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Atmospheric Electricity Data From Lerwick During 1964 to 1984

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ABSTRACT

A dataset of the atmospheric Potential Gradient (PG) from Lerwick observatory in Shetland is now available, which provides hourly-averaged PG for each month, from January 1964 to July 1984. The measurements were made consistently, with calibrated and well-maintained instrumentation. Co-located meteorological observations are also available from the same site, where disturbing effects of air pollution are small. Other sources of atmospheric data such as satellite observations became increasingly abundant during the era of the measurements, making broader comparisons possible. On average, the Lerwick PG measurements contain a diurnal cycle characteristic of the global circuit and show relationships with the El Niño-Southern Oscillation (ENSO), especially in December. The value of the data is in the information it contains about the global atmospheric electric circuit, which is embedded in the climate system.

1 | Introduction

A long series of atmospheric electricity measurements was made at Lerwick observatory in Shetland by the Met Office, between 1925 and 1984 (Harrison and Riddick 2022). This dataset is being progressively transcribed from the original paper records of individual hourly samples to digital form, through a Citizen Science project[1]. This paper describes the later part of the data recently made available (Mkrtchyan et al. 2024) and summarises the properties found. Surface measurements from a single site can provide information on the global atmospheric electric circuit, which couples charge separation in disturbed weather regions of the planet with fair weather regions (Figure 1a). The global circuit is sensitive to internal climate variability and, separately, to changes in space weather conditions: the dataset therefore has a range of applications.

Lerwick observatory is at a remote site (60°08′17″ N 1°10′56″ W), on land at 85 m asl above the small town of Lerwick in the Shetland Isles, Figure 1b. Climatological mean properties for the site offer a basic characterisation of conditions at the site (Met Office, n.d.). For the relevant climatological interval 1971–1990, the site had a mean annual rainfall of 1238 mm, with 198 days annually having 1 mm or more. The warmest month was August, with a mean maximum temperature of 14.2°C; the coldest month was February, having a mean minimum temperature of 1.4°C. In this period, Lerwick had an annual average of 1067 sunshine hours, ranging from 14.9 h of sunshine in December to 124.6 h in August. The mean wind speed was 8 ms^{-1}. There was lying snow for 30 days on average annually, between November and April.

The Lerwick atmospheric electricity dataset consists primarily of hourly potential gradient (PG) measurements, made using similar methods during the entire duration of the dataset. (Some air-earth current measurements were also made (Harrison and Nicoll 2008)). The PG is also sometimes referred to as the 'fair weather electric field' or 'atmospheric electric field'. These

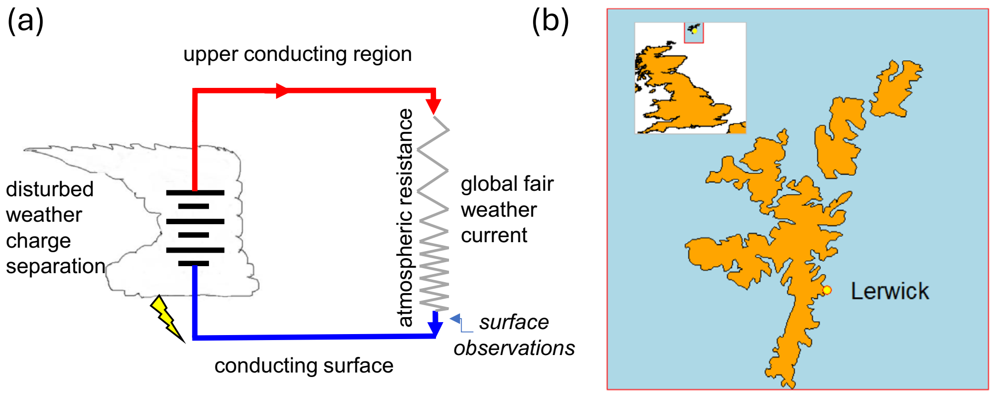

FIGURE 1 | (a) Simplified depiction of the global atmospheric electric circuit, in which current flows from disturbed weather regions through the conductive upper atmosphere to distant fair weather regions, passing through the varying electrical resistance of the atmosphere and returning through the planetary surface. (b) Location of the Lerwick observatory site in Shetland, to the north-east of the UK mainland.

descriptions reflect the historically important question of explaining why an electric field was observed to be constantly present in fair weather conditions, when no thunderstorms were nearby. The ubiquitous fair weather atmospheric electric field is now understood to arise from the charging action of distant tropical thunderstorms and shower clouds, conveyed through the global atmospheric electric circuit (Wilson 1929). It can be considered as the voltage developed across the lowest part of the resistance in Figure 1a. In fair weather conditions, the atmospheric electric field is negative and typically about (–) 150 Vm^{-1}. By convention, the PG is considered as positive in fair weather, but of the same magnitude as the electric field.

In the final decades of the Lerwick data series provided, the PG measurements were made using a radioactive probe and chart recorder system (Harrison and Riddick 2022). These measurements ceased in July 1984, probably related to the closure of Kew observatory at the end of 1980 due to economic pressures (Anonymous 1980), although 'organisation...of observations of... atmospheric electricity...' remained stated as a function of the Met Office in their 1985 annual report. (Anonymous 1985).

The dataset now available contains averaged hourly data for each month from January 1964 to July 1984, and some explorative investigations are discussed here. In section 2, details of the instrumentation and site are given, followed by a summary of the data properties in section 3. In sections 4 and 5, the measurements are examined for global circuit and climate signals. Conclusions are given in section 6.

2 | Site and Instrumentation

Lerwick observatory primarily provides meteorological and geomagnetic measurements (Tyldesley 1971). However, atmospheric electricity measurements were also made over a long period, and, as disturbing effects of air pollution at the site are small and co-located meteorological information is also available, the PG dataset from Lerwick seems especially valuable.

From the 1960s, the PG measurements were made with a radioactive probe sensor, which was exposed at the rear of the observatory building. The probe was connected to a valve electrometer of the Brewer design and a chart recorder (Brewer 1953). Values were read from the chart and tabulated. An important feature of the observations was the careful and regular attention given to calibrations and corrections. Corrections of the probe voltage measurements to the equivalent PG at an open site were made through the occasional use of a stretched wire electrometer system, which provided absolute measurements of the atmospheric electric potential at the height of 1 m. By comparing measurements made simultaneously with the stretched wire sensor and the radioactive probe, a correction (or reduction factor) could be found, allowing conversion of the probe's voltage measurements to the equivalent PG values which would have been obtained over a flat open surface. These reduction factor determinations were made regularly, and any small variations were smoothed before applying them to the Brewer chart recorder measurements.

3 | Data Overview

The data files provide, for each month, twenty-four PG values, which are the average hourly values of PG for that month. Each hourly value is centred on the subsequent half hour, for example, the entry for 00 UTC provides the average for measurements taken between 00 UTC and 01 UTC, and that for 23 UTC between 23 UTC and 24 UTC. The data values were classified by whether the local meteorological conditions were those of 'fair weather' (FW), or merely without precipitation, referred to as 'No hydrometeor' (NH) conditions. The FW definition was the stricter of the two, as, in addition to requiring the absence of hydrometeors, it required no low stratus cloud, less than three-eighths cumuliform cloud, and wind speed less than 8 ms^{-1}.

The hourly averaged values have been combined to derive monthly averages. Figure 2 shows monthly time series of the PG data from Lerwick between 1964 and 1984. Figure 2a and 2b show, respectively, the two timeseries of PG with the FW and NH criteria applied.

In both time series, an increase in the mean value of the PG is apparent in the initial few years. This is due to the recovery from radioactive contamination at the site in the era of atmospheric nuclear weapons tests in the late 1950s and early 1960s. The effect of deposited surface radioactivity is to increase the local air conductivity, and reduce the PG, which has also been observed in the aftermath of the Fukushima and Chernobyl reactor accidents (Kubicki et al. 2021). By about 1966, the mean PG value was within the variability typical of the later period, and hence the radioactivity effects had diminished sufficiently that they were no longer apparent. For later analysis using the PG data, only values from 1966 onwards are considered: summary values are provided in Table 1.

FW conditions occurred less frequently than NH conditions, and Figure 3 shows the mean seasonal and diurnal variation in measurements made in these different circumstances. Overall, the total duration of NH measurements is approximately twice that for FW conditions, especially from April to July in the afternoons. As mentioned, the NH criterion is less restrictive than the full FW criteria, and hence the NH data contains more individual values, but in which local effects were less likely to be completely suppressed. Nevertheless, there are fewer outliers apparent in the NH values of Figure 2b than the FW values in Figure 2a.

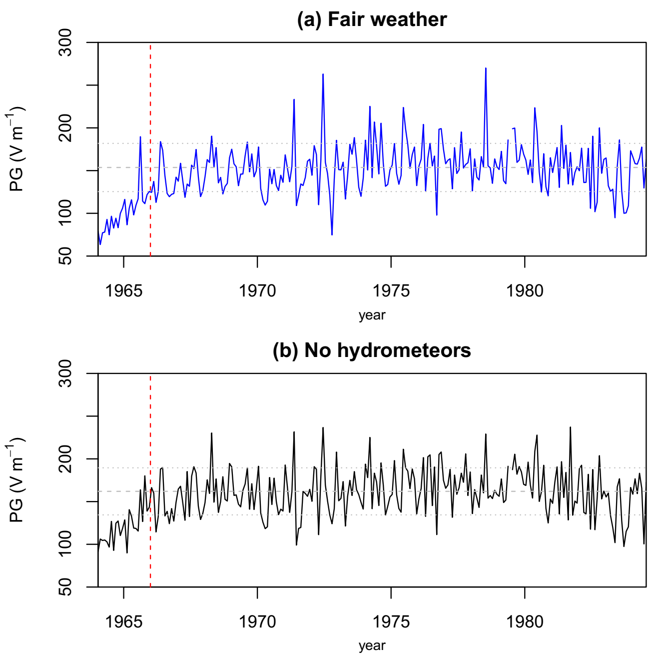

FIGURE 2 | Time series of monthly PG from Lerwick, selected for (a) Fair Weather and (b) no hydrometeor conditions. The red vertical line marks 1966. Horizontal grey lines show the mean (dashed line) and one standard deviation about the mean (dotted lines), calculated from the later data (i.e., after 1966).

4 | Diurnal Variation

The characteristic diurnal variation of the global atmospheric electric circuit is known from the Carnegie curve, which is an observed diurnal variation in PG named after the survey ship on which the defining initial measurements were made (Ault and Mauchly 1926). The Carnegie curve has a single minimum at about 03 UTC and a maximum between 19 and 20 UTC (Torreson et al. 1946), and this variation was shown to agree closely with the diurnal variation in global thunderstorm activity (Whipple and Scrase 1936). Such a diurnal variation is also apparent in the Lerwick PG data, for both the FW and NH data. Figure 4 and Figure 5 show the Lerwick diurnal variations, averaged from the FW and NH datasets respectively.

Figures 4 and 5 also show the seasonal variation averaged over data from 1966 to 1984, showing, at most hours of the day, that a maximum occurs in the northern hemisphere summer. The magnitude of the seasonal variation is less than that of the diurnal variation. Two minima are apparent in spring (April) and autumn (November), which are not evidently related to any change in the sampling, as summarised in Figure 3. A complex seasonality, related to semi-annual variations in tropical convection, was suggested in modelling work representing the global circuit (Ilin et al. 2020), but a single summer maximum is now considered more likely (Slyunyaev et al. 2025).

Both figures show strong similarities with the standard annual Carnegie curve (Harrison 2013), summarised by calculating the correlation in Table 2. The correlation with the NH data has a slightly greater statistical significance, with the persistence in the data allowed for (Ebisuzaki 1997).

5 | El Niño-Southern Oscillation Related Variation

Previous work has shown that the December PG values at Lerwick are correlated with sea surface temperature anomalies associated with the El Niño-Southern Oscillation (Harrison et al. 2011). The PG values at Lerwick were found to increase with the sea surface temperature (SST) anomaly in the Niño 3.4 region (5°N-5°S, 120°-170°W), which is a region of the Pacific Ocean specifically monitored for the El Niño phenomenon. Modelling of the global atmospheric electric circuit has subsequently validated and explained these results, as arising from changes in the positions of electrified clouds due to ENSO (Slyunyaev et al. 2021). The results originally obtained for the period between 1968 and 1984 have since been augmented with southern hemisphere measurements for the earlier 20th century, using data from Watheroo Observatory in western Australia (Harrison et al. 2022). Similar effects to those at Lerwick were

TABLE 1 | Summary statistics of the monthly PG values (1966–1984).

Data classification	Mean (Vm^{-1})	Standard deviation (Vm^{-1})	Median (Vm^{-1})	Inter-quartile range (Vm^{-1})
No hydrometeors	162.0	27.5	159.5	40.1
Fair weather	153.6	28.2	152.5	34.3

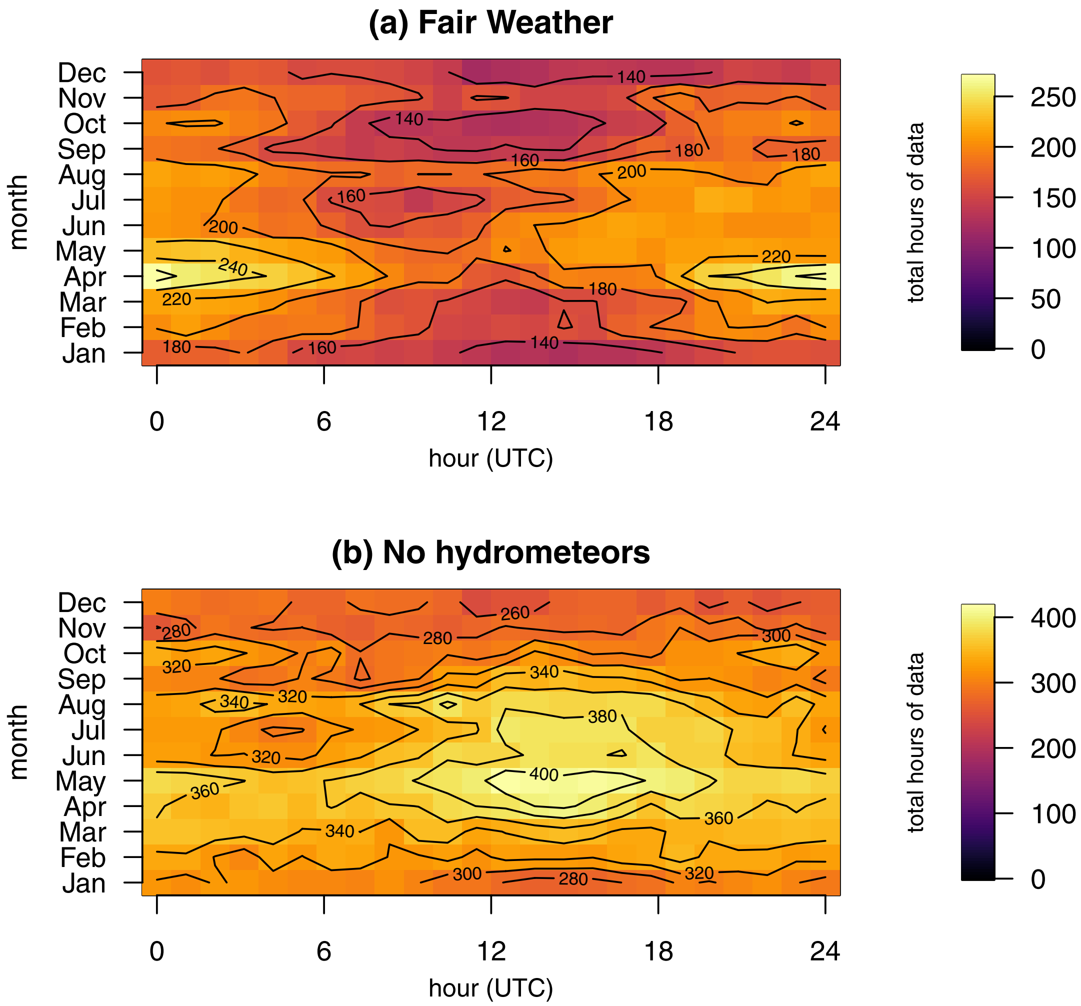

FIGURE 3 | Seasonal and diurnal variation in the total number of hours of PG data obtained at Lerwick between 1964 and 1984, for (a) fair weather conditions and (b) conditions without hydrometeors.

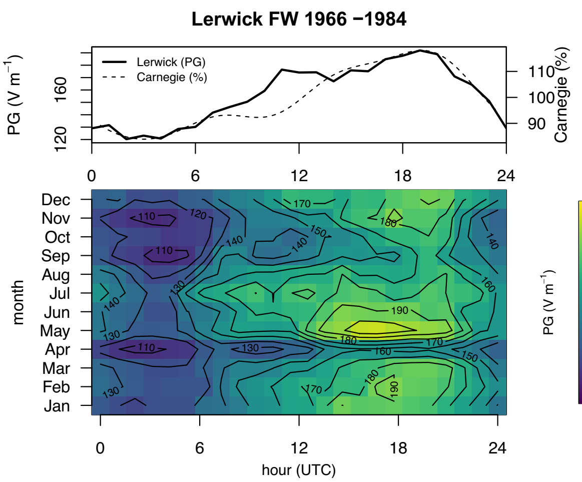

FIGURE 4 | Upper panel shows the mean hourly PG at Lerwick, selected for fair weather (FW) and compared with the Carnegie curve. Lower panel shows the seasonal and diurnal variations in the mean PG for the same conditions.

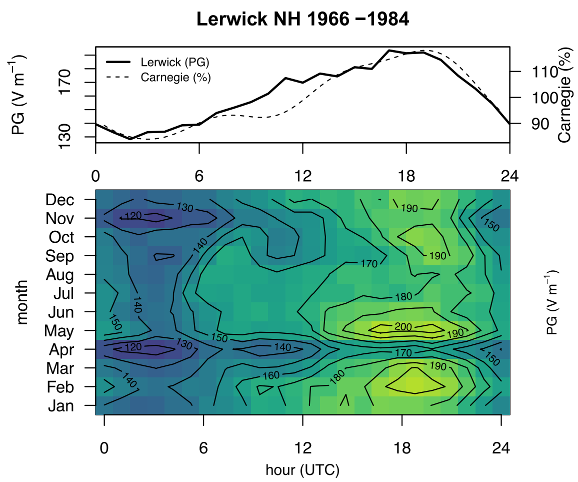

FIGURE 5 | Upper panel shows the mean hourly PG at Lerwick between 1966 and 1984, selected for no hydrometeor (NH) conditions. Lower panel shows the seasonal and diurnal variations in the mean PG for the same conditions.

TABLE 2 | Correlation with annual Carnegie curve.

Data classification	Correlation (Spearman)	Probability of occurring by chance, *p*
No hydrometeors	0.96	0.03
Fair weather	0.93	0.04

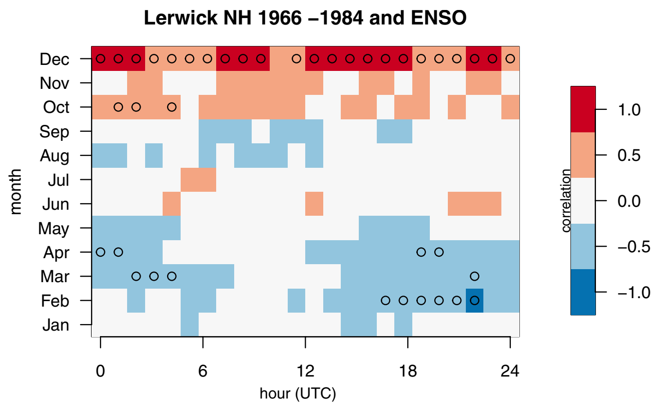

FIGURE 6 | Correlation (Spearman) of the mean monthly PG, by hour, with the monthly Ocean Niño Index (a Pacific temperature anomaly). Statistically significant correlations (having a probability *p* of chance correlation, $p < 0.05$) are marked with a circle.

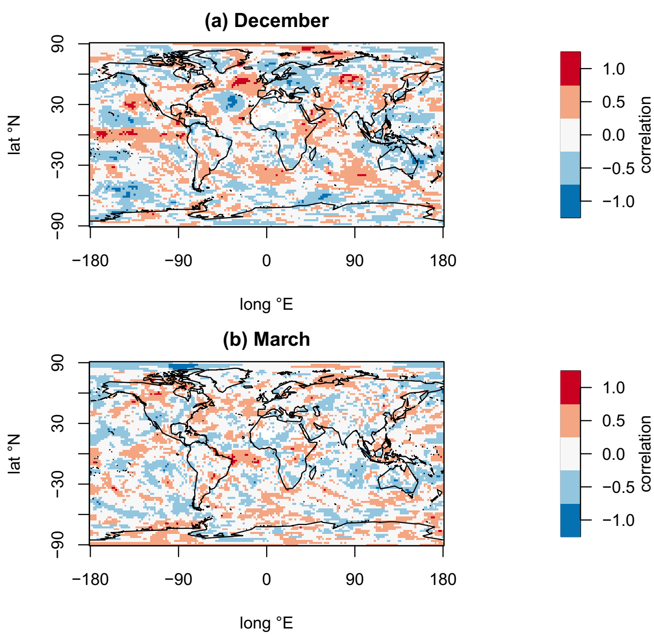

FIGURE 7 | Spatial correlation of the mean monthly Lerwick PG with the global NCEP reanalysis monthly mean precipitation rate between 1966 and 1984, for (a) December and (b) March.

observed between the Watheroo PG data and the sea surface temperature anomalies.

The newly recovered hourly-averaged Lerwick data has been examined for the ENSO relationships in Figure 6. This figure shows the correlation between the SST anomaly and the Lerwick PG on an hourly and monthly basis, using the monthly Ocean Niño Index (ONI) for the SST. The strong correlation previously observed for December is clearly apparent, but there are also episodes of inverse correlation, mainly centered around March.

For further insight into these correlations, global rainfall rate has been compared with the Lerwick PG data, using meteorological reanalysis data from NCEP. The rainfall rate is assumed to provide a proxy for electrification in the thunderclouds and shower clouds driving the global circuit (Liu et al. 2010), and hence ultimately the Lerwick PG. The relationships between the Lerwick PG and rainfall rate are shown for December and March in Figure 7. In the December data, it is evident that there are tropical and other regions where the precipitation rate is correlated with the Lerwick PG data. In contrast, there are fewer such regions in the March data, indicating that, if anything, there is a less coherent origin for the negative correlations of Figure 6 than for the positive correlations.

6 | Conclusions

Lerwick observatory has provided a long and well managed series of PG data during the majority of the twentieth century. The hourly-averaged monthly dataset considered here, for the period after the effects of radioactive contamination had diminished, was obtained at a time when increasing amounts of data from other sources were becoming available, especially satellite observations.

The PG dataset shows global influences, such as a daily variation which, on average, follows the Carnegie curve of the global electric circuit. Further, effects due to ENSO are apparent in the Lerwick PG, which again reflect atmospheric electrical long-distance coupling due to influences on the global circuit.

This dataset provides a new resource with which relationships between the global circuit and climate can be investigated.

Acknowledgements

The Met Office originally obtained the PG measurements. The National Meteorological Archive retrieved the paper summary sheets, which were scanned through a collaboration with the Hadley Centre. The Pacific Ocean temperature anomalies were obtained from https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php and the NCEP rainfall from the NOAA Physical Sciences Laboratory web site at https://psl.noaa.gov/. We thank the many volunteers of the *AtmosEleC* project (https://rdg.ac/electricity) who have helped in recovering the data for this and future investigations. Hripsime Mkrtchyan acknowledges funding from UKRI for Postdoc Guarantee Fellowship Grant EP/X024547/1 (AtmosEleC).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The Lerwick dataset discussed here is available via the University of Reading data archive (Mkrtchyan et al. 2024). A dataset providing monthly resolution data from Lerwick from the outset of the measurements is also available (Harrison et al. 2023). The data that support the findings of this study are openly available in University of Reading at https://doi.org/10.17864/1947.001367.

Endnotes

[1] The *AtmosEleC* project is implemented on the Zooniverse platform, at https://rdg.ac/electricity.

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