Topical Discussion Meeting Report (TDM 20)

TDM Title: Ground-based instrumentation for space weather: how to improve the data products for both researchers and operational users/services?

Conveners: Jim Wild, Norah Kwagala, Audrey Schillings, Jesse Andries

Secretary: Suzy Bingham

Date: Friday 24th November 2023, 11:45-12:45

Location: Spot Room, ESWW 2023, Toulouse, ESWW TDM webpage

Form of TDM: Panel Forum

Number of Participants: ~45

Panellists: Gemma Richardson *(British Geological Survey, UK)*, Alexandar Mishev *(University of Oulu, Finland)*, Pietro Zucca *(ASTRON, Netherlands)*, Manuel Hernández-Pajares *(Universitat Politècnica de Catalunya, Spain)*

TDM Description: The Space Weather and Space Climate communities include a diverse group of data stakeholders, including technical operational and scientific users. Ground-based instruments play a crucial role in space weather research as well as services. Their measurement data feed into and underpin models, event-based data analysis and alerting and forecasting services. Instruments, such as all-sky cameras, radars, magnetometers, GNSS stations, riometers and ionosondes provide specific information about the prevailing space weather and climate conditions at their respective locations, but collectively they also provide a global perspective capturing the spatial variation and the evolution of the conditions. This is essential to obtain a more detailed understanding of space weather effects and their evolution and hence to the capability to forecast local space weather conditions. In this TDM, we will facilitate a discussion around opportunities and strategies for improvement of ground-based measurements both for research and services. While services and research may pose different demands (focus on real-time access vs continuity and calibration), harmonization of the data and networking across the different sites is clearly valuable to both. Needs and priorities for securing ongoing support for the various ground-based facilities and their networks will be discussed.

Objective of the TDM

To identify opportunities and strategies for enhancing support to ground-based instruments and networks, for sustained data for research and operational needs.

Discussion Highlights

A good range of space weather ground-based instruments/networks were represented in the TDM. The four panellists represented (1) magnetometers, variometers, electric field instruments, (2) neutron monitors, (3) LOFAR, (4) PITHIA-NRF (GNSS receivers, ionosondes, EISCAT, LOFAR, Continuous Doppler Sounding System (CDSS)). Conveners and the audience had expertise in network types too, for example: radar, GONG, Super DARN, e-Callisto.

Panellists shared their experiences and insights on the differences between providing 'research' data and 'operational' data and the key blockers in providing real-time data. For providing real-time data there appears to be more of a *software infrastructure* issue than a *science* issue. To provide an operational network, it would be beneficial if there were more focus on software engineers working to implement and maintain operational infrastructure, then sharing this with other instruments in the network. However, a science 'expert' is also often required in the dissemination of an instrument's data, to understand what data to send to whom, and also to quality check the data.

It was suggested (although some concern was also raised) that a suitable model for international funding was required, led by an international organisation, to coordinate funding of world-wide ground-based networks (for example, by adapting the WMO terrestrial weather process).

International 'recognition' was identified as an important aspect for institutes to get further funding from national funding agencies.

Main Conclusion of the TDM

There is very deep concern within the various ground-based networks that world-wide coverage/provision of data, for space weather services and for research, is lacking and that there is no long-term planning. Space weather is a global phenomenon but there is a lack of international coordination to maintain and support networks – initiatives are generally done on a best-efforts basis per country/institution. To maintain the current coverage of ground-based networks, and to further enhance these networks, there is a requirement for world-wide coordination in particular, for funding. Adopting data standards/formats when an instrument is first installed or used for a particular purpose, would help during the later R2O transition of data when there is currently a myriad of formats used. To provide 'operational' data, software infrastructure/engineers are required. An approach to support sustainable data provision could be for an international organisation to help with international recognition of instrumentation and with coordination of funding paid for by nations.

Annexes

Materials Presented

TDM Minutes

Chair of the TDM, Prof. Jim Wild, welcomed the in-person and online participants and introduced the TDM topic. This TDM followed the earlier P02 Plenary Session, "Synergies between ground-based and space-based instrumentation: what, where, why, when, and how?", Wednesday 22nd November. Panellists provided brief introductions.

Gemma Richardson is in the geomagnetism team at the British Geological Survey, UK, where they provide data for both research use and for operational services. The team at BGS has many years of experience in magnetometer, variometer and geomagnetic field measurements. The main focus at BGS is on geomagnetic observatories.

Manuel Hernández-Pajares' expertise is in GNSS ionospheric measurements at the *Universitat Politècnica de Catalunya*, particularly in real-time applications and forecasting. Manuel is part of the PITHIA-NRF team and so was able to provide a perspective from each of the instrument types in the project.

Alex Mishev from the University of Oulu has expertise in the global neutron monitor network, data which are available through NMDB. Alex also is an expert in SEPs, mainly radiation effects and in particular extreme SEPs.

Pietro Zucca works at ASTRON in The Netherlands in Radio Astronomy; his expertise is in coordinating efforts for using LOFAR for space weather purposes – the technique can be used as a proxy in models for space weather forecasting.

Jim Wild commented that he himself has an interest in radars and invited the audience to provide any input from other instruments that may not be represented by the panel.

Each of the panel members were asked to comment on what they felt were the main issues blocking the effective use of their instrument operationally. Gemma Richardson explained that it is very difficult to make real-time, quality, geomagnetic field measurements; not every observatory across the globe is able to do this as it takes time to quality check the data. It's also difficult to ensure the quality of variometer data. For instance, if a farm animal disturbs a variometer then the orientation

of the measurement may be changed and the data may not actually be what is intended. It is a daily task to quality control the data. Sourcing funding is also an issue to keep and maintain land for geomagnetically quiet sites (which can be fairly large areas). There was a comment (Martin Connors, Canada), that electric field measurements were required as well as from magnetometers. Jim Wild noted that the SuperDARN network appears very large but that it was a collaboration between many institutes – some of the institutes may have around 5 radar that are well-resourced whereas others may have one instrument and no steady flow of funding. It was noted that another issue for a steady stream of data is when the instrument is located in a remote place.

Manuel Hernández-Pajares said that the PITHIA-NRF instruments (ionosondes, GNSS receivers, EISCAT, LOFAR, Continuous Doppler Sounding System (CDSS)) experience a number of issues. For ionosonde data there is a lack of near real-time software although the community is trying to overcome this. Weather conditions can be a problem, particularly for antennae. Maintenance costs can be an issue, for example for hundreds of 24/7 receivers with less than 2s latency for real-time ionospheric maps. Real-time data aren't produced by EISCAT. The main purpose of LOFAR is in Radio Astronomy and so some of the analysis isn't done in real-time. There was a comment that there was ionosonde software to provide real-time ionospheric maps but that quality control of the data was required – so potentially there are possible activities that can be done now but need more work and knowledge sharing.

Alex Mishev said that one particular current problem was the Russia/Ukraine war with the issue of Russia not sharing neutron monitor data. The worry is that there is uncertainty in the continuation of the current network coverage, with universities/institutes receiving only small amounts of short-term funding – any reduction in the current network will jeopardise coverage. Some operators have a couple of instruments, for example Oulu has two.

Pietro Zucca commented that the main issue for radio telescopes is that there is not a global network that can provide 24h coverage and that the instruments aren't inter-calibrated. The instruments are mainly for astronomical use and not for real-time. There's only one dedicated station for space weather. Management of Radio Astronomy sites are reluctant to run 'monitoring stations' as this is a big step requiring resource and expectations of data provision.

Alexei Pevtsov from the NSO GONG network explained that the GONG network began 28 years ago as a science project and that it will continue running until end-of-life. The data are used operationally but there is currently no planned funding for replacement, which costs money and takes time to plan.

Jesse Andries asked the panel to comment on which ground-based systems would be used differently for research purposes and for operational purposes – suggesting that perhaps magnetic measurements are similar for both uses but that LOFAR may be different depending on the use.

Gemma Richardson agreed that magnetometers are largely used in the same way for both research and operations but that for electric field, there can be differences – for example there can be research field campaigns for electric field measurements whereas operational monitoring is different.

Manuel Hernández-Pajares explained that there are different uses of GNSS for science and for applications. GNSS software is used by some companies to provide a real-time service to support high positioning accuracy. Centres can use combined post-processed GNSS data, for example, to provide an index.

Pietro Zucca confirmed that for IPS, in theory the data are the same for research and operational use but that for real-time data the software infrastructure is required to quality check and to disseminate quickly. There is possibly less time cadence required for science data.

Alex Mishev commented that more precise measurements for monitoring extreme SEPs were required for operational use, for use in radiation models.

Masha Kuznetsova asked for clarification – was it generally the same data that are used for science and operations but that for real-time monitoring/operations there was more development needed in software infrastructure? i.e. there wasn't a 'science' issue. There were mixed responses from the panel. For real-time TEC, software engineering work is required to enable speedy dissemination of data. For GNSS, software engineering is not enough, an expert in the field is required (for determining the useful data/cleaning the data). For variometers (and likely magnetometer data too), having a software engineer to develop infrastructure would help most.

For LOFAR, both a software engineer to develop infrastructure (to collect correctly and stream the data) and an expert (to understand the use of the scientific data) are required.

Alex Mishev highlighted that it is easy to lose the data processing knowledge in a team if there is change in software engineer(s).

Jim Wild commented that SuperMAG is funded by NSF but that so many countries benefit from it. Also, that SuperDARN had a similar model. That the issue is that if there is a sole country/institute/agency making funding decisions, issues can arise if there is a decision to stop funding.

Pietro Zucca emphasised the problem with ground-based assets compared to space-based – there can be one space-based instrument observing the Sun but for ground-based, a network has to be established for 24/7 observations. E-callisto was highlighted as a good example of cooperation efforts for coverage. Mario Bisi commented that for LOFAR, all the individual groups acted on a best efforts basis – trying to provide free data.

Alexei Pevtsov made the comment that operations is a production line and different to research (where there is value in ad hoc networks). For operations, one needs to start with requirements, a plan and identify who will fund – then there needs to be a research-to-operations transition. It was emphasised that there was also another step - to begin with, users need to communicate their requirements to science. There are so many different methods of producing data and different types of data in the research community without their being standards – and this is difficult when one wants to then transition to operations.

The question was posed, "What could help secure funding for operational instruments?" There was a suggestion that a solution could be a world-wide fund/pot to maintain and support the networks with an international organisation distributing the funding – which could mean funding available to countries that weren't in a position to pay for such instruments. Space weather is global but there are data/instrument gaps particularly in the southern hemisphere – it is important to integrate these. ISWI was established through UN COPUOS and Callisto was first started through ISWI. Pressure can be put on nations/members through the UN and many countries have benefitted through this process.

There was concern/disagreement voiced to the suggestion of a world-wide fund for distribution. Different countries work in different ways so countries should work autonomously and then share. There needs to be some kind of insurance that if a country provides funding to another country then

the funding country will have access to the data (an international organisation could provide this guarantee). In terrestrial meteorology, the distribution of funding through an international organisation generally works but there's not a world-wide fund that is distributed, rather, nations are responsible to fund activities. GNSS receivers are cheap to purchase and data can be provided free of charge – EISCAT, on the other hand, has a big power consumption and uses a subscription model for funding. Running a geomagnetic observatory is not cheap – international recognition (e.g. through INTERMAGNET) is important – countries can provide letters of support which helps to show the importance of another nation's instrument(s). BGS offer older instruments to countries that don't have the funds to purchase a new instrument.

An analogy for research data and operations data: operations is like a reliable, family car and research is like a sports car protptype – they are somewhat different.

Jim Wild wrapped-up the discussion after 1h, thanking the panellists, co-conveners, IT technicians and the audience.