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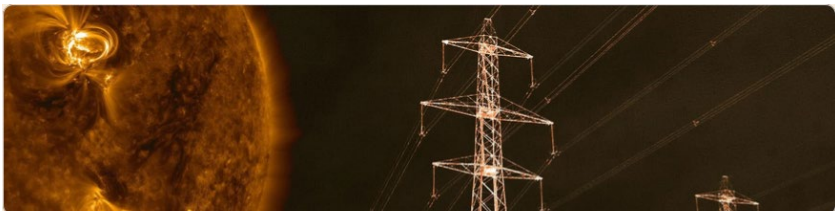
SWIGS
SPACE WEATHER IMPACT ON GROUND-BASED SYSTEMS



Space Weather and the Solid Earth:
The hazard to technology at the Earth's surface

Royal Astronomical Society

12 March 2021

Programme

Click the links to see abstracts

10:30	**Welcome** Alan Thomson *British Geological Survey*	
	Session 1	Chair: Juliane Hübert
10:35	**Keynote address** Lisa Rosenqvist *Swedish Defence Research Agency (FOI)*	Modelling and verification of geomagnetically induced currents in Sweden
11:05	Stefano Maffei *University of Leeds*	The future location of auroral zones as described by the geomagnetic field of internal origin
11:25	**Coffee break**	
	Session 2	Chair: Neil Rogers
11:35	Andy Smith *University College London*	The contribution of Sudden Commencements to the rate of change of the surface magnetic field
11:55	Carl Haines *University of Reading*	Towards GIC forecasting: Increasing the time resolution of magnetic field data using statistical downscaling
12:15	**Keynote address** Matthew Allcock *EDF Energy*	Building nuclear energy infrastructure resilient to space weather
12:45	**Introductions to posters** Short (2 min) talks by those presenting posters	Chair: Gemma Richardson
13:00	**Lunch**	

13:15	**Posters**	
	John Coxon *University of Southampton*	The distribution of Birkeland currents in time and space
	Xiangcheng Dong *RAL Space, STFC, UK*	Intense ground dB/dt variations, and scaled FACs, driven by near-Earth Bursty Bulk Flows (BBFs)
	Juliane Hübert *British Geological Survey*	A new data set of line GICs measured with the Differential Magnetometer Method in the UK high voltage power grid for the years 2018-2020
	Anna Martí *University of Barcelona*	The role of the lithospheric electrical conductivity of Iberia in the characterisation and prediction of the GIC in critical infrastructures
	Cameron Patterson *Lancaster University*	The impact of space weather on UK railways
	Neil Rogers *Lancaster University*	Climatological statistics of extreme geomagnetic fluctuations with periods from 1 s to 60 min
	Robert Shore *British Antarctic Survey*	Converting a model of ionospheric reconfiguration timescales into a forecast model of ground level geomagnetic variations
	Session 3	Chair: Alan Thomson
14:00	Peter Gallagher *Dublin Institute for Advanced Studies*	Solar and geomagnetic monitoring and modelling in Ireland
14:20	Jonathan Eastwood *Imperial College London*	Translation of the Gorgon magnetospheric model for operational space weather forecasting in the context of the SWIMMR/SAGE project
	Keynote address	
14:40	Chigomezyo Ngwira *ASTRA LLC*	Geomagnetically induced currents in the United States: Past, present, and future efforts
15:10	**Discussion**	
15:30	**End**	

Abstracts

Session 1

Lisa Rosenqvist

Swedish Defence Research Agency (FOI)

Modelling and verification of geomagnetically induced currents in Sweden

Lisa Rosenqvist[1], J-.O. Hall[1], T. Fristedt[2], Andrew P. Dimmock[3], Daniel Welling[4], J. Kjäll[1], Emiliya Yordanova[3]

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[4] University of Texas at Arlington, Texas, USA

Geomagnetically induced currents (GIC) flowing in long conductors can pose a threat to critical infrastructure such as the power grid in cases of extreme geomagnetic activity. Geomagnetic activity is more pronounced at high latitudes, thus Nordic countries, such as Sweden, can potentially be vulnerable to problems caused by GICs. Previous studies have identified the southern region of Sweden as most vulnerable to extreme space weather but most studies have relied on 1D models of the ground conductivity. Sweden, however, has large-scale national variations in the ground conductivity structure across the country as well as regional sharp gradients in lateral conductivity, e.g. in coastal regions.

A proof-of-concept modelling capability that incorporates a detailed 3D structure of Earth's electrical conductivity in a GIC estimation procedure has been developed (GIC-SMAP) and verified based on measurements in northern and southern Sweden. The resulting electric fields are dominated by the ocean-land boundary in southern Sweden, which is exposed to stronger electric fields. As a result, GICs are underestimated by about 50% based on 1D plane-wave methods in the coastal region.

The model has been used to quantify the hazard of severe GICs in the Swedish power grid based on historical geomagnetic disturbances and a worst case "perfect" storm. According to the model, three historical storms with the largest GIC values coincide with observed impacts on the Swedish power network. The impact sites are closely related to large rapid magnetic variations and occur in a region of enhanced electric fields due to the combined effect of the regional low crustal conductivity and 3D effects due to neighbouring high conductivity regions. We evaluate the capability of the Space Weather Modelling Framework (SWMF) to reproduce the observed disturbances over Scandinavia that are likely to be responsible for the impacts.

Back to programme

Stefano Maffei

University of Leeds

The future location of auroral zones as described by the geomagnetic field of internal origin

The internal component of the geomagnetic field (generated within the Earth's core) is of crucial importance in modulating the impact of space weather events. Although primarily a dipolar field of slowly decreasing intensity, multipolar components can cause changes on interannual time-scales that are important for space weather applications. Of particular importance for space weather application is the location of the auroral oval, the region where it is most likely to see polar auroras. The auroral zone can be defined as a time-averaged auroral oval and it is possible to describe it via the internal geomagnetic field. To be able to forecast interannual and decadal changes of the auroral oval location can benefit the design of future space missions and the planning of mitigation strategies for countries particularly exposed to severe space weather events (such as the UK). Here we combine various future evolution scenarios for the geomagnetic field of internal origin with a definition of the auroral zones that rests on the calculation of non-orthogonal, magnetic coordinates. This methodology agrees well with calculations based on more complete magnetospheric and ionospheric physics. We apply our methodology to derive quantitative forecasts for the auroral zones' location over the next decades.

Back to programme

Session 2

Andy Smith

University College London

The contribution of Sudden Commencements to the rate of change of the surface magnetic field

Rapid changes in the surface geomagnetic field can induce potentially damaging currents in conductors on the ground; this is a critical consideration for the operation of power networks. In this work we investigate how sudden commencements (SCs), associated with sharp increases in solar wind dynamic pressure, impact the (one minute) rate of change of the horizontal magnetic field (R) measured on the ground.

We find that though SCs last for a very small fraction of the total time, up to 25% of the most extreme R is accounted for at the lowest magnetic latitudes. However, this fraction decreases strongly with latitude, and by ~55° latitude has dropped to below 1%.

Sudden commencements are also related to other magnetospheric phenomena, geomagnetic storms for example. We find that the probability of observing large R is greatly enhanced for 3 days after a SC. Below 60° latitude, around 90% of data over 50nT min^{-1} is recorded within three days of a SC. Further, subdividing the sudden compressions into sudden storm commencements (SSCs) and sudden impulses (SI), shows that SSCs in particular are related to much larger R.

These results suggest that accurately predicting sudden commencements is important to identify intervals during which the power networks are at risk from GICs.

Back to programme

Carl Haines

University of Reading

Towards GIC forecasting: Increasing the time resolution of magnetic field data using statistical downscaling

GIC forecasting requires the use of magnetospheric models as drivers of geoelectric field models. However, estimation of the geoelectric field requires knowledge of the geomagnetic field with variability on a higher time resolution than current global MHD models can provide. We present proof of concept results for a statistical method that temporally downscales hourly average magnetic field data to minute resolution. We do this using an analogue ensemble (AnEn) approach in which we look for similar hourly averages in a historical dataset and lift the high resolution noise to add on top of the considered hourly average values. We evaluate this method against a "do nothing" approach which we take as the linear interpolation between the hourly mean value at the start and end of the hour under consideration.

Back to programme

Matthew Allcock

EDF Energy

Building nuclear energy infrastructure resilient to space weather

EDF is Britain's biggest generator of zero carbon energy. As safety is EDF's overriding priority, our nuclear power stations are built to withstand the effects of space weather and other natural hazards. In this talk, I will describe EDF's unique perspective on the space weather hazard, drawing upon academic science, research from the energy industry, and government regulation. I will introduce EDF's space weather research portfolio that aims to characterise this hazard and mitigate its impact on safety-critical infrastructure. In particular, I will discuss the modelling of geomagnetically induced currents (GIC) in the electricity networks in UK and France and data analysis of historical ground level solar particle events (GLE). Finally, I will describe EDF's vision for what progress in space weather resilience looks like for the next generation of nuclear energy infrastructure.

Back to programme

Posters

John Coxon

University of Southampton

The distribution of Birkeland currents in time and space

Field-aligned currents link the ionosphere to the magnetopause (Region 1) and the ring current (Region 2), and are a key part of the way in which energy is transferred into the ionosphere; as such, they are of relevance to modelling the effects of space weather on the surface of the Earth. We use data from the Active Magnetosphere and Planetary Electrodynamic Response Experiment (AMPERE) in two ways to examine this effect. Firstly, we employ a novel technique called SPIDER (Shore *et al.*,

2019) to analyse the timescales on which solar wind driving is likely to affect the ionosphere after triggers from the Interplanetary Magnetic Field and during geomagnetic storms. Secondly, we quantify the way in which the field-aligned current densities are distributed in each spatial coordinate, and analyse the implications that this has for the parts of the system likely to see the largest amounts of current. We fit a Tsallis distribution to the current densities in spatial coordinate, to generate maps of the probability of field-aligned current densities above certain thresholds in both hemispheres. We discuss this in terms of its ramifications for space weather energy pathways.

Back to programme

Xiangcheng Dong

RAL Space, STFC, UK

Intense ground dB/dt variations, and scaled FACs, driven by near-Earth Bursty Bulk Flows (BBFs)

Xiangcheng Dong and Malcolm Dunlop

Individual events sampled by higher altitude spacecraft (e.g. the 4 Cluster spacecraft), in conjunction with Swarm (mapping both to region 1 and 2), show two different domains of FACs: time variable, small-scale (10s km), and more stationary large-scale (>100 km) FACs. Both the statistical trends, and individual conjugate events, show comparable effects seen in the ground magnetometer signals (*dH/dt*) during storm/substorm activity and show distributions that are similar. Demonstration of intense *dB/dt* variations which are directly driven by bursty bulk flows (BBFs) at geosynchronous orbit is rare. The characteristics and response during the recovery phase of a geomagnetic storm that occurred on 7 January 2015 were covered by multi-point measurements, combining Cluster and SWARM measurements, and a group of ground-based magnetometer observations. The locations of Cluster and SWARM map to the same conjugate region as the magnetometer ground stations at the time of the BBF. The measurements show that corresponding signals in all measurements occur simultaneously (with suitable time lags) in this region. The most intense *dB/dt* (*dH/dt*) variations are associated with FACs corresponding to a modified SCW that are driven by BBFs at geosynchronous orbit around substorm onset.

Back to programme

Juliane Hübert

British Geological Survey

A new data set of line GICs measured with the Differential Magnetometer Method in the UK high voltage power grid for the years 2018-2020

Hübert, J., Beggan, C., Richardson, G., Collins, A., Perez Gomez, N. and Thomson, A.

Extreme events of space weather can have severe effects on ground-based infrastructure like power lines, railways and gas pipe lines through the induction of geomagnetically induced currents (GICs) not only in mid-to-higher latitude countries. Modelling GICs requires knowledge about the source magnetic field and the electrical conductivity structure of the Earth to calculate electric fields during enhanced geomagnetic activity. The electric field in combination with detailed information about the network topology enable the derivation of GICs in power lines. Directly monitoring GICs in power grid substations is possible with a Hall probe, but scarcely realised in the UK. Therefore we deployed the

differential magnetometer method (DMM) to measure GICs at twelve sites in the UK power grid. The setup of the DMM includes the installation of two fluxgate magnetometers, one directly under a power line affected by GICs, and one as a remote site further away. The difference in recordings of the magnetic field in both instruments allows for the calculation of GICs in the respective power line segment via Biot-Savart law during geomagnetically enhanced periods.

We collected data all around the UK power grid in the years 2018-2020, monitoring line segments that in our model connect to transformer substations with high GIC risk. Albeit in the solar minimum with few periods of larger geomagnetic activity, we recorded data during many smaller geomagnetic storms that allow an in detail analysis of the GIC model. The data set provides a solid base to refine and validate our computational model of GICs in the UK power network.

Back to programme

Anna Martí

University of Barcelona

The role of the lithospheric electrical conductivity of Iberia in the characterisation and prediction of the GIC in critical infrastructures

A. Martí[1], A. Marcuello[1], J. Ledo[1], P. Queralt[1] and the IBERGIC-CAST team

[1] Institut de Recerca Geomodels, Universitat de Barcelona (UB)

In the frame of the Spanish Ministry of Science Research and Development Program Oriented to Challenges of the Society, we have submitted the coordinated proposal “Modelling and forecasting of Geomagnetically Induced Currents in Spain (IBERGIC-CAST)”, with the objective of developing tools to advance preparedness against such phenomena, particularly in the Spanish Power Network. This proposal is a continuation of the current project IBERGIC (CGL2017-82169-C2) and involves a multidisciplinary team with expertise in Geomagnetism (Ebro Observatory), Theoretical Physics and Deep Learning (University of Valencia) and Geophysics (UB), in order to tackle the complex problem of modelling and forecasting the impact of threatening solar storms on Spanish critical infrastructures.

The subproject of UB will focus on the study of the geoelectrical structure of the lithosphere of Iberia, the Balearic and Canary Islands, which can be characterised by the magnetotelluric method, improving and creating new geoelectrical models, generating hazard maps of the geoelectrical field and exploring the use of new relationships between the MT measurements and the GICs.

In the present contribution we will explain the outcomes of the first project IBERGIC and the goals of this subproject, which results will be used for the other subprojects to model and forecast the GICs in the Spanish Power Grid. On the other way round, the modelled field and predictions will be inputs to validate our models and hazard maps.

Back to programme

Cameron Patterson

Lancaster University

The impact of space weather on UK railways

Cameron Patterson and Jim Wild

Some of the many manifestations of space weather's effects on ground-based infrastructure are hazards to railway assets, with the potential of false signalling, damage to a train's onboard transformer and even injury of track-side workers. Railway track circuits are key signalling mechanisms that are responsible for the safe and smooth operation of a railway network. By utilising track circuit modelling, geomagnetic field interpolation and UK conductivity models, the impact of space weather on the UK railways can be investigated. Initial results from a UK-focused modelling project will be presented and next steps proposed.

Back to programme

Neil Rogers

Lancaster University

Climatological statistics of extreme geomagnetic fluctuations with periods from 1 s to 60 min

Neil Rogers, James Wild, and Emma Eastoe

We present climatological statistics of extreme fluctuations in the horizontal geomagnetic field (*dB/dt*) generated at the Earth's surface by electrical currents in the ionosphere and magnetosphere. Using a global database of 125 magnetometer data covering several decades we present occurrence statistics for fluctuations exceeding the 99.97th percentile ($P_{99.97}$) for both ramp changes (R_n) and the root-mean-square (S_n) of fluctuations over periods, τ, from 1–60 min and describe their variation with corrected geomagnetic latitude and magnetic local time (MLT). Rates of exceedance are explained by reference to the magneto-ionospheric processes dominant in different latitude and MLT sectors, including ULF Pc5, Ps6 waves, interplanetary shocks, auroral substorm currents, and travelling convection vortices. By fitting Generalised Pareto tail distributions above a $P_{99.97}$ threshold we predict return levels (RLs) for R_n and S_n over periods up to 500 years. $P_{99.97}$ and RLs increase monotonically with frequency ($1/\tau$) – with a few exceptions at auroral latitudes – and this is well modelled by quadratic functions whose coefficients vary smoothly with latitude. For three UK magnetometers providing 1-s cadence measurements, the analysis is extended to cover periods from 1 to 60 seconds and empirical Magnetotelluric Transfer functions are used to predict percentiles and return levels of the geoelectric field for τ = 1 s to 60 min assuming a vertically propagated sinusoidal field. These statistics may inform the choice of frequency dependence to use with *dB/dt* when used as a proxy for geomagnetically induced currents.

Back to programme

Robert Shore

British Antarctic Survey

Converting a model of ionospheric reconfiguration timescales into a forecast model of ground level geomagnetic variations

We summarise some recent and new advances in geomagnetic field modelling, both from during the SWIGS project, and from the new SWIMMR-SAGE project. These advances are aimed at determining the location, extent, and timescales of surface geomagnetic field variations caused by space weather, and also aim to describe the underlying space physics. Shore *et al.* (2018) have isolated and identified the spatio-temporal patterns of large-scale surface geomagnetic variations by combining Empirical Orthogonal Functions (EOF) and network analysis. This provides us a toolset and database to understand and quantify the relative contributions to the surface geomagnetic field from different physical processes. Shore (2019a,b) have related each individual geomagnetic field pattern, or ionospheric equivalent current system, to its driving by the Sun via the solar wind. The authors have shown that different modes of geomagnetic variability have different correlations with the solar wind coupling function epsilon (Perreault and Akasofu, 1978). This research defines the extent to which the solar wind causes a geomagnetic response at each high-latitude location on the Earth's surface, in addition to how big the effect will be, and how long it will persist for. In the SWIMMR-SAGE project, we are using this new understanding of the physics underlying space weather to build a forecast model of geomagnetic variations at ground level, dependent on solar wind driving and auroral oval boundary proximity. This research is laying the groundwork for the next generation of Met Office space weather forecast models.

References

https://doi.org/10.1111/j.1365-246X.1978.tb05494.x
https://doi.org/10.1002/2017JA024420
https://doi.org/10.1029/2019SW002161
https://doi.org/10.1029/2019JA026543

Back to programme

Session 3

Peter Gallagher

Dublin Institute for Advanced Studies

Solar and geomagnetic monitoring and modelling in Ireland

Peter Gallagher[1], Sophie Murray[2,1], John Malone-Leigh[1,2,3], Joan Campanya[3,4]

[1] Dublin Institute for Advanced Studies
[2] Trinity College Dublin
[3] Geological Survey of Ireland
[4] Carlow Institute of Technology

Space weather can have adverse impacts on the ground- and space-based technologies on which society depends. In Ireland, we have set up instruments and tools to monitor and forecast phenomena associated with space weather, from their origins on the Sun to their impacts at Earth. In this presentation, we will give an update on the status of our solar monitoring and forecasting service, www.SolarMonitor.org, together with recent progress with the Magnetometer Network of Ireland (MagIE; www.MagIE.ie) and VLF monitoring of the ionosphere. In addition, we will give an update on new tools to model electric and magnetic field variations across Ireland in near-realtime.

Back to programme

Jonathan Eastwood

Imperial College London

Translation of the Gorgon magnetospheric model for operational space weather forecasting in the context of the SWIMMR/SAGE project

The objectives of the SWIMMR Activities in Ground Effects (SAGE) consortium, working under the auspices of the overall UKRI/SPF-funded Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR) project are (1) to provide accurate now/forecasts of the ground geomagnetic field (GGF) and of the ground electric field across the UK, as the space weather source of power grid Geomagnetically Induced Currents (GIC), pipeline Pipe-to-Soil Potential (PSP), and rail network faults and (2) to make operational, at Met Office, new UK capabilities in space weather now/forecasting of GIC, PSP and rail hazard. Forecast capability will, in part, be based on first-principles physics models using magneto-hydrodynamic (MHD) simulation codes as these are an increasingly valuable tool for space weather forecasters to quantify GIC hazard. As part of the SWIMMR/SAGE consortium, Imperial will implement an operational version of the Gorgon global magnetospheric model at the Met Office as part of an integrated SAGE modelling suite. This will ultimately be used by the Met Office Space Weather Operations Centre (MOSWOC) as part of its suite of forecasting tools. In this presentation, we will review development of the Gorgon global magnetospheric model in the context of the NERC 'Space Weather Impacts on Ground-based Systems' (SWIGS) project, and describe current and planned work required to meet the scientific and operational challenges of the SWIMMR/SAGE project.

Back to programme

Chigomezyo M. Ngwira

Atmospheric and Space Technology Research Associates, Louisville, CO, USA

Geomagnetically induced currents in the United States: Past, present, and future efforts

Disturbances from the Sun often referred to as “space weather”, cause geomagnetic storms that can affect critical infrastructure, such as navigation systems, high-voltage electric power transmission grids, and pipelines. Understanding the dynamic response of the coupled solar wind-magnetosphere-ionosphere system to severe space weather is an on-going challenge. This talk highlights some of recent and on-going applied geomagnetically induced current (GIC) research efforts in the USA and how space weather studies in general are being used to address societal needs.

Back to programme