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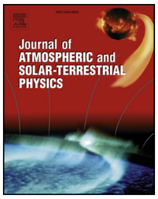

Fair weather criteria for atmospheric electricity measurements

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ABSTRACT

The global atmospheric electric circuit, which links the space environment with terrestrial weather, has mostly been investigated using fair-weather surface atmospheric electricity measurements. Retrieving global circuit information, however, requires the selection of “fair weather” data, to avoid local meteorological disturbances. The research results presented here challenge the applicability of long-standing definitions of electrically fair weather atmospheric conditions. From detailed new measurements and theory, three improved requirements (FW1 to FW3) for fair weather atmospheric electricity conditions are described. These are: (FW1) absence of hydrometeors, aerosol and haze, as apparent through the visual range exceeding 2 km, (FW2) negligible cumuliform cloud and no extensive stratus cloud with cloud base below 1500 m, and (FW3) surface wind speed between 1 m s^{-1} and 8 m s^{-1}. Automatic and manual measurement approaches to identifying these requirements are given. Through applying these criteria at the many measurements sites now operating, the noise from meteorological variability will be reduced, leading to data more representative of the global electric circuit.

1. Introduction

Surface atmospheric electricity measurements, typically those of the vertical electric field and the vertical current density have been made during the past 150 years, and are often undertaken to obtain information on the global atmospheric electric circuit. The global circuit concept, originated by CTR Wilson (e.g. Wilson, 1929), retains much value for understanding electric current flow in the troposphere (Rycroft et al., 2000, 2012; Tinsley, 2008). Some global circuit quantities are less sensitive to local effects than others, such as the positive potential at about 10 km above the surface (Markson, 2007). Although this potential is essentially a global parameter, it is not routinely measured because of the need for an ascending platform from which to make the measurements. In contrast, surface measurements are more abundant and readily obtained, but the global circuit influence is likely to be obscured in them by local factors such as aerosol pollution, radioactivity or meteorological disturbances.

Improvements in technology have contributed to renewed interest in providing atmospheric electricity measurements at many sites internationally. The GLOCAEM (GLObal Coordination of Atmospheric Electricity Measurements) project[1] is specifically intended to bring together many of the disparate sets of near surface atmospheric electricity measurements, as the lack of such data has been a major limitation for research in fair weather atmospheric electricity. It is therefore timely to consider how such data should be selected to minimise local effects. In this paper, considerations for effective data selection are discussed and the principal selection criteria identified.

The most commonly measured surface quantity in atmospheric electricity is the vertical electric field or Potential Gradient (PG), which represents the difference[2] in potential between two vertically separated points, the lower of which is typically the surface itself. This atmospheric property has been observed using a range of experimental techniques since the late 1700s (Chalmers, 1967; Israël, 1970). During the 1800s, such observations became increasingly systematic, most notably through Lord Kelvin's invention of the “water dropper” potential equaliser, implemented with photographic recording (Aplin and Harrison, 2013). Such a system was first installed at Kew Observatory, near London, in 1861 (Everett, 1868; Harrison, 2006). The Kelvin instrumentation became widely used, including during the 1890s for above-surface measurements on the Eiffel Tower (Harrison and Aplin, 2003) and in instrumented balloons from Salzburg (Tuma, 1899; Nicoll, 2012), as well as at the Scottish observatory of Eskdalemuir from 1910 to the 1930s (Harrison, 2003). As the practice of recording hourly PG measurements became more widely adopted at other sites, radioactive probe sensors were employed as they provided greater convenience compared with the Kelvin water dropper, for example at Porto Observatory (Portugal), Nagycenk Observatory (Hungary) and Lerwick Observatory (Shetland). Use of Kelvin water dropper technology

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[1] https://glocaem.wordpress.com.

[2] For a vertical component of the electric field E_z, the potential gradient F is given by $F = -E_z$. This sign convention is adopted so that, in locally undisturbed (fair weather) atmospheric electrical conditions, F is positive.

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continues at Kakioka Magnetic Observatory in Japan (Takeda et al., 2011).

Broader applications of PG measurements exist beyond investigating the global circuit. Past observations of PG at highly polluted sites have been interpreted as historical proxy air pollution measurements (Harrison, 2006; Aplin, 2012), as the PG increases in proportion to the aerosol concentration (Harrison and Aplin, 2002). Measurements of PG also respond sensitively to increased environmental radioactivity, which acts to reduce the PG (Hamilton, 1965; Pierce, 1972; Takeda et al., 2011). Fair weather PG observations can also provide a sensing method for obtaining characteristics of the atmospheric boundary layer (Anisimov et al., 2017, 2018).

Developments in electronic technologies now allow PG measurements to be obtained relatively easily using electric field mills. Field mills are robust instruments operating on electrostatic principles, often intended for lightning warning applications but nevertheless sufficiently sensitive to provide measurements in the much weaker electric fields necessary for global circuit analysis. Many field mills are also able to run continuously in hostile conditions, such as snow and heavy rain.

Before considering the perturbing effect of local conditions, it is important to point out that the absolute value of PG from a field mill, radioactive probe or Kelvin water dropper is affected both by the physical environment around the sensor as well as by the calibration of the sensor itself. Metal masts or guy lines act to distort the electric field environment, and therefore modify the PG which is measured. For PG measurements to be comparable with those at other sites, and remain independent of long-term changes occurring at the measurement site itself, the PG measurements need to be standardised to an open situation where there are no distorting effects. Methods for achieving this are briefly summarised in the Appendix.

In the following sections, previously-used criteria for fair weather data selection of PG are discussed (section 2). Section 3 presents new insights into local meteorological influences on PG, and section 4 proposes refined fair weather criteria, building on the additional information available through new high sampling rate PG measurements and modern instrument developments.

2. Data selection approaches

Approaches already used to select PG measurements are now summarised. Whilst ultimately the local effects on the PG at a site are random in some respects, allowing a mean global signal to emerge by averaging (e.g. for obtaining the diurnal cycle), the principle behind data selection is pragmatic, which is to reduce the amount of random local noise in the data through first removing values clearly dominated by local influences. This should provide the most effective use of the measurements made in exploring the related geophysical influences and phenomena.

2.1. Electrical character method

As mentioned above, many early installations of PG instrumentation apparatus occurred at existing geomagnetic observatories. Even the PG measurements made during the cruises of the survey ship *Carnegie,* of huge importance through their role in establishing the globally-synchronised single maximum in the diurnal variation of PG, arose from plans for a survey of geomagnetic measurements (Harrison, 2013). The geomagnetic heritage was influential. Daily geomagnetic recordings were originally classified by how disturbed they appeared in terms of the variability of the quantities measured: days were simply described as "Quiet" or "Disturbed". It is therefore perhaps not surprising that a similar approach to classification was initially applied to the atmospheric electricity records, in which variability was a known characteristic feature, famously remarked on by Lord Kelvin (Aplin and Harrison, 2013). The Carnegie Institution classified their PG data in this geomagnetism-inspired approach, as did the UK Met Office (UKMO).

Table 1
Met Office "electrical - character figure" classification system for daily Potential Gradient records.

First character	Requirement
0	**No negative PG measured**, midnight to midnight
1	**One or more negative PG measurements**, in total for less than three hours
2	**Negative PG measured**, with total duration longer than three hours
Second character	**Requirement**
a	**PG always less than 1000 V m^{-1}** throughout all 24 periods of one hour
b	PG greater than 1000 V m^{-1} for less than six individual hours
c	PG greater than 1000 V m^{-1} for more than six individual hours

The UKMO character system classified a day with solely positive PG values as of type "0", with "1" or "2" applied to days with increasing negative PG durations. A letter was added after the number to indicate the range of PG values (see Table 1).

Much as the "electrical character" classification system does serve to organise PG data, and was very effective in identifying the days used for further analysis from the *Carnegie* cruises, it leads to an inefficient use of data at sites which are subject to frequent weather disturbances. As an illustration, consider the case of a brief thunderstorm lasting an hour in an otherwise calm day. This would cause the UKMO character scheme to classify the whole day as disturbed or even highly disturbed, despite the fact that, for almost all the hours of the day, the conditions were not disturbed. Those undisturbed data values may nevertheless still contain globally-pertinent information.

2.2. Fair weather method

At Lerwick Observatory, where the weather is highly variable, the electrical character system was used from the outset of the site's measurements in January 1927 (Harrison and Nicoll, 2008). From January 1957, a modification was made in that only hours without precipitation were considered in obtaining the mean daily values. Further, from January 1964, a new selection system was employed experimentally, which classified values on an hour by hour basis, rather than using a single description for the entire day. An important aspect was that this classification was not made on the basis of the measured quantity itself, which can be regarded as effectively an arbitrary selection and therefore open to criticism, but by applying independent criteria based on the local meteorological conditions. To achieve this, hourly PG data values were individually designated as having "no hydrometeors" (i.e. no rain, hail or snow), or "fair weather" (OYB, 1922–1967).

Values identified as having been obtained during fair weather in the later period of the Lerwick site's operation during the 1970s show, on further processing, both a Carnegie curve diurnal variation (Harrison and Nicoll, 2008), and a relationship with sea surface temperatures modulated by El Niño (Harrison et al., 2011). These independent findings indicate that the hourly designation approach to data selection can be considered successful in extracting globally-relevant information.

To classify the hourly data values as having occurred during fair weather, the UKMO originally required that the following **four** meteorological criteria[3] were fulfilled:

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[3] These criteria were based on recommendations from a working group of the Joint Committee on Atmospheric Electricity, formed from the International Association of Meteorology and Atmospheric Physics (IAMAP) and the International Association of Geomagnetism and Aeronomy (IAGA).