Long term monitoring of the geoelectric field in the UK – 2012-2024

Robert Lyon1, Gemma S. Richardson1, Orsi Baillie1
1British Geological Survey, Research Ave South, Riccarton, EH14 4AP Edinburgh, UK
Correspondence to: Robert Lyon (rlyon@bgs.ac.uk)

Reviewer Report

General Comment:

Overall, the paper presents the site selection, design, installation, and ongoing development of geoelectric observation systems installed in 2012–2013 at three remote locations: Hartland Point, Eskdalemuir, and Lerwick. These sites were co-located with INTERMAGNET observatories and chosen to be as far as possible from anthropogenic noise sources. The development of the systems was primarily driven by the need to adapt to changes observed in the data series, to address typical failures, and to mitigate challenges arising from local anthropogenic influences.

The paper provides sufficient detail on the problems encountered and the solutions implemented, thereby demonstrating the practical difficulties of operating a permanent geoelectric monitoring system with high accuracy. It discusses aspects such as digitization, site-specific filtering of the data, and the real-time transmission of processed datasets to users and to the ESA Space Weather Portal.

In my opinion, the work described in the paper constitutes a valuable contribution to our understanding of geomagnetic induction and the coupling of space weather effects into the Earth system via induction processes. The resulting dataset fills a significant gap in the field. The team has done a thorough and careful job to extract the highest quality, low-noise, and drift-free geoelectric time series from the potential differences measured between electrode pairs at the three sites. They have found appropriate responses to the challenges encountered and have produced a dataset that will be instrumental in improving the modeling of geomagnetically induced currents (GICs) during space weather events.

Section-by-Section Review:

Chapter 1 provides a clear overview of the motivation and scientific background for installing permanent geoelectric observation stations. The authors emphasize the importance of long-term monitoring of the geomagnetic field, both for capturing long-term trends and short-term variations. The chapter also includes a brief list of the very few existing permanent geoelectric observation sites worldwide, underlining the uniqueness and value of the presented work.

Section 2.1 introduces the environmental and scientific considerations that guided site selection and installation. The practical choices regarding electrode geometry and materials are well justified, especially given the spatial limitations at each observation site.

Sections 2.2 to 2.3.3 provide an authentic and thorough account of the key considerations in designing and implementing geoelectric field measurements. The paper outlines the challenges encountered during installation and operation, and how these were anticipated or resolved over the course of ten years of operational experience. The authors describe the digitization process, potential sources of offset, and the iterative development of effective lightning protection systems, along with advances in multistage amplification techniques. Site-specific anthropogenic noise filtering is shown to be a critical aspect of geoelectric monitoring, requiring carefully considered trade-offs. These decisions are well illustrated with practical examples from the field.

Chapter 3 draws attention to the typical challenges of detecting natural geoelectric signals, many of which are familiar from our own experience at the Széchenyi István Geophysical Observatory (SzIGO). These include various anthropogenic noise sources, instrumental drift, and leakage currents — such as those originating from DC railways or the grounding systems of nearby buildings. Step-like disturbances, which are notoriously difficult to filter out automatically, are also discussed. The authors highlight how periodic interferences are often tied to nearby local sources, varying by site, and not always easy to identify. At the LER site, they successfully investigated and identified most interference sources and applied appropriate filtering techniques.

Of particular interest is the observation of strong tidal signals at the HAD station — a phenomenon we do not observe at inland stations such as NCK. The paper also covers the signatures of distant lightning strikes and the effect of precipitation-induced drift in telluric field measurements. Section 3.2.3 clearly demonstrates how precipitation can influence geoelectric measurements if electrodes are not buried deep enough. At the Nagycenk station, for example, 1 m^2 lead plate electrodes are buried more than 2 meters below the surface. Despite this, some seasonal variation can still be observed, although the electrodes are installed on a hilltop.

Chapter 4 provides an overview of the scientific applications and research directions enabled by this unique and valuable time series of permanent telluric observations. The data's accessibility via the ESA Space Weather Portal and the BGS Geomagnetism Portal further enhances its value for the wider research community.

Comments:

The HUN-REN Research Institute of Earth Physics and Space Science (and its predecessor institutions: MTA GGKI, MTA GGI MTA CSFK GGI, ELKH GGI) has operated a permanent telluric observation system at the Széchenyi István Geophysical Observatory in Nagycenk, Hungary, since 1956. This was the first geophysical measurement system established at the observatory, later supplemented by geomagnetic observations in 1957. The original electrode spacing was 500 meters in both the north–south and east–west directions, determined to match the sensitivity of the galvanometers available at the time. However, the system often operated in saturation during at least moderately disturbed intervals due to the lack of automatic range switching.

A new telluric monitoring system, developed by the Space Research Laboratory of the Budapest University of Technology and Economics, is currently being tested at the Nagycenk observatory. It operates with a 40 Hz sampling rate, filtered to an effective 10 Hz, and features dual-range recording: when the higher-resolution (narrow-range) channel saturates, the system automatically switches to a lower-resolution (extended-range) mode. This new system has been in operation with a 250-meter electrode spacing since 2023. Similar solution to the same problem, as it is introduced in the paper under review in 2.3.2 subsection.

Review based on the provided aspects:

1. Relevance to GI

Yes, the paper addresses scientifically relevant questions within the scope of *Geoscientific Instrumentation, Methods and Data Systems (GI)*. It focuses on long-term geoelectric monitoring, hardware development, and operational challenges—central to GI's objectives.

2. Novelty

The paper presents several novel aspects:

- Over a decade of operational data from co-located geomagnetic and geoelectric sensors in the UK, previously non-existent.
- Iterative hardware developments specifically designed for geoelectric monitoring.
- Practical field lessons in lightning protection and anthropogenic noise mitigation.
- Insights into natural geoelectric signatures such as tidal effects and their site-specific variation.

3. Conclusions

Substantial conclusions are reached, particularly regarding:

- The feasibility and value of long-term monitoring.
- Engineering trade-offs for sensor robustness.
- Data utility for both space weather and Earth system science.

4. Methods and Assumptions

Yes. The technical descriptions (e.g., amplifier noise, ADC specs, filtering strategies, lightning modeling) are thorough. Assumptions—such as regarding signal frequency bands or tidal coupling—are realistic and explicitly discussed.

5. Support for Interpretations

Yes, the presented results are sufficient to support interpretations. The use of spectral density plots, case studies (e.g., May 2024 storm, tidal signals at HAD), and historical comparisons reinforce the validity of conclusions.

6. Reproducibility

Yes. The system's design, installation procedures, electronics schematics (described in text), and filtering/data acquisition pipelines are all detailed enough for reproduction, with some site-specific exceptions (e.g., terrain constraints).

7. Credit to Related Work

Yes. The authors cite key foundational and recent works in the field, such as Boteler (2019), Love et al. (2018), and regional studies (e.g., Ádám et al., 2009; Blum et al., 2017). They clearly distinguish their original contributions, especially hardware/system design and long-term UK data generation.

8. Title Appropriateness

Yes, the title accurately and succinctly reflects the content.

9. Abstract Clarity

Yes. The abstract is concise and informative. It defines the scope, significance, instrumentation, and goals clearly.

10. Presentation Quality

The structure is logical: introduction, system description, challenges, outputs, discussion, and conclusions. Figures are well-integrated and informative. The evolution of the system over time is clearly tracked.

11. Language

Generally fluent and precise.

12. Mathematical Clarity

Yes. Formulae (e.g., thermal noise via Nyquist) are used correctly and well contextualized. Units are consistent and appropriate throughout.

13. Content Streamlining

Minor suggestion: Figures 6–11 are crucial, but the narrative could benefit from grouping the spectral analysis figures (Figures 7–8, 10–11) into composite panels for compactness. Just a recommendation.

14. References

Yes. References are numerous, up-to-date, and include most key papers in the domain. The authors appropriately cite both foundational and niche studies relevant to their work.

15. Supplementary Material

There is no mention of separate supplementary materials. However, the description of data availability (e.g., via ESA space weather portal) is sufficient for transparency. Providing links to design schematics or PCB layouts in supplemental material might further enhance reproducibility.

Recommendation

I recommend **minor revisions** before acceptance. The paper is an excellent and much-needed contribution to the field of geoelectric monitoring and instrumentation. Its long-term perspective, detailed hardware development, and integration into broader space weather networks are especially commendable.

1. Clarifications or Expansions Recommended

1.1. Cross-Talk Due to Misalignment at ESK

- **Issue**: The paper mentions a ~12° misalignment at ESK leading to ~20% cross-coupling (Section 5), but stops short of quantifying its impact on the long-term dataset.
- **Suggestion**: Include a rough estimate or preliminary analysis of how much this misalignment might bias tidal studies or storm response data.

1.2. Filter Design Parameters

- **Issue**: The filtering is critical in dealing with anthropogenic noise, but only the **type (low-pass, 5 Hz)** is mentioned.
- **Suggestion**: Please add the **filter order** (e.g., Butterworth, Bessel?) and analog vs digital implementation details. This improves reproducibility and transparency for others aiming to replicate the design.

2. Small Technical or Editorial Corrections

Typographical / Stylistic Issues

- **"In areas where one electrode becomes waterlogged this can cause..."**
  → insert a comma after "waterlogged".
- A few places use **"this required mitigation"** repeatedly. Vary phrasing or tighten wording (e.g., "*mitigated by…*").
- In line 428, you mention **O1** — could this be a typo? Should it perhaps be **M1?**
- In kine 471: Locationthat

3. Possibly Missing Aspects Worth Mentioning

3.1. Instrument Calibration and Inter-site Consistency

- **Missing**: The paper does not state how consistency between sites was validated after each hardware upgrade.
- **Suggestion**: Add a sentence about whether **cross-calibration or inter-site comparison** (e.g., response to shared storms) was done to ensure uniformity in measurements.

3.2. Power Backup or Data Gaps

- **Missing**: No mention of **backup power, data loss handling**, or system uptime statistics.
- **Suggestion**: One sentence on whether power outages caused downtime or how data continuity is ensured (e.g., battery backup, local buffering) would close this small gap.