Use of reanalysis data in atmospheric electricity studies

Report for COST Action CA15211 "ElectroNet" Short-Term Scientific Missions (STSM)

1. **APPLICANT**

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2. **HOST**

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3. **STSM PERIOD:** From 15-22 April 2018

Proposal objective

The Global Coordination of Atmospheric Electricity Measurements (GloCAEM) network has been created to bring together experts and to make the first steps towards an effective global network for fair weather atmospheric electricity monitoring. One of the novel aspects of GLOCAEM is to make both electric field and meteorological data available from the same site, allowing straightforward classification of fair weather conditions, which is vital for Global Electric Circuit (GEC) studies. This is of key relevance to the COST action CA15211 which aims to drive forward research in atmospheric electricity studies, in particular by encouraging access to existing datasets. Although meteorological data is available at some sites in the GLOCAEM network, this is not the case for all sites. The aim of this STSM is to investigate alternative sources of meteorological data where in-situ surface measurements are not available to more accurately classify fair weather days. The proposed method is to use the ERA-Interim reanalysis dataset produced by ECMWF (Dee et al 2011). This is a freely available dataset which assimilates many observational datasets and follows on from the original ERA-40 reanalysis (Uppala, 2005). ERA-Interim data is available from 1979 to the present day and provides 6 hourly observations of many meteorological as well as hydrological parameters including temperature, RH, wind, solar radiation and cloud cover.

The ultimate goal of this STSM is to use reanalysis data to extract meteorological conditions at the GLOCAEM sites where no in-situ meteorology data is available. This was achieved through the visit of Hripsime Mkrtchyan to the Department of Meteorology at the University of Reading, and separately the Department of Electronic and Electrical Engineering at the University of Bath, where there is knowledge and familiarity with the reanalysis dataset at both UK institutions.

Reasons for choosing host institute

The UK institutions are chosen to host this project for a number of reasons:

- The PI of the GLOCAEM project, Dr Keri Nicoll is located at both institutions. Dr. Nicoll is an excellent advisor and provided guidance and expertise on the GLOCAEM dataset as well as input on the wider subject of atmospheric electricity and the GEC as a whole.
- Both the Department of Meteorology at the University of Reading, and the Department of Electronic and Electrical Engineering at the University of Bath have considerable expertise in using the ERA-interim and ERA5 dataset. The expertise from Dr Nicoll's colleagues has been utilized during the STSM visit to provide training which has quickly familiarized me with the ERA-interim and ERA5 dataset.
- The University of Reading is one of the GLOCAEM measurement sites therefore a visit to the field site here has exposed me to a variety of meteorological and atmospheric electricity instrumentation which help with interpretation of the in-situ measurements.

Potential Outcomes and Relevance to COST action

The aim of this project is to provide meteorological information for atmospheric electricity measurement sites where no in-situ measurements are available. This is vital to interpret atmospheric electric field (or Potential Gradient, PG) measurements which are heavily influenced by local meteorological conditions. Although it is primarily motivated by the GLOCAEM network, if this STSM shows it to be of use, this concept can be applied to any site for atmospheric electricity measurements (and even historical measurements). This has the potential to improve the quality of many atmospheric electrical measurements, as well as to increase the number of scientific problems which can be investigated with such datasets.

It should be noted that the tasks mentioned here extend much further than the short period of time in which the STSM visit has taken place and work on this project will be continued in Armenia after the duration of the visit.

Description of the work carried out during the STSM

1. ***Overview of STSM visit***

The STSM visit was split between the University of Reading and the University of Bath in the UK. This was because the host scientist Dr Keri Nicoll works in both these institutions and splits her time between them. The first two days of the STSM were spent in Reading where a tour of the observatory and labs was performed. The STSM fellow participated in discussions about the plans and format of the data analysis with Dr. Keri Nicoll, Dr. Graeme Marlton and Prof. Giles Harrison. During this period the STSM fellow became familiar with the Reading observatory measurements and the format of the ERA5 data files.

The second half of the week was spent in Bath, where development of processing code and preliminary data analysis was performed. The STSM fellow attended the weekly group meeting of the Atmospheric Electricity group in the Department of Electronic and Electrical Engineering, where she discussed her research with the group members and presented an oral seminar.

2. *University of Reading atmospheric and electrical measurements*

The Department of Meteorology at the Reading University, UK has made atmospheric measurements, micrometeorological research and meteorological observations since 1968, with atmospheric electricity measurements being made continuously from 2007. It is located in the town of Reading, location 51.44136°N, 0.93807°W with altitude 66 m above MSL. The annual mean temperature at the Observatory site is 10.6 °C (mean daily maximum 14.5 °C, mean daily minimum 6.7 °C), with annual average precipitation of 634 mm, falling on 154 days per year. Thunderstorms occur on around nine days per annum, most frequently during the summer. Atmospheric electricity measurements have been made since 2007, with the Potential Gradient (PG) being measured with a JCI Chilworth 131 electric field mill at a height of 3m. Measurements are available at 1Hz and (along with many other meteorological parameters measured at the site), and archived through the GLOCAEM database with data uploaded to this daily.

Figure 1. Atmospheric measurement site at the University of Reading.

3. *ERA5 dataset*

In the original STSM application it was intended that the ERA-interim dataset would be used for analysis. However, instead of ERA-interim ERA5 has been used, for a variety of reasons presented below:

European Centre for Medium-Range Weather Forecasts' (ECMWF's) meteorological archive contains petabytes of operational and research data. A number of datasets are made available free of charge, including Global Reanalysis, which includes ERA-Interim and ERA5.

The ERA5 dataset covers the period January 1950 to near real time (NRT). ERA5 data so far released covers the period 2008-present. ERA5 was produced using ECMWF's Integrated Forecast System (IFS). Atmospheric data are interpolated to 37 pressure, 16 potential temperature and 1 potential vorticity level(s), with the top level at 0.01 hPa. "Surface or single level" data are also available, containing 2D parameters such as precipitation, 2m temperature,

top of atmosphere radiation and vertical integrals over the entire atmosphere. (https://www.ecmwf.int/en/forecasts/datasets/archive-datasets).

ERA5 has:

- Much higher spatial resolution (**31 km** horizontal grid square instead of 79km for ERA-Interim),
- Higher temporal information on variation in quality over space and time (1 hourly resolution instead of 6 hourly),
- Much improved troposphere,
- Better global balance of precipitation and evaporation,
- Uncertainty estimation,
- More measurement parameters than ERA-Interim.

For the purpose of the STSM we have focused on ERA5 data for the period from 2010-2017, at surface level, downloaded over the entire globe so that specific measurement locations can be extracted.

Description of the main tasks performed during the STSM

A breakdown of the implemented tasks during the STSM is presented below.

- ❖ The ERA5 dataset has been downloaded from ECMWF (via https://www.ecmwf.int/en/forecasts/datasets/archive-datasets/reanalysis-datasets/era5) with the help of post-doctoral fellow Dr. Graeme Marlton at the University of Reading. In-situ site measured meteorological data from Reading has been downloaded from the GLOCAEM database, which has been processed and transferred into new files.
  - ✓ ERA5 and Reading data selection for period 2010-2017.
  - ✓ Reading data averaged for hourly intervals to match ERA resolution (since raw data is measured at 1HZ – this has been processed by writing code during the STSM).
- ❖ Familiarization with new data format of ERA5 has been done with the selection of meteorological parameters which has been extracted from initial files.
  - ✓ Initially pressure, temperature, dew point, wind speed and precipitation have been examined from the ERA5 dataset.
- ❖ For extracting ERA5 data for the specific locations of the GLOCAEM Network sites (primarily Reading, and three sites in Armenia) new code has been produced using Python programming language.
- ❖ Seven selected meteorological parameters from ERA5 have been checked and compared at first with in-situ meteorological data from University of Reading where meteorological data exists. This was done for testing the validity of the reanalysis data of the ERA5 dataset. This will be required for Aragats where data will be checked after STSM short period.

- ✓ Selected meteorological parameters for initial analysis are
  - Temperature
  - Pressure
  - Wind Speed
  - Precipitation

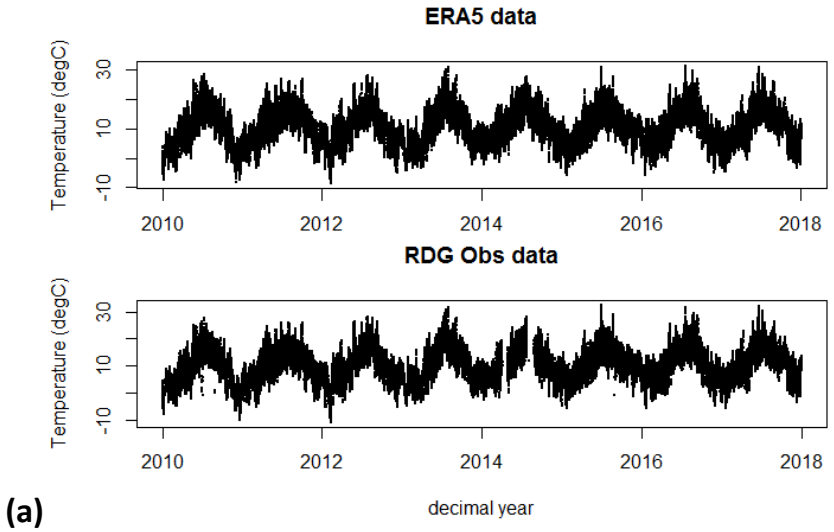
- ❖ Rainfall causes the most variability in PG, and should therefore be removed for fair weather determination of PG. A preliminary study of PG selected for no rainfall on the basis of ERA5 reanalysis, and separately for Reading observation data has been performed to assess whether the two methods are at all comparable.

Data analysis during STSM

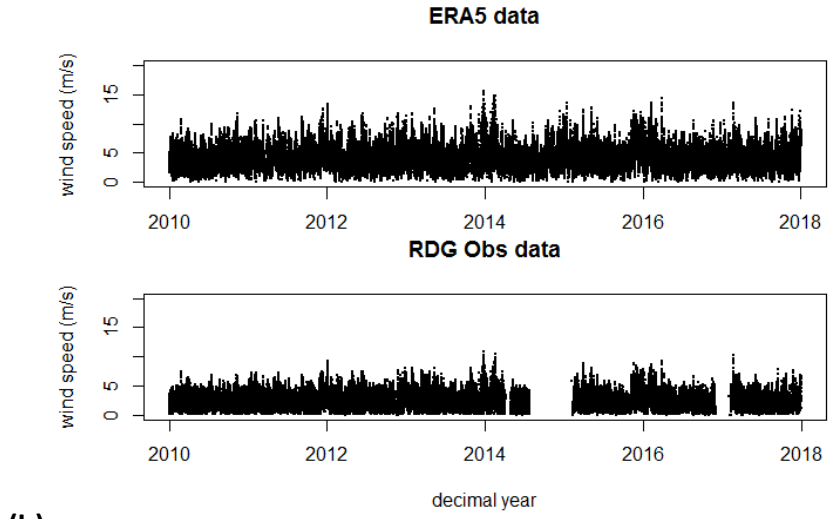
1. ***Comparison of ERA-5 with Reading observations***

The first step in the data analysis procedure was to compare the University of Reading observations with the ERA5 data extracted for the Reading grid square. Time series of the Reading data and ERA5 reanalysis data are shown in Figure 2, at hourly intervals, for the period 2010-2017. This allows a preliminary check that both datasets are sensible and also makes any gaps in the data visible. Figure 2 shows that both temperature series are comparable (a), but that the ERA5 wind speeds are generally higher than Reading wind speed. This is due to ERA5 wind speed being derived for 10m height above the surface, whereas Reading observations are made at 2m. There is also a difference between the absolute values of ERA and Reading rainfall rates. The reason for this is currently under investigation and both of these issues will be addressed in further analysis.

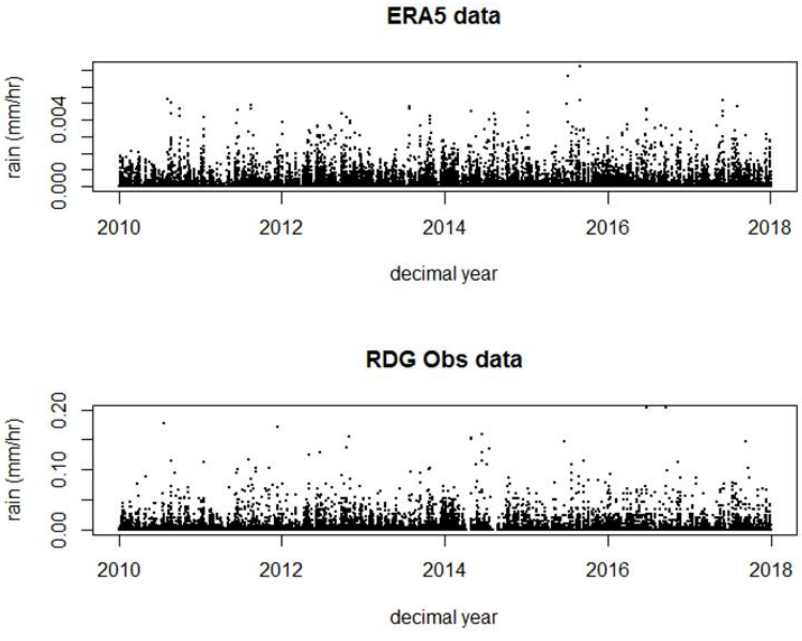
To directly compare ERA data with RDG data, they were selected for the same hourly interval from each data set. Scatter plots of RDG against ERA data were produced to examine how closely the ERA reanalysis matches the RDG observations. By comparing the datasets with exact registration date and time the results for pressure and wind speed, are depicted in Figure 3(A and B).



(a)



(b)



(c)

Figure 2. Time series of (a). Temperature, (b). Wind speed, (c). Rainfall from ERA5 and Reading datasets. Data points are at hourly intervals.

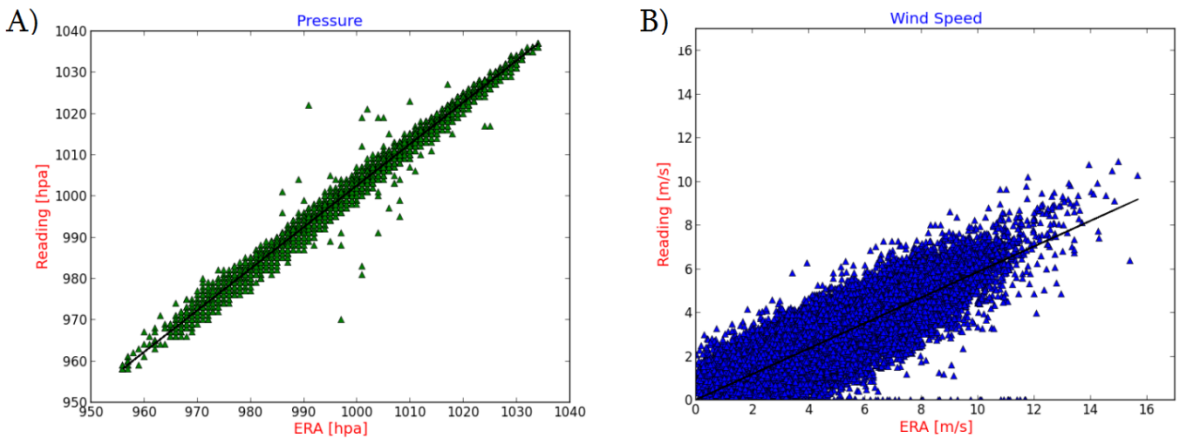


Figure 3. Scatter plot of Pressure (A) and Wind Speed (B) according ERA and Reading observations.

As can be seen from figure 3 A) the pressure at Reading and ERA5 dataset are very similar. This is to be expected as pressure changes only very slowly and pressure changes are large scale phenomena. In contrast there is much more spread between ERA and RDG for wind speed (see Figure 3 B)). This is also expected as wind speed is a much more locally depended phenomena, which varies accordingly to surface features and geography.

To assess the differences between Reading observations and ERA5 rainfall, a different approach is required. Table 1 shows a contingency table, which summaries all occurrences of rainfall according to ERA data and Reading observations. This compares periods when ERA registers rainfall ("ERA rain") with when Reading registers rain ("Reading rain") etc. As can be seen from Table 1, the predominant behavior is for it to be dry (53966 occurrences of no rain registered by either dataset), with both ERA and Reading registering rain on 4335 occurrences. There are however a significant number of occurrences when either ERA or Reading register rain, but not both. This is likely due to a combination of the local variability in rainfall and differences in sensitivity of instrumentation (e.g. tipping bucket rain gauges vs satellite). This is an important assessment to make when using rainfall as an input for determination of fair weather conditions for PG analysis, as it is likely to result in fewer cases of fair weather than actually occur.

Table 1. Precipitiation comparision

	ERA rain	**NO ERA rain**
Reading rain	4335	4183
NO Reading rain	7183	53966

2. *Selection of PG for fair weather*

Investigation of atmospheric electricity parameters is most often done in fair weather conditions (i.e. when no substantial changes in meteorological parameters are occurring). This is required for the study of the global electric circuit and to analyse the influence of space weather on atmospheric electricity. One of the most locally disturbing meteorological parameters is rainfall, which causes large amounts of variability in the Potential Gradient, PG. During the STSM an initial attempt has been made to select PG for fair weather on the basis of no rainfall only. This has been done by selecting PG when no rainfall is measured at Reading and no rainfall is measured by ERA, to compare the similarities/differences in the two methods. The PG distribution for these cases is shown in Figure 4 and statistics of the distributions in Table 2. Also shown in Figure 4 (top) is the PG distribution for all PG values (i.e. including rainfall). As can be seen from Table 2 the removal of rainfall conditions removes many of the large negative PG values, and acts to increase the mean and median in PG towards more fair weather values. Comparison of PG selected according to ERA and Reading rainfall shows that the PG mean, median and IQR are very similar (e.g. median for no Reading rainfall = 87.9 V/m, median for no ERA rainfall = 89 V/m). The similarity between the two distributions gives confidence in the potential of this method for selection of fair weather PG, although much more thorough analysis (and using other parameters too) is required to fully test this.

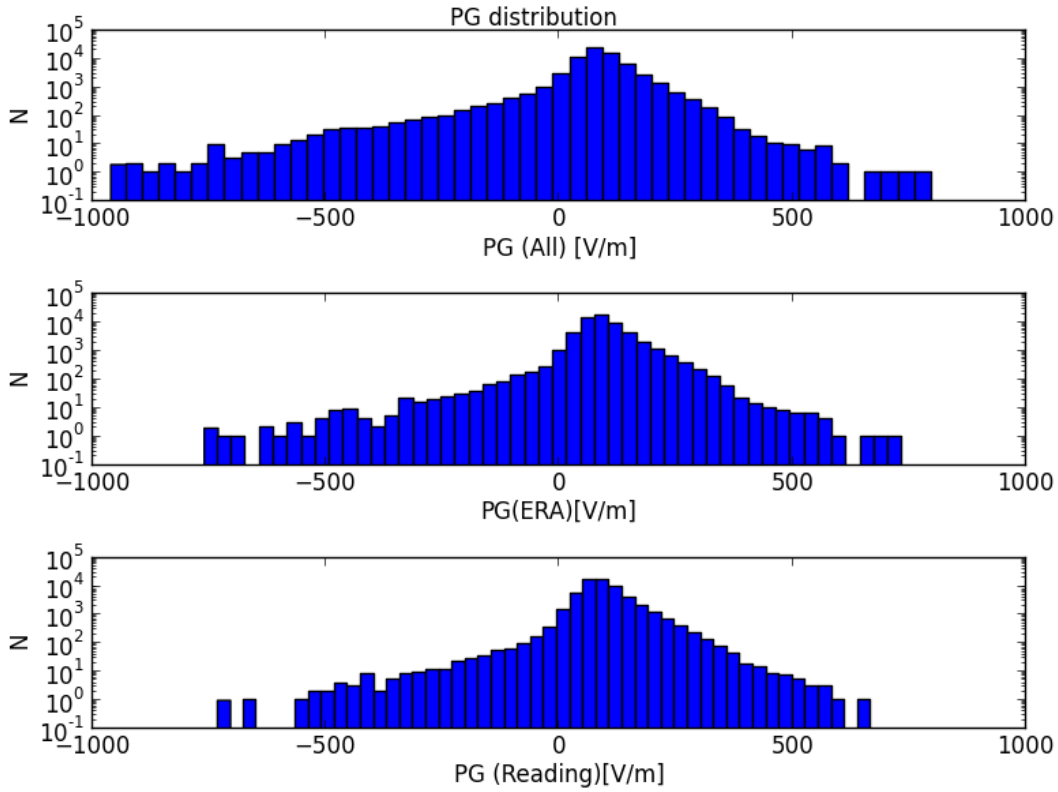


Figure 4. PG records from 2013-2017 at Reading Observatory. Upper plot presents all PG measurements; middle plot – when dry conditions according to ERA; bottom plot – when dry conditions according to Reading observations.

Table 2. Statistics of PG distributions with rainfall and no rainfall.

	Count	Mean	Median	Minimum	Maximum	IQR
All	66484	84.11	84.3	-960	797	53.4
All with only rain	19437	21.58	47.62	-960	797	82.9
PG, no RDG rain	57914	94.53	87.9	-733	668	50.06
PG, no ERA rain	55436	95.13	89	-761	735	51.1

Future collaboration with host institution

After the initial visit during the STSM period, the STSM fellow and Dr. Keri Nicoll plan to continue work on this topic and complete the analysis started here (which as mentioned is only a very preliminary analysis due to the short timescale available).

Future work will include:

- Full comparison of all 7 met parameters to assess how representative ERA5 is of Reading observations.
- Repeat this analysis for 3 sites in Armenia, which are close together (within 16km horizontally and therefore within the same ERA grid square). The orography in Armenia is much more complicated and involves a mountain sites therefore it is expected that ERA 5 will not perform so well as for Reading.
- Extend the fair weather selection of PG from just rainfall to also wind speed and cloud cover for Reading and Armenia and assess how similar or different the PG distributions are. This will help to inform how suitable this method is for fair weather determination of PG. If promising, this method will also be extended to the other GLOCAEM sites which do not have meteorological data.

Foreseen publications to result from the STSM

It is expected that results will be used to prepare a paper to a refereed journal and presentations for scientific conferences, with acknowledgements to the COST CA15211 action.

References

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Uppala, S. M., Kållberg, P. W., Simmons, A. J., Andrae, U., Bechtold, V. D., Fiorino, M., ... & Li, X. (2005). The ERA-40 re-analysis. *Quarterly Journal of the royal meteorological society*, *131*(612), 2961-3012.