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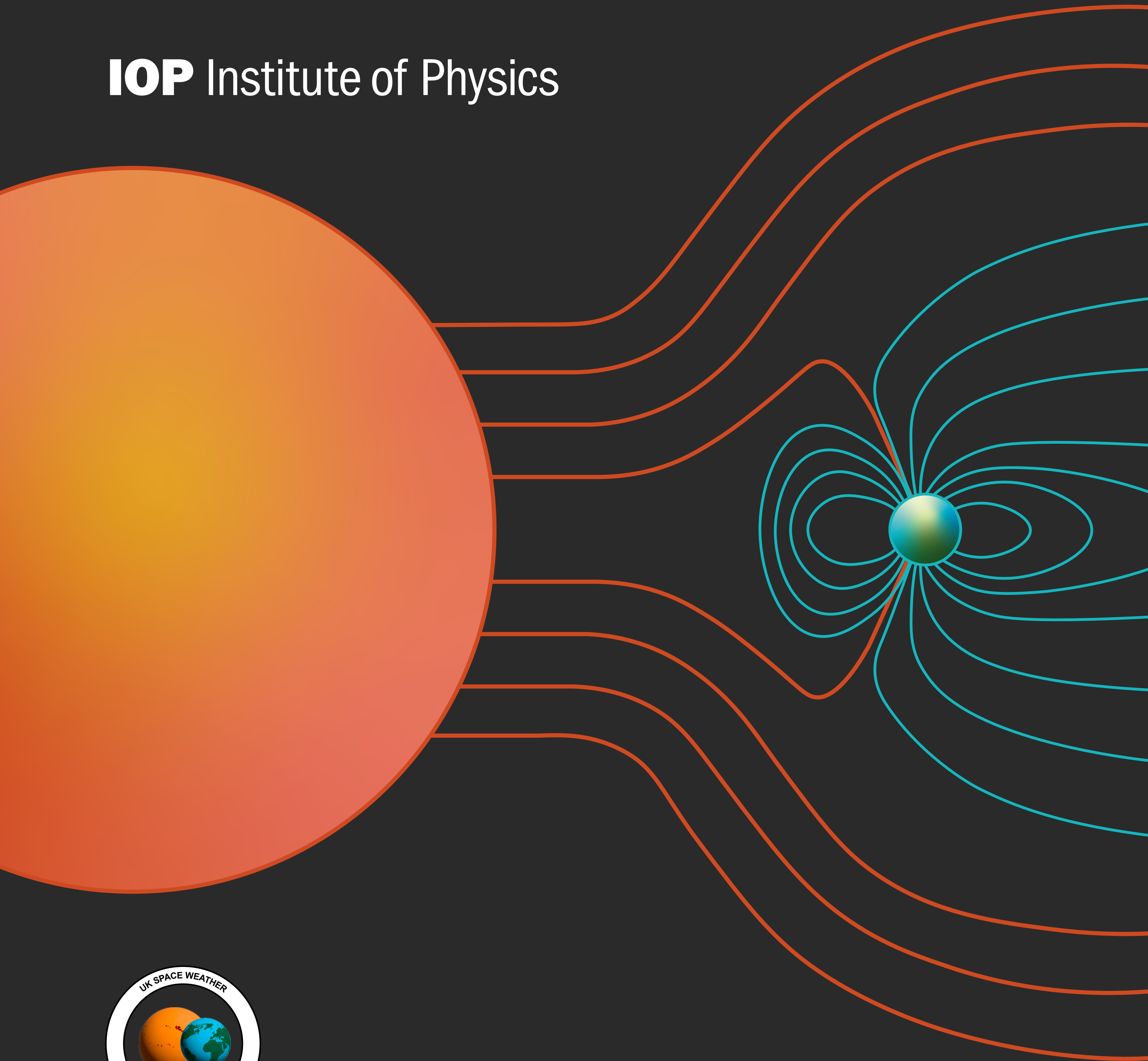

UK Space Weather and Space Environment Meeting II:
Celebrating 10-years of 24/7 space-weather operational forecasting in the UK

9–12 September 2024
Sandy Park Conference & Banqueting Centre, Exeter, UK

iop.org

Transforming Met Office space weather systems with AWS

BJSS turbocharged the Met Office's space weather programme by modernising and migrating to AWS. This upgrade boosted:

- Availability and resilience
- Scalability
- Cost efficiency

Through partnership with BJSS, the Met Office now has a futureproofed system, capable of handling the increasing demands of space weather forecasting in a rapidly-changing world. This collaboration has ensured the reliability and resilience of forecasts, safeguarding vital national infrastructure, and public safety.

The Met Office is now better equipped to predict and respond to the challenges of space weather.

"Working with senior stakeholders to establish trust and transparency, BJSS helped us develop 'right first time', meeting user and regulatory needs in a complex and highly specialised domain."

(Senior Delivery Manager, Met Office)

Want to chat about your technology challenges? Our people are ready to discuss your situation and share options to help meet your needs.

Scan the QR code and get in touch!

UK SPACE AGENCY

The UK Space Agency's work on space weather includes:

The ESA Vigil and Aurora missions as part of our involvement in the ESA Space Safety Programme.

The National Space Operations Centre (NSpOC) as well as many other missions that protect the space environment.

Image: ESA

Programme

Monday 9 September 2024

10:00 AM - 11:00 AM	**Registration and Refreshments**
11:00 AM - 1:00 PM (Room: Exeter Suite 2)	**Open Conference, Policy Focused, Celebrating 10 Years of MOSWOC** **Mario Bisi, UKRI STFC RAL Space (11:00 AM – 11:05)** UKSWSE II Welcome and Logistics **Mark Gibbs, Met Office (11:05 AM – 11:10 AM)** Introduction to Penny Endersby **Penny Endersby, Met Office (11:10 AM – 11:20 AM)** Welcome and MOSWOC 10-Year Anniversary Achievement **Mark Gibbs, Met Office (11:20 AM – 11:35 AM)** The Story of the Last 10-Years of MOSWOC and a Plan for the Future **Abigail Clarke, DESNZ (11:35 AM – 11: 55 AM)** Space Weather and Energy Security – Linkages to the UK's Severe Space Weather Preparedness Strategy **Sarah Sharples, DFT (11:55 AM – 12:15 PM)** Space Weather and Transport in the UK **Jennifer Meehan (12:15 PM – 12:35 PM)** **Clinton Wallace**, NOAA SWPC **(12:35 PM – 12:50 PM)** The SWPC-MOSWOC Partnership **Lt Col Todd Blum, US Space Force (12:50 PM – 1:00 PM)** 2023 Space Weather Implementation – USSF's Path to Execution
1:00 PM - 2:00 PM	**Lunch**
2:00 PM - 4:00 PM (Room: Exeter Suite 2)	**Space Weather End Users Panel** **Mark Gibbs: Invited Speaker (2:00 PM - 2:10 PM)** Discuss the wide range of user needs, including space weather forecasters, as a specialist user group **Kingsley Akpeji and Matthew Hofton: Invited Speakers (2:10 PM - 2:20 PM)** Mitigating the Impact of Geomagnetic Disturbances on the UK Power Grid: Status Quo and Future Requirements **Gemma Attrill: Invited Speaker (2:20 PM - 2:30 PM)** Working in partnership with the Space Weather Community **Suzy Bingham: Invited Speaker (2:30 PM - 2:40 PM)** Space weather models for the user - understanding operational models for effective use **Joanna Hart: Invited Speaker (2:40 PM - 2:50 PM)** Summarising breadth & depth of UK space weather related activities

	Petra Vanlommel (2:50 PM - 3:00 PM) Space Weather Courses for Industry and Users **Sean Elvidge (3:00 PM - 3:10 PM)** Rethinking the Space Weather Scales **Panel and Q&A (3:10 PM - 4:00 PM)**
4:00 PM - 4:30 PM	**Afternoon Break**
4:30 PM - 5:10 PM (Room: Exeter Suite 2)	**Space Safety with UKSA and ESA Panel** **Mike Willis and Caroline Harper: Invited Speakers (4:30 PM - 4:40 PM)** How the UK Space Agency is supporting Space Weather R&D and Operations **Alexi Glover: Invited Speaker (4:40 PM - 4:50 PM)** Space Weather Developments and Capabilities in the ESA Space Safety Programme **Panel and Q&A (4:50 PM - 5:10 PM)**
5:10 PM - 6:00 PM (Room: Exeter Suite 2)	**A Global Perspective on Space Weather and Policy** **David Southwood (5:10 PM - 5:20 PM)** Future Politics and UK Space Weather and Space Safety activities **Yana Maneva (5:20 PM - 5:30 PM)** 5 years of STCE's space weather service to aviation **James Favors (5:30 PM - 5:40 PM)** TBC **Discussion (5:40 PM - 6:00 PM)**
6:00 PM - 8:00 PM	**Drinks Reception and Buffet**

Tuesday 10 September 2024

8:15 AM - 8:45 AM	Arrival Refreshments
8:45 AM - 11:00 AM (Room: Exeter Suite 2)	LOC session - Invited Talks Including Industry Sponsors/Stakeholders **Paul Monks, DESNZ (8:45 AM – 9:00 AM)** **Wg Cmdr Neal Henley, UK Space Command (9:00 AM – 9:15 AM)** An Overview of NSPOC **Athene Gadsby, UKSA (9:15 AM – 9:30 AM)** UKSA, Space Domain Awareness and NSpOC - The Civil Perspective **Sarah Beardsley, UKRI STFC RAL Space (9:30 AM – 9:45 AM)** **Bill Murtagh, NOAA SWPC (9:45 AM – 10:00 AM)** Updating the NOAA Space-Weather Scales **Kristen Reeson, BOM (10:00 AM – 10:15 AM)** MET5 contributions to space weather **Maria Kuznetsova, COSPAR ISWAT and/or NASA CCMC (10:15 AM – 10:30 AM)** Successes, Challenges and Opportunities in our Quest to Improve Research-to-Operations and Operations-to-Research Pipelines **Eric Adamson, NOAA SWPC (10:30 AM – 10:45 AM)** Advancements in Research to Operations and Operations to Research in the United States **Andrew Monham, EUMETSAT (10:45 AM – 11:00 AM)** Ensuring Space Environment Sustainability at EUMETSAT
11:00 AM - 11:30 AM	Morning Break
11:30 AM - 1:00 PM (Room: Exeter Suite 2)	SDA/SSA/SST Panel **Melissa Quinn: Invited Speaker (11:30 AM - 11:40 AM)** Managing Director, Slingshot Aerospace **Harneet Kaur Sangha: Invited Speaker (11:40 AM - 11:50 AM)** Monitor Space Hazards: The National Space Operations Centre's Civil Space Protection Services **Don Pollacco: Invited Speaker (11:50 AM - 12:00 PM)** At the sharp end: optical characterisation of the satellite and debris population **Robert Massey: Invited Speaker (12:00 PM - 12:10 PM)** Dark and quiet skies: for astronomers and for all of us **Leah-nani Alconcel and Gruffudd Jones (12:10 PM - 12:20 PM)** Rotulus: A 3U CubeSat Drag-sail Technology Demonstration for LEOsat Disposal

	Victor U. J. Nwankwo (12:20 PM - 12:30 PM) Investigation of atmospheric drag effect on the trajectory of cataloged LEO objects and its implication for the safety of active satellites in the 25th solar cycle **Panel and Q&A (12:30 PM - 1:00 PM)**
1:00 PM - 2:00 PM	**Lunch**
2:00 PM - 3:30 PM (Room: Exeter Suite 2)	**Solar Science for Space Weather** **Lucie Green: Invited Speaker (2:00 PM - 2:15 PM)** Solar science and its application to forecasting coronal mass ejections **Antonio Niemela: Invited Speaker (2:15 PM - 2:30 PM)** Heliospheric Wind and CME Evolution Modelling with EUHFORIA **Anthony Yeates: Invited Speaker (2:30 PM - 2:45 PM)** An Outflow Equilibrium Model for the Solar Corona **Natasha Jeffrey: Invited Speaker (2:45 PM - 3:00 PM)** Diagnosing the properties of solar flare energetic particles at the Sun and in the heliosphere **Timo Laitinen (3:00 PM - 3:15 PM)** Solar Energetic Particle forecasting with physics-based tools: current status and future developments **Sandra Chapman: Invited Speaker (3:15 PM - 3:30 PM)** A regular clock for the solar cycle variation of extreme space weather risk
3:30 PM - 4:00 PM	**Afternoon Break**
4:00 PM - 5:00 PM (Room: Exeter Suite 2)	**Space Skills Panel** **Heidi Thiemann: Invited Speaker (4:00 PM - 4:10 PM)** Results of the 2024 Space Census and Space Training in the UK **Mike Hapgood: Invited Speaker (4:10 PM - 4:20 PM)** Skills for space weather understanding and mitigation **Alice Bunn: Invited Speaker (4:20 PM - 4:30 PM)** Future Skills Requirements **Michaela Mooney (4:30 PM - 4:40 PM)** Orbyts: Research in School Partnerships **Panel and Q&A (4:40 PM - 5:00 PM)**
5:00 PM - 6:15 PM (Room: Exeter Suite 2)	**R2O2R Panel** **Alexa Halford: Invited Speaker (5:00 PM - 5:10 PM)** A framework for tracking progress: The Application Usability Levels and how they can enable the R2O2R process

	Richard Horne: Invited Speaker (5:10 PM - 5:20 PM) May 2024 Magnetic Storm: Some Reflections and Suggestions for Future Work **Luke Barnard: Invited Speaker (5:20 PM - 5:30 PM)** Improving space weather forecasts with heliospheric imager data assimilation **Hazel Bain: Invited Speaker (5:30 PM - 5:40 PM)** Advancing Radiation Storm Models at NOAA's SWPC: Insights from Research to Operations to Research Process **Sean Elvidge (5:40 PM - 5:50 PM)** Placing May 2024 in Context: Space Weather Impacts and the Importance of Communications **Panel and Q&A (5:50 PM - 6:15 PM)**
6:15 PM - 8:00 PM	**Networking with Drinks Reception and Buffet**

Wednesday 11 September 2024

8:30 AM - 9:00 AM	Arrival Refreshments
9:00 AM - 9:45 AM (Room: Exeter Suite 2)	EISCAT & LOFAR **Maria Mihalikova: Invited Speaker (9:00 AM - 9:15 AM)** EISCAT_3D – A Multi-Static Phased-Array Incoherent Scatter Radar in Northern Fennoscandia **Sophie Maguire: Invited Speaker (9:15 AM - 9:30 AM)** Observations of plasma structures of varying scale sizes in the high-latitude ionosphere with a suite of instrumentation **Biagio Forte (9:30 AM - 9:45 AM)** Radio wave scintillation observed through LOFAR to infer properties of ionospheric structures
9:45 AM - 10:30 AM (Room: Exeter Suite 2)	The May 2024 Storm **Anthony Iampietro (9:45 AM - 10:00 AM)** A Perspective of the Real Time Analysis of the May 2024 Storm from The Moon to Mars Space Weather Analysis Office **Eva Weiler (10:00 AM - 10:15 AM)** Assessing the geo-effectiveness of CMEs from a sub-L1 perspective **Siegfried Gonzi (10:15 AM - 10:30 AM)** An Analysis of the May 2024 Superstorm with the tools used by Met Office Forecasters
10:30 AM - 11:00 AM	Morning Break
11:00 AM - 12:00 PM (Room: Exeter Suite 2)	Parallel 1A: The Ionosphere **Michaela Mooney (11:00 AM - 11:15 AM)** Evaluating auroral forecasts against satellite observations under different levels of geomagnetic activity **David Themens: Invited Speaker (11:15 AM - 11:30 AM)** High latitude ionospheric response to the May 2024 Storm and its impacts on GNSS **Cathryn Mitchell: Invited Speaker (11:30 AM - 11:45 AM)** MIDAS ionospheric data assimilation and applications to GNSS **Martin Cafolla (11:45 AM - 12:00 PM)** Identifying and Tracking TEC Enhancements seen in JPL GIMs and their response to Geomagnetic Activity

11:00 AM - 12:00 PM (Room: County Suite)	Parallel 2A: Solar **Thomas Howson: Invited Speaker (11:00 AM - 11:15 AM)** A Review of Contemporary Models of the Solar Corona **Andrew Hillier (11:15 AM - 11:30 AM)** Prominence/filament dynamics and their potential role in the eruption of quiet Sun filaments **William Beckwith-chandler (11:30 AM - 11:45 AM)** A Precursor to Solar Prominence Eruptions: Detection and Analysis of EUV Prominence Oscillations **Jennifer O'Hara (11:45 AM - 12:00 PM)** Bridging Operations to Research: Development and Utilization of the SIDC Moderated Solar Weather Event List
12:00 PM - 1:00 PM (Room: Exeter Suite 2)	Parallel 1B: Instrumentation **John Morgan (12:00 PM - 12:15 PM)** High resolution mapping of the inner heliosphere via ground-based radio observations with state-of-the-art instruments: an australian perspective **Jackie Davies (12:15 PM - 12:30 PM)** Results of stray-light testing of the COR Stray-light Qualification Model (CSQM) **Fan Lei (12:30 PM - 12:45 PM)** Development of Compact Cherenkov Proton Detectors and Telescopes **Mario Bisi (12:45 PM - 1:00 PM)** RASOR: Radio Astronomy and Space Observation Research Facility - An Opportunity for the Future
12:00 PM - 1:00 PM (Room: County Suite)	Parallel 2B: The Magnetosphere **Thomas Berger (12:00 PM - 12:15 PM)** The Space Weather Operational Readiness Development Center: a new NASA space weather center of excellence **Robert Fear: Invited Speaker (12:15 PM - 12:30 PM)** Joint Cluster/Ground-Based Studies in the First 20 Years of the Cluster Mission **Tom Elsden: Invited Speaker (12:30 PM - 12:45 PM)** Numerical Modelling of ULF Waves in Asymmetric Media **Enrico Camporeale (12:45 PM - 1:00 PM)** Probabilistic forecasting with physics-informed machine learning: Sun-to-mud
1:00 PM - 2:00 PM	Lunch
1:30 PM - 2:00 PM (Room: Exeter Suite 2)	MIST/UKSP Lunch Session

2:00 PM - 4:00 PM	Poster Session Sponsored by UK Space Agency
4:00 PM - 5:00 PM (Room: Exeter Suite 2)	**Parallel 1C: The Mesosphere and Thermosphere and Ionosphere** **Anna Belehaki (4:00 PM - 4:15 PM)** Large Scale Travelling Ionospheric Disturbances AI/ML based forecasting model **John Plane: Invited Speaker (4:15 PM - 4:30 PM)** Meteoric ablation and metallic layers in the mesosphere and lower thermosphere: impacts of space weather **Benjamin Reid (4:30 PM - 4:45 PM)** A Real-Time Data Assimilation International Reference Ionosphere **Natalie Reeves (4:45 PM - 5:00 PM)** Understanding the sensitivity of TIe-GCM's forcing parameters
4:00 PM - 5:00 PM (Room: County Suite)	**Parallel 2C: The Solar Wind and Coupling to the Magnetosphere** **Harriet Turner: Invited Speaker (4:00 PM - 4:15 PM)** Data assimilation in the solar wind **Mathew Owens (4:15 PM - 4:30 PM)** Solar-wind Modelling: The Importance of Boundary Evolution **Bernard Jackson (4:30 PM - 4:45 PM)** Heliospheric Mesoscale 3-D Reconstructions and the UCSD Plan for the NASA Small Explorer PUNCH Analyses **Dusan Odstrcil (4:45 PM - 5:00 PM)** Improving the Arrival-Time Prediction of Coronal Mass Ejections by Heliospheric Imagery and Ensemble Modeling
5:00 PM - 6:00 PM (Room: Exeter Suite 2)	**Parallel 1D: Ground and Infrastructure** **Cameron Patterson: Invited Speaker (5:00 PM - 5:15 PM)** Could Space Weather Delay Your Train? Modelling the Impacts of Geomagnetically Induced Currents on Railway Signalling Systems **Matthew Allcock (5:15 PM - 5:30 PM)** Space weather and autonomous transport: Voices from industry on risk and resilience **Joseph Eggington: Invited Speaker (5:30 PM - 5:45 PM)** Extreme space weather risks to power plants: assessing vulnerability, building resilience and improving preparedness **Ciaran Beggan (5:45 PM - 6:00 PM)** SWIMMR N4: An overview of the completed SAGE project

5:00 PM - 6:00 PM (Room: County Suite)	**Parallel 2D: The Radiation Belts** **Sarah Glauert: Invited Speaker (5:00 PM - 5:15 PM)** Energy diffusion in the Earth's radiation belts **Ravindra Desai (5:15 PM - 5:30 PM)** Electron injections and decays during solar cycle 22 observed by CRRES **Fraser Baird (5:30 PM - 5:45 PM)** Observations of the Radiation Belts during Solar Minimum **Dedong Wang: Invited Speaker (5:45 PM - 6:00 PM)** Prediction of Adverse effects of Geomagnetic storms and Energetic Radiation (PAGER) Project and Follow-On
7:00 PM - 10:00 PM (Room: Chiefs Suite)	**Conference Dinner**

Thursday 12 September 2024

8:30 AM - 9:00 AM	Arrival Refreshments
9:00 AM - 10:00 AM (Room: Exeter Suite 2)	**Funding of UK Space Weather** **STFC, Chloe Woodcock and Robert Fear (9:00 AM – 9:20 AM)** **NERC, Ian McCrea (9:20AM – 9:30 AM)** **EPSRC, (9:30 AM – 9:40 AM)** **DSTL, Jennifer O'Kane (9:40 AM – 9:50 AM)** **Panel and Q&A (9:50 AM – 10:00 AM)**
10:00 AM - 10:30 AM (Room: Exeter Suite 2)	**Upcoming Missions for Space Weather Science** **Colin Forsyth: Invited Speaker (10:00 AM - 10:15 AM)** Unique global viewing of Earth's dynamic magnetosphere with the Solar wind – Magnetosphere – Ionosphere Link Explorer (SMILE) **Jennifer Carter: Invited Speaker (10:15 AM - 10:30 AM)** Elfen: A novel CubeSat to understand plasma composition upstream and downstream of the Earth
10:30 AM - 11:00 AM	Morning Break
11:00 AM - 12:00 PM (Room: Exeter Suite 2)	**Parallel 1E: Ground & Infrastructure** **Andy Smith (11:00 AM - 11:15 AM)** Evaluating Solar Wind-Driven ML Models of Ground Level Space Weather in the UK **Gemma Richardson: Invited Speaker (11:15 AM - 11:30 AM)** Modelling Geomagnetically Induced Currents in high voltage power networks in the UK and beyond **Mark Clilverd (11:30 AM - 11:45 AM)** The May 2024 'Gannon' G5 storm: The application of GIC mitigation during a very large geomagnetic disturbance **Michael Aspinall: Invited Speaker (11:45 AM - 12:00 PM)** Design and implementation of the United Kingdom's first operational ground level neutron monitor for four decades
11:00 AM - 12:00 PM (Room: County Suite)	**Parallel 2E: The Solar Wind and Coupling to the Magnetosphere** **Mike Heyns (11:00 AM - 11:15 AM)** Global Simulations for Space Weather Forecasting: GorgonOps Forecasting Suite **Alexandra Ruth Fogg: Invited Speaker (11:15 AM - 11:30 AM)** Extreme Space Weather in the Earth's Space Environment **Gemma Bower: Invited Speaker (11:30 AM - 11:45 AM)** Solar cycle and solar wind control of the occurrence of large dB/dt events **Hua-Liang Wei (11:45 AM - 12:00 PM)** Detecting Potential Drivers of Geomagnetic Activity Using Nonlinear System Identification and Machine Learning Techniques
12:00 PM - 1:00 PM (Room: Exeter Suite 2)	**Parallel 1F: SWIMMR Outputs** **Ian McCrea (12:00 PM - 12:15 PM)** R202R – SWIMMR model validation and international collaboration **Simon Machin (12:15 PM - 12:30 PM)** Capability development - Aligning to better meet user needs

	Ben Clewer (12:30 PM - 12:45 PM) SAIRA Atmospheric Radiation Monitors Delivered for SWIMMR **Matthew Allcock (12:45 PM - 1:00 PM)** Recommendations to policymakers to improve space weather resilience of UK critical national infrastructure (SWIMMR S6)
12:00 PM - 1:00 PM (Room: County Suite)	**Parallel 2F: Solar** **Marianna Korsos: Invited Speaker (12:00 PM - 12:15 PM)** Harmonising Long-Term and Short-Term Solar Flare Predictions **Rami Qahwaji (12:15 PM - 12:30 PM)** Improved 24/7 Solar Flares Prediction using Deep Learning and Data Fusion Techniques **Sarah Matthews: Invited Speaker (12:30 PM - 12:45 PM)** Solar explosive energy release – what we still don't know and why we need to know it **Amrita Prasad (12:45 PM - 1:00 PM)** Solar Cycle 25: Forecasts vs. Reality – A Mid-Cycle Check-In
1:00 PM - 2:00 PM	Lunch
2:00 PM - 3:00 PM (Room: Exeter Suite 2)	**Parallel 1G: Instrumentation and Data** **Shane Maloney (2:00 PM - 2:15 PM)** SolarMonitor 2.0 **Jonathan Eastwood (2:15 PM - 2:30 PM)** Development of the MAGIC minaturized magnetometer sensor for measurements in low Earth orbit, cis-lunar space, and the upstream solar wind beyond L1 **Supriya Chakrabarti (2:30 PM - 2:45 PM)** A new technique designed to obtain ionospheric parameters from Very Low Earth Orbit (VLEO) **Neil Rogers (2:45 PM - 3:00 PM)** Near-real-time riometer measurements for nowcasting High Frequency radio wave absorption
2:00 PM - 3:00 PM (Room: County Suite)	**Parallel 2G: The Radiation Belts** **Richard Boynton (2:00 PM - 2:15 PM)** A system identification approach to modelling the electrons in the radiation belts measured by POES **Frances Staples: Invited Speaker (2:15 PM - 2:30 PM)** Evaluating the Performance of a Real-Time Electron Radiation Belt Specification Model **Peter Kirsch (2:30 PM - 2:45 PM)** From Research to Operation: Development of the SWIMMR N1 Radiation Belt Forecasts **Richard Horne (2:45 PM - 3:00 PM)** May 2024 magnetic storm: A comparison between radiation belt models and observations
3:00 PM - 3:30 PM	Afternoon Break
3:30 PM - 4:00 PM (Room: Exeter Suite 2)	**Community Discussion: Next Steps for the UKSWSE Meeting**

4:00 PM - 5:00 PM (Room: Exeter Suite 2)	**Community Discussion: The Future of Space Weather in the UK and the Wider Community** **Ian McCrea (4:00 PM - 4:10 PM)** SWIMMR Retrospective - The Good, the Bad and the Ugly **Ian McCrea (4:10 PM - 4:20 PM)** What might happen next? SWIMMR, SWOPPER and the NSS
5:00 PM - 5:30 PM (Room: Exeter Suite 2)	**Conference Close**

Oral Presentations

Advancements in Research to Operations and Operations to Research in the United States

Dr Eric Adamson[1]
[1]NOAA Space Weather Prediction Center, United States

LOC session - Invited Talks Including Industry Sponsors/Stakeholders, September 10, 2024, 08:45 - 11:00

In response to an increasing acknowledgment of the broad societal impacts posed by space weather, recent legislation in the US, namely the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act, has stimulated efforts toward improving the national space weather R2O2R paradigm. As such, the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the Department of the Air Force (DAF) have set forth plans to hone existing R2O2R functions and to implement components which have not yet existed, with the overall aim of collectively generating an efficient national process which expedites the maturation of nascent research efforts toward critical operational space weather forecasting capabilities and which feeds critical gaps back to the research community for improvements. This talk will provide a detailed description of the R2O2R process, the status of the overall program, and highlight recent advancements.

Mitigating the Impact of Geomagnetic Disturbances on the UK Power Grid: Status Quo and Future Requirements

Mr Mathew Hofton, Mr Kingsley Akpeji
[1]Electricity System Operator (ESO), United Kingdom

Space Weather End Users Panel, September 9, 2024, 14:00 - 16:00

The Electricity System Operator (ESO) is aware of the risk posed by geomagnetic disturbances (GMDs) driving geomagnetically induced currents (GICs) into high-voltage power grids. Extreme GMDs could cause catastrophic failures of large transmission-connected power transformers and maloperation of protection devices and power electronics, leading to wide-area power outages. To ensure operational readiness and mitigate costly impacts from extreme GMDs, the ESO has developed guidelines to support its operational decision-making and coordination with other stakeholders before, during, and after an event. The ESO also leads projects to improve the understanding of the effects of GICs on the UK power grid and implementation of optimal cost-effective mitigation measures.

Operational experience from the recent GMD events of 10 and 11 May 2024, classed as low G5 and causing peak GIC of up to 140A (modelled) in Wales, indicate that the UK power grid is robust to moderately extreme GMDs. Although there were reports of transformer GIC alarms, and one transformer trip in England overnight 10/11 May, and there were some daytime infeed losses on 12 May, neither asset damages nor power outages were recorded. Investigations are ongoing to verify whether GICs were the cause of these events.

This presentation will highlight our current guidelines for operational decision-making, challenges and knowledge gaps, and requirements from the Space Weather community to improve our operational readiness and mitigation plans.

Rotulus: A 3U CubeSat Drag-sail Technology Demonstration for LEOsat Disposal

Dr Leah-nani Alconcel[1], Mr Thomas Martindale, Dr Lily Beesley, **Mr Gruffudd Jones**
[1]University Of Birmingham, United Kingdom

SDA/SSA/SST Panel, September 10, 2024, 11:30 - 13:00

We present a novel drag system for a 3U CubeSat that could be used to accelerate LEOsat disposal. The Rotulus technology demonstrator's deployment technique greatly simplifies the primary sail deployment mechanism compared to established dragsail demonstrations, reducing the segmentation of the sail and the mechanical complexity of the boom system. Rotulus is intended as a technology demonstration for the drag system and its deployment, which will be stowed in the payload volume of a 3U CubeSat and deployed in LEO. We hope to prove its efficacy at increasing the effective surface area of the craft, accelerating the timeframe over which the satellite will re-enter the Earth's atmosphere. The system will also demonstrate the use of gravity gradient stabilisation of the deployed dragsail.

Rotulus has four primary objectives.
1. Demonstrate the deployment of a novel 3U dragsail design.
2. Demonstrate gravity gradient stabilisation of the deployed dragsail.
3. Demonstrate the de-orbit of the deployed 3U dragsail from a densely populated LEO orbit.
4. Demonstrate accelerated de-orbit within the timeframe predicted for the current solar activity conditions.

These objectives have been defined to minimise interdependency, so that should any of the failure modes unfortunately be realised, they may at least be partially fulfilled.

We will present the results of our preliminary studies into the feasibility of Rotulus.

Space weather and autonomous transport: Voices from industry on risk and resilience

Dr Matthew Allcock[1], Dr Randa Natras[2], Mr Andy Proctor[3], Dr Siddartha Khastgir[4], Mr Simon Machin[5], Mr Michael Szczepanski[5], Ms Alyssa Frayling[6], Ms Sara Cucaro[6]
[1]Starion UK, United Kingdom, [2]Starion Germany, Germany, [3]RethinkPNT, United Kingdom, [4]Warwick Manufacturing Group, United Kingdom, [5]Met Office, United Kingdom, [6]know.space, United Kingdom

Parallel 1D: Ground and Infrastructure, September 11, 2024, 17:00 - 18:00

By 2035, just in time for the next solar maximum, 40% of new cars in the UK could have self-driving capabilities according to a market forecast by Connected Places Catapult. The rapid advancement of autonomous transport systems brings immense potential for increased safety, efficiency, and accessibility in mobility, yet the space weather vulnerabilities are largely unexplored.

This talk will present preliminary results of the Space Weather Autonomous Vehicle Effects (SWAVE) project, an ongoing study funded by the European Space Agency (ESA). We are consulting with autonomous transport industry stakeholders across Europe to understand their experience with space weather – including the impacts of the Gannon storm in May 2024 that affected precision agriculture systems. We will discuss the possible mechanisms that space weather can affect autonomous transport, what mitigation measures the industry can take, and how researchers can help to fill gaps in our understanding of these effect.

Recommendations to policymakers to improve space weather resilience of UK critical national infrastructure (SWIMMR S6)

Dr Matthew Allcock[1], Mr Alastair Pidgeon[1], Mr Gordon Black[1], Ms Emily Prestwood[1], Ms Alyssa Frayling[2], Ms Sara Cucaro[2], Prof Jonathan Rae[3], Dr Andy Smith[3], Dr Sarah Bentley[3], Dr John Coxon[3], Prof Robert Wicks[3], Prof Clare Watt[3]
[1]Starion UK, United Kingdom, [2]know.space, United Kingdom, [3]Northumbria University, United Kingdom

Parallel 1F: SWIMMR Outputs, September 12, 2024, 12:00 - 13:00

A decade on from the seminal Royal Academy of Engineering report by Cannon et al. 2013 on Extreme Space Weather, the SWIMMR S6 project has developed a new set of recommendations to UK policymakers to improve the space weather resilience of UK critical national infrastructure (CNI). Specific recommendations are made to the Energy, Communications, Space, and Transport sectors and overarching recommendations have been identified from common vulnerabilities across multiple sectors. Looking ahead at emerging trends in UK CNI, we identify specific technologies that may bring an increased vulnerability to space weather. I will close with a reflection on the project, the state of space weather understanding in UK CNI industries, and lessons learned for future projects of this type.

Design and implementation of the United Kingdom's first operational ground level neutron monitor for four decades

Dr Michael Aspinall[1], Dr Tilly Alton[1], Mr Cory Binnersley[3], Mr Steven Bradnam[2], Dr Carlo Cazzaniga[4], Professor Stephen Croft[1], Dr Christopher Frost[4], Dr Dakalo Mashao[1], Mr Lee Packer[2], Mr Tony Turner[2], Professor James Wild[1]
[1]Lancaster University, United Kingdom, [2]United Kingdom Atomic Energy Authority, United Kingdom, [3]Mirion Technologies (Canberra UK) Limited, United Kingdom, [4]STFC Rutherford Appleton Laboratory, United Kingdom

Parallel 1E: Ground & Infrastructure, September 12, 2024, 11:00 - 12:00

We provide an overview of the work done under the Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR) S5 opportunity for networkable instruments for ground-level neutron monitoring. Starting in June 2021, the Ground Level Enhancement Event Monitor (GLEEM) project, has designed and implemented a new neutron monitor that is cheaper, more compact and capable of producing comparable count rates to a common standard 6-NM-64; following convention, the monitor is named the NM-2023. We have achieved this by evaluating the latest neutron detector technologies suited for the challenging application requirements of cosmic ray neutron monitoring and employing Monte Carlo N-Particle transport code simulations to guide the design. Parameterised models were used to evaluate a variety of geometries before optimising the highest performing arrangement, considering count rate per unit mass of material and detector volume, and cost and ease of manufacture. Simulations and calculations were experimentally validated via distance scaling laws, use of the ISIS ChipIr facility and long background count comparisons at several cut off rigidities across the UK. From September 2022 work transitioned to implementation, working with a systems vendor to produce engineering drawing packs and to fabricate the first of the new NM-2023 design. Exploiting the established supply chain serving nuclear safeguards and security, and utilising commercial-off-the shelf and International Atomic Energy Agency 'approved for use' components where possible, we have engineered a solution appropriate of an operational instrument. NM-2023s are now operational at the Camborne Met Office observatory, Cornwall, and at Lancaster University, UK. Initial data are presented.

Working in partnership with the Space Weather Community

Prof. Gemma Attrill[1]
[1]Dstl, United Kingdom

Space Weather End Users Panel, September 9, 2024, 14:00 - 16:00

Outline Dstl's role in working with Defence end users.

Advancing Radiation Storm Models at NOAA's SWPC: Insights from Research to Operations to Research Process

Hazel Bain[1]
[1]Space Weather Prediction Center, United States

R2O2R Panel, September 10, 2024, 17:00 - 18:15

This presentation will discuss the evolution of radiation storm models within the NOAA Space Weather Prediction Center, emphasizing insights gained from transitioning these models through the Space Weather Proving Ground and Testbed environment. It will explore the bi-directional flow of knowledge between research and operations, highlighting lessons learned from advancing models to higher readiness levels. Special focus is placed on validating these models against SWPC's current baseline capability, showcasing improvements in forecasting precision and operational utility. The talk underscores the collaborative synergy essential for enhancing space weather resilience, ensuring robust support for satellite operations, astronaut and airline crew/passenger safety in the dynamic space environment.

Observations of the Radiation Belts during Solar Minimum

Dr Fraser Baird[1], Fan Lei[1], Keith Ryden[1], Clive Dyer[1]
[1]Surrey Space Centre, United Kingdom

Parallel 2D: The Radiation Belts, September 11, 2024, 17:00 - 18:00

The Defence and Space Experiments (DSX) satellite flew through small parts of the inner and outer radiation belts from June 2019 to June 2021. The CREDANCE instrument was part of the NASA Space Environment Testbed payload onboard DSX, and featured a SURF detector (surface charging), proton telescope, LET telescope, and two RADFETs for measuring total ionising dose. This contribution presents the observations made by each of CREDANCE's detectors.
Electron and proton fluxes were obtained from the AE/AP-8 and IRENE models for the orbit of DSX. These fluxes were combined with response functions and software like SHIELDOSE to produce predicted charging currents, proton fluxes, and ionising dose rates. These predictions are compared to the observations, and model performance is assessed.

Improving space weather forecasts with heliospheric imager data assimilation

Dr Luke Barnard[1]
[1]University Of Reading, United Kingdom

R2O2R Panel, September 10, 2024, 17:00 - 18:15

Severe space weather is driven by Coronal Mass Ejections (CMEs) and much research effort is spent on forecasting the arrival and properties of CMEs at Earth. There is a crucial need to both better understand the physics of CMEs and to improve space weather forecasting capability. However, CME prediction has failed to significantly improve in a decade of research, due to both knowledge gaps and observational limitations. Typically, numerical models are used to simulate and forecast CMEs. However, although these models include the core physics, they struggle to accurately represent observed CMEs. There are two key reasons for this; the boundary conditions of these models are very uncertain due to observational limitations; and the representation and balance of processes in the models is incorrect.
Heliospheric Imagers (HI) provide the only consistent observations of CMEs and the solar wind flowing over the whole domain, from the corona to Earth. These observations show CMEs being both distorted and eroded as they flow through the solar wind, but they are under-exploited in space weather research and forecasting. Here I will describe my work to incorporate HI data into CME simulations and forecasts with Data Assimilation (DA). I'll review my efforts to build a particle filter DA scheme for the reduced physics HUXt model and how hindcasts from this system perform relative to other CME prediction systems. Finally, I'll highlight some upcoming R2O2R opportunities in the HI-DA field and what improvements these might yield to CME forecasting.

A Precursor to Solar Prominence Eruptions: Detection and Analysis of EUV Prominence Oscillations

William Beckwith-chandler[1], Claire Foullon[1], Erwin Verwichte[2]
[1]University Of Exeter, United Kingdom, [2]University of Warwick, United Kingdom

Parallel 2A: Solar, September 11, 2024, 11:00 - 12:00

The eruption of prominences can have a significant influence on the solar-terrestrial environment. However, accurately predicting these eruptions remains a challenge. We apply automated detection methods for extreme ultraviolet (EUV) prominences observed by the Solar Terrestrial Relations Observatory (STEREO) and Solar Dynamics Observatory (SDO). We study an event, during March 2011, when each STEREO spacecraft is in quadrature with respect to the Earth (SDO). For two time ranges, we obtain longitudinal height profiles as a function of time. We also track the corresponding EUV filaments across the solar disk, which reveal the emergence of ultra-long-period oscillations in the EUV filament channels. Our analysis shows a correlation between the prominence's increasing height and the oscillation periods, suggesting a potential link to the subsequent eruption observed by the STEREO spacecraft off-limb. These findings offer new insights into prominence dynamics and may pave the way for improved eruption prediction, aiding future space weather forecasting.

SWIMMR N4: An overview of the completed SAGE project

Dr Ciaran Beggan[1], Jonathan Eastwood[2], Mike Heyns[2], Adrian LaMoury[2], Colin Forsyth[3], Mervyn Freeman[4], Gemma Richardson[1], Juliane Huebert[1], Oli Chambers[1], Andy Smith[5]
[1]British Geological Survey, United Kingdom, [2]Imperial College, United Kingdom, [3]University College London, United Kingdom, [4]British Antarctic Survey, United Kingdom, [5]Northumbria University, United Kingdom

Parallel 1D: Ground and Infrastructure, September 11, 2024, 17:00 - 18:00

The NERC (N4) component of the SWIMMR programme, Activities in Ground Effects (SAGE), was tasked with implementing models and forecasts of magnetic field variation in the UK and creating operational tools to predict the magnitude of Geomagnetically Induced Currents (GIC) in grounded infrastructure. The tools, based on scientific models, convert magnetic field measurements and forecasts to geoelectric field variation using models of subsurface conductivity. The geoelectric field is used to estimate GIC in the high voltage power network, pipe-to-soil potential in the high-pressure gas pipeline network and the potential effects of GIC via a rail index. Nowcasts are produced from real-time magnetic field observations while forecasts of the magnetic field come from either a machine learning (SPIDER) or physics-based MHD model (GorgonOps). The project was completed in March 2024 and has been coded into a private GitHub repository for Met Office which can be built and deployed automatically to Amazon Web Services system. Fourteen different products are provided by the AWS outputs which are available in real-time to MOSWOC space weather forecasters. We describe the project, give an overview of the development over the past four years and present example results of modelled outputs, in particular for the 10-May-2024 G5 geomagnetic storm.

Large Scale Travelling Ionospheric Disturbances AI/ML based forecasting model

Dr Anna Belehaki[1], Dr Konstantinos Themelis[1]
[1]National Observatory of Athens, Greece

Parallel 1C: The Mesosphere and Thermosphere and Ionosphere, September 11, 2024, 16:00 - 17:00

In this contribution we propose a new short-term forecast model of Large Scale Travelling Ionospheric Disturbances (LSTIDs). The model is based on the concept that the intensity of the auroral electrojets is regulated by the Lorentz force and the Joule heating that generate AGWs in the lower thermosphere and LSTIDs in the ionosphere. Based on this scenario, the TEC gradients calculated over Europe by DLR as well as the electrojet indices intensity calculated by the magnetometers of the Finish IMAGE network, can be considered as representative drivers for LSTIDs occurrence over the European sector. LSTID characteristics are calculated with the HF Interferometry method (HF-INT) over Digisonde stations. The method provides the Period, Amplitude, Velocity and Direction, and contribution of the TID to the total variability (i.e. the Spectral Energy Contribution, SEC) for a given time series. These features are used for the identification of LSTIDs utilizing different types of Machine Learning Classifiers, some traditional and the more advanced Block Recurrent Neural Networks (Block-RNNs). Several experiments are performed for two distinct scenarios: (a) values of SEC greater than 50% indicate moderate and strong LSTID activity and (b) values of SEC greater than 70% indicate strong LSTID activity. The performance is assessed through the F1-score metric. The forecasting accuracy decreases from 0.9 to 0.6 approximately with increasing forecasting horizon up to 2 hrs ahead, for Block-RNN showing the best performance. The success also depends on the combination of input features and the geographic latitude of the Digisonde.

The Space Weather Operational Readiness Development Center: a new NASA space weather center of excellence

Dr. Thomas Berger[1], Dr. Dan Baker[2], Prof. Tuija Pulkkinen[3], Prof. Tamas Gombosi[3]
[1]University Of Colorado, Space Weather Technology, Research, and Education Center, United States, [2]University of Colorado, Laboratory for Atmospheric and Space Physics , United States, [3]University of Michigan, Climate and Space Sciences and Engineering, United States

Parallel 2B: The Magnetosphere, September 11, 2024, 12:00 - 13:00

The Space Weather Operational Readiness Development (SWORD) Center is an international, multi-disciplinary focal point where space weather researchers, operational forecasters, industry partners, and the space weather community will collaborate on transformative research to improve forecasts and nowcasts of the orbital and cis-lunar space environment. SWORD research will focus on coupling the UMich Geospace model, part of the Space Weather Modeling Framework (SWMF), with the CU Whole Atmosphere Model with Ionosphere Plasmasphere Electrodynamics (WAM-IPE), both of which are currently operational at the NOAA Space Weather Prediction Center (SWPC). In addition, SWORD will develop new data assimilation systems, based on the NOAA/NASA/DOD JEDI framework, for both the operational WAM-IPE model and the NCAR Whole Atmosphere Community Climate Model – eXtended (WACCM-X) research models. SWORD research will include advanced physics-informed machine learning research to enhance computational efficiency as well as cloud-based model development and deployment systems to accelerate the transition to operations at NOAA. SWORD consists of research teams from the University of Colorado (CU) Boulder, the University of Michigan (UMich) Ann Arbor, NCAR's High Altitude Observatory, the University of Alaska Fairbanks, and the University of Iowa, in partnership with Amazon Web Services, SpaceX, LeoLabs, GeoOptics, and Muon Space. In addition to close coordination with NOAA/SWPC through the NOAA Technical Transition Representative (TTR), SWORD will leverage international partnerships with the UK Met Office Space Weather Operations Center and the South African Space Agency Space Weather Forecasting Office to expand the reach of NASA space weather research.

Space weather models for the user - understanding operational models for effective use

Dr. Suzy Bingham[1], Francois-Xavier Bocquet, David Jackson, Mike Marsh, Edmund Henley, Siegfried Gonzi, Richard Mace, Ishita Gulati, Anders Englyst
[1]Met Office, United Kingdom

Space Weather End Users Panel, September 9, 2024, 14:00 - 16:00

The main role of the Met Office Space Weather Research (SWR) group is to support forecasters (model 'users') in the Met Office Space Weather Operations Centre (MOSWOC). Forecasters monitor the Sun 24/7 and rely on data and on the output from a number of operational space weather models to produce forecasts, watches, warnings and alerts for 'end-users' in various sectors including Energy, Aviation, Marine, Satellite, Rail and Telecommunications.

To support forecasters, the SWR group engages in space weather model research-to-operations (R2O) and operations-to-research (O2R) activities. Verification is a crucial element running through the R2O2R process; understanding model strengths and weaknesses through verification and evaluation is essential for effective space weather forecasting. Additionally, an efficient O2R process allows forecasters to provide feedback on model and data issues in the operational environment, and to suggest improvements. As SWIMMR models become operational, MOSWOC will benefit from an expanded range of models/systems, all of which will require understanding, maintaining and improving by the SWR group through collaboration with SWIMMR partners.

This presentation outlines the SWR group's current activities and future plans related to O2R and verification. Ultimately, the goal is to establish (1) an effective O2R process, including SWIMMR models, for identifying recurring model issues, understanding model characteristics and enhancing forecasting capabilities, and (2) a verification framework that provides continuous, well-integrated, and accessible verification information, tailored to user and end-user decisions, and to develop the appropriate levels of trust in the models and in the resulting forecasts for end-users.

RASOR: Radio Astronomy and Space Observation Research Facility - An Opportunity for the Future

Dr Mario Bisi[1], Prof. Michael Garrett[2], Prof. Marco Martorella[3], Prof. Simon Garrington[2], Dr Biagio Forte[4], Prof. Rob Beswick[2], Dr Richard Fallows[1]
[1]Research And Innovation - Science & Technology Facilities Council - Rutherford Appleton Laboratory, United Kingdom, [2]Jodrell Bank Centre for Astrophysics, The University of Manchester, United Kingdom, [3]Microwave Integrated Systems Laboratory, University of Birmingham, United Kingdom, [4]Department of Electronic & Electrical Engineering, University of Bath, United Kingdom

Parallel 1B: Instrumentation, September 11, 2024, 12:00 - 13:00

RASOR: Radio Astronomy and Space Observation Research Facility, a potential new facility operating at wide-band radio frequencies (10s MHz to several GHzs) to provide unique observational and monitoring capabilities (high angular/temporal resolution) for frontier science in space weather, cosmology, astrophysics, and also to address strategic requirements for the prediction of adverse space-weather events and characterisation of assets/debris in orbit - tackling many areas across the Earth's space environment. This advancement, when realised, represents a major step-change in current capabilities (e.g. 5x e-MERLIN, 10x SKA resolution), addresses up to 13 of the 23 of the STFC Science Challenges, looks at UN Sustainability Development Goals (SDGs), and will have substantial near- and long-term direct economic and societal impacts beyond research for the UK and further afield.

This would be a truly multi-disciplinary/interdisciplinary world-class project on UK soil, going beyond current and planned capabilities, and working as a standalone infrastructure and/or with international facilities (SKAO/LOFAR/VLBI). It would be able to support a very-broad, highly-engaged, diverse UK scientific community, providing direct access to high-resolution, rapid-response radio imaging and dedicated space-weather monitoring, unavailable anywhere else, and feed into Met Office space-weather monitoring requirements across the Sun-Earth chain.

This is a project opportunity submitted for UKRI/STFC infrastructure funding based on a two-year preliminary project, followed by a four-year full roll-out. Here, we will give an overview of RASOR with a focus on space weather and the space environment, an overview of the project plan, and where we are in terms of obtaining funding for the future.

Solar cycle and solar wind control of the occurrence of large dB/dt events.

Gemma Bower[1], Steve Milan[1], Suzie Imber[1], Amy Fleetham[1], Audrey Schillings[2,1], Herman Opgenoorth[2], Jesper Gjerloev[3], Larry Paxton[3], Sarah Vines[4], Benoit Hubert[5], Marc Hairston[6]
[1]University Of Leicester, United Kingdom, [2]Umeå University, Sweden, [3]3Johns Hopkins University Applied Physics Laboratory, United States, [4]Southwest Research Institute, United States, [5]Laboratory of Planetary and Atmospheric Physics, University of Liège, Belgium, [6]William B. Hanson Center for Space Sciences, University of Texas , United States

Parallel 2E: The Solar Wind and Coupling to the Magnetosphere, September 12, 2024, 11:00 - 12:00

Rapid changes in the magnetic field can cause electric currents to be induced at the surface of Earth, and these geomagnetically induced currents can cause damage to pipelines and power grids. Using one minute cadence SuperMAG data the occurrence distribution of large dB/dt 'spike' events has been investigated during solar cycle 23 and 24. Three local time hotspots are found: the pre-midnight sector associated with substorms, the dawn sector often associated with omega band activity and the pre-noon sector associated with the Kelvin-Helmholtz instability (KHI) occurring at the magnetopause. Substorm spikes occur during moderate solar wind driving at all phases of the solar cycle, but maximize in the declining phase. Omega band spikes occur during strong solar wind driving, whereas KHI spikes occur during quiet conditions with high solar wind speed. Both occur during solar maximum and the declining phase. The shapes of these distributions do not depend on the magnitude of the spikes, so the results can be extrapolated to extreme events.
The spikes have been further investigated during different types of geomagnetic activity for 2010. The dawn sector spikes are not directly related to substorms but occur with auroral activity within the westward electrojet region. These auroral features share some characteristics with omega bands, but can also appear as north-south aligned auroral streamers suggesting a single underlying cause. Pre-midnight and dawn sector spikes can occur at the same time, as strong coupling favours both substorms and westward electrojet activity however, the mechanisms that create them seem independent.

A system identification approach to modelling the electrons in the radiation belts measured by POES

Richard Boynton[1], Michael Balikhin[1], Hua-Liang Wei[1]
[1]University Of Sheffield, United Kingdom

Parallel 2G: The Radiation Belts, September 12, 2024, 14:00 - 15:00

A spatiotemporal model of the electrons throughout the radiation belts are deduced using Nonlinear AutoRegressive Moving Average eXogenous (NARMAX) models. The system identification method based on NARMAX deduces models from input-output data, similar to other machine learning methods. Here, the output data is taken as electron counts measured by POES at locations between L = 1.5-8 RE for the 3 energy channels corresponding to >30 keV, >100 keV and >300 keV. The inputs are the solar wind values measured at L1 by ACE and DSCOVR. The predicted output from the models were then compared to the POES measurements and analysed using a number of performance metrics. A forecasting system was then developed that ingests the real time solar wind inputs from ACE and DSCOVR to produce real time forecasts of the electron counts for the Met Office system.

Future Skills Requirements

Alice Bunn

Space Skills Panel, September 10, 2024, 16:00 - 17:00

Alice will offer a perspective on the future skills requirements facing the engineering sector more widely, at a time when the pace of technological development is faster than ever, meaning engineers must be agile and adapt to new programme requirements. She will then focus on the specific skill sets required for the space sector in light of developments happening in our global space programmes. This will include the increased opportunity in the low earth orbit economy and the accompanied challenges for the sustainability of our operating environment, through to the increased cadence of exploration missions to the moon. She will finally reflect on the non-traditional set of engineering skills that we will all need to draw on to make the right decisions for the future of our global space programmes.

Identifying and Tracking TEC Enhancements seen in JPL GIMs and their response to Geomagnetic Activity

Martin Cafolla[1], Dr Sandra Chapman[1,2,3], Dr Nick Watkins[1,4], Dr Xing Meng[5], Dr Olga Verkhoglyadova[6]
[1]Centre for Fusion, Space and Astrophysics, Physics Department, University of Warwick, , United Kingdom, [2]Department of Mathematics and Statistics, University of Tromso, Norway, [3]International Space Science Institute, Switzerland, [4]Grantham Research Institute, London School of Economics and Political Science, United Kingdom, [5]School of Earth and Space Sciences, University of Science and Technology of China, China, [6]Jet Propulsion Laboratory, California Institute of Technology, United States

Parallel 1A: The Ionosphere, September 11, 2024, 11:00 - 12:00

Space weather events affect GPS positioning and timing, resulting in issues with navigation and communication. It is therefore important to monitor such events, which can be done through ground GNSS observations of Total Electron Content (TEC). Our study uses 20 years of TEC data from the Jet Propulsion Laboratory (JPL) compiled from over 200 globally distributed ground stations to create 15-minute cadence Global Ionospheric Maps (GIMs) with a spatial resolution of $1^\circ \times 1^\circ$ in longitude/latitude. Maps are analysed in a geomagnetic coordinate frame aligned with the dipole axis of the Earth with longitude centred about the sub-solar point, the position of the sun on the Earth's surface. We take a threshold of the top 1% of TEC measurements to isolate large-scale TEC enhancements, known as High Density Regions (HDRs). We use image processing tools to detect and track these HDRs over 2 solar cycles to obtain a set of labelled, contiguous space-time TEC HDRs. We can determine the locations of HDRs, how long they last and their size/brightness. Our analysis detects, labels and tracks HDR origin, path, areas, TEC intensities and duration. This extensive data set allows us to determine how these properties of HDRs depend on geomagnetic activity, season and latitude. Since our results are statistical in nature, they can differentiate reproducible trends in the data which could then be potentially captured by predictive models for ionospheric enhancements at these spatial/temporal scales.

Probabilistic forecasting with physics-informed machine learning: Sun-to-mud

Enrico Camporeale[1]
[1]Queen Mary University of London, United Kingdom, [2]University of Colorado, United States

Parallel 2B: The Magnetosphere, September 11, 2024, 12:00 - 13:00

We present out latest efforts in forecasting solar wind velocity, geomagnetic indices and ground electric field by using physics-informed machine learning.
The models developed are probabilistic in nature and have been comprehensively benchmarked. They currently represent the state of the art in space weather forecasting, outperforming corresponding physics based models.
We conclude by discussing plans to make those models available in real-time 24/7.

Elfen: A novel CubeSat to understand plasma composition upstream and downstream of the Earth

Jennifer Carter[1], Jonathan Eastwood, Susan Lepri, Jim Raines, Bhargav Narassimha Swamy, Piyal Samara-Ratna, Simona Nitti, Amy Fleetham, Oliver Blake, Patrick Brown, Ravindra Desai
[1]University Of Leicester, United Kingdom

Upcoming Missions for Space Weather Science, September 12, 2024, 10:00 - 10:30

The Elfen mission has two science goals: (1) To understand the heavy ion composition of the solar wind and its influence on the Earth's magnetosphere, (2) To understand the origin of and ion processing in the plasma sheet. We propose a mission using two instruments; a mass spectrometer to determine composition, and a magnetometer to locate the contemporaneous plasma regime traversed by the spacecraft.

The influence of solar wind heavy ions, such as C6+, or O7+ in the solar-terrestrial system is poorly understood, and no dedicated mission to understand these ions has been undertaken. For example, iron in the magnetosphere maybe of ionospheric or solar wind origin, with recent analysis from Cluster suggesting that both the inflow and outflow contribute. Ion spatial segregation,
such as in the magnetospheric cusps, has unknown influence on magnetosphere-ionosphere coupling. Temporal changes in solar wind composition will lead to changes in the total X-ray emission via charge exchange, with implications for current and future X-ray imaging missions, e.g. SMILE. Heavy ion processes and ion entry into the plasma sheet have only been sampled by an extremely limited number of previous missions. Diffusion may occur through the flanks of the magnetosheath, e.g. through the Kelvin Helmholtz instability, or ions may be injected via nightside reconnection in the tail.

Elfen is a ~16U CubeSat mission concept, to be placed in a 12 RE circular equatorial orbit with 1 year lifetime. The Elfen team comprises partners from the UK, US, France, and Norway. See: https://elfen.le.ac.uk/

A new technique designed to obtain ionospheric parameters from Very Low Earth Orbit (VLEO)

<u>Professor Supriya Chakrabarti</u>[1], Professor Timothy Cook[1]
[1]University of Massachusetts, United States

Parallel 1G: Instrumentation and Data, September 12, 2024, 14:00 - 15:00

Many attractive features such as, higher image resolution for remote sensing applications, smaller orbital debris collisional cross-section, improved communication and navigation possibilities, lower launch costs and favorable radiation environment have made VLEO a desirable platform for scientific, commercial and military applications. Due to historic inaccessibility of this region to direct in-situ scientific probing, it has also been called the ignorosphere.

We have developed a new measurement approach for remote sensing of the mesosphere and lower thermosphere (MLT) and its embedded plasma (the ionosphere) that is ideally suited for observations from VLEO platforms. The technique called, Ionospheric Characterization using Emission Ratios (ICER), utilizes the link between atmospheric and geophysical conditions with the brightness and morphology of optical emissions. Primarily due to significant advancements in detector, electronics, additive manufacturing, computing and other technologies, our optical remote sensing of upper atmospheric processes near the ionospheric F-region peak by affordable instruments aboard small (CubeSat) is now within reach.

Conventional in situ measurements aboard spacecraft in VLEO/MLT perturb the observing region. Our approach avoids these local effects by measuring optical emissions from gas at a small, but significant distance from the spacecraft. We have modeled responses of a pair of simple optical sensors aboard a spacecraft in VLEO observing optically thin emissions such as the OI 135.6 nm line. We find that this technique can retrieve large-scale ionospheric structures as well as features such as plumes. In this talk we will describe the principle and simulation results of ICER.

A regular clock for the solar cycle variation of extreme space weather risk

Professor Sandra Chapman[1]
[1]CFSA, University of Warwick, United Kingdom

Solar Science for Space Weather, September 10, 2024, 14:00 - 15:30

Whilst the sun has an approximately 11 year cycle of activity, no two cycles are of the same duration. Since this activity is a direct driver of space weather at earth, this presents an operational challenge to quantifying space weather risk. The sunspot number (SSN) record can be used to map the variable cycle length onto a regular 'clock' and this reveals in each cycle a clear active-quiet switch-off and quiet-active switch-on of activity, with around 2% of extreme space weather events occurring within the quiet intervals of the cycles over the last 155 years [1,2]. Some of the most extreme geomagnetic storms occurred around the switch-on and switch-off times, rather than at solar maximum, motivating their determination and prediction. The switch-on/off times can be estimated directly from SSN [3] so that future switch-on and switch-off times can be identified in SSN model predictions for future solar activity. The clock supports charting – a tool to integrate observed events with narrative reports of impacts on technological systems to improve our understanding of space weather hazard. The SSN Hilbert transform phase is found to correspond to solar-cycle scale evolution of sunspot latitudinal bands, establishing a direct relationship between the sunspot butterfly pattern and the intensity and character of geomagnetic activity [4]. This suggests a direct connection between extreme space weather risk estimation and solar dynamo models.

[1] S.C.Chapman, S.W.McIntosh, R.J Leamon, N.W.Watkins, GRL(2020)doi:10.1029/2020GL087795

[2] S.C.Chapman, S.W.McIntosh, R.J.Leamon, N.W.Watkins, Ap.J.(2021)doi:10.3847/1538-4357/ac069e

[3] S.C.Chapman, Front.Astron.SpaceSci.(2023)doi:10.3389/fspas.2022.1037096

[4] S.C Chapman, T.DudokdeWit, Scientific Reports(2024)doi:10.1038/s41598-024-58960-5

SAIRA Atmospheric Radiation Monitors Delivered for SWIMMR

Ben Clewer[1], Paul Morris[1], Keith Ryden[1]
[1]University Of Surrey, United Kingdom

Parallel 1F: SWIMMR Outputs, September 12, 2024, 12:00 - 13:00

The Surrey Space Centre will present a significant update on the development and delivery of the new SAIRA atmospheric radiation monitors for the SWIMMR program. Both aircraft and radiosonde versions have been developed, manufactured and supplied to STFC and the Met Office. The balloon version will be launched by the Met Office, and the aircraft version will be flown by major UK commercial airlines. The data generated from these instruments will significantly increase the UK's capability to measure and respond to atmospheric radiation enhancement events, particularly for the aviation industry.
We will present the full delivery of SWIMMR aviation instrumentation, including the latest flight data for both instrument versions. The radiosonde instrument has been launched from the Met Office weather station at Camborne, and the aircraft instrument has been flown on a variety of international routes over the last 9 months.
We will also show the extensive dose calibration work being undertaken to ensure the reliability and accuracy of the measurements.

The May 2024 'Gannon' G5 storm: The application of GIC mitigation during a very large geomagnetic disturbance

Mark Clilverd[1], Prof Craig Rodger[2], Dr Daniel Mac Manus[2], Mr Andrew Renton[3], Mr Michael Dalzell[3], Dr John Malone-Leigh[2], Dr Tanja Peterson[4], Dr James Brundell[2], Mr Victor Lo[3]
[1]British Antarctic Survey, United Kingdom, [2]University of Otago, New Zealand, [3]Transpower New Zealand Limited, New Zealand, [4]GNS Science, New Zealand

Parallel 1E: Ground & Infrastructure, September 12, 2024, 11:00 - 12:00

In early May 2024 the giant sunspot complex AR3664 launched ~6 Coronal Mass Ejections towards the Earth, which triggered the G5 "Gannon" geomagnetic storm. This disturbance lasted from ~17 UT on 10 May 2024 to ~9UT on 12 May 2024, producing auroral displays throughout New Zealand. In 2022 space physics researchers worked with the New Zealand power grid system operator, Transpower New Zealand Ltd, to develop an "All of New Zealand" GIC mitigation strategy in the form of targeted line disconnections. The goal was to reduce GIC magnitudes and durations at transformers at most risk to GIC during large geomagnetic storms, while still maintaining the continuous supply of power throughout New Zealand. This strategy was declared operational in 2023, following training of control room staff. It was the result of many years of industry-research collaboration.

Once the May 2024 storm disturbance levels reached the G5 threshold, the GIC mitigation strategy was enacted by the Transpower control room staff following the plan protocols. The mitigation remained in place until 16UT on 12 May 2024, after which the circuits were restored. There was no customer-end impact to New Zealand's electrical supply from this storm. In this presentation we will discuss the development of the GIC protocol enacted by the New Zealand power grid, and show some evidence of transformer saturation responses measured at the Halfway Bush substation in Dunedin, South Island.

This research is part of the New Zealand Solar Tsunamis programme.

Results of stray-light testing of the COR Stray-light Qualification Model (CSQM)

Jackie Davies[1]
[1]RAL Space, United Kingdom

Parallel 1B: Instrumentation, September 11, 2024, 12:00 - 13:00

The most critical and challenging aspect of a solar coronagraph is its stray-light design. RAL Space led an ESA General Support Technology Programme (GSTP)-funded Phase A/B1 study of such an instrument, SCOPE (the Solar Coronagraph for Operations), in which a prototype Optical Bread-Board (OBB) was manufactured and tested, firstly at CSL and then, after some modification of the OBB, at RAL Space. The instrument development was continued as part of ESA's Lagrange (now Vigil) Phase A/B1 & Pre-developments study, funded by the Space Situational Awareness (SSA) programme (now Space Safety Programme, S2P). This included the manufacture and testing at RAL Space of an upgraded OBB, called the COR Stray-light Qualification Model (CSQM). As well as implementing additional design improvements, CSQM was more representative than SCOPE in its manufacture: for example with flight-like coatings, lens barrel and heat-rejection mirror. In this presentation, we discuss the CSQM and the results of its stray-light testing.

Electron injections and decays during solar cycle 22 observed by CRRES

Ravindra Desai[1]
[1]University Of Warwick, United Kingdom

Parallel 2D: The Radiation Belts, September 11, 2024, 17:00 - 18:00

The Combined Release and Radiation Effects Satellite (CRRES) launched in 1990 into the maximum of solar cycle 22 and provided unprecedented advances in our understanding of radiation belt dynamics. These observations include the radiation belt response to a solar cycle much more active than recent ones, and include the extreme event of 24 March 1991 where a large interplanetary shock rapidly compressed the magnetosphere inside of geosynchronous orbit for an extended period of 6 hours, and accelerated a new radiation belt inside the normally depleted slot region. In this study, we re-examine data from the CRRES High Energy Electron Fluxometer (HEEF) dataset to determine the extent and scale of energetic electron injections into the slot region and inner belt. Upon examining this dataset we find that electron injections deep into the slot region and inner belt occur throughout the mission, and characterise their decay rates according to various geomagnetic indices.

Development of the MAGIC minaturized magnetometer sensor for measurements in low Earth orbit, cis-lunar space, and the upstream solar wind beyond L1

Jonathan Eastwood[1], Patrick Brown[1], Martin Archer[1], Richard Baughen[1], John Hodgkins[1], Tim Oddy[1], Cara Waters[1]
[1]Imperial College London, United Kingdom

Parallel 1G: Instrumentation and Data, September 12, 2024, 14:00 - 15:00

The ability to assess and respond to severe space weather events requires real-time knowledge and alerts relating to conditions in space from widely-distributed locations. As part of this, in situ magnetic field measurements provide critical information. Measurements within the magnetosphere from different locations enable assessment of structure and dynamics, and knowledge of the interplanetary magnetic field is crucial for understanding the geoeffectiveness of solar wind drivers. In many applications, the resource envelope is highly limited, and this has driven the development of a variety of low-resource instruments suitable for space weather monitoring. In this context, we describe here the current status of the minaturised MAGnetometer from Imperial College (MAGIC) instrument, focussing on active and future missions. We discuss the in-flight performance of the MAGIC instrument on the RadCube technology demonstration CubeSat in Low Earth Orbit, including observations made on 11 May 2024 during a G5 geomagnetic storm interval. We then present the development of MAGIC as part of the ERSA space weather payload that will be included on the Lunar Gateway, and describe the measurements that will be made both in transit to the Moon and in lunar orbit. Finally, we present the planned implementation of MAGIC on the HENON deep-space CubeSat that will measure the solar wind upstream of L1, currently anticipated to launch in late 2026.

Extreme space weather risks to power plants: assessing vulnerability, building resilience and improving preparedness

Dr Joseph Eggington[1]
[1]EDF R&D UK, United Kingdom

Parallel 1D: Ground and Infrastructure, September 11, 2024, 17:00 - 18:00

Severe space weather is increasingly recognised as a key hazard for the UK energy sector. The risks posed by geomagnetically induced currents (GICs) and ground level enhancements (GLEs) are of particular interest for nuclear power plants (NPPs). As the UK's biggest generator of zero-carbon electricity, EDF maintains a large fleet of operational NPPs and is investing heavily in the future of the UK nuclear industry, with two more NPPs in building/planning phase over next decade. EDF R&D UK carries out research dedicated to understanding the risks of extreme space weather to EDF's energy assets in the UK and internationally, considering scenarios as rare as 1-in-10,000-years as per regulatory expectations. I will discuss current understanding of the potential impacts of such events, possible mitigations, and knowledge gaps. I will also discuss the potential role that bespoke space weather services and on-site monitoring can play in building operational resilience, and the unique requirements of nuclear industry end-users. Finally, I will present how the recent extreme geomagnetic storm of 10-12 May 2024, despite not impacting operations, provided useful lessons which will inform future vulnerability assessments and aid in developing preparedness strategies.

Numerical Modelling of ULF Waves in Asymmetric Media

Dr Tom Elsden[1]
[1]University Of St Andrews, United Kingdom

Parallel 2B: The Magnetosphere, September 11, 2024, 12:00 - 13:00

Ultra-low frequency (ULF) waves are oscillations of Earth's magnetic field with frequencies of ~1mHz – 1Hz, and represent the lowest frequency and largest scale waves of the magnetosphere. Driven predominantly by the interaction of the inhomogeneous solar wind with the magnetopause, they transport momentum and energy throughout the magnetosphere. In doing so, they critically affect several aspects of magnetospheric dynamics: they couple different magnetospheric regions together through the coupling of different wave modes; they drive electric currents responsible for some auroral emission as well as driving currents on the ground; they can be used as a remote sensing tool to infer plasma properties in space (magnetoseismology); they interact with energetic particles trapped in Earth's magnetic field which form the radiation belts.

In this talk, I will discuss recent numerical results from magnetohydrodynamic (MHD) simulations showing how the generation and structure of ULF waves are affected by asymmetry of the background medium. I'll cover the background of MHD wave coupling and field line resonance (FLR), showing in particular how the polarisation of resonant ULF waves is affected by changes in the plasma density. I will discuss the potential implications of such results for the interaction with radiation belt particles.

Placing May 2024 in Context: Space Weather Impacts and the Importance of Communications

Sean Elvidge[1], David Themens[1], Matthew Brown[1]
[1]SERENE, University Of Birmingham, United Kingdom

R202R Panel, September 10, 2024, 17:00 - 18:15

The May 2024 geomagnetic storm, triggered by a series of coronal mass ejections, serves as a significant case study in space weather forecasting and communication. This presentation will explore the probability of such events, the successes and failures in forecasting, and the broad spectrum of impacts observed.

The storm had multifaceted impacts, necessitating critical responses such as the re-routing of high-latitude flights whilst also causing interruptions to precise Global Navigation Satellite System (GNSS) positioning, affected High Frequency (HF) communications, and increased atmospheric drag on satellites, impacting systems like Starlink.

The worldwide viewing of auroras, extending to regions unaccustomed to such displays, illustrated the storm's diverse effects. These events underscore the complexities of accurately communicating space weather impacts without causing unnecessary alarm. The presentation will emphasize the importance of effective communication to industry, governments, and the general public, balancing the need for awareness and preparedness without "crying wolf."

Collaboration is paramount in space weather communication. This talk will also highlight the need for coordinated efforts among the space weather community, subject matter experts, and operational centres. Such collaboration ensures that messages are scientifically accurate, timely, and tailored to the needs of different stakeholders.

By examining the May 2024 storm, this presentation aims to highlight lessons we can learn in preparedness for future space weather events.

Rethinking the Space Weather Scales

Sean Elvidge[1]
[1]SERENE, University Of Birmingham, United Kingdom

Space Weather End Users Panel, September 9, 2024, 14:00 - 16:00

The NOAA Space Weather Scales, established to classify and communicate the impact of space weather to industry and government, have been effective but may need rethinking.

This presentation introduces an impact-based approach to space weather alerts through the Space Weather Warning Map, aiming to enhance the responsiveness and effectiveness of warnings. The current NOAA scales—covering geomagnetic storms, solar radiation storms, and radio blackouts (R-scale)—are limited by their fixed numerical ranges and can fail to accurately convey the severity and specific impact of extreme space weather events. The proposed Warning Map addresses these limitations by providing a more intuitive, sector-specific alert system. This system uses a color-coded warning matrix—yellow, orange, and red—to indicate increasing levels of impact risk across various sectors, such as power grids, aviation, communications, and satellite operations.

This new approach integrates all relevant information into a single, cohesive warning system, eliminating the need for multiple, potentially confusing scales. The color-coded warnings simplify the communication process, allowing users to quickly assess their risk levels and take appropriate actions. Furthermore, the system's flexibility allows for real-time updates and escalation of warnings based on the latest data and modelling, accommodating the dynamic nature of space weather events.

By refining classification and reporting systems, this approach aims to better align public perception with the reality of space weather impacts, ensuring a more informed and prepared society. The presentation will discuss the development, implementation, and benefits of the Space Weather Warning Map, advocating for its adoption as a standard in space weather communication.

Joint Cluster/Ground-Based Studies in the First 20 Years of the Cluster Mission

Robert Fear[1]
[1]University Of Southampton, United Kingdom

Parallel 2B: The Magnetosphere, September 11, 2024, 12:00 - 13:00

Ground-based facilities make an important contribution to our understanding of the magnetospheric system. Coordination with ground-based facilities has been embedded within the European Space Agency's Cluster mission since before launch, and this has given rise to a large number of studies which have exploited data from both Cluster and one or more of the diverse range of ground-based instrumentation that have been available during the mission timespan. In this invited talk, we summarise a recent review paper on the advances that have been made to our understanding of the magnetosphere-ionosphere system, in which insight has been enhanced by combining ground-based observations with observations from Cluster. Topics covered span from the bow shock to the magnetotail and down to the aurora.

Extreme Space Weather in the Earth's Space Environment

Alexandra Ruth Fogg[1], Dr D. Healy[2], Prof C. M. Jackman[1], A. Parnell[3], Dr M. J. Rutala[1], S. C. McEntee[1], Dr S. J. Walker[1], Dr C. F. Bowers[1], Prof P. T. Gallagher[1]
[1]Dublin Institute for Advanced Studies, Ireland, [2]Università Ca' Foscari Venezia, [3]Maynooth University

Parallel 2E: The Solar Wind and Coupling to the Magnetosphere, September 12, 2024, 11:00 - 12:00

Although not routinely used in space science, Extreme Value Theory (EVT) is used commonly to estimate return periods and return values of earthquakes or extreme weather. For example, the magnitudes of 1 in 100-year events for many natural phenomena are estimated to assist in societal preparedness. In this paper we present results from the application of bi- and multi-variate EVT to highly complex, multi-dimensional space weather datasets, and unravel the nature of extreme space weather observations. We estimate the return levels of system-scale observations of Earth's ionosphere, and relate them to driving phenomena including storms, substorms, and sudden commencements.

Unique global viewing of Earth's dynamic magnetosphere with the Solar wind – Magnetosphere – Ionosphere Link Explorer (SMILE)

Colin Forsyth[1], G Branduardi-Raymont[1], C Wang[2], C.P. Escoubet[3], S Sembay[4], L Dai[2], L Li[2], X-X Zhang[5], J Li[2], D Agnolon[3], W Raab[3], C Runciman[3], B Vanoutryve[3], S Vey[3], W Chen[7], A Masson[6], X Shi[7], A Read[4], E Donovan[8], E.L. Spanswick[8], J.A. Carter[4], H Connor[9], T Sun[2], A Samsonov[1], Z-H Zheng[2], S-Y Hsieh[10], D Sibeck[9], G Nicolaou[1], J Sanchez Palma[11]
[1]UCL-MSSL, United Kingdom, [2]NSSC/CAS, China, [3]ESA/ESTEC, Netherlands, [4]University of Leicester, United Kingdom, [5]NCSW/CMA, China, [6]ESA/ESAC, Spain, [7]IAMC/CAS, China, [8]University of Calgary, Canada, [9]NASA/GSFC, United States, [10]JHU/APL, United States, [11]Airbus, Spain

Upcoming Missions for Space Weather Science, September 12, 2024, 10:00 - 10:30

The interaction between the plasma leaving the Sun and neutral particles in the exospheres of solar system bodies results in a soft X-ray emission which, if imaged, can help us to understand these interactions of the solar wind with these bodies on large scales. At magnetized bodies, the impact of the solar wind results in global deformations of planetary magnetic fields and physical processes at kinetic, fluid and global scales that capture and energise particles within magnetospheres which ultimately deposits energy into planetary ionospheres and atmospheres. While in-situ measurements have provided deep insights into small-scale processes in these regions, the global configuration of the system remains elusive, revealed only through simulation or climatological empirical models. A new joint mission between the European Space Agency (ESA) and Chinese Academy of Sciences (CAS) will provide a unique global view of our near-Earth space environment, enabling us understand the links between the Sun, magnetosphere and ionosphere.

Due for launch in mid-2025, the SMILE (Solar wind Magnetosphere Ionosphere Link Explorer) mission is a novel endeavour to observe the coupling of the solar wind with the magnetosphere through to the ionosphere. To do this, SMILE will remotely sense the magnetosheath and cusps through X-ray emissions from solar wind charge exchange – a process by which neutral particles in Earth's exosphere exchange charges with highly charged heavy solar wind ions. SMIILE will also measure the in-situ magnetic field and plasma properties and remotely sensing the northern hemisphere aurora in UV.

In this talk, we will present the underlying science of the SMILE mission as well as the latest mission developments from ESA, CAS and the international instrument teams. We will also highlight possible synergies with existing missions and ground-based facilities, enabling global and local plasma processes to be studied in unprecedented detail and context, and how this will help to transform our understanding of space weather events.

Radio wave scintillation observed through LOFAR to infer properties of ionospheric structures

Biagio Forte[1], Pawel Flisek[2], Kacper Kotulak[2], Andrzej Krankowski[2], Richard A. Fallows[3], Mario M. Bisi[3]
[1]Department of Electronic and Electrical Engineering, University Of Bath, United Kingdom, [2]Space Radio-Diagnostics Research Centre, University of Warmia and Mazury in Olsztyn, Poland, [3]RAL Space, United Kingdom Research and Innovation (UKRI) – Science & Technology Facilities Council (STFC), United Kingdom

EISCAT & LOFAR, September 11, 2024, 09:00 - 09:45

Radio wave scintillation originates from the propagation through plasma density irregularities forming in the Earth's ionosphere as a consequence of plasma instabilities. Scintillation can be utilised to infer properties of the irregularities distributed in the propagation medium. However, scintillation depends on the radio wave frequency which implies that different instruments can be sensitive to different irregularities, occurring over different spatial scales.

Radio telescopes such as LOFAR (LOw Frequency ARray) can be utilised to measure scintillation induced, for example, by ionospheric structures during various space weather conditions. These radio telescopes are capable of observing a wider range of radio wave frequencies simultaneously, thus allowing for the detection of structures occurring over multiple scales.

The ability to deduce information on the propagation medium relies on the accuracy in the description of the propagation problem and the limits within which the description is carried out.

This contribution will discuss aspects of the propagation problem that are useful for the evaluation of scintillation measurements, for example, in the context of typical radio astronomy observations.

User Perspectives

Mark Gibbs[1]
[1]Met Office, United Kingdom

Space Weather End Users Panel, September 9, 2024, 14:00 - 16:00

Discuss the wide range of user needs, including space weather forecasters, as a specialist user group.

Energy diffusion in the Earth's radiation belts

Dr Sarah Glauert[1], Dr Thomas Daggitt[1], Prof Richard Horne[1]
[1]British Antarctic Survey, United Kingdom

Parallel 2D: The Radiation Belts, September 11, 2024, 17:00 - 18:00

The electron flux in the Earth's radiation belts can be highly variable, changing by orders of magnitude on a timescale of hours. Understanding this variability is important as high radiation levels can affect satellites orbiting through the belts, causing temporary issues or even permanent damage. One driver of this variability is the interaction between electromagnetic chorus waves and electrons. Particularly during disturbed geomagnetic conditions, gyro-resonant interactions between chorus and electrons produce significant energy diffusion leading to the acceleration of lower energy (100s keV) electrons up to MeV energies.

This presentation will discuss several aspects related to this energy diffusion. Using 2d diffusion simulations we show where and when (in terms of geomagnetic activity) it is significant and its effect on both pitch angle distributions and energy spectra using a standard diffusion model. We demonstrate that radiation belt models need to capture a change in the balance between loss and acceleration that occurs when the strong diffusion limit is reached and that realistic information about the plasma density leads to more accurate reconstructions of multi-MeV electron enhancements.

Space Weather Developments and Capabilities in the ESA Space Safety Programme

Alexi Glover[1]
[1]ESA, France

Space Safety with UKSA and ESA Panel, September 9, 2024, 16:30 - 17:10

The European Space Agency (ESA) has been developing the ESA Space Weather System since the start of the ESA Space Situational Awareness Programme in 2009. Now part of the ESA Space Safety Programme (S2P), the Space Weather System development aims at mitigating and preventing the effects of space weather on vital infrastructure on Earth and in space.

Current capabilities include the Space Weather Service Network providing pre-operational space weather services to end users and hosted payloads providing near-real time data along with supporting data systems. ESA's Space Weather Service Network is a strong example of international collaboration through the active participation of more than 50 groups representing institutes, industry and academia from all ESA Member States participating in the Programme

Current and upcoming space weather space system development activities include implementation of the Vigil deep space mission to enhance monitoring of solar activity, the Aurora mission to provide continuous monitoring of the Auroral zone in both hemispheres, a nanosatellite constellation for space environment monitoring and studies on future missions to improve monitoring of the Earth radiation belts for operational applications, and radiation monitoring of the cislunar environment.

This presentation will highlight key recent developments and upcoming activities of the ESA Space Weather System focusing on the system-wide approach from measurements through to data utilisation and R2O(2R) processes producing pre-operational services tailored to end users.

An Analysis of the May 2024 Superstorm with the tools used by Met Office Forecasters

Siegfried Gonzi[1], Richard Stone[1], Francois-Xavier Bocquet[1]
[1]Met Office, UK, United Kingdom

The May 2024 Storm, September 11, 2024, 09:45 - 10:30

On the 8th of May Coronal Mass Ejections (CMEs) lifted off from the Sun in rapid succession resulting in a severe geomagnetic storm of magnitude G5 on the 10th of May. The CMEs and subsequently X-class flares were linked to a massive sunspot group which could even be observed with the unaided eye. This active region started out as Dai when it first appeared on the East limb of the Sun, and developed into Fkc, which is the most complex group on the McIntosh sunspot classification chart. The CMEs morphed into a massive super CME while travelling from the Sun to Earth. The bulk of that CME arrived in the afternoon on the 10th of May at around 4.30pm UTC. MOSWOC forecasters did an excellent job and predicted, on the 8th of May, the arrival of that formidable CME to be on the 10th of May at 8pm. On the NASA CCMC scoreboard only the Mars to Moon Office issued an arrival time with such a low error compared to the observation. On the 9th it became clear to MOSWOC forecasters that this CME may result in a G4 storm with the potential to scramble to G5 on the geomagnetic storm scale.
We discuss the tools that MOSWOC forecasters on the bench used to forecast these CMEs. A crucial aspect of forecasting the arrival time is the initial fitting of the CMEs from coronagraph images. We also review these fitting parameters that MOSWOC forecasters derived with the CME Analysis Tool.

Solar science and its application to forecasting coronal mass ejections

Lucie Green[1]
[1]UCL-MSSL, United Kingdom

Solar Science for Space Weather, September 10, 2024, 14:00 - 15:30

Since their discovery in the early 1970s, coronal mass ejections have been a major research focus of the solar research community. There have been significant developments in understanding the physical origin of coronal mass ejections. For example, they are known to be the catastrophic end product of an evolutionary sequence in portions of the Sun's magnetic field. During this evolution, the magnetic field is subject to flows that inject energy into the field and also build certain magnetic configurations that then erupt due to an instability/loss of equilibrium and/or the occurrence of a process called magnetic reconnection. This talk will review the state-of-the-art understanding of the physical origins of coronal mass ejections, and will discuss how this understanding can be used in a practical way for operational space weather forecasting using currently available datasets such as from the Solar Dynamics Observatory. With a focus on forecasting coronal mass ejections in advance of their initiation at the Sun.

A framework for tracking progress: The Application Usability Levels and how they can enable the R2O2R process.

Dr. Alexa Halford[1]
[1]Nasa/gsfc, Greenbelt, United States

R2O2R Panel, September 10, 2024, 17:00 - 18:15

Space physics continues to become more interdisciplinary and intertwined with commercial and government operations. This has necessitated a framework that helps translate between different work cultures and helps one to quickly identify what projects can be used for specific applications and how close each project is to routine autonomous or on-demand implementation and operation. We have developed the Application Usability Level (AUL) framework using lessons learned from other tracking frameworks. The AULs can help the community quantify the progress of successful applications, metrics, and validation efforts.

Each project path within the AUL framework requires a diverse ecosystem of individuals. For example, independent validators are essential for validation efforts and comparing like products for a specified application. In many cases, the players throughout the process, will act in multiple roles and different roles for different projects and AUL pathways.

Here, we will discuss the collaborative roles that lead from basic research to successful application within or outside the scientific community and provide examples of how this collaborative application ecosystem can be maintained and benefit all involved.

This work is part of the Assessment of Understanding and Quantifying Progress working group which is part of the International Forum for Space Weather Capabilities Assessment.

Skills for space weather understanding and mitigation

Dr Mike Hapgood[1]
[1]RAL Space, United Kingdom

Space Skills Panel, September 10, 2024, 16:00 - 17:00

Whilst records of space weather impacts go back to the 1840s, the societal risk it poses has become significant for society-as-a-whole only in recent decades. This trend reflects how everyday life has become critically dependent on a range of technological infrastructures, a trend that will continue as technology evolves further, e.g. as discussed in the recent SWIMMR S6 study on space weather impacts. Thus there is a current and continuing need for people with skills to understand, assess and mitigate the risks posed by space weather. This is a topic that needs wider discussion across the whole community engaged with space weather: academia, industry and government. Thus it is timely to start such discussion –if possible via a session at the meeting, and, if not, as a presentation to call for discussions in other fora. The discussion should consider a number of key questions including: (a) how has the current UK skills base evolved since space weather was added to the National Risk Register in 2012? (b) how may support for this skills base be spread across the community (in-house within operators of vulnerable technologies, specialist companies, public sector organisations, and academia)? (c) how to encourage networking that enables skilled people to work together and that breaks down any silo thinking that inhibits that? and (d) how to maintain an adequate flow of new people into the skills base, e.g. via advanced training (PhD, post-doc) in appropriate scientific and engineering disciplines?

Summarising breadth & depth of UK space weather related activities

Dr. Joanna Hart[1]
[1]The Space Partnership, United Kingdom

Space Weather End Users Panel, September 9, 2024, 14:00 - 16:00

The Space Partnership brings together industry, academia and government from across the UK space sector to work on shared priorities and identify collective action to deliver the ambition in the National Space Strategy (NSS). Capabilities is one such shared priority and the Space Partnership has been working closely with the Department of Science, Innovation & Technology's Capabilities team to develop a set of 'Capability Roadmaps', which identify the collective action required to deliver the Capability Goals identified in the NSS in Action. As part of this process, the Space Partnership has brought together the Space Weather community in the UK to summarise the breadth and depth of Space Weather activity at a top-level on a 2-slide narrative roadmap. This roadmap forms part of a set that cover space activity across the UK to inform government policy makers.

Global Simulations for Space Weather Forecasting: GorgonOps Forecasting Suite

Dr Mike Heyns[1], Dr Adrian LaMoury[1], Prof Jonathan Eastwood[1], GorgonOps Team[1]
[1]Imperial College London, United Kingdom

Parallel 2E: The Solar Wind and Coupling to the Magnetosphere, September 12, 2024, 11:00 - 12:00

Providing actionable space weather forecasts has become crucial in ensuring the resilience of modern infrastructure in the face of severe geomagnetic storms. Physics-based models, such as global magnetohydrodynamic (MHD) simulations, provide an attractive approach to deliver generalised forecasting products globally. Here we present recent developments and benchmarking of the GorgonOps forecasting suite, running faster than real-time in an operational context to deliver tailored space weather forecasts. Key deployments of GorgonOps include its implementation at the UK Met Office as part of the SWIMMR programme, European Space Agency (ESA) as part of the BIGG project, and its current real-time service provision at Imperial College London. We will demonstrate the forecasting paradigm utilised, highlighting the adaptive forecast horizon and use of ground field measurements to constrain forecast baselines. Validation efforts within this paradigm are showcased, focusing on the accuracy and reliability of the model's forecasts during recent geomagnetic storms. We will discuss the implications of these findings and provide recommendations for future deployments across the space weather forecasting community. Additionally, we will introduce the current service provision of real-time data access and visualisation at Imperial College London.

Prominence/filament dynamics and their potential role in the eruption of quiet Sun filaments

Andrew Hillier[1], Thomas Berger[2]
[1]University of Exeter, United Kingdom, [2]SWX TREC, United States

Parallel 2A: Solar, September 11, 2024, 11:00 - 12:00

Invited talk - Filament eruptions are a key component of solar activity that produces space weather. Though a lot of focus is understandably placed on the eruption of active region filaments, quiescent and intermediate filament eruptions can also lead to geoeffective CMEs. In this talk I will look at the observed dynamics of quiescent filaments to explore how these may connect with filament eruptions and how we may forecast them.

May 2024 magnetic storm: A comparison between radiation belt models and observations

Richard Horne[1], Sarah Glauert[1], Pak Yin Lam[1], Peter Kirsch[1], Matthew Lang[1], Alex Lozinski[2], Hugh Evans[3], Ingmar Sandberg[4], David Pitchford[5]
[1]British Antarctic Survey, United Kingdom, [2]University of California, United States, [3]European Space Agency, The Netherlands, [4]SPARC, [5]CarringtonSpace, Germany

Parallel 2G: The Radiation Belts, September 12, 2024, 14:00 - 15:00

We review what happened to the electron and proton radiation belts during the May 2024 storm using results from the SWIMMR N1 forecasting system. The BAS radiation belt model (BAS-RBM) predicted that the magnetopause was "pushed" inside geostationary orbit. This was confirmed by observations by GOES 16 and 18. The model also predicted that the outer belt would be depleted and re-formed much closer to the Earth affecting satellites in the slot region. This was also confirmed by satellites in low earth orbit (LEO). The flux in the slot region increased by over 4 orders of magnitude and charging currents (behind 0.5 mm of Al shielding) exceeded NASA design guidelines. We estimate that it would take between a few weeks to months for this high level of flux to decay. Charging currents also reached high levels where Galileo and GPS satellites orbit. The BAS proton radiation belt model showed that the outer proton belt region decreased during the storm. This was confirmed by satellite data and is consistent with a reduction in single event upsets reported by some spacecraft in medium Earth orbit (MEO). Data show that proton belt was enhanced at lower L but this was not reflected in the model. We discuss the need to revise the models and to include new physics. We conclude that the changes in the electron and proton belts would increase radiation exposure to satellites undergoing electric orbit raising over the next few months.

May 2024 Magnetic Storm: Some Reflections and Suggestions for Future Work

Richard Horne[1], Mike Hapgood[2], Mario Bisi[2], Jim Wild[3], Jonathan Eastwood[4], Mark Gibbs[5], Simon Machin[5]
[1]British Antarctic Survey, United Kingdom, [2]Rutherford Appleton Lab, United Kingdom, [3]Lancaster University, United Kingdom, [4]Imperial College London, United Kingdom, [5]Met Office, United Kingdom

R202R Panel, September 10, 2024, 17:00 - 18:15

The May 2024 storm was only a 1 in 10-year event, comparable in size to the storm of 2003, but the way in which events unfolded was very different. There were only minor impacts on the power grids, satellites, aircraft, communications, GNSS signals, orbiting space debris and low altitude satellites, but the storm tested our forecasting systems and provided valuable data. We will discuss some of the lessons learned, including the difficulty of making predictions, areas for model development, the need for a new system of classifying magnetic storms and how new space missions can help improve our forecasting capability. We will also suggest some of the areas where we need more directed research and closer cooperation between researchers, forecasters and business.

A Review of Contemporary Models of the Solar Corona

Dr Thomas Howson[1]
[1]Abertay University, United Kingdom

Parallel 2A: Solar, September 11, 2024, 11:00 - 12:00

Solar flares, coronal mass ejections, rain, filament eruptions, nanojets, MHD waves; this is just a selection of the huge variety of physical processes which drive the evolution of the largest and the hottest layer of the Sun's atmosphere, the corona. In recent years, the latest generation of state-of-the-art, high-cadence and high-resolution remote sensing observing facilities, have revealed the ever-present dynamism occurring throughout the corona in unprecedented detail. Across a huge range of temporal and spatial scales, we detect a vast array of physical processes which challenge our understanding of astrophysical plasmas. In this review talk, I will explore the energy cycle in the Sun's atmosphere from the injection by photospheric convective motions through current sheet formation as the atmospheric field is continuously stressed, to impulsive release during magnetic reconnection events or due to ideal instabilities. I will discuss recent progress in our understanding of coronal dynamism from coronal heating at the very smallest scales to violent events at the very largest, which have significant consequences throughout the heliosphere.

A Perspective of the Real Time Analysis of the May 2024 Storm from The Moon to Mars Space Weather Analysis Office.

Anthony Iampietro[1,2], Teresa Nieves-Chinchilla[1], Michelangelo Romano[1,2], Anna Chulaki[1,2], Mary Pasanen[1,4], Carina Alden[1,2], Mary Aronne[1,3], Madeleine Anastopulos[1,2], Hannah Hermann[1,2], Melissa Kane[1,2], Elizabeth Juelfs[1,3]
[1]NASA GSFC, United States, [2]Catholic University of America, United States, [3]George Mason University, United States, [4]ADNET, United States

The May 2024 Storm, September 11, 2024, 09:45 - 10:30

Moon to Mars Space Weather Analysis Space Weather Analysis Office (M2M SWAO) located at NASA's Goddard Spaceflight Center, conducts human-in-the-loop real-time space weather analysis in support of NASA robotic missions and human exploration activities. These activities are integrated in a close collaboration with NASA's Space Radiation Analysis Group, and the Community Coordinated Modeling Center (CCMC) and in partnership with the NOAA Space Weather Prediction Center. These efforts are focused on validating solar energetic particle (SEP) research model development, transition to operations (R2O), monitoring space weather impacts to NASA robotic missions, and the transition from operations to research (O2R) by making real-time and post-analysis evaluations available in CCMC databases. 2024 May 8-15 marked the highest peak of Earth-impacting space weather activity so far observed in Solar Cycle 25. The activity, led by the Active Region 13664, included several coronal mass ejections (CMEs), X-class solar flares, and two unique SEP events alongside the arrival of these CMEs triggering the first extreme G5-level geomagnetic storm observed since 2003. M2M SWAO adapted the routine activities to this exceptional event to provide longer and more comprehensive coverage and analysis for supported agencies. The team stressed the models' performance and monitored NASA missions. Thanks to the low-latency data from the ESA/NASA Solar Orbiter Collaboration mission, located at the back of the Sun, as well as MAVEN and Perseverance Rover, the team was able to monitor the heliosphere. We will present an overview of the activities during this period along with the lessons learned for future events.

Heliospheric Mesoscale 3-D Reconstructions and the UCSD Plan for the NASA Small Explorer PUNCH Analyses

BERNARD Jackson[1], Matthew Bracamontes[1], Andrew Buffington[1]
[1]Department of Astronomy and Astrophysics, University of California, United States

Parallel 2C: The Solar Wind and Coupling to the Magnetosphere, September 11, 2024, 16:00 - 17:00

UCSD's iterative time dependent three dimensional (3-D) reconstruction program has characterized heliospheric topology throughout the inner heliosphere based on interplanetary scintillation (IPS) and Thomson scattering brightness observations. Using Solar Mass Ejection Imager (SMEI), and STEREO Heliospheric Imager (HI) brightness, we have worked to provide a system that uses these instrument's full imagery sets and all available lines-of-sight in our iterative programming. We now provide time-dependent, high-resolution, 3-D reconstruction analyses of the inner heliosphere to mesoscale sizes from SMEI and STEREO data. At 1 AU our 3-D reconstructed densities at one-hour cadences, have latitude and longitude resolutions of less than two degrees, and solar distance resolutions of 0.02 AU. Our current system has been used to reconstruct Coronal Mass Ejections (CMEs), their shock responses, and corotating structures in great detail. This system has now been modified to provide pseudo Thomson-scattering brightness and polarization brightness from the volumetric density data as is intended from the Polarimeter to Unify the Coronal and Heliosphere (PUNCH). The UCSD technique shows brightness or polarization brightness can recreate the 3-D analyses of given heliospheric density structures by mapping the brightness fall-off and structure outward flow over large solar distances. Polarization brightness to brightness ratios that are planned from PUNCH are also used from these pseudo analyses and promise better 3-D reconstruction fidelity and less of a requirement need to map heliospheric flow over large distances.

Diagnosing the properties of solar flare energetic particles at the Sun and in the heliosphere (invited)

Natasha Jeffrey[1]
[1]Northumbria University, United Kingdom

Solar Science for Space Weather, September 10, 2024, 14:00 - 15:30

Solar flares are a key component of space weather and responsible for the efficient production of energetic particles and associated radiative emissions (e.g., UV, X-ray and radio) that can affect technology in space and in the near-Earth environment. Understanding the processes that create these particles and their related emissions is essential for understanding the energy release process in flares and how such events may affect us in the future. In this talk, I will concentrate on the production of flare-accelerated electrons. Unlike other particle populations, we routinely observe different populations of energised electrons in the 10s–100s keV range via remote sensing observations and at different locations in the heliosphere with in-situ observations. Here, I will provide a summary of some of the new methods for constraining the properties of electron acceleration in flares, including: (1) the use of stereoscopic X-ray observations with SolO/STIX and Earth-orbiting missions and (2) the use of joint datasets (e.g., STIX and in-situ) to detect signatures of hot, over-dense plasma in the spectra of electron in-situ data that will help to pinpoint the locations of acceleration, helping to resolve the poorly understood relationship between different flare-accelerated electron populations.

From Research to Operation: Development of the SWIMMR N1 Radiation Belt Forecasts

Peter Kirsch[1], Dr. Sarah Glauert[1], Mr Pak Lam[1], Professor Richard Horne[1]
[1]British Antarctic Survey, United Kingdom

Parallel 2G: The Radiation Belts, September 12, 2024, 14:00 - 15:00

The British Antarctic Survey Radiation Belt Model (BAS-RBM) is a physics-based model of the Earth's radiation belts that was initially conceived as a research tool to investigate the behaviour of this highly dynamic environment. Over the course of several projects the model has evolved as a research tool, but it has also become the basis of two space weather forecasting systems, providing information on the radiation environment for satellite operators, insurers and designers. Since 2019 we have been providing 24/7 nowcasts and forecasts for the European Space Agency on a publicly available website and recently we have deployed a similar system to the UK Met Office. The new SWIMMR system uses real-time data from multiple providers collected by the Met Office. Here we describe the challenges arising from processing the data, running the model 24/7, calculating the effects of the environment on satellites, and producing multiple graphical displays. These challenges include management of the data files, archiving, management of multiple computer codes and docker instances, and the process of integration into the Met Office infrastructure. The Met Office infrastructure, processes, and interfaces all evolved during the project which required significant additional effort. However, the system is now working successfully. In the light of this experience, we suggest that there is more focus on system specification in advance of any new projects.

Harmonising Long-Term and Short-Term Solar Flare Predictions

Marianna Korsos[1]
[1]University Of Sheffield, United Kingdom

Parallel 2F: Solar, September 12, 2024, 12:00 - 13:00

The integration of long-term and short-term solar flare predictions is a crucial component of space weather forecasting, given their potential impacts on Earth's technological infrastructure and astronaut safety. This presentation examines the importance of long-term and short-term solar flare prediction methods and the potential benefits of combining them to enhance the reliability and precision of forecasts.

Long-term predictions (weeks) provide a broad understanding of solar activity, facilitating better preparedness for heightened periods of solar activity. In contrast, short-term predictions are based on studying the evolution of individual solar active regions in the solar atmosphere, offering warnings within hours or a daily timeframe.

By combining long-term and short-term insights, a more robust and effective solar flare prediction framework can be established. This comprehensive approach enhances the accuracy of specific flare event predictions and significantly advances our understanding of solar dynamics.

Successes, Challenges and Opportunities in our Quest to Improve Research-to-Operations and Operations-to-Research Pipelines.

Dr. Maria Kuznetsova[1]
[1]Nasa Goddard Space Flight Center, United States

LOC session - Invited Talks Including Industry Sponsors/Stakeholders, September 10, 2024, 08:45 - 11:00

The Community Coordinated Modeling Center (CCMC, https://ccmc.gsfc.nasa.gov) was founded in 2000 as a multi-agency strategic investment into the national space weather program. The main goals identified in the CCMC concept of operations are: to facilitate space weather research and model development; and to support the transition of latest advances in research to space weather operations. On-going CCMC activities are linked to action items in the Implementation Plan for National Space Weather Strategy and Action Plan. The CCMC's continuous real-time runs, performance logs, Integrated Space Weather Analysis (ISWA) system, Database of Notifications, Knowledge, Information (DONKI), Scoreboard software for community-wide pre-event ensemble predictions, and other tools and interactive displays serve as a showroom to demonstrate the operational potential of models, applications, and forecasting techniques. The CCMC serves as a centralized portal for research product candidates entering the Research-to-Operations (R2O) transition pipeline, The presentation will discuss opportunities and approaches to community modeling based on capabilities currently utilized in operations as well as development of next generation operational capabilities.

Solar Energetic Particle forecasting with physics-based tools: current status and future developments

Timo Laitinen[1], Charlotte Waterfall[2], Silvia Dalla[1], Mike Marsh[3]
[1]University Of Central Lancashire, United Kingdom, [2]Goddard Space Flight Center NASA, USA, [3]Met Office, United Kingdom

Solar Science for Space Weather, September 10, 2024, 14:00 - 15:30

(Invited) Solar Energetic Particles (SEPs), accelerated during solar eruptions, cause a hazard to human endeavours in space as well as to high latitude aviation and communication. To mitigate the potential Space Weather impact of SEPs, it is important to develop the capability to forecast critical SEP event parameters such as onset time, peak flux, duration and fluence. We present the current status of two physics-based space weather tools for SEPs: SPARX and FORGE. SPARX is a real time tool using a pre-calculated database of full-orbit SEP simulations to forecast SEP fluxes at Earth. The original version of SPARX [Marsh et al 2015], considering proton energies >10 MeV and >60 MeV, was recently extended to >300 MeV protons [SPARX-H, Waterfall et al 2023]. SPARX is triggered by the detection of a solar eruption and has a run time of just a few minutes. FORGE is a separate GLE in-progress forecasting tool, triggered by the onset of a GLE and including the effect of the heliospheric current sheet on the propagation of relativistic protons. It uses machine learning to forecast the event's profile for the current HCS configuration based on previously run simulations. We discuss future planned developments of these SEP tools which include adding the effects of turbulent field line meandering on the SEP event evolution, to improve their accuracy in forecasting SEP events at locations that are not well connected to Earth.

Development of Compact Cherenkov Proton Detectors and Telescopes

Dr Fan Lei[1], Dr Joey O'Neill[1], Dr Ben Clewer[1], Mr Paul Morris[1], Prof Clive Dyer[1], Prof Keith Ryden[1]
[1]Surrey Space Centre, University of Surrey, United Kingdom

Parallel 1B: Instrumentation, September 11, 2024, 12:00 - 13:00

With UKSA and ESA funding, we are developing new detection techniques based on the Cherenkov radiation for measuring the solar and trapped relativistic, i.e. > 300 MeV, protons. Over the past year we have established the baseline requirements; developed a modular baseline design and evaluated the performance for different configurations; a breadboard implementation has been completed and a beam test at the TRIUMF proton irradiation facility is to take place in July. We will report on all these activities and the preliminary results achieved.

Capability development - Aligning to better meet user needs

Mr Simon Machin[1]
[1]Met Office, United Kingdom

Parallel 1F: SWIMMR Outputs, September 12, 2024, 12:00 - 13:00

As the UK's SWIMMR programme comes to a conclusion, now is a great time to reflect and consider the successes and shortfalls of the programme. This should help inform further advances in operational space weather capability and the underpinning development that is needed to further enhance effective, timely and robust decision making and mitigations across government and industry.

It is important that an enduring research to operations to research framework can be realised, that is driven by understanding potential vulnerabilities, alongside an appreciation of the ways of working across a variety of critical sectors, in order to deliver consumable and actionable advice.

To deliver this effectively for the UK it will be important to retain expertise among the existing SWIMMR partners, whilst fostering outreach and engagement between research and operations across the whole community, to engage the most promising new scientific and technical research.

Future services will benefit from better understanding the coupling between driver and outcome and developing a deeper understanding of the triggers that may lead to cascading impacts.

It is also vital to develop effective international partnerships that through collaboration and sharing will deliver better models, data and information that could ultimately lead to a global observing and forecasting system for space weather.

Observations of plasma structures of varying scale sizes in the high-latitude ionosphere with a suite of instrumentation.

Miss Sophie Maguire[1], Dr Alan Wood[1], Dr David Themens[1], Derek McKay[2]
[1]Space Environment And Radio Engineering (SERENE), University Of Birmingham, United Kingdom,
[2]Metsähovi Radio Observatory, Aalto University, Finland

EISCAT & LOFAR, September 11, 2024, 09:00 - 09:45

Within the high-latitude ionosphere, large-scale plasma structures, such as polar cap patches and blobs, have been observed. These large-scale structures can seed smaller-scale irregularities in the presence of instability mechanisms. It is these smaller-scale irregularities which can lead to the scintillation of trans-ionospheric radio signals, such as those used for Global Navigation Satellite Systems (GNSS). Irregularities which lead to scintillation are on much smaller scale sizes than high-latitude structuring such as polar cap patches. Thus, the Scales of Ionospheric Plasma Structuring (SIPS) experiment was conducted in January 2024 to observe the multi-scale ionosphere and its effects for scintillation.

Given that the aim of the SIPS experiment was to observe the ionosphere across various scale sizes, an extensive suite of instrumentation was needed. This experiment utilised a variety of both ground-based and space-based instrumentation such as incoherent scatter radars, radio telescopes, and the Swarm satellites, in combination with data modelling techniques. In this experiment, the large-scale structures were observed using the European Incoherent SCATter (EISCAT) radars, the medium-scale structures with the Kilpisjärvi Atmospheric Imaging Receiver Array (KAIRA), and the smaller-scale structures from GNSS receivers. The combination of these instruments in conjunction with modelling techniques gives unprecedented coverage of the varying scale sizes which is not possible with individual instrumentation alone. This presentation showcases the results from this experiment, explaining the relationship between structures of varying scale sizes and their associated scintillation effects.

SolarMonitor 2.0

Paul Wright[1], <u>Shane Maloney</u>[1], Sophie Murray[1], Peter Gallagher[1], Alasdair Wilson[2], David Connolly[3], Imogen Nagle[4]
[1]Dublin Institute For Advanced Studies, Ireland, [2]University of Oxford, United Kingdom, [3]Technical University Dublin, Ireland, [4]Brown University, United States

Parallel 1G: Instrumentation and Data, September 12, 2024, 14:00 - 15:00

For over 2 decades, Solarmonitor.org has presented scientists, forecasters, and the general public with an up-to-date summary of solar activity. This includes observational data in the form of in-situ and remote observations and derived data such as coronal hole mapping and flare forecasts.

The system was originally written with a combination IDL, PHP, HTML and CSS and is overdue for a significant update. SolarMonitor 2 combines imaging and timeseries data from space missions such as Solar Orbiter, SDO, GOES, and STEREO with ground-based observations, derived data and meta-data, such as events or active region information. It is a near real-time, integrated tool for monitoring solar activity as well as providing historical data all via a fast, easy-to-use and reliable website and API.

SolarMonitor 2 aims to improve on the original with a streamlined user experience, by providing an even more extensive suite of data products and, most importantly, by increasing reliability and reducing the cost of continual development. This has been achieved with a switch to a modern, robust Python, JavaScript and SQL based application framework.

We present a look at the framework that has made this possible, the current status of the project, the future direction of the project and how the community can be involved in shaping this revamped website, which we hope will continue to serve the solar community for decades more to come.

5 years of STCE's space weather service to aviation

Dr Yana Maneva[1], Dr Judith de Patoul[1], Dr Jennifer O'Hara[1], Dr Dimitrious Millas[1]
[1]Royal Observatory of Belgium/Solar-Terrestrial Centre of Excellence, Belgium

A Global Perspective on Space Weather and Policy, September 9, 2024, 17:10 - 18:00

Since many years the International Civil Aviation Organization (ICAO) has requested the development of space weather services tailored to the needs of civil aviation sector. In 2019 three world centres started to provide continuous 24/7 near-real time space weather services to aviation, namely the NOAA Space Weather Prediction Centre (SWPC), the Australia-Canada-France-Japan consortium (ACFJ) and the Pan-European Consortium for Aviation Space Weather User Services (PECASUS). Later on, a fourth centre, the China-Russia-Consortium (CRC), joined the service provision in 2021. As part of PECASUS the role of the Solar-Terrestrial Centre of Excellence (STCE) is to serve as a primary data hub unit for various data and models provided by partnering members, to continuously monitor the space weather conditions and generate the content of space weather advisories for aviation. To estimate the space weather conditions and possible impacts to aviation the STCE makes further use of its internal space weather monitoring and forecasting capabilities and also serves as an internal data provider for GNSS services and supporting radiation alert products. This work aims to present the lessons learned from the first 5 years of 24/7 near-real time operational space weather service provision to aviation within STCE and PECASUS. We will review the issued space weather advisories and showcase the relevant aviation impacts for selected events. We will further discuss the coordination between the four global centres and comment on preliminary end-user feedback. Finally we will list some of the open challenges in the service provision and envisioned steps towards future improvements.

Dark and quiet skies: for astronomers and for all of us

Professor Robert Massey[2]
[1]The Royal Astronomical Society (ras) - London, United Kingdom, [2]University of Sussex, United Kingdom

SDA/SSA/SST Panel, September 10, 2024, 11:30 - 13:00

2019 saw a paradigm shift in the use of Low Earth Orbit, with the first satellites of the SpaceX Starlink constellation. In the years since the number of operational spacecraft in LEO has increased fivefold, and there could be hundreds of thousands of satellites by the early 2030s.

This is a new area of consideration for the sustainable use of space, one likely to have a major impact on the science of astronomy and on humanity's view of the sky. I will give an overview of why it should not just matter to astronomers, but to all of us, and the UK and international progress so far, as we seek a managed coexistence between the many users of the space around our planet.

Solar explosive energy release – what we still don’t know and why we need to know it

Sarah Matthews[1]
[1]University College London, United Kingdom

Parallel 2F: Solar, September 12, 2024, 12:00 - 13:00

The magnetic field of the corona stores the energy that is released via magnetic reconnection during solar flares and coronal mass ejections (CMEs). Flares with CMEs are often described by the ‘standard’ eruptive flare which offers a conceptual framework in which to investigate the global characteristics of the energy release and transport in the context of the magnetic field configuration. The low plasma beta environment of the corona means the magnetic field plays a central role in the energy transport, and different magnetic field configurations can lead to a variety of outcomes in terms of the evolution of the energy release, the efficiency of the energy transport mechanisms, and the ultimate location of the energy deposition. Which in turn can lead to ‘unexpected’ outcomes for space weather. In this talk I will discuss recent advances as well as how we might address remaining open questions in the hope of reducing ‘unexpectedness’.

R2O2R – SWIMMR model validation and international collaboration

Dr Ian McCrea[1]
[1]UKRI, United Kingdom

Parallel 1F: SWIMMR Outputs, September 12, 2024, 12:00 - 13:00

R2O2R (Research to Operations to Research) is intended to be the process in which research, which has the potential to improve operational capability, is matured in a targeted way toward optimal operational implementation. Once operationalised, the operators of the models and instruments concerned should have a key role in identifying needs for further refinements and conveying these back to the research community. This will deliver the improvements necessary for better operations, and so on. By virtue of its definition, the R2O2R process is supposed to be cyclical and iterative and there could, in principle, be several cycles of the "R2O2R loop" before observational and forecasting capabilities are optimised. What this definition shows is that, in programmes such as SWIMMR, the UK has so far done "R2O", but not yet done any true "R2O2R".
In this talk, I will try to look ahead to what might happen when SWIMMR models are in operation and how R2O2R cycles might come about as the result of a collaboration between entities like the Met Office and National Space Operations Centre working in close coordination with the academic community. We will also look at how R2O2R has been organised in the US, where it has been part of the space weather landscape for some time. I will then sketch an idea for a future UK programme to enable R2O2R for space weather, which ought to be a key pillar of future improvements in this area.

What might happen next? SWIMMR, SWOPPER and the NSS

Dr Ian McCrea[1]
[1]UKRI, United Kingdom

Community Discussion: The Future of Space Weather in the UK and the Wider Community, September 12, 2024, 16:00 - 17:00

(for the SWIMMR Retrospective and Next Steps session)

The UK National Space Strategy, whose implementation plan is now beginning to take effect, seems to be putting the areas of space weather and space domain awareness at the centre of UK efforts to secure "space sustainability". Because space domain awareness is seen as an essential requirement for the sustainable use of space, these areas have been targeted as being the first to be implemented. The forthcoming completion of SWIMMR, plus the development of MOSWOC and NSpOC, mean that the UK community is already in an advanced position to implement this area of the NSS; however the implementation cannot end at this point. In this talk we will look at the NSS roadmaps and implementation plans as they exist so far. I will look ahead to how we might secure a further space weather programme beyond SWIMMR, what such a programme might do and how (in an ideal world) it might be funded. A possible future programme would include model validation based on extended operation and iterative improvement via R2O2R. It would also need to address the needs of the main UK stakeholder groups, which extend well beyond the science community from which the models and instruments originate. Ideally it should also look forward to more integrated and collaborative international development in space weather monitoring and forecasting and lay the foundations for the UK to contribute to, and take a lead in, such an international effort in the future.

SWIMMR Retrospective - The Good, the Bad and the Ugly

Dr Ian McCrea[1]
[1]UKRI, United Kingdom

Community Discussion: The Future of Space Weather in the UK and the Wider Community, September 12, 2024, 16:00 - 17:00

In this talk (which could introduce the SWIMMR retrospective session on Thursday) I will provide a high-level overview of the original stated aims of SWIMMR, highlighting which of those original aims have already been achieved and which further aims should be completed by the time that the last SWIMMR project ends in March 2025. We will cover a few unexpected bonuses that were not originally planned, but have nonetheless materialised as a result of the interaction of SWIMMR projects. We will also look at those SWIMMR aims which have not been achieved in the way that was hoped for and discuss some of the reasons for this. I will use this as the basis for a "lessons learned", in which I will discuss things that could have been done better and things which we might do differently if the chance arises to do a SWIMMR follow-on programme along similar lines in the future.

EISCAT_3D – A Multi-Static Phased-Array Incoherent Scatter Radar in Northern Fennoscandia

Maria Mihalikova[1]
[1]Eiscat Scientific Association, Sweden

EISCAT & LOFAR, September 11, 2024, 09:00 - 09:45

The EISCAT_3D radar system, which is under construction in the European Arctic, will be a world-leading international research infrastructure using the incoherent scatter technique for studies of the atmosphere and near-Earth space environment. EISCAT_3D consists of three phased array antenna sites located in northernmost Norway, Sweden and Finland that, thanks to modern signal processing and radar techniques, will be able to obtain observations with significantly higher resolution than is possible with currently operating radar systems. EISCAT_3D will be able to carry out simultaneous observations within a large volume of the ionosphere above northern Scandinavia, making it both a good instrument for detailed studies of space weather impacts on the ionosphere as well as for model verification. The array site at Skibotn, Norway, will have both transmitting and receiving possibilities and it consists of around 10,000 aerials plus ten 91-aerial outrigger receivers in the immediate vicinity. The receive-only array sites at Kaiseniemi, Sweden, and Karesuvanto, Finland, each consist of about 5,000 aerials each. The construction of the system started after a project kick-off in September 2017. During 2024, EISCAT_3D will gradually begin operations, starting with a seven-element test system and expanding the operations from that.

EISCAT_3D will replace the EISCAT mainland radars, i.e. the mono-static, 930-MHz UHF radar at Tromsø and the tri-static, 224-MHz radar at Tromsø with additional receivers at Sodankylä (Finland) and Kiruna (Sweden). The EISCAT Svalbard Radar (ESR) and the Ionospheric Heating facility at Tromsø will not be affected by EISCAT_3D becoming operational. Here we will present an overview of the present status and plans for the EISCAT_3D system.

MIDAS ionospheric data assimilation and applications to GNSS

Cathryn Mitchell[1]
[1]University of Bath, United Kingdom

Parallel 1A: The Ionosphere, September 11, 2024, 11:00 - 12:00

3D electron density mapping has applications in predicting the response of communication, navigation and radars to the ionised medium of the upper atmosphere. The critical aspect of the achievable accuracy of the ionospheric specification has been the primary motivation for much of the applied ionospheric research for almost 100 years.

In the late-1990's the new computer age enabled ionospheric data assimilation to be proposed. It offered the promise of better ionospheric specification and forecasting than the capabilities of statistical (empirical) ionospheric models. The past 30 years has seen algorithms such as GAIM, IDA4D and MIDAS produce a proliferation of publications detailing the accuracy and applicability of data assimilation to applied systems that are affected by the ionosphere.

This talk gives a perspective what has been achieved to date and on the future applicability of ionospheric data assimilation mapping algorithms such as MIDAS (Multi-Instrument Data Analysis and Assimilation System) for GNSS applications.

Evaluating auroral forecasts against satellite observations under different levels of geomagnetic activity

Dr Michaela Mooney[1], Dr Colin Forsyth, Dr Mike Marsh, L. Bradley, T. Finnagon, F. Forde, F. Garrigan, C. Mancini-Tuffier, T. Mancini-Tuffier, E. Roberts, P. Vessoni, Mr J. Powell, Dr S. Clark, Christian Lao, Dr Andy Smith, Prof. David Jackson, Dr Suzy Bingham, Dr Michael Sharpe, Teresa Hughes, Dr Gareth Chisham, Prof Steve Milan
[1]University Of Leicester, United Kingdom

Parallel 1A: The Ionosphere, September 11, 2024, 11:00 - 12:00

The aurora and associated high energy particles and currents pose a space weather hazard to communication networks and ground-based infrastructure. Forecasting the location of the auroral oval forms an integral component of daily space weather operations. In this study, we evaluate a version of the OVATION-Prime 2013 auroral forecast model that was implemented for operational use at the UK Met Office Space Weather Operations Centre (MOSWOC).

We evaluate the ability of the OVATION-Prime 2013 model to predict the location of the auroral oval in all latitude and local time sectors under different levels of geomagnetic activity, defined by the Kp index. Our analysis shows that the model performs well at predicting the average location of the auroral oval with the forecast occurrence of aurora generally predicted between the mean observed auroral boundaries, particularly for mid levels of geomagnetic activity of Kp = 4. However, the model performance is reduced in the high latitude region near the poleward auroral boundary, particularly in the nightside sectors where the model does not accurately capture the expansion and contraction of the polar cap as the open flux content of the magnetosphere changes. For increasing levels of geomagnetic activity (Kp ≥ 3), the performance of the model decreases, with the poleward edge of the auroral oval typically observed at lower latitudes than forecast. As such, the forecast poleward edge of the auroral oval is less reliable during the most active and hazardous intervals.

Orbyts: Research in School Partnerships

Dr Michaela Mooney[1], Dr Jasmine Sandhu, Dr Will Dunn, Team Orbyts
[1]University Of Leicester, United Kingdom

Space Skills Panel, September 10, 2024, 16:00 - 17:00

STEM subjects, and particularly physics, suffer from a systemic lack of diversity and long-standing barriers to inclusion. Girls, Black students and students from low-income backgrounds are highly under-represented at all levels of physics from age 16+. Meanwhile, UK science education faces substantial shortages in physics teachers, with 1 in 7 UK schools not having a physics teacher. The Orbyts programme aims to address these issues by partnering passionate science researchers with school students to work on original science research projects.

In Leicester we have successfully run 5 researcher-school partnership projects since 2022, directly involving around 50 school students in cutting-edge science research. The science covered in these projects has included space weather, supporting science for the upcoming SMILE mission and exploring Jupiter's upper atmosphere using JUNO data.

The long-term engagement and partnership style of Orbyts projects is key to widening access to science. Orbyts researchers provide relatable role models and humanise science research on an individual level, breaking down harmful stereotypes and misconceptions of who can be a scientist. Our programme evaluation shows that Orbyts delivers profound improvements in inclusivity (e.g. the programme sees 100% increases in girls taking A-level physics when run at GCSE and similar impact across income background and ethnicity).

The research-focus of an Orbyts partnership supports researchers to carry out their science research in a different context while mentoring and inspiring young people. The programme has proven to enhance essential transferable skills for our researchers including communication skills training, project leadership and applied pedagogical experience.

High resolution mapping of the inner heliosphere via ground-based radio observations with state-of-the-art instruments: an australian perspective.

Dr John Morgan[1]
[1]CSIRO, Australia

Parallel 1B: Instrumentation, September 11, 2024, 12:00 - 13:00

A major challenge in Space Weather is probing the region between that covered by white-light coronagraphs (out to a few solar radii), and in-situ observations made at L1. This region, comprising almost all of the volume of the heliosphere within 1 AU, remains only sparsely sampled by in-situ observations with few exceptions.

Radio propagation observations, of both astrophysical and spacecraft emitters, is one approach to probing this volume. Propagation through the interplanetary medium causes group delay, scintillation (IPS, similar to stars twinkling) as well as Faraday rotation. Measurement of these signatures provide proxies for solar wind density and velocity (integrated along the line of sight), as well as information on the intervening magnetic field. For example, observations from established IPS observatories have been shown to improve forecasts of solar wind density and velocity at L1, both for ambient solar wind and Coronal Mass Ejections (CMEs).

In this presentation I will focus on the use of a new generation of radio telescopes for these observations. With their unprecedented combination of sensitivity, wide field of view, and snapshot imaging capability, these instruments can measure hundreds of sources in parallel, providing a resolution sufficient to reveal the existence of smaller-scale structures in interplanetary space, as well as the capability to map the morphology of interplanetary CMEs.

I will describe how a broad range of ground-based radio observations here in Australia are providing information that is complementary both to more conventional measurements and similar work being carried out using European instruments such as Lofar.

Heliospheric Wind and CME Evolution Modelling with EUHFORIA

Mr. Antonio Niemela[1,2], Prof. Dr. Stefaan Poedts[1,5], Dr. Luis Linan[1], Anwesha Maharana[1], Dr. Jinhan Guo[1], Dr. Michaela Brchnelova[1], Tinatin Baratashvili[1], Dr. Fan Zhang[3], Dr. Andrea Lani[1], Dr. Brigitte Schmieder[1,4]
[1]Ku Leuven, Belgium, [2]Royal Observatory of Belgium, Belgium, [3]University of Oslo, Norway, [4]Observatoire Paris-Site de Meudon, France, [5]University of Maria Curie-Skłodowska, Poland

Solar Science for Space Weather, September 10, 2024, 14:00 - 15:30

Solar Coronal Mass Ejections (CMEs) are large-scale eruptive events in which large amounts of plasma (up to 1013-1016 g) and magnetic field are expelled into interplanetary space at very high velocities (up to 3000 km/s). They are nowadays considered to be the major drivers of “space weather” and the associated geomagnetic activity. The detectable space weather effects on Earth have various harmful effects for human health and for our technologies. Severe conditions in space can hinder or damage satellite operations, communications and navigation systems, leading to a variety of socio-economic losses. In order to mitigate these effects, numerical physics-based models are developed to unravel the physics behind these phenomena and predict the effects a few days in advance.
To predict the impact of a CME, its so-called geo-effectiveness, it is important to take into account the internal magnetic structure of the CMEs upon arrival at Earth. I will present the challenges in modelling the solar wind and the evolution of CMEs . Then I will go deeper in the latest results on magnetic flux-rope models for CMEs implemented in EUHFORIA, our heliospheric wind and CME evolution model (Pomoell & Poedts, 2018). I will also mention our novel modified Titov-Démoulin and RBSL flux-rope CME models launched from the low solar corona using our global MHD coronal model COCONUT (Perri, Leitner et al. 2022). Finally I will present our state-of-the-art SEP model PARADISE (Wijsen et al. 2019), already coupled with EUHFORIA and COCONUT, and showcase our current capabilities to model SEPs.

Improving the Arrival-Time Prediction of Coronal Mass Ejections by Heliospheric Imagery and Ensemble Modeling

Dusan Odstrcil[1,2], Jackie Davies[3], Siegfried Gonzi[4], Jie Zhang[2], Vic Pizzo[5], Leila Mays[6]
[1]NASA Goddard Space Flight Center, Greenbelt, USA, [2]George Mason University, Fairfax, USA, [3]STFC Rutherford Appleton Lab, UK, [4]UK Met Office, UK, [5]NOAA Space Weather Prediction Center , United States, [6]NASA Community Coordinated Modeling Center, United States

Parallel 2C: The Solar Wind and Coupling to the Magnetosphere, September 11, 2024, 16:00 - 17:00

The WSA-ENLIL-Cone modeling system enables faster-than-real-time simulations of corotating and transient disturbances in the inner and middle heliosphere. This modeling system has been used at the NASA/Community Coordinated Modeling Center (CCMC), NOAA/Space Weather Prediction Center (SWPC), and UK Met Office/Space Weather Operations Centre (MOSWOC). Although all coronal mass ejections (CMEs) observed by coronagraphs can be routinely simulated, the predicted time of arrival at Earth is sometimes inaccurate. We present the possibility of improving the prediction accuracy by incorporating heliospheric imagery. White-light images of CMEs remotely observed in the heliosphere by the STEREO-A spacecraft are compared with synthetic images calculated from numerical simulations realized by the 3D heliospheric code ENLIL. Such comparison enables ``mid-course correction" of predictions and thereby helps avoid incorrect/inaccurate initialization of the heliospheric simulation. We also investigate possibilities and limitations of ensemble modeling. Future space weather monitoring missions PUNCH and Vigil will provide excellent imagery to further improve the operational prediction by this approach.

Bridging Operations to Research: Development and Utilization of the SIDC Moderated Solar Weather Event List

Dr Jennifer O'Hara[1], Dr Yana Maneva, Mr Lukas Vinoelst, Dr Freek Verstringe, Dr Veronique Delouille, Dr Judith de Patoul, Dr Camilla Scolini
[1]Solar-terrestrial Centre Of Excellence (STCE) - SIDC, Royal Observatory Of Belgium, Belgium

Parallel 2A: Solar, September 11, 2024, 11:00 - 12:00

One of the vital components for Operations to Research (O2R) is having reliable datasets and catalogues. In recent years, various event catalogues and datasets have been developed, covering both manually and automatically detected events, such as flares, sunspots, CMEs, K-indexes, coronal holes etc. Some have also become standard references for research. However, too often these are treated and studied as distinct datasets.

The SIDC is developing a dedicated workflow for forecasters to analyse, link and catalogue space weather events using multiple information sources. The "SIDC Moderated Solar Weather Event List," available through the ESA SWE portal, currently includes SIDC sunspot groups, SIDC solar flares, and SIDC coronal holes. This list employs a versioning database system that allows for updates and tracking, enabling forecasters to adjust the data as new information emerges. To support research on chains of events from solar sources to their impacts on Earth, forecasters use their expertise to identify relationships between events, such as recurring sunspot groups, coronal holes, and the connections between sunspot groups and flares. They also associate the SIDC event data with other catalogues, such as NOAA active regions.

This presentation will explain how forecasters capture their analysis of the events and outline plans to expand the service with additional datasets and connections, such as with CMEs, solar radio bursts, solar wind shocks, and the K index, integrating associations with other catalogued events. Additionally, we will discuss the advantages of the new SIDC catalogue for research, highlighting differences from the CCMC DONKI catalogue.

Solar-wind Modelling: The Importance of Boundary Evolution

Prof Mathew Owens[1]
[1]University Of Reading, United Kingdom

Parallel 2C: The Solar Wind and Coupling to the Magnetosphere, September 11, 2024, 16:00 - 17:00

The solar wind is a highly driven system, meaning the accuracy of solar-wind models and forecasts is primarily determined by the inner-boundary conditions. These are are typically provided by a coronal model, itself constrained by the observed magnetic at the photosphere. While coronal models generally provide steady-state (SS) "snapshots" of the near-Sun solar-wind conditions, those snapshots are regularly updated as new photospheric observations become available, producing indirect information about time evolution. However, at present, independent SS solar-wind solutions are generated for each coronal-model snapshot, discarding all time-history information. In this study, we use one year of daily-updated coronal-model solutions to compare SS and fully time-dependent (TD) approaches to solar-wind modelling. We demonstrate how the SS approach misrepresents the accuracy of coronal models. We attribute three key problems with current space-weather forecasting directly to the SS approach. These are: (1) the somewhat paradoxical situation that forecasts based on observations from 3-days previous are more accurate than forecasts based on the most recent observations; (2) high inconsistency, with forecasts for a given day jumping significantly as new observations become available, which is a barrier to acting on a forecast; and (3) insufficient variability in the heliospheric magnetic field connection to Earth, which control solar energetic particle (SEP) propagation. We show the TD approach, applied to the exact same inner-boundary conditions, alleviates all three issues.

Could Space Weather Delay Your Train? Modelling the Impacts of Geomagnetically Induced Currents on Railway Signalling Systems

Dr Cameron Patterson[1], Prof Jim Wild[1], Prof David Boteler[2], Dr Ciaran Beggan[3], Dr Gemma Richardson[3], Dr Juliane Hübert[3]
[1]Lancaster University, United Kingdom, [2]Natural Resources Canada, Canada, [3]British Geological Survey, United Kingdom

Parallel 1D: Ground and Infrastructure, September 11, 2024, 17:00 - 18:00

Track circuit signalling systems are widely utilised across the world, and their ability to accurately detect trains is crucial for the safe and smooth operation of a railway network. These systems use electric circuits to detect the presence or absence of trains in sections along a railway line, as such, they can be susceptible to interference from geomagnetically induced currents.

The model we have developed to analyse the impacts of space weather on the UK railway network has been expanded to include new arterial routes across Great Britain.

Results from the model, including case studies of historical extreme events will be presented.

Meteoric ablation and metallic layers in the mesosphere and lower thermosphere: impacts of space weather

Professor John Plane[1], Dr Wuhu Feng[1,2], Dr Jing Jiao[3], Professor Daniel Marsh[1]
[1]University of Leeds, United Kingdom, [2]National Centre for Atmospheric Science, United Kingdom, [3]State Key Laboratory of Space Weather, National Space Science Center, Chinese Academy of Sciences, China

Parallel 1C: The Mesosphere and Thermosphere and Ionosphere, September 11, 2024, 16:00 - 17:00

Cosmic dust particles are produced from the sublimation of comets and by collisions between asteroids. Because the particles enter the atmosphere at hypersonic velocities, collisional heating with air molecules causes a fraction of them to melt, leading to vaporization of their metallic constituents. The injection of these elements causes a wide variety of atmospheric phenomena, including the formation of global layers of metal atoms between 80 and 105 km; airglow emissions; layers of metallic ions which affect radio communications; and the production of meteoric smoke particles which enable the nucleation of mesospheric ice clouds and the freezing of polar stratospheric clouds. Some metal atoms can be observed very precisely by ground-based lidar and from satellites, providing an excellent tracer of dynamics and chemistry at the edge of geospace.

Atmospheric models of 10 meteoric elements (Na, Mg, Al, Si, P, S, K, Ca, Fe and Ni) have been constructed from laboratory measurements of the rate coefficients of over 180 individual reactions involving neutral and ionized species. This chemistry, together with the relevant metal injection rates as a function of height, location and time, has been inserted into the Whole Atmosphere Community Climate model. Model simulations compare well against pertinent observations of metal atoms/ions from ground-based lidar, rocket-borne mass spectrometry and satellite remote sensing.

This paper will describe how WACCM can be used to simulate the effects of space weather on the metallic layers, principally through increased ionization above 95 km and an increase in H and O below 90 km.

At the sharp end: optical characterisation of the satellite and debris population

Don Pollacco[1]
[1]University of Warwick, United Kingdom

SDA/SSA/SST Panel, September 10, 2024, 11:30 - 13:00

While objects In LEO smaller than a golf ball can contain sufficient kinetic energy to destroy a satellite in a head on collision, the numbers and distribution of debris of this size is still only badly known. What we do know is that the numbers of LEO satellites is hugely increasing and so the risk collisions are growing. Current efforts to monitor the debris population is limited to tracking about 35000 objects while models predict maybe a million objects capably of disabling a space craft in a collision. I will discuss some of our attempts at Warwick to developing new optical techniques useful to characterise the debris population. In particular I'll discuss the "Digital Telescope" (under construction) will be transformational in our ability to track these objects.

Solar Cycle 25: Forecasts vs. Reality – A Mid-Cycle Check-In

Dr Amrita Prasad[1], Dr. Soumya Roy[2], Dr. Arindam Sarkar[3]
[1]Cardiff Metropolitan University, Western Avenue, United Kingdom, [2]Dept. of Applied Electronics & Instrumentation Engineering, Haldia Institute of Technology, India, [3]Dept.of Computer Science & Electronics, Ramakrishna Mission Vidyamandira, India

Parallel 2F: Solar, September 12, 2024, 12:00 - 13:00

In the current work, we have checked how our developed deep-learning models performed in predicting Solar Cycle 25 so far. Using monthly smoothed sunspot number data from WDC-SILSO, Royal Observatory of Belgium, Brussels, we developed stacked Long Short-Term Memory (LSTM) and Vanilla LSTM models to predict the solar cycle 25 intensity and peak time. Both the model performances have been validated by forecasting the peak amplitude of past Cycles. As we reach the midpoint of Solar Cycle 25, comparing the predictions made by our developed model with actual data is crucial to refine our models further and enhance our understanding of solar dynamics. When the actual (2020-2023) and the predicted SSN (2020-2023) were compared it was observed that both the models could not predict the peak time correctly as cycle 25 hasn't reached the max peak yet, but we have to wait and see how successful the models were in predicting the maximum amplitude. But one interesting aspect that is being noted is that the vanilla LSTM is closely following the observed SSN for cycle 25 with mean absolute error (MAE) and mean absolute percentage error (MAPE) of 11.61 and 27.06% respectively. In the case of stacked LSTM, MAE and MAPE are found to be 36.69 and 95.52% respectively. The error analysis shows that the Vanilla LSTM demonstrates strong performance, capturing long-term dependencies and trends within the data. Still, time will tell how accurate the models were in predicting the overall profile of cycle 25.

Improved 24/7 Solar Flares Prediction using Deep Learning and Data Fusion Techniques

<u>Prof Rami Qahwaji</u>[1], Mr Herbert Caxton-Martins
[1]University of Bradford, United Kingdom

Parallel 2F: Solar, September 12, 2024, 12:00 - 13:00

The ASAP (Automated Solar Activity Prediction) system is an automated real-time AI-based system for the 24/7 monitoring and prediction of extreme solar flares by processing the latest satellite images. ASAP's predictions are publicly available at https://spaceweather.bradford.ac.uk/. ASAP is working with NASA's Solar Dynamics Observatory (SDO) satellite images, integrated with NASA's Community Coordinated Modelling Center (CCMC), used as a decision-making tool for NASA's robotic missions and to manage radiation effects on NASA's Chandra X-ray Observatory orbit, among other uses. The development, operation and impact of ASAP were submitted as an impact case study for the Research Excellence Framework (REF 2021) and was rated as 100% Internationally Excellent (3*).

This talk will introduce the planned upgrades and future modifications for ASAP, which include deep learning techniques for processing a large number of SDO images and determining the flaring potential of sunspot groups. We are also developing a new framework to predict solar flares by making use of the Geostationary Operational Environmental Satellite (GOES) X-ray flux 1-minute time series data using time-series feature extraction techniques and deep learning. The new predictions could be used to improve current ASAP predictions using Data Fusion. In this talk, we will present early findings and early evaluation of the flare prediction performance for these new systems using space weather metrics.

Managing Director, Slingshot Aerospace

Melissa Quinn

SDA/SSA/SST Panel, September 10, 2024, 11:30 - 13:00

In this presentation, we will take a deep dive into the data through the lens of a satellite's lifecycle, from launch to on-orbit operations to end-of-life activities. This story of a satellite will provide context for our SSA/SDA/STM risks and challenges, as well as indicators of responsible behavior.

We will then examine the sources of data, including contextual, optical sensors, on-orbit data, and owner-operator information. By layering space weather events and using AI to predict and confirm anomalous activities, we gain a complete picture of the trends. This helps us understand the state of our orbits and identify where we can make the most impact.

We all know the saying 'Data is King (or Queen!)', but it is what we do with the data that will help us keep space safe, secure, and sustainable for future generations.

Understanding the sensitivity of TIe-GCM's forcing parameters

Natalie Reeves[1], Sean Elvidge, David Themens
[1]University of Birmingham, United Kingdom

Parallel 1C: The Mesosphere and Thermosphere and Ionosphere, September 11, 2024, 16:00 - 17:00

The Thermosphere Ionosphere Electrodynamics General Circulation Model (TIE-GCM) is a physics-based, three-dimensional, and time-dependent representation of the coupled thermosphere-ionosphere system. TIE-GCM requires various forcing parameters to describe solar and magnetospheric activity, as well as the internal dynamics from the lower boundary. However, there is limited research on the interrelationships among the model's forcing parameters and which parameters most significantly impact its behaviour. Therefore, global sensitivity analysis techniques, along with Latin Hypercube Sampling, have been used to explore the entire parameter space for TIE-GCM's inputs. Additionally, the Partial Rank Correlation Coefficients were used to quantify the relationships between the input parameters, indicating the degree of monotonicity between specific input and output variables. The outcome of this analysis can be used to generate better ensembles for data assimilation models, e.g. the Advanced Ensemble Networked Assimilation System (AENeAS).

A Real-Time Data Assimilation International Reference Ionosphere

Benjamin Reid[1], David R. Themens[1], Sean Elvidge[1], M. Afraz Ahmed[1], Warrick Ball[1]
[1]University Of Birmingham, United Kingdom

Parallel 1C: The Mesosphere and Thermosphere and Ionosphere, September 11, 2024, 16:00 - 17:00

The International Reference Ionosphere (IRI) is a global empirical model of the ionosphere. The ionosphere exhibits variability on smaller spatial and temporal scales than the climatological IRI can resolve, particularly during periods of elevated geomagnetic activity. This has lead to a great deal of interest in using data assimilation to augment the IRI, including producing a real-time ionospheric specification or nowcast. The limitations of the IRI are shared by other empirical climatological models, such as the Empirical Canadian High Arctic Ionospheric Model (E-CHAIM) or the NeQuick model. The Advanced Ionospheric Data Assimilation (AIDA) model is an operational, real-time data assimilation model of the global ionosphere and plasmasphere. It uses NeQuick as a background state, and so is effectively a high-resolution, real-time NeQuick. AIDA assimilates live data streams from over 2000 Global Navigation Satellite System (GNSS) receivers worldwide, along with automatically scaled ionosonde data from the Global Ionosonde Radio Observatory (GIRO). AIDA uses a Monte Carlo data assimilation technique known as a Particle Filter to ingest the nonlinear slant Total Electron Content (sTEC) observations produced by the GNSS receivers. This same technique can be used to assimilate this data into any ionospheric model, including the IRI. This study will examine how the existing AIDA framework can be adapted to produce a real-time ionospheric specification and forecast based on the IRI.

Modelling Geomagnetically Induced Currents in high voltage power networks in the UK and beyond

Dr Gemma Richardson[1], Dr Lauren Orr[1], Dr Ciarán Beggan[1], Dr Daniel Mac Manus[2], Dr Juliane Hübert[1]
[1]British Geological Survey, United Kingdom, [2]University of Otago, New Zealand

Parallel 1E: Ground & Infrastructure, September 12, 2024, 11:00 - 12:00

At BGS we have a long history of modelling geomagnetically induced currents (GIC) in high voltage power grids, both for real-time operational services and research. In recent years we have been part of several studies to model GIC for both historical geomagnetic storms, and theoretical extreme events to try to quantify the risk of space weather events on power grids, not just in the UK, but also across Europe, New Zealand and the US.

The storm on 10th-11th May provides an opportunity to study the effects of GIC in multiple power grids, at different local times and latitudes. We will investigate the similarities and differences between the different grids and their response to the storm.

Near-real-time riometer measurements for nowcasting High Frequency radio wave absorption

Dr Neil Rogers[1], Prof Farideh Honary[1], Mr Peter Chapman[1], Dr Steve Marple, Dr Robyn Fiori[2], Dr Antti Kero[3]
[1]Lancaster University, United Kingdom, [2]Canadian Hazards Information Service, Natural Resources Canada, Canada, [3]Sodankylä Geophysical Observatory, University of Oulu, Finland

Parallel 1G: Instrumentation and Data, September 12, 2024, 14:00 - 15:00

We describe a new programme of work to improve the delivery of near-real-time (NRT) (<15-min latency) measurements from riometers across the arctic region.   Riometers measure the ionospheric absorption of ~30 MHz cosmic radio noise and historic measurements have formed the basis for several High Frequency radio absorption models such as the US National Oceanic and Atmospheric Administration's D-Region Absorption Prediction (DRAP) model [1]. Under the Space Weather Instrumentation, Measurement, Modelling and Risk (SWIMMR) programme we implemented an Optimised D-Region Absorption Model (ODRAM) [2] which incorporates NRT riometer measurements to optimise absorption model coefficients (including proton rigidity cutoff latitude boundaries) during solar energetic particle events.
We describe the construction and deployment of a new riometer in Iceland (and, potentially, another in Norway) in summer/autumn 2024. The aim is to stream data from these riometers and existing systems operated by our project partners (Natural Resources, Canada, and Sodankylä Geophysical Observatory , Finland) into the UK Met Office Space Weather Operations Centre. We will describe various methods of data calibration, the definition of a unified standard data format, quality flag indicators (e.g., identifying freezing rain, snowfall, wind, animal disturbance, or radio interference), and technical issues regarding intercalibration between riometers of differing design.

References:
[1] Sauer, H. H., and D. C. Wilkinson (2008), Space Weather, 6, S12002. https://doi.org/10.1029/2008SW000399.
[2] Rogers, N. C., A. Kero, F. Honary, P. T. Verronen, E. M. Warrington, and D. W. Danskin (2016), Space Weather, 14, https://doi.org/10.1002/2016SW001527.

Monitor Space Hazards: The National Space Operations Centre's Civil Space Protection Services

Dr Harneet Kaur Sangha[1]
[1]National Space Operations Centre, UK Space Agency, United Kingdom

SDA/SSA/SST Panel, September 10, 2024, 11:30 - 13:00

The National Space Operations Centre (NSpOC) is a joint civilian and military body led by the UK Space Agency and UK Space Command, in partnership with the Met Office. NSpOC is responsible for developing and operating the UK Government's space surveillance and protection capabilities. One of NSpOC's civilian products is a digital service for UK-licenced satellite operators and government members known as Monitor Space Hazards. Monitor Space Hazards is an online platform which provides users with information, alerts, and support on space-domain risks and hazards. UK-satellite operators can currently access our collision avoidance service and the Met Office Space Weather Operations Centre's (MOSWOC) space weather alerts. Digitalised versions of our re-entry, fragmentation and CAA support services will be hosted on Monitor Space Hazards soon.

Evaluating Solar Wind-Driven ML Models of Ground Level Space Weather in the UK

Dr Andy Smith[1], Jonathan Rae[1], Colin Forsyth[2], John Coxon[1], Maria Walach[3], Christian Lao[2], Shaun Bloomfield[1], Sachin Reddy[2], Mike Coughlan[4], Amy Keesee[4], Sarah Bentley[1]
[1]Northumbria University, United Kingdom, [2]University College London, United Kingdom, [3]Lancaster University, United Kingdom, [4]University of New Hampshire, United States

Parallel 1E: Ground & Infrastructure, September 12, 2024, 11:00 - 12:00

Geomagnetically Induced Currents (GICs) are a severe space weather hazard, driven through coupling between the solar wind and magnetosphere. GICs are rarely measured directly, instead the ground magnetic field variability is often used as a proxy. Recently space weather models have been developed to forecast whether the magnetic field variability (R) will exceed specific, extreme thresholds. We test an example machine learning-based model developed for the northern United Kingdom, one currently running as a part of the SWIMMR programme. We evaluate its performance (discriminative skill and calibration) as a function of magnetospheric state, solar wind input and magnetic local time.

We find that the model's performance is highest during active conditions, for example geomagnetic storms, and lowest during isolated substorms and ``quiet'' intervals, despite these conditions dominating the training dataset. Correspondingly, the performance is high when the solar wind conditions are elevated (i.e. high velocity, large total magnetic field strength, and the interplanetary magnetic field oriented southward), and at a minimum when the north-south component of the magnetic field is highly variable or around zero. Regarding magnetic local time, performance is highest within the dusk and night sectors, and lowest during the day. The model appears to capture multiple modes of magnetospheric activity, including substorms and viscous interactions, but poorly predicts impulsive phenomena (i.e. storm sudden commencements) and longer timescale coupling processes.

We discuss the implications of these results for future forecasting efforts.

Future Politics and UK Space Weather and Space Safety activities

David Southwood[1]
[1]London Institute Space Policy And Law, United Kingdom

A Global Perspective on Space Weather and Policy, September 9, 2024, 17:10 - 18:00

Space Weather (SW) research yields more than simple scientific worth; it has societal importance both in civil matters and defence. In an ideal world, SW operations would be a globally coordinated service. However, SW research and operational services are an increasingly politically sensitive topic. Present political unknowns for UK in both Space Weather and Space Safety in particularly relate to Europe. European coordination may cause problems since, although it has remained an active player in ESA and EUMETSAT, UK is no longer in the EU. The advent of war in Europe and the burgeoning EU space capability combined with the increasing EU interest in space links with defence and security have complicated matters. Along with a space regulation (space law) that may have impact, EU is a primary candidate for providing SW operations for Europe in future as well as research. This matters to UK as the EU has used exclusion of non-EU nations, such as Switzerland and UK from space programmes (e.g. exclusion of UK from Copernicus, SST activities and Galileo) in a wider political context. However, also to be considered is that UK has close relations with the US Govt civil and defence space organisations.

Evaluating the Performance of a Real-Time Electron Radiation Belt Specification Model

Frances Staples[1], Adam Kellerman, Janet Green
[1]University of California Los Angeles, United States

Parallel 2G: The Radiation Belts, September 12, 2024, 14:00 - 15:00

The Radiation Belt Forecasting Model and Framework (RBFMF) provides real-time forecasts and hindcasts of the radiation environment, which are used as inputs for the Satellite Charging Assessment Tool (Sat-CAT). Sat-Cat is used by satellite operators to model both long term and real-time effects of internal charging on satellite components. We will present the validation results of the RBFMF, and will show how combining real-time electron flux observations with physics based modelling improves hindcasting capabilities of either method used alone. We will also highlight how new missions must consider data provision for real-time operational applications, and discuss the observational requirements and model development necessary for improved specification of the radiation environment through hindcasts and forecasts.

High latitude ionospheric response to the May 2024 Storm and its impacts on GNSS

<u>Dr David Themens</u>[1,2], Prof Sean Elvidge[1], Prof P.Thayyil Jayachandran[2], Dr Anthony McCaffrey[2], Dr Benjamin Reid[1,2], Ms Sophie Maguire[1]
[1]University Of Birmingham, United Kingdom, [2]University of New Brunswick, Canada

Parallel 1A: The Ionosphere, September 11, 2024, 11:00 - 12:00

The May 10-11, 2024, geomagnetic storm was a severe 1 in ~12 year event that persisted at Kp 8 or greater activity levels for more than 24 hours. In the ionosphere, this event resulted in particle precipitation driving ionospheric phase scintillation on Global Navigation Satellite System (GNSS) signals well into conventional midlatitudes. The initial phases of the storm created a distinct Tongue of Ionization (ToI), where lifted midlatitude plasma was drawn into the polar cap and generated streams of patches that produced both strong phase and amplitude scintillation. Repeated substorm expansions throughout the event drive scintillation activity across the polar and midlatitude regions as severe Joule Heating drives correspondingly severe thermospheric mixing and the depletion of the ionosphere, which subsequently suffocates the high latitude convection region from the enhanced plasma density needed to produce ToIs and patches, thereby resulting in only weak ToI and patch generation on the 11th. This study will elaborate on the impacts of this storm on the high latitude ionosphere, leveraging ground based-GNSS, Incoherent Scatter Radar, and ionosonde observations to build an understanding of the processes at play during this event and the subsequent impacts on GNSS applications, including Precise Point Positioning convergence time and stability.

Results of the 2024 Space Census and Space Training in the UK

Heidi Thiemann[1]
[1]Space Skills Alliance, United Kingdom

Space Skills Panel, September 10, 2024, 16:00 - 17:00

The Space Census is a national survey of individuals in the UK space sector and provides a unique insight into the pathways that people take to enter the space workforce. The results of the 2024 Space Census will build on the baseline data collected from the inaugural 2020 Space Census, and will provide us with detailed information about the routes that people take to join the UK space workforce, from what inspired them to work in space, through to the undergraduate and postgraduate degrees studied, and their access to continuing professional development. The release of the 2024 Space Census results will mark a significant step in our ongoing efforts to understand the UK space workforce. By providing detailed insights into workforce demographics and trends, the 2024 Space Census will support decision-makers in developing evidence-based policies and strategies that address the evolving needs of the sector. The results will serve as a valuable benchmarking tool, allowing the UK space sector to compare its workforce with those of other nations.

Data assimilation in the solar wind

Harriet Turner[1], Mathew Owens, Matthew Lang, Siegfried Gonzi, Mike Marsh
[1]University Of Reading, United Kingdom

Parallel 2C: The Solar Wind and Coupling to the Magnetosphere, September 11, 2024, 16:00 - 17:00

Accurate space weather forecasting requires knowledge of the solar wind conditions. Current forecasting methods are initialised with photospheric magnetic field observations but typically contain no information from observations of the solar wind. Data assimilation (DA) methods aim to combine a model of a system with observations to find an optimum estimation of reality. DA has led to large forecast improvements in terrestrial weather forecasting but has been underused is space weather forecasting, especially in the solar wind. In this talk I will outline the methods behind using DA in the solar wind and the most recent findings within the field.

Space Weather Courses for Industry and Users

Petra Vanlommel[1], Elke D'Huys, Jan Janssens, Ronald Van der Linden
[1]STCE, Belgium

Space Weather End Users Panel, September 9, 2024, 14:00 - 16:00

Sporadic and massive solar eruptions of very high-energy matter and radiation from the Sun can have an impact on navigation, communication and transport of energy. In extreme cases, these eruptions pose a safety risk to human health.
Businesses and organisations possibly impacted by space weather want to learn about this natural hazard to increase their resilience. But, it is not always straightforward to read, understand and interpret space weather bulletins and data available on the internet. Some users might be in the initial phase of space weather awareness and understanding and might not have found their way to an easy accessible space weather service yet.
The Space Weather Education Centre, SWEC, offers basic and tailored courses for stakeholders that run space weather impacted operations and services. The courses address the barriers that users encounter while dealing with the question what space weather is, as well as where to find and how to interpret space weather parameters and indices.

SWEC is an organisation of the STCE, the Solar-Terrestrial Centre of Excellence. The STCE is the place for research, data & services and education about Sun-Space-Earth and their interactions. The institute can rely on a rich history and expertise in solar and terrestrial observations & measurements, both on ground and from space. The STCE incorporates a Space Weather Service Centre, issuing daily space weather bulletins and warnings in case of space storms.
SWEC builds on this firm academic and service experience and has qualified teachers and communicators.

Prediction of Adverse effects of Geomagnetic storms and Energetic Radiation (PAGER) Project and Follow-On

Dr. Dedong Wang[1], Prof. Yuri Shprits[1]
[1]Gfz German Research Centre For Geosciences, Germany

Parallel 2D: The Radiation Belts, September 11, 2024, 17:00 - 18:00

The PAGER project provides space weather predictions initiated from observations on the Sun to predict radiation in space and its effects on satellite infrastructure. Real-time predictions and a historical record of the dynamics of the cold plasma density and ring current allow for the evaluation of surface charging, and predictions of relativistic electron fluxes allow for the evaluation of deep dielectric charging. The project provides a 1-2 day probabilistic forecast of ring current and radiation belt environments, which allow satellite operators to respond to predictions that present a significant threat. As a backbone of the project, we use the most advanced codes that currently exist and adapt existing codes to perform ensemble simulations and uncertainty quantifications. PAGER project includes a number of innovative tools including data assimilation and uncertainty quantification, new models of near-Earth electromagnetic wave environment, ensemble predictions of solar wind parameters at L 1, and data-driven forecast of the geomagnetic Kp index and plasma density. The developed codes may be used in the future for realistic modelling of extreme space weather events. The PAGER consortium is made up of leading academic and industry experts in space weather research, space physics, empirical data modelling, and space environment effects on spacecraft from Europe and the US. In this presentation, we will show the real-time operating forecasting data product from the PAGER project and the follow-on of this project. We validate our models against observations using different matrices and we are now improving the operational forecasting models in our follow-on research.

Detecting Potential Drivers of Geomagnetic Activity Using Nonlinear System Identification and Machine Learning Techniques

Dr Hua-Liang Wei[1], Professor Michael Balikhin[1], Dr Richard Boynton[1]
[1]The University of Sheffield, United Kingdom

Parallel 2E: The Solar Wind and Coupling to the Magnetosphere, September 12, 2024, 11:00 - 12:00

Quantifying the response of the Earth's magnetosphere to the solar wind activity is important for monitoring the influences of space weather on the Earth. The detection and analysis of potential drivers of the geomagnetic activity is essential for building high quality and parsimonious predictive models for space weather forecasting. In this work, a transparent, interpretable, parsimonious and simulatable (TIPS) machine learning and nonlinear system identification approach, called Nonlinear Autoregressive Moving Average with eXogenous inputs (NARMAX) method, is developed to detect and identify the potential drivers of geomagnetic activity, e.g., measured by Dst (SYM-H), Ap (or Kp), and AE indices, from solar wind parameters.

Assessing the geo-effectiveness of CMEs from a sub-L1 perspective

Eva Weiler[1,2], Christian Möstl[1], Emma E. Davies[1], Tanja Amerstorfer[1], Ute V. Amerstorfer[1], Hannah T. Rüdisser[1,2], Rachel L. Bailey[3], Julia Thalmann[2], Astrid Veronig[2], Noé Lugaz[4], Satabdwa Majumdar[1], Veronika Haberle[3]

[1]Austrian Space Weather Office, GeoSphere Austria, Austria, [2]Institute of Physics, University of Graz, Austria, [3]Conrad Observatory, GeoSphere Austria, Austria, [4]Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, United States

The May 2024 Storm, September 11, 2024, 09:45 - 10:30

Coronal mass ejections (CMEs) are huge plasma eruptions from the Sun and are considered to be the most geo-effective events, causing space weather phenomena. However, if a CME is geo-effective or not depends on whether the magnetic field embedded in the CME is southward orientated or not. The reliable prediction of the southward magnetic field component is yet an unsolved problem in space weather research, known as Bz problem. Future missions such as HENON and the proposed MIIST mission will address this problem by deploying spacecraft on distant retrograde orbits around the Earth, up to ten times closer to the Sun than L1. This sub-L1 position is expected to extend the lead time for predicting the impact of CMEs.

In this study, we use the close encounter of STEREO-A and Wind from November 2022 to June 2024, where STEREO-A passed 0.05 AU ahead of Wind at +/- 15 degrees heliospheric longitude. We apply a Dst model to STEREO-A in situ data and check whether we can reproduce the most severe geomagnetic storms (Dst < -80 nT) that occurred during this time period. Since the 2024 May superstorm or Mother's Day event was also measured at STEREO-A 2.57 hours before it was measured at Earth, we can quantify the accuracy with which the geomagnetic effects of a highly interactive superstorm can be forecasted. With the statistics we get from this analysis, our study sets an unprecedented benchmark for future mission designs using upstream monitoring for space weather prediction.

How the UK Space Agency is supporting Space Weather R&D and Operations

Mike Willis[1], **Caroline Harper**[1]
[1]UKSA, United Kingdom

Space Safety with UKSA and ESA Panel, September 9, 2024, 16:30 - 17:10

Through ESA, the UK Space Agency is supporting the VIGIL mission, smaller missions including Aurora and space weather core R&D activities aimed towards operational service development, including how to incorporate new mission data into forecasting models. The Agency is also supporting heliophysics missions in partnership with ESA and NASA. This includes ongoing support for Solar Orbiter, STEREO, Hinode and Cluster and new mission and instrument development, SMILE, IMAP and Helioswarm. These science missions are supported for two reasons – they advance our scientific knowledge and they inform operational space weather forecasting.

An Outflow Equilibrium Model for the Solar Corona

Professor Anthony Yeates[1], Dr Oliver Rice[1]
[1]Durham University, United Kingdom

Solar Science for Space Weather, September 10, 2024, 14:00 - 15:30

Many space weather forecasting and scientific applications would benefit from improved extrapolation of the solar coronal magnetic field, since this acts as the main "boundary condition" for models of the heliospheric magnetic field and solar wind. I will present a practical extension to the PFSS (potential field source surface) model to incorporate an axisymmetric solar wind. A steady state is obtained by balancing magnetic relaxation against the opening effect of the solar wind outflow. Perhaps surprisingly, but thanks to the axisymmetric flow, the problem is susceptible to an efficient eigenfunction/spectral treatment similar to that used in our PFSS solver ("pfsspy"), so remains practical for "real-time" forecasting. Preliminary exploration shows that the model removes the artificial source surface, leading to more realistic coronal streamer morphologies. It also enhances the open flux in a time-dependent way, partially addressing the well-known "open flux problem".

Poster Presentations

The challenge to understand the zoo of particle transport regimes during resonant wave-particle interactions for given survey-mode wave spectra

Dr Oliver Allanson[1], Donglai Ma, Adnane Osmane, Jay Albert, Jacob Bortnik, Clare Watt, Sandra Chapman, Joseph Spencer, Daniel Ratliff, Nigel Meredith, Thomas Elsden, Thomas Neukirch, David Hartley, Rachel Black, Nicholas Watkins, Sean Elvidge
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Poster Session, September 11, 2024, 14:00 - 16:00

It is well known that the resonant diffusion quasilinear theory for the case of a uniform background field may formally describe particle dynamics when the electromagnetic wave amplitude and growth rates are sufficiently “small”, and the bandwidth is sufficiently “large”. Using a high-performance test-particle code, we present a detailed analysis of the applicability of quasilinear theory to a range of different wave spectra that would otherwise “appear quasilinear” if presented by e.g., satellite survey mode data. We present these analyses as a function of wave amplitude, wave coherence and resonant particle velocities (energies and pitch-angles), and contextualise the results using theory of resonant overlap and small amplitude criteria. In doing so, we identify and classify five different transport regimes that are a function of particle pitch angle. The results in our paper demonstrate that there can be a significant variety of particle responses (as a function of pitch angle) for very similar looking survey-mode electromagnetic wave products, even if they appear to satisfy all appropriate quasilinear criteria. In recent years there have been a sequence of very interesting and important results in this domain, and we argue in favour of continuing efforts on: (i) the development
of new transport theories to understand the importance of these, and other, diverse electron responses; (ii) which are informed by statistical analyses of the relationship between burst- and survey-mode spacecraft data.

Repurposing Hydrological Neutron Detectors to Observe Ground Level Enhancements

Dr Fraser Baird[1], Keith Ryden[1], Fan Lei[1], Clive Dyer[1]
[1]Surrey Space Centre, United Kingdom

Poster Session, September 11, 2024, 14:00 - 16:00

Neutron monitors (NMs) provide invaluable observations of ground level enhancements (GLEs) of atmospheric radiation. GLEs are a hazard to aviation activities, as the enhanced radiation dose damages biological tissue and avionic systems. The network of ground level NMs provides global observations of these events, which are used in real-time models of the aviation radiation environment. However, the network has atrophied since its institution in the late 1950s: today there are around 50 NMs in operation.
This contribution highlights the ability of a pre-existing, dense network of neutron detectors to boost the observations of the NM network. The network in question is the Cosmic Ray Soil Moisture Observation System UK (COSMOS-UK), uses neutron detectors to observe soil moisture. COSMOS-UK observations of Forbush decreases and the solar cycle dependence of cosmic rays are presented, along with an analysis of the network's sensitivity to GLEs.
The Compact Neutron Monitor (CNM), will also be discussed in this contribution. This instrument features COSMOS-UK neutron detectors deployed indoors to remove the influence of soil moisture. The observations of the first CNM in Guildford are presented, alongside plans for a second CNM in Shetland.

Aviation Doses During Recent Space Weather Events: Results from the MAIRE+ Model

Dr Fraser Baird[1], Dr Fan Lei[1], Dr Ben Clewer[1], Prof Keith Ryden[1], Prof Clive Dyer[1], Simon Machin[2], Krista Hammond[2]
[1]Surrey Space Centre, United Kingdom, [2]Met Office, United Kingdom

Poster Session, September 11, 2024, 14:00 - 16:00

MAIRE+ is a model of the atmospheric ionising radiation field at aviation altitudes. Its purpose is to predict radiation dose rates and single event effect rates during both quiescent conditions and ground level enhancements (GLEs) of the radiation field. The real-time model has recently been delivered to the Met Office as part of the SWIMMR program.

In this contribution, the output of MAIRE+ during two recent space weather events are presented. The first event is the geomagnetic storm of March 25th 2024. This event was only brief, but caused some consternation in aviation communities due to two false ICAO severe radiation advisories, and one false GLE alert. The second event is the extreme geomagnetic storm of May 2024, which also featured the exceptionally small GLE 74.

For both events, the temporal and spatial structures of dose rates and single event effect rates are investigated. Furthermore, the behaviour of the MAIRE+ GLE trigger during both events is examined, as well as changes in predicted dose rates during the times of interest. Finally, the Met Office perspective on the challenges of these events and the additional capability provided by MAIRE+ is discussed.

A novel approach to the quantification of magnetic complexity in solar active regions to modernise the Mount Wilson classification scheme in space weather.

Mr Stephen Bannister[1], Dr Shaun Bloomfield[1]
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Poster Session, September 11, 2024, 14:00 - 16:00

Active regions are distinct, separable regions of the Sun where sub-surface magnetic flux has emerged. The level of magnetic complexity within active regions is well-known to influence the frequency of eruption events which occur in their surrounding plasma volume, such as solar flares and coronal mass ejection events. Therefore, the quantification of active region magnetic complexity is an important consideration to more accurately track their flaring and evolution potential from a space weather standpoint. Currently, the most widely used magnetic classification scheme in space weather is the Mount Wilson system, which is purely categorical and therefore insensitive to any detail contained within the broader groups, i.e. two active regions with the same classification can be tremendously different in both magnetic complexity and eruption frequency. We present a new method to quantify the magnetic complexity of active regions by introducing our Polarity Inversion Measure (PIM), built on top of an automatic feature detection algorithm, to examine their complexity as a continuous quantity. We then compare the evolution of PIM to the evolution of Mount Wilson classifications using data from over 1,000 active regions within the last decade to demonstrate the utility of using a quantified complexity measure over a human-assigned daily label.

Quantum Magnetometry for Space Weather Monitoring

Dr Ciaran Beggan[1], Dr Stuart Ingleby[2], Dr Mark Bason[3], Dr Dominic Hunter[2], Dr Mike Salter[3], Mr Adam Filip[3]
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Poster Session, September 11, 2024, 14:00 - 16:00

Variations of the magnetic field driven space weather events impacts the surface, and creates hazards to grounded technology e.g. via geomagnetically induced currents.
Innovations in magnetic field monitoring can help improve present-day measurement capabilities for both Earth’s core field and space weather monitoring. Specifically, optically-pumped magnetometers (OPMs), are the most sensitive and accurate magnetic sensors available for full field conditions. Quantum magnetic sensing offers several advantages over the classic combination of triaxial fluxgates and proton precession magnetometers. Recent advances have enabled single sensors to measure full field, high frequency, temperature insensitive measurements of the natural field. The low noise, high bandwidth OPMs can be used to detect variations in the Earth's natural magnetic field arising from space weather activity.

Here, we report on the progress of a three-year programme to build and deploy five ground-based OPMs and work towards deploying such OPMs in low-Earth orbit. As part of this work, we are developing high-frequency vectorised scalar magnetometers (University of Strathclyde) combined with custom electronics (RAL Space). The BGS-run geomagnetic observatory at Eskdalemuir (Dumfries & Galloway, Scotland) will allow the OPM systems to be compared and calibrated against the highest scientific standards for observatories (INTERMAGNET). The sensors will then be deployed to five field locations around Britain to reduce the spacing between operational observatories and variometers in the UK to less than 200 km. This will provide one of the densest magnetic networks in the world, meeting the World Meteorological Office (WMO) breakthrough goal for space weather monitoring.

Radio Investigations for Space Environment Research (RISER): Year 1 Progress

Dr Mario Bisi[1], Dr Biagio Forte[2], Prof. Steve Milan[3], Prof. David Jackson[4], Dr Richard Fallows[1], Dr Bernard Jackson[5], Dr Dusan Odstrcil[6,7], Dr Edmund Henley[4], Dr David Barnes[1], Dr Oyuki Chang[1], Mr Matthew Bracamontes[2], Dr Siegfried Gonzi[4], Dr Paul Kinsler[2]
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Poster Session, September 11, 2024, 14:00 - 16:00

The NERC-funded Radio Investigations for Space Environment Research (RISER) project addresses the chain of events through which the Sun creates adverse space-weather conditions at Earth and within the Earth's space environment. RISER aims to investigate how the LOw Frequency ARray (LOFAR) can be utilised for continuous and accurate tracking of inner-heliospheric and ionospheric plasma structures, combined with magnetospheric modelling, leading to more-precise and advanced forecasts of space-weather conditions and their impacts at Earth. RISER will provide a comprehensive understanding of the Earth's space-environment through the use of novel radio observations and modelling techniques to investigate coupling between solar-driven inner-heliospheric structures and the Earth.

RISER brings together a unique set of different radio techniques along with various types of modelling and other data sets. It is a five-year project, which commenced on 01 September 2023 with partners in the UK and the USA. RISER will facilitate the upgrading of the LOFAR-UK Rawlings Array at Chilbolton to the new dual-beam, LOFAR For Space Weather (LOFAR4SW) capability, providing the potential for 24/7 space-weather observations towards the end of the five-year project.

Here, we give a reminder of the RISER project and its high-level objectives including the importance and relevance to advancing our understanding of space-weather science and impacts. We will report on progress to date throughout the first year of the project with an outlook on the next steps.

Investigating the variability of chorus waves in the radiation belts for improved understanding of nonlinear interactions

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Poster Session, September 11, 2024, 14:00 - 16:00

Earth's radiation belts can be described by two zones containing energetic charged particles; a more stable inner belt, and a highly dynamic outer belt. The electron dynamics within the outer belt occur over many different time and length scales, governed by several processes including wave-particle interactions. This variability means that it is difficult to create a model capable of real-time prediction.

The most common method used by the international community for reproducing radiation belt dynamics involves Fokker-Planck diffusion models. Whilst, in many cases, these models effectively describe the global changes and interactions within the region, the Fokker-Planck approach depends upon a quasilinear theory. This assumes "small" amplitude and incoherent waves; however, recent spacecraft observations have shown that this assumption may not always hold. Accounting for this type of wave would require an extension of the modelling to include nonlinear effects.

In this work, we utilise two datasets of wave measurements from the Van Allen Probe satellites with differing resolutions to allow closer inspection of the larger amplitude waves, and their potential implications for energetic electron dynamics in radiation belt modelling. Particularly, the work investigates how the underlying variability of the waves may alter our interpretations of their properties.

The M-MATISSE mission: understanding magnetosphere-ionosphere-thermosphere coupling at Mars

Daniel Verscharen[1], Beatriz Sánchez-Cano[2], Francois Leblanc[3], **Gemma Bower**[2]
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Poster Session, September 11, 2024, 14:00 - 16:00

The "Mars Magnetosphere ATmosphere Ionosphere and Space-weather SciencE (M-MATISSE)" mission is a medium class (M7) candidate currently in Phase A study by the European Space Agency (ESA). M-MATISSE's main scientific goal is to unravel the complex and dynamic couplings of the Martian magnetosphere, ionosphere, and thermosphere (M-I-T) coupling. The M-I-T coupling controls the dissipation of incoming energy from the solar wind, and therefore, the evolution of Mars' atmosphere and climate (including atmospheric escape, auroral processes, and incoming radiation). Moreover, understanding the behaviour of Mars' M-I-T system and of the chain of processes that control space weather and space climate at Mars, as well as the radiation environment, is essential for robotic and human exploration as it leads to accurate space weather forecasts and, thus, motivates the development of mitigation strategies for its impacts.

M-MATISSE consists of two orbiters with focused, tailored, and high-heritage payloads to observe the plasma environment from the surface to space through coordinated simultaneous observations. It will utilise a unique multi-vantage point observational perspective combining in-situ measurements by both orbiters and remote observations of the lower atmosphere and ionosphere by radio crosstalk between the spacecraft.

We will discuss the science potential of M-MATISSE and present the current status of the mission development.

The ring current during geomagnetic disturbances

Gemma Bower[1], Steve Milan[1], Suzie Imber[1], Audrey Schillings[1,2], Amy Fleetham[1], Jesper Gjerloev[3]
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Poster Session, September 11, 2024, 14:00 - 16:00

Geomagnetic disturbances (GMDs) are rapid changes in the magnetic field of the Earth leading to geomagnetically induced currents (GICs) that can impact infrastructure. Recent studies have shown that there are two main populations of GMDs, one in the pre-midnight sector and one in the dawn sector. The pre-midnight GMDs have been related to the substorm current wedge. The dawn population of GMDs has previously been found to occur during multiple intensification events, which are related to rapid changes in the AL index with little change in the size of the polar cap. Currently multiple intensification events have only been identified for 2010. We adapt the SOPHIE substorm algorithm to identify more instances of multiple intensifications. Recent models suggest that the formation of a 'dawnside current wedge' (DCW) during the main phase of geomagnetic storms could lead to dawn sector GMDs. We investigate the GMD at all latitudes in relationship to local time measurements of the magnetic field at low latitudes using the SuperMAG SMR local time indices (SMR-LT). During multiple intensification events the dawn sector magnetic field (SMR06) is typically higher than the dusk sector (SMR18), which is indicative of a DCW. Statistical analysis of the SMR-LT values during the dawn and pre-midnight GMD shows that the dawn GMD occur when the SMR06-SMR18 is largest and thus when a DCW is present.

New methods for spatio-temporally distributed multipoint space weather data in the transition to a data-rich era

Professor Sandra Chapman[1], Dr Lauren Orr[2], Dr Jesper Gjerloev[3], Prof Weisi Guo[4], Dr Matt Friel[3], Mr Artur Benedito-Nunes[1], Ms Jekaterina Gamper[1], Dr Ciaran Beggan[2]
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Poster Session, September 11, 2024, 14:00 - 16:00

We are moving into a data-rich era with multiple heterogeneous satellite and ground based observations. Spatially irregular observations such as earth surface magnetic field perturbations in the auroral region, currents induced in power grids can be tested for spatio-temporal patterns of correlation by extracting correlated extremes (values above a threshold) and by using dynamical networks. Whilst networks are in widespread use in the data analytics of societal and commercial data, there are additional challenges in their application to physical time-series [1]. Once the network is constructed, network parameters can be used to discriminate competing physical theories of the system dynamics [2] and to quantify the response of power grids to extreme space weather [3]. Detailed spatio-temporal pattern can be captured with a few parameters [4] so that many events can be compared with each other and with models for the system evolution. Statistical significance is quantified using random phase surrogates, and data quality can also be explored using the Newcomb-Benford law [5]. These specific applications will be used to demonstrate generic methodology for space weather relevant data, and common approaches to characterization and visualization with other fields such as earth climate.

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Kp Forecasting: The Good, the Bad and the Ugly

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Poster Session, September 11, 2024, 14:00 - 16:00

Accurate forecasting of the Kp index, a measure of geomagnetic activity, is crucial for managing the impacts of space weather on various technological systems and running space weather forecast models. This presentation analyses our current capability to forecast Kp, highlighting its importance and evaluating different models' performance. We compare operational Kp forecasting skills from the US Space Weather Prediction Center (SWPC) and the UK Met Office Space Weather Operations Centre (MOSWOC), alongside other non-operational data-driven models.

The Kp index is vital for applications such as ionosphere and thermosphere modelling, satellite orbit determination, aurora location, and issuing ICAO auroral absorption alerts. Despite its significance, forecasting Kp is challenging due to the complex interactions between the solar wind and Earth's magnetosphere, requiring high-quality, real-time data and sophisticated modelling techniques.

Our analysis covers both 3-hourly Kp forecast values and probabilistic daily maximum values, assessing forecast performance up to 7 days in advance. This evaluation identifies strengths and weaknesses in current methodologies, providing insights into areas for improvement.

We also introduce a new, simplistic, statistics-only model for Kp forecasting. Based on probability distributions, this model shows significant skill and offers a reliable alternative to complex data-driven approaches. By sampling from fitted distributions, it provides uncertainty estimates and demonstrates significant improvement over traditional methods, particularly for 24-hour forecasts.

This presentation aims to enhance understanding of Kp forecasting capabilities, promoting the development of more accurate and reliable models. Improved Kp forecasts will better prepare us for geomagnetic storms, safeguarding critical infrastructure and technological systems.

10-years of the Space Environment and Radio Engineering (SERENE) Research Group

Sean Elvidge[1], Matthew Angling[2], Paul Cannon[1]
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Poster Session, September 11, 2024, 14:00 - 16:00

The Space Environment and Radio Engineering (SERENE) research group at the University of Birmingham is celebrating a decade of contributions to space weather research and its applications. Since its inception, SERENE has focused on understanding and mitigating the effects of space weather on crucial technologies, including GPS, HF radar, and satellite orbits. This poster highlights key achievements and ongoing projects that underscore SERENE's impact on both scientific advancement and societal resilience.

A central accomplishment of SERENE is the development of advanced data assimilation models including: the Advanced Ensemble Networked Assimilation System (AENeAS), the Assimilation Canadian High Arctic Ionospheric Model (A-CHAIM) and the Advanced Ionospheric Data Assimilation (AIDA) model. These models use sophisticated data assimilation techniques to provide real-time space weather nowcasts and forecasts. These forecasts are vital for informing policy decisions and protecting infrastructure against space weather disruptions.

SERENE's multidisciplinary approach also includes the development of new engineering systems which leverage the advancements in ionospheric modelling. A particular highlight is the development of a novel “Networked Over-the-Horizon Radar” system, which is both relocatable and mobile with an ability to detect and track low velocity targets against clutter as well as staring at multiple targets.

As SERENE continues to push the boundaries of space weather research, its work remains crucial in safeguarding modern technological systems and advancing our understanding of the near-Earth space environment. This poster will celebrate these achievements and outline future directions for the group, highlighting its role in both scientific discovery and practical application.

The Electrodynamics of Fine Scale Aurora and Associated Joule Heating

Patrik Krcelic[1], Robert Fear[1], Daniel Whiter[1], Betty Lanchester[1]
[1]University Of Southampton, United Kingdom

Poster Session, September 11, 2024, 14:00 - 16:00

Fine-scale auroral arcs are characterized by highly variable electric fields leading to extreme Joule heating. We used the Auroral Structure and Kinetics (ASK) instrument, located on Svalbard, to measure various electrodynamic properties of fine scale auroral arcs. We found two significant correlations. The first is between the mean precipitation flux of event and the variability of flux, which we assume is because of the dynamic and bursty nature of the acceleration mechanism and its dependence on Alfvén waves. The second is between the variability of the precipitating electron flux and the variability of the tangential component of the electric field close to the arc and perpendicular to the magnetic field. We propose that both variabilities occur because of the variability of the upward (field-aligned) current sheet in and around the arc, which is dynamic and non-uniform. The correlation between the two variabilities can therefore be explained by their common source.

Additionally, we estimated the Joule heating caused by such variability by analysing two case studies. In both cases the Joule heating appeared in burst-like form with median distribution values of few hundreds mW/m2, with the lower 10% of the distribution having values close to or around 100 mW/m2. Extreme increases in the neutral temperature were also observed in both cases. Our results suggest that the averaging of intense and variable electric fields near fine-scale auroral features may be responsible for underestimates of the Joule heating.

Assessing the difference between several different methods of calculating dB/dt and the implications of these differences in using dB/dt as a proxy for estimating geomagnetically induced currents

Samuel Fielding[1]
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Poster Session, September 11, 2024, 14:00 - 16:00

With the importance of measuring geomagnetically induced currents (GICs), it is crucial to be able to predict the possible impacts of geomagnetic activity at different geomagnetic observatories, where we have a consistent and large dataset of relevant values to analyse. Often, the rate of change of the magnetic field in the horizontal direction dB/dt is used as a proxy for GICs. In thismstudy, we look at two different methods for calculating dB/dt, and show thatmthere is a significant difference in the methods, especially close to the agonic line and during quiet times. We conclude by suggesting the preferred method for calculating dB/dt when it is being used as a proxy for GICs.

RISER: a case study of applying AULs to benchmark progress in transitioning research to operations

Edmund Henley[1], David Jackson[1], Siegfried Gonzi[1], Mario Bisi[2], Biagio Forte[3], Steve Milan[4], Dusan Odstrcil[5], Bernie Jackson[6]
[1]Met Office, United Kingdom, [2]Rutherford Appleton Laboratory, United Kingdom, [3]University of Bath, United Kingdom, [4]University of Leicester, United Kingdom, [5]George Mason University, United States, [6]University of California San Diego, United States

Poster Session, September 11, 2024, 14:00 - 16:00

The Radio Investigations for Space Environment Research (RISER) project, funded by NERC, is applying observations made by the LOw Frequency Array (LOFAR, the world's largest low-frequency radio telescope) to space weather: by observing radio waves from astronomical sources, and the scintillation in these waves as they travel through plasma structures in the solar wind, it becomes possible to remotely-sense the 3D structure of the solar wind, and provide advance warning of the arrival time and likely impact of Earth-directed features.

RISER comprises an ambitious mix of cutting-edge fundamental research, as well as more established space weather modelling systems. The overall aim is to integrate advances in all areas, to better understand and predict the chain of events through which the Sun creates adverse space weather conditions at Earth.

When considering research-to-operations (R2O) efforts like RISER, operational agencies need to understand whether the new techniques or software are sufficiently robust, well-characterised, and reliable for operational use. This is particularly challenging for multi-component systems such as RISER, with individual components at different levels of maturity.

In this presentation, we outline an effort to apply the Halford et al (2019) Application Usability Level framework to evaluate the RISER components, at the start and end of RISER. This will give a very useful benchmarking of maturity for RISER's operational partners, and should also benefit RISER's research partners, by giving a valuable measure of research impact, helpful to demonstrate in evaluations such as the UK's Research Evaluation Framework (REF).

Local Products from Global Simulations: Latest Developments in the GorgonOps Forecasting Suite

Dr Adrian LaMoury[1], Dr Mike Heyns[1], Jason Ran[1], Adriana Bercebal Ruiz[1], Professor Jonathan Eastwood[1]
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Poster Session, September 11, 2024, 14:00 - 16:00

In order to most effectively safeguard society and infrastructure from hazardous space weather, mitigation strategies must be informed by actionable forecasts that are tailored to end users. While global indices are pertinent to characterising the overall significance of a space weather event, it is region-specific forecasting that allows industry stakeholders to make critical decisions with the greatest degree of confidence. GorgonOps is an operational magnetohydrodynamic (MHD) global magnetosphere model accompanied by a suite of bespoke analysis tools. Taking measured or modelled solar wind conditions, the physics-based model creates space weather forecasting products in faster than real time. This operational pipeline has seen numerous recent deployments, including at the Met Office and ESA Space Weather Service Network. Here, we highlight the need for regional forecasting and demonstrate the latest product developments in the GorgonOps suite, which include novel estimations of simulation-based geomagnetic indices. We contrast global and regional responses, specifically in Kp, AE, and Joule heating. The implementation of these products allows us to deliver actionable forecasts for the UK and European sectors that are relevant and interpretable to end users, including in the energy and satellite industries.

AniMAIRE - An Anisotropic Model for the Atmospheric Ionization Radiation Effects

Dr Fan Lei[1], Dr Fraser Baird[1], Dr Chris Davis[1], Dr Ben Clewer[1], Prof Clive Dyer[1], Prof Keith Ryden[1]
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Poster Session, September 11, 2024, 14:00 - 16:00

The atmospheric ionization radiation field is the result of the continuous cosmic ray bombardment, and it is dominated by the secondary particles generated in the cascades of interactions of these energetic particles with the atmosphere. Most models of the atmospheric radiation environment assume the cosmic rays are isotropic, and while this is largely true in the case of galactic cosmic rays, the solar energetic particles are not, particularly in the early phase of a solar particle event.

AniMAIRE is a new model based on the physics behind its precursor model MAIRE+, which we developed for the UK Met Office, but with the additional feature that it can simulate the radiation effects during anisotropic conditions. The model is available on Github and open to members of the community who wish to make their own contributions and improvements to the model.

In this presentation, we will discuss the physics and algorithm the model based on, its design and implementation, and demonstrate its applications to galactic cosmic ray conditions and during ground level enhancement events.

Multi-thermal Analysis of Slow Magnetoacoustic Waves and Thermal Limit Cycles in a Coronal Bright Point

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Poster Session, September 11, 2024, 14:00 - 16:00

Coronal bright points (BPs) are ubiquitous small-scale point-like structures on the solar surface observed by extreme ultraviolet (EUV) and X-ray wavelengths. We present a method to analyse characteristics of oscillations in EUV emissions observed by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) that are potentially due to different mechanisms. Our analysis method includes spatial morphological segmentation and running FFT techniques. For 35 regions of interest within a BP, the mean intensity of 171Å and 193Å EUV emissions are used to estimate the temperature and electron number density of the coronal plasma as a function of time, which exhibit oscillatory behaviour. We detect and analyse 801 oscillation events with periods ranging from 3 to 240 minutes. We observe spatial coherence across regions. We study the phase differences between the two AIA light curves and between temperature and density. Based on phase relations, we find that oscillations with periods less and greater than 6 minutes are likely associated with slow magnetoacoustic waves and thermal limit cycles, respectively. The simultaneity of oscillations over the range of periods suggests the coexistence of the two types of oscillatory processes in BPs.

Towards Near-Real-Time Active Region Classification with ARCAFF

Paul Wright[1], Shane Maloney[1], **Sophie Murray**[1], Peter Gallagher[1], Anna Massone[2], Michele Piana[2], Valentina Candiani[2], Sabrina Guastavino[2], Edoardo Legnaro[2], Tamas Kiss[3], Gabor Terstyanszky[3], Dimitris Kagialis[3], Robert Lovas[4], Attila Farkas[4]
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Poster Session, September 11, 2024, 14:00 - 16:00

The Active Region Classification and Flare Forecasting (ARCAFF) project aims to deliver cutting-edge solar flare predictions via SolarMonitor.org, a familiar and user-friendly interface. Leveraging rich solar flare and active region classification datasets from NOAA SWPC and the Met Office, a key objective of ARCAFF is to generate near-real-time active region detection and classifications using full-disk magnetograms. These automated classifications will complement our curated flare lists to (1) feed existing statistical models based on the flaring rates of individual active region classes and (2) be the basis of end-to-end deep learning flare forecasting pipelines.

We will discuss how these hand-labelled datasets have been curated and evaluated and the methodologies used to develop explainable deep learning models for active region classification. Additionally, we will explore the transition from research to operations, emphasising the role of manual classifications provided by NOAA SWPC and the Met Office in benchmarking and validating the performance of these models in operational settings. This continual monitoring–enabled by expert forecasters–is crucial in ensuring the accuracy and reliability of active region classification and space weather prediction facilitated by ARCAFF.

Investigation of atmospheric drag effect on the trajectory of cataloged LEO objects and its implication for the safety of active satellites in the 25th solar cycle

Dr Victor U. J. Nwankwo, Dr Jens Berdermann, Dr Frank Heymann, Dr Naveen Timothy Kodikara, Dr Isabel Fernandez-Gomez
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SDA/SSA/SST Panel, September 10, 2024, 11:30 - 13:00

In the recent years we have witnessed unprecedented increase in both active and expired space missions (debris) – a scenario, if continued, can lead to generation of additional debris through possible 'satellite-satellite' collision, 'satellite-debris' collision and/or 'debris-debris' collision (Kessler effect), especially in the heavily used low Earth orbit (LEO). Consequently, the possibility of a risk-free utilization and sustainable use of the near-earth space environment is significantly threatened due to the risks to both manned (e.g., the ISS) and unmanned active spacecrafts in this region of space. Space weather-enhanced atmospheric drag (and consequent increase in the rate of orbit decay) makes the risk even more worrisome. In this work, we investigate atmospheric drag effect on the trajectory of some cataloged LEO objects (debris) during the 25th solar cycle and perform collision risk analysis for the active satellites (e.g., the ISS) operating in debris field around h≈450 km. We present relevant results and observations from this effort that are beneficial for orbit sustainability in LEO.

Multi-Step X-Class Solar Flare Forecasting: A Global and Multiple Channel Recurrent Neural Network Learning Approach

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Poster Session, September 11, 2024, 14:00 - 16:00

It is important yet challenging to construct an X-class flare forecast model, especially when the specific physics of flare initiation are still not fully understood. Previous attempts using deep learning has failed to take into consideration solar flare dynamics, current instrumental capability and extensive observational data sequences now available. The approach adopted here employs a Bidirectional Gated Recurrent Network to learn the global features from NASA's Solar Dynamics Observatory Atmospheric Imaging Assembly (SDO AIA) multi-channel (171, 193, 211, and 335 Angstroms) EUV active region images containing examples of X-class flares. Flare and no-flare characterisations are defined AIA observations over a 13-year period, employing a temporal sequence of multi-step images across the aforementioned channels. Training data class imbalance between X-flare and no X-flare classes is adaptively minimised based on the statistics up to the peak of the flare emission. It is found that forecasting of future X-class events can be improved by sampling global max features from each channel. In particular, the model was tested by extending the forecasting period, with each employing a time resolution of 12 seconds per active region image. A forecast period of approximately 48s is employed across >2700 randomly sampled test observations which results in a performance accuracy of 96.67%, a 97.93% True Positive Rate (TPR), a 95.44% True Negative Rate (TNR), and a 0.93 True Skill Statistics (TSS). Increasing the forecasting period to 8, 16 and 32 minutes shows a limited decrease but promising level of performance (TSS being 0.88, 0.84, 0.74 accordingly).

Investigation of an Exceptionally Long Forbush Decrease-Like Dip in AMS02 proton observations: From the Sun to the Heliosphere

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Poster Session, September 11, 2024, 14:00 - 16:00

The unexpectedly large and long-term decrease (depression) in the cosmic ray flux observed by the Alpha Magnetic Spectrometer (AMS02) at 1 AU in the second half of 2017 is investigated. Galactic cosmic ray observations, both those averaged over Bartel rotations and the daily-resolution observations measured by the AMS02, are utilized along with solar wind plasma and magnetic field measurements, HMI magnetograms and AIA images to explore the cause and to investigate the impacts of this large depression. The early onset of CMEs (as an expected cause of this depression) is investigated with the ARTop code, and a 3D numerical modulation model based on the numerical solution of Parker's transport equation is utilized to simulate AMS02 observations for different cosmic ray species, allowing for a comparison with observations. Based on these results and findings, the causes of this depression and its consequences over a wide range of rigidity and dependence on particle charge are discussed.

Storms are important, but so is climatology: An exploration of high latitude ionospheric model performance in climate and user contexts

Dr David Themens[1,2], Dr Matthew Brown[1], Prof Sean Elvidge[1], Dr Benjamin Reid[1,2], Prof P.Thayyil Jayachandran[2]
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Poster Session, September 11, 2024, 14:00 - 16:00

Ionospheric models are used in a wide range of contexts and in applications that sometimes put disparate requirements on model capabilities. Model validation has historically focused on performance during extreme events and disturbed conditions with limited comprehensive assessment across timescales and varying ionospheric conditions. What large scale validations that do exist focus on parameters, like Total Electron Content (TEC), that provide little diagnostic or user application value; as such, we lack a comprehensive picture of the strengths and deficiencies of our models both in scientific and in user-specific contexts. In this presentation, we will explore methods of assessing models across timescales spanning minutes to several solar cycles using metrics that provide both diagnostic value and directly inform user contexts, such as Over-The-Horizon Radar and Global Navigation Satellite System (GNSS) Position, Navigation, and Timing (PNT) applications. To this end, 80+ years of ionospheric observations from within the polar cap will be used to understand the long-term behaviour of physics-based ionospheric models, while Super Dual Auroral Radar Network (SuperDARN) and ground-based GNSS observations will be used to quantify the performance of these models in OTHR coordinate registration and GNSS Precise Point Positioning (PPP) applications.

Chorus Waves and Their Effect on Energetic Electrons in the Inner-magnetosphere

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Poster Session, September 11, 2024, 14:00 - 16:00

Chorus waves play an important role in the dynamic evolution of energetic electrons. To quantify the effect of chorus waves, we developed analytical models for them using more than 5 years of Van Allen Probe data. These models depended on L, MLT, magnetic latitude and geomagnetic condition. However, due to the limitation of the Van Allen Probes orbit, these models are confined to magnetic latitude 20. Previous studies suggested that chorus waves at higher latitudes are capable of producing very fast losses of the relativistic electrons on the scale of one day. Referring to observations from Cluster satellites, we extend our chorus wave models to higher latitudes. By performing long-term simulations using the three-dimensional Versatile Electron Radiation Belt code, we find that the variability of chorus waves at high latitudes is critical for modelling of MeV electrons. We show that, decrease in high-latitude chorus waves can tip the balance between acceleration and loss towards acceleration, or alternatively, the increase in high-latitude waves can result in a net loss of MeV electrons. Variations in high-latitude chorus may account for some of the variability of MeV electrons. Based on these knowledge, we perform long-term simulations for the Van Allen Probe era and systematically validate our simulation results against Van Allen Probe observations. We also calculate and parameterise the lifetime of the electrons with an energy range from 1 keV to 2 MeV. By performing simulations, we show the importance of
including realistic plasma density model to quantify the effect of chorus waves.

When is a 1/f spectrum not a Power Spectrum ? Revisiting Mandelbrot's 1967 Switching Model

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Poster Session, September 11, 2024, 14:00 - 16:00

A key assumption behind widespread use of Fourier and wavelet power spectra in space weather (and throughout STP) is the "ergodic" one. This is the assumption that an operation (like FFT) performed on only one measured time series can nonetheless estimate a property (like the power spectrum) that is only defined for an ensemble. In a still neglected 1967 paper, however, Mandelbrot dealt with systems where this assumption is broken, as may sometimes happen in solar wind, and certainly happens in physical systems like the blinking quantum dots which were very recently the subject of the Nobel Prize for Chemistry. I will argue that Mandelbrot's "old" work is both timeless and timely for many STP problems for which power spectra have been an important diagnostic, and will illustrate this contention using solar wind "switchbacks".

See also Watkins (2019). Mandelbrot's stochastic time series models. Earth and Space Science. 6(11), 2044-2056. DOI:10.1029/2019EA000598 and Watkins (2017). On the Continuing relevance of Mandelbrot's non-ergodic fractional renewal models of 1963 to 1967. The European Physical Journal B. 90(12), 241. DOI:10.1140/epjb/e2017-80357-3.

A novel technique to predict magnetic flux emergence on the Sun

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Poster Session, September 11, 2024, 14:00 - 16:00

Helioseismology allows us to probe the turbulent and dynamic solar interior, utilising Doppler velocity measurements to determine the properties of pressure waves (p-modes) and surface gravity waves (f-modes). The potential of the f-modes to predict magnetic flux emergence has only very recently been recognized with recent reports of the f-mode to be enhanced 1-2 days prior to the appearance of concentrated magnetic fields which in turn form active regions. The f-mode was then observed to be continuously quenched once the flux was fully emerged. However the technique relied on various normalisations that introduce bias to the f-mode computation (e.g., using a selected 'quiet' patch). Here, we eliminate such biases using a data-driven flat-fielding technique at the selected location. This is more sensitive to fluctuations and obtains the f-mode power at any location on the solar disk and is independent of any normalisation from 'quiet' regions, making it more robust and accurate than current techniques. Here, we demonstrate that our novel technique reproduces f-mode behaviour observed from previous studies, with the addition of error bars and additional science information (e.g., geometry). We note that the chosen time of emergence is a key factor in determining the context of f-mode behaviour. Finally, we present a catalogue and associated statistics demonstrating the potential usefulness of this novel technique for space weather forecasting, predicting solar flux emergences leading to formation of active regions.

Did space weather delay the 10:05pm train departure from Exeter on 18 October 1841?

Prof Jim Wild[1], Dr Ciarán Beggan[2], Prof David Boteler[3], Dr William Cade[4], Dr Brett Carter[5], Dr Mike Hapgood[6]
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Poster Session, September 11, 2024, 14:00 - 16:00

Although the Carrington Event of 1859 is typically cited as the first extreme space weather event of the scientific era, it is not the earliest example of modern human technology being impacted by geomagnetic activity. The literature includes reliable accounts of disturbances to telegraph equipment during geomagnetic storms dating to the late 1840s, but the rediscovery by Cade III (Space Weather, 2013) of a report published in the journal Nature (1871) suggests that the first recorded space weather impact may have occurred in 1841. The Nature article reports interference in the telegraph system of the South Devon Railway Company on 18 October 1841 due to a “very intense magnetic disturbance” which caused the departure of the 10:05pm express train from Exeter to Newton Abbot to be delayed by 16 minutes. However, our research reveals that the railway line from Exeter to Newton Abbot was not opened until 1846, so the timing of the events reported in Nature (some 30 years after the event) cannot be correct. In this study, we present the results of an investigation into contemporary records and geomagnetic observations that suggest the misreported 1841 event occurred several years later, on 18 October 1848. It therefore still represents one of the earliest recorded examples of space weather impacting technical infrastructure.

Poster Presentations

Poster No.	First Name	Last Name	Organisation	Poster Title
1	Oliver	Allanson	University of Birmingham; University of Exeter	The challenge to understand the zoo of particle transport regimes during resonant wave-particle interactions for given survey-mode wave spectra
2	Fraser	Baird	University of Surrey	Repurposing Hydrological Neutron Detectors to Observe Ground Level Enhancements
3	Fraser	Baird	University of Surrey	Aviation Doses During Recent Space Weather Events: Results from the MAIRE+ Model
4	Stephen	Bannister	Northumbria University	A novel approach to the quantification of magnetic complexity in solar active regions to modernise the Mount Wilson classification scheme in space weather
5	Ciaran	Beggan	British Geological Survey	Quantum Magnetometry for Space Weather Monitoring
6	Mario	Bisi	United Kingdom Research And Innovation - Science and Technology Facilities Council	Radio Investigations for Space Environment Research (RISER): Year 1 Progress
7	Rachel	Black	University of Exeter/British Antarctic Survey	Investigating the variability of chorus waves in the radiation belts for improved understanding of nonlinear interactions
8	Gemma	Bower	University of Leicester	The ring current during geomagnetic disturbances
9	Gemma	Bower	University of Leicester	The M-MATISSE mission: understanding magnetosphere-ionosphere-thermosphere coupling at Mars
10	Sandra	Chapman	CFSA, University of Warwick	New methods for spatio-temporally distributed multipoint space weather data in the transition to a data-rich era
11	Sean	Elvidge	SERENE, University of Birmingham	10-years of the Space Environment and Radio Engineering (SERENE) Research Group
12	Sean	Elvidge	SERENE, University of Birmingham	Kp Forecasting: The Good, the Bad and the Ugly

13	Robert	Fear	University of Southampton	The Electrodynamics of Fine Scale Aurora and Associated Joule Heating
14	Samuel	Fielding	University of Edinburgh	Assessing the difference between several different methods of calculating dB/dt and the implications of these differences in using dB/dt as a proxy for estimating geomagnetically induced currents
15	Edmund	Henley	Met Office	RISER: a case study of applying AULs to benchmark progress in transitioning research to operations
16	Adrian	LaMoury	Imperial College London	Local Products from Global Simulations: Latest Developments in the GorgonOps Forecasting Suite
17	Fan	Lei	Surrey Space Centre, University of Surrey	AniMAIRE - An Anisotropic Model for the Atmospheric Ionization Radiation Effects
18	Susumu	Matsumoto		Multi-thermal Analysis of Slow Magnetoacoustic Waves and Thermal Limit Cycles in a Coronal Bright Point
19	Sophie	Murray	Dublin Institute For Advanced Studies	Towards Near-Real-Time Active Region Classification with ARCAFF
20	Ndifreke	Nyah		Multi-Step X-Class Solar Flare Forecasting: A Global and Multiple Channel Recurrent Neural Network Learning Approach
21	Muhammed Aslam	Ottupara	School of Mathematics and Statistics, University of Glasgow	Investigation of an Exceptionally Long Forbush Decrease-Like Dip in AMS02 proton observations: From the Sun to the Heliosphere
22	Benjamin	Reid	University of Birmingham	A Real-Time Data Assimilation International Reference Ionosphere
23	David	Themens	University of Birmingham	Storms are important, but so is climatology: An exploration of high latitude ionospheric model performance in climate and user contexts
24	Dedong	Wang	Gfz German Research Centre For Geosciences	Chorus Waves and Their Effect on Energetic Electrons in the Inner-magnetosphere
25	Nicholas	Watkins	Cfsa, University of Warwick	When is a 1/f spectrum not a Power Spectrum ? Revisiting Mandelbrot’s 1967 Switching Model
26	Dale	Weigt	Aalto University	A novel technique to predict magnetic flux emergence on the Sun

27	Jim	Wild	Lancaster University	Did space weather delay the 10:05pm train departure from Exeter on 18 October 1841?

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