. Figure 2(a) shows the classical Universal Time (UT) variation of global thunderstorm area [8], which also identifies the active source regions. When the Lerwick December PG data are averaged to give hourly values (figure 2(b)), the resulting diurnal cycle closely resembles the Carnegie curve, following the total thunderstorm area in figure 2(a).

Comparing the hourly PG data with the phasing known from figure 2(a) permits a more detailed analysis than just the

monthly mean PG values of figure 1(b). The hour by hour PG values can be correlated with the Niño3.4 index and the linear sensitivity found as before, to allow the response of the yearly PG to the SST anomaly to be attributed to different regions, using the Carnegie curve. Results from deriving the linear sensitivity of the PG at each hour are given in figure 2(c). The greatest PG sensitivity clearly occurs between 10 and 16 UT, which, when compared with figure 2(a), indicates a dominant positive African electrical storm response to ENSO. (Both afternoon UT, and to a lesser extent, post-midnight UT responses exceed 95% significance through a Monte Carlo procedure.)

3. Discussion

The curve in figure 2(c) is principally positive, consistent with figure 1, i.e. across the day, the Lerwick PG shows a proportionality to the Pacific temperature anomaly through the global circuit. The increased east/central African thunderstorm activity implied by figure 2 is consistent with other observations of ENSO effects, such as the observed increase in precipitation in Kenya and East Africa during an El Niño [9]. The increase in PG around midnight UT also apparent cannot, however, be explained by African thunderstorm activity. South American rainfall changes cannot explain the midnight peak either, as this region’s rainfall is known to decrease during the positive phase of ENSO [9]. A midnight UT response is consistent with more rainfall in the central Pacific ocean around the dateline during the positive phase of ENSO. Such a rainfall—and hence shower cloud—response is a classic response to ENSO, and also occurs at the correct local time [10]. One possible alternative explanation of increased North American lightning can be discounted because the data were obtained during the Boreal winter, at which time thunderstorm activity over North America is minimized. Even if, as for the 1997–98 El Niño [11], increased lightning occurred, the 1997 response primarily occurred over the Gulf of Mexico rather than in the continental interior, and therefore at a different local time [10].

Previous work identified an increase in lightning over the Maritime continent during the 1997–98 El Niño [15, 16],

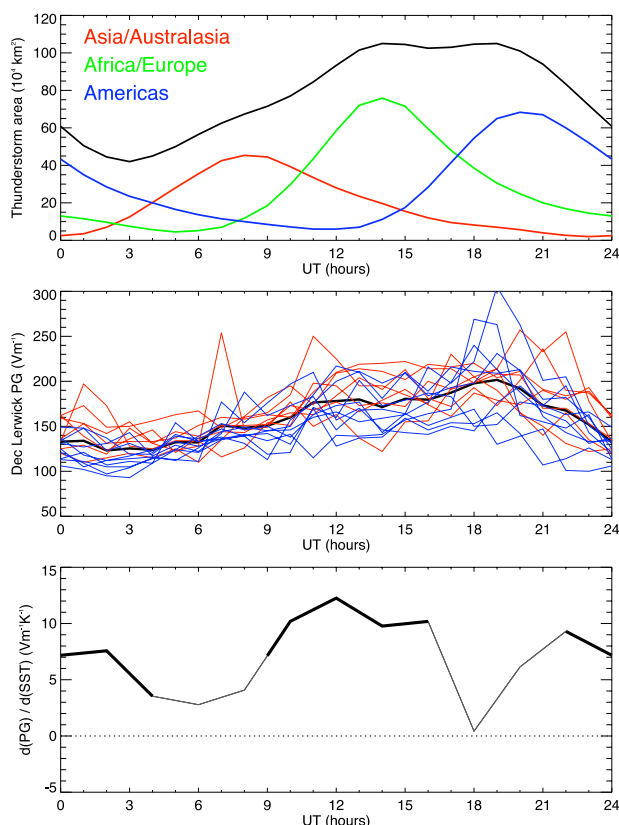


Figure 2. (a) Conventional estimation of diurnal variation in global thunderstorm area (units of 10 000 km²), with the relative contribution of geographical regions identified [4, 8, 12]. (b) Hourly averages of fair weather potential gradient (PG) at Lerwick in December, for each of 1968–84; positive (negative) Niño3.4 anomaly years are shown in red (blue), together with the mean over all the years 1968–84 PG (black). (c) Gradient of the linear regression between the 16 years of December PG data at each UT hour and the same years' Niño3.4 December anomaly, i.e. the linear response in PG to SST anomaly; the response at each hour is given, with the lines thickened for those hours when the relationship shows significance above 95%, as derived from a Monte Carlo method.

despite a reduction in rainfall over the Maritime continent being a key signal associated with the positive phase of ENSO. Such an increase might contribute to the signal before noon (UT). However, complex ocean–land interactions do obscure a clear diurnal cycle signature in precipitation over that region [10], and observations of lightning suggest an increase between 6 UT and 12 UT [15]. This may not be the only interpretation though, as electrified shower clouds also contribute current to the global circuit, without generating lightning [17]. Finally the smaller PG sensitivity around 18 UT hints at reduced South American thunderstorm activity, consistent with observations of reduced precipitation over large parts of the continent during an El Niño [9].

4. Conclusion

Our method diagnoses climatic phenomena by remote measurement of convective electrical activity embedded in the global circuit, which can assist in unraveling the detail

of the complex global scale relationships (teleconnections) with ENSO. The interconnectivity of the global circuit makes the measurement position unimportant; therefore contemporary [14] and historic PG data sources, some of which have already been identified [6], selected appropriately, may also reveal large-scale climatic phenomena, and hence should be examined for such signals.

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