SCOSTEP STP-16

Thessaloniki, Greece
1-5 June 2026

6th Quadrennial Solar-Terrestrial Physics Symposium

(STP-16)

1 – 5 June 2026

CONFERENCE PROGRAM AND ABSTRACT BOOK

ORGANISERS

SPONSORS

KAKENHI 21H04518, 22K21345, 26H02086

Edited by

Evangelia Christodoulou

National and Kapodistrian University of Athens

evangchr@phys.uoa.gr

Adamantia Dimitrakoula

National and Kapodistrian University of Athens

addimitr@phys.uoa.gr

Scientific Organizing Committee

Kazuo Shiokawa (Chair)	Institute for Space-Earth Environmental Research (ISEE), Japan
Bernd Funke (Vice-Chair)	Spanish National Research Council, Spain
Lucilla Alfonsi	Scientific Committee on Antarctic Research (SCAR)
Jorge Chau	International Union of Radio Science (URSI)
Odele Coddington	Laboratory for Atmospheric and Space Physics (LASP), USA
Ioannis A. Daglis	National and Kapodistrian University of Athens, Greece
Harriet George	Swedish Institute of Space Physics (IRF), Uppsala, Sweden
Nat Gopalswamy	NASA/GSFC, USA
Yuki Harada	Institute for Space-Earth Environmental Research (ISEE), Japan
Mamoru Ishii	World Data System (WDS)
Sowmya Krishnamurthy	University of Graz, Austria
Natalie Krivova	Max Planck Institute for Solar System Research, Germany
Monica Laurenza	National Institute for Astrophysics (INAF), Italy
Renata Lukianova	International Association of Geomagnetism and Aeronomy (IAGA)
Cristina Mandrini	International Union of Pure and Applied Physics (IUPAP)
Astrid Maute	CIRES, Boulder, USA
Yenca Migoya-Orue	ICTP, Italy
Yoshizumi Miyoshi	COSPAR
Maria Graciela Molina	Tucuman Space Weather Center, Argentina
Rumi Nakamura	Austrian Academy of Sciences, Austria
Valery Nakariakov	International Astronomical Union (IAU)
Nick Pedatella	NCAR, USA
Peter Pilewskie	IAMAS
Anil Raghav	University of Mumbai, India
Laysa Resende	INPE, Brazil
Hannah Schunker	University of Newcastle, UK
Timofei Sukhodolov	World Radiation Center, Switzerland
Yiqun Yu	Beihang University, China

Local Organizing Committee

Ioannis A. Daglis (Chair)	National and Kapodistrian University of Athens, Greece
Vasilis Amiridis	National Observatory of Athens, Greece
Anastasios Anastasiadis	National Observatory of Athens, Greece
Georgios Balasis	National Observatory of Athens, Greece
Evangelia Christodoulou	National and Kapodistrian University of Athens, Greece
Adamantia Dimitrakoula	National and Kapodistrian University of Athens, Greece
Christos Katsavrias	National and Kapodistrian University of Athens, Greece
Konstantinos Kourtidis	Democritus University of Thrace, Greece
Stergios Misios	Academy of Athens, Greece
Spiros Patsourakos	University of Ioannina, Greece
Theodoros Sarris	Democritus University of Thrace, Greece
Nick Sergis	Hellenic Space Center, Athens, Greece
Kleareti Tourpali	Aristotle University of Thessaloniki, Greece

SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

Table of Contents

SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

PROGRAM OVERVIEW

Day 1 - June 1st, 2026

Time	Session	Number	Title of Abstract	Presenter
09:00 – 09:15			Conference Opening	K. Shiokawa & I. A. Daglis
09:15 – 09:30			Presentation of the WMO Professor Mariolopoulos Trust Fund Award 2026	C. Liatsos (MKF) & K. Radics (WMO)
09:30 – 10:15	Session 1	K1	In Search for the Exit from the Heliosphere The Odyssey of Voyagers 1&2, 1977-2026	S. M. Krimigis
10:15 – 10:35	Session 1	O1-1	The SCOSTEP COURSE New Scientific Program for 2026-2030	M. Laurenza
10:35 – 10:50	Session 1	O1-2	Ionospheric Impacts of Bursty Bulk Flow through Conjunctive Observations	G. Harriet
10:50 – 11:20			Coffee Break	
11:20 – 11:40	Session 1	O1-3	Advancing Cross-Scale Understanding of Geospace Through Global Modelling	A. Sciola
11:40 – 11:55	Session 1	O1-4	Multi-Instrument Study of an Intense Auroral Breakup with Space Weather Impacts	A. Spicher
11:55 – 12:15	Session 2	O2-1	Current Understanding of Solar Internal Convection and Magnetic Fields	H. Hotta
12:15 – 12:30	Session 2	O2-2	The Origin of Anti-Hale Regions	K. Petrovay
12:30 – 13:45			Lunch Break	
13:45 – 14:00	Session 2	O2-3	The Current Layer Missing in the Standard Model of Photospheric Flux Cancellation and CME Initiation	B. Kliem
14:00 – 14:15	Session 2	O2-4	Century-Scale Reconstruction of Solar Magnetic Fields from the Photosphere to the Heliosphere	S. Pal
14:15 – 14:30	Session 2	O2-5	Predicting Magnetic Flux and Continuum Intensity During the Emergence of Active Regions Using Machine Learning	S. Kasapis
14:30 – 14:50	Session 2	O2-6	Long-Term Proxies and Reconstructions of Past Solar Activity	T. Chatzistergos
14:50 – 15:05	Session 2	O2-7	Reconstruction of Annual Solar Irradiance Over Nine Millennia	D. Temaj
15:05 – 15:20	Session 2	O2-8	The NASA-NOAA-LASP Solar Irradiance Models: The Observations Key for Development and Validation	O. Coddington
15:20 – 16:00			Coffee Break	
16:00 – 16:15	Session 2	O2-9	Using Modern Observation to Understand Historical Solar Variability	A. K. Yadav
16:15 – 16:30	Session 2	O2-10	Different Occurrence of CME and HSS/SIR Storms During the Modern Maximum: Consequences to Solar Structure and Predictions on Future Space Climate	K. Mursula
16:30 – 16:45	Session 2	O2-11	Interpreting Complex Solar Flare Ribbons in the Context of the Magnetic Skeleton	G. Barnes
16:45 – 17:00	Session 2	O2-12	What Are the Solar Ingredients to Get Extreme Geoeffective Events?	B. Schmieder
17:00 – 17:15	Session 2	O2-13	Radial evolution of periodic density structures observed by Solar Orbiter	C. Katsavrias
17:15 – 17:30	Session 2	O2-14	Impacts of Pre-Existing Magnetic Structures on Solar Energetic Particle Events	Z. Ding
17:30 – 17:45	Session 2	O2-15	Results from REPTile-2 Measurements Onboard CIRBE	X. Li
17:45 – 20:00			Welcome Reception	

Day 2 - June 2nd, 2026

Time	Session	Number	Title of Abstract	Presenter
09:00 – 09:45	Session 1	K2	The ESA Vigil Mission at L5: Enabling Cross-Scale Studies of Sun–Earth Coupling from a New Vantage Point	M. J. West
09:45 – 10:30	Session 2	K3	Space Climate and Space Weather in the Past: What We Know and How	M. Owens
10:30 – 10:55			Coffee Break	
10:55 – 11:15	Session 3	O3-1	Recent Progress and Future Potential on Understanding Magnetosphere-Ionosphere Coupling over the Polar Caps	Q. - H. Zhang
11:15 – 11:30	Session 3	O3-2	Characterizing the High-Latitude Ionospheric Irregularities Dynamics via Spectral Analysis: The May 2024 Geomagnetic Storm Case Study	L. Alfonsi
11:30 – 11:45	Session 3	O3-3	High-latitude ionosphere response to solar wind forcing in TIE-GCM using different plasma convection models during 2012-2013 winter	P. Iochem
11:45 – 12:00	Session 3	O3-4	Effects of Ionospheric Disturbances on GNSS Positioning Errors During the Geomagnetic Storm on May 2024	K. Nakamura
12:00 – 12:15	Session 3	O3-5	Statistical Study of Ionospheric GNSS TEC Response to Pc3–6 ULF Waves	C. Watson
12:15 – 12:30	Session 3	O3-6	Sensing Earth's Plasmasphere and Ionosphere from the Moon: First Observations from the LuGRE Mission	L. Spogli
12:30 – 13:30			Lunch Break	
13:30 – 13:45	Session 3	O3-7	Magnetospheric Drivers of Field-Aligned Currents During Negative Solar Wind Dynamic Pressure Pulse: Quantifying MHD Contributions Using the MAGE Global Model	G. Kakoti
13:45 – 14:05	Session 3	O3-8	The Role of Kinetic Instabilities and Waves in Collisionless Magnetic Reconnection	G. Cozzani
14:05 – 14:20	Session 3	O3-9	Selected Highlights from the Cluster Ion Spectrometry (CIS) Experiment, After 24 Years of Successful Operation	I. Dandouras
14:20 – 14:35	Session 3	O3-10	Equinoctial and Solstitial Averages of Magnetospheric Relativistic Electrons	D. Baker
14:35 – 14:50	Session 3	O3-11	Characterisation of the Newly Formed Proton Belt Following the May 2024 Geospace Magnetic Superstorm	E. Christodoulou
14:50 – 15:05	Session 3	O3-12	Spatial Scales and Cross-Connection of Whistler-Mode Chorus and Hiss Waves in the Earth's Radiation Belts from Multi-Spacecraft Projects Cluster, Van Allen Probes, and THEMIS	O. Agapitov
15:05 – 15:20	Session 3	O3-13	How Can Propagation Speed of Interplanetary Shocks Affect the Radiation Belts Dynamic: A Comparative Observational and Statistical Investigation	D. Zhang
15:20 – 16:00			Coffee Break	
16:00 – 16:15	Session 3	O3-14	Calculation of Radial Diffusion Coefficients Combining Data from RBSP and THEMIS Missions	K. Thanasoula
16:15 – 16:30	Session 3	O3-15	Couplings in the Magnetosphere During the Super Geomagnetic Storm of 10-11 May 2024	V. Pierrard
16:30 – 16:45	Session 3	O3-16	Latest Results on High-Frequency VLF Bursty Emissions from Multi-Point Observations	C. Martinez - Calderon
16:45 – 17:00	Session 3	O3-17	Evidence of Interhemispheric Asymmetry in Swarm Geomagnetic Activity Indices Using Complexity Measures	G. Balasis
17:00 – 17:15	Session 3	O3-18	The Impact of Inductive Electric Fields on Magnetospheric Particle Dynamics	R. Ilie
17:15 – 17:35	Session 3	O3-19	Multi-Scale Irregularities and Solar Wind-Driven Waves in the Martian Ionosphere	C. M. Fowler
17:35 – 17:50	Session 3	O3-20	Coupling Between the Solar Wind and Martian Ionosphere and Its Impact on Space Weather at Mars	Y. Harada
17:50 – 18:05	Session 3	O3-21	Upper Limit on the Electron Flux in Jupiter's Inner Magnetosphere	A. Dovles
18:05 – 18:20	Session 3	O3-22	Cross-Sectional Sizes of Potential Solar Triggers of Near-Sun Magnetic Switchbacks	S. Patsourakos

Time	Session	Number	Title of Abstract	Presenter
18:30 – 20:30			SCOSTEP Bureau Meeting (Closed)	

Day 3 - June 3rd, 2026

Time	Session	Number	Title of Abstract	Presenter
09:00 – 16:00		E1	Excursion	
16:00 – 18:00		P	Poster Session (with Coffee Break)	
18:00 – 19:30			SCOSTEP COURSE Steering Meeting (Closed)	

Day 4 - June 4th, 2026

Time	Session	Number	Title of Abstract	Presenter
09:00 – 09:45	Session 3	K4	Progress and Prospects in Solar Wind–Magnetosphere–Ionosphere Coupling	V. Angelopoulos
09:45 – 10:30	Session 4	K4	Atmospheric Influence of Solar-Terrestrial Coupling: From Satellite Observations to Chemistry-Climate Models	M. Sinnhuber
10:30 – 11:10			Coffee Break	
11:10 – 11:30	Session 4	O4-1	Es as an Indicator for Atmosphere-Ionosphere-Magnetosphere Coupling	H. Liu
11:30 – 11:45	Session 4	O4-2	Atypical Sporadic E Layer (Es) over Equatorial Brazilian Regions During Intense Magnetic Storms.	L. C. A. Resende
11:45 – 12:00	Session 4	O4-3	The Atmospheric Waves Experiment (AWE)	L. Scherliess
12:00 – 12:15	Session 4	O4-4	Concentric Mesoscale Wave Patterns in the Middle and Upper Atmosphere Revealed in High-Resolution GEOS-FP During Hurricane Patricia	G. Liu
12:15 – 12:30	Session 4	O4-5	Multi-Static Volumetric Spectral Imaging of PMSE with MAARSY-3D for Measurements of MLT Dynamics	D. Huyghebaert
12:30 – 13:30			Lunch Break	
13:30 – 13:45	Session 4	O4-6	The Characteristics of Pekeris Modes Revealed by Long-Term Reanalysis Data JAWARA Covering the Entire Middle Atmosphere	K. Sato
13:45 – 14:00	Session 4	O4-7	The Need for In-Situ Measurements at Altitudes Below 200 km to Resolve Ion-Neutral Interactions in the Lower Thermosphere - Ionosphere	T. E. Sarris
14:00 – 14:20	Session 4	O4-8	Long-Term Variability in the Middle and Upper Atmosphere From WACCM-X: Trends in Neutral and Plasma Parameter	L. Qian
14:20 – 14:35	Session 4	O4-9	A Retrospective Study of Climate Response to Solar Variability	W. Huo
14:35 – 14:50	Session 4	O4-10	Solar Irradiance Impacts on Climate in Idealized Time-Slice Simulations	J. Sedlacek
14:50 – 14:05	Session 4	O4-11	Impacts of Stratosphere Polar Vortex Variability on the Ionosphere-Thermosphere	N. M. Pedatella
14:05 – 15:20	Session 4	O4-12	Diagnosing the 11-Year Solar Cycle Influence on the North Atlantic Winter	S. Misios
15:20 – 16:00			Coffee Break	
16:00 – 16:15	Session 4	O4-13	Short-Term Solar Variability Effects on the Earth's Mesosphere/Lower Thermosphere	M. Kunze
16:15 – 16:30	Session 4	O4-14	Common Excitation and/or Amplification Mechanisms of Rossby and Rossby-Gravity Normal Modes Revealed by Long-Term Reanalysis Data for the Whole Middle Atmosphere	H. Sekido
16:30 – 16:45	Session 4	O4-15	The SPARTA Research Center: An Approach to Forecasting Ionospheric Scintillation	K. Groves
16:45 – 17:00	Session 4	O4-16	Investigating the Role of Atmospheric Gravity Waves in Seeding Equatorial Plasma Bubbles via Coordinated Radar Observations	S. K. Das
17:00 – 17:15	Session 4	O4-17	Equatorial spread-F characteristics using HF Doppler shift measurements: results from upgraded Doppler sounder system in Tucuman, Argentina	H. M. Alemu

Time	Session	Number	Title of Abstract	Presenter
17:15 – 17:30	Session 4	O4-18	Dynamics of Total Electron Content in the Ionosphere During Different Phases of Solar Flares	S. Z. Bekker
17:30 – 17:45	Session 4	O4-19	Comparison of MAGE Simulations with EISCAT and SuperDARN Measurements	F. Günzkofer
17:45 – 18:00	Session 4	O4-20	Quiet-Time Electron Density Enhancements at Low- and Mid-Latitudes	R. Vaishnav
18:00 – 18:15	Session 4	O4-21	Solar Wind – Ionosphere – Troposphere Coupling Via the Polar Branch of the Global Electric Circuit	R. Lukianova
18:30 – 20:30			Conference Dinner	

Day 5 - June 5th, 2026

Time	Session	Number	Title of Abstract	Presenter
09:00 – 09:15	Session 6	O6-1	LoLa: A Low-Latitude Meteor Radar Network for Studying MLT Global-Scale Dynamics and Vertical Coupling	J. L. Chau
09:15 – 09:35	Session 6	O6-2	Citizen Science for Auroral Research: Achievements of the ARCTICS Working Group	M. Grandin
09:35 – 09:50	Session 6	O6-3	Observing the Sun and Other Cosmic Radio Sources from the Moon	N. Gopalswamy
09:50 – 10:10	Session 6	O6-4	Ensuring the Long-Term Sustainability of Space Weather and Space Climate Activities in Europe: The Role of E-SWAN	L. Spogli
10:10 – 10:30	Session 6	O6-5	AGATA Scientific Research Programme as a Platform for Collaboration in the Polar Regions	W. J. Miloch
10:30 – 10:05			Coffee Break	
10:05 – 11:25	Session 5	O5-1	Mesospheric Wind Field Reconstruction from Multistatic Meteor Radar Networks: A Diagnostic Perspective	J. M. Urco
11:25 – 11:40	Session 5	O5-2	Physics-Based Modelling of Radial Diffusion in the Outer Van Allen Belt	A. Dimitrakoula
11:40 – 11:55	Session 5	O5-3	Validating the ESPERTA Model for Forecasting Solar Energetic Particles at Off-Earth Locations	N. Chrysaphi
11:55 – 12:10	Session 5	O5-4	Magnetic Climatology from the Optical-B2I	E. Donovan
12:10 – 12:30	Session 5	O5-5	Probabilistic Solar Corona Evolution Forecasting with Denoising Diffusion Models: A Proof-of-Concept for Uncertainty-Aware Predictions	D. Del Moro
12:30 – 12:45	Session 5	O5-6	Towards 2031 Vigil Mission: Algorithmic and Data-Driven Segmentation of Coronograph Data and Dynamic 3D Reconstruction of Coronal Mass Ejections	O. Stepanyuk
12:45 – 13:45			Lunch Break	
13:45 – 14:00	Session 5	O5-7	Review of Machine Learning Models for Solar Energetic Particle Prediction	S. Kasapis
14:00 – 14:15	Session 5	O5-8	Solar Wind Speed Forecasting at 1 AU from Solar Coronal Images and Physics-Informed Time-Dependent Deep Neural Network	V. Delouille
14:15 – 14:35	Session 5	O5-9	Two-Phase Stormtime Response of Ionospheric Electron Temperature Overshoot Uncovered by Neural Networks	A. Smirnov
14:35 – 14:50	Session 5	O5-10	Machine-Learning Reconstruction and Interpretation of the Earth's Inner Magnetospheric Environment	J. Bortnik
14:50 – 15:05	Session 5	O5-11	AI-Driven Approach to Ionospheric Modelling	L. El Zaatari

SESSION 1: Cross-scale coupling processes in Sun-Earth relationship

In Search for the Exit from the Heliosphere The Odyssey of Voyagers 1 & 2, 1977-2026 K1

Stamatios M. Krimigis [1,2]
[1]Johns Hopkins University Applied Physics Laboratory, USA, [2]Academy of Athens, Greece

The two Voyager spacecraft launched in 1977 are, arguably, the most celebrated space science missions of the 20th century. Designed for a four-year mission to perform a comprehensive exploration of Jupiter and Saturn, they not only encountered all four giant planets but also proceeded to cross the Termination Shock (TS) of the solar wind, and discovered the Heliosheath, a region of intense energetic particle radiation about 30 AU wide in 2004 (V1) and 2007 (V2). The two spacecraft subsequently crossed the boundary between the Heliosphere and the Local Interstellar Medium (LISM) named the heliopause (HP) in 2012 (V1) and 2018 (V2) at a distance of ∼121 Astronomical Units (AU). Now on their 49th year in space, they continue to explore uncharted waters as their mission is winding down due to diminished power from the Radioisotope Thermoelectric Generator power source. The instrumentation during this last part of the Voyager Interstellar Mission consists of a Magnetometer, Plasma Wave, Plasma Instrument Science, Low Energy Charged Particles, and Cosmic Ray Science.
Knowledge of the outer heliosphere at the time of launch of Voyager in the late seventies was rudimentary, with model predictions for the border of the heliosphere with LISM ranging from ∼5 AU to perhaps ∼100 AU. The V2 encounter with Neptune at ∼30 AU occurred in 1989, and the general expectation was that the Voyagers, travelling at 3. and 3.6 AU per year would cross the Heliopause soon thereafter. The actual crossing took place some 22 years later at ∼121 AU by V1, followed 6 years later by V2 at about the same distance. The author has been Principal Investigator for the Low Energy Charged Particle instrument since the program's inception in 1972, and will narrate the journey and discoveries of this remarkable mission through the solar system and beyond.

The ESA Vigil Mission at L5: Enabling Cross-Scale Studies of Sun–Earth Coupling from a New Vantage Point K2

Matthew J. West [1], *G. Mandorlo* [1], *M. Dean* [1], *E. De Witte* [1], *M. Palomba* [1], *and J. -P. Luntama* [1]
[1]European Space Agency

The ESA Vigil mission will be the first operational space-weather mission stationed at the Sun–Earth L5 Lagrange point, providing a continuous, off-Sun–Earth-line perspective on solar activity and heliospheric structure. This unique vantage point enables sustained observations of solar source regions, coronal and heliospheric transients, and background solar-wind structures that are critical for understanding cross-scale coupling processes throughout the Sun–Earth system.
Vigil's payload combines remote-sensing and in-situ measurements that together link physical processes across spatial and temporal scales. The Compact Coronagraph (CCOR) and Heliospheric Imager (HI) will track the initiation, evolution, and heliospheric propagation of coronal mass ejections and large-scale solar-wind structures, while the Photospheric Magnetic Imager (PMI) provides photospheric magnetic-field measurements essential for solar-wind and coronal modelling. The EUV Imager (JEDI), contributed by NASA, will observe the full solar disk and extended corona in multiple EUV passbands out to approximately 6 solar radii, capturing the evolution of magnetic and plasma structures that seed heliospheric disturbances. These remote observations are complemented by in-situ measurements from a magnetometer (MAG) and plasma analyser (PLA), enabling direct sampling of the solar wind and interplanetary magnetic field at L5. By combining observations of solar magnetic structure, coronal dynamics, heliospheric evolution, and local plasma conditions, Vigil provides a coherent observational framework for studying how small-scale solar processes cascade into large-scale heliospheric variability and ultimately drive geospace responses. Designed for continuous, low-latency operations as well as high-quality science data products, Vigil bridges operational space-weather monitoring and fundamental research, offering new opportunities to investigate predictability, cross-scale coupling, and system-level Sun–Earth interactions in support of SCOSTEP's forthcoming COURSE program.

The SCOSTEP COURSE New Scientific Program for 2026-2030 O1-1

Monica Laurenza [1], *on behalf of the COURSE Steering Committee*
[1]INAF-IAPS

The upcoming 2026–2030 scientific program of the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP), entitled COURSE (Cross-scale cOUpling pRocesses in the Solar–tErrestrial system), aims to foster comprehensive and interdisciplinary research through coordinated international efforts. The overarching theme of the program is the investigation of cross-scale coupling processes within the Sun–Earth system.
The COURSE program (Laurenza et al., 2025) is structured around three key scientific focus areas: (1) sources of Space Weather and Space Climate; (2) solar wind, magnetosphere, and ionosphere coupling; and (3) external impacts and internal dynamics of the Earth's atmosphere. Each is characterized by specific long-term key questions and objectives to be addressed over a five-year time-frame. The focus areas are closely interconnected through other common themes, including societal impacts, extreme events, human and robotic exploration, and the enhancement of predictive capabilities. In addition, COURSE emphasizes innovative implementation strategies, such as the use of machine learning and artificial intelligence techniques, integrated modelling approaches, new space missions, the combination of multipoint in-situ measurements with ground-based observations, improved metadata standards, and the adoption of the Findable, Accessible, Interoperable, and Reusable (FAIR) data principles.
This talk will provide an overview of the COURSE program and outline the preparatory activities conducted prior to the COURSE Kick-off at the STP-16 meeting.

Ionospheric Impacts of Bursty Bulk Flow through Conjunctive THEMIS, Swarm and Radar Observations **O1-2**

Harriet George [1], A. Dimmock [1], H. Vanhamäki [2], S. Buchert [1], A. Aikio [2], O. Marghitu [3], I. Virtanen [2]
[1]Swedish Institute for Space Physics, Uppsala, Sweden, [2]University of Oulu, Oulu, Finland, [3]Institute for Space Sciences, Bucharest, Romania

The role of mesoscale events in the coupling between the magnetosphere and ionosphere is a key open question in magnetospheric physics, and bursty bulk flows (BBFs) are a key phenomena that must be understood to address this question. BBFs are ejected from magnetic reconnection site(s) in the magnetotail and propagate through the plasma sheet at velocities of 100's km/s. They have cross-tail spatial scales of 1 to a few RE and their duration (when observed by a satellite located within the plasma sheet) is on the order of 10 minutes. BBFs are responsible for the majority of transport of mass and energy from the magnetotail towards the Earth, and case studies have determined that electron precipitation and auroral features are correlated with BBFs. However, it is not yet known how the energy and mass transported by BBFs propagate through the nightside transition region to reach the inner magnetosphere and ionosphere, and the ionospheric impacts of BBFs are currently not well constrained.
In this study, we analyse a case study of a BBF during a rare triple conjunction of magnetospheric, ionospheric and ground-based observations. THEMIS-A and E were located within the plasma sheet and observed a BBF within the magnetotail (THEMIS-D was within the magnetic lobe and THEMIS-B and C were in lunar orbit during this event). The magnetic footpoint of the BBF observation was traced to the ionosphere using four magnetic field models, and this footpoint was located less than 400 km from the Poker Flats radar station (PKR). Furthermore, the Swarm-B spacecraft orbited over the PKR station and BBF footpoint only 9 minutes after the BBF start time, as determined from the THEMIS observations, which is consistent with the approximate propagation time of the field aligned current from the BBF location to the ionosphere. These conjunctive THEMIS, Swarm and PKR observations during this BBF provides us with the opportunity to analyse the ionospheric impacts of this event. The magnetospheric and solar wind conditions were relatively quiet during this event, enabling us to isolate the impacts of the BBF. In this presentation, we will present the results of the analysis of this triple conjunction, supplemented by auroral observations, to study the cross-scale and cross-domain coupling during this event.

Advancing Cross-Scale Understanding of Geospace Through Global Modelling **O1-3**

Anthony Sciola [1], V. Merkin [1], K. Sorathia [1], M. Atkinson [1], J. Garretson [1], K. Pham [2], M. Wiltberger [2], D. Lin [3], and S. Bao [4]
[1]Johns Hopkins Applied Physics Laboratory, [2]National Center for Atmospheric Research, [3]Clemson University, [4]Rice University

Geospace is a complex system of systems coupled across multiple domains, particle populations, and scales. Recent years have highlighted the impacts that mesoscale processes (on the order of a few Earth radii in the magnetosphere) have on the evolution of the global system. Of particular importance to stormtime geospace is the multiscale build-up of the ring current, and how mesoscale structuring of the ring current impacts larger-scale current closure and transport mass, energy, and magnetic flux. However, due to the cross-scale nature of these interactions, it is challenging to understand and quantify the impact of these processes through observations alone. Computational modelling, constrained by heterogenous datasets, provides a means of relating these observations to the magnetospheric processes at play and quantifying their relative role in the evolution of stormtime geospace.
We present insights into the impact of cross-scale geospace dynamics obtained by recent advancements of the Multiscale Atmosphere-Geospace Environment (MAGE) global geospace model. We highlight across multiple studies how mesoscale inner magnetosphere dynamics are commonly a direct or indirect result of mesoscale plasma sheet flows that penetrate into the inner magnetosphere, the details of which are also influenced by the state of the ring current. By calculating synthetic aurora from the model, we relate these phenomena to commonly-observed auroral forms including omega bands, giant undulations, and stable auroral red arcs. We conclude with a discussion of future developments in modelling and data-model fusion that will enhance our capability to understand the complexities of the geospace environment.

Multi-instrument Study of an Intense Auroral Breakup with Space Weather Impacts **O1-4**

Andres Spicher [1], Y. Ogawa [2], Y. Miyoshi [3], B. Gusstavsson [1], T. Hori [3], K. S. Jacobsen [4], Y. Jin [5], M. G. Johnsen [6], S. Kasahara [7], Y. Kasahara [8], K. Keika [7], A. Kero [9], S. Matsuda [8], A. Matsuoka [10], T. Mitani [11], M. Teramoto [12], T. Takashima[11], I. Shinohara [11], J. Vierinen [1], K. Yamamoto [3], and S. Yokota [13]
[1]Department of Physics and Technology, UiT The Arctic University of Norway, Norway, [2]National Institute of Polar Research (NIPR), Japan, [3]Institute for Space-Earth Environmental Research, Nagoya University, Japan, [4]Geodetic Institute, Norwegian Mapping Authority, Norway, [5]Department of physics, University of Oslo, Norway, [6]Tromsø Geophysical Observatory, Norway, [7]The University of Tokyo, Japan, [8]Kanazawa University, Japan, [9]Sodankylä Geophysical Observatory/University of Oulu, Finland, [10]Kyoto University, Japan, [11]JAXA/ISAS, Japan, [12]Kyushu Institute of Technology, Japan, [13]Osaka University, Japan

Auroras are dynamic displays often associated with intense outbursts of energy accumulated in the magnetosphere and released into the ionosphere. They are intrinsically multi-scale phenomena resulting from a complex interplay between different physical processes and systems intricately coupled. Here we take advantage of the fortuitous conjunction between several ground-based instruments in Tromsø, Norway, and the Exploration of energization and Radiation in Geospace satellite (ERG), or "ARASE", in the magnetosphere to study a short-lived "non-classical" auroral substorm. We combine measurements such as those obtained from optical instruments, ground-based magnetometers, the European Incoherent Scatter Scientific Association (EISCAT) radar, and Global Navigation Satellite Systems (GNSS) receivers to study the development and impact of the aurora. We show that the most intense breakup aurora deposited most of its energy in the D-region ionosphere, caused strong ionospheric absorption and significant disturbances to GNSS signals in the area. We then present in-depth characterization of particle energies and pitch angle distributions measured by Arase in the magnetosphere during the event and place them in context of the detected field structures and waves. Combined, the multi-platform observations are used to to establish a coherent picture of the substorm, from the acceleration in the magnetosphere to the impact in the ionosphere. Such fortuitous extensive set of observations may provide additional clues to advance our understanding of magnetosphere-ionosphere coupling and about the effect that the aurora can have on technology infrastructures such as GNSS.

Interplanetary Radio Emission due to CME-CME Interaction **P1-1**

Diyorbek Pulatov [1]
[1]*Samarkand State University*

We analysed the interaction between two CMEs observed in the interplanetary medium at 18:06 UTC and 19:30 UTC on 6 April 2001, respectively, and the associated long-wavelength radio observations using DH type II burst. We identified the first (CME1) and second (CME2) CMEs and their associated DH type II burst using the SOHO/LASCO catalog and the Wind/Wave catalog, respectively. CME1 travelled through the SOHO FOV at a linear velocity of 648 km/s at an position angle (PA) of 106°. CME2 is a halo-CME, travelled much faster than the CME1, at a linear speed of 1270 $km\ s^{-1}$ and interacted with CME1 at 20:42 UTC at a distance of 11.82 Rs. The CME that separated at 19:30 UTC reached Earth on 8 April and caused a geomagnetic storm (Dst = -59 nT). Both CMEs ejected from the NOAA AR9415 active region in the eastern part of the Solar surface and did not trigger a Solar Energetic Particle (SEP) event. As a given Gopalswamy et al (2008), space weather events are more likely to trigger a SEP event if a CME originating in the western hemisphere is accompanied by a DH type II burst. The DH type II burst began at 19:35 UTC on 6 April and ended at 01:50 UTC on 7 April and duration for ∼6 h. The center frequency of the emission in the DH spectrum during the interaction appears to decrease with increasing interaction height.

Unveiling a New β Scaling of the Tearing Instability in Gyrotropic Plasmas **P1-2**

Gabriel Luiz Ferreira-Santos [1], *G. Kowal* [2], *and D. Falceta-Gonçalves* [2]
[1]*Instituto Nacional de Pesquisas Espaciais (INPE), Brazil,* [2]*Escola de Artes, Ciências e Humanidades da Universidade de São Paulo, EACH, USA*

Magnetic reconnection is a fundamental cross-scale coupling process governing the dynamics of the solar-terrestrial system, determining how energy is transferred from the solar wind into the Earth's magnetosphere. The onset of reconnection is frequently governed by the tearing instability, which leads to the formation of magnetic islands, or plasmoids. While classical magnetohydrodynamic (MHD) theories predict that the tearing growth rate is independent of the plasma-β (the ratio of thermal to magnetic pressure), observations from modern missions such as the Magnetospheric Multiscale (MMS) and Parker Solar Probe (PSP) confirm that these environments are weakly collisional and exhibit significant pressure anisotropy.
This work challenges the universality of standard MHD predictions by investigating the linear tearing instability within a non-ideal gyrotropic MHD framework, specifically tailored to model the realistic conditions of space plasmas. We performed a linear stability analysis of a Harris current sheet, incorporating the evolution of gyrotropic pressure and accounting for energy transfer via Ohmic and viscous heating. The analytical predictions were rigorously validated through numerical solutions of the generalized eigenvalue problem using the Pseudo-Spectral Eigenvalue Calculator with an Automated Solver (PSECAS).Our primary finding is the discovery of a novel scaling law for the tearing instability in high-β environments. We demonstrate that the maximum growth rate is suppressed as plasma-β increases, following the scaling relation $\sigma_{max} \propto \beta^{-1/4}$.
This deviation from classical theory arises from a dynamic thermodynamic feedback loop: velocity perturbations inherent to the instability induce fluctuations in pressure anisotropy. These fluctuations, in turn, generate a restoring force in the momentum equation that opposes the flow, effectively "stiffening" the plasma. Furthermore, we show that this mechanism shifts the instability to larger spatial scales, with the wavenumber scaling as $k_{max} \propto \beta^{-3/8}$.These results have profound implications for understanding solar-terrestrial coupling. The β-dependent suppression suggests that in high-β regions, such as the solar corona, the heliospheric current sheet, and specific sectors of the magnetosphere, the onset of fast reconnection may be significantly more constrained than previously believed. Additionally, the shift toward macroscopic wavelengths indicates that magnetic field evolution in these gyrotropic regimes might be dominated by large-scale structures rather than small-scale turbulence. By bridging the gap between fluid models and kinetic features, this study underscores the necessity of incorporating pressure anisotropy effects into global models to accurately describe the energy release and particle acceleration processes in the solar-terrestrial environment. (DOI 10.3847/1538-4357/ae046e).

Quantifying the Impact of Solar Irradiance Uncertainty on Thermosphere-Ionosphere Variability Using Ensemble Forecasts **P1-3**

Chih-Ting Hsu [1] *and N. M. Pedatella* [1]
[1]*High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado*

This study investigates the sensitivity of the thermosphere and ionosphere to variations in solar spectral irradiance. Using data from the SDO and SORCE missions collected between 2010 and 2018, we quantified the variability and uncertainty of solar spectral irradiance across wavelengths from 0.1 to 190 nm and developed a data-driven method to generate perturbed versions of the irradiance. These perturbations were used to drive ensemble simulation experiments conducted during the 2021/2022 winter to assess sensitivity in the thermosphere and ionosphere. In addition to the experiment using statistically derived perturbations, three more ensemble experiments driven by different perturbation methods were also performed.
Results show that both neutral temperature and electron density are highly sensitive to uncertainty in solar spectral irradiance, especially above 200 km altitude. Electron density is particularly influenced by soft X-ray variability in the lower ionosphere. Comparisons with Swarm, ICON, and COSMIC-2 satellite observations confirm the performance of ensemble simulation experiments on capturing the realistic thermospheric and ionospheric variability.

Among the experiments, the one driven by statistically derived perturbations produces ensemble spreads that best match the observed variability. This experiment shows good agreement with all three datasets, while the others tend to overestimate or underestimate the variability.
This work highlights the importance of accounting for uncertainty in external solar energy input in space weather models and demonstrates the value of data-informed ensemble simulations in improving the accuracy and reliability of thermosphere and ionosphere forecasts.

Multi-Scale Magnetospheric Modeling for Space Weather: Bridging Global and Kinetic Physics through Adaptive Multi-Fluid Approaches — P1-4

Simon Lautenbach [1] *and M. E. Innocenti* [1]
[1] *Ruhr University Bochum*

Operational space weather forecasting requires magnetospheric models that balance physical accuracy with computational feasibility. Magnetohydrodynamic (MHD) simulations are affordable in terms of computational cost but miss critical kinetic effects, while hybrid/kinetic models provide accuracy at prohibitive costs.
We present a novel approach readying the muphy2 framework for adaptive multi-fluid simulations for space weather. By spatially coupling two-fluid 5-moment and 10-moment models, we dynamically adjust physical fidelity to local magnetospheric requirements. This enables cross-scale coupling, accurate reconnection physics with differential electron-ion heating, and proper representation of the generalized Ohm's law—all critical for particle acceleration and magnetosphere-ionosphere coupling.
Our model maintains computational costs orders of magnitude below kinetic simulations while preserving species-specific dynamics lost in MHD. We present the theoretical framework and integration strategy.

SESSION 2: Sources of Space Weather & Space Climate

Space Climate and Space Weather in the Past: What We Know and How **K3**

Mathew Owens [1]
[1]Department of Meteorology, University of Reading, Reading, UK

The solar magnetic field varies across all observed timescales. Most prominently, short-term variations—on the order of a day or less—can be directly observed by spacecraft and give rise to space weather, which can impact our technological systems. Such space weather has long been known to display a cyclical pattern, following the approximately decadal sunspot cycle.
However, the Sun also exhibits longer-term "climate" variations on centennial and millennial timescales. Our knowledge of space climate comes from increasingly indirect observational proxies preserved in natural reservoirs, such as tree rings and ice sheets.
This talk will review what information about solar activity can be extracted from different observational sources, and how space weather and space climate are coupled across timescales.

Current Understanding of Solar Internal Convection and Magnetic Fields **O2-1**

Hideyuki Hotta [1]
[1]ISEE/Nagoya University

The ultimate source of space weather phenomena lies in the solar interior. Highly turbulent plasma motions, in combination with solar rotation, i.e., dynamo processes, generate the magnetic fields observed on the solar surface. One of the most prominent manifestations of solar magnetism is the 11-year activity cycle, which is also believed to be maintained by dynamo action. Owing to the inherent difficulty of observing the solar interior, the underlying dynamo processes are still not fully understood. In particular, turbulent thermal convection poses serious challenges, commonly referred to as the convective conundrum, which significantly hampers our understanding of the solar dynamo. In this talk, we review recent progress in probing the solar interior through helioseismic observations and numerical simulations, and discuss current challenges and future perspectives.

The Origin of Anti-Hale Regions **O2-2**

Kristóf Petrovay [1]
[1]Department of Astronomy, ELTE Eötvös Loránd University, Budapest

We determine solar active region (AR) scaling laws based on a recently constructed data base. We confirm earlier findings that the tilt angle distribution of non-Hale ARs shows a significant excess at low tilts (anti-Hale ARs). These anti-Hales ARs are found to have substantially lower flux than the general population, while their pole separation is intermediate between high-tilt non-Hale ARs and Hale ARs. In contrast to earlier studies we show that neither the anti-Hale ARs nor non-Hales in general follow Joy's law: instead, their tilt angle distribution is best represented by vanishing mean tilt. Despite these characteristics setting them apart as a different population, in other properties, such as butterfly diagram and scaling laws, they are remarkably similar to the general AR population. A simple physical scenario will be suggested for the subsurface structure and origin on anti-Hale regions that can simultaneously explain allthe observational constraints.

The Current Layer Missing in the Standard Model of Photospheric Flux Cancellation and CME Initiation **O2-3**

Bernhard Kliem [1]
[1]Physics & Astronomy, University of Potsdam, Potsdam, Germany

Flux cancellation, driven by flows that converge at the polarity inversion line (PIL), is a common process in the evolution of photospheric magnetic flux. It occurs at the polar crown, in the dispersal of flux in active-region decay, due to the sunspot moat flow in the life time of active regions, and even when new flux emerges into existing flux concentrations, known as collisional shearing. The standard model of photospheric flux cancellation predicts the formation and growth of a magnetic flux rope above the PIL, low in the corona (van Ballegooijen & Martens 1989). Consequently, the cancellation process is considered a pathway to CME initiation by magnetohydrodynamic (MHD) instability, which requires a flux rope to exist at the onset point. Recent MHD simulations of flux cancellation additionally reveal the formation of a vertical current layer or sheet between the PIL and the forming flux rope. This allows for CME initiation by tearing of the vertical current layer, which forms a plasmoid (seed flux rope) during the initiation of a subsequent eruption and is known as the reconnection model for CME initiation. MHD simulations of flux cancellation will be presented, which address the initiation of eruption by MHD instability vs. reconnection and its parametric dependence. Some runs reveal the formation of plasmoids in the slow-rise phase, merging with the main forming flux rope. This could be a model of confined precursor flares and can lead to a non-equilibrium state of the main rope prior to its eruption.

Century-Scale Reconstruction of Solar Magnetic Fields from the Photosphere to the Heliosphere **O2-4**

Shaonwita Pal [1] *and D. Nandi* [1,2]
[1]CESSI, IISER Kolkata, [2]Department of Physical Science, IISER Kolkata

Understanding how the Sun's magnetic field evolves over decades is central to describing the long-term variability of the heliosphere and its influence on geospace. However, direct measurements of heliospheric magnetic fields span only a few solar cycles, limiting our ability to assess long-term trends. In this work, we develop a physically consistent reconstruction of the Sun's global magnetic field over the past century by coupling data-driven surface flux transport simulations with coronal magnetic field models. Photospheric observations are assimilated into a surface flux transport framework which are then used to compute the evolving coronal structure and solar open flux. These results are further constrained using polar field data, historical geomagnetic observations and eclipse-derived coronal morphology, allowing us to tackle long-standing open solar flux problem. This reconstruction captures multi-cycle variations of the solar magnetic environment and provides new insight into how long-term surface magnetic evolution governs heliospheric conditions, offering a valuable resource for studying the long-term space-climate variability.

Predicting Magnetic Flux and Continuum Intensity During the Emergence of Active Regions Using Machine Learning **O2-5**

Spiridon Kasapis [1], *J. Tirona* [2], *E. Dogan* [2], *S. Patil* [2], *I. Kitiashvili* [3], *A. Kosovichev* [2,3], *M. Xu* [2], *and J. Stefan* [2]
[1]Princeton University, Princeton, NJ , USA, [2]New Jersey Institute of Technology, Newark, NJ, USA, [3]NASA Ames Research Center, Moffett Field, CA, USA

To support the development of early warning systems for solar Active Region (AR) emergence, we investigated deep learning approaches for forecasting the formation of large ARs manifested as a rapid decrease in continuum intensity and an increase in unsigned magnetic flux. This effort is based on the continuum intensity, Doppler velocity, and line-of-sight magnetic field observations from the Helioseismic and Magnetic Imager (HMI) onboard the Solar Dynamics Observatory (SDO), which are tracked over the solar disk and compressed into a set of 1D time series that characterize evolution over 3.4 $\times$ 3.4 degrees areas covering the upcoming emergence and quiet-Sun regions. The resulting data are organized into an ML-ready Solar Active Region Emergence Dataset (SolARED) dataset. In this work, we used Long Short-Term Memory (LSTM) and Transformer architectures to predict a fast decrease in the continuum inten- sity associated with AR emergence. The LSTM model can predict the onset of the continuum intensity decrease associated with AR emergence several hours before it becomes visible in HMI images, when the magnetic flux has reached only 4–9.6% of its eventual maximum. Using a sliding-window Transformer architecture and introducing an Early Detection model with attention biases and a timing-aware loss allows us to achieve a 10.6% improvement in RMSE over the LSTM baseline and an average advance warning time of 4.73 hours under a stricter emergence criterion. Exploration of capabilities to predict evolution of unsigned magnetic flux using the LSTM-based models shows that a simpler single-stage model generalizes better and trains more robustly than a higher-complexity encoder–decoder architecture. Our results show that the developed LSTM model can forecast magnetic flux emergence 3-10 hours ahead for the test ARs.

Long-Term Proxies and Reconstructions of Past Solar Activity **O2-6**

Theodosios Chatzistergos [1]
[1]Max Planck Institute for solar system research, Göttingen, Germany

The Sun is the primary external energy source driving Earth's climate system, making long, consistent, and reliable records of solar activity and variability essential. Direct measurements of total solar irradiance (TSI) have been available only since the late 1970s, a period that is relatively short for climate studies, while measurements of the solar magnetic field span a similarly limited time-frame.
Fortunately, several types of solar observations enable us to investigate different aspects of solar magnetic activity and thus reconstruct irradiance variations over much longer periods. Among these, Ca II K observations are particularly valuable. Extending back to 1892, they provide information on chromospheric plage regions, which are closely linked to the solar surface magnetic field. As such, Ca II K data offer one of the most promising means of reconstructing the evolution of past solar magnetism and improving solar irradiance reconstructions over more than a century.
Sunspot observations constitute the longest direct record of solar activity, spanning approximately four centuries. These observations were made by numerous observers worldwide, necessitating careful cross-calibration. Recent efforts have focused on identifying and correcting inconsistencies in historical compilations, which will lead to more accurate reconstructions of past sunspot activity.
Solar variability on even longer timescales can be investigated using cosmogenic isotopes, which serve as indirect proxies preserved in natural archives. In particular, 14C and 10Be records extend back roughly 9,000 years with decadal resolution. More recently, high-quality annual 14C measurements have made it possible to resolve individual solar cycles over at least the past 3,000 years. Here, I provide an overview of recent advances in long-term proxies of solar activity.

Reconstruction of Annual Solar Irradiance Over Nine Millennia Reconstruction of Annual Solar Irradiance Over Nine Millennia **O2-7**

Duresa Temaj [1,2], N. A. Krivova [1], T. Chatzistergos [1], S. K. Solanki [1,3], I. G. Usoskin [3], and C.-Ju Wu [1]
[1]Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany, [2]Technische Universität Braunschweig, Braunschweig, Germany, [3]Space Climate Research Unit and Sodankylä Geophysical Observatory, University of Oulu, Finland

Space-based measurements of solar irradiance have been available since 1978, revealing variability across all observable timescales. However, this record is too short to assess the Sun's influence on climate variability, making long-term irradiance reconstructions crucial. On climate-relevant timescales, irradiance variability is driven by changes in solar surface magnetism, through sunspot darkening and facular brightening. While sunspot number (SN) has been recorded for about 400 years, direct long-term observations of faculae do not exist for the same period.
We use the SATIRE-T (Spectral And Total Irradiance Reconstructions for the Telescopic era) model, which reconstructs total and spectral irradiance using only the SN record as input. In the recently revised magnetic-flux model underlying SATIRE-T, modern observations are used to determine how the emergence of faculae and small-scale magnetic features is related to sunspot emergence. This allows us to reconstruct solar irradiance over the past 400 years, showing excellent agreement with direct measurements.
To extend irradiance reconstructions yet further back to the pre-telescopic times, indirect proxies of solar activity are required. Concentrations of cosmogenic isotopes (14C and 10Be) preserved in terrestrial archives were earlier used to recover decadal SN for the past nine millennia. Because this decadal record does not contain individual solar cycles, we use statistical relationships between average activity levels and cycle properties to reconstruct annual SN. These reconstructed SN are then used as input to SATIRE-T to produce total and spectral irradiance over the entire Holocene.

The NASA-NOAA-LASP Solar Irradiance Models: The Observations Key for Development and Validation **O2-8**

Odele Coddington [1]
[1]Laboratory for Atmospheric and Space Physics, University of Colorado Boulder

Incoming solar energy drives coupled radiative, dynamical, and chemical processes that establish Earth's terrestrial environment. High-accuracy and precision knowledge of the magnitude and variability of total solar irradiance (TSI) and solar spectral irradiance (SSI) are necessary for multiple Earth science applications including geophysical property retrieval algorithms, satellite calibration and inter-calibration, and developing and validating solar irradiance models. Solar irradiance variability models supplement the measurement record by extrapolating the measurement record to a broader spectral range and longer time period than directly observed.
Version 1 of the NASA-NOAA-LASP (NNL) solar irradiance variability models are observation-based models that prescribe change in TSI and SSI from quiet Sun conditions based on change in solar magnetic activity features called faculae, that enhance solar irradiance at most wavelengths, and sunspots that reduce solar irradiance. Variability in the TSI model is prescribed by the net bolometric effect of sunspot darkening derived from the National Solar Observatory (NSO) Global Observing Oscillation Network (GONG) images and facular brightening from Magnesium II (Mg II) core-to-wing measurements by the Geostationary Operational Environmental Satellites (GOES) and a composite Mg II record by the University of Bremen. Variability in the SSI model is prescribed using multiple linear regression of the sunspot darkening and facular brightening indices with irradiance observations from the Total and Spectral Solar Irradiance Sensor (TSIS-1). The NNL models estimate daily averaged solar variability since 1874 and annually averaged solar variability since 1610. Furthermore, the NNL models were translated as Version 3 of the operational NOAA National Centers for Environmental Information (NCEI) Solar Irradiance Climate Data Record in 2024.
In this work, we describe the observational advances in solar irradiance, sunspot darkening, and facular brightening that have informed the new and enhanced capabilities of the NNLTSI and NNLSSI models and are used in ongoing model validation. We also present the importance of TSI measurement stability in constraining and validating model projections of future TSI.

Using Modern Observation to Understand Historical Solar Variability **O2-9**

Ajay Kumar Yadav [1], T. Chatzistergos [1], N. Krivova [1] S. K. Solanki [1], and Sunrise III Team [1]
[1]Max Planck Institute for Solar System Research, Goettingen, Germany

Solar irradiance is one of the key external forcing agents of Earth's climate. To quantify the effect of its variability on climate, knowledge of past irradiance changes over as long periods of time as possible is required. As direct measurements are only available for less than a half-a-century, this necessitates reconstructions of irradiance with the help of models. The main driver of irradiance changes on climate-relevant timescales is the solar surface magnetism, and thus proxies of past solar magnetic activity are crucial for such reconstructions. One such proxy is the brightness of the Sun in the Ca II K spectral line.
Images of the Sun in Ca II K have been taken since 1892 at different sites around the globe, with data from individual observatories covering different time intervals. Combining these data has the potential to give insight into changes in solar surface magnetism and thus irradiance over more than a century. However, such a combination requires accounting for differences in instruments and observational settings. One crucial issue is varying passbands among and across the various observational archives.
To study the effect of different passbands on the Ca II K observations, we make use of the recent state-of-the-art data provided by the balloon-borne observatory Sunrise 3. Using high spectral-resolution Sunrise 3 data, we simulate different passbands used in historical archives and study the relationships between Ca II K intensity as would be observed with such filters. These results will allow a cross-calibration of various historical observations.

Different Occurrence of CME and HSS/SIR Storms During the Modern Maximum: Consequences to Solar Structure and Predictions on Future Space Climate **O2-10**

Kalevi Mursula [1], *T. Qvick* [1], *and T. Asikainen* [1]
[1] *Space Climate Group, Space Physics and Astronomy Research Unit, University of Oulu, Oulu, Finland*

Magnetic storms are mainly driven by two solar wind structures: coronal mass ejections (CME) and high-speed solar wind streams with related stream interaction regions (HSS/SIR). CME occurrence closely follows sunspots, the emergence of new strong magnetic flux on the solar surface. HSS/SIR occurrence depends on the global structure of solar corona, in particular the occurrence of coronal holes, which is determined by the evolution of decaying solar active regions (plages) with magnetic field weaker than sunspots.
We study here the occurrence of magnetic storms during the last 92 years (1933-2024), using the Dxt index, a homogeneous extension of the Dst storm index. The studied time interval covers almost the whole Modern Maximum (MM), the latest cycle of the centennial Gleissberg cyclicity of solar activity. Studying storms of different strength and origin can give interesting information on the evolution of the Sun during this exceptional period of solar activity.
We find that CME storms were relatively more frequent than HSS/SIR storms in the growth and maximum phase of the Modern Maximum. On the other hand, the relative occurrence of HSS/SIR storms increased with respect to CME storms in the MM decay phase. This curious change in the relative occurrence of storms of different origin is in good agreement with the recent finding of a changing long-term relation between sunspots and plages [1, 2]. Sunspots are found to be relatively more frequent than plages in the MM growth and maximum phases, while the opposite relation is valid in the MM decay phase.
We discuss the interesting consequences of these results on the long-term change of the structure of solar magnetic fields and the solar atmosphere, as well as on the stellar evolution of the Sun and Sun-like stars. We also make a prediction on the future space climate, in particular on the occurrence of CME and HSS/SIR storms at the Earth.
[1] K. Mursula, A. A. Pevtsov, T. Asikainen, I. Tähtinen and A. Yeates (2024). Transition to a weaker Sun: Changes in the solar atmosphere during the decay of the Modern maximum, Astron. Astrophys., 685, A170, https://doi.org/10.1051/0004-6361/202449231.
[2] K. Mursula (2025). Centennial solar EUV irradiance from ionospheric currents: Varying sunspot-EUV irradiance relation and modified spot-facula ratio, J. Atm. Solar-Terr. Phys., https://doi.org/10.1016/j.jastp.2025.1066532025.

Interpreting Complex Solar Flare Ribbons in the Context of the Magnetic Skeleton **O2-11**

Graham Barnes [1] *and Karin Dissauer* [1,2]
[1] *NWRA,* [2] *University of Graz*

Solar flare ribbons, manifesting as transient brightenings in the upper photosphere and chromosphere, are believed to trace out the footpoints of magnetic field lines that are reconnecting higher in the solar atmosphere. These field lines lie in a separatrix or quasi-separatrix layer that separates domains of different magnetic connectivity and hence forms a natural location for reconnection. Solar flares are typically characterized as being circular ribbon flares, two-ribbon flares, or complex ribbon flares based on the number and shape of the ribbons. There are relatively well-developed models to explain the first two types of flares based on the location of the reconnection powering the flare. The case of complex ribbons is less well understood, but is often posited to be a result of reconnection at multiple locations. By locating magnetic null points and their associated separatrix surfaces, and using Carl's Indirect Coronal Current Imager (CICCI; Schuck et al. 2022) to determine the location of current channels, and comparing their photospheric footprints to the location of flare ribbons, we demonstrate how reconnection at a sequence of sites can result in complex ribbons.

What Are the Solar Ingredients to Get Extreme Geoeffective Events? **O2-12**

Brigitte Schmieder [1−3], *J. H. Guo* [2,4], *G. Aulanier* [5], *A. Maharana* [2] *and S. Poedts* [2,6]
[1] *Observatoire de Paris, LIRA, France,* [2] *CmPA, Dept. of Mathematics, KU Leuven, Belgium,* [3] *LUNEX Space HUB, NL,* [4] *Nanjing Univsersity, China,* [5] *LPP, Paris, France,* [6] *Lublin University, Poland*

Many questions have to be answered before understanding the relationship between the emerging magnetic flux through the solar surface and the extreme geoeffective events. Which threshold determines the onset of the eruption? What is the upper limit in energy for a flare? Is the size of the sunspot the only criterion to get extreme solar events? Based on observations of previous solar cycles and theory, the main ingredients for getting X-ray class flares and large interplanetary Corona Mass Ejections, e.g. the built-up of the electric current in the corona, are presented, such as the existence of magnetic free energy, magnetic energy/helicity ratio, twist and stress in active regions. The upper limit of solar energy in the space research era, and the possible chances of getting super-flares and extreme solar events can be predicted using MHD simulations of coronal mass ejections. For eruptive flares with CMEs or confined flare magnetic solar energy is discussed in this context with data-driven MHD simulations of the events of May 2024. Good predictions of arrival time are achieved with EUHFORIA simulation with the cone model.

Radial evolution of periodic density structures observed by Solar Orbiter **O2-13**

Christos Katsavrias [1,2], *S. Di Matteo* [2,3], *L. Kepko* [2], *N. Viall* [2], *and A. Walsh* [4]
[1]National and Kapodistrian University of Athens, [2]NASA-GSFC, [3]The Catholic University of America, [4]ESA/ESAC

The quasi-periodic density structures (PDSs) are quasiperiodic variations of solar wind density ranging from a few minutes to a few hours. They are trains of advected density structures with radial length scales LR $\approx 100 - 10,000\ Mm$, thus belonging to the class of solar wind "mesoscale structures". Even though PDS at L1 have been extensively studied both through statistical and event analysis, their investigation at distances closer to the Sun is limited. This study performs a statistical investigation of PDS at various distances from the Sun between 0.3 and 1 AU by exploiting Solar Orbiter data. We compiled and made publicly available an extensive list of PDSs following a well-established methodology that combines the Multitaper method as well as wavelet analysis to reveal the distribution of PDS radial length scales and how they vary with respect to the radial distance. Our results indicate that PDS advected with the ambient slow solar wind are expanded, while PDS detected during fast solar wind segments show compression indicative of their interaction with stream interaction regions.

Impacts of Pre-Existing Magnetic Structures on Solar Energetic Particle Events **O2-14**

Zheyi Ding [1] *and R. F. Wimmer-Schweingruber* [1]
[1]University of Kiel

Recent Solar Orbiter observations reveal pronounced bidirectional energetic particle signatures prior to and during the early phase of the event, indicating particle trapping within closed or quasi-closed magnetic structures associated with magnetic flux ropes. These structures substantially modified the magnetic connectivity between the acceleration region and the inner heliosphere. As large-scale magnetic connection was established, changes in connectivity and the release of trapped particles modulated the energetic particle intensity observed in the inner heliosphere. The 2025 November 11 ground level enhancement (GLE) event observed at Earth and Solar Orbiter provides a unique opportunity to examine how pre-existing magnetic structures (pre-CMEs), influence energetic particle intensities in the inner heliosphere . Our results demonstrate that pre-existing magnetic structures play a critical role in shaping SEP timing, anisotropy, and the in-situ enhancement of particle intensity.

Results from REPTile-2 Measurements Onboard CIRBE **O2-15**

Xinlin Li [1]
[1]LASP and Department of Aerospace Engineering, University of Colorado Boulder, USA

REPTile-2 (Relativistic Electron and Proton Telescope Integrated Little Experiment-2), onboard the Colorado Inner Radiation Belt Experiment (CIRBE) CubeSat, which was launched on 19 April 2023 into a highly inclined (97.4°) low Earth orbit at an altitude of ∼509 km and re-entered on 4 October 2024 due to atmospheric drag. REPTile-2 provided high–energy-resolution measurements of electrons from 0.25 to 6 MeV and protons from 6.5 to 100 MeV.
These observations revealed numerous fine-scale and previously unresolved features of relativistic electrons, including: (1) clear zebra stripes, or drift echoes, of 0.25–1.4 MeV electrons spanning the entire inner belt and extending into part of the outer belt; (2) multiple "wisps" of precipitating electrons associated with very-low-frequency (VLF) transmissions from the North West Cape (NWC) transmitter in Australia; (3) electron precipitation events attributed to electromagnetic ion cyclotron (EMIC) waves, identified through their distinct energy-dependent signatures; (4) bursty precipitation of relativistic electrons over a broad energy range (300 keV to $>$2 MeV), likely driven by chorus wave scattering; and (5) the identification of a newly formed electron belt and a proton belt following the intense geomagnetic storm of May 2024.
In addition, REPTile-2 recorded more than ten solar energetic particle (SEP) events while traversing high-latitude regions. Cross-calibration with other low Earth orbit observations, including POES and MetOp, enables the construction of a more complete global SEP distribution with improved spectral resolution and accuracy.
The energetic electrons and protons are sources of Space Weather, understanding better their characteristics and the underlining physical mechanisms will enable more accurate forecast and specification of their variations and impacts.

SAWS-ASPECS Performance During GLE77: Real-Time Forecasting of High-Energy Solar Particle Radiation **P2-1**

Anastasios Anastasiadis [1], A. Papaioannou [1], and G. Vasalos [1], for the ASPECS Team
[1]Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS), National Observatory of Athens, Greece

SAWS-ASPECS is an advanced space radiation modelling and forecasting framework developed to support space missions through real-time monitoring and prediction of particle radiation environments across energies from >10 to >300 MeV, with particular emphasis on extreme solar energetic particle (SEP) events such as Ground Level Enhancements (GLEs). The intense GLEs of 2024 and the exceptional GLE77 event of 11 November 2025 provide critical benchmarks for validation. GLE77, triggered by an X5-class solar flare and fast Earth-directed CME, was among the strongest events of Solar Cycle 25, producing rapid global responses across space- and ground-based instruments, with neutron monitor increases reaching ∼120% at South Pole. For GLE77, ASPECS delivered highly accurate real-time predictions at energies above 100 MeV, successfully reproducing the event onset, peak intensity, and duration with high precision. These results demonstrate the system's strong forecasting capability for high-energy radiation hazards and its operational value for mission planning, launch decisions, and in-flight risk mitigation. In this work, the ASPECS operational pipeline together with the resulting predictions at E>100 MeV is being presented and discussed.
Acknowledgement: SAWS-ASPECS tool developed under the ESA Contract No. 4000120480/NL/LF/hh "Solar Energetic Particle (SEP) Advanced Warning System (SAWS)"

Relationship between Ca II K Contrast and Solar Surface Magnetic Field near the Solar Limb **P2-2**

Ajay Kumar Yadav [1], N. Krivova [1], T. Chatzistergos [1], S. K. Solanki [1], K. Albert [1], J. Hirzberger [1], G. Valori [1], D. Calchetti [1], D. Orozco Su´arez [2], H. Strecker [2], A. Ulyanov [1], and J. Blanco Rodr´ıguez [3]
[1]Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany, [2]Instituto de Astrofísica de Andalucía, CSIC, Glorieta de la Astronomía, Granada, Spain, [3]Universitat de Valencia Catedrático José Beltrán, Paterna-Valencia, Spain

The brightness of the Sun in the Ca II K line is a good proxy for solar magnetic activity and is a key to improved reconstructions of past variations in solar magnetism. In particular, the long-term changes and the amplitude of the UV irradiance variability remain uncertain, and are hence a critical limitation for studies of the Sun's influence on Earth's atmosphere and climate. Ca II K observations therefore provide an important observational constraint on irradiance models.
This effort requires a quantitative relation between Ca II K brightness and the solar surface magnetic field. Such relations have been established over most of the solar disc by calibrating Ca II K brightness against magnetic field on a pixel-by-pixel basis. However, the calibration remains uncertain close to the solar limb due to the low signal-to-noise ratio and foreshortening effects.
The unique vantage point of Solar Orbiter, particularly during its near quadrature configurations with Earth, offers a way to overcome these limitations. We combine Ca II K observations from the Kanzelhoehe Solar Observatory with near-simultaneous magnetograms from the Polarimetric and Helioseismic Imager (PHI) onboard Solar Orbiter. In this configuration, regions observed near the limb in Ca II K images are seen close to disc center by SO/PHI. This allows a significantly more reliable assessment of the magnetic field in the near-limb regions and thus a more accurate calibration of the Ca II K brightness
to the magnetic field. We will present the resulting contrast – magnetic field relation and compare it with previous studies.

First Detection of Preflare Heating at 30 THz in an M7.4 Solar Flare **P2-3**

Solomon M. Perriyil [1] and G. G. G. de Castro [1,2]
[1]Center for Radio Astronomy and Astrophysics (CRAAM), Mackenzie Presbyterian University, São Paulo, Brazil, [2]Institute of Astronomy and Space Physics (IAFE), UBA/CONICET, Buenos Aires, Argentina

We present mid-infrared observations of the M7.4 solar flare SOL2025-01-17T13:35. In this event, we identify a clear preheating phase that occurs before the start of the main impulsive phase of the flare. The start time of the flare is 13:24 UT, while clear signatures of non-thermal electrons acceleration, seen in Hard X-ray and microwave data, appear only after 13:31 UT. This time difference shows that heating starts several minutes before the injection of high energy electrons.
During this early phase, an increase in emission is observed simultaneously in the mid-infrared signal, UV and soft X-ray emissions. The presence of these signals before the hard X-ray and microwave rise indicates that the lower solar atmosphere is heated even before the main particle acceleration begins. Since no strong non-thermal emission is detected during this period, the early heating is likely caused by processes other than electron beams, such as thermal conduction or gradual energy release.
Preflare heating has been reported earlier in other wavelengths, However it has not been observed at 30 THz mid-infrared wavelengths. To our knowledge, this is the first clear detection of preflare heating in the mid-infrared. These study highlight the importance of mid-infrared measurements for studying the earliest stage of flare energy release and provides new insight.

Radio Insights into Large-Scale Chromospheric Flows: Connection with the Solar Magnetic Field **P2-4**

Srinjana Routh [1], A. Kumari [3,4], R. Bose [1], V. Pant [5], J. Kandekar [6], and D. Banerjee [7−9]
[1]Aryabhatta Research Institute of Observational Sciences, Nainital, Uttarakhand, India, [2]Department of Applied Physics, Mahatma Jyotiba Phule Rohilkhand University, Bareilly, Uttar Pradesh, India, [3]Department of Physics, University of Helsinki, Helsinki, Finland, [4]Udaipur Solar Observatory, Physical Research Laboratory, Dewali, Badi Road, Udaipur, Rajasthan, India, [5]Indian Institute of Technology, Delhi, India, [6]Department of Physics, Ahmednagar College, Station Road, Ahilyanagar, Maharashtra, India, [7]Indian Institute of Space Science and technology, Valiamala, Thiruvananthapuram,Kerala, India, [8]Indian Institute of Astrophysics, Koramangala, Bangalore, India, [9]Center of Excellence in Space Sciences India, IISER Kolkata, Mohanpur, West Bengal, India

Understanding solar differential rotation and the existence of meridional circulation across atmospheric heights is essential to deciphering the solar magnetic cycle. Traditional measurements of solar differential rotation based on EUV and optical observations often suffer from uncertainties in height attribution due to temperature-dependent emission. In this study, we analyse over two solar cycles (1992–2020) of full-disc 17 GHz radio imaging from the Nobeyama Radioheliograph (NoRH), which offers a more height-stable diagnostic of the upper chromosphere. A tracer-independent, automated image correlation technique was employed to extract rotation rates across 16 latitude bins. The resulting profile reveals a significantly faster and less differential rotation in the upper chromosphere compared to the photosphere, with best-fit coefficients consistent with previous chromospheric estimates derived from EUV diagnostics. A weakly significant anti-correlation between the equatorial rotation rate and solar activity was observed. These findings reinforce the utility of radio wavelengths in isolating atmospheric rotation layers with minimal ambiguity often associated with using tracers of the higher atmosphere which often comprise of multi-thermal plasma. Additionally, we also discuss the hypothesized magnetic tree in the solar atmosphere through these findings.

Relativistic Solar Energetic Particle Transport in the Widespread 2021 October 28 Event **P2-5**

Eleni Lavasa [1], J. T. Lang [3], A. Papaioannou [2], R. D. Strauss [4], S. A. Mallios [2], A. Hillaris [1], A. Kouloumvakos [5], A. Anastasiadis [2], and I. A. Daglis [1]
[1]National & Kapodistrian University of Athens, Greece, [2]Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS), National Observatory of Athens, Greece, [3]Space Research Laboratory, University of Turku, Finland, [4]Centre for Space Research, North-West University, Potchefstroom, South Africa, [5]The Johns Hopkins University Applied Physics Laboratory, USA

The transport of solar energetic particles (SEPs) during the relativistic and longitudinally widespread event on 28 October 2021 is investigated, with the aim to quantify parallel and perpendicular diffusion processes as well as the size of the injection region. Inverse modelling is applied using numerical simulations of particle focused transport and cross-field diffusion, to reproduce multi-spacecraft observations from STEREO-A, Solar Orbiter, and near-Earth missions over a broad range of electron and proton energies. Simulated intensity and anisotropy time profiles are compared across different longitudes to constrain particle transport parameters. Results indicate parallel mean free paths consistent with dynamical turbulence models for pitch-angle scattering. The inferred perpendicular mean free paths correspond to a considerable fraction of the parallel ones, 1-3% for electrons and 5-10% for protons, tending to increase with particle rigidity. The injection region is found to be relatively narrow ($\lesssim 20^\circ$) and decreasing with particle rigidity. These constraints imply that a localized injection coupled with strong perpendicular diffusion explain the observed widespread particle signatures.
Acknowledgement: This research received funding from the European Union's Horizon Europe programme under grant agreement No 101135044 (SPEARHEAD) [https://spearhead-he.eu/]

SPEARHEAD Tools for High-Energy Particle Data Analysis **P2-6**

Georgios Vasalos [1], A. Papaioannou [1], and A. Anastasiadis [1], SPEARHEAD Team
[1]National Observatory of Athens, Greece

The Horizon Europe SPEARHEAD (SPEcification, Analysis & Re-calibration of High Energy pArticle Data) project delivers a suite of open-access tools designed to advance the analysis of high-energy particle observations relevant to heliophysics research. The toolkit includes:

- Bowtie: performs bow-tie analysis on instrument energy channels to derive geometric factors and effective energies from CSV response tables.
- FDAT (Forbush Decrease Analysis Tool): a graphical interface for identifying ICME/Forbush decrease events, fitting ForbMod models, and generating visual and statistical analysis outputs.
- G4VM (GEANT4 Virtual Machine): provides pre-configured GEANT4 simulations for instruments like SOHO/Chandra EPHIN and Solar Orbiter HET, incorporating realistic GDML models and spacecraft shielding.
- VDA (Velocity Dispersion Analysis): automates velocity dispersion analysis of Solar Energetic Particle (SEP) events using customizable Jupyter Notebook workflows.
- These tools, accessible via the SPEARHEAD GitHub repository and JupyterHub, support improved dataset calibration, event characterization, and simulation workflows for the space weather and heliophysics community.

An Observational Survey of Solar Energetic Particle Events in the Inner Heliosphere Using Solar Orbiter **P2-7**

Athanasios Papaioannou [1], L. Rodríguez-García [2,3], R. Gómez-Herrero [3], E. Lavasa [1,4], A. Kouloumvakos [5], G. Vasalos [1], A. Warmuth [6], I. G. Richardson [7,8], D. Lario [8], I. Zouganelis [2], B. Heber [9], M. Köberle [9], M. Jarry [1], M. Laurenza [10], F. Espinosa Lara [3], I. Cernuda [3], P. Kühl [8], J. Gieseler [11], C. Palmroos [11], F. Schuller [6], K. Barczynski [12,13], S. Fleth [9], A. Anastasiadis [1], A. Walsh [2], D. Müller [14], J. Rodríguez-Pacheco [3], R. F. Wimmer-Schweingruber [9], R. Vainio [11], and A. P. Rouillard [15]
[1] Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS), National Observatory of Athens, Greece, [2] European Space Agency (ESA), European Space Astronomy Centre (ESAC), Camino Bajo del Castillo s/n, 28692 Villanueva de la Cañada, Madrid, Spain, [3] Universidad de Alcalá, Space Research Group, 28805 Alcalá de Henares, Spain, [4] National & Kapodistrian University of Athens, Athens, Greece, [5] The Johns Hopkins University Applied Physics Laboratory, 11101 Johns Hopkins Road, Laurel, MD 20723, USA, [6] Leibniz-Institut für Astrophysik Potsdam (AIP), An der Sternwarte 16, 14482 Potsdam, Germany, [7] NASA Goddard Space Flight Center, Heliophysics Science Division, Greenbelt, MD 20771, USA, [8] Department of Astronomy, University of Maryland, College Park, MD 20742, USA, [9] Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, 24118 Kiel, Germany, [10] INAF-Istituto di Astrofisica e Planetologia Spaziali, Via del Fosso del Cavaliere 100, I-00133 Rome, Italy, [11] Department of Physics and Astronomy, University of Turku, 20500 Turku, Finland, [12] ETH Zürich, Hönggerberg Campus, HIT Building, Zürich, Switzerland, [13] PMOD/WRC, Dorfstrasse 33, 7260 Davos Dorf, Switzerland, [14] European Space Agency (ESA), European Space Research and Technology Centre (ESTEC), Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands, [15] IRAP, Université Toulouse III—Paul Sabatier, CNRS, CNES, Toulouse, France

We present a catalogue of 212 Solar Energetic Particle (SEP) events observed by the High Energy Telescope (HET) of the Energetic Particle Detector (EPD) onboard Solar Orbiter during the ascending and peak phases of Solar Cycle 25 (2020–2025). The survey is based on parallel measurements of ∼1 MeV electrons and ∼8 MeV protons, including events with proton energies exceeding 25 MeV and 50 MeV. SEP events were identified through statistically significant enhancements above background, and for each event we derived onset and peak times, peak intensities, fluences, and electron-to-proton (e/p) ratios. Particle release times at the Sun were estimated using both time-shifting and velocity-dispersion analyses (VDA). These were compared with solar flare observations and associated Coronal Mass Ejections (CMEs) to identify the most probable parent sources and investigate the relationship between SEP characteristics and eruption properties. In situ measurements of the solar wind plasma and magnetic field were used to characterize the heliospheric environment of each event and to compute magnetic connection angles, enabling an assessment of the role of magnetic connectivity in SEP onset and intensity. We also examine the diagnostic value of e/p ratios and elemental abundance signatures for distinguishing between impulsive and gradual SEP events. As part of this work, we developed two open-source tools – SEP – PACT for catalogue construction and VDA for release-time analysis – available via the SPEARHEAD GitHub repository (https://github.com/spearhead-he). The complete catalogue will be released through Zenodo and the SPEARHEAD web interface (https://spearhead-he.eu), providing a valuable resource for future studies of SEP acceleration and transport in the inner heliosphere.

Study of the GLE76 – a Far-side SEP Event **P2-8**

Manon Jarry [1], A. Papaioannou [1], N. T. Sheshvan [2], A. P. Rouillard [2], A. Anastasiadis [1], E. Lavasa [1], and G. Vasalos [1]
[1]Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS), National Observatory of Athens, Greece, [2]Institut de Recherche en Astrophysique et Planétologie (IRAP), CNRS, Université de Toulouse, France

On 21 November 2024, the GLE76 event was associated with a solar eruption originating from the far side of the Sun as seen from Earth. Due to this viewing geometry, the associated flare produced only weak soft X-ray signatures in Earth-based observations.
A fast coronal mass ejection (CME) propagating along the limb closely followed the flare and drove a shock wave at its leading edge. Using remote-sensing observations, the three-dimensional shock is reconstructed and combined with global magnetohydrodynamic (MHD) simulations to derive its parameters.
We study the magnetic connectivity between the shock and different observing spacecraft, and explore how variations in its properties along connected field lines are related to the observed characteristics of the associated solar energetic particle (SEP) event in terms of timings, intensities and energies reached, and spectrum hardness.
This poster presents an analysis of the event and discusses its implications for particle acceleration and transport during far-side eruptions.

Global Multi-Species Modelling of the Widespread SEP Event on May 20, 2024 **P2-9**

Artem Epifanov [1] and K. Kozarev [1]
[1]Bulgarian Academy of Sciences

We present a global numerical modelling study of the early evolution and global propagation of several species of solar energetic particles (SEPs) during the intense, widespread, impulsive event of 20 May 2024, focusing on the region between 30 solar radii and 1 au. The simulations employ an expanded and modified version of the Energetic Particle Radiation Environment Model (EPREM), coupled to an observation-driven heliospheric plasma and magnetic-field configuration derived from a Magnetohydrodynamics Around a Sphere (MAS) model magnetohydrodynamic solution.

This framework enables a self-consistent treatment of SEP transport in a structured inner heliosphere. The event was exceptionally well observed by Parker Solar Probe and Solar Orbiter, which were separated by nearly 90° in heliolongitude. It was also observed near Earth with some delay, further separated from PSP by 80 degrees. The observations thus provide stringent constraints on the longitudinal extent, timing, and spectral evolution of the multi-ion (H, He, C, O, Fe) fluxes. We study the early-time SEP intensities throughout the domain and compare them to the fluxes observed at widely separated heliocentric locations. We explore how transport processes modified the SEP time profiles and energy spectra during the first several days of the event. By tracking multiple ion species, the study lays the groundwork for assessing how rigidity-dependent transport effects may produce apparent temporal variations in elemental ratios, even in the absence of intrinsic changes in source composition.

Contribution of Poloidal Pc4 Waves to the Acceleration of Electrons of the Outer Radiation Belt to Relativistic Energies **P2-10**

Belakhovsky B. Belakhovsky [1] and V. A. Pilipenko [2]
[1]Polar Geophysical Institute, Apatity, [2]Institute of Space Research RAS, Moscow

The acceleration of electrons at the outer radiation belt to relativistic energies (~1 MeV) is associated mainly either with their interaction with ULF waves (toroidal Pc5 pulsations) or with VLF chorus emissions. However, the growth of Pc5 and VLF activity in the magnetosphere ends, as a rule, before the start of the growth of relativistic electrons, and their flux reaches a maximum already after a magnetic storm. Therefore, the question arises as to what mechanisms are responsible for the relativistic electron fluxes continuing to increase after the decline in Pc5 and VLF activity.
In our opinion, poloidal Pc4 pulsations can be a quite likely candidate for the role of an electron accelerator up to MeV energies. These waves are observed only under calm geomagnetic conditions; they can last for several days. The report presents cases where Pc4 pulsations were recorded by the GOES satellites during a period of increasing relativistic electron fluxes. Observations show that the rise and fall of MeV electron fluxes in geostationary orbit occurs almost simultaneously with the rise and fall of energetic proton fluxes (95 keV).
Thus, Pc4 pulsations turn out to be an agent that transfers energy from energetic protons to electrons of MeV energies. The mechanism of excitation of Pc4 waves and subsequent acceleration of electrons is associated with the resonant drift-bounce interaction of waves and particles.
The study was supported by the Russian Science Foundation grant N° 25-17-20038.

The Polytropic Index of Interplanetary Coronal Mass Ejections and Stream Interaction Regions near L1 **P2-11**

Christos Katsavrias [1], G. Nicolaou [2], G. Livadiotis [3], A. Vourlidas [4], D. Vercharen [2], and L. B. Wilson [5]
[1]National and Kapodistrian University of Athens, [2]Mullard Space Science Laboratory, University College London, [3]Princeton University, [4]Applied Physics Laboratory, Johns Hopkins University, [5]NASA Goddard Space Flight Center

A polytropic process describes the transition of a fluid from one state to another through a specific relationship between the fluid density and temperature, and the value of the polytropic index that governs this relationship determines the heat transfer and the effective degrees of freedom of this specific process. In this study, we investigate in depth (for the first time to such an extent) the behaviour of both the total and partial proton polytropic indices in ICMEs and SIRs. To that end, we used Wind measurements over more than two solar cycles (1995–2022), from which we derived the distributions of the polytropic index in the near-Earth space (L1) for 186 SIRs and 401 ICMEs. Our results show that sheaths and interaction regions are sub-adiabatic, indicating compression and turbulent heating. Furthermore, the polytropic behaviour of the protons inside the ICME magnetic obstacles is dependent on the magnetic field configuration, with flux ropes with rotation above 90 deg exhibiting sub-adiabatic, while ejecta with no clear rotation exhibiting super-adiabatic, supporting the scenario that changes during the interplanetary evolution might affect the magnetic field configuration inside the magnetic obstacle. Finally, high-speed streams exhibit a super-adiabatic polytropic behaviour, which is consistent with a decrease in the effective degrees of freedom and/or an additional energy release mechanism. We discuss the consistency of our findings with the fluctuating-moment effect in large-scale compressive fluctuations as such an energy release mechanism.

Probabilistic Solar Flare Forecasting from Magnetograms with Weakly Supervised Contrastive Learning **P2-12**

Ekaterina Dineva [1], J. Magdalenić [1,2], and S. Poedts [1]
[1]KU Leuven, Centre for mathematical Plasma-Astrophysics (CmPA), [2]Royal Observatory of Belgium (ROB)

Reliable solar flare forecasting is limited by two forms of class imbalance in active region time series: (i) the overwhelming dominance of the non-flaring, quiet state over the eruptive state, and (ii) the insufficient separability between common, physically similar event classes (e.g. C-class versus M-class flares). Although empirical parameters derived from the photospheric vector magnetic field (VMF), such as those provided by SDO/HMI SHARP products, capture aspects of active region complexity and free energy build-up, they often evolve smoothly and overlap across flare classes. Consequently, while many models can distinguish between flares and no-flares reasonably well, they struggle to distinguish flare magnitude and association with eruptive phenomena (e.g. CMEs) using photospheric information alone. This suggests that improved flare-class separation requires (a) the explicit definition of what constitutes 'similarity' between pre-flare states, and (b) parametrization that emphasizes flare-relevant structure over common active region features.

We investigate a representation learning strategy that combines the parametrization of SDO/HMI SHARP VMF cutouts using a Variational Autoencoder (VAE) with a contrastive stage to reshape the resulting embedding geometry. First, a VAE is trained to encode SHARP cutouts into compact latent vectors that capture active region morphology. These vectors are then refined using a Siamese-like objective constructed from weak supervision, which uses event labels and empirical SHARP parameters as proxies for elevated flare likelihood. The contrastive stage then uses this weak supervision to encourage a latent geometry that better reflects flare-relevant evolution. This study emphasizes latent-space structure, i.e. neighbourhood consistency and class-conditional clustering, and evaluates whether these properties facilitate improved probabilistic prediction across multiple forecast horizons, by training lightweight downstream models on (i) empirical parameters, (ii) VAE latents and (iii) their combined representations.

Observational Constraints on the Critical Height of Eruptive Filaments and the Role of Electric Current Neutralization **P2-13**

Johan Muhamad [1], K. Kusano [2], S. Masuda [2], and A. D. Pangestu [1,2]
[1]Research Center for Space, National Research and Innovation Agency (BRIN), Indonesia, [2]Institute for Space-Earth Environmental Research, Nagoya University, Japan

A fundamental challenge in solar physics is identifying the precise conditions that trigger magnetic flux rope eruptions, specifically determining the critical height for torus instability onset within Active Regions (ARs). Unlike quiescent filaments, AR filaments are situated at lower altitudes and are often obscured by the high-intensity background of the active corona. Here we present a rare observational determination of the critical height for an eruptive AR filament by utilizing stereoscopic reconstructions from SDO and STEREO data. We discuss the relationship between the magnetic structure of active regions and filament eruptivity, building upon the theoretical framework established in Muhamad and Kusano (2025). Our previous work demonstrated that the ratio of the degree of electric current neutralization and critical height significantly influences the stability and early acceleration of eruptive events. Here, we present a new observational confirmation of this relationship. Our findings provide observational confirmation that the combination of current neutralization and decay index are important factors in determining the eruptivity. This result offers a clearer physical link between the pre-eruptive magnetic environment and the trigger mechanism of solar eruptions.

Multi-Solar Cycle Analysis of Magnesium II Index Correlation with Extreme Ultraviolet Irradiance and Implications for Space Weather Applications **P2-14**

Lawal Hammed Adeniyi [1,2], E. Isrel.al Leke [1], and S. Martin [3,4]
[1]Department of Physics, Faculty of Science, Air Force Institute of Technology, Nigerian Air Force Base, Nigeria, [2]Africa Space Innovation Centre / French South African Institute of Technology, Department of Electrical, Electronic, and Computer Engineering Cape Peninsula University of Technology, Cape Town, South Africa, [3]South African National Space Agency, [4]Department of Physics and Astronomy, University of the Western Cape, Bellville, South Africa

Solar extreme ultraviolet (EUV) radiation is the primary energy input governing Earth's thermospheric and ionospheric dynamics, yet its direct measurement remains challenging. This necessitates the use of reliable proxy indices. This study presents a multi-solar cycle analysis (Cycles 22-25) evaluating the performance of the Mg II core-to-wing ratio index against the traditional F10.7 cm radio flux as proxies for He II 30.4 nm irradiance, a critical EUV emission line. Using the Bremen composite dataset spanning 1978-2025, our results demonstrate the Mg II index's superior efficacy, governed by its formation in the chromosphere—a region more directly linked to the underlying photospheric magnetic flux that drives solar variability through the solar dynamo process. We find the Mg II-He II correlation remains robust ($r = 0.96$) across all solar activity levels, adhering closely to the principles of linear regression and exhibiting minimal degradation during solar minimum. In contrast, the F10.7-He II correlation shows significant phase-dependent weakening ($r = 0.85$ overall, dropping to 0.70 during minima), consistent with its origin in thermal bremsstrahlung processes in the corona that can become decoupled from photospheric magnetic drivers in quiet-Sun conditions. The derived empirical relationship between Mg II and He II provides a reliable transfer function, with $R^2 = 0.92$ for the linear regression. Consequently, integrating the Mg II index into space weather models, particularly for satellite drag calculations based on thermospheric density laws (e.g., photochemical absorption and heating principles), is recommended to significantly reduce prediction errors and enhance operational reliability.

Automation of the Spectroscopic Chuo-university Astronomical Telescope (SCAT) for Monitoring and Follow-up Observations of Transient Objects **P2-15**

Nagisa Nagashima [1], H. Ogaki [1], T. Suzuki [1], Y. Ishihara [1], H. Kawai [1], Y. Tsuboi [1], H. Takahashi [2], T. Yoneyama [3], and D. Ishi [4]
[1] Chuo University, Japan, [2] Institute for Space-Earth Environmental Research, Nagoya University, Japan, [3] The University of Tokyo, Japan, [4] ISAS/JAXA, Japan

Solar flares induce ionospheric disturbances and geomagnetic storms through Coronal Mass Ejections (CMEs) and Solar Energetic Particles (SEPs), affecting modern technological systems. Recent observations by the Kepler space telescope and MAXI have detected "superflares" that release energies $10^3 - 10^6$ times greater than typical solar flares, highlighting the need to understand their physical mechanisms. Because stars cannot be spatially resolved like the Sun, the physical nature of stellar flare loops remains poorly constrained. Extending magnetic reconnection models established in solar physics to stellar flares is therefore important for plasma physics.

In addition, mass ejections associated with giant flares may influence exoplanet habitability through atmospheric stripping. To investigate the occurrence rates and physical processes of such transient phenomena, simultaneous multi-wavelength observations of solar and stellar events are required.
The Spectroscopic Chuo-university Astronomical Telescope (SCAT) has played an important role in such observations (e.g., Kawai et al. 2022). SCAT is a 36-cm telescope installed on the rooftop of Chuo University's Korakuen campus in downtown Tokyo and is mainly used for low-resolution spectroscopy. Because spectroscopic observations employ a narrow slit with a width of approximately 10 arcseconds, target acquisition requires much higher positional accuracy than imaging or photometric observations. This requirement presents a major challenge for autonomous operation. In particular, unlike modern alt-azimuth mounts with high-precision encoders, equatorial mounts often suffer from mechanical backlash and non-linear pointing errors, making accurate slit acquisition intrinsically difficult.
As a consequence, conventional SCAT operations have relied on manual control, resulting in limited responsiveness to transient alerts and a significant operational burden during long-term monitoring. This study aims to address these limitations by developing an efficient and fully unmanned spectroscopic observation system.
The system adopts a database-centric architecture to manage independent control modules and employs a hybrid operating environment: Windows for hardware control, including the telescope mount and cameras, and Linux (via the Windows Subsystem for Linux, WSL) for image analysis. This configuration enables integration of standard astronomical software, such as SExtractor and WCSTools, into an automated control loop. The ultimate goal is to implement a three-stage acquisition process—an initial telescope slew based on catalog coordinates, a coarse pointing correction using plate solving, and a final fine-guidance step—to introduce targets into a 10-arcsecond spectroscopic slit.
In this work, we focus on the implementation and verification of the Wide Field Program (WFP), corresponding to the second stage of this process. The WFP applies plate solving to wide-field images to determine the celestial coordinates of the telescope's current pointing. Demonstration experiments show that the WFP operates correctly within the hybrid system architecture. Log analyses confirm that even when the initial pointing error exceeds 2000 arcseconds, the software can identify target coordinates, calculate offsets, and automatically correct the telescope position to place the target at the center of the wide field camera's field of view. Through this work, the implementation of the WFP, one of the core components of the automated acquisition sequence, has been completed.

BABAR-ERI: An Innovative Solution for Imaging Broadband Radiation at High Spatial Resolution

P2-16

Odele Coddington [1] *and the BABAR-ERI team*
[1] *Laboratory for Atmospheric and Space Physics, University of Colorado Boulder*

Measuring outgoing broadband radiation is an essential component to quantifying the energy budget of planetary bodies. On Earth, these measurements are used in the detection and attribution of climate change signals to their underlying sources. Advancing the radiometric accuracy and enhancing the spatial resolution to increase the information content of broadband radiation measurements are key to enhancing and accelerating the process-level understanding of climate drivers, such as clouds and aerosols. On other planetary bodies, such as the Moon, broadband radiation measurements at high accuracy and high spatial resolution are essential for determining the location and extent of water ice, measurements essential for understanding lunar volatile evolution and enabling future exploration.
In this presentation, we will present the development and performance capabilities of a new, low size, weight and power (SWaP) instrument designed to enhance and accelerate process-level understanding from broadband radiation measurements at higher spatial resolution and accuracy.
The Black Array of Broadband Absolute Radiometers (BABAR) Earth Radiation Imager (ERI) is an innovative, small, and adaptable satellite instrument developed to image outgoing broadband radiation at 1-km spatial footprint and $<1\%$ uncertainty under the support of NASA's Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP). BABAR-ERI is a 12U CubeSat push-broom imager. It measures the total emitted (0.3 to 100 μm) and shortwave reflected (0.3 to 4 μm m) broadband radiation at 32 x 1 km spatial resolution from two co-registered telescopes. The longwave broadband radiation is derived from the subtraction of the shortwave radiation from the total channel. The primary technology advancement is the 32-element, ambient temperature, microbolometer linear array detectors with vertically aligned carbon nanotubes (VACNT) as the optical absorber. Closed-loop electrical substitution techniques at each detector pixel provide fast and precise radiometry and eliminate the need for on-orbit radiometric calibration. Absolute radiometry is verified during ground calibrations using blackbody sources and an absolute detector standard, the Planar Bolometric Radiometer for Radiance (PBR-R), also developed under the program. An extremely long-life optical chopper was also designed to modulate the incident radiation at 7 Hz, making more than 2 million revolutions over a 2.5-year mission life. Chopping the incident light allow for measurements relative to each detector's baseline in order to maintain high accuracy power readings.

Type II Radio Bursts and Their Relationship with Space Weather Phenomena

P2-17

Pooja Devi [1], *R. Miteva* [2], *R. Chandra* [3], *K. Koleva* [4], *and B. Lawrance* [5]
[1] Institute of Theoretical Astrophysics, University of Oslo, Norway, [2] Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences, Sofia, Bulgaria, [3] Department of Physics, DSB Campus, Kumaun University, Nainital, India, [4] Space Research and Technology Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria, [5] Department of Big Data Management, Gangseo University, Seoul 07661, Republic of Korea

We present the first comprehensive statistical investigation of type II radio bursts spanning the metric (m) to dekametric–hectometric (DH) wavelength ranges and their associations with solar and space weather (SW) phenomena. These phenomena include solar flares (SFs), sunspot (SN) configurations, filament eruptions, coronal mass ejections (CMEs), their interplanetary counterparts (ICMEs) and shocks, in situ particle enhancements, and geomagnetic storms (GSs). Metric-only and combined m + DH type II bursts are identified using dynamic spectra from the global Radio Solar Telescope Network (RSTN) together with Wind/WAVES observations, while DH-only type II events are taken from an established Wind/WAVES catalog. Temporal and spatial associations between the radio bursts and the aforementioned phenomena are examined over solar cycle 24, separately for the three subclasses of type II bursts: m-only, m + DH, and DH-only. We quantify occurrence rates as a function of the intensity of the associated SW phenomena and find the strongest associations with CMEs, SFs, filament eruptions, and SN configurations, while significantly weaker relationships are observed for ICMEs, interplanetary shocks, energetic particles, and GSs. Finally, we discuss the implications of these results for their potential application in empirical and physics-based SW forecasting models.

Exploring the Dominant Process of Solar Toroidal Magnetic Flux Loss **P2-18**

Zebin Zhang [1] *and Y. Chen* [1]
[1]Institute of Frontier and Interdisciplinary Science, Shandong University, Qingdao, Shandong 266237, People's Republic of China
[2]Institute of Space Sciences, Shandong University, Shandong 264209, People's Republic of China

As the solar magnetic cycle evolves, subsurface toroidal magnetic flux is systematically generated and lost, and this work aims to identify the dominant process behind the flux loss. By employing a data-driven dynamo model and holding surface magnetic flux transport identical across the cycles 12–21, we conducted numerical experiments to isolate and assess the loss of subsurface toroidal flux, and then compared the results with two observational constraints: the butterfly diagram and the observed correlation between the polar field at cycle minimum and the strength of the next cycle. We found that under weak bulk diffusivity, the loss of the previous cycle's toroidal flux is dominated by cancellation with newly generated flux, causing the new cycle's actual flux to differ from its generated value and thereby preventing the simulation of the observed polar field–cycle strength correlation. When diffusivity is increased to a level where it dominates flux loss, residual flux is more effectively removed, restoring the polar field–cycle strength correlation, yet operating in the diffusion-dominated regime suppresses the formation of the butterfly diagram. In contrast, active region emergence acts as an efficient mechanism for removing residual flux, and when it dominates the flux loss, both the correlation and the butterfly diagram are successfully reproduced. Thus, we conclude that active region emergence dominates the subsurface toroidal flux loss.

SESSION 3: Solar Wind, Magnetosphere, and Ionosphere Coupling

Progress and Prospects in Solar Wind–Magnetosphere–Ionosphere Coupling **K4**

Vassilis Angelopoulos [1]
[1]University of California at Los Angeles

Recent availability of coordinated multipoint observations of the near-Earth space environment, from the ground and from low- and high-altitude missions, has enabled major breakthroughs in our understanding of solar wind-geospace coupling. A central theme emerging from studies of the geospace response to dayside reconnection, under a wide range of upstream conditions, is the localization of energy input, release, and ultimate dissipation. This localization is an important contributor to geoeffectiveness, as it allows energy conversion far from the Earth to penetrate the dipole field. Energy is then deposited in the ring current and radiation belts, as well as to the ionosphere through field-aligned currents and particle precipitation. Future advances will depend on well-designed missions, with significant ground-space-modelling coordination, focused on critical aspects of this system-wide coupling, able to test our theories and advance our predictive models. International coordination toward this goal—under the auspices of organizations such as SCOSTEP and COSPAR—is essential to encourage better planning; foster commensurate or complementary instrumentation; establish agreements on data exchange and common analysis tools; and promote efficient exchange of ideas.

Recent Progress and Future Potential on Understanding Magnetosphere-Ionosphere Coupling over the Polar Caps **O3-1**

Qing-He Zhang [1,2], *Y.-L. Zhang* [3], *C. Wang* [1], *K. Oksavik* [4,7], *L. Lyons* [5], *M. Lockwood* [6], *B.-B. Tang* [1], *Z.-Y. Xing* [2], *Y.-Z. Ma* [2], *Y. Wang* [2], *D. Zhang* [1], *S. Lu* [2], *Z.-F. Xiu* [2], *and X.-Y. Wang* [2]
[1]State Key Laboratory of Solar Activity and Space Weather, National Space Science Center, Chinese Academy of Sciences, Beijing, China, [2]Shandong Provincial Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, Institute of Space Sciences, Shandong University, Weihai, China, [3]The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, USA, [4]Department of Physics and Technology, University of Bergen, Bergen, Norway, [5]Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, CA, USA, [6]Department of Meteorology, University of Reading, Earley Gate, UK, [7]Arctic Geophysics, University Centre in Svalbard, Longyearbyen, Norway

The polar cap ionosphere is often filled with plasma patches and auroras. Their appearance not only directly links to solar wind-magnetosphere-ionosphere coupling processes, but also indicates meso-scale flows that result in different space weather disturbances. Here we summarize the recent progress on the formation and evolution of polar cap patches and auroras: 1) Polar cap patches evolve along polar ionospheric convection streamlines and can be used to directly trace the full Dungey convection cycle. Patches as well as polar cap arcs aid in describing meso-structuring of polar-cap convection. 2) A space hurricane has been identified above the magnetic north pole with strong accelerated electron precipitation, intense clockwise circulation of the plasma flow, ion upflow, upward FAC and circular magnetic field perturbation, triggered by quasi-steady single-lobe reconnection. 3) A general mechanism has been proposed for the formation of multiple transpolar auroral arcs (TPA) during northward IMF: strong flow shear sheets in the magnetosphere generate field aligned current (FAC) sheets which field-aligned accelerate electrons through the Knight's current-voltage process to precipitate into the polar cap ionosphere. 4) A merging of poleward edges of a conjugate horse-collar aurora (HCA) has been identified in both hemispheres' polar ionosphere, indicating an almost complete disappearance of the open-flux polar cap and a shrunk and nearly closed magnetosphere due to quasi-steady dual-lobe reconnection continuously eroding magnetotail open and even closed magnetic field lines that re-closed at the dayside magnetopause under long-time strong northward IMF. These results indicate that there is significant energy disposition under a northward IMF condition. These results invite us to answer following questions: 1) how do the formation and evolution of polar cap patches/auroras and related polar cap dynamics reflect and affect solar wind-magnetosphere-ionosphere coupling processes? 2) how does polar cap dynamics impact the lower atmosphere and GNSS navigation and radio communications? 3) how to develop models to predict the polar cap dynamics and their associated scintillation?

Characterizing the High-latitude Ionospheric Irregularities Dynamics via Spectral Analysis: The May 2024 Geomagnetic Storm Case Study **O3-2**

Lucilla Alfonsi [1], *L. Spogli* [1], *C. Cesaroni* [1], *and E. Pica* [1]
[1]Istituto Nazionale di Geofisica e Vulcanologia (INGV)

Ionospheric irregularities, characterized by localized plasma density fluctuations, significantly impact the propagation of trans-ionospheric radio signals. These structures induce refractive and diffractive effects known as ionospheric scintillations posing a substantial threat to the reliability of Global Navigation Satellite Systems (GNSS) and associated navigation services.
This study investigates the formation and dynamics of high-latitude irregularities using high-rate data from GNSS Ionospheric Scintillation Monitoring (ISM) receivers. We adopt the spectral analysis of raw GNSS measurements sampled at 50 Hz by analysing the Power Spectral Density (PSD) of the scintillation signals to extract characteristic Fresnel scales and estimate irregularity drift velocities. To validate the results, we compare the obtained drift velocity with the results of a cross-correlation analysis performed by using nearby GNSS stations. This quantitative approach provides critical insights into the physical mechanisms driving ionospheric structuring, specifically the coupling between auroral precipitation, magnetospheric forcing, and plasma dynamics during periods of intense space-weather activity.

The proposed framework is applied to the geomagnetic storm of May 2024, the most severe event in the last two decades. The extreme intensity of this storm produced unique irregularity features that serve as a benchmark for validating spectral methodologies.
Acknowledgments: This study was carried out in part within the Space It Up project funded by the Italian Space Agency, ASI, and the Ministry of University and Research, MUR, under contract n.2024-5-E.0 - CUP n. I53D24000060005

High-Latitude Ionosphere Response to Solar Wind Forcing in TIE-GCM Using Different Plasma Convection Models During 2012-2013 Winter **O3-3**

Pelin Iochem [1], C. Borries [1], S. Tasnim [1], F. Günzkofer [1], F. Heymann [1], and J. Kusche [2]
[1]Institute for Solar-Terrestrial Physics, German Aerospace Center (DLR), Neustrelitz, Germany, [2]Institute of Geodesy and Geoinformation, University of Bonn, Bonn, Germany

The solar wind forcing drives a systematic and persistent modulation of the high latitude ionosphere, particularly during winter nighttime conditions. In our previous studies, we identified and quantified the two sources of this response with corresponding time lags over Tromsø location during a time period of 26-years using long term solar wind and ionosphere observations, demonstrating that the auroral particle precipitation (magnetospheric loading-unloading processes) and plasma convection (transport processes) contribute with distinctive response times. The study focused on Tromsø location, as multiple data sources locally collocate there. The extent to which physics-based thermosphere model is able to reproduce this persistent response and its spatial variability in high-latitude northern hemisphere remains unquantified mostly due to the challenges in modelling the high-latitude electrodynamics.
In this study, we extend the investigation from a regional observation-based perspective to global modelling one by using Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM). We perform multiple TIE-GCM runs for the previously studied 2012-2013 northern hemisphere winter driven by three different types of convection forcing: AMGeO, Weimer and Heelis. We use identical boundary conditions and spatial resolutions for a comparative assessment of high-latitude electrodynamic response. The TIE-GCM Total Electron Content (TEC) values are compared with the TEC from global ionosphere maps given by International GNSS System (IGS) to quantify the temporal and spatial differences. Using statistical metrics including mean bias, standard deviation and root mean square error, we characterize the model capabilities under varying convection forcing. Our results provide a better understanding of how the persistent ionospheric response to solar wind variations is represented by high-latitude modelling of the electrodynamics. We discuss the details in the meeting with respect to model capabilities.

Effects of Ionospheric Disturbances on GNSS Positioning Errors during the Geomagnetic Storm on May 2024 **O3-4**

Kyosei Nakamura [1], Y. Otsuka [3], A. Shinbori [3], M. Nishioka [2], S. Perwitasari [2], and W. Fu [1]
[1]Graduate School of Engineering, Nagoya University , [2]National Institute of Information and Communications Technology (NICT), [3]Institute for Space-Earth Environmental Research, Nagoya University

Signals from the Global Navigation Satellite System (GNSS) travel through the ionosphere before being received by ground-based receivers. Consequently, ionospheric disturbances in electron density can degrade signal quality and reduce positioning accuracy. Previous studies have established that ionospheric disturbances during geomagnetic storms can impact GNSS positioning. Specifically, during the geomagnetic storm of May 2024, a region of increased Total Electron Content (TEC) was observed extending northwestward over Japan. Within this region, plasma bubbles—localized TEC depletions—were also detected. Previous studies have also shown that the appearance of these structures correlates with an increase in GNSS positioning errors.
This study investigates the relationship between ionospheric disturbances and GNSS kinematic positioning errors during the May 10–11, 2024 geomagnetic storm, using data from the Geospatial Information Authority of Japan's GNSS Earth Observation Network System (GEONET) and SoftBank Corporation's GNSS network. As a result, the vertical TEC in Morioka, Japan, was observed to increase to 27.2 TECU. To detect the electron density irregularities in the ionosphere, we examined the Rate of TEC change Index (ROTI), which is calculated as the 5-minute standard deviation of 30-second TEC differences. ROTI values were found to increase between 16:00 and 17:00 UT, with an average of 2.1 TECU/min. Using data from receivers installed in the Tohoku region, we performed kinematic positioning with RTKLIB. A significant increase in the three-dimensional positioning errors was observed between 13:00 and 21:00 UT on May 11, 2024.
We further investigated the dependence of kinematic positioning errors on the orientation of the baseline between the base and rover stations. Errors tended to be larger for north–south oriented baselines compared to east–west baselines. The error ratio between north–south and east–west baselines was approximately 1.2 before the disturbances but rose to about 2.2 between 13:00 and 13:30 UT, when ROTI value increased. These results suggest that the structure of ionospheric disturbances influences positioning errors. In this presentation, we will discuss the relationship between baseline-direction-dependent positioning errors and the structures of these ionospheric disturbances.
Acknowledgments: The SoftBank's GNSS observation data used in this study are provided by SoftBank Corp. and ALES Corp. through the framework of the "Consortium to utilize the SoftBank original reference sites for Earth and Space Science"

Statistical Study of Ionospheric GNSS TEC Response to Pc3–6 ULF Waves O3-5

Chris Watson [1] *and P. T. Jayachandran* [1]
[1] *University of New Brunswick, Fredericton, Canada*

Several case studies have demonstrated fluctuations in ionospheric total electron content (TEC) associated with ultra-low-frequency (ULF) magnetic field variations observed by satellite and ground-based magnetometers. Despite these observations, the TEC response to ULF waves remains poorly understood, appearing intermittent and difficult to predict, and the physical mechanisms driving these variations are still unresolved.
We present a climatological survey of the TEC response to Pc3–6 ULF waves (frequencies up to 200 mHz) using high-rate Global Positioning System (GPS) receivers at Sanikiluaq (56.54°N, 280.77°E) and Fort Simpson (61.76°N, 238.77°E), located in the auroral region of the Canadian Arctic. In situ ULF wave activity was monitored using magnetometer measurements from the GOES-13 and GOES-15 satellites, whose magnetic footprints map near Sanikiluaq and Fort Simpson, respectively. Corresponding ground magnetic field variations were obtained from co-located ground magnetometers.
Between 2010 and 2021, we identified 8,290 narrowband Pc3–6 ULF wave events observed by GOES during periods of simultaneous GPS TEC and ground magnetometer coverage. Cross-spectral analysis between GOES magnetic field fluctuations, GPS TEC, and ground magnetic field measurements was used to assess coherence and phase relationships among the datasets. ULF wave occurrence exhibited discrete peaks in the morning, afternoon, and nighttime sectors, with maximum seasonal occurrence near the December solstice.
Coherent TEC fluctuations were detected in approximately 15% of GOES ULF wave events. Of these TEC-responsive events, 92% were accompanied by coherent ground magnetic field variations, while 8% exhibited no corresponding ground magnetic signature. TEC perturbation amplitudes generally increased with ULF wave amplitude and decreased with increasing wave frequency, although notable exceptions were observed. In particular, significant TEC variations occasionally accompanied small-amplitude Pc3-band waves. Additional factors influencing the TEC response, including season, local time, background ionospheric conditions, and energetic particle fluxes measured by GOES, will also be discussed.

Sensing Earth's Plasmasphere and Ionosphere from the Moon: first observations from the LuGRE mission O3-6

Luca Spogli [1], *C. Cesaroni* [1], *M. Guerra* [1], *R. Ghidoni* [1], *V. Ventriglia* [1], *A. Minetto* [2], *A. Nardin* [2], *L. Alfonsi* [1], *and F. Dovis* [2]
[1] *Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy,* [2] *Politecnico di Torino, Turin, Italy*

The Lunar GNSS Receiver Experiment (LuGRE) is a recently accomplished lunar mission, jointly developed by NASA and Italian Space Agency (ASI), which successfully extended Global Navigation Satellite System (GNSS) based navigation and timing to the Moon. Indeed, it demonstrated the possibility to use the terrestrial GNSS signals from the Moon's surface, originally designed for Positioning, Navigation, and Timing (PNT) in the cislunar environment.
This paper exploits the LuGRE dataset as an ultra-long baseline reference for unprecedented scientific observations of Earth's plasma environment. The unique signal path, traversing the vast expanse between the orbiting GNSS satellites and the lunar receiver, allows for the highly sensitive measurement of integrated Total Electron Content (TEC) dominated by the Earth's topside ionosphere and plasmasphere.
Unlike traditional radio occultation observations from Low-Earth Orbits (which limit the ionospheric probing up to the satellite's altitude), the unique geometry of the LuGRE receiver on the lunar surface allows probing the plasma up to the outer boundary of Earth's charged atmosphere.
We detail the methodology for isolating the various plasma contributions from the dual-frequency GNSS observables and present the first characterization of this high-altitude plasma environment from a lunar vantage point. LuGRE's first scientific findings validate its potential and establish the Moon as an outpost to monitor the planetary boundary of the charged atmosphere that governs space weather at Earth.

Magnetospheric drivers of Field-Aligned Currents during Negative Solar Wind Dynamic Pressure Pulse: Quantifying MHD contributions using the MAGE global model O3-7

Geetashree Kakoti [1,2], *K. Shiokawa* [1], *and D. Lin* [2]
[1] *Institute for Space–Earth Environmental Research, Nagoya University,* [2] *Clemson University, South Carolina, USA*

Negative solar wind dynamic pressure pulses are important transient drivers of magnetosphere-ionosphere (M-I) coupling, causing rapid magnetospheric expansion, magnetic field reconfiguration, and restructuring of current systems and plasma convection patterns throughout the ionosphere. Abrupt perturbations in ground magnetometer measurements, known as negative sudden impulses (SIs), are direct manifestations of solar wind dynamic pressure changes in global magnetospheric reconfiguration. At high latitudes, the negative SI responses are controlled by changes in field-aligned current (FAC) systems and their ionospheric closure. In this study, simulations from the Multiscale Atmosphere-Geospace Environment (MAGE) model are used to perform a quantitative comparison of observed SI signatures during strong negative pressure pulse event and to identify the dominant magnetospheric drivers of these SIs. High-resolution ground magnetometer data are used to identify and characterize both the preliminary reverse impulse (PRI) and main impulse (MI) signatures during a strong negative pressure pulse event on 23 March 2023 at 14:33 UT, focusing on their amplitude, timing, and local time dependence. Newly formed FACs and their strengths and spatial distributions are analysed using both observations and simulations. MAGE successfully reproduces these key features, enabling a detailed examination of the underlying physical processes.

To achieve this, we used the field-aligned current density ($j_{||}$) formulation suggested by Hasegawa and Sato (1979), which separates contributions from three terms: magnetic field gradients acting on the perpendicular current, flow shear (vorticity), and density gradients in the direction of the inertial current. The MHD parameters simulated from MAGE are used to compute each term along model magnetic field lines for the negative pressure pulse event, allowing a quantitative assessment of their relative roles in generating FACs during the negative SI.

This work provides a novel approach for quantifying the dominant magnetospheric drivers of FACs during a negative solar wind pressure pulse using the self-consistent MAGE model, establishing a framework for connecting global MHD formulations of $j_{||}$ with observed negative SI signatures in the coupled M-I system.

Reference: Hasegawa, A., Sato, T. (1979). Generation of Field Aligned Current During Substorm. In: Akasofu, SI. (eds) Dynamics of the Magnetosphere. Astrophysics and Space Science Library, vol 78. Springer, Dordrecht. https://doi.org/10.1007/978-94-009-9519-2_28.

The Role of Kinetic Instabilities and Waves in Collisionless Magnetic Reconnection **O3-8**

Giulia Cozzani [1,2], D. B. Graham [3], Y. V. Khotyaintsev [3,4], V. D. Wilder [5], J. C. Holmes [6], T. K. M. Nakamura [7], J. Büchner [8,9], K. Dokgo [10], L. Richard [3], K. Steinvall [11], C. Norgren [3,12], L.-J. Chen [13], H. Ji [14,15], J. F. Drake [16], J. E. Stawarz [17], and S. Eriksson [18]

[1]Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E), Orléans, France, [2]Department of Physics, University of Helsinki, Helsinki, Finland, [3]Swedish Institute of Space Physics, Uppsala, Sweden, [4]Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden, [5]Department of Physics, University of Texas at Arlington, Arlington, TX, USA, [6]Los Alamos National Laboratory, Los Alamos, NM, USA, [7]Space Research Institute, Austrian Academy of Sciences, Graz, Austria, [8]Max Planck Institute for Solar System Research, Göttingen, Germany, [9]Centre for Astronomy and Astrophysics, Technical University of Berlin, Berlin, Germany, [10]Southwest Research Institute, San Antonio, TX, USA, [11]Department of Physics, Chalmers University of Technology, Göteborg, Sweden, [12]Department of Physics and Technology, University of Bergen, Bergen, Norway, [13]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [14]Department of Astrophysical Sciences, Princeton University, Princeton, NJ, USA, [15]Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, NJ, USA, [16]Department of Physics, Institute for Physical Science and Technology and Joint Space Science Institute, University of Maryland, College Park, MD, USA, [17]Northumbria University, Newcastle upon Tyne, UK, [18]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, USA

Magnetic reconnection converts magnetic field energy into particle energy by breaking and reconnecting magnetic field lines. Magnetic reconnection is a kinetic process that generates a wide variety of kinetic waves via wave–particle interactions. Kinetic waves have been proposed to play an important role in magnetic reconnection in collisionless plasmas by, for example, contributing to anomalous resistivity and diffusion, particle heating, and transfer of energy between different particle populations. These waves range from below the ion cyclotron frequency to above the electron plasma frequency and from ion kinetic scales down to electron Debye length scales. In this talk, I will summarize the progress made in understanding the relationship between magnetic reconnection and kinetic waves that has been presented in a recent review paper [1].

In this review, we focus on the waves in different parts of the reconnection region, namely, the diffusion region, separatrices, outflow regions, and jet fronts. Particular emphasis is placed on recent observations from the Magnetospheric Multiscale (MMS) spacecraft and numerical simulations, which have substantially increased our understanding of the interplay between kinetic waves and reconnection.

[1] Graham, D.B., Cozzani, G., Khotyaintsev, Y. V. et al. The Role of Kinetic Instabilities and Waves in Collisionless Magnetic Reconnection. Space Sci Rev 221, 20 (2025). https://doi.org/10.1007/s11214-024-01133-7

Selected Highlights from the Cluster Ion Spectrometry (CIS) Experiment, After 24 Years of Successful Operation **O3-9**

Iannis Dandouras [1,2]

[1]Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse / CNRS / CNES, Toulouse, France , [2]Center for Space Research and Technology, Academy of Athens, Greece

Following 24 years of space operations, during which the Cluster spacecraft have greatly advanced our understanding of the dynamics of the Earth's magnetosphere and its interaction with the solar wind, the first two of the four-spacecraft performed a controlled re-entry into the Earth's atmosphere in September 2024 and October 2025. The CIS (Cluster Ion Spectrometry) experiment has been one of the spearheads of the Cluster mission, with more than 1300 science papers published, based on the analysis of the data provided by the experiment. Major breakthroughs were possible in topics such as collisionless shocks, boundary layers, substorm development, auroral physics, the dynamics of the plasmasphere, ionospheric ion outflow and escape, ring current dynamics, or extreme space weather events. All the high-resolution CIS data are archived and publicly available at the Cluster Science Archive (https://csa.esac.esa.int).

Equinoctial and Solstitial Averages of Magnetospheric Relativistic Electrons **O3-10**

Daniel Baker [1] *and S. Kanekal* [2]
[1]*University of Colorado, Boulder, CO,* [2]*NASA Goddard Space Flight Center*

Data from SAMPEX, POLAR, and other spacecraft missions has previously shown that high energy electrons ($E \gtrsim 1\ MeV$) vary in a remarkably coherent way throughout the entire outer radiation zone of the Earth ($2.5 \lesssim L \lesssim 6.5$).These data have been used to perform analysis of the flux variations of relativistic electrons throughout the outer trapping zone. This talk reports similar analyses of Van Allen Probes data from the REPT sensor system from 2012 to 2019. Averages are performed over monthly intervals centered on the spring and fall equinoxes and on the winter and summer solstices. Modulation is found such that equinoctial fluxes of electrons are larger than the solstitial fluxes based upon a superposed epoch analysis. These semiannual modulations of relativistic electron fluxes are compared with concurrent solar wind data and are examined in terms of prior models of geomagnetic activity modulation. This reveals a fascinating picture of solar wind coupling.

Characterisation of the Newly Formed Proton Belt Following the May 2024 Geospace Magnetic Superstorm **O3-11**

Evangelia Christodoulou [1,2], *H. D. R. Evans* [2], *M. Vuolo* [2], *I. A. Daglis* [1], *G. Santin* [2], *and P. Nieminen* [2]
[1]*Department of Physics, National and Kapodistrian University of Athens,* [2]*European Space Research and Technology Centre, European Space Agency*

Accurate detector response modelling is essential for interpreting particle flux measurements in space radiation environments. Consequently, it improves the characterisation of the low-Earth-orbit radiation environment and enhances our understanding of particle dynamics within the South Atlantic Anomaly (SAA). In this work, we derive a high-fidelity angular response function for the Next Generation Radiation Monitor (NGRM) unit on-board Sentinel-6 Michael Freilich (S6-MF) using Monte Carlo simulations implemented within ESA's GEANT4 Radiation Analysis for Space (GRAS) toolkit. The response function is used to reconstruct proton pitch-angle distributions (PADs) and to derive accurate S6-MF/NGRM omnidirectional fluxes using the Level 1 Version 1 directional proton differential flux measurements.
The PADs are parameterised using $\sin^n \alpha$ functional form, enabling retrieval of the anisotropy index n. For comparison, we also implement a smoothed top-hat response function to quantify the uncertainties introduced by simplified angular response models. We show that S6-MF/NGRM observations are strongly directional, and that uncorrected fluxes can substantially underestimate omnidirectional fluxes.
We highlight that realistic detector response modelling is critical for robust radiation belt characterisation, particularly under strongly anisotropic conditions. High-resolution maps of the PAD exponent and the derived omnidirectional fluxes are produced to examine the spatial gradients within and around the SAA and to assess temporal variability. Particular attention is given to the newly formed proton belt that was observed after the intense magnetic superstorm of May 2024, which resulted in significant changes to the inner magnetospheric proton population.

Spatial Scales and Cross-connection of Whistler-Mode Chorus and Hiss Waves in the Earth's Radiation Belts from Multi-spacecraft Projects Cluster, Van Allen Probes, and THEMIS **O3-12**

Oleksiy Agapitov [1], *D. Mourenas* [2], *and A. Artemyev* [3]
[1]*University of California Berkeley, CA, USA,* [2]*CEA France,* [3]*University of California Los Angeles, CA, USA*

Whistler-mode chorus and hiss waves play a central role in shaping outer radiation belt dynamics by governing electron acceleration and scattering across a broad energy range. A precise quantification of their temporal and spatial scales-encompassing generation, propagation, and damping processes - is essential for robustly modelling wave - article interactions in both non-linear and quasi-linear frameworks. Here we present multi-point measurements that constrain these scales across L = 2 - 6 and all magnetic local time (MLT), using coordinated observations from the Van Allen Probes (2013–2019) and, where applicable, THEMIS. Our analysis focuses on (1) the spatial extent of active wave regions (source generation and propagation), (2) the amplitude distribution of waves within source regions, and (3) the characteristic sizes and coherence of chorus wave packets.
Time-domain correlation analyses were applied to chorus power dynamics for spacecraft separations closer than 1,000 km (approximately every 70 days in 2012–2018 and every 35 days in 2018–2019), enabling empirical constraints on chorus packet extents. We find that chorus power correlations remain significant up to inter-spacecraft separations of roughly 400–750 km transverse to the ambient magnetic field, corroborating prior estimates of chorus packet scales.
The chorus source region exhibits slight asymmetry, with elongation biased toward either the azimuthal or radial directions. This asymmetry offers a natural explanation for the presence of two distinct scale regimes observed in the data.
Averaged wave amplitudes for chorus and hiss, analysed at multiple locations, reveal distinct radial and azimuthal extents of the corresponding active regions. These spatial patterns complement previous statistics derived from THEMIS, which were largely focused on larger L-shells ($L > 6$). In particular, both the source-region scale and the active-region size appear smaller inside the inner outer radiation belt ($L < 6$) relative to higher L-shells, implying a regional modulation of wave–particle interaction efficiency.
An unprecedentedly long interval of coordinated VLF measurements aboard the Van Allen Probes (9 hours of high-rate data, 16,384 samples per second, across two consecutive apogees on 15 July 2014) provides stringent constraints on wave packet coherence and source scales. Across spacecraft separations ranging from ∼100 to ∼5,000 km (predominantly radial), we quantify temporal coherence and spatial coherence scales, informing models of non-linear wave–particle coupling and quasi-linear diffusion.

The combination of Van Allen Probes and THEMIS data yields robust estimates for the transverse source-region scales of chorus waves, found to be on the order of 400–600 km for L-shells 4–6, with coherence scales for chorus approaching or slightly below 100 in both spatial and temporal domains, depending on local plasma conditions and magnetosphere dynamics.
The waveform phase processing of the VLF signals collected aboard the four Cluster SC and two VAP SC allowed to resolve the chorus coherence scale around 60-150 km.

How Can Propagation Speed of Interplanetary Shocks Affect the Radiation Belts Dynamic: A Comparative Observational and Statistical Investigation **O3-13**

Dianjun Zhang [1,2], *W. Liu* [1,2]
[1]School of Space and Earth Science, BeihangUniversity, Beijing, China, [2]Key Laboratory of Space Environment Monitoring and Information Processing of MIIT,Beihang University, Beijing, China

Relativistic electron dynamics in Earth's radiation belts are significantly influenced by interplanetary shocks (IPSs) associated with coronal mass ejections. We show that the propagation speed of an IPS controls the motion of the induced impulsive electric field. This field then drives the resonant "drift-in-phase" acceleration of relativistic electrons. As a consequence, the relativistic electron energy with the maximum variation of residual flux observed is determined by the IPS propagation speed, which contrasts with the traditional assumption that fast magnetosonic wave speed controls the resonance. To validate this hypothesis, we compare two IPS-driven radiation belt enhancement events with distinct shock speeds and perform a statistical analysis of 39 IPS events observed from 2013 to 2018. The case studies and statistical results consistently show that the drift velocity of electrons at the energy of peak flux enhancement correlates much more strongly with the IPS shock speed than with the localized fast magnetosonic wave speed in the inner magnetosphere.
These findings provide the first comprehensive observational confirmation that IPS propagation speed is the key parameter governing "drift-in-phase" acceleration of radiation belt electrons. This insight emphasizes the importance of IPS kinematics in radiation belt modelling and could improve the forecasting of shock-induced energetic electron enhancements.

Calculation of Radial Diffusion Coefficients combining data from RBSP and THEMIS missions **O3-14**

Konstantina Thanasoula [1], *C. Katsavrias* [1], *I. A. Daglis* [1], *C. Papadimitriou* [2], *A. W. Breneman* [3], *S. Tian* [4], *G. Balasis*[5] *and T. Sarris* [6]
[1]Department of Physics, National and Kapodistrian University of Athens, Greece, [2]SPARC – Space Applications and Research Consultancy, Athens, Greece, [3]Goddard Space Flight Center, NASA, Greenbelt, MD, USA, [4]Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, CA, USA, [5]IAASARS, National Observatory of Athens, Greece, [6]Department of Electrical & Computer Engineering, Democritus University of Thrace, GreeceUSA

In this study, we estimate radial diffusion coefficients (DLL) in the outer Van Allen belt using the Fei et al. (2006) formalism, which assumes a uniform azimuthal wave power distribution. However, in-situ measurements indicate that the azimuthal wave power distribution depends on the origin and propagation characteristics of the waves. Our goal is to create a comprehensive database that includes Power Spectral Density (PSD) and DLL data from multiple missions, thereby increasing both spatial and temporal coverage. In this way, the uncertainty caused by using only single-mission data, which could lead to under- or overestimation of radial diffusion coefficients, is reduced. We initially use magnetic and electric field data from the THEMIS and RBSP missions, and our future goal is to include additional missions such as ARASE, in order to increase azimuthal coverage. The derived products will be added to the existing "SafeSpace" database (https://synergasia.uoa.gr/modules/document/?course=PHYS120), which includes PSD and DLL computed from THEMIS mission data over a nine-year period.
Our results indicate that when spacecraft from the two missions (RBSP and THEMIS) are located at the same L^* and MLT, there is a strong correlation between their magnetic field measurements. We also perform a statistical analysis to investigate the dependence of radial diffusion coefficients on solar wind parameters, geomagnetic indices, and solar wind drivers, showing a significant energy dependence of DLL, particularly when the solar wind dynamic pressure is maximized. These findings provide deeper physical insight into the conditions under which radial diffusion is dominated by electric or magnetic field fluctuations and highlight the importance of combining data from multiple missions, as the increased coverage in MLT, L^*, and time provides a more comprehensive calculation of ULF wave PSD and, consequently, a more reliable estimation of DLL.

Couplings in the Magnetosphere During the Super Geomagnetic Storm of 10-11 May 2024 **O3-15**

Viviane Pierrard [1,2]
[1]Royal Belgian Institute for Space Aeronomy, Brussels, Belgium, [2]Université Catholique de Louvain, Earth and Life Institute – Climate Sciences ELI-C, Louvain-la-Neuve, Belgium

On 10 May 2024 at 17h:07 UTC, the simultaneous arrival of several solar coronal mass ejections (CME) generated the strongest geomagnetic storm of the last twenty years with a minimum Dst = -412 nT, usually referred to as the Mother's Day event. This event generated nice auroras visible in many countries of the world at unusual low latitudes. We have shown that the geomagnetic storm had important consequences on the radiation belts, especially an exceptional injection of protons in the South Atlantic Anomaly observed with PROBA-V/EPT instrument. We discovered also the first observation of four electron belts appearing during more than one month after the event [1]. This seems due to the influence of the cold background plasma of the plasmasphere on the loss of energetic electrons via hiss waves.

Moreover, with measurements of vertical total electron contents and with ionosonde observations from Europe, USA and South Korea, we showed that the ionization of the upper atmosphere shortly increased at the arrival of the CME, followed by a fast decrease at all latitudes [2]. The ionization remained very low for more than a full day. The sudden recovery in the middle of the second day on 12 May was very unusual.

The analysis of the observations at different latitudes and longitudes showed that the causes of the ionization variations during the superstorms were mainly due to strong perturbations in the ionospheric F layer and amplified by the plasmasphere's influence on the vertical total electron content.

Using many spacecraft and ground-based measurements and comparing with other strong events like the geomagnetic storm of 10 October 2024 corresponding to the second strongest event of the solar cycle 25 with Dst = - 335 nT, we show what were the most exceptional consequences of the Mother's Day event of 11 May 2024.

[1] Pierrard V., A. Winant, E. Botek, and M. Péters de Bonhome, The Mother's Day solar storm of 11 May 2024 and its effect on Earth's radiation belts, Universe, 10, 10, 391, 2024, doi: 10.3390/universe10100391

[2] Pierrard V. Verhulst T.G.W., Chevalier J.-M., Bergeot N., Winant A., Effects of the Geomagnetic Superstorms of 10–11 May 2024 and 7–11 October 2024 on the Ionosphere and Plasmasphere, Atmosphere, 16, 299, 2025, doi: 10.3390/atmos16030299

Latest Results on High-Frequency VLF Bursty Emissions from Multi-Point Observations — O3-16

Claudia Martinez-Calderon [1], J. Manninen [2], K. Shiokawa [1], Y. Kasahara [3], S. Matsuda [3], I. Shinohara [4], Y. Miyoshi [1], A. Shinbori [1], H. Yatsuya [1], M. Hanzelka [5], and D. Pisa [5]

[1] Institute for Space-Earth Environmental Research, Nagoya University, Japan, [2] Sodankylä Geophysical Observatory, Sodankylä, Finland, [3] Graduate School of Natural Science and Technology, Kanazawa University, Kanazawa, Japan, [4] Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Japan, [5] Institute of Atmospheric Physics of the Czech Academy of Sciences, Prague, Czechia

Relativistic electron dynamics in Earth's radiation belts are significantly influenced by interplanetary shocks (IPSs) associated with coronal mass ejections. We show that the propagation speed of an IPS controls the motion of the induced impulsive electric field. This field then drives the resonant "drift-in-phase" acceleration of relativistic electrons. As a consequence, the relativistic electron energy with the maximum variation of residual flux observed is determined by the IPS propagation speed, which contrasts with the traditional assumption that fast magnetosonic wave speed controls the resonance. To validate this hypothesis, we compare two IPS-driven radiation belt enhancement events with distinct shock speeds and perform a statistical analysis of 39 IPS events observed from 2013 to 2018. The case studies and statistical results consistently show that the drift velocity of electrons at the energy of peak flux enhancement correlates much more strongly with the IPS shock speed than with the localized fast magnetosonic wave speed in the inner magnetosphere.

These findings provide the first comprehensive observational confirmation that IPS propagation speed is the key parameter governing "drift-in-phase" acceleration of radiation belt electrons. This insight emphasizes the importance of IPS kinematics in radiation belt modelling and could improve the forecasting of shock-induced energetic electron enhancements.

Evidence of Interhemispheric Asymmetry in Swarm Geomagnetic Activity Indices Using Complexity Measures — O3-17

Constantinos Papadimitriou [1,2], G. Balasis [1], A.Z.Zoe Boutsi [1], and I. A. Daglis [2]

[1] IAASARS, National Observatory of Athens, Athens, Greece, [2] Physics Department, National and Kapodistrian University of Athens, Athens, Greece

Swarm data can be used to derive spaceborne indices of geomagnetic activity, capturing the same dynamic processes and exhibiting the same behaviour as ground-based geomagnetic indices traditionally used to monitor magnetic storm (SYM-H index) and substorm (AE index) activity. Given the fact that the official ground-based index for the substorm activity (i.e., the Auroral Electrojet – AE index) is constructed by data from 12 ground stations, solely in the northern hemisphere, it can be said that this index is predominantly northern, while the Swarm-derived AE index may be more representative of a global state, since it is based on measurements from both hemispheres. A few studies have addressed the question of whether the auroras are symmetric, between the northern and southern hemispheres. Therefore, the possibility to have different Swarm-derived AE indices for the northern and southern hemispheres respectively, may provide, under appropriate time series analysis techniques based on information theoretic approaches, an opportunity to further confirm the recent findings on interhemispheric asymmetry. Here, we also provide evidence for interhemispheric energy asymmetry in the ionosphere based on the analyses of Swarm-derived auroral indices AE North and AE South.

The Impact of Inductive Electric Fields on Magnetospheric Particle Dynamics — O3-18

Raluca Ilie [1], JH Liu [1], and L. Chen [2]

[1] University of Illinois at Urbana-Champaign, [2] University of Texas at Dallas

A detailed description of particle acceleration and transport throughout the Earth's magnetosphere requires accurate knowledge of both magnetic and electric field structures. Magnetic field topology governs guiding-center drifts, whereas electric fields control large-scale particle transport, energization, and access to different magnetospheric regions.

Despite substantial advances in magnetic field modelling, from simplified analytical formulations to empirical reconstructions and fully self-consistent numerical simulations, models of the magnetospheric electric field remain comparatively limited. Widely used approaches are predominantly empirical and quasi-static, typically based on mapping the solar wind dawn–dusk electric field into the polar ionosphere. Such treatments neglect the inductive electric field arising from time-dependent magnetic field variations. These inductive contributions are dynamic, continuous, and globally distributed, and their exclusion can lead to inaccurate representations of particle motion and loss processes.
In this work, we investigate the role of inductive electric fields in controlling particle acceleration and transport, using a combination of global MHD, regional drift-kinetic, and test-particle simulations. This framework allows the electric field to be separated into electrostatic and inductive components. Simulations that neglect the inductive term show increased inward penetration of energetic particles, distortion of the Alfvén boundary, and enhanced particle loss along open drift paths toward the dayside magnetosphere. In contrast, simulations that include both electric field components yield improved particle confinement and a more stable ring current configuration. These findings demonstrate that inductive electric fields are a critical ingredient for realistic modelling of inner magnetospheric dynamics and control the trapping of energetic particle populations in the region.

Multi-Scale Irregularities and Solar Wind-Driven Waves in the Martian Ionosphere **O3-19**

Christopher M. Fowler [1]
[1]Department of Physics and Astronomy, West Virginia University, WV, USA

Mars doesn't possess a global magnetic field, and the interaction of the solar wind with the gravitationally bound and electrically conducting ionosphere produces an induced magnetosphere that acts to decelerate and deflect the incident supersonic solar wind flow about the planet. Mars does however possess remnant crustal magnetic fields that rotate with the planet. This rotation combined with natural variability in the upstream solar wind drive a highly dynamic magnetosphere. The resulting environment is rich with plasma instabilities and processes that drive energy conversion and electromagnetic waves, for example. These phenomena can play important roles in transporting energy and momentum through the collisionless system. This talk will focus on ionospheric structure and dynamics at Mars that are driven by this solar wind interaction and the resulting coupling. In particular, this talk will describe a variety of coupling mechanisms, their impacts on the ionosphere, and summarize where current knowledge is lacking. This talk will finish by placing current knowledge at Mars in context with other planets such as Earth and Venus, highlighting what we may be able to learn from comparative studies, and outlining needs for future missions to address current unknowns at Mars.

Coupling Between the Solar Wind and Martian Ionosphere and Its Impact on Space Weather at Mars **O3-20**

Yuki Harada [1], *B. Sánchez-Cano* [2], *A. Ippolito* [3], *and Y. Migoya-Orue* [4]
[1]Nagoya University, [2]University of Leicester, [3]Istituto Nazionale di Geofisica e Vulcanologia, [4]The Abdus Salam International Centre for Theoretical Physics

The Martian space environment is characterized by the solar wind interaction with the upper atmosphere and crustal magnetic fields of Mars. The absence of a strong dipole magnetic field of internal dynamo origin leads to more direct interactions between the plasmas of solar wind and ionospheric origins at their interfaces, while localized crustal magnetic fields give rise to partially intrinsic magnetosphere-like behaviours. This unique and complicated situation is an intriguing aspect of the Martian magnetosphere in the context of comparative studies with other planetary magnetospheres. Meanwhile, the rapid response of the Martian magnetosphere and ionosphere to solar wind variations poses a challenge for understanding the Martian space environment in the space weather context. In particular, many past observational studies have indicated that the Martian ionosphere and magnetosphere can become highly disturbed during space weather events such as interplanetary coronal mass ejections and solar energetic particle events. It remains elusive what physical processes drive these disturbances and what impacts they have on the radiation and radio environments relevant to future explorations of Mars. We present a brief review of recent observations of the Martian ionosphere and magnetosphere during space weather events with a particular focus on multiple spacecraft studies and their implications for comparative studies with the terrestrial ionosphere and magnetosphere.

An Upper Limit on the Electron Flux in Jupiter's Inner Magnetosphere **O3-21**

Agapitos Dovles [1], *I. A. Daglis* [1,2], *G. Moutsiana* [1], *and L. Olifer* [3]
[1]Department of Physics, National and Kapodistrian University of Athens (NKUA), Athens, Greece, [2]Hellenic Space Center, Athens, Greece, [3]Department of Physics, University of Alberta, Edmonton, Alberta, Canada

Recent observational studies indicate that the so-called Kennel & Petshek limit, a theoretical upper limit on electron flux in Earth's magnetosphere, may exist. Studying the limit in environments such as Jupiter's magnetosphere can provide further valuable information about the behaviour of electrons in magnetospheres with intense activity. This study uses data from the Juno mission, specifically from the Jupiter Energetic particle Detector Instrument (JEDI) and Magnetometer (Mag) instruments. The former is used to extract the electron flux at energies of 30-1000 keV for different magnetospheric shells, while the latter is used to calculate the magnetic field value. The data is analysed using Python routines and compared with the corresponding theoretical KP limit, as derived for each flux, according to the method developed by Mauk & Fox (2010) and Olifer et al. (2022). The aim of the study is to pave the way for a statistical analysis for the whole duration of the mission.

Cross-Sectional Sizes of Potential Solar Triggers of Near-Sun Magnetic Switchbacks **O3-22**

Spiros Patsourakos [1]
[1]Department of Physics, Section of Astrogeophysics, University of Ioannina, 45110, Greece

An important result of the Parker Solar Probe (PSP) mission was the discovery of near-Sun magnetic switchbacks (SBs), namely transient and ubiquitous deflections in the direction of the interplanetary magnetic field. Several theories and models link the triggers of near-Sun SBs to small-scale, transient solar phenomena occurring in the low solar atmosphere. A key test of these theories and models is the determination of the cross-sectional size of the potential SB triggers in the low solar atmosphere.
We develop a simple method based on magnetic flux conservation along flux tubes connecting near-Sun SBs with their potential source regions in the low solar atmosphere, and apply it to data from the first solar encounter of PSP. We find SB trigger radii in the low solar atmosphere in the range of 10–26,000 km (with a most representative range of 125–3,500 km) and discuss these results in terms of the accessibility of such spatial scales with current instrumentation and the occurrence rates of observed small-scale solar transient phenomena.dynamics and control the trapping of energetic particle populations in the region.

Investigating the Acceleration Efficiency of VLF/ULF Waves on Different Populations of Outer Radiation Belt Electrons, through Multi-point Observations and Modelling **P3-1**

Afroditi Nasi [1], C. Katsavrias [1], S. Aminalragia-Giamini [1,2], N. Dahmen [3], A. Brunet [3], C. Papadimitriou [1,2], S. Bourdarie[3], O. Santolik [4], I. Sandberg [2,5], F. Darrouzet [6], Y. Miyoshi [7], W. Li [8], G. Balasis [9], H. D. R. Evans [10], I. A. Daglis[1,11], V. Pierrard [6], E. Botek [6], B. Grison [4], I. Kolmasova [4], D. Pisa [4], T. Mitani [12], A. Matsuoka [13], I. Shinohara [12], T. Takashima [12], and T. Hori [7]
[1]Department of Physics, University of Athens (UOA), Greece, [2]SPARC, Greece, [3]ONERA, France, [4]IAP, Czechia, [5]Department of Aerospace Science and Technology, UOA, Greece, [6]BIRA-IASB, Belgium, [7]ISEE, Nagoya University, Japan, [8]Center for Space Physics, Boston University, USA, [9]IAASARS, NOA, Greece, [10]ESTEC, ESA, The Netherlands, [11]Hellenic Space Center (HSC), Greece, [12]ISAS, JAXA, Japan, [13]Kyoto University, Japan

During the second half of 2019, the Earth's magnetosphere was impacted by a sequence of Corotating Interaction Regions (CIRs) during four consecutive solar rotations. Based on the solar wind properties, the CIRs can be divided in four groups, with the 3rd group, which arrived on August-September 2019, resulting in significant multi-MeV electron enhancements, up to ultra-relativistic energies of 9.9 MeV. Each CIR group has a different effect on the outer radiation belt electron populations; we investigate them by exploiting combined measurements from the Van Allen Probes, THEMIS, and Arase satellites. We produce Phase Space Density (PSD) radial profiles and inspect their dependence on the values of the first and second adiabatic invariants (μ,K), ranging from seed to ultra-relativistic electrons and from near-equatorial to off equatorial mirroring populations, respectively.
Focusing on the 3rd CIR group, and in order to assess the relative contribution of radial diffusion and gyro-resonant acceleration, we perform numerical simulations of the radiation belt environment, combining several relevant models: EMERALD (NKUA), GEO model (NKUA), Salammbô (ONERA), VLF model (IAP), Plasmaspheric model (BIRA-IASB), FARWEST (ONERA). We further compare the temporal evolution of the simulated electron PSD with the above observations.
Our simulation results indicate that local acceleration seems to better describe the acceleration of relativistic and ultra-relativistic electrons, for both near- and more off-equatorial mirroring populations, during the selected event.
This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870437 for the SafeSpace project.

Impact of High-intensity Long-duration Continuous Auroral Electrojet Activity (HILDCAAs) on Relativistic Electrons in Earth's Outer Radiation Belt During Van Allen Probes Era **P3-2**

Ayushi Nema [1], A. Bhaskar [2], K. N. Pathak [1], S. V. Thampi [2], and A. Datta [3]
[1]Department of Physics, Sardar Vallabhbhai National Institute of Technology, Surat, India, [2]Space Physics Laboratory, Vikram Sarabhai Space Centre, ISRO, Trivandrum, India, [3]Indian Institute Technology-Indore, Indore, India

This study investigates the impact of High-Intensity Long-Duration Continuous Auroral Electrojet Activity (HILDCAA) on the relativistic electrons in the outer radiation belt of Earth. Utilizing in situ observations from the Van Allen Probe mission of NASA, we conducted a comprehensive analysis to understand the impact of HILDCAA events on the outer radiation belt electron fluxes. A superposed epoch analysis was performed to determine how relativistic electron fluxes respond to HILDCAA events as a function of L-shell, pitch angle, and energy. Results show a significant flux enhancement in the relativistic electron fluxes, predominantly occurring with a delay of 0 to 2 days following the onset of HILDCAA events. The general response indicates that the maximum energy of accelerated electrons reaches up to 6 MeV. Notably, electrons with perpendicular pitch angles exhibit greater enhancement than field-aligned populations, implying a critical role for pitch angle-dependent acceleration mechanisms. While the very-low frequency (VLF) waves, specifically chorus waves, also showed enhanced power during the HILDCAA period, the time-delayed and pitch angle-dependent response related to the onset of HILDCAAs highlights the significant influence of wave-particle interactions, particularly driven by ultra-low frequency (ULF) waves in this context.
Rather than classical radial diffusion, typically requiring coherent ULF wave structures, the observed acceleration is likely facilitated by persistent, enhanced ULF wave activity, even in the presence of partial incoherence. This is further supported by ground-based magnetometers and in situ magnetic field observations from the RBSP probe, which demonstrated enhanced power of ULF waves during HILDCAA events. These findings reinforce the pivotal role of ULF waves in particle acceleration processes of the outer radiation belt, with implications for satellite operations and other space-based technologies, both on Earth and in the magnetospheres of other planets.

Web Application for Geomagnetic Storm Detection and for the Identification of Solar Wind Influence on Storm Intensity **P3-3**

Daniil Papakonstantinou [1] and I. A. Daglis [1]
[1]Department of Physics, National and Kapodistrian University of Athens, Athens, Greece

Geomagnetic storms are major disturbances of Earth's magnetosphere resulting from variations in the solar wind, leading to significant changes in magnetospheric currents, plasma populations, and electromagnetic fields. In this study, all geomagnetic storms from 1964 to the present are investigated, with the aim of examining the solar wind as a primary driver of storm activity. Solar wind parameters and disturbance storm time (Dst) data from the OMNI database are analysed, with particular focus on the storm main phase. Storm detection and main-phase characterization are performed using a comprehensive algorithm, which constitutes the core of this work.

Correlations between solar wind parameters and the decrease of the Dst index during storm evolution are examined in order to identify those most strongly associated with storm intensity. The program is implemented as a web application, providing flexibility by allowing users to adjust algorithm parameters according to their analysis preferences.

Comparison between Geomagnetic Storms of Different Intensities and their Correlation with Magnetospheric Substorms **P3-4**

Eirini Nakopoulou [1] *and I. A. Daglis* [1,2]
[1]Department of Physics, National and Kapodistrian University of Athens, Greece, [2]Hellenic Space Center, Athens, Greece

It is well established that a southward orientation of the interplanetary magnetic field (IMF) constitutes a common driving mechanism for both geomagnetic storms and magnetospheric substorms. However, there is no strong statistical evidence supporting a causal relationship in which magnetospheric substorms trigger geomagnetic storms or vice versa. In this study we utilize data from 1990 to 2015, focusing on 50 intense ($Dst_{min} \leq -130nT$) and 50 medium geomagnetic storms ($-100nT \leq Dst_{min} \leq -50nT$). We use 72 hours of data for each storm, derived both from SuperMAG, the SML and SMU indices, as well as from the WDC for Geomagnetism in Kyoto, the AL and AU indices. These two index pairs serve the same analytical purpose but differ in spatial coverage and in the number of the contributing magnetometer stations. The basis for the identification of substorms was Newell and Gjerloev's method. Superposed epoch analysis was applied to each of the four dataset combinations, moderate or intense storms each analysed using either the SML/SMU or the AL/AU index pair. The identified substorms were binned by their time of occurrence and also classified in four groups by intensity. Our results show a clear trend for intense storms; about 12 hours prior to storm minimum the count as well as the mean intensity are increasing, with SML identifying a bigger count and a bigger intensity of substorms. Afterwards, both the count and the intensity are decreasing, as expected. For the medium storms the count and the intensity of the substorms seem to increase 12 hours prior to storm minimum as well, but although their count decreases afterwards, their mean intensity shows fluctuations in the post-main phase section. These findings provide a clear statistical picture of substorm activity across storm phases and highlight the role of magnetometer network coverage in substorm identification. They also show the different trend that storm-time substorms follow during magnetic storms of different intensities. However, the common IMF driving mechanism makes it difficult to disentangle any direct relationship between the two phenomena, underscoring the need for more detailed magnetospheric modelling.

Space-ground Coupling of ULF (Pc3-Pc5) Waves in the South American Sector **P3-5**

Jayne Alencar Melo [1]*, L. Alves* [1]*, O. Mendes* [1]*, L. Silva* [1]*, P. Marchezi* [1]*, L. Resende* [1]*, and T. Moeda* [2]
[1]National Institute for Space Research (INPE), [2]National Observatory (ON)

Ultra-Low Frequency (ULF) waves are fundamental drivers of energy transport within the coupled Magnetosphere-Ionosphere system. While the generation mechanisms for Pc5 (1.7 - 6.7 mHz) and Pc3 (22 - 100 mHz) pulsations are global—driven respectively by Kelvin-Helmholtz instabilities or internal resonances, and upstream ion-cyclotron waves—their transmission to the ground at low latitudes is significantly modified by regional electrodynamics. The South American sector acts as a unique natural laboratory for this coupling due to the South American Magnetic Anomaly (SAMA) and the Equatorial Electrojet (EEJ). This study presents an initial investigation into the Space-Ground coupling efficiency of ULF waves, testing the hypothesis that the South American ionosphere functions as an active electrodynamic filter. We employ a multi-point observation strategy combining in-situ magnetic field data from the Swarm constellation with ground-based magnetograms from the Embrace/INPE and Intermagnet network. Focusing on selected geomagnetic storm events, we analyse satellite passes traversing low-latitude L-shells ($L < 2$) over the South American sector to compare wave signatures in space with their magnetic footprints on the ground. Studies by Li et al. (2025) reveal a distinct North-South asymmetry, with wave packets in the SAMA region exhibiting significantly higher amplitudes compared to their conjugate footprints in the Northern Hemisphere. Concurrently, ground-based analysis by Camacho and Benyosef (2025) indicates a distinct amplification of Pc5 wave power within the SAMA region during the recovery phase, distinct from trends observed at conjugate control stations, while also highlighting that Pc3 pulsation energy is influenced by ionization in the SAMA region. Specifically, we assess whether particle precipitation in the SAMA enhances local conductivity and Field Line Resonance (FLR) efficiency, and whether the EEJ modulates these modes. This work aims to establish a framework for quantifying the active role of South American electrodynamics in modulating global magnetospheric energy transfer.

Whistler Waves and Their Relation with Heat Flux in the Solar Wind: A Kappa Distribution Approach **P3-6**

Laíne Bengo Soares Rosales [1]*, L. E. A. Vieira* [1]*, L. A. Alves* [1]*, and J. P. Marchezi* [1]
[1]National Institute for Space Research

The solar wind is a weakly collisional, magnetized plasma that expands continuously from the solar corona, serving as a natural laboratory for studying kinetic processes in space plasmas. In situ observations reveal that solar wind electrons exhibit strongly non-Maxwellian velocity distributions, characterized by suprathermal halo and field-aligned strahl populations. These populations are usually well described by Kappa distribution functions and are responsible for carrying a significant heat flux along the interplanetary magnetic field. However, the observed electron heat flux is systematically lower than predictions based on collisional or adiabatic transport models, indicating the presence of collisionless mechanisms. Whistler-mode waves driven by electron heat flux instabilities are widely considered a key mechanism for limiting electron energy transport in the solar wind. Previous studies employing linear kinetic theory, numerical dispersion solvers, and fully kinetic particle-in-cell simulations have demonstrated that whistler waves can scatter suprathermal electrons and reduce the heat flux through wave-particle interactions. Despite this progress, a clear analytical understanding of how suprathermal electrons described by Kappa distributions modify whistler wave dispersion and stability remains incomplete.

In this work, we present an analytical investigation of electron heat flux regulation by whistler-mode waves in the solar wind, focusing on the role of the electron Kappa distribution function. The plasma is modelled as homogeneous and magnetized, with electrons described by Kappa that captures the essential non-thermal features observed in situ. At the same time, ions are treated as a stationary neutralizing background. Starting from the Vlasov-Maxwell system, we derive the linear dispersion relation for parallel and/or quasi-parallel whistler waves and examine how the presence of suprathermal tails influences wave frequency, growth rates, and instability thresholds as functions of the electron heat flux and plasma beta. To connect wave growth with transport regulation, we adopt a simplified quasilinear interpretation in which resonant interactions between whistler waves and electrons lead to pitch-angle scattering of the heat-flux-carrying populations. Rather than addressing the full non-linear evolution, we focus on identifying stability conditions that define natural upper bounds on the electron heat flux. Representative numerical solutions of the dispersion relation are obtained using Python to visualize the dependence of whistler properties on key plasma parameters and to support the analytical results.
Our analysis shows that whistler instabilities driven by electron Kappa distribution function impose intrinsic limits on the electron heat flux in the solar wind. These results complement previous numerical and simulation studies by offering a transparent analytical framework that highlights the fundamental role of suprathermal electrons in collisionless heat-flux regulation in space plasmas.

Characteristics of Field-Aligned Poynting Flux of Pc5 ULF Waves Based on Arase Measurements — P3-7

Li Yan [1,2], W. Liu [1,2], D. Zhang [1,2*], Z. Wang [1,2], X.-Z. Zhou [3], T. E. Sarris [4,5], X. Li [5], X. Tong [1,2], A. Matsuoka [6], Y. Kasaba [7], Y. Kasahara [8], Y. Miyoshi [9,10], T. Hori [9], K. Yamamoto [9], I. Shinohara [11], and M. Teramoto [12]*
[1]School of Space and Earth Sciences, Beihang University, China, [2]Key Laboratory of Space Environment Monitoring and Information Processing of MIIT, Beihang University, China, [3]School of Earth and Space Sciences, Peking University, China, [4]Department of Electrical and Computer Engineering, Democritus University of Thrace, Xanthi, Greece, [5]Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, Boulder, CO, USA, [6]Kyoto University, Kyoto, Japan, [7]Department of Geophysics, Tohoku University, Sendai, Japan, [8]Graduate School of Natural Science and Technology, Kanazawa University, Kanazawa, Japan, [9]Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan, [10]Kyung Hee University, Suwon, Korea, [11]Institute of Space and Astronautical Science, JAXA, Sagamihara, Japan, [12]Graduate School of Engineering, Kyushu Institute of Technology, Kitakyushu, Japan

Ultra-low frequency (ULF) waves play a critical role in energy transport within the magnetosphere-ionosphere (M-I) coupling system. Using approximately 7-years of Arase satellite observations, we perform a comprehensive statistical analysis of the field aligned Poynting flux ($S//$) in the Pc5 band in the inner magnetosphere. A pronounced enhancement in $S//$ at higher latitudes is consistent with the trend inferred from the product of electric and magnetic wave amplitudes modelled by Cummings et al. (1969). Comparison between inward and outward fluxes reveals a net energy flux toward the ionosphere, indicating energy dissipation in the ionosphere. To understand the cause of this net energy flux, a simplified model illustrates how the phase difference between electric and magnetic fields (θ_{EB}) affect net $S//$, suggesting that phase shifts, likely induced by ionospheric dissipation, play a key role in modulating $S//$. Latitudinal profiles of $S//$ and θ_{EB} for poloidal and toroidal modes at 6.82 mHz within $L = 5.5 - 6.5$ further demonstrate this effect of θ_{EB} on $S//$. The magnetic local time (MLT) dependence of $S//$ shows pronounced day-night asymmetry at higher latitudes, with stronger fluxes on the nightside, consistent with variations in ionospheric conductance. Finally, the latitudinal distribution of $S//$ under varying geomagnetic activity conditions exhibits systematic enhancements with increasing Kp, particularly at higher latitudes. These results provide offer insights into the dynamics of energy dissipation and transport within the M-I coupling system.

Correlation between the Dst index and Solar Wind Conditions during Geomagnetic Storms — P3-8

Markella Zannou [1] and I. A. Daglis [1]
[1]Department of Physics, National and Kapodistrian University of Athens, Athens, Greece

Geomagnetic storms are influenced by multiple solar wind and magnetospheric parameters. In this study, we focused on 45 intense magnetic storms from 2013 to 2023 with disturbance storm time (Dst) index of less than -80 nT. We analysed solar wind conditions associated with them, specifically the peak south component of the magnetic field Bs, the peak dawn-to-dusk electric field Ey and the integrated electric field Ey during each storm's main phase. We obtained good correlations between —min.Dst— and these parameters, as well as empirical equations.

Connection between the Foreshock Activities and the Magnetosheath Jets — P3-9

Niki Xirogiannopoulou [1], O. Goncharov [1], J. Šafránková [1], and Z. Němeček [1]
[1]Charles University, Faculty of Mathematics and Physics, Department of Surface and Plasma Science, Prague, Czechia

The magnetosheath jets are transient plasma structures with enhanced dynamic pressure, frequently observed in the Earth's magnetosheath. These structures are more often detected downstream of the quasi-parallel bow shock, i.e., behind the foreshock. This turbulent region is dominated by waves and reflected particles which interact with each other and create various transients. Xirogiannopoulou et al. (2024) found that the subsolar foreshock contains several types of structures with enhanced density or/and magnetic field magnitude, called plasmoids, SLAMS and mixed structures respectively. Multiple previous studies, based on the dynamic nature of the bow shock, established that some of these foreshock structures can be a source of the magnetosheath jets (e.g., Raptis et al., 2022).

Following these conclusions, we use multi-spacecraft data collected by THEMIS, Magnetospheric Multiscale Spacecraft (MMS) and OMNI missions between the years 2020-2025 and we present analytical multi-spacecraft statistics and case studies on the connection between the structures around the bow shock. We provide results using simultaneous measurements of the solar wind, the foreshock and the magnetosheath during the presence of foreshock structures and magnetosheath jets. Based on our results and previous research, we discuss the occurrence rates of these events under different upstream conditions and the possible relation between the upstream and the downstream structures. According to our observations, we suggest that the generation of foreshock structures and magnetosheath jets is associated with the changes of the solar wind in the foreshock. We also conclude that the origination of jets is based on some additional, more complicated mechanisms from the ones we already know (e.g., bow shock ripples).

Effects of Magnetic Reconnection Dynamics in Earth's Cusp: Investigating Plasma Filaments and Flux Transfer Events using MMS Data **P3-10**

Nitya Agarwala [1,2], G. Poh [1,2], W. Sun [3], Y. Chen [4], J. A. Slavin [5], and G. Le [2]
[1]The Partnership for Heliophysics and Space Environment Research, Catholic University of America, Washington, D.C., USA, [2]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, [3]Space Sciences Laboratory, University of California Berkeley, Berkeley, California, USA, [4]Center for Space Physics, Boston University, Boston, Massachusetts, USA, [5]Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, Michigan, USA

Energetic particles injected from dayside reconnection serve as a source for ionospheric particle precipitation in the cusp region. The cusp comprises poleward-moving plasma structures, cusp plasma filaments due to discontinuous reconnection events which are considered footprints of flux transfer events (FTEs). These structures remain relatively unexplored on Earth, however an examination of MESSENGER data from Mercury's magnetosphere suggests that cusp filaments represent the magnetospheric extensions of FTEs originating at the magnetopause due to localized magnetic reconnection. This underscores the need for a comprehensive investigation of similar phenomena within Earth's magnetosphere. Reconnection often takes place at the dayside magnetopause, where the solar wind's magnetic field interacts with the Earth's magnetic field. This interaction leads to the merging and rearrangement of magnetic field lines, creating open magnetic field lines that connect the high-latitude magnetospheric cusp to the solar wind forming FTEs which are flux-rope-like structures filled with magnetosheath plasma. In this study, data obtained from the MMS spacecraft was examined which is strategically positioned to traverse the cusp region. The spacecraft's orbit facilitates multi-spacecraft in situ measurements within the cusp, providing crucial data for the analysis of phenomena such as cusp plasma filaments. Cusp filaments were analysed using multi-spacecraft analysis techniques and high-resolution measurements were utilized to reconstruct and analyse the internal plasma structure of these cusp filaments. Characteristics and spatial distribution of cusp plasma filaments within Earth's cusp region were also investigated. The primary focus was to comprehend the role of these filaments in particle precipitation and their correlation with dayside magnetic reconnection events. Our preliminary results suggest that cusp plasma filaments are indeed low latitude, high altitude footprints of FTEs. Moreover, there appears to be a correlation between the presence of plasma filaments and dayside reconnection events.

Persistent Equatorial Plasma Bubbles During 2025-New Year's Day Geomagnetic Storm: Insights from Multi-instrument Observations over East and Southeast Asian Longitude Sectors **P3-11**

Siva Sai Kumar Rajana [1] and S. K. Panda [2]
[1]Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Green Fields, Vaddeswaram, India
[2]Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Green Fields, Vaddeswaram, India

The present study investigated the anomalous formation and evolution of Post-Sunset to Pre-Sunrise Equatorial Plasma bubbles (EPBs) during the 2025 New Year's Day geomagnetic storm over the East/Southeast Asian regions. Multi-instrument observations such as amplitude scintillation Index (S4) derived from the GNSS Ionospheric Scintillation and Total Electron Content Monitor (GISTM), GPS-derived Rate of change of TEC Index (ROTI), in-situ satellite measurements of electron density and Digisonde observations of foF2 and h'F to characterize the occurrence of EPBs. During the main phase of the storm, EPBs are initially formed in equatorial and low-latitude regions with moderate intensity and sustained for more than five hours. After 1800 UT on January 01, coinciding with the storm recovery phase, the EPBs are intensified and extended to the mid-latitude regions. These EPBs then persisted for over four hours, which disappeared before sunrise. The prolonged development and persistence of these EPBs are attributed to the storm-induced Prompt Penetration Electric Fields (PPEFs) during main phase and the abrupt northward flipping of the Interplanetary Magnetic Field (IMF) Bz during recovery phase. Supplementary observations from other ground and satellite-based techniques are used to examine the latitudinal variability and the evolution process of Post-sunset to Pre-Sunrise EPBs. This research aims to develop strategies for mitigating the impact of severe space weather events on critical infrastructure, such as satellite communication and navigation systems over the equatorial and low latitude regions.

Electromagnetic Ion Cyclotron Waves in Initial Phases of Geomagnetic Storms **P3-12**

Taylor Whitney Aegerter [1,2] *and L. Blum* [1,2]
[1]*Department of Astrophysical and Planetary Sciences, University of Colorado Boulder, Boulder, CO, USA,* [2]*Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, Boulder, CO, USA*

Between September 2015 and October 2019, there are 10 satellites across the Van Allen Probes, Magnetospheric Multiscale (MMS), Time History of Events and Macroscale Interactions during Substorms (THEMIS), and Geostationary Operational Environmental Satellite (GOES) missions that can be used to detect electromagnetic ion cyclotron (EMIC) waves in the inner magnetosphere. Using these simultaneous spacecraft magnetic field observations and an automated wave detection algorithm, we identify broad regions of plasma wave activity during initial phases of geomagnetic storms. Due to the compression of the dayside magnetosphere in a storm's initial phase, we expect the majority of activity to be found here. However, in 62.5% of initial phases examined in this study, there is EMIC activity in the nightside magnetosphere.
The solar wind dynamic pressure at the onset of a storm, particularly the solar wind speed, and substorm activity level within the phase as well as phase duration show the most consistent indicators of whether or not a storm had nightside activity in the initial phase. In storms with inbound solar wind speeds above 425 km/s, compression-driven dayside EMIC waves dominate. As time advances throughout an initial phase, there is more substorm activity, or there is a higher SYM-H value there is an increased occurrence rate of EMIC activity in the nightside magnetosphere. Generally, there is a lag of at least 60 minutes before any nightside EMIC activity begins.

Contrasting Nighttime Ionospheric Responses over the American and Atlantic Sectors during the May and October 2024 Geomagnetic Storms **P3-13**

Deepak Kumar Karan [1], *R. W. Eastes* [1], *C. R. Martinis* [2], *R. E. Daniell* [3], *and W. E. McClintock* [1]
[1]*Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, USA,* [2]*Center for Space Physics, Boston University, Boston, MA, USA,* [3]*Ionospheric Physics, Stoughton, MA, USA*

The geomagnetic storms of 10–11 May 2024 and 10–11 October 2024 were among the most intense events of Solar Cycle 25 and produced markedly different low-latitude and equatorial ionospheric responses. In this study, we present a comparative analysis of nighttime ionospheric variability over the American and Atlantic sectors during these two storms, using Global-scale Observations of the Limb and Disk (GOLD) observations in conjunction with complementary ground- and space-based measurements. During the May 2024 "Mother's Day" superstorm, GOLD observations revealed an unusual poleward expansion and merging of the southern equatorial ionization anomaly (EIA) crest with auroral emissions, indicating extreme storm-time electrodynamic coupling between low and high latitudes. This event was characterized by large-scale restructuring of the nighttime ionosphere, with relatively suppressed plasma bubble activity despite strong geomagnetic forcing, suggesting dominant control by disturbance dynamo electric fields and enhanced thermospheric composition changes. In contrast, the October 2024 storm exhibited super equatorial plasma bubbles (EPBs) with strong longitudinal variability, particularly over the American sector, where deep depletions and large-scale plasma structuring persisted well into the post-sunset and midnight sectors. The pronounced longitudinal asymmetry observed during this storm highlights the critical role of background ionospheric preconditioning, local time–dependent electrodynamics, and storm-time penetration electric fields in modulating EPB growth. By contrasting these two events, our results demonstrate that storm intensity alone is insufficient to predict nighttime ionospheric outcomes; rather, the interplay between storm phase, longitudinal sector, and background conditions governs whether large-scale EIA restructuring or intense EPB development dominates.

Space Weather during Extremely Disturbed Geomagnetic Conditions and Associated Cosmic Rays Intensity Variation **P3-14**

Subhash Chandra Kaushik [1]
[1]*Department of Physics, Government P.G. Autonomous College, Datia, MP, India*

The kind of interaction between solar wind and terrestrial magnetosphere depends up on the plasma structures present in the solar wind. This interaction builds a chain of activities on the geomagnetic environment. However the intensity of these activities depends up on the orientation and the strength of IMF Bz embedded within the solar wind. One such plasma structure is a magnetic cloud identified by its unique and measurable features. It is a kind of large scale interplanetary solar wind plasma structure resulted as a transient ejection of the solar plasma in the solar wind. Its characteristics were first time reported in 1981 by a group of scientists, who have studied the solar wind ejection with the help of several satellites data simultaneously. Present study deals with the behaviour of these interplanetary magnetic clouds and the behaviour of ground level enhancement events (GLEs) as well as studying the Forbush decrease events simultaneously. We studied these events during the phase of highly intense or ultra-intense geomagnetic field perturbations. We have utilized the IMF and Solar data provided by Omniweb-NASA and the geomagnetic data obtained through magnetometers, measured and provided by WDC Kyoto.
Our results indicate that energetic particles coming from deep surface interact with these abnormal solar and IP conditions (Magnetic clouds) and suffer modulation effects. It is found that AP and AE indices show rise before the forward turnings of IMF, while the Dst index depicts a classic storm time decrease. The analysis indicates that the magnitude of all the responses depends on BZ component of IMF being well correlated with solar maximum and minimum periods.

The statistics of the extreme GICs in power lines in the north-west of Russia — P3-15

Vladimir B. Belakhovsky [1], V. A. Pilipenko [2], V. N. Selivanov [3], Y. A. Sakharov [1], J. J. Zhang [4], and V. V. Kolobov [3]
[1]Polar Geophysical Institute, Apatity, Russia, [2]Institute of the Physics of the Earth, Moscow, Russia, [3]Northern Energetics Research Centre of the Kola Science Centre RAS, Apatity, Russia, [4]National Space Science Center, Chinese Academy of Science, Beijing, China

In this work a statistical study of extreme values of GICs in power lines on the North of Russia since 2012 year was conducted. The Polar Geophysical Institute and the Northern Energy Research Center of the Kola Science Center RAS have created and have been operating the only one GIC recording system in Russia on the "Northern Transit" power transmission line across the Murmansk region and Karelia. This registration system measures a quasi-DC current in dead-grounded neutral of the transformers at 4 sub-stations: Vykhodnoy (VKH), Titan (TTN), Louhi (LKH), and Kondopoga (KND) on the 330 kV line, and at sub-station Revda (RVD) on the 220 kV line. For the VKH sub-station CGM Lat=65.5°, for the KND CGM Lat=60.8°.
The extreme values of the GIC for 11 years of observations (2012-2022 years) were analyzed based on data from the auroral substation VKH (92 cases, GIC $>$ 20A) and the subauroral substation KND (32 cases, GIC $>$ 5A). The number of extreme GIC events is higher during the decline and maximum of the solar cycle. According to the VKH station, GICs reach extreme values more often during CME magnetic storms ($\sim$54.7%) than during CIR magnetic storms (33.7%). At the same time, 10.5% of GIC cases were observed during substorm without a magnetic storm, 1 % during SC. According to the KND station, extreme values of GIC are observed during CME storms in 80% of cases. So CIR magnetic storms, despite their lower intensity, must also be taken into account when forecasting the impact of space weather on technological systems.
Analyses showed that extreme values of GIC are mainly caused by substorms ($>$80% of cases) in both the post-midnight and pre-midnight MLT sectors. Daytime jumps of GIC are associated with positive magnetic bays, Pc5 pulsations, SC impulse. For CME storms, extreme GICs are mainly observed during the main phase of the magnetic storm.
On average, upon an increase of $|dB/dt|$, a higher GIC magnitude is recorded. A strong enhancement of GIC coincides with the period of elevated dB/dt. However, there is no one-to-one correspondence between the GIC and dB/dt magnitudes. On average, with an increase of the intensity of magnetic storm (SYM-H), substorm (IE), higher GIC values are registered. But there is no clear linear dependence of the GIC amplitude on the parameters of the interplanetary medium (V, Es, ϵ) and geomagnetic indices (IE, AE, SYM-H), which indicates the difficulty of predicting GICs based only on these parameters. This is because GICs depend on local ionosphere factors: configuration of the ionospheric current systems, frequency of the signal. To predict the amplitude of the GICs in power lines at high latitudes, we need to know more information about the formation of mesoscale and small-scale ionospheric current systems. At subauroral latitudes the dB/dt variations show much better correlation with these parameters than GICs.
The study was supported by grant No. 25-17-20038 from the Russian Science Foundation and a grant from the Ministry of Education and Science of the Murmansk Region.

Comparative Analysis of Low-Latitude Ionospheric Responses to Intense Geomagnetic Storms Using NavIC/IRNSS (2017–2024) — P3-16

Dadaso Shetti [1], S. Chougule [1], and P. Chougule [1]
[1]Smt. Kasturbai Walchand College of Arts and Science, Sangli, India

This study examines the low-latitude ionospheric response over the Indian region during six intense geomagnetic storms between 2017 and 2024, including the extreme May 2024 superstorm, using NavIC/IRNSS and IGS observations. Variations in Total Electron Content (TEC), Rate of TEC Index (ROTI), and the scintillation index (S4) are analysed using data from a NavIC receiver at Sangli (16.5°N, 74.3°E) and regional GNSS stations. The observed ionospheric responses are interpreted in relation to interplanetary drivers (IMF Bz and solar wind parameters), geomagnetic indices (Dst, SYM-H), Equatorial Electrojet (EEJ) variations, prompt penetration and disturbance dynamo electric fields (PPEF/DDEF), and thermospheric composition changes (O/N_2) derived from GUVI/TIMED observations. The September 2017 and August 2018 storms exhibited strong positive ionospheric effects, while the April 2023 storm showed a dominant negative response associated with extreme EEJ suppression and reduced O/N_2. The February and March 2023 storms displayed mixed behaviour due to competing electrodynamic processes. CME-driven storms produced abrupt daytime TEC enhancements, whereas CIR-HSS-driven storms caused prolonged disturbances. The May 2024 superstorm (Dst ≈ - 412 nT) resulted in widespread TEC depletion with short-lived flare-induced enhancements, demonstrating the effectiveness of NavIC/IRNSS in capturing storm-time ionospheric variability.
Keywords: NavIC/IRNSS; Total Electron Content (TEC); Geomagnetic storms; Low-latitude ionosphere; Ionospheric irregularities; Equatorial Electrojet (EEJ)

Predicting Solar Energetic Particles Proton Flux using Machine Learning Techniques — P3-17

Daniel Atnafu Chekole [1]
[1]Space Science and Geospatial Institute

Solar Energetic Particles (SEPs), especially high-energy protons, represent a major component of space weather hazards that can disrupt satellite operations, communication networks, and pose radiation risks to astronauts. Accurate forecasting of SEP proton flux at different energy levels is therefore essential for early warning systems. In this study, we develop a hybrid deep learning model combining a Convolutional Neural Network (CNN) with a Bidirectional Long Short-Term Memory (BiLSTM) network to predict SEP proton flux for

energy thresholds of >10 MeV, ≥30 MeV, and ≥50 MeV. The CNN module efficiently extracts high-level spatial and temporal features from multivariate solar and interplanetary datasets, including solar wind parameters, interplanetary magnetic field components, and soft X-ray flux, while the BiLSTM component captures bidirectional temporal dependencies and long-term dynamics in proton flux evolution. Historical SEP event data obtained from GOES spacecraft observations are used to train and validate the model. The proposed CNN–BiLSTM hybrid approach demonstrates superior predictive performance compared to traditional statistical and single deep learning models, achieving higher accuracy and lower false alarm rates across all three energy channels. These results suggest that hybrid deep learning architectures can serve as reliable and effective tools for real-time SEP forecasting and radiation environment monitoring in support of space mission safety and operational planning.

Supersubstorms in some Last Superstorms of the 25th Solar Cycle — P3-18

Irina V. Despirak [1], A. A. Lubchich [1], N. G. Kleimenova [2], P. V. Setsko [1], and L. I. Gromova [3]
[1]Polar Geophysical Institute, Apatity, Russia, [2]Schmidt Institute of Physics of the Earth, RAS, Moscow, Russia, [3]IZMIRAN, RAS, Troitsk, Moscow, Russia

The term "supersubstorm" was first proposed in 2015 by Dr. Tsurutani et al. A supersubstorm was defined as a substorm with an auroral zone index AL/SML <-2500 nT. Note this value is arbitrary, it has been used as estimate because it is important to have a quantitative description of the phenomenon for the investigations of very intense substorms. There are not many published articles on the properties and nature of supersubstorms yet, and most of them describe only some individual supersubstorm events, so an overview of the available information on SSS will be given. Supersubstorms are a relatively rare phenomenon observed mainly during intense, major storms and superstorms, when high values of the southward IMF and solar wind dynamic pressure are recorded. Besides being extreme in intensity, supersubstorms can lasts extremely long intervals of time. Supersubstorms have been shown to have different auroral evolution and a specific character of magnetic disturbances than a regular substorm. It was also found that the supersubstorms are mainly observed during magnetic storms caused by CME. The features of supersubstorms during the last superstorms during 25th solar cycle, May and October 2024, are examined, and various possible SSS drivers, including convective bays, are discussed.

Extreme geomagnetic storms contribution to the ULF waves and Pulsations: How disturbed South Auroral Electrojet conditions affect SAMA. — P3-19

Livia R. Alves [1], T. M. Sant'Anna [2], J. A. Melo [1], L. A. da Silva [1], J. P. Marchezi [1], L. C. A. Resende [1], V. Degeronne [1], K. C. Ferreira [1,3], G. M. Nóbrega [1], L. B. Rosales [1], P. H. F. Fister [1], E. Rockenback [1], and D. G. Sibeck [3]
[1]INPE, National Institute for Space Research, Sao Jose dos Campos, Brazil,[2]National Observatory (ON), Rio de Janeiro, Brazil, [3]NASA Goddard Space Flight Center, Greenbelt, MD, USA

The Earth's magnetosphere is immersed in the Sun's atmosphere. Because of the solar activity, the atmospheric plasma varies and often changes its moments dramatically. Under disturbed conditions of the solar wind, the Earth's magnetic field experiences geomagnetic storms by enhancing electric currents and plasma waves that change energetic charged particle populations. In 2024, two extreme geomagnetic storms were observed. First, on May 10, a series of at least seven coronal mass ejections (ICMEs) hit the geomagnetic field and caused the most intense geomagnetic storm in the last solar cycles. Then, on October 10, an ICME hits the Earth. The first (second) storm started on 10 May (10 October) with a strong compression of the dayside magnetosphere to the geosynchronous orbit, exposing satellites to the magnetosheath and bow shock. During the main phase, the magnetosphere experienced an enhanced convection that increased the ring current (Dst ∼-409 nT (-333 nT)) and the ionospheric auroral electrojet currents (AE $> 2000nT$). Simultaneously, the plasmasphere was significantly eroded and the trough density reduced. Besides, particle precipitation over the South Atlantic Magnetic Anomaly (SAMA) was intensified and changed the ionospheric conductivity. These parameters indicate that the magnetosphere and the low-latitude ionosphere were markedly disturbed, imposing changes in the wave propagation in the inner magnetosphere through ground instruments. We use wavelet tools to investigate the solar wind parameter driving the ULF wave as the storm evolves. In addition, we evaluate how particle precipitation from the inner radiation belt over the SAMA ionosphere changes the ULF wave parameters as they propagate towards the ground. Then, we characterize the wave parameters (i.e., amplitude, mode, and polarization) as the waves diffuse through the SAMA. The results provide a more detailed description of pulsations measured on the ground during the most intense geomagnetic storms in the last two solar cycles and provide us a better understanding of the geomagnetic field contribution to pulsations measured above the SAMA ionosphere during disturbed conditions.

Extreme Space Weather in Antarctica: Observations of Magnetosphere-Ionosphere Coupling from Talos Dome — P3-20

Lucia Santarelli [1], M. Regi [1], and P. De Michelis [1]
[1]Istituto Nazionale di Geofisica e Vulcanologia (Italy)

This study investigates two of most significant space weather events in recent decades, i.e the May 2024 geomagnetic storm, known as the "Gannon" or "Mother's Day" storm, and the October 2024 storm, using a longitudinal array of Antarctic stations, including a new remotely operated magnetic station in Antarctica, called Talos Dome (TLD). The exceptional characteristics and comprehensive observational record of these storms make them ideal case studies for investigating polar-cap dynamics and magnetosphere–ionosphere coupling processes under extreme driving conditions. One-minute magnetic measurements from TLD, combined with data from permanent polar observatories as well as satellite measurements are analysed to resolve the temporal evolution of Ultra-Low Frequency (ULF) wave

power throughout the main and recovery phases of the storms. A dynamic spectral analysis of the H, D, Z components at each station was performed to quantify the frequency-time characteristics of geomagnetic field fluctuations energy. We focused on the ULF Pc6 (<1.7 mHz), Pc5 (1.67 - 5.67 mHz), and Pc4 (6.67 - 22.2 mHz) frequency ranges, which reflect key processes such as solar wind–magnetosphere coupling, field-line resonances, and inner magnetospheric wave activity. Coherent ULF wave signatures across spatially distributed observatories were found, providing insight into the storm-time evolution of magnetospheric oscillations and their propagation characteristics. During the May 2024 storm, TLD recorded pronounced magnetic local time–dependent variations in the H component, consistent with polar-cap convection patterns. The detection of simultaneous and coherent magnetic bays along approximately 80°S magnetic latitude during substorm intervals suggests that enhanced electrojet activity at lower latitudes influences polar-cap current systems. The overall behaviour of the H component at the permanent observatories mirrored that recorded at TLD, confirming the reliability of the TLD magnetic station relative to well-established ones.
Analysis of Z-component perturbations further provided diagnostic information on the station's position relative to electrojet centers. Comparison with the October 2024 storm offers new insights into polar-cap electrodynamics under extreme space weather conditions. Notably, the installation of the TLD station provided enhanced longitudinal coverage enabling a more detailed analysis. Our results from TLD emphasize the importance of distributed observatory networks with remote, pristine locations to better resolve the complex interactions associated with extreme events in the polar region.
This study was carried out in part within the Space It Up project funded by the Italian Space Agency, ASI, and the Ministry of University and Research, MUR, under contract n. 2024-5-E.0 - CUP n.I53D24000060005.

Formation and Evolution of the Ring Current During the Intense Geomagnetic Storm of May 2024 — P3-21

Sofia Lemonidi [1], and I. A. Daglis [1]
[1]National and Kapodistrian University of Athens

The ring current is a westward-moving population of charged particles with energies of 1–300 keV, located at approximately 2–9 Earth radii (Re) from Earth. During intense geomagnetic storms, particles from the solar wind and the ionosphere enhance the ring current, causing the weakening of the geomagnetic field and space weather phenomena. This study focuses on the formation, composition, and evolution of the ring current during the intense geomagnetic storm of May 2024. Geomagnetic indices (Sym-H, Kp, AE) and solar wind parameters (Vsw, IMF, Bz) are used to describe the storm and determine its phases and intensity. The main sources of energetic particles feeding the ring current are examined through the time evolution of the $O+/H+$ and $He+/H+$ ion flux ratios. These ratios are studied at various times: before the storm, during its initial and main phases, and during the recovery phase, to evaluate the contribution of ionospheric and solar wind ions to the enhancement of the ring current. In addition, the energy spectrum of the ring current ions is analysed before and throughout the geomagnetic storm to identify changes in the spectrum caused by particle injection, acceleration, and loss mechanisms. Finally, the temporal evolution of the plasma pressure perpendicular to the magnetic field is examined to assess the ring current enhancement and the weakening of the Earth's magnetic field intensity.

Similar Intensity Red-green Emissions in Low Latitudes under Distinct Magnetospheric Conditions — P3-22

Varghese Manu [1], K. Shiokawa [2], Q. Zhang [1], N. Balan [2,3], K. R. Jijin [3], P. R. Shreedevi [2], C. M. Claderon [2], D. Zhang[1], and X. Wang [1]
[1]National Space Science Center, Chinese Academy of Sciences, Beijing, China, [2]Institute of Space-Earth Environmental Research, Nagoya University, Nagoya, Japan, [3]Institute of Space Sciences, Shandong University, Weihai, China

Auroras appear in low latitudes under extreme geomagnetic conditions caused by the low energy electron precipitation from the near plasmapause region. Inward movement of the plasma sheet as well as the coulombic collisions prevalent in the plasmasphere-ring current overlapping region accelerates the electrons in the inner magnetosphere. The selective acceleration of electrons by Kinetic Alfven waves can also contribute to the auroras in lower latitudes. Past observations indicate such auroras are red dominant while green emissions are hidden below the horizon. But recently, during the rising phase of solar cycle 25, two aurora events of comparable intensity in red-green emissions observed from 35 MLAT on February 27, 2023 and April 24, 2023, in the recovery phase of geomagnetic storms. Conjugate ionosphere measurements reveal red emissions for both events caused by <10 eV electron precipitation, however the green emissions caused by two distinct processes. Substorm occurrence observed from local magnetometers on February 28, probably caused the inward movement of plasma sheet resulted in 50 eVs of electron precipitation to cause the green aurora. The intense airglow under strong geomagnetic disturbance and the strong auroral heating cause the green emission on April 24. Electron precipitation flux indicates the auroral oval expanded to ~50 MLAT for both events. Since magnetosphere satellites not available during these events, modelling studies are underway to investigate magnetospheric conditions during these observations.underway to investigate magnetospheric conditions during these observations.

Spatial Structure of the Harmonic ULF Wave Electromagnetic Energy Flux **P3-23**

Wenlong Liu [1], *Li Yan* [1], *and D. Zhang* [1]
[1]*School of Space and Earth Sciences, Beihang University*

Using nearly 8 years of Arase observations, we present a comprehensive analysis of the spatial distributions of field-aligned Poynting flux ($S_{//}$) and phase difference between electric and magnetic fields (θ_{EB}) of Ultra-low frequency (ULF) waves in the inner magnetosphere across frequencies of 1-50 mHz. We examine the statistical distributions of $S_{//}$ and θ_{EB} as functions of L and magnetic latitudes (MLAT) at five selected frequencies that approximately correspond to the first through the fifth harmonics, providing first observational evidence of latitudinal structures consistent with the theoretical harmonic model of Cummings et al. (1969). Subsequently, we investigate the spatial distributions of $S_{//}$ and θ_{EB} as functions of MLAT and frequency in a fixed L-shell around L = 6, demonstrating the systematic emergence of higher-order harmonic features with increasing frequency, including an increasing number of nodes and their progressive shift toward higher MLATs. These insights enhance our understanding of energy transfer within magnetosphere-ionosphere coupling and advancing magnetospheric diagnostics.

SESSION 4: External Impacts and Internal Dynamics of the Earth Atmosphere

Atmospheric Influence of Solar-terrestrial Coupling: From Satellite Observations to Chemistry-climate Models **K4**

Miriam Sinnhuber [1]
[1]*Karlsruhe Institute of Technology, Karlsruhe, Germany*

Solar forcing by the variable UV radiation and solar wind affects the composition and dynamics of the middle atmosphere in different ways. Both solar UV and solar wind variations impact the chemical composition from the upper stratosphere to the thermosphere, initiating a composition-radiative-dynamical feedback with implications for atmospheric dynamics potentially down to the troposphere. Consequently, solar spectral UV and ionization by energetic particle precipitation are recommended as external forcing for coordinated chemistry-climate experiments like, e.g., the upcoming CMIP7 experiments. However, multi-model intercomparison experiments have shown deficiencies particularly in the altitude region most affected by EUV and electron precipitation forcing, the lower thermosphere. These are likely due to a combination of chemical and dynamical processes involving secondary gravity waves, which lead to order-of-magnitude differences in thermospheric NO, and limit our ability to quantitatively derive the so-called indirect effect of energetic particle precipitation. Here, a short overview of the processes by which solar forcing affects middle atmosphere composition will be given, as well as a summary of the new solar forcing recommendations for CMIP7, and main issues in modelling of solar forcing with state-of-the art chemistry-climate models are highlighted.

Es as an Indicator for Atmosphere-ionosphere-magnetosphere Coupling **O4-1**

Huixin Liu [1], *T. Maeda* [1], *F. Rifqi* [1], *L. Qiu* [2], *and Y. Yamazaki* [3]
[1]*Kyushu University, Japan,* [2]*China Geoscience University, China,* [3]*Institute of Atmospheric Physics (IAP), Germany*

The sporadic E (Es) layer is a prominent ionospheric irregularity that strongly impacts HF communications. Driven dominantly by vertical wind shear at mid-latitudes, it is sensitive to both geomagnetic forcing and lower atmosphere forcing that can influence the neutral wind in the mesosphere and lower thermosphere region at various time and spatial scales. In this talk, I review 3 examples that demonstrate Es as an indicator for these vertical coupling processes. This includes Es responses to magnetic storms at the scale of a day, SSW at the scale of weeks, also to increasing CO2 at the scale of decades.

Atypical Sporadic E layer (Es) Over Equatorial Brazilian Regions During Intense Magnetic Storms **O4-2**

Laysa C. A. Resende [1], *L. A. Da Silva* [1], *R. A. J. Chagas* [1], *C. M. Denardini* [1], *L. R. Alves* [1], *J. P. Marchezhi* [1], *K. V. S. Espinosa* [1], *S. S. Chen* [1], *J. Moro* [1], *A. M. Santos* [1], *S. Laranja* [1], *and J. R. Costa* [1]
[1]*National Institute for Space Research (INPE)*

The central region of the South American Magnetic Anomaly (SAMA), located over southern Brazil, is characterized by enhanced low-energy (<40 keV) energetic particle precipitation (EPP), which can strongly perturb the ionosphere during intense geomagnetic storms. Sporadic E layers with spread-type traces, normally restricted to high latitudes, have previously been reported near the SAMA center. During several intense geomagnetic storms of the current solar cycle, however, this atypical Es structure was also observed over equatorial Brazilian ionosonde stations, including Belém (BLM; 1.45°S, 48.49°W, dip $= -2.5°$) and São Luís (SLZ; 2.3°S, 44.2°W, dip $= 8°$). These Es layers exhibited pronounced blanketing characteristics, inhibiting the detection of the overlying ionospheric regions. Such behaviour suggests the coexistence and possible competition of multiple physical mechanisms, including storm-time electric fields and neutral wind dynamics, acting in conjunction with EPP. Satellite measurements indicate that EPP-driven ionization extended beyond the core of the SAMA toward its northern boundary, reaching equatorial latitudes. Complementary numerical simulations demonstrate that precipitating particle energy fluxes with E<2 keV significantly contributed to the enhancement of electron density within the Es layer. Collectively, these results provide compelling evidence that the formation and storm-time behaviour of sporadic E layers are governed by the combined effects of energetic particle precipitation, wind shear processes, and disturbed electrodynamics.

The Atmospheric Waves Experiment (AWE) **O4-3**

Ludger Scherliess [1], *P.-D. Pautet* [1], *Y. Zhao* [1], *J. Forbes* [2], *S. Eckermann* [3], *D. Fritts* [4], *D. Janches* [5], *H. Liu* [6], *and J. Snively*[7]
[1]*Utah State University,* [2]*University of Colorado,* [3]*Naval Research Laboratory,* [4]*GATS,* [5]*NASA Goddard Space Flight Center,* [6]*National Center for Atmospheric Research,* [7]*Embry-Riddle Aeronautical University*

Theory and modelling indicate that atmospheric gravity waves (AGWs) play an important role in the vertical coupling of the atmosphere-ionosphere system. The Atmospheric Waves Experiment (AWE) mission is designed to investigate how terrestrial weather affects space weather, via small-scale AGWs produced in Earth's atmosphere. Following its launch to the International Space Station (ISS) in November 2023, AWE began a 2-year mission to explore the global distribution of AGWs, study the processes controlling their propagation throughout the upper atmosphere, and estimate their impacts on the ITM system. The AWE instrument consists of an Advanced Mesospheric Temperature Mapper (AMTM) that quantifies gravity wave-induced temperature disturbances in the hydroxyl (OH) airglow layer at ∼87 km altitude.

AWE images are collected once per second and processed into intensity and temperature swaths that to date have revealed a wide range of gravity waves arising from various sources, including mountain waves and convective gravity waves, secondary gravity waves, and instabilities due to GW breaking over deep convection, large- and small-scale terrain, and regions where no sources were apparent. This paper will present an overview of the AWE mission and discuss initial science results.

Concentric Mesoscale Wave Patterns in the Middle and Upper Atmosphere Revealed in High-resolution GEOS-FP During Hurricane Patricia **O4-4**

Guiping Liu [1], F. Sassi [1], R. S. Lieberman [1], D. E. Rowland [1], J. Pettit [1,2], and W. Putman [1]
[1]NASA Goddard Space Flight Center, [2]George Mason University

Convectively generated waves from severe weather in the lower atmosphere can be significant drivers of variability in the upper atmosphere. For this study, we analyse a high-resolution (∼0.25 degree latitude/longitude grid) version of the analysis product with data assimilation from the Goddard Earth Observing System Forward Processing (GEOS-FP). We identify transient concentric mesoscale (hundreds of kms in the horizontal direction) wave structures in vertical wind perturbations with amplitudes exceeding 10% of the background wind changes from ∼20-60 km altitude over North America near the track of Category 5 hurricane Patricia during October 20-24, 2015. These wave perturbations are accompanied by strong northward and upward transport of eastward momentum as shown in the calculation of localized transient momentum fluxes during the hurricane. Similar concentric wave patterns are observed in high-resolution observations of the CO2 emission brightness temperatures at nominal ∼30-40 km altitude from the Atmospheric Infrared Sounder (AIRS) operated on the Aqua satellite. This study shows the capability of high-resolution GEOS-FP to resolve small-scale waves in the stratosphere and lower mesosphere.

Multi-static Volumetric Spectral Imaging of PMSE with MAARSY-3D for Measurements of MLT Dynamics **O4-5**

Devin Huyghebaert [1], R. Latteck [1], T. Renkwitz [1], M. V. Hafteh [1], J. Vierinen [2], J. M. Urco [3], and J. L. Chau [1]
[1]Leibniz Institute of Atmospheric Physics, Kühlungsborn, Germany, [2]UiT The Arctic University of Norway, Tromsø, Norway, [3]Pontificia Universidad Catolica del Peru, Lima, Peru

Near the boundary between the terrestrial atmosphere and space and within the mesosphere-lower-thermosphere (MLT), polar mesospheric summer echoes (PMSE) are measured with radar systems at altitudes of 80-90 km during the summer months at high latitudes. These PMSE measurements can be used as a tracer of the MLT dynamics occurring. The MAARSY radar system, operated by the Leibniz Institute of Atmospheric Physics and located in northern Norway, measures PMSE consistently with close to full-time operations. The expanded MAARSY-3D system is currently under commissioning with 2 of the 3 receiver sites now operational, providing multi-directional details on the velocity of the PMSE in the scattering region. Here we highlight the use of advanced synthetic aperture imaging techniques to determine volumetric wind fields from 2 different observing angles in high spatio-temporal resolution (1 km and 30 s) in the 80-90 km altitude range, and present some case studies of the different phenomena that can be measured with the MAARSY-3D system, including km-scale processes and potentially rogue vertical drafts.

The Characteristics of Pekeris Modes Revealed by Long-Term Reanalysis Data JAWARA Covering the Entire Middle Atmosphere **O4-6**

Kaoru Sato [1] and H. Sekido [1]
[1]Department of Earth and Planetary Science, The University of Tokyo, Japan

Atmospheric normal modes are important as disturbances excited in the neutral atmosphere that cause strong ionospheric fluctuations. In addition to the vertically phase-aligned Lamb modes, which have been studied for a long time, there is another type of normal modes with a single vertical node called the Pekeris modes. Although the existence of Pekeris modes was theoretically predicted, they were only recently identified in the real atmosphere among the waves excited during the Hunga Tonga–Hunga Ha'apai eruption in January 2022. In this study, we performed a two-dimensional spectral analysis of the zonal wavenumber and frequency to identify and examine the characteristics of both Lamb and Pekeris modes, including their dominant altitudes. We used the JAWARA reanalysis data for the analysis, which covers the entire middle atmosphere from the surface to an altitude of ∼110 km, over a long time period of ∼19 years from September 2004 to December 2023. This dataset was released by our research group in January 2025. It is shown that the Lamb modes dominate in the stratosphere, while the Pekeris modes dominate in the mesosphere and lower thermosphere. The quasi-6-day wave, which is known to exist in the ionosphere, has a slightly longer period than the quasi-5-day wave which is frequently observed in the stratosphere. Our results suggest that, although both waves are first-order symmetric Rossby modes with a zonal wavenumber of 1, they have different wave periods because the former is the Pekeris mode and the latter is the Lamb mode.
[1] Sekido, H., & K. Sato (2026). The characteristics of Pekeris modes revealed by long-term reanalysis data JAWARA covering the entire middle atmosphere. Journal of Geophysical Research: Atmospheres, 131, e2025JD045099. https://doi.org/10.1029/2025JD045099 [2] Koshin, D., K. Sato, S. Watanabe, and K. Miyazaki (2025), The JAGUAR-DAS whole neutral atmosphere reanalysis: JAWARA. Prog. Earth Planet Sci., 12, 1. https://doi.org/10.1186/s40645-024-00674-3 [3] Sato, K.,and D. Koshin (2025), JAGUAR Data Assimilation System Whole neutral Atmosphere Reanalysis (JAWARA) [Data set] National Institute of Polar Research. https://doi.org/10.17592/002.2025010407

The Need for In-situ Measurements at Altitudes Below 200 km to Resolve Ion-neutral Interactions in the Lower Thermosphere - Ionosphere **O4-7**

Theodoros E. Sarris [1] *and the members of the Daedalus mission proposing team*
[1] *Democritus University of Thrace, Department of Electrical and Computer Engineering, Xanthi, Greece*

At the interface between the atmosphere and space, within the Lower Thermosphere and Ionosphere (LTI, altitudes roughly between 100 and 200 km), complex processes take place due to the interactions between neutral and charged particles in the presence of electric and magnetic fields. These processes uniquely characterize and shape this region. Even though a wealth of information comes from remote sensing measurements by instruments either onboard satellites or on the ground, understanding and quantifying processes related to ion-neutral interactions within this region require co-temporal and co-spatial measurements with high spatial resolution, such that can only be provided by in-situ sampling. Required measurements include plasma density and temperature, ion drifts, neutral density and wind, ion and neutral composition, electric and magnetic fields, and energetic precipitating particles. In this talk we will provide an overview of key processes within this region related to energetics, dynamics and chemistry that require such comprehensive measurements for their unambiguous characterization; we will summarize the current status of understanding as indicated by discrepancies in the representation of these processes in current global circulation models and methodologies based on remote sensing measurements; and we will make the science case for a proposed in-situ mission targeting to provide the first ever systematic and comprehensive measurements to resolve key open questions within this critically unexplored region. Together with modelling, such mission would enable significant advancements in the understanding of neutral-ion interactions and other related science and space weather topics in this critical region of Geospace.

Long-Term Variability in the Middle and Upper Atmosphere From WACCM-X: Trends in Neutral and Plasma Parameter **O4-8**

Liying Qian [1], *J. McInerney* [1], *C.-T. Hsu* [1], *W. Wang* [1], *S.-R. Zhang* [2], *and H. Liu* [1]
[1] *High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA,* [2] *MIT Haystack Observatory, Westford, MA, USA*

Long-term changes in the middle and upper atmosphere arise from a combination of anthropogenic forcing, solar irradiance variability, and the evolving geomagnetic field, acting on a system that is strongly coupled across scales. In this presentation, we synthesize results from Whole Atmosphere Community Climate Model eXtended (WACCM-X) simulations to quantify multi-decadal to century-scale changes in the ionosphere-thermosphere- mesosphere (ITM) system. The analysis highlights long-term trends in key state parameters—including neutral temperature, winds, and composition, and mass density, as well as electron density and ion temperature. We further present results using derived ionospheric diagnostics that provide deeper insight into space-climate variability. These include long-term changes in ionospheric slab thickness, the climatology and secular evolution of low-latitude Rayleigh-Taylor instability (RTI), and implications for the occurrence of equatorial plasma bubbles. Together, these results illustrate how internal atmospheric variability and anthropogenic climate change interact with solar and geomagnetic forcing to shape long-term trends in the coupled atmosphere–ionosphere system.

A Retrospective Study of Climate Response to Solar Variability **O4-9**

Wenjuan Huo [1], *C. Garfinkel* [2], *D. Avisar* [2], *A. Kuchař* [3], *S. Misios* [4], *and S. Minobe* [5]
[1] *GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany,* [2] *Fredy and Nadine Herrmann Institute of Earth Sciences, Hebrew University, Jerusalem, Israel,* [3] *Institute of Meteorology and Climatology, BOKU University, Vienna, Austria,* [4] *Institute for Astronomy, Astrophysics, Space Applications, and Remote Sensing, National Observatory of Athens, 11810 Athens, Greece, ,* [5] *Faculty of Science, Hokkaido University, Sapporo, Japan*

Solar variability has been proposed influence Earth's climate from the middle atmosphere to the surface. However, the detection and interpretation of solar signals in the climate system remain uncertain because their amplitudes are small compared to strong internal climate variability and other external forcings (e.g., greenhouse gases), leading to inconsistencies among observational- and model-based studies. Using simulations from the Large Ensemble Single Forcing Model Intercomparison Project (LESFMIP), with a particular emphasis on solar-only experiments, we isolate the solar-forced response from internal variability and responses to other external forcings. This retrospective analysis evaluates the robustness and statistical significance of the detected solar signals in the coupled climate system, including downward coupling processes and surface climate responses at both global and regional scales. By comparing solar forcing with other external forcings – namely well-mixed greenhouse gases, anthropogenic aerosols, volcanic eruptions, and ozone changes – we quantify the contribution of solar variability to the decadal predictability of atmospheric and surface temperature. In addition, we re-examine the potential modulation of solar signals by the Quasi-Biennial Oscillation and by different background climate states.

Solar Irradiance Impacts on Climate in Idealized Time-slice Simulations — O4-10

Jan Sedlacek [1], T. Sukhodolov [1], T. Egorova [1], M. Geurts [1,2], and E. Rozanov [1]
[1]PMOD / WRC, Switzerland, [2]Wageningen University, Netherlands

During the last millennia, prior to the industrialization, long-term climatic variations correlated with low-frequency total solar irradiance (TSI) changes. An additional natural forcing is volcanic activity. The exact magnitudes of these two natural forcings are not known as the reconstructions are subject to substantial uncertainty. There is still a debate on which forcing, i.e., solar vs. volcanic, influenced to which extend the climate during that time. The amplitude of the TSI decrease is especially uncertain and suggestions range from a few W/m^2 to a few tens of W/m^2 lower than today's value. In this project, we address the problem from an idealized perspective analysing simulations with the chemistry-climate model SOCOL where different solar forcings ranging from $+10\ W/m^2$ to $-20\ W/m^2$ in TSI terms are applied. In addition, some sensitivity simulations with changes in the UV radiation are performed.
On a global scale the surface temperature changes linearly with changing TSI. On a regional scale the picture is more complex and the climate response to TSI changes is not that straightforward. Most of these changes are related to changes in the North Atlantic Oscillation, Southern Annular Mode, Walker Circulation and changes in the strength and extend of the Hadley Cell. We will present our modelling results and discuss the mechanisms and relations leading to the different climatic changes. Understanding these processes and regional sensitivities can help interpreting observational proxies.

Impacts of Stratosphere Polar Vortex Variability on the Ionosphere-Thermosphere — O4-11

Nicholas M. Pedatella [1], B. Martinez [2]
[1]High Altitude Observatory, NSF National Center for Atmospheric Research, [2]Department of Physics and Astronomy, Clemson University

We present results highlighting the impacts of stratosphere polar vortex variability on the ionosphere and thermosphere. Sudden stratospheric warmings (SSWs), which are associated with a weakening of the stratosphere polar vortex, are known to significantly influence the middle and upper atmosphere. However, it will be shown that the polar vortex variability is not restricted to time periods of polar vortex weakening. Rather, the influence of the stratosphere polar vortex on the ionosphere during Northern Hemisphere winter occurs across the continuum of vortex variability. As the SSW signal in the stratosphere is potentially predictable out to ∼2 weeks, SSWs have been considered as a potential source of predictability in the ionosphere. The presentation will conclude with preliminary results illustrating the potential predictability of the ionosphere during SSWs. predictability. Preliminary results illustrating this predictability are presented.

Diagnosing the 11-year Solar Cycle Influence on the North Atlantic Winter — O4-12

Stergios Misios [1], P. L. M. Gonzalez [2,3], L. J. Gray [2,4], S. Osprey [2,4], H. Ma [5]
[1]Research Centre for Atmospheric Physics and Climatology, Academy of Athens, Greece, [2]National Centre for Atmospheric Science, United Kingdom, [3]University of Reading, United Kingdom, [4]Department of Physics, Oxford University, United Kingdom, [5]Hubei Key Laboratory for Heavy Rain Monitoring and Warning Research, China Meteorological Administration, Wuhan, China

The North Atlantic sector has been identified as a region where the 11-year solar cycle has small but potentially non-negligible impacts on winter climate, but a debate persists about the robustness of such impacts. This work explores the signatures of the 11-yr solar cycle over the North Atlantic in the ERA5 and 20th Century reanalysis datasets. The results confirm previous studies with a robust positive boreal winter response in mean sea level pressure (mslp) in the region of the Azores at lags of 3 years after solar maximum. The spatial evolution of the response is examined in detail by first decomposing the mslp time-series into the dominant modes of North Atlantic winter mslp variability, including the North Atlantic Oscillation (NAO), the East Atlantic (EA) and the Scandinavian patterns, before performing a multi-linear regression analysis. We find that the maximum 11-yr solar response in the December-January-February average does not project directly onto the NAO. However, when the early/late winter responses are examined separately, a statistically significant NAO response is seen in late winter (Jan-Feb) at lag 0-1 years and a statistically significant NAO response is also seen at lag $+3$ years in early winter (Nov-Dec). These results are consistent with predicted responses from previously proposed top-down influences from the stratosphere in late winter followed by the re-emergence of a signal from underlying sea surface temperatures in early winter. However, the NAO response is not the primary contributor to the total DJF response at lag $+3$ years. A previously unidentified solar cycle response in the EA pattern is found in late winter at lag $+3$ years with larger amplitude than the NAO response. The evolution of the DJF mslp response over the Azores region can thus be understood as a summation of the NAO and EA patterns at lag $+3$ years.

Short-term Solar Variability Effects on the Earth's Mesosphere/Lower Thermosphere **O4-13**

Markus Kunze [1], M. Sinnhuber [2], A. Siebelts [2], J. M. Wissing [3]
[1]Leibniz Institute of Atmospheric Physics at the University of Rostock, Kühlungsborn, Germany, [2]Karlsruhe Institute of Technology, Institut für Meteorologie und Klimaforschung, Karlsruhe, [3]Deutsches Zentrum für Luft- und Raumfahrt

Large increases in spectral solar irradiance (SSI) and energetic particle precipitation (EPP) are observed in conjunction with flares and coronal mass ejections (CMEs). A recent period of high solar activity in May 2024 included a CME and several solar flares with classes ranging from M5.1 to X4.5. These solar events were followed by solar proton events (SPEs) and geomagnetic storms in the Earth's magnetosphere shortly after the CME. Both SSI increases during solar flares and increases in EPP from SPEs, auroral electrons, and medium-energy electrons (MEE) lead to higher ionization in the thermosphere and mesosphere. Subsequently, the production of NOx and HOx is initiated, which in the polar regions propagate downward and have the potential to destroy ozone. In our study, we model this period of high solar activity with a chemistry-climate model extending from the troposphere to the lower thermosphere.
We use the upper atmosphere (UA) extension of the ICOsahedral Non-hydrostatic model (ICON) framework which is an open-source numerical weather prediction and climate model jointly developed by the German Weather Service (DWD), the Max-Planck Institute of Meteorology (MPI-M), Deutsches Klimarechen-zentrum (DKRZ), the Karlsruhe Institute of Technology (KIT), and the Center for Climate Systems Modelling (C2SM).
Our UA-ICON setup with a horizontal resolution of $\sim$160 km and a top height near 150 km includes interactive chemistry with basic ion-chemistry for molecular and atomic nitrogen and oxygen. The meteorology during the simulation is specified from ERA-5 reanalyses up to 50 km, where the nudging fades out, allowing the mesosphere and lower thermosphere to develop freely. We use daily NNLSSI from Lyman-α to the near-infrared and 5-minute resolved FISM2 SSI for X-ray/extreme ultraviolet. The EPP forcing, in terms of ion pair production rates (IPRs), is a combination of IPRs for Protons and Auroral electrons provided by the AISstorm model. The analysis focuses on atmospheric composition changes due to the direct EPP effects, the subsequent indirect effects on the ozone concentration in the stratosphere, and the dynamical feedback.

Common Excitation and/or Amplification Mechanisms of Rossby and Rossby-Gravity Normal Modes Revealed by Long-Term Reanalysis Data for the Whole Middle Atmosphere **O4-14**

Hiroto Sekido [1] and K. Sato [1]
[1]Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, Japan

Using the recently available reanalysis data set JAWARA, which covers the whole middle atmosphere over a long period of 19 years from September 2004 to December 2023, four Rossby-gravity and 10 Rossby normal modes have been identified. In the upper mesosphere, the geopotential height (GPH) amplitudes of all Rossby-gravity modes are maximized near the summer solstice except for the zonal wavenumber s = 1 Rossby-gravity mode. For all Rossby modes, except for the s = 1 first symmetric Rossby mode, GPH amplitudes exhibit enhancement in the pre- and post-summer solstice periods. It is inferred that the enhancements of the s = 3 and s = 4 Rossby-gravity modes around the summer solstice as well as those of Rossby modes in the post-summer solstice share a common feature: Eliassen-Palm (EP) flux divergence is positive near the critical line over the region with a negative latitudinal gradient of potential vorticity. This feature strongly suggests that dynamical instability commonly plays a key role in the excitation and/or amplification of these modes. In contrast, characteristics of the Rossby modes in the pre-summer solstice suggest a common but different mechanism from the above-described acting to their enhancement: strong upward EP fluxes are observed from the middle stratosphere to the upper mesosphere on the equatorward side of the negative latitudinal gradient of potential vorticity at high summer latitudes in the mesosphere. Moreover, the slight difference in the enhancement timing of individual normal modes is probably attributable to that of the phase speed.

The SPARTA Research Center: An Approach to Forecasting Ionospheric Scintillation **O4-15**

Keith Groves [1]
[1]Boston College

The SPAce Research and Technology Applications (SPARTA) Center aims to implement a comprehensive program to address the scientific and technical challenges posed by the need to specify and forecast ionospheric irregularities and associated radio wave propagation effects (i.e., scintillation), particularly as they impact GNSS applications. The overall objectives are: 1. Develop and establish a baseline capability for forecasting global irregularities with an operational background model; 2. Develop deep learning algorithms that may be demonstrated in real-time to replace the cumbersome physics-based models for operational purposes; and 3. Develop a technical roadmap that informs future data collection and background model capabilities requirements and quantifies associated improvements in scintillation forecast skill. Our modular approach employs the current NOAA operational WAM-IPE model (https://registry.opendata.aws/noaa-nws-wam-ipe/) to specify and forecast the background ionosphere and associated physical drivers. Regional models will then be applied to perform stability analyses used to cue algorithms calculating the non-linear development of instabilities at low, mid and high latitudes and the resulting small-scale density irregularity spectra. Finally, an advanced propagation algorithm will be used to determine scintillation effects on radio wave signals and anticipated impacts on the performance of global navigation satellite systems (GNSS). Validation, a key capability enhanced by access to extensive data sources and unique exploitation techniques provided by our diverse team, will be performed at each step to measure performance and support analyses aimed at optimizing the entire system for scintillation forecasting. At low latitudes,

the primary source of scintillation activity is equatorial spread F, which occurs predominantly during quiescent periods, whereas significant activity at mid- and high latitudes is associated with the formation of gradients and irregularities, typically during geomagnetic disturbances. Thus, we pursue two separate tracks to address these phenomena. At low-latitudes, accurate physics-based models to forecast the non-linear evolution of the post-sunset background ionosphere and subsequent equatorial bubble formation have been developed, along with machine learning emulators that run thousands of times faster than their physics-based equivalents to support real-time operational applications. At mid-high latitudes, the direct dependence on external solar drivers, whose forecasts are well-beyond the capability of current (and future?) models, suggests a less rigorous approach focused on defining and identifying key boundaries and regions to produce probabilistic semi-empirical forecasts. We describe the current status of the work as well as key challenges and shortcomings of existing solutions with the hope of informing the community as well as establishing new collaborations and potentially identifying new models and ideas leading to scientific progress and improved forecasting performance.

Investigating the Role of Atmospheric Gravity Waves in Seeding Equatorial Plasma Bubbles via Coordinated Radar Observations — O4-16

Suman Kumar Das [1], C. Stolle [1], Y. Yamazaki [1], A. Maute [1], F. Conte [1], J. L. Chau [1], and R. Rodríguez [2]
[1]Leibniz Institute of Atmospheric Physics at the University of Rostock, Kühlungsborn, Germany, [2]University of Piura, Peru

Equatorial plasma bubbles (EPBs) are critical ionospheric irregularities whose development depends on the interplay between background electrodynamics and small-scale seed perturbations. Atmospheric gravity waves (AGWs) originating in the lower atmosphere have long been proposed as a potential seeding mechanism, yet direct observational evidence of this coupling remains sparse. In this study, we examine the relationship between mesoscale AGW activity and EPB onset using coordinated radar observations.
We analyse horizontal wind measurements up to approximately 100 km altitude from the Spread Spectrum Interferometric Multistatic Meteor Radar Observing Network (SIMONe) in Piura ($5°S$, $80°W$; dip latitude $\sim 5.8°N$) to isolate AGW-induced perturbations in the mesosphere–lower thermosphere region. After removing background winds and tidal components, complex Morlet wavelet analysis is applied to characterize the temporal variability, dominant periodicities, and phase structure of the AGW field. These diagnostics are examined alongside EPB onset information obtained from the JULIA (Jicamarca Unmanned Line-of-sight Ionospheric Antenna) radar at Jicamarca ($11°S$, $76°W$; dip latitude $\sim 0.8°S$).
Given the limited altitude range of the wind observations, the potential influence of AGWs on EPB initiation is interpreted in terms of indirect coupling mechanisms, most plausibly through the generation of polarization electric fields that can map along magnetic field lines to the equatorial F region. Rather than asserting definitive causal relationships, this work focuses on developing an observational and methodological framework to examine AGW-related electrodynamic coupling associated with EPB initiation. The combined radar analysis provides quantitative metrics to assess the potential role of AGWs as seed perturbations under varying ionospheric conditions, offering a foundation for future statistical studies and predictive modelling of equatorial space weather.

Equatorial Spread-F Characteristics Using HF Doppler Shift Measurements: Results from Upgraded Doppler Sounder System in Tucuman, Argentina — O4-17

Habtamu Marew Alemu [1] and Ke Li [1] J. Chum [2], M. G. Molina [3], U. Ashrani [4], and Carlos Martinis [5]
[1]Institute of Atmospheric Physics of the Czech Academy of Sciences, Prague, Czech Republic, [2]Institute of Atmospheric Physics of the Czech Academy of Sciences, Prague, Czech Republic, [3]Tucumán Space Weather Center, Facueltad de Ciencia Exactas y Tecnología (FACET), Universidad Nacional de Tucumán (UNT), Tucumán, Argentina, [4]Center for Space Physics, Boston University, Boston, MA, USA, [5]Center for Space Physics, Boston University, Boston, MA, USA

Horizontals drifts of equatorial Spread F (ESF) at post-sunset and post-midnight are investigated by analyzing six ESF events observed during the period of November 2022–March 2023. Horizontal drift velocities of ESFs are calculated from the time lags between signals recorded by different transmitter–receiver pairs of a new Continuous Doppler Sounding (CDS) system operating at 6.80 MHz in a low latitude station, Tucumán, Argentina (26° 49' S, 65° 13' W, mag. latitude ∼13°) and by the older CDS system working at 4.63 MHz. A new method of time lags determination for spread structures is presented. In addition, the occurrence of airglow depletions associated with ESF events is verified using images of airglow emissions of atomic O red line, 630 nm. We found that the typical speeds of the ESF drift in the post-sunset hours (around 130 m/s) are about two times greater than the speeds of ESF occurring around midnight or in post-midnight hours (around 80 m/s). The drift speeds obtained using 4.63 and 6.80 MHz systems were practically the same with the exception of one event, which might have been due to wind shear. Azimuths obtained by 4.63 and 6.80 MHz systems are almost similar. No systematic dependence of the azimuth on the local time and sounding frequency was found. All ESF events drift roughly eastward with an average azimuth of about 105° with respect to the geographic north.

SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

Dynamics of Total Electron Content in the Ionosphere During Different Phases of Solar Flares **O4-18**

Susanna Z. Bekker [1], *A. N. O'Hare* [1], *L. A. Hayes* [2], *and R. O. Milligan* [1]
[1] Queen's University Belfast, [2] Dublin Institute for Advanced Studies

During solar flares, a sharp increase in solar electromagnetic radiation occurs across a wide range of wavelengths, leading to enhanced ionisation of the Earth's ionosphere at various altitudes. During intense events, such variations in the concentration of charged particles in the ionosphere often result in disruptions to communication and navigation systems.
The impact of the flare's main phase on the ionosphere has been studied for several decades using both theoretical and experimental methods. However, recent studies have revealed the existence of delayed warm coronal emissions that arise from magnetic reconnection minutes to hours after the impulsive phase. These enhancements are known as the extreme ultraviolet late phase (ELP) of a solar flare, and their influence on the ionosphere was first detected only in 2024.
Previously, using X-class flares with pronounced late phases, strong linear relationships were found between increases in total electron content and enhancements of radiation in the warm coronal Fe XV 28.4 nm line and the cool chromospheric He II 30.4 nm line during the impulsive and late phases, respectively. The present study extends this research by analysing C- and M-class flares accompanied by anomalously strong late-phase emissions in warm coronal lines. These emissions are shown to cause increased ionospheric ionisation even in cases where no detectable ionospheric response is observed during the impulsive phase of the flare.

Comparison of MAGE simulations with EISCAT and SuperDARN measurements **O4-19**

Florian Günzkofer [1], *D. R. Themens* [2,3], *K. Pham* [4], *F. Heymann* [1], *and Claudia Borries* [1]
[1] Institute for Solar-Terrestrial Physics, German Aerospace Center (DLR), Neustrelitz, Germany, [2] Space Environment and Radio Engineering Group (SERENE), School of Engineering, University of Birmingham, Birmingham, UK, [3] Department of Physics, University of New Brunswick, Canada, [4] National Center for Atmospheric Research, Boulder, CO, USA

Physics-based geospace simulations of the coupled Magnetosphere-Ionosphere-Thermosphere system promise to improve the modelling of space weather effects on the Earth system. Recently, a public version of the MAGE geospace model was released. The thermosphere-ionosphere component of this MAGE version is the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM).
We evaluate the MAGE simulation results against electron density measurements with the EISCAT VHF incoherent scatter radar and polar convection potential measurements by the Super Dual Auroral Radar Network (SuperDARN). Since geospace models are computationally expensive, we focus on two EISCAT campaigns for this first validation: To assess the quiet-time representation, we compare model results and measurements on 7 July 2020. For an evaluation of geomagnetically disturbed conditions, the 16 May 2024 is analysed, for which a strong particle precipitation event was identified. As a reference, we conducted two TIE-GCM runs driven by the empirical Heelis convection model for these days.
Initial results promise a significant improvement in model-measurement agreement with physics-based geospace simulations. MAGE is shown to reproduce the localized particle precipitation event detected in EISCAT measurements with moderate to strong correlation.

Quiet-Time Electron Density Enhancements at Low- and Mid-latitudes **O4-20**

Rajesh Vaishnav [1] *and C. Jacobi* [1]
[1] Leipzig Institute for Meteorology, Leipzig University, Germany

Understanding ionospheric irregularities is essential for reliable satellite communication and navigation. While geomagnetic storms are commonly linked to electron density enhancements, significant variability also occurs during geomagnetically quiet periods. This study examines the occurrence and drivers of low- and mid-latitude electron density enhancements under quiet geomagnetic conditions. Using observational datasets, including GNSS total electron content (TEC) and the Global-Scale Observations of the Limb and Disk (GOLD) measured O/N_2 ratio, we identify several enhancement events occurring during geomagnetically quiet times. These events are analysed alongside variations in solar EUV flux, lower atmospheric forcing, and thermospheric composition changes simulated by the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM). Results show that lower atmospheric forcing and subtle solar irradiance variations can substantially modulate the low- and mid-latitude ionosphere during quiet conditions.

Solar Wind–Ionosphere–Troposphere Coupling Via the Polar Branch of the Global Electric Circuit **O4-21**

Renata Lukianova [1,2], *A. Frank-Kamenetsky* [2], *and J. Victor* [3]
[1] Space Research Institute, RAS, [2] Arctic and Antarctic Research Institute, [3] Indian Institute of Tropical Meteorology

The global electric circuit (GEC) is believed to provide a possible link between the troposphere, ionosphere, magnetosphere, and the solar activity. In polar regions, the variable electric potential arising in the ionosphere due to the interaction of the solar wind and the interplanetary magnetic field with the magnetosphere is superimposed on the "background" ionospheric electric potential maintained by global thunderstorm activity. At high latitudes, sporadic fluxes of energetic particles of galactic, solar, and magnetospheric origin ionize atmospheric gases, increasing the conductivity of the air column. As a result, the electrical environment in the atmosphere is changed, including the height distribution of charged particles and the electric current flowing between the ionosphere and the Earth's surface in fair weather conditions. Using atmospheric electric field measurements in Antarctic, Vostok station (87 MLat), we show that a linear correlation exists between the near-surface potential gradient (PG) and the overhead ionospheric potential as predicted by convection models. During a magnetic storm, the actual measured PG and the vertical (z) geomagnetic component, which accumulates

magnetic signals from auroral electrojets and field-aligned currents, vary in accordance with each other without any time lag. In the southern polar region, atmospheric air pressure increases when the IMF By becomes negative. In the northern hemisphere, the effect is reversed. Persistent periodicities in PG associated with the solar rotation and atmospheric internal and gravity waves are revealed. Short-term ($<$2 min) oscillations, likely caused by turbulent processes, are detected in local summer.

Ionospheric Anomalous Variation During Five Earthquake Events: A Case Study of M ≥ 7.0 Earthquakes **P4-1**

Afolabi Kotoye [1], *B. J. Adekoya* [1], *B. Adelaja* [1], *K. Bamidele* [1], *and O. E. Falayi* [1]
[1] *Tai Solarin University of Education Ijagun*

In this paper, the pre-earthquake ionospheric anomaly that was observed before 5 earthquakes of magnitude M ≥ 7.0 have been studied using Total Electron Content (TEC) and critical frequency of the F2 layer (f0F2) data. The events studied were chosen based on their latitudinal spread from the northern hemisphere, through the low-latitude and equatorial region to the southern hemisphere. Our results reveal anomalous variations in either TEC or f0F2 or both, up to 10 days before the chosen earthquakes. It was also established that the method of percentage deviation using the reference days performed better that the method of percentage deviation using the bound method. Lastly, the anomalous variation in f0F2 showed clear latitudinal pattern which was absent in TEC.

Response of the Global Atmospheric Electric Circuit to Cloud Generators and Space Weather Forcing in the EGATEC Model **P4-2**

Rubén M. Romero [1], *A. Odzimek* [2], *J. C. Tacza* [2], *S. Szpigel* [1], *and J.-P. Raulin* [1]
[1] *Center for Radio Astronomy and Astrophysics Mackenzie, Engineering School, Mackenzie Presbyterian University, São Paulo, Brazil,* [2] *Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland*

The Global Atmospheric Electric Circuit (GAEC) can be effectively represented using engineering-type models that describe the atmosphere as an equivalent electrical network. The EGATEC model (Odzimek et al., 2010) provides such a framework by combining global satellite observations of clouds, precipitation, lightning activity, and atmospheric conductivity profiles to simulate ionospheric potential, global current, and the surface electric field, commonly expressed as the potential gradient (PG).
This study presents ongoing work aimed at the further development of the EGATEC model within a unified and modular modelling framework. The focus is on refining the representation of convective cloud current generators by exploring adaptive, physically based classification schemes that extend the original EGATEC formulation while preserving its physical foundations. The modular structure of the model enables systematic sensitivity experiments to examine how alternative but physically consistent generator parametrizations influence circuit behaviour.
Using the updated EGATEC framework, we investigate the diurnal and seasonal variability of key GAEC parameters, including ionospheric potential, total global current, and the fairweather PG. Model simulations are evaluated through comparison with ground-based electric field observations, with particular emphasis on South American measurements from the AFINSA network, complemented by long-term records from the Świder Observatory in Poland. In parallel, modern satellite datasets, including recent ISCCP products, are explored to support the updated generator representation.
In addition, we present preliminary simulations investigating the response of the modelled global circuit to selected space weather disturbances, including strong Forbush decrease events. These results provide insight into the sensitivity of surface electric field variability to transient changes in atmospheric ionization. Overall, this work contributes to the continued evolution of the EGATEC model as a tool for studying atmosphere–geospace coupling and for improving the interpretation of surface electric field observations within the Global Atmospheric Electric Circuit.
This work is supported by the National Science Centre (NCN, Poland), project 2021/41/B/ST10/04448, and by CAPES (Brazil) through the PDSE program, Process No. 88881.220881/2025-01.

Spread F Observations in the Argentine Sector During the November 2025 Geomagnetic Storm **P4-3**

Yamila D. Melendi [1,2,3], *G. González* [4,3], *M.G Molina* [3,5,6,7], *A. Villegas* [3,5,6], *N. Argüelles* [3,5,6], *M. F. Paz* [3,5], *T. J. Torres Peralta* [3,5,6], *and L. De Pasquale* [8]
[1] *Universidad Nacional del Sur, Bahía Blanca, Argentina,* [2] *Instituto de Física del Sur (IFISUR-CONICET), Bahía Blanca, Argentina,* [3] *Tucumán Space Weather Center, Tucumán, Argentina,* [4] *Space Sciences Laboratory, University of California, Berkeley, CA, USA,* [5] *Facultad de Ciencias Exactas y Tecnología, Universidad Nacional de Tucumán (FACET–UNT), Tucumán, Argentina,* [6] *Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina,* [7] *Istituto Nazionale di Geofisica e Vulcanologia (INGV), Roma, Italia,* [8] *Universidad Tecnológica Nacional UTN-FRBB, Bahía Blanca, Argentina*

We investigate the ionospheric response over the Argentine sector during an intense, two-step geomagnetic storm on 12–13 November, 2025, driven by the arrival of two interplanetary coronal mass ejections. The storm was marked by sudden storm commencements at 00:16 UT and 20:10 UT on 12 November, followed by SYM-H minima of -254 nT and -165 nT.
Automatically scaled and manually validated ionograms and GNSS-derived rate-of-TEC-index (ROTI) observations were analysed at two stations: a low-latitude site in Tucumán (26.9°S, 65.4°W; -17.6° magnetic latitude) and a midlatitude site in Bahía Blanca (38.7° S, 62.3°W; -29.4° magnetic latitude), Argentina.
In the South American low-latitude sector, spread F exhibits a clear seasonal dependence, with enhanced occurrence during the December solstice months (November–February). While post-sunset spread F is typically observed at low latitudes, its occurrence at Bahía Blanca is particularly notable, as such phenomena are infrequent at this midlatitude station. Spread F was detected at both stations during both storm intervals, indicating storm-driven ionospheric structuring across a wide latitudinal range.

GNSS-derived ROTI maps reveal enhanced ionospheric irregularities extending from ∼20°S to ∼40°S magnetic latitude during the storm. During the first storm interval, spread F developed before midnight and was short-lived at both stations. In contrast, during the second interval, spread F initiated before midnight and persisted into the post-midnight sector, with longer duration at Tucumán than at Bahía Blanca. At Tucumán, a pronounced reduction in foF2 relative to the 27-day mean was observed throughout the recovery phases of both storm intervals. This behaviour is consistent with storm-time disturbance dynamo electric fields driven by altered thermospheric circulation. Supporting this interpretation, GUVI O/N_2 maps over the Argentine sector show reduced values on 12 November, a minimum on 13 November, and partial recovery on 14 November.
These observations demonstrate that intense, multi-step geomagnetic storms can drive ionospheric irregularities and spread F from low to midlatitudes in the South American sector, including regions where such phenomena are rarely observed. The results highlight the importance of storm phase and recovery-time electrodynamics in controlling ionospheric structuring, and provide observational constraints for improving space-weather characterization and modelling in the Southern Hemisphere.

Scale-dependent Evaluation of Mesospheric Winds from Meteor Radar Using HYPER — P4-4

J. M. Urco [1] *and J. L. Chau* [1]
[1]*Pontificia Universidad Catolica del Peru, Leibniz-Institute of Atmospheric Physics*

Accurate characterization of mesoscale winds in the mesosphere and lower thermosphere (MLT) remains challenging due to sparse sampling, strong intermittency, and intrinsic limitations of conventional radar wind retrievals. The HYPER framework provides a physics-informed approach for reconstructing time-evolving, three-dimensional wind fields from multistatic meteor radar observations, offering new opportunities to examine mesoscale MLT dynamics.
This presentation will investigate the scale-dependent performance of HYPER mesospheric winds, with emphasis on identifying the spatial and temporal scales that can be robustly resolved under realistic observational conditions. Rather than relying solely on pointwise comparisons, the planned analysis will employ spectral and band-limited diagnostics, including kinetic energy spectra, coherence measures, and scale-dependent correlations, to assess reconstruction behavior across scales.
HYPER wind products will be evaluated independently against high-resolution simulations from the UA-ICON model and against campaign-grade observations from VORTEX, without data fusion or joint assimilation. These independent references will serve as external benchmarks to explore how reconstruction characteristics vary with horizontal wavelength, temporal averaging, altitude, and meteor sampling density.
The anticipated outcome of this work is a scale-explicit characterization of reliability limits for radar-based four-dimensional wind products in the mesosphere. By clarifying where physics-informed reconstruction improves interpretability and where unresolved variability dominates, this study aims to provide guidance for the analysis of mesospheric dynamics and for the design of future radar observing strategies.

Cross-Scale Impacts of Space Weather and Atmospheric Variability on Radio Communication Systems in a Tropical Environment — P4-5

Temitope Ojebisi [1], *J. T Ibitokun* [1], *O.V Omole* [2], *and E. O Ogunniyi* [3]
[1]*Department of Physics, Bamidele Olumilua University of Education, Science and Technology Ikere Ekiti, Ekiti State, Nigeria*

Space weather-driven disturbances in the near-Earth environment pose significant challenges to the reliability of modern communication systems, particularly in tropical regions where ionospheric and tropospheric dynamics are strongly coupled. This study investigates the combined effects of geomagnetic activity and atmospheric variability on radio wave propagation over southwestern Nigeria, focusing on total electron content (TEC) and tropospheric refractivity as key drivers of signal degradation.
TEC variations derived from GNSS observations are analysed alongside storm indices (Dst, and Kp) to quantify ionospheric disturbances during geomagnetically quiet and active periods. Simultaneously, refractivity profiles computed from local meteorological and ERA5 reanalysis data provide insights into tropospheric contributions to signal attenuation and bending. Cross-correlation analysis between TEC anomalies and refractivity variations identifies periods when ionospheric and tropospheric effects coincide, representing maximum risk for communication degradation.
Preliminary results indicate that geomagnetic storms induce significant TEC fluctuations, which coincide with enhanced tropospheric refractivity during the wet season. This co-occurrence leads to amplified signal fading, increased GNSS positioning errors, and potential microwave link disruptions. Statistical analysis shows strong correlations between storm indices, TEC deviations, and refractivity anomalies, revealing cross-scale coupling mechanisms from solar forcing to atmospheric propagation effects.
The findings demonstrate that standard propagation models may underestimate signal degradation when ionospheric and tropospheric effects are treated independently. These results have direct implications for the design, operation, and resilience of communication systems in tropical regions.
Keyword: Space weather, Ionosphere, Total Electron Content (TEC), Tropospheric refractivity, Radio communication

Lower Atmosphere, Upper Atmosphere, and Solar Influences on the Atmospheric Electric Field Near Ground **P4-6**

Athanasios Karagioras [1], *K. Kourtidis* [1], *and I. Kosmadakis* [1]
[1]*Democritus University of Thrace, Department of Environmental Engineering, Xanthi, Greece*

The atmospheric electric field, commonly referred to as the potential gradient (PG), represents a vertical electric field within the atmosphere, whose magnitude near the ground is modulated by local weather conditions as well as the Global Electric Circuit (GEC), a component of the latter being formed by the ionosphere. We present 15 years of measurements of PG at Xanthi, NE Greece and discuss its controlling factors. We also present a preliminary study of the potential influence of space weather on the atmospheric electric field. Long-term variations in the atmospheric electric field are examined with respect to the evolution of solar cycles 24 and 25. The PG response to solar–terrestrial coupling events, such as Solar Proton Events, Coronal Mass Ejections/X-ray flares, mid-latitude auroras and a solar eclipse. In addition, for the first time, we present evidence that near-ground PG increases as a result of Sudden Stratospheric Warmings events. The influence of above-ground nuclear tests on PG is also discussed, using historical PG data from Athens.

Investigating the Impact of Solar X-ray Radiation on the Global Atmospheric Electric Circuit **P4-7**

Konstantina Kapnia [1], *I. A. Daglis* [1], *S. Misios* [2], *A. Karagioras* [3], *and K. Kourtidis* [3]
[1]*SNational and Kapodistrian University of Athens, Department of Physics,* [2]*Academy of Athens, Research Centre for Atmospheric Physics and Climatology,* [3]*Democritus University of Thrace, Department of Environmental Engineering*

The variability of the activity of the Sun influences the climate of the Earth in multiple ways. This study investigates the impact of solar X-rays on the Global Atmospheric Electric Circuit (GEC), which is considered as a link of the space environment with terrestrial weather. Specifically, the correlation between solar X-ray radiation and the potential gradient of the GEC is examined, by means of data from the GOES satellites and the GloCAEM database. We have calculated the correlation between X-ray fluence and the daily values of the potential gradient of the GEC over a timespan of six years, i.e., roughly half a solar cycle. We have found no evidence of correlation between these two variables within the framework of this study.

SW2-TW3 Tidal Modulation Associated With Stratospheric Polar Vortex Variability **P4-8**

Zishun Qiao [1] *and N. Pedatella* [1]
[1]*NSF NCAR High Altitude Observatory*

The impact of strong and weak Northern Hemisphere stratospheric polar vortices (SPV) on the migrating semidiurnal (SW2) and terdiurnal (TW3) tides in the mesosphere and thermosphere is investigated using 40 Northern Hemisphere winter simulations from the Whole Atmosphere Community Climate Model with thermosphere-ionosphere eXtension (WACCM-X). Constant F10.7 index is configured in order to focus on the role of SPV variability while minimizing the influence of solar forcing. As reported by Pedatella and Harvey (2022) and Pedatella (2023), the SW2 increases during weak polar vortices while decreases during strong vortices. This work expands the analysis to the TW3 and similarly to SW2, the daily TW3 amplitude anomaly presents negative correlation with the daily NAM index. The daily SW2 and TW3 amplitude anomalies are moderately to strongly correlated with daily NAM at 10 hPa in the spatial region where their amplitudes are statistically significant. Stronger SW2-TW3 phase locking during weak polar vortices is identified compared to that during the strong SPV, which suggests enhanced modulation of SW2 on TW3 when their amplitudes are increased during weak SPV periods.

Ionospheric Irregularities Detected from GNSS Measurements Collected at COSMIC-2 Precise Orbit Determination Antennas **P4-9**

Ayomide Olabode [1], *L. Schreitter* [2], *M. Alizadeh* [1], *L.-C. Tsai* [3], *and H. Schuh* [5]
[1]*Institute of Geodesy and Geoinformation Science, Technical University of Berlin, Berlin, Germany,* [2]*German Geodetic Research Institute, Technical University of Munich, Munich, Germany,* [3]*Center for Space and Remote Sensing Research, National Central University, Taiwan*

At equatorial regions, complex physical processes trigger plasma instability and generate localized volumes of lower electron density around sunset, the so-called equatorial plasma bubbles. When GNSS radio-frequency signals are propagating through the ionosphere, they encounter these plasma bubbles, and rapid phase and amplitude fluctuations can be induced in the signals. The effect on GNSS is more significant in the F-region of the ionosphere where the background electron density is usually high. Although there has been a significant amount of ionospheric observations up to date using ground-based GNSS receivers and radar systems, these irregularities that vary across spatial and temporal scales are still not completely understood. In this study, we investigate phase fluctuations in GNSS measurements of the precise orbit determination antennas of the FormoSat-7 / COSMIC-2 satellite. Using the geometry-free linear combination, we derive relative values of Total Electron Content (TEC) along the line of sight of the satellites from which the Rate Of change of TEC Index (ROTI) is estimated to examine plasma bubble activity during the ascending phase of the solar cycle 25.

Traveling Ionospheric Disturbances Observed During the 2024 Typhoon Shanshan: Effects of Atmospheric Waves and Electro-dynamical Forces **P4-10**

Junxian Fu [1] *and Y. Otsuka* [1]
[1]*Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan*

Here, we report findings on travelling ionospheric disturbances (TIDs) during typhoon Shanshan, using the total electron content (TEC) data derived from the Global Navigation Satellite System (GNSS) network in Japan and Australia. TIDs with different propagating directions were observed during local nighttime over Japan. Southwestward and northeastward TIDs exhibited clear conjugate signatures in the opposite hemisphere, whereas northwestward and southeastward TIDs did not. We noticed the southwestward TIDs were nearly in phase with their conjugate counterparts, while the northeastward TIDs showed a distinct phase difference. The conjugate TIDs are primarily driven by polarization electric fields, whereas the other TIDs represent passive ionospheric responses to typhoon-induced gravity waves.

The Solar Influence on Tropical Cyclones Occurs over Ban of Bengal and Arabian Sea Area **P4-11**

Dhrube Banerjee [1]
[1]*Swami Vivekananda Institute of Science and Technology*

During last few decades a prominent example of extreme weather event in Indian ocean region is Cyclonic Storm. In this paper annual variation of different categories of tropical Cyclonic Storms like Tropical cyclone(CS), Severe Cyclonic Storm (SCS), Very Severe Cyclonic Storm (VSCS) and Super Cyclonic Storm (SuCS) over Bay Of Bengal (BOB) and Arabian Sea (ARS) have been analysed .The analysis revels that the total number of cyclone (TNC) has increased with high rate (gradient being $+1.67$ per year) and although C.S. is more over BOB than that over ARS.The rate of increase of C.S. over Arabian Sea is more than that over Bay of Bengal. Furthermore, two interesting features have been noted: (i) Monsoon tends to prohibit the formation of C.S (ii) Cyclonic Storm(C.S.) increases with the increase of Global Sea Surface Temperature (GSST) during said period.
An attempt has also been made to find out the influence of solar activity on these extreme weather events. Keeping in mind that the Sun Spot Number (SSN) is an indicator of the strength of solar effects, it has been found that in most of the times the high value of SSN is associated with small number of total cyclone (C.S.). Specifically, when only the years of high Sun's Spot Number (approximately greater than 90) are taken into consideration then Correlation Coefficient (C.C.) between SSN and number of cyclones comes out to be quite high (0.78) significance at 99.99% level while Correlation Coefficient (C.C.) of cyclones with time is 0.53 and with SSN < 60 it is 0.095. Thus it appears that although C.S. frequency is increasing with time, Sun's Spot's influence is such that it basically opposes the formation of cyclone provided SSN exceeds certain critical value (roughly 90). In principle, this is very important for any such event, and it is consistent with the trend of different phenomena occurring in nature.

Wavenumber-4 Longitudinal Structure in ICON-MIGHTI Thermospheric Meridional Wind **P4-12**

A. S. Meenakshi [1]*, and B. S. Sridharan* [1]
[1]*National Atmospheric Research Laboratory, Gadanki, AP, India*

The four-peaked longitudinal structure (wave-4) observed in the ionosphere and thermosphere has been extensively studied to understand its seasonal and interannual variability across various parameters like electron density, vertical drifts, hmF2 (peak height of electron density of F-layer), thermospheric winds, temperature, etc. The longitude variation of the ionospheric parameters is considered to be driven by atmospheric tides propagating from below. The non-migrating diurnal eastward-propagating tide with zonal wavenumber-3 (DE3), which is excited by the latent heat release in the troposphere, is widely considered the primary driver of the wave-4 structure in ionospheric parameters. The Wave-4 pattern has also been observed in the distribution of convective clouds, reinforcing the connection between tropospheric processes and ionospheric variability. The wave-4 longitudinal structure is crucial, as it influences the distribution of ionospheric plasma, thermospheric winds, and neutral composition. Understanding the driving mechanisms of the longitudinal structure of upper atmospheric parameters provides valuable insights into lower-upper atmospheric coupling and helps us to improve ionospheric models. We have investigated the wavenumber-4 (wave-4) structure in the longitude variation of zonal and meridional winds observed by the Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGHTI) instrument onboard the Ionospheric Connection Explorer (ICON) satellite. The amplitude of the wave-4 pattern in meridional wind displays semi-annual variation with equinoctial maxima. In contrast, its seasonal variation in zonal wind shows maxima during August-October over the equatorial and low latitudes. The wave-4 longitude variation maximizes at lower thermospheric heights (below 130 km) in zonal and meridional winds. It is primarily driven by the non-migrating eastward propagating diurnal tide with zonal wavenumber-3 (DE3) in the zonal wind. However, the amplitude of the DE3 tide in the meridional wind does not show any enhancement during September-October. The seasonal variations of the wave-4 amplitude and the DE3 tide are not similar in the zonal and meridional winds. The migrating ter-diurnal tide (TW3) exhibits significant amplitudes during March-April and September-November in the meridional wind. In addition, the latitude variation of the nonmigrating TE1 tide shows maximum amplitude during September-October. These results suggest that the non-linear interaction between the TW3 and TE1 tides can be a potential source for the wave-4 longitude variation in the meridional wind at lower thermospheric altitudes.

Coupling Between Long-Term Arctic Surface Variability and the Stratosphere–Mesosphere–Lower Thermosphere System **P4-13**

Sunil Kumar [1], *J. Oberheide* [2], *J. Zhang* [3], *N. M. Pedatella* [4], *and X. Lu* [5]
[1]Physics and Astronomy Department, Clemson University, Clemson, SC, USA, and Cooperative Programs for the Advancement of Earth System Science, University Corporation of Atmospheric Research, Boulder, CO, USA, [2]Physics and Astronomy Department, Clemson University, Clemson, SC, USA, [3]Department of Physics, Utah State University, Logan, UT, US, [4]High Altitude Observatory, NSF National Center for Atmospheric

We investigate long-term trends in the Arctic stratospheric polar vortex (SPV) and its coupling to the mesosphere and lower thermosphere (MLT) using Modern-Era Retrospective Analysis for Research and Applications version 2 (MERRA-2) reanalysis data and simulations from the Specified Dynamics Whole Atmosphere Community Climate Model with thermosphere–ionosphere extension (SD-WACCM-X). Our results show that the Arctic SPV experienced a weakening trend from 1980 to the early 2000s, followed by a strengthening trend thereafter. This transition is primarily linked to changes in planetary wave (PW) activity, particularly zonal wavenumber-1, which is strongly influenced by Arctic surface variability. Positive trends in sea surface temperature (SST) over the Barents–Kara (B–K) Sea region prior to the early 2000s, and over the Central North Pacific (CNP) region after the early 2000s, are identified as key drivers of the observed PW variability. Furthermore, changes in SPV strength significantly impact MLT dynamics, including zonal winds and the migrating solar semidiurnal tide (SW2). The SW2 tide exhibits a positive trend of approximately 13% per decade before the early 2000s and a negative trend of about 1% per decade afterward. These results provide evidence of the impact of Arctic surface variabilities, on the MLT dynamics, especially SW2 tide. More details will be presented.

Response of Migrating Semidiurnal Solar Tide in the Mesosphere, Thermosphere, and Ionosphere to the Arctic and Antarctic SPV Strength **P4-14**

Sunil Kumar [1], *J. Oberheide* [2], *and X. Lu* [3]
[1]Physics and Astronomy Department, Clemson University, SC, USA, and Cooperative Programs for the Advancement of Earth System Science, University Corporation of Atmospheric Research, Boulder, CO, USA, [2]Physics and Astronomy Department, Clemson University, SC, USA, [3]Physics and Astronomy Department, Clemson University, SC, USA

We extensively examined the migrating solar semidiurnal tide (SW2) variabilities with the strength of Arctic and Antarctic Stratospheric Polar Vortices (SPV), wherein the Specified Dynamics Whole Atmosphere Community Climate Model with thermosphere-ionosphere extension simulations have been used. Our analyses reveal that SW2 show a substantial response to both hemisphere SPV, but with a weaker sensitivity to the Antarctic SPV. In the hough mode analysis, we find a clear relationship between first two symmetric and antisymmetric hough modes of SW2 with Arctic SPV with biggest change in (2,3). Whereas only second symmetric (2,4) hough mode shows a variability with Antarctic SPV. These kinds of distinctive differences in hough modes variations are found to be due to the dynamical differences in the middle atmosphere. In addition, the role of the stratospheric ozone caused by SPV variations is also examined. We report a small role of the stratospheric ozone in the SW2 variations during different state of Arctic SPV. But in case of Antarctic SPV, we have not found a significant impact of stratospheric ozone on the SW2 variabilities. Furthermore, these distinct variations in Hough modes associated with the Arctic and Antarctic SPV contribute to a hemispherical asymmetric response in the ionosphere.

The Influence of Solar Activity Level on Sudden Stratospheric Warming Events during Solar Cycle 23 (1998-2008) **P4-15**

Kotoye Afolabi [1], *K. J. Bamidele* [3], *A. S. Ajose* [3], *and E. O. Falayi* [2]
[1]Science Laboratory Technology Department, Abraham Adesanya Polytechnic, Ijebu-Igbo, Nigeria, [2]Department of Physics, Tai Solarin University of Education, Ijagun, Nigeria, [3]Department of Physics, Lagos State University of Technology, Oto/ Ijanikin, Nigeria

The Sudden Stratospheric Warming (SSW) events which occurred during solar cycle 23 (1998-2008) were investigated using daily stratospheric data (temperature, planetary wave, and zonal mean wind). A total of 10 events that occurred in the period were investigated, and they were all major events. The Wavelet Power Spectrum approach was also used to analyse the stratospheric parameters. It provides more details about the transient variabilities in stratospheric parameters. The analysis of the effect of the solar activity level on sudden stratospheric warming and the direction or phase of the Quasi-Biennial Oscillation (QBO) were also considered.

The planetary wave (PW) amplification was observed to precede the rise in temperature and the reduction in speed of the zonal mean wind. It was noted that planetary wave amplification drives SSW. When the QBO was westerly, the stratospheric temperature shows a positive correlation with solar activity level, PW-1 showed a weak positive correlation (0.21), while PW-2 showed a negative correlation (-0.55). In the easterly phase, temperature and solar activity level show an inverse relationship, while both PW-1 and 2 showed a positive correlation with solar activity level. The result suggested that in the westerly phase, the solar activity level drives stratospheric temperature via adiabatic energy transfer, but has no influence on the strength of the PW. In the easterly phase, the solar activity level does not influence stratospheric temperature, but it influences the generation of stronger PWs which drive intense SSW events. These results clearly show the influence of solar activity level on SSW and the coupling mechanism between the equatorial troposphere and the polar stratosphere.

The Effect of the SSW/ES Event in 2018 on the VLF signal of Three Transmitter-receiver Links in High Latitude **P4-16**

Helen Schneider [1], V. Wendt [1], M. Clilverd [2], and T. Raita [1]
[1]German Aerospace Centre,Solar Terrestrial Institute,Neustrelitz,Germany, [2]Physical Sciences Division,British Antarctic Survey,Cambridge,UK, [3]Sodankylä Geophysical Observatory,University of Oulu,Sodankylä,Finland

Man-made very low frequency (VLF, 3 - 30 kHz) radio signals travel from transmitter to receiver within the Earth-ionosphere waveguide, confined between the Earth's surface and the lower ionosphere in approximately 60 - 90 km altitude, known as the D-region. While ground conditions do not change significantly over time, variations in the reflected VLF signal can be linked to changes in the upper reflection boundary, thus to changes in the ionization of the D-region. Ionization variability in this region can be driven by atmospheric processes such as Sudden Stratospheric Warmings (SSWs) and Elevated Stratopause (ES) events. These wave-driven SSW/ES events, typically occurring at mid- to high latitudes, cause significant disturbances in temperature, wind patterns, and vertical mass transport.
In this study, we investigated how the SSW/ES event of the 2017–2018 winter season affected VLF signal amplitudes across three high-latitude transmitter-receiver (Tx–Rx) links. During the SSW period, all three links showed an increase in amplitude. However, in the subsequent ES period, amplitude variations differed among the links. Only one link showed a decrease in amplitude – a signature also observed in previous ES events and likely characteristic of such events under quiet solar and geomagnetic conditions.
Our analysis indicates that the 2018 ES event displayed considerable spatial variability. Consequently, the processes responsible for amplitude decreases did not occur uniformly across all VLF propagation paths. We conclude that the observed differences in VLF amplitude behaviour among the three Tx–Rx links are due to the spatial distribution of the 2018 ES event.

Horseshoe-Shaped Vortices Accompanied With Breaking of Upward Propagating Gravity Waves and Their Relation to Mean-Flow Acceleration **P4-17**

M. Kohma [1], K. Sato [1], D. C. Fritts [2], and T. S. Lund [2]
[1]The University of Tokyo, Tokyo, Japan, [2]GATS, Boulder, CO, USA

Breaking gravity waves (GWs) are a major source of turbulence and momentum deposition in the middle atmosphere. In spite of the importance of this phenomenon, the small-scale vortex structures associated with wave breaking remain poorly documented under realistic conditions. We perform a three-dimensional compressible simulation of orographic GWs observed above Syowa Station, Antarctica, using 125 m horizontal grid spacing from the ground to the mesosphere. In the 75 – 80 km region upward-propagating waves break and exhibit numerous horseshoe-shaped vortices whose bends extend obliquely downward. By examining the time evolution of a representative horseshoe-shaped vortex, we identify the mechanism responsible for the downward elongation of the vortex tube: (a) horizontal vorticity aligned with the GW phase lines is amplified as the wave approaches the overturning condition; (b) a convectively driven downward flow displaces the vortex tube downward, creating the initial horseshoe shape; (c) vertical shear associated with the GW tilts and stretches the tube, reinforcing the downward flow. The direction of the initial vortex tube is determined largely by the baroclinic effect of the GW. The present study also addresses the relationship between the vortex tube structure and the mean flow acceleration . The vortex tube deformation associated with wave breaking can be interpreted as a manifestation of the irreversible cascade that transfers the GW momentum to the mean flow.

Investigation of the Statistical Relationship Between MF R-Mode and VLF signals in Relation to D- and E-layer Variability **P4-18**

Maja Grützmann [1], H. Schneider [1], V. Wendt [1], L. Grundhöfer [2], and F. Heymann [1]
[1]German Aerospace Center (DLR), Solar-Terrestrial Institute, Neustrelitz, Germany, [2]German Aerospace Cennter (DLR), Institute of Communication and Navigation, Neustrelitz, Germany

In an era of high demand for international trade and concurrent increases in GNSS signal manipulation in the Baltic Sea region, ensuring safe and reliable maritime navigation has become challenging. To address this issue, the R-Mode system, a terrestrial navigation system with medium frequency (MF) and very high frequency (VHF) signal subsystems, is being established as a backup to GNSS. Here we focus on the MF R-Mode, operating at frequencies of 283.5 – 315 kHz.
The MF R-Mode signal can be described as a combination of the ground wave, which propagates near the earth's surface, and the sky wave, which is reflected off the E-layer of the lower ionosphere and directed back towards the earth. While the ground wave provides the desired positional information, the sky wave interferes with it, degrading navigation accuracy. During the day, the sky wave is damped in the D-layer by absorption and scattering, reducing its disruptive influence. At night, however, the D-layer dissipates, allowing the sky wave to return at nearly full intensity and severely impair MF R-Mode performance. The interactions between the sky wave and the E- and D-layers make MF R Mode performance intrinsically dependent on the state of the lower ionosphere. A deeper understanding of these mechanisms and their dependence on ionospheric variability is required to (a) allow for real-time MF R-Mode accuracy estimation and (b) apply well-founded corrections to the received signal to compensate for the sky wave's influence.
The D- and E-region lie at altitudes of about 50-150 km, where drag is too high for satellites and buoyancy too low for balloons, making in-situ data acquisition challenging. A possible source of information about these altitudes are very low frequency (VLF, 3 – 30 kHz) radio waves, which also reflect off the lower ionosphere and can thus provide insights into the state of the D- and E-regions under varying solar and geomagnetic conditions.

This work examines the statistical relationship between MF R-Mode and VLF signals to assess whether VLF data allow inferences about the MF R-Mode's positioning accuracy. Initial analyses indicate a potential anti-correlation between the two signals, suggesting that VLF observations could be used as a proxy for MF R Mode sky wave behaviour. We aim to identify seasonal and diurnal changes in MF R-Mode accuracy driven by variations in atmospheric and solar parameters. Ultimately, this work shall pave the way to establish an MF R-Mode accuracy forecast system guided by VLF measurements. At this conference, we present the first results of this ongoing research.

The Migrating Terdiurnal Tide (TW3) Effect on the Ionosphere as Simulated by TIEGCM Driven by ICON Observations **P4-19**

Astrid Maute [1], C. Cullens [2], J. Forbes [3], S. Karol [4], S. England [5], and R. Agarwal [5]
[1]Leibniz Institute of Atmospheric Physics, Germany, [2]LASP, CU Boulder USA, [3]Ann & H.J. Smead Department of Aerospace Engineering Sciences, CU Boulder USA, [4]CIRES, CU Boulder USA, [5]Virginia Tech USA

ICON observations provide day- and nighttime measurements of neutral winds and temperatures in the 90 – 105 km region, which can be used to drive the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM). Until now, TIEGCM simulations based on ICON data have included only the diurnal and semidiurnal tidal components. However, ICON observations indicate that the migrating terdiurnal tide (TW3) can reach substantial amplitudes in the E region, up to 1/3 of the migrating semidiurnal tide (SW2). For this reason, TW3 derived from ICON observations has been incorporated into the lower boundary of the TIEGCM.
This study examines the influence of TW3 on low latitude vertical plasma drifts and the resulting plasma distribution. We quantify its impact by comparing simulations performed with and without TW3 included at the model's lower boundary. Overall, adding TW3 at the TIEGCM lower boundary shifts the daytime vertical drift peak toward the pre noon sector and reduces the post noon drift. Because low latitude vertical drifts strongly shape the plasma distribution, the effect of TW3 is evaluated. Model results are compared with ICON and COSMIC 2 observations. The findings highlight the role of TW3 for the daytime and nighttime dynamics, offering new insight into how TW3 contributes to ionospheric variability.

Electromagnetic Field Structures associated with an Equatorial Plasma Bubble Observed on 23 September 2014 by a Ground-Based Airglow Imager and the Swarm Satellite **P4-20**

Sefria Anggarani [1,2], K. Shiokawa [1], Y. Otsuka [1], A. Shinbori [1], and C. Stolle [3]
[1]Institute for Space-Earth Environmental Research (ISEE), Nagoya University, Nagoya, Japan, [2]National Institute of Aeronautics and Space, Bandung, Indonesia, [3]Leibniz Institute of Atmospheric Physics at the University of Rostock (IAP), Kühlungsborn, Germany

We investigate the electromagnetic field structures associated with an equatorial plasma bubble (EPB) observed on 23 September 2014 using simultaneous ground-based and satellite measurements. The horizontal development of the EPB was captured by 630.0 nm airglow observations from an all-sky imager at Darwin, Australia (12.44°S, 130.96°E), operated as part of the Optical Mesosphere Thermosphere Imagers (OMTI) network. These optical measurements were combined with in situ observations from the European Space Agency (ESA) Swarm A and Swarm C satellites, which crossed the same region during the event and provided simultaneous measurements of plasma density, electric field, and magnetic field.
The airglow data were mapped onto geographic coordinates assuming a reference altitude of 350 km, and the Swarm measurements were projected along geomagnetic field lines using the IGRF model to the same altitude, so that the airglow intensity depletions spatially coincide with the electron density depletions measured by Swarm. This approach allows the EPB structures identified in the airglow images to be examined together with the associated electric and magnetic field variations measured by the satellites. To the best of our knowledge, this is the first study in which EPB structures observed by a ground-based airglow imager are directly overlaid with both electric and magnetic field vectors from the Swarm mission. Near-simultaneous crossings by Swarm A and Swarm C at around 14:37–14:38 UT reveal clear plasma density depletions accompanied by localized electric field variations and magnetic field perturbations. During this interval, Swarm A intersected a branch of the EPB, while Swarm C crossed the main body of the EPB, allowing different parts of the EPB structure to be sampled simultaneously.
The electric field variations reflect active electrodynamic processes within the plasma depletion. The magnetic field perturbations indicate a southwestward vector with amplitudes of less than 1 nT, related to the EPB structures that are elongated in the NE-SW direction. We discuss a possibility that this magnetic field perturbation may be associated with field-aligned currents flowing along the eastern and western edge of the EPB. These results demonstrate that EPBs are governed by coupled electric and magnetic field processes and highlight the utility of combining airglow imaging with in situ Swarm observations.

Energetic Particle Precipitation Impacts on the Atmosphere and Climate in Idealized Time-slice Simulations **P4-21**

Timofei Sukhodolov [1], S. Wigger [1,2], G. Chiodo [3], E. Rozanov [1], S. Vattioni [1,2], T. Asikainen [4], J. Sedlacek [1], and M. Sinnhuber [5]
[1]Physical-Meteorological Observatory Davos / World Radiation Center (PMOD/WRC), Davos, Switzerland, [2]ETH Zurich, Zurich, Switzerland, [3]Instituto de Geociencias(IGEO), CSIC-UCM, Madrid, Spain, [4]Space Climate Group, Space Physics and Astronomy Research Unit, University of Oulu, Oulu, Finland, [5]Karlsruhe Institute of Technology, Karlsruhe, Germany

Energetic particle precipitation (EPP) is a key driver of chemical and dynamical processes in the middle atmosphere, influencing ozone concentrations, radiative heating, and large-scale circulation patterns. Investigating EPP impacts in observations and historical simulations is complicated by the sporadic nature of EPP events, sparse and noisy datasets, and the presence of internal atmospheric variability and other forcings that can obscure EPP-driven signals. Trying to overcome these limitations, we performed long-term idealized time-slice simulations with the fully coupled chemistry-climate model SOCOLv4 under different CO2 concentrations and EPP forcing scenarios, contrasting the strong EPP forcing year 2003, which culminated in the Halloween storms, with the weak EPP forcing reference year 2008. In all simulations, EPP increased polar NOx in the mesosphere and upper stratosphere, mainly via low- and medium-energy electrons, with minor proton contributions. Continuous and persistent EPP forcing also caused substantial global and inter-hemispheric transport, persisting beyond the events, spreading NOx to lower altitudes and latitudes, resulting in almost world-wide statistically significant ozone changes. Despite radiative cooling induced by ozone-loss, the polar stratosphere shows a temperature dipole of positive stratosphere and negative upper stratosphere/lower mesosphere temperature anomalies, strongest in Northern Hemisphere winter, and cooling in the tropical stratosphere. This temperature pattern weakens the stratospheric meridional temperature gradient, alters planetary wave propagation, weakens the polar vortex, and triggers surface responses resembling shifts in the Southern Annular Mode and North Atlantic Oscillation. Less frequent EPP forcing scenario, in contrast, resulted in the strongest temperature anomalies in the Southern Hemisphere, reversing sign in late winter and early spring, with negative polar stratosphere and positive mesospheric temperature anomalies, strengthening the polar vortex. Under 4×CO2, the Southern Hemisphere shows amplified NOx descent, while the Northern Hemisphere response is weaker, reflecting hemisphere-dependent and, likely, model-dependent anomalies.
While this study confirms the robust atmospheric and surface effects of EPP and their modulation by climate change, it also highlights a strong variety of EPP impacts even in terms of the sign of the response depending on many factors. The results also indicate that the time-slice setup could not fully isolate the polar EPP effects conventionally considered in the previous literature. Conversely, the simulations show that the EPP signal in ozone can be present globally in the stratosphere, because of the long lifetime of NOx, which provides an additional modulation to the related thermodynamical response of the polar middle atmosphere and its connection to the surface climate. This raises a question to which extent this mechanism is manifested under non-idealized realistic conditions, given that there are multiyear periods of enhanced EPP related to the maximum phase of the 11-year solar cycle.

The Neutral October Effect in Atmosphere Models **P4-22**

Vivien Wendt [1], H. Schneider [1], M. Ern [2], F. Günzkofer [1], H. Liu [3], and M. Kunze [4]
[1]Institute of Solar-Terrestrial Physics, German Aerospace Center, Neustrelitz, Germany, [2]Institute of Climate and Energy Systems: Stratosphere (ICE-4), Forschungszentrum Jülich GmbH, Jülich, Germany, [3]High Altitude Observatory, NSF National Center for Atmospheric Research, Boulder, CO, USA, [4]Leibniz Institute of Atmospheric Physics at the University of Rostock, Kühlungsborn, Germany

The October effect is well known as a sharp decrease in the amplitude of Very Low Frequency (VLF) radio waves reflected in the D-region (60–90 km). However, the underlying mechanism of the October effect remains unclear. Recent studies suggest that neutral atmosphere dynamics may play a key role. Coincident with the October effect in the ionized D-region, a warming occurs in the lower mesosphere. We refer to this feature as the neutral October effect. Notably, this warming is absent in spring, resulting in a pronounced spring-fall asymmetry.
This spring-fall asymmetry is reproduced by models that assimilate satellite observations in the mesosphere, such as MERRA-2 and JAWARA. However, MERRA-2 captures the neutral October effect only after 2005, when mesospheric satellite data began to be assimilated. In contrast, models that are free-running in the mesosphere generally fail to reproduce the neutral October effect (e.g., WACCM-X, ERA5, GAIA, UA-ICON). One notable exception is CMAM30, which successfully reproduces the neutral October effect. This study aims to investigate the mechanism responsible for the neutral October effect in the mesosphere and to identify why most models struggle to simulate it.
Using CMAM30 model output and satellite observations from SABER and MLS, we examine the dynamics of the fall transition, with a particular focus on planetary and gravity waves. Our results indicate that gravity waves play a key role in generating the neutral October effect. This finding provides further evidence of deficiencies in current gravity wave parametrizations. At present, these deficiencies can be mitigated only by assimilating mesospheric observations or by increasing model resolution, as demonstrated by a high-resolution WACCM-X simulation.

SESSION 5: Modelling, Data Analysis Tools, and Data Science

Mesospheric Wind Field Reconstruction from Multistatic Meteor Radar Networks: A Diagnostic Perspective — O5-1

Juan M. Urco [1] *and J. L. Chau* [2]
[1]Pontificia Universidad Católica del Perú, [2]Leibniz-Institute of Atmospheric Physics

Recent advances in multistatic meteor radar networks and physics-informed reconstruction methods have enabled new approaches for studying mesospheric dynamics beyond traditional mean-wind retrievals. The HYPER framework is a physics-informed approach that combines multistatic meteor radar observations with dynamical constraints to reconstruct time-evolving, three-dimensional wind fields, enabling analysis of mesoscale variability in the mesosphere and lower thermosphere (MLT). However, the capabilities and limitations of multistatic meteor radar networks remain poorly quantified, particularly in terms of the spatial and temporal scales that can be reliably resolved given their distinct geometry and sampling.
This presentation focuses on the use of HYPER as a mesospheric analysis framework and on the characterization of the scale-dependent properties of its wind reconstructions through comparisons with independent datasets. HYPER wind products are examined independently in comparison with high-resolution simulations from the UA-ICON model and with campaign-based observations from VORTEX. These comparisons are used to assess reconstruction characteristics as a function of horizontal wavelength, temporal averaging, altitude, and meteor sampling density, using spectral and band-limited diagnostics that quantify agreement across spatial and temporal scales.
The contribution provides a perspective on what physics-informed, network-based wind reconstruction from meteor radar can and cannot provide, supporting analysis of mesospheric winds and guiding future applications and observing strategies.

Physics-based Modelling of Radial Diffusion in the Outer Van Allen Belt — O5-2

Adamantia Dimitrakoula [1], *C. Katsavrias* [1,2], *C. Papadimitriou* [1,2], *and I. A. Daglis* [1]
[1]Department of Physics, National and Kapodistrian University of Athens (NKUA), Athens, Greece, [2]Space Applications & Research Consultancy (SPARC), Athens, Greece

The Earth's radiation belts were the first major population of charged particles discovered in space. It is now well established that the Van Allen belts consist of two distinct zones of energetic particles azimuthally drifting around the Earth: a relatively stable inner belt located at $L < 2$, composed mainly of energetic protons and electrons, and a highly dynamic outer belt at $L > 3$, dominated by relativistic electrons. These two regions are separated by a 'slot' region of reduced particle fluxes. Outer belt electrons have been observed to reach ultra-relativistic energies exceeding 10 MeV (i.e. $\gamma > 20$, where γ is the Lorentz factor). Understanding the mechanisms responsible for this extreme energization remains a key topic in space physics, with both astrophysical relevance and implications for spacecraft operations and radiation hazard mitigation. Two principal processes are known to contribute to the acceleration of relativistic electrons, both relying on seed populations originating from the plasma sheet: (a) radial diffusion and (b) local acceleration through wave–particle interactions. During inward radial diffusion, electrons drift earthward due to violations of the third adiabatic invariant, while conserving the first adiabatic invariant, resulting in an energy increase. In this work, we model the radial evolution of relativistic electrons in the outer Van Allen belt by numerically solving the time-dependent Fokker–Planck equation under constant adiabatic invariants μ and K. The solution is approximated using radial basis function (RBF) collocation methods. The simulation results are compared with in situ observations of the electron phase space density, $f(\mu, K, L^*, t)$, obtained during geomagnetic storm events. Finally, we perform a statistical analysis of different RBF types and their associated shape parameters.

Validating the ESPERTA Model for Forecasting Solar Energetic Particles at Off-Earth Locations — O5-3

Nicolina Chrysaphi [1], *M. Laurenza* [1], *T. Alberti* [2], *M. Stumpo* [1], *S. Benella* [1], *and M. F. Marcucci* [1]
[1]INAF – Istituto di Astrofisica e Planetologia Spaziali (IAPS), Rome, Italy, [2]INGV, Rome, Italy

Solar flares and shocks driven by Coronal Mass Ejections (CMEs) are major accelerators of Solar Energetic Particles (SEPs) that interact with planetary environments and our technological infrastructure, posing space weather hazards. Critical in our ability to assess and mitigate the impacts of space weather is the identification of reliable indicators of incoming SEPs. Electrons accelerated during solar flares can produce X-rays at the Sun and can also be released into the heliosphere exciting radio waves known as solar radio bursts. These radio bursts provide valuable information reflecting the properties of the electrons themselves as they propagate through the heliosphere. In this work, we incorporate radio measurements from the solar-orbiting STEREO spacecraft into the ESPERTA SEP forecasting model. We compare the results from STEREO measurements at different longitudes to that of Earth with the results from other ground- and space-based instruments near Earth. We evaluate the ability to exploit radio data as a reliable short-term warning of SEP events at any longitude, a crucial requirement for the protection of spacecraft cruising the heliosphere and space exploration. We also confirm that solar radio measurements are useful diagnostic tools for SEP events and thus for space weather forecasting models.

Magnetic Climatology from the Optical-b2i **O5-4**

Eric Donovan [1] *and E. Spanswick* [1]
[1] *University of Calgary*

In Earth's coupled magnetosphere and ionosphere, an isotropy boundary (IB) demarks two different regions, one (poleward) in which strong pitch angle diffusion keeps the downgoing loss cone full and the other (equatorward) in which the downgoing loss cone is empty (stable bounce trapped particles). The IB pertains o a specific energy, charge and mass, so one can speak of, for example, the IB for 50 keV electrons, and the IB for 5 keV protons. The IB for different energies of a given species are different. Whether the energy of the IB increases or decreases with increasing geomagnetic latitude (radial distance in the tail) depends on the nature of the mechanism filling the loss cone. Example mechanisms for loss cone filling include high field line curvature relative to gyroradius, and wave-particle interactions. The IB is closely related to the b2i (Newell, et al., JGR, 1996) and the optical b2i (Donovan et al., JGR, 2003), which are the geomagnetic latitude, in a given meridian, across which the CPS ion (ostensibly proton) downgoing loss cone changes from full (poleward of the b2i) to empty (equatorward of the b2i). This latter is understood to be the ionospheric footprint of the transition between strong pitch angle diffusion and stable bounce trapping of the protons that are responsible for the bight proton aurora. Finally, the magnetotail index or 'MT-Index' (Sergeev and Gvozdevsky, AnnGeo, 1995) synthesises this concept, relating the b2i at any MLT to a state of the magnetotail. While not perfect, these indices provide surprisingly robust indicators of the stretching of the magnetic field around geosynchronous orbit, and are surprisingly well grouped by Kp. he former relationship points to their nascent value in remote sensing magnetic topology, while the latter points to convection somehow playing a controlling role in that stretching. In this presentation, we present a new, synthesised optical-b2i and optical-MT data set that spans 1990 to the present (35 years), and illustrate how it highlights 'magnetic climatology' in the Nightside transition Region. Further, we present results of our efforts to add some energy dependence to the optical-b2i/MT via spectrally resolved proton auroral observations from the TREx meridian imaging spectrographs.

Probabilistic Solar Corona Evolution Forecasting with Denoising Diffusion Models: A Proof-of-Concept for Uncertainty-Aware Predictions **O5-5**

Grégoire Francisco [1,2], *S. Chierichini* [1], *F. P. Ramunno* [3,4], *T. Barata* [2], *M. K. Georgoulis* [5,6], *J. Fernandes* [2], *and D. Del Moro* [1]
[1] *Department of Physics, University of Rome Tor Vergata, Rome, Italy* , [2] *IA, Instituto De Astrofisica E Ciˆencias Do Espac¸o, University of Coimbra, Coimbra, Portugal,* [3] *Institute for Data Science, University of Applied Sciences North Western Switzerland (FHNW), Switzerland,* [4] *Department of Computer Science, University of Geneva, Switzerland,* [5] *Johns Hopkins University Applied Physics Laboratory Laurel, USA,* [6] *Research Center for Astronomy and Applied Mathematics of the Academy of Athens, Greece*

Recent advances in AI-driven heliophysics demonstrate the potential of deep learning for space weather applications. We present a complementary approach using Denoising Diffusion Probabilistic Models (DDPMs) to generate probabilistic forecasts of Active Region evolution in extreme ultraviolet wavelengths, addressing the need for uncertainty quantification in solar physics.Our method employs a modified UNet architecture with spatio-temporal convolutions and attention mechanisms to model the full conditional distribution P(Y—X) of 12-hour EUV emission evolution from SDO/AIA 94Å observations at 2-hour cadence.Unlike deterministic approaches, DDPMs capture coronal dynamics—including non-linear processes and stochastic flux emergence—by generating ensemble forecasts from which probabilistic inferences about brightening events can be derived. The model achieves ∼40% mean absolute percentage error for maximum peak flux and fluence metrics, with well-calibrated probability distributions confirmed through reliability diagrams showing accurate confidence interval coverage across solar activity levels. Notably, standard deviation maps successfully identify high-risk spatio temporal regions where extreme events occur in observations,demonstrating the model's ability to capture both likelihood and uncertainty of EUV brightenings. Key findings include: Reliable uncertainty quantification with empirical coverage matching nominal confidence intervals Ensemble generation producing visually realistic and diverse coronal evolution scenarios Most effective for regions exhibiting activity during the 12-hour input period, enabling probabilistic inference of subsequent evolution. This proof-of-concept demonstrates the feasibility of generative AI for medium-range probabilistic space weather forecasting. Current limitations include broad prediction intervals reflecting both intrinsic system variability and model uncertainty due to coarse resolution (2-hour cadence, 128×128 pixels) and limited input information (single EUV channel, disk-center regions only). The model's wide uncertainties, while well-calibrated, result from these constraints rather than representing optimal predictive sharpness.Future work targets higher temporal resolution (10-15 minutes) and multi-wavelength inputs including magnetic field data to reduce epistemic uncertainty and improve predictive sharpness. With these enhancements, such models could help distinguish intrinsic stochasticity of coronal evolution from measurement and/or modelling limitations, advancing both fundamental solar physics understanding and practical space weather forecasting capabilities. The ultimate goal is full-disk coverage at operational cadences, bridging current gaps between short-term deterministic alerts and strategic planning horizons requiring probabilistic risk assessment.

Towards 2031 Vigil Mission: Algorithmic and data-driven segmentation of coronagraph data and dynamic 3D Reconstruction of Coronal Mass Ejections **O5-6**

Oleg Stepanyuk [1] *and K. Kozarev* [1]
[1] *Institute of Astronomy and National Astronomical Observatory of Bulgarian Academy of Sciences*

The ESA Vigil mission, scheduled for launch in 2031, will provide unique solar and space weather observations from the Sun–Earth Lagrange point L5, capturing Earth-directed coronal mass ejections (CMEs) simultaneously observed from L1 and Earth. NASA's STEREO mission demonstrated the power of such stereoscopic observations by revealing CME three-dimensional structure through multi-angle imaging. Previously, we developed algorithmic and data-driven multi-instrument methods for recognizing and tracking solar eruptive features from the low corona to 30 solar radii using ground- and space-based coronagraphic and EUV observations. Here, we extend this approach and demonstrate our techniques on Compact Coronagraph (CCOR) data using improved wavelet-based algorithms and pre-trained image segmentation CNN models, preparing our methodology for future Vigil observations. In addition to feature tracking, we develop AI-driven methods for reconstructing the three-dimensional structure of CME fronts, moving beyond oversimplified geometric assumptions by incorporating neural surface representations (NeRF). We plan to evaluate these methods using synthetic CME datasets with known 3D ground truth and historical multi-spacecraft observations.These developments lay the groundwork for exploiting Vigil's unique L5 perspective, enabling stereoscopic tracking and accurate 3D reconstruction to advance real-time space weather predictions and mitigate risks to technological infrastructure.

Review of Machine Learning Models for Solar Energetic Particle Prediction **O5-7**

Spiridon Kasapis [1], *P. Hosseinzadeh* [3], *K. Whitman* [4,5], *R. Egeland* [4], *M. Georgoulis* [6,7], *A. Vourlidas* [6], *A. Papaioannou* [8], *E. Lavasa* [8], *A. Anastasiadis* [8], *G. Giannopoulos* [8], *A. Muñoz-Jaramillo* [9], *B. Poduval* [10], *I. N. Kitiashvili* [2], *A. G. Kosovichev* [2,11], *V. Sadykov* [12], *S. F. Boubrahimi* [3], *T. T. Hutchins* [13,1], *H. A. Farooki* [1], *M. E. Cuesta* [1], *L. Y. Khoo* [1], *S. Pak* [1], *R. Czarnota* [14,1], *J. S. Rankin* [1], *J. Szalay* [1], *M. M. Shen* [1], *G. Livadiotis* [1], *Z. Xu* [15], *D. J. McComas* [1], *N. Sarlis* [16], *D. Hristopoulos* [17], *A. Posner* [4], *A. J. Engell* [18], *M. A. Ali* [19], *A. G. A. Abdelkawy* [20], *A. M. K. Shaltout* [20], *M. M. Beheary* [20], *C. O. Lee* [21], *S. Aminalragia-Giamini* [22], *C. Papadimitriou* [22,16], *I. Sandberg* [22], *S. Raptis* [6], *S. M. Hamdi* [3], *M. Laurenza* [23], *M. Stumpo* [23], *S. A. Rotti* [12,24], *I. Jackson* [12], *A. Ali* [12], *A. G. Baydin* [25], *N. Schwadron* [10,1], *S. Chatterjee* [26], *M. A. Dayeh* [26], *G. M. Nita* [11], *P. M. O'Keefe* [27], *C. J. Chong* [27], *P. Kosovich* [11], *R. D. Marroquin* [28], *B. Aydin* [29], *P. C. Martens* [12], *L. Zhao* [30], *Y. Chen* [31], *Y. Yu* [31], *M. G. Bobra* [32], *W. Manchester* [30], *T. Gombosi* [30], *M. Zhang* [33], *J. Torres* [33], *P. K. Chan* [33], *M. Nedal* [34], *K. Kozarev* [35], *P. Zhang* [36,37], *K. Moreland* [26,38,39,40], *H. M. Bain* [39], *S. Hart* [26,40], *M. J. Starkey* [26], *A. G. Ling* [41], *and S. Benella* [23]
[1]*Department of Astrophysical Sciences, Princeton University, Princeton, NJ, USA,* [2]*Computational Physics Branch, NASA Ames Research Center, Moffett Field, CA, USA,* [3]*Department of Computer Science, Utah State University, Logan, UT, USA,* [4]*Space Radiation Analysis Group, NASA Johnson Space Center, Houston, TX, USA,* [5]*KBR Wyle Services, LLC, TX, USA,* [6]*Johns Hopkins Applied Physics Laboratory, Laurel, MD, USA,* [7]*Research Center for Astronomy and Applied Mathematics, Academy of Athens, Athens, Greece,* [8]*Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS), National Observatory of Athens, Athens, Greece,* [9]*Southwest Research Institute, Boulder, CO, USA,* [10]*Space Science Center, University of New Hampshire, Durham, NH, USA,* [11]*Department of Physics, New Jersey Institute of Technology, Newark, NJ, USA,* [12]*Department of Physics and Astronomy, Georgia State University, Atlanta, GA, USA,* [13]*Department of Computer Science, Princeton University, Princeton, NJ, USA,* [14]*Department of Mathematics, Rowan University, Glassboro, NJ, USA,* [15]*Division of Physics, Mathematics and Astronomy, California Institute of Technology, Pasadena, CA, USA,* [16]*Department of Physics, National and Kapodistrian University of Athens, Athens, Greece,* [17]*School of Electrical and Computer Engineering, Technical University of Crete, Chania, Greece,* [18]*NextGen Federal Systems, Morgantown, WV, USA,* [19]*National Authority for Remote Sensing and Space Science, Cairo, Egypt,* [20]*Department of Astronomy and Meteorology, Faculty of Science, Al-Azhar University, Cairo, Egypt,* [21]*Space Sciences Laboratory, University of California, Berkeley, CA, USA,* [22]*Space Applications and Research Consultancy, Athens, Greece,* [23]*Institute for Space Astrophysics and Planetology, Via del Fosso del Cavaliere, Rome, Italy,* [24]*Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, Uttarakhand, India,* [25]*Department of Computer Science, University of Oxford, Oxford, UK,* [26]*Southwest Research Institute, San Antonio, TX, USA,* [27]*Computer Science Department, New Jersey Institute of Technology, Newark, NJ, USA,* [28]*Department of Physics, University of California San Diego, La Jolla, CA, USA,* [29]*Department of Computer Science, Georgia State University, Atlanta, GA, USA,* [30]*Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, MI, USA,* [31]*Department of Statistics, University of Michigan, Ann Arbor, MI, USA,* [32]*Office of Data and Innovation, State of California, Sacramento, CA, USA,* [33]*Department of Electrical Engineering and Computer Science, Florida Institute of Technology, Melbourne, FL, USA,* [34]*Astronomy and Astrophysics Section, Dublin Institute for Advanced Studies, Dublin, Ireland,* [35]*Institute of Astronomy, Bulgarian Academy of Sciences, Sofia, Bulgaria,* [36]*Center for Solar-Terrestrial Research, New Jersey Institute of Technology, Newark, NJ, USA,* [37]*Cooperative Programs for the Advancement of Earth System Science, UCAR, Boulder, CO, USA,* [38]*CIRES, University of Colorado Boulder, Boulder, CO, USA,* [39]*Space Weather Prediction Center, NOAA, Boulder, CO, USA,* [40]*Department of Physics and Astronomy, The University of Texas at San Antonio, San Antonio, TX, USA,* [41]*Atmospheric and Environmental Research, Inc., MA, USA*

Solar energetic particle (SEP) events have been attracting increasing attention due to their significant radiation hazards for aviation, spacecraft electronics, and future human missions beyond Earth's magnetosphere. From a scientific perspective, SEP events are compelling as they result from a set of physical processes extending from the solar surface and corona through the heliosphere, offering insight into particle acceleration and transport mechanisms that are widely applicable across astrophysics. Therefore, advancing our ability to understand and predict SEP events is essential to deepen our knowledge of such mechanisms and to protect space technologies and exploration. Traditionally, researchers have modelled SEPs using physics-based simulations and empirical methods. Recently, machine learning (ML) has emerged as a new tool for understanding and predicting SEP events. The purpose of this community effort is to systematically review all currently available ML-based models for SEP prediction, identify the datasets used for their training, and compare their inputs, outputs, and architectural design choices. We summarize the results and provide a comparative analysis of 22 ML models identified in the English-language literature, developed by researchers across North America, Europe, and North Africa. This work maps the current state of research in machine-learning-based SEP prediction and highlights common trends, challenges, and future directions in the field.

Solar Wind Speed Forecasting at 1 AU from Solar Coronal Images and Physics-Informed Time-Dependent Deep Neural Network — O5-8

Veronique Delouille [1], F. Kamalabadi [2], K. Li [2], J. Davila [3], D. Shukhobodskaia [1], D. Millas [1], L. Vinoelst [1], F. Verstringe [1], and J. de Patoul [1]
[1]Royal Observatory of Belgium, [2]University of Illinois Urbana-Champaign, [3]Retired, formerly at NASA GSFC

Accurate forecasting of solar wind speed remains a grand challenge of space weather prediction. Estimation of the solar wind speed at 1 AU from information contained in the EUV images of the solar corona based on machine learning approaches has been proposed in recent years. However, most of such developments typically utilize generic pre-trained models as a dimensionality reduction technique to extract feature descriptors from EUV images, leading to under-performance in the final forecasting results.
In this work, we propose a deep neural network model that captures the temporal component of the solar wind propagation and where physical constraints are incorporated to train the model and optimize the prediction. The generalization capability of the proposed model is investigated via cross-validation, whereby careful separation into training, validation, and test datasets is performed as a function of solar activity. We report on the capability of the deep neural network architecture to capture the temporal relationship between solar EUV characteristics and solar wind speed at 1 AU. Furthermore, we introduce the ongoing work at the Royal Observatory of Belgium to record and structurally link individual type of events into an event-chain, with the ultimate goal to perform statistical studies on a large sample of such event-chains and improve the prediction of complex space weather phenomena.

Two-Phase Stormtime Response of Ionospheric Electron Temperature Overshoot Uncovered by Neural Networks — O5-9

Artem Smirnov [1,2], Y. Shprits [2], H. Lühr [2], A. Pignalberi [3], E. Kronberg [1], F. Prol [4], and C. Xiong [5]
[1]Ludwig Maximilian Universits of Munich, Earth and Environmental Sciences, Munich, Germany, [2]GFZ Helmholtz Centre for Geosciences, Potsdam, Germany, [3]Istituto Nazionale di Geofisica e Vulcanologia, Environment department, Rome, Italy, [4]Finnish Geospatial Research Institute, Department of Navigation and Positioning, Kirkkonummi, Finland, [5]Wuhan University, Department of Space Physics- School of Earth and Space Science Technology, Wuhan, China

An intense surge in equatorial electron temperature (T_e) at sunrise, known as the morning T_e overshoot, has been one of the most widely studied ionospheric features since its discovery in the early Space Age. Despite extensive research, its behaviour during geomagnetic storms remains poorly understood. Using global electron temperature observations by the CHAllenging Minisatellite Payload (CHAMP) mission in 2002-2010, we develop a global neural network Te model that can be considered a digital twin of the global T_e distribution due to its excellent performance on independent data. The model revealed an unexpected two-phase storm time response of the morning T_e overshoot. During the storm's main phase, electron temperatures in the overshoot region exhibit a pronounced enhancement, followed by a dramatic depletion exceeding 1000 K and disappearance of the overshoot during the recovery phase. This evolution corresponds to the initial influence of a westward prompt penetration electric field (PPEF), which reduces electron densities, allowing for more efficient energy exchange between newly ionized sunrise particles and the lower-energy (depleted) ambient plasma. Later in the storm, the eastward disturbance dynamo field flips the $E \times B$ drift from downward to upward and lifts more electrons into the F-region. The resulting increase in electron density enhances cooling rates, leading to the overshoot's disappearance in the recovery phase. Our findings shed new light on the dynamics of the morning electron temperature overshoot and highlight the capability of digital twin models of the near-Earth space environment to uncover previously unrecognized physical patterns even for the most commonly studied phenomena.

Machine-Learning Reconstruction and Interpretation of the Earth's Inner Magnetospheric Environment O5-10

Jacob Bortnik [1], D. Ma [1], X. Chu [2], R. Matsuura [1], and Q. Ma [1,3]
[1]Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, CA, USA, [2]Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, Boulder, CO, USA, [3]Center for Space Physics, Boston University, Boston, MA, USA

The Earth's inner magnetospheric environment consists of a number of quantities, including cold plasma, whistler-mode waves such as chorus and hiss, as well as high-energy electrons and protons that are trapped in the geomagnetic field, presenting a hazard for spacecraft and astronauts. Accurate specification and prediction of the dynamic variability of these quantities, has been a long-standing, and extremely challenging problem which has traditionally been addressed using a variety of approaches that are disconnected from one another, for example radiation belt dynamics are typically modelled using a quasilinear diffusion framework, driven by parametrized and deterministic diffusion coefficients and boundary conditions. In the first part of this presentation, we show an alternative approach to modelling the dynamical behaviour of a number of these quantities, utilizing machine learning techniques, and driven solely by solar wind conditions and geomagnetic indices, based on data from the Van Allen Probes mission.
Such machine learning models are valuable for specifying and forecasting of the state of the inner magnetosphere, but are hard for human users to understand how the model works internally and what factors it uses to make its decisions. In the second part of this presentation, we show work that aims to interpret and understand how the model works, and importantly, leads to improved insight and physical understanding of the system involved. This work shows tremendous promise for the use of machine learning models not only as a prediction tool, but also for scientific insight discovery.

AI-driven Approach to Ionospheric Modelling O5-11

Lina El Zaatari [1], N. Pedatella [2], and C. C. Stephan [1]
[1]Leibniz Institute of Atmospheric Physics, Kühlungsborn, Germany, [2]National Center for Atmospheric Research, Boulder, Colorado

The ionosphere plays a critical role in atmospheric dynamics by coupling to the neutral atmosphere through ion drag and Joule heating, thereby influencing the circulation of the mesosphere and thermosphere from regional to global scales. However, state-of-the-art general circulation models (GCMs), such as the Icosahedral Non-hydrostatic model (ICON), lack detailed ionospheric representation and instead rely on simplified parametrizations or externally prescribed forcing.
We develop a machine-learning-based surrogate model to predict ion drag and Joule heating for ICON, trained on output from WACCM-X, which includes interactive electrodynamics. The surrogate model uses physically motivated input features, including solar activity (F10.7), geomagnetic forcing (Kp), geographic location, time, and altitude. Multiple model architectures are evaluated, including random forests and neural networks, to assess accuracy, generalization, and computational efficiency.
First results demonstrate that the surrogate reproduces key spatial and temporal patterns of ion drag and Joule heating with good fidelity while significantly reducing computational cost compared to physics-based schemes. This approach offers a scalable pathway toward incorporating ionospheric forcing into whole-atmosphere simulations and highlights both the potential and limitations of machine-learning methods in space-atmosphere coupling studies.

Data Science Techniques Applied to Space Weather and Ionospheric Conditions: Recent Results **P5-1**

Maria Graciela Molina [1,2,3], N. Arguelles [1,2], A. Villegas [1,2], Y. Melendi [1,2,4,5], T. Torres Peralta [1,2], M. Paz M. F. [3,5], G. Gonzalez [1,6], C. Cesaroni [3], R. Hidalgo Bini [1], M. Girbau [1], A. Amenabar [1], and J. Namour [1]
[1]Tucumán Space Weather Center (TSWC), Facultad de Ciencias Exactas y Tecnología (FACET), Universidad Nacional de Tucuman (UNT), Tucumán, Argentina, [2]Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Tucumán, Argentina, [3]Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy, [4]Universidad Nacional del Sur, Bahía Blanca, Argentina, [5]Instituto de Física del Sur (IFISUR-CONICET), Bahía Blanca, Argentina, [6]Space Sciences Laboratory, University of California, Berkeley, CA, USA

Different artificial intelligence techniques, such as machine learning, have begun to be extensively used in various areas of space science, with significant and promising results for the coming years. Research on the ionosphere and Space Weather are no exception to this trend, especially but not limited to, short- and medium-term forecasting for operational applications. In this context, it is important to focus on the main challenges in efficiently implementing these techniques. Some of these challenges include: the volume of available data (and its quality), the low representativeness of extreme cases in the datasets (which are often one of the main interest in space weather), the collection and curation of data that is not always coordinated or robust, the need for multi-point observations and the combination of spatial data alongside ground-based instruments, the challenge of analysing multiple scales, etc.
In this talk, the latest results from the group will be presented for machine learning applications in the forecasting of global and regional ionospheric conditions using different parameters (during quiet and disturbed conditions), analysing ionospheric irregularities using ionosonde data, GCRs analysis using single Cherenkov detector, among others. Different techniques and stages of model development will be discussed, such as feature engineering and selection, hyperparameter determination, explainable AI, Bayesian analysis, the deployment of models in operational environments, etc.

Modelling of Trapped Energetic Electron Populations in the Earth's Radiation Belts **P5-2**

Olga Belli [1], I. A. Daglis [1], and C. Papadimitriou [1,2]
[1]Department of Physics, National and Kapodistrian University of Athens, Athens, Greece, [2]Space Applications & Research Consultancy (SPARC), Athens, Greece

Since the onset of space exploration, the near-Earth space environment has been a significant topic of research. Understanding the particle radiation environment surrounding Earth, and especially the Van Allen Radiation Belts, has both scientific and practical importance, given the increasing number of satellites supporting modern society through communication, navigation, and Earth observation. In this work we developed a data-driven model to estimate the electron flux encountered by a spacecraft along its orbit in the Radiation Belt region. In particular, we used pitch angle resolved electron measurements from six energy channels (54 keV to 4.2 MeV) of the Energetic Particle Composition and Thermal Plasma (ECT) instrument suite onboard the Van Allen Probe B (RBSP-B), covering nearly six years of data during the Solar Cycle 24. We constructed two-dimensional electron flux maps, using the Roederer - L^* and the equatorial pitch angle a_{eq} coordinate system, that provide statistical metrics such as the mean, median, 95th percentile. Moreover, we generated separate maps that correspond to different phases of the solar cycle. In the second part of this work, the fly-in module, we estimated the directional electron flux encountered along a given spacecraft trajectory using the aforementioned flux maps, for nine pitch angles. The produced climatological model can provide an estimate of the electron fluxes that a spacecraft would expect in the Earth's radiation belts. Such models are suitable to support the design of multi-year space missions, since the outer radiation belt electrons pose a significant hazard to spacecraft. This work was carried out as part of the first author's diploma thesis.

Total Eclipse on August 12, 2026: Observations in Spain and Prediction with COCONUT **P5-3**

B. Schmieder [1,2,3], T. Baratashvili [2], S. Poedts [2,4], A. Lani [2], H. P. Wang [2], B. Foing [3,5], S. Sansari [3,5], S. Zeegers [3,5], J. Pascual [3,6], R. Nahum [3,6], and K. Nagainis [3,7]
[1]Observatoire de Paris, LIRA, France, [2]CmPA, KU Leuven, Belgium, [3]LUNEX Space HUB, Netherlands, [4]UMCS, Lublin, Poland, [5]Leiden University, Netherlands, [6]Kosmica Institute, Santiago de Compostela, Spain, [7]University of Latvia, Latvia

Because of the lack of white light coronagraph observations in the low solar corona (1-1.5 solar radius), total solar eclipses are a standard way of assessing coronal structures and testing coronal models. Total solar eclipses constrain the validation period of coronal modelling, as they occur rarely. However, currently, it is the only way to distinguish features in the low corona near the solar surface. Soon, the PROBA 3 mission will provide continuous observations of the low corona. Total solar eclipses provide a single snapshot of the solar corona, whereas time-dependent simulations require continuous white-light observations. COCONUT was utilised to predict the previous total solar eclipse in April 2024 (Baratashvili et al. 2025, A&A, in press). In the setup demonstrated in the manuscript, a low-resolution, simplified approach is used. However, multiple developments in the COCONUT model since the previous total solar eclipse allow the continuous time-dependent and high resolution simulations for the predictions on the upcoming total solar eclipse on August 12, 2026, at 18:27 UT. Additionally, we plan a network of observations in Spain with multiple sites to obtain the best coverage of the total solar eclipse and obtain high-quality images to use them for validating the predictions performed by the COCONUT model. Synthetic white-light images will be generated from the COCONUT simulations to compare to the observed images directly. This way we can use the total solar eclipse on August 12, 2026, to validate the COCONUT model, and identify its strengths and weaknesses.

Quantitative Analysis of Ultra-Low Frequency Geomagnetic Variations from MAGDAS Data in Relation to Seismic Activity **P5-4**

Ahmad Hariz Bely [1], S. N. A. Syed Zafar [1], R. Umar [1], N. H. Sabri [2], M. H. Jusoh [3], and A. Yoshikawa [4]
[1]East Coast Environmental Research Institute, Universiti Sultan Zainal Abidin (UniSZA), Malaysia, [2]Advanced Nano Materials (ANoMa) Research Group, Universiti Malaysia Terengganu (UMT), Malaysia, [3]Applied Electromagnetic Research Group (UiTM), Malaysia, [4]International Center for Space Weather Science and Education (ICSWSE), Kyushu University, Japan

Ultra low frequency (ULF) geomagnetic pulsations in the Pc4–Pc5 bands provide an important diagnostic of magnetosphere ionosphere coupling driven primarily by solar wind variability. Groundbased magnetometer networks such as the Magnetic Data Acquisition System (MAGDAS) enable long term monitoring of these fluctuations with high temporal resolution. In recent years, ULF variations have also been explored as potential indicators of lithosphere atmosphere ionosphere interactions associated with seismic activity. However, the dominant influence of geomagnetic forcing introduces significant ambiguity, making it difficult to distinguish possible earthquake related signatures from space weather effects.
The objective of this study is to characterize Pc4–Pc5 geomagnetic variability using MAGDAS observations and to evaluate their statistical relationship with nearby earthquake occurrence under controlled geomagnetic conditions. Continuous magnetic field data are processed using band pass filtering and spectral power estimation, followed by hourly averaging to ensure consistency with geomagnetic index time scales. Statistical analyses include correlation assessment, multiple regression modelling and comparative evaluation between pre event and control windows. Geomagnetic indices are incorporated to constrain disturbed periods and reduce confounding effects. The analysis focuses on near field earthquakes occurring within approximately 40–100 km of the magnetometer station and with magnitudes between M4.5 and M5.6, allowing improved sensitivity to potential local electromagnetic influences.

Results derived from the thesis demonstrate that Pc4–Pc5 power is strongly controlled by geomagnetic activity and solar wind conditions, confirming the necessity of rigorous filtering and statistical control. Weak but statistically detectable deviations in ULF power are observed in a limited subset of near-l field earthquake cases; however, large variability persists, indicating that single-event interpretation is unreliable and that multi-event stacking is required for robust inference.
The motivation of this work is to establish a reproducible, statistically defensible framework for evaluating ULF geomagnetic variability in relation to seismic activity. By emphasizing transparent methodology, confounder control, and quantitative validation, this study contributes toward improving analytical rigor in future investigations of magnetosphere–lithosphere coupling within the solar terrestrial physics community.

Day-to-Day Vertical Drift Estimation Using Deep Learning Based on Jicamarca Radar Observations **P5-5**

A. Castro [1] and R. Flores [1]
[1]Instituto Geofisico del Peru, Radio Observatorio de Jicamarca, Lima, Peru

Ionospheric drifts allow the analysis of ion diffusion velocities at different altitudes. These velocities are fundamental for studying the dynamics of the F layer during both quiet and disturbed conditions, contributing to space weather analysis. Using the JULIA operating mode of the Jicamarca Radio Observatory (JRO), it is possible to obtain continuous measurements of ionospheric drifts; however, these observations may be affected by logistical constraints and maintenance activities.
Several studies have addressed the estimation of vertical drifts using climatological and seasonal approaches based on sinusoidal series, as well as more recent Machine Learning–based methods, which have demonstrated improved predictive performance compared to traditional climatological models. Nevertheless, most of these models have been trained primarily for relatively quiet days, characterized by geomagnetic K index values less than or equal to 2.
In this work, we present the development of a Deep Learning model that combines neural networks with Long Short-Term Memory layers and Attention Mechanisms for the prediction of vertical and zonal drift velocities, using geomagnetic and solar indices and considering days with K values of up to 5. Five years of vertical and zonal drift data obtained from the JULIA mode of the Jicamarca Radio Observatory were used to train the proposed model. The results are compared with other existing models, showing that the proposed approach achieves superior performance in capturing the day-to-day variability of ionospheric drifts.

Propagation of MHD Waves in Inhomogeneous Media at the Solar Atmosphere **P5-6**

Dennis Katherine Viveros Sanabria [1] and F. D. L. Clavijo [1]
[1]Universidad Industrial de Santander, Colombia

The dynamic behaviour of the solar atmosphere remains one of the most relevant open problems in solar physics, especially regarding energy transport and dissipation. For this reason, the propagation of magnetohydrodynamic (MHD) waves has been used to describe phenomena such as the heating of the solar corona. However, most studies have focused on homogeneous media, even though the solar plasma presents significant inhomogeneities in density, pressure, and magnetic field.
This work proposes to study how these inhomogeneities affect the propagation of linear MHD waves, both in free media and in magnetic flux tubes. The analysis will focus on variations in the wave morphology, their efficiency in energy transport, and the redistribution of energy into kinetic energy, enthalpy, and Poynting flux. The methodology includes the selection of realistic inhomogeneity profiles and the solution of the linearized MHD equations through numerical simulations using the MAGNUS code. Different oscillation modes and

boundary conditions will be evaluated to represent typical solar scenarios. This study will help to understand how plasma gradients influence the observable properties of MHD waves, contributing to the improvement of existing theoretical models and facilitating the interpretation of data obtained by high-resolution solar missions.

Prediction of F2-layer Height of the Peak Electron Density (hmF2) over the Southern Africa Region using Artificial Neural Network — P5-7

Emmanuel P. Mushi [1], E. D. Sulungu [1], and A. Pamain [1]
[1]The University of Dodoma, Tanzania

The ionospheric F2 layer is the essential layer in the propagation of high-frequency radio waves, and height of the peak electron density (hmF2) is one of the important parameter. However, ionosondes are not installed at every location on earth to allow for global measurements of hmF2, especially within the southern African region. This study therefore focuses on developing a regional model for predicting the hmF2 using Artificial Neural Network techniques. In this study, prediction model was developed using year, day of the year, time in 30 minutes intervals, Sunspot Number (SSN), Solar flux at 10.7 cm (F10.7), geomagnetic activity (Kp) and Averaged planetary Index (Ap), longitude, latitude and critical frequency (foF2) as the input. Data from ionosondes were used as targets to the model, and were taken from Grahamstown, Madimbo and Louisvale located in South Africa from 2005 to April 2023. The developed hmF2 prediction model based on ANN was able to detect the non-linear relationship that exists between input parameters and measured hmF2. Also, the learning efficiency of the developed ANN architecture is good.

Multilayered Structure of Sporadic E(Es) caused by Wind Velocity, Wind Shear, Electric Field and their Combined Effects — P5-8

Goderdzi G. Didebulidze [1], G. Dalakishvili [1], and M. Todua [1]
[1]Ilia State University, Center of Space Research, Tbilisi, Georgia

The multilayered structure of ionospheric sporadic E(Es) is an observable phenomenon. This phenomenon can be caused by the presence of several altitude regions with nodes of the vertical ion drift velocity, where near these nodes the maximum rate of their vertical convergence is achieved, which leads to the formation of Es layers. In this case, regions with maximum ion convergence rate in the lower thermosphere (at an altitude of about 90-150 km) can be caused by the propagation of atmospheric gravity waves (AGWs), tidal wind and the presence of an electric field. In this case, the combined effect of wind velocity, wind shear and electric field can lead to the formation of additional Es layers, in contrast to the case where only one given factor dominates in the vertical convergence of ions. Here a combined effect of these factors, the disappearance of Es layers formed in the presence of only wind velocity, wind shear or electric field is also possible. These processes of formation of multilayer sporadic E and/or its disappearance, using the horizontal wind model (HWM14) data and electric field (with constant vertical and zonal components), are considered numerically in equatorial and mid-latitude regions. A case of the formation of sporadic E with two Es-type sub-layers will be demonstrated, which formed without taking into account the wind shear factor. Here we will show the predominance of the downward motion of the Es layers and the possibility of their unification into one high-density Es layer localizing in their most observable regions (about 95-105 km) of the lower thermosphere.

Modelling the Solar Cycle Nonlinearities into the Algebraic Approach — P5-9

Mohammed H. Talafha [1]
[1]RISE, University of Sharjah, United Arab Emirates

Understanding and predicting solar-cycle variability requires accounting for non-linear feedbacks that regulate the build-up of the Sun's polar magnetic field. We present a simplified but physically grounded algebraic approach that models the dipole contribution of active regions (ARs) while incorporating two key non-linearities: tilt quenching (TQ) and latitude quenching (LQ). Using ensembles of synthetic cycles across the dynamo effectivity range λ_R, we quantify how these mechanisms suppress the axial dipole and impose self-limiting feedback.
Our results show that (i) both TQ and LQ reduce the polar field, and together they generate a clear saturation ("ceiling") of dipole growth with increasing cycle amplitude; (ii) the balance between LQ and TQ, expressed as $R(\lambda_R) = \mathrm{dev(LQ)}/\mathrm{dev(TQ)}$, transitions near $\lambda_R \approx 12^\circ$, with LQ dominating at low λ_R and TQ at high λ_R; (iii) over $8^\circ \leq \lambda_R \leq 20^\circ$, the ratio follows a shallow offset power law with exponent $n \approx 0.36 \pm 0.04$, significantly flatter than the $n = 2$ scaling assumed in many surface flux–transport (SFT) models; and (iv) symmetric, tilt-asymmetric, and morphology-asymmetric AR prescriptions yield nearly identical $R(\lambda_R)$ curves, indicating weak sensitivity to AR geometry for fixed transport.
These findings demonstrate that non-linear saturation of the solar cycle can be captured efficiently with algebraic formulations, providing a transparent complement to full SFT simulations. The method highlights that the LQ–TQ balance is primarily controlled by transport (λ_R), not by active-region configuration, and statistically disfavours the SFT-based $1/\lambda_R^2$ dependence.

Predicting Ionospheric Total Electron Content over Ethiopia Using a Hybrid CNN-LSTM-SVR Model **P5-10**

Lamessa Tamasgen Mogasa [1], *N. M. Giday* [1], *and N. S. Shiferaw* [1]
[1] *Space Science and Geospatial Institute (SSGI), Addis Ababa, Ethiopia*

Reliable forecasting of Ionospheric Total Electron Content (TEC) is essential for improving the accuracy of satellite communication, navigation, and positioning systems. This need is especially important in equatorial regions such as Ethiopia, where the ionosphere exhibits strong variability driven by both solar activity and local geophysical processes. As part of ongoing efforts to strengthen space-weather monitoring and prediction capabilities in the region, this study explores a data-driven approach for predicting TEC over Ethiopia. The work investigates the use of a hybrid modelling strategy that incorporates modern data-analysis techniques to capture the temporal and spatial behaviour of TEC. GNSS-based TEC measurements collected across Ethiopia serve as the primary dataset, complemented by key solar-terrestrial indicators. The study aims to assess whether combining different modelling components can lead to more stable and reliable TEC forecasts, particularly during periods of rapid ionospheric fluctuations.
Although the research is still in progress, preliminary analysis indicates that hybrid data-driven models show promise in identifying trends, reducing short-term prediction errors, and improving the representation of ionospheric variability. This approach may offer a practical pathway toward enhancing regional space-weather forecasting capability and supporting applications that depend on accurate ionospheric information, such as aviation, satellite communication, and GNSS-based services.
By focusing on Ethiopia an area positioned under the highly dynamic equatorial ionosphere this study contributes to broader international efforts to improve ionospheric modelling in regions where observational data and operational forecasting tools remain limited. The results are expected to support the long-term development of reliable, locally informed space-weather services and strengthen the scientific foundation for future operational systems within the Space Science and Geospatial Institute (SSGI).

Characterizing the Ionosphere above the GMRT **P5-11**

Tanmay Das [1], *S. Mangla* [2], *D. Oberoi* [1], *and N. Shinde* [1]
[1] *National Centre for Radio Astrophysics, Tata Institute of Fundamental Research (NCRA-TIFR), Pune, India,* [2] *University Observatory, Faculty of Physics, Ludwig-Maximilians-Universität*

The Giant Metrewave Radio Telescope (GMRT) (lat: 19.10°N, long: 74.05°E, geographic; dip: 23°N magnetic) lies in the vicinity of the Equatorial Ionization Anomaly (EIA), a dominant low-latitude ionospheric feature which shows significant dynamics and has a considerable impact on trans-ionospheric radio signal propagation. These effects of ionospheric propagation are especially important at the metrewave part of the spectrum where the GMRT operates. Additionally, for linearly polarization studies, ionospheric Faraday rotation (FR) introduces a potentially significant contamination in the measured polarization signals. Global Navigation Satellite System (GNSS) based ionization density distribution in terms of Total Electron Content (TEC) measurements have long been used in characterizing the ionosphere on a global scale. In this paper author have tried to explore the use of GNSS based TEC measurements for addressing the ionospheric challenges for the upgraded GMRT (uGMRT) and compare with the International Reference Ionosphere (IRI) empirical model, which has evolved and improved for several decades and has been playing a vital resource for ionospheric characterization. This study aims at understanding and quantifying the limitations imposed by the use of simple mapping functions routinely employed across the community to convert the slant-TEC (STEC) measured towards the lines-of-sight (LOS) to the TEC in the vertical column towards the local zenith in the GMRT sector. The authors also tried to estimate the range of ionospheric FR contamination by employing these two datasets which is very important for ionospheric and as well as radio astronomy observations.

Solar Forcing for CMIP7: Historical Reconstructions and Future Projections **P5-12**

Bernd Funke [1], *T. Dudok de Wit* [2,3], *M. Haberreiter* [4], *D. Marsh* [5,6], *I. Ermolli* [7], *D. Kinnison* [5], *H. Nesse* [8], *A. Seppälä* [9], *M. Sinnhuber* [10], *I. Usoskin* [11], *T. Asikainen* [11], *S. Bender* [1], *T. Chatzistergos* [12], *O. Coddington* [13], *S. Koldoboskiy* [11], *J. Lean* [14], *M. van de Kamp* [15], *T. Sukhodolov* [4], *and P. Verronen* [11,15]
[1] *Instituto de Astrofísica de Andalucía (CSIC), Spain,* [2] *LPC2E, CNRS and University of Orléans, France,* [3] *International Space Science Institute, Switzerland,* [4] *Physikalisch-Meteorologisches Observatorium Davos/WRC, Switzerland,* [5] *NCAR, USA,* [6] *University of Leeds, UK,* [7] *INAF Osservatorio Astronomico di Roma, Italy,* [8] *University of Bergen, Norway,* [9] *University of Otago, New Zealand,* [10] *Karlsruhe Institute of Technology, Germany,* [11] *University of Oulu, Finland,* [12] *Max Planck Institute for Solar System Research, Germany,* [13] *University of Colorado, USA,* [14] *Naval Research Laboratory, USA,* [15] *Finnish Meteorological Institute, Finland*

In 2017, the solar forcing recommendations for the Coupled Model Intercomparison Project Phase 6 (CMIP6) provided, for the first time, a comprehensive suite of solar irradiance and energetic particle contributions. Since then, this dataset has been extensively utilized in climate experiments and validated through various intercomparison studies. Building on these advancements and incorporating newly available data, an International Space Science Institute (ISSI) Working Group was established to define the strategy for the CMIP7 solar forcing dataset. Following community feedback, the historical solar forcing for CMIP7 has been finalized. Key updates relative to CMIP6 include the adoption of the Total and Spectral Solar Irradiance Sensor (TSIS-1) solar reference spectrum and an improved description of top-of-the-atmosphere energetic electron fluxes, reconstructed back to 1850 using geomagnetic proxy data. Solar irradiance variability in the reference dataset is driven by the new empirical NASA-NOAA-LASP (NNL) Solar Spectral Irradiance Version 1 model (NNLSSI1).

Additionally, an alternative irradiance dataset based on SATIRE is provided to facilitate sensitivity experiments. To address future climate projections, a stochastic ensemble of solar forcing scenarios has been developed. Based on surrogate analysis of cosmogenic isotope records, this ensemble provides a realistic framework for assessing natural forcing uncertainties. For the standard CMIP7 projections, an intermediate scenario was selected as the reference future forcing. This presentation discusses the specific modifications implemented for CMIP7 and evaluates their implications for climate modelling through a series of dedicated evaluation experiments.

Canadian Geomagnetic Data, Indices, and Statistical Analysis of Geomagnetic Activity for 1973-2025 **P5-13**

Ljubomir Nikolic [1]
Natural Resources Canada

Canada has a long history of geomagnetic field observations which include government run magnetic observatories. Currently, Natural Resources Canada (NRCan) operates a network of 14 observatories which provide real-time data used by the Canadian Space Weather Forecast Centre (CSWFC) to monitor and forecast space weather and geomagnetic conditions. The Canadian magnetic environment is complex, and these observatories are spread across the country to cover three zones of geomagnetic activity: polar cap, auroral zone and sub-auroral zone. To describe geomagnetic conditions, the geophysical community uses a number of indices. Since mid-1980, to describe the geomagnetic activity, CSWFC uses an hourly range index (HR), which is based on variations of the X and Y magnetic field components during each UT hour. To modernize and improve space weather forecasts, CSWFC is undertaking work to improve forecast accuracy and re-examine its indices and activity levels. Therefore, to unlock future implementation of machine learning techniques with our geomagnetic data, we generated a catalogue and clean data sets which cover 1973-2025. The data sets consist of yearly files of minute geomagnetic data from NRCan observatories. These data are used to explore improvements in the Canadian geomagnetic activity indices of geomagnetic activity. This includes an index based on the running-hourly range (rHR), which represents a sliding one hour interval window. This sliding window can take minute steps and can capture magnetic field variations which could be underestimated by the HR index. Further, a statistical analysis of the occurrence of the magnetic field variations, based on HR and rHR, is performed for

the 1973-2025 period and new activity levels are proposed for implementation in the CSWFC monitoring and forecasting services.

Recent Advances in Incoherent Scatter Radar Data Processing and the Study of TID **P5-14**

Qihou Zhou [1], *Y. Li* [1], *and Y. Gong* [1]
[1]*Miami University, USA,* [2]*Wuhan University, China*

The versatility of incoherent scatter radar (ISR) in measuring ionospheric state variables makes it one of the most important ground-based instruments for studying space weather and solar–terrestrial interactions. We report recent progress in using Arecibo ISR data to simultaneously derive electron density (Ne), plasma drift velocity (Vi), ion temperature (Ti), electron temperature (Te), and the molecular ion fraction (M^+/N) in the F1 region. In the upper F region, we report the simultaneous derivation of Ne, Vi, Ti, Te, and the light ion fractions He^+/Ne and M^+/Ne. We apply both traditional least-squares fitting and modern AI transformer techniques to derive these parameters. The AI models we have developed significantly outperform the traditional least-squares fitting approach. We also discuss travelling ionospheric disturbances (TIDs) that are simultaneously present in Ne, Ti, Te, and Vi over the altitude range of 150–500 km above Arecibo.

On Modelling the Vertical Ionospheric Density Distribution from Concurrent Ground and Space based GNSS Measurements **P5-15**

Stanimir Stankov [1]
Royal Meteorological Institute (RMI), Belgium

The presentation is concerned with the retrieval of the vertical ionospheric electron density profile at a given location by combining two simultaneously measured quantities of the columnar electron content. One is measuring the total electron content from the ground up to the GNSS height, and the other measuring only the electron content between the low-earth orbiting (LEO) satellite and the GNSS satellite, the so-called over-satellite electron content (OSEC). The method relies also on ionosonde soundings for constructing the bottom-side density profile and standard analytical profilers for the topside. For reliable results, all measurements need to be co-located and carried out concurrently. The presentation will outline the method and provide examples of successful constructions of the ionospheric profiles at the mid-latitude observatory in Dourbes, Belgium.

Dynamical Complexity in Geomagnetically Induced Current Activity Indices using Information Theory **P5-16**

Adamantia Zoe Boutsi [1], P. Manshour [2], C. Papadimitriou [1,3], G. Balasis [1], and M. Palus [2]
[1]National Observatory of Athens, Greece, [2]Institute of Computer Science, Czech Academy of Sciences, Czech Republic, [3]National and Kapodistrian University of Athens, Greece

Geomagnetically Induced Currents (GICs) are a manifestation of space weather events at ground level. GICs have the potential to cause power failures in electric grids. The GIC index is a proxy of the ground geoelectric field derived solely from geomagnetic field data. Information Theory (IT) can be used to shed light on the dynamics of complex systems, such as the coupled solar wind–magnetosphere–ionosphere–ground system. Previously, we have performed block entropy analysis of the GIC activity indices at middle-latitude European observatories around the St. Patrick's Day March 2015 intense magnetic storm and Mother's Day (or Gannon) May 2024 super-intense storm. We found that the GIC index values were generally higher for the May 2024 storm, indicating elevated risk levels. Furthermore, the entropy values of the SYM-H and GIC indices were higher in the time interval before the storms than during the storms, indicating transition from a system with lower organization to one with higher organization. Recently, IT has proven itself as a powerful approach to study causal relationships among various coupled complex systems. Here, we use Conditional Mutual Information as a measure of causality to investigate the possible coupling direction and pattern of interactions among different GIC indices, solar wind variables, and geomagnetic activity indices.

SESSION 6: Initiatives for Ground- and Space-Based Solar-Terrestrial Physics Research

LoLa: A Low-Latitude Meteor Radar Network for Studying MLT Global-scale Dynamics and Vertical Coupling **O6-1**

Jorge L. Chau [1], S. Mani [1], J. Suclupe [1], A. Maute [1], R. Latteck [1], T. Renkwitz [1], M. Garbanzo-Salas [2], W. Hocking [3], L. M. Lima [4], A. Liu [5], C. M. Martins [6], M. Nigussie [7], I. Reid [8], B. Rabiu [9], S. V. B. Rao [10], R. V. Ratnam [11], R. Rodriguez [12], P. Terra [13], and D. Scipion [14]

[1]Leibniz Institute of Atmospheric Physics, Germany, [2]University of Costa Rica, Costa Rica, [3]University of Western Ontario, Canada, [4]Universidade Estadual da Paraíba, Brazil, [5]Embry-Riddle Aeronautical University, USA, [6]Universidade Federal do Pará, Brazil, [7]Bahir Dar University, Ethiopia, [8]ATRAD, Australia, [9]National Space Research and Development Agency, Nigeria, [10]Sri Venkateswara University, Tirupati, India, [11]National Atmospheric Research Laboratory, India, [12]Universidad de Piura, Peru, [13]University of Central Florida, USA, [14]Instituto Geofísico del Perú, Peru

The mesosphere and lower thermosphere (MLT, ∼60-120 km) form a critical boundary region between atmospheric weather and near-space weather, playing a key role in coupling processes between the lower atmosphere and the ionosphere–thermosphere (IT) system. At low latitudes, the influence of lower-atmospheric forcing on the IT region is particularly efficient because geomagnetic field lines in the F region connect to the ionized MLT in both hemispheres, especially during daytime when the E-region dynamo is strongest.
Over the past decade, significant efforts have been devoted to understanding vertical atmospheric coupling processes. It is now well established that approximately 20–30% of IT variability originates from lower-atmospheric forcing across a range of spatial and temporal scales. While satellite observations provide valuable climatological representations of global-scale dynamics, including tides and planetary waves, their ability to resolve short-term variability (on the order of days) is limited. Conversely, single ground-based instruments such as meteor radars offer continuous MLT wind measurements with high temporal resolution but lack longitudinal (wavenumber) information.
To address these limitations, we are developing a low-latitude meteor radar network, termed LoLa, consisting of systems located within ±20° of the geographic or magnetic equator. LoLa is a multi-institutional and multinational effort that integrates existing radars, reinstalled systems, and newly deployed instruments, with opportunities for additional radars to participate on a campaign or long-term basis. In this study, we present preliminary results from the LoLa network investigating different components of MLT diurnal tides and their coupling to IT weather through observations and modelling. We also outline future expansion plans for the network.

Citizen Science for Auroral Research: Achievements of the ARCTICS Working Group **O6-2**

Maxime Grandin [1], B. Gallardo-Lacourt [2,3] and the ARCTICS Working Group [4]

[1]Finnish Meteorological Institute, Finland, [2]Heliophysics Science Division, NASA, Goddard Space Flight Center, Greenbelt, MD, USA, [3]Department of Physics, The Catholic University of America, Washington, DC, USA, [4]International Space Science Institute, Bern, Switzerland

With the tremendous technological improvement of commercial cameras and smartphones, a growing number of (professional and amateur) auroral photographers capture high-quality images of the night-sky. This novel type of optical data has enabled the discoveries of previously unknown optical emission displays which reveal the presence of complex and unexplored processes at work in the near-Earth plasma. Those discoveries are the result of what is known as "citizen science", i.e. scientific research involving contributors outside the academic world and who provide data and are co-authors of the resulting publications. Typically, auroral citizen science has been combining auroral photographers' pictures with observations from ground-based instruments and satellites, hence requiring a multidisciplinary approach and a broad range of expertise and skills. In the past few years, it has also led to the design of new auroral imaging instruments, both by citizen scientists themselves and by academic researchers, that are being deployed to collect optical data of new kinds.
The ARCTICS (Auroral Research Coordination: Towards Internationalised Citizen Science) Working Group, sponsored by the International Space Science Institute in Bern since 2023, brings together academics and citizen scientists from Europe, North America and Oceania to investigate auroral and sub-auroral physics. We combine citizen scientist observations with satellite and ground-based measurements to shed light on elusive optical phenomena such as STEVE, the dunes, fragments, and continuum emissions. We also produced an open-access Handbook to provide guidance and recommendations for collaborations between academics and citizen scientists to be as smooth and fruitful as possible, accompanied by a Field Guide for citizen scientists.
In this presentation, we will give a brief overview of citizen science initiatives in auroral research and highlight some of the recent achievements by the ARCTICS collaboration.

Observing the Sun and other Cosmic Radio Sources from the Moon **O6-3**

Nat Gopalswamy [1], P. Mäkelä [1], S. Yashiro [1], S. Boardsen [1], J. O. Burns [2], and J. J. Hibbard [2]

[1]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [2]Center for Astrophysics and Space Astronomy, University of Colorado, Boulder, CO 80309, USA

The first robotic commercial lunar lander, Intuitive Machines' Odysseus, was launched using a SpaceX Falcon 9 rocket from the Kennedy Space Center on February 15, 2024 and landed on the Moon a week later. The landing location was Malapert-A on the near side ∼300 km from Moon's south pole. This mission was part of NASA's Commercial Lunar Payload Services (CLPS) program. Odysseus carried NASA's first radio telescope, known as Radio-wave Observations at the Lunar Surface of the photoElectron Sheath (ROLSES).

The ROLSES spectrometer obtained spectra over the range 2 kHz – 30 MHz with 8 sec time resolution. One of the antennas self-deployed enroute to the Moon because of excess solar flux falling on that antenna. Odysseus soft-landed, but was tilted, limiting communications with the lander. A second antenna self-deployed again because of excess heating as a consequence of the tilted landing. Two antennas were deployed by command as planned. ROLSES was able to take engineering and science data using the antenna that deployed in transit for ∼83 min. On the surface, ROLSES collected spectral data for another 36 min. Furthermore, raw waveform data was obtained for ~ 5 min from the surface. Analyses of these data show (i) radio frequency interference (RFI) near and on the Moon from ground based radio transmitters, (ii) variable ionospheric cutoff, and (iii) galactic radio emission. The Sun was extremely quiet, so no radio burst occurred. An improved version of the radio telescope, ROLSES 2, is in the works for a launch in 2028. ROLSES 2 will have improved antenna actuators, power converter, a calibration scheme to monitor gain variations, and to measure all Stokes parameters for polarization.

Ensuring the Long-Term Sustainability of Space Weather and Space Climate Activities in Europe: The Role of E-SWAN — O6-4

Luca Spogli [1], S. Poedts [2,3], M. Brchnelova [4], J. Urbar [5], S. Chabanski [6], and R. Van der Linden [7]
[1]Istituto Nazionale di Geofisica e Vulcanologia, Italy, [2]KU Leuven, Belgium, [3]University of Maria Curie-Skłodowska, Poland, [4]Ministry of Defence of Netherlands, [5]Institute of Atmospheric Physics, Czech Republic, [6]Royal Belgian Institute for Space Aeronomy, Belgium, [7]Royal Observatory of Belgium, Belgium

The complex and interdisciplinary nature of Space Weather and Space Climate requires robust institutional frameworks to sustain consolidated activities and that effort remains robust, coordinated, and sustainable for the future. Established in 2022 as an international non-profit association, the European Space Weather and Space Climate Association (E-SWAN) was created to address this need. The core mission of E-SWAN is to unite, sustain, and develop Space Weather and Space Climate (SWSC) activities in Europe. This presentation outlines how E-SWAN serves as a central hub to harmonize European efforts, minimize fragmentation, and represent the community on the global stage.
To unite the community, E-SWAN has implemented a robust governance structure comprising a General Assembly, an Executive Board, a Council, and eight active Working Groups. Among the latter, one is explicitly dedicated to reviewing, proposing, and harmonizing operational activities, infrastructure, data, and models.
E-SWAN facilitates the running of three cornerstone activities: the European Space Weather Week (ESWW), through its Program Committee (ESWW PC), the Journal of Space Weather and Space Climate (JSWSC), through its Publication Committee (PubCom), and the International Space Weather and Space Climate medals, through its Awards Committee (AwCom).
To sustain the field, E-SWAN focuses heavily on human capital and the next generation. The Education and Outreach Committee (EOCom) has launched an E-SWAN school series and a series of accessible booklets to communicate SWSC effects to a broader audience. E-SWAN actively engages with stakeholders, including research institutions, ESA, national space agencies, and the private sector. The association has established strategic partnerships with global bodies such as COSPAR, WMO, and ISES, including collaboration on the standardization of naming large space weather storms.
By coordinating these diverse initiatives, ranging from high-level policy advocacy to grassroots educational outreach, E-SWAN ensures that European Space Weather and Space Climate community remains efficient, interconnected, and sustainable for the future.

AGATA Scientific Research Programme as a Platform for Collaboration in the Polar Regions — O6-5

Wojciech J. Miloch [1,2] and AGATA Leadership Team [2]
[1]Department of Physics, University of Oslo, Norway, [2]AGATA, Scientific Committee on Antarctic Research

The solar-terrestrial studies in the polar regions often require joint efforts in sharing and analysing data and in conducting research campaigns. This is in particular true in the southern hemisphere, in the Antarctic region, where both limited accessibility, sparse infrastructures, and logistical constraints put limitations on continuous monitoring of the upper polar atmosphere and its response to geomagnetic forcing. Such limitations, can be mitigated by coordinated approaches and multinational efforts.
The Antarctic Geospace and Atmosphere ReseArch (AGATA) is the Scientific Research Programme (SRP) of the Scientific Committee on Antarctic Research (SCAR) that started its activities in 2025. The main scientific questions addressed by AGATA are: i) How are different atmospheric layers coupled in the polar regions? ii) How does the high latitude upper polar atmosphere respond to increased geomagnetic activity, including energy transfer from space? iii) How does the whole polar atmosphere impact short- and long-term climate variations? To understand the global context, the AGATA SRP is set in the interhemispheric perspective: it considers the Antarctic and Arctic upper atmosphere to understand the differences and similarities between the polar regions and their role for the global atmospheric processes. AGATA, having a nominal duration of 8 years (from 2025 to 2032), is involved in preparations towards the next International Polar Year (2032-2033; https://ipy5.info/).
AGATA's scientific activity is organized in working groups and task groups. AGATA Working Groups focus on revealing the role of physical processes in the polar atmosphere in: i) coupling between different atmospheric layers (i.e., different "spheres", such as troposphere, stratosphere, ionosphere); ii) coupling between the neutral and ionized atmospheric components within the respective atmospheric layers; iii) coupling of the Antarctic atmosphere to geospace and processes in the magnetosphere. AGATA Task Groups complement the working groups by addressing common issues related to for example infrastructure, coordination of activities, outreach, capacity building, training, and others.
In this talk, we summarize the achievements of AGATA after the first year of its activities, its status, plans, and collaborative initiatives both in the framework of AGATA Scientific Research Programme and beyond.

Maryland Space Weather UnderGround: Pushing the Boundaries of Next-Generation Low-Cost Ground Magnetometers **P6-1**

Gangkai Poh [1,2], F. Erinfolami [1,2], K. Sukhina [1,3], and H. Conner [1]
[1]NASA Goddard Space Flight Center, [2]Catholic University of America, [3]University of Maryland College Park

The Maryland Space Weather UnderGround (MD-SWUG) program is a Heliophysics research and education outreach collaboration between the Catholic University of America (CUA) and NASA Goddard Space Flight Center (GSFC), co-led by Dr. Gangkai Poh and Dr. Hyunju Connor. It was expanded from the SWUG program in the University of Alaska Fairbanks. Since its inception in early 2022, the MD-SWUG core team (consisting of 3 research scientists and engineers, and 3 graduate and undergraduate students) have (1) developed and deployed multiple low-cost magnetometers to sites along the October 2023 and April 2024 solar eclipse path to understand the impact of solar eclipse on ionospheric currents, (2) organized the SWUG summer workshops in 2023 and 2024 for HS students to learn the basics of space weather, and to build the Simple Aurora Monitor (SAM)-III magnetometer kits, and (3) integrated magnetometry for space weather research into the curriculum of CUA's Master's degree program in Applied Space Weather Research. Here, we will discuss about our ongoing collaborations with NASA GSFC and the United States Geological Survey to improve the data quality of our SWUG magnetometers, and present results from our recent calibration efforts. We will also discuss future plans for the MD-SWUG programs in our continuous efforts towards enhancing the performance of low-cost magnetometers for array deployments, inspiring and growing the next-generation of highly-skilled workforce in Heliophysics research, and promoting sustainability for future low-cost magnetometer programs in the United States and worldwide.

Coordinated Observations from Solar Orbiter, SST, and IRIS of an Active Chromospheric Fibril Singularity **P6-2**

Reetika Joshi [1], L. Rouppe van der Voort [1], G. Aulanier [2], S. Danilovic [3], A. Prasad [1], C. J. Díaz Baso [1], D. Nóbrega-Siverio [1], N. Poirier [2], and D. Calchetti [1]
[1]University of Oslo, Norway, [2]George Mason University, USA, [3]Max Planck Institute for Solar System Research

The fine structures of the solar chromosphere, driven by photospheric motions, play a crucial role in the dynamics of solar magnetic fields. Many have been already identified such as fibrils, filament feet, and arch filament systems. Still, high resolution observations show a wealth of structures that remain elusive. We have observed a puzzling, unprecedented chromospheric fibril singularity in close vicinity of a blow-out solar jet and a flaring loop. We aim to understand the magnetic nature of this singularity and the cause of its activity using coordinated high- resolution multi-wavelengths observations. We aligned datasets from Solar Orbiter, SST, IRIS, and SDO. We re-projected the Solar Orbiter datasets to match the perspective of the Earth-based instruments. We performed potential field extrapolations from Solar Orbiter/PHI data. We analysed the spatial and temporal evolution of the plasma structures and their link with the surface magnetic field. This leads us to derive a model and scenario for the observed structures which we explain in a general schematic representation. We have discovered a new feature, a singularity in the chromospheric fibril pattern. It is formed in a weak magnetic field corridor between two flux concentrations of equal sign, at the base of a vertically inverted-Y shape field line pattern. In this specific case some activity develops along the structure. Firstly a flaring loop at one end, secondly a blow-out jet at the other end, where a coronal null-point was present and associated with a chromospheric saddle point being located onto the fibril singularity. The observations suggest that both active phenomena were initiated by converging photospheric moat flows that exerted pressure on this fibril singularity.

Performance Assessment of Low-Cost GNSS Receiver for Ionospheric Monitoring **P6-3**

Teddy Surco Espejo [1], T. Beach [1], D. Paznukhov [1], and K. Groves [1]
[1]Boston College, Institute for Scientific Research, Chestnut Hill, MA, USA

The ionosphere is a dispersive medium, and radio waves passing through it experience refraction which is proportional to the total electron content (TEC) value of the medium. Also, wave diffraction on the ionospheric irregularities produce rapid fluctuations in signal amplitude or phase, which are called ionospheric scintillations. These metrics exhibit regional dependence due to the varying nature of ionospheric physics and serve as a reference for the space weather. These ionospheric effects can produce signal time delay, and reduce the carrier-to-noise ratio and even cause loss-of-lock of the Global Navigation Satellite System (GNSS) signals that can degrade the accuracy, performance and availability of navigation systems particularly in the equatorial and low-latitude regions.
Specialized GNSS receivers have been used for ionospheric monitoring and research around the world. These receivers are capable of providing multi-frequency (at least two frequencies), high rate (∼5 – 50 Hz) data. However, the cost of these types of receivers is high, which restricts the accessibility of such receivers for many users. As a consequence, recent advances in GNSS technology resulted in the availability the new generations of low-cost GNSS equipment, multi-constellation, multi-frequency and high rate (∼5 – 20 Hz) data chipsets that allow innovations in many applications. The implementation of low-cost GNSS receiver has made it possible to develop a system for space weather monitoring.
The focus of this work is to evaluate the performance of the U-blox receiver as a low-cost GNSS receiver installed at Ascension Island (7.9750°S, 14.4093°W, dip latitude 16°S). This location is just below the southern crest of the equatorial anomaly in the F-region and, as such, TEC and scintillations are enhanced during the post-sunset period, especially during the solar maximum period. GNSS signals were recorded every night of March 20 – April 6, 2023.

The TEC, amplitude (S4) and phase ($\sigma\phi$) scintillation indexes were computed using the measurements collected from U-blox receiver. The results for GPS L1 and L2 signals are evaluated in this study. To validate these results, a comparative study between a costly geodetic grade receiver (Septentrio PolarX), and the low-cost receiver (U-blox), is carried out to explore the suitability of the latter for ionosphere probing. Also, we aim to extend this analysis by incorporating a statistical analyses of position errors estimated from the GPS observables collected by the low-cost receiver. The single and precise point positioning (SPP and PPP) methods are applied to explore the potential of the low-cost devices during moderate and strong scintillation activity.

Characterization of Equatorial F- and E-Region Ionospheric Scintillation from COSMIC Radio Occultation and SCINDA GNSS Measurements — P6-4

Aramesh Seif [1], *S. Kumar Panda* [2], *and S. M. Bailey* [3]
[1]*Department of Physics, Shahid Beheshti University, Evin, Tehran, Iran*, [2]*Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, India*, [3]*Center for Space Science and Engineering Research, Bradley Department of Electrical and Computer Engineering, Virginia Tech, Blacksburg, VA, USA*

This study investigates the characteristics of ionospheric irregularities in the equatorial region using data from both space- and ground-based sources. Specifically, we utilize radio occultation (RO) observations from the FORMOSAT-3/Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) mission and GNSS-based amplitude scintillation measurements from the Scintillation Network Decision Aid (SCINDA) at four longitudinal stations near the magnetic equator. The amplitude scintillation index (S4) derived from these datasets is employed to analyse the morphology of both nighttime and daytime plasma irregularities in the F and E regions of the ionosphere.
By integrating ground-based measurements with limb-viewing geometry from space, the study provides complementary insights into the occurrence and distribution of equatorial irregularities—namely, equatorial plasma bubbles (EPBs) in the F region and sporadic E (Es) layers in the E region. The occurrence of amplitude scintillation retrieved from COSMIC RO data is examined to assess its diurnal and seasonal variability.
A statistical analysis of 2013 data reveals consistent patterns between the two observation techniques. Notably, daytime scintillation associated with Es is predominantly observed over the Asian sector, while nighttime scintillation linked to EPBs is more frequently detected over the African sector. These findings underscore the value of RO measurements from current and future missions as effective tools for regional and global monitoring of ionospheric scintillation events

Broad-band Riometers as a Tool for Ionospheric Tomography — P6-5

Alexander Kozlovsky [1]
[1]*Sodankylä Geophysical Observatory, University of Oulu, Finland*

Radio waves at frequencies of tens MHz (HF-VHF band) may propagate in the Earth-ionosphere waveguide for such long distances as few thousand kilometres, if the ionospheric electron density is high enough. For example, in late October 2023 the meteor radar operating in the Sodankylä Geophysical Observatory (SGO, 67°N, 27°E, Finland) at a frequency 36.9 MHz detected powerful signal from a transmitter at presumable distance 1500 km. On the other hand, in November 2024 transmission of the Sodankylä meteor radar was received in the South UK, at 2500 km. These events occurred during high solar activity when ionospheric electron density was high. This feature was also manifested in the power of radio noise at the SGO network of spectral (broad-band) riometers, which now consists of 8 receivers operating in the frequency band 20-55 MHz. We present and discuss dependences of the radio noise power on the solar activity and ionospheric F2 layer density. Further, we suggest that the data of spectral riometers may be used for passive ionospheric tomography to get 3D structure of the ionosphere.

A Long-term Sustainable Canadian Auroral Observing Program — P6-6

Eric Donovan [1], *E. Spanswick* [1], *and J. Liang* [1]
[1]*University of Calgary, Canada*

Around 1980, the University of Calgary deployed a digital all-sky imager (ASI) at Gillam Canada. In the intervening years, the Calgary team has maintained and grown its network of ASIs and other optical instruments. Today, this network spans Canada, and is comprised of the THEMIS-ASI network (panchromatic imagers), REGO (redline imagers), the TREx RGB, near Infrared, and blueline ASIs, two Meridian Imaging Spectrographs, the beginnings of the continent-wide SMILE-ASI color imager network (that will replace THEMIS-ASI), and the AuroraMax and ARCTICS-SMILE citizen science engagement cameras. What started 45 years ago in Gillam as an experiment with a one or two year plan has evolved into an ongoing, growing, dynamic program that has fueled countless space weather, space science, and data science research programs.
Calgary has evolved a long-term strategy which guides the evolution of the observing program. At the same time, for all of those 45 years, the program has been funded by dozens of one to six year grants from numerous programs, tied in many cases to specific mission opportunities (e.g., THEMIS and GDC), a reality that is sometimes at odds with sticking to a long term plan, however sensible that plan might be. This is a generational program and a global resource, and Calgary is presently involved in an effort to change the playing field, nationally, with an eye to global impact. The goal is to create an environment where this optical program has long-term sustainable operations that support a global geospace initiative, independent of specific missions which however many decades they last, ultimately come and go. With 45 years of history, the Calgary team is optimistic that it will create this new path.

What is the vision? In this presentation, we briefly visit our history, pointing out new tools that connect data users to a PByte of fully open online image data comprised of billions of individual images, with rapidly evolving tools that support discovery and analysis. More importantly, we present a vision that includes a baseline set of continent-wide observations that the world can count on, nested within which with are networks with smaller areas of coverage but that provide a richer set of observations. This vision also includes an ongoing innovation program, supporting the development of new instruments on one hand, and new science and space weather on the other.
This is Calgary's plan for a key part of the Great Heliophysics Observatory envisioned in the last US National Academies Decadal Survey.

TID Signatures on Ionograms — P6-7

Haris Haralambous [1] *and K. S. Paul* [1]
[1]*Frederick Research Center*

Travelling ionospheric disturbances (TIDs) represent an ionospheric manifestation of the effect of gravity waves on the ionosphere. There is an interest in understanding the correlation between various forms of such irregularity signatures on ionograms such as spread F with the actual characteristics and severity of TIDs and therefore these signatures provide an important tool for TID identification and monitoring. In the existing literature there is evidence that tilted surfaces generated by TIDs at mid-latitude regions are the reason for supplementary nighttime traces appearing on ionograms which are satellites of the main ionogram traces. Therefore the term "satellite" traces signifies the formation of oblique echoes which are the reflecting patterns of the tilt manifested at the F-layer bottomside. In turn, these satellite traces (STs) are apparently associated with spread F traces. Another form of characteristic signature/irregularity on ionogram traces is the fork trace. This presentation will discuss recent results from typical (5-min) but also high-time resolution ionogram datasets suggesting that the identification of such ionogram signatures can be used as an indicator of MSTID activity over ionosonde stations.

Current Status of Multi-point Ground-based Instruments by OMTIs, PWING, and PBASE, for Measurements of the Upper Atmosphere — P6-8

Kazuo Shiokawa [1], *PWING team* [2], *and PBASE team* [3]
[1]Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan, [2]https://www.isee.nagoya-u.ac.jp/dimr/PWING/en/, [3]https://www.isee.nagoya-u.ac.jp/dimr/PBASE/en/

The Optical Mesosphere Thermosphere Imagers (OMTIs), stated in 1998 (Shiokawa et al., 1999), measure two-dimensional airglow images in the mesopause region and the thermosphere, wind and temperatures in the lower thermosphere, and airglow rotational temperatures in the mesopause region. OMTIs consist of more than 20 all-sky cooled-CCD imagers, 5 Fabry-Perot interferometers, 3 airglow temperature photometers, and 3 meridian-scanning photometers. We also develop low-cost all-sky cameras and distribute them in African and Asian countries. The PWING project (study of dynamical variation of Particles and Waves in the INner magnetosphere using Ground-based network observations, 2016-2022, Shiokawa et al., 2017) operates OMTIs all-sky airglow/aurora imagers, 64 Hz sampled induction magnetometers, 40 kHz VLF receivers, and 64 Hz riometers at 8 stations at magnetic latitudes of $\sim$60 degree around the north-pole. The PWING stations cover longitudinal variation of aurora and electromagnetic disturbances in the inner magnetosphere. Although the PWING project of JSPS Kakenhi budget officially ended on March 2023, these PWING and OMTIs instruments are in automatic operation at various locations from high to equatorial latitudes in Canada, US (Alaska), Russia, Norway, Finland, Iceland, Japan, Thailand, Indonesia, and Australia. From January 2023, a new project "International joint research of geospace variability by combining multi-point ground and satellite observations and modelling (PBASE program)" has been started (https://www.isee.nagoya-u.ac.jp/dimr/PBASE/index-e.html). This program encourages combining these ground-based observation suits with satellite observations and modelling through supporting students and early-career scientists. In the presentation, we introduce current configuration of ground instruments of OMTIs and PWING and introduce the PBASE program activities. Shiokawa et al. (EPS, 1999, https://doi.org/10.1186/BF03353247), Shiokawa et al. (EPS, 2017, https://link.springer.com/article/10.1186/s40623-017-0745-9)

SCHOOL PROGRAM OVERVIEW

School Day 1 - May 30th, 2026

Time	Session	Number	Title of Abstract	Presenter
09:00 – 09:10			School Opening	
09:10 – 10:10	Session 0	S1-1	Cross-scale coupling processes in the sun as the source of space weather and space climate	Bernhard Kliem
10:10 – 10:30			Break	
10:30 – 11:30	Session 0	S1-2	Lecture 1 assignment/experiment	Bernhard Kliem
11:30 – 13:00			Lunch Break	
13:00 – 14:00	Session 0	S2-1	Interplanetary disturbances as space weather drivers	Spiros Patsourakos
14:00 – 14:20			Break	
14:20 – 15:20	Session 0	S2-2	Lecture 2 assignment/experiment	Spiros Patsourakos
15:20 – 15:40			Break	
15:40 – 16:40	Session 0	S3-1	Cross-scale coupling processes of the solar wind, magnetosphere, and ionosphere	Rumi Nakamura
16:00 – 17:00			Break	
17:00 – 18:00	Session 0	S3-2	Lecture 3 assignment/experiment	Rumi Nakamura

School Day 2 - May 31st, 2026

Time	Session	Number	Title of Abstract	Presenter
09:00 – 10:00	Session 0	S4-1	Storms, substorms and energetic particles in geospace	Ioannis A. Daglis
10:00 – 10:30			Break	
10:30 – 11:30	Session 0	S1-2	Lecture 4 assignment/experiment	Ioannis A. Daglis
11:30 – 13:00			Lunch Break	
13:00 – 14:00	Session 0	S5-1	Vertical Coupling in Earth's Middle and Upper Atmosphere	Nicholas M. Pedatella
14:00 – 14:20			Break	
14:20 – 15:20	Session 0	S5-2	Lecture 5 assignment/experiment	Nicholas M. Pedatella
15:20 – 15:40			Break	
15:40 – 16:40	Session 0	S6-1	External impacts on the thermosphere-ionosphere system and their effects	Astrid Maute
16:00 – 17:00			Break	
17:00 – 18:00	Session 0	S6-2	Lecture 6 assignment/experiment	Astrid Maute

SESSION 0: STP-16 School Lectures

Cross-scale coupling processes in the sun as the source of space weather and space climate **S1-1**

Bernhard Kliem [1]
[1] *University of Potsdam, Germany*

This lecture will focus on the solar sources of space weather disturbances, i.e., on the physics of solar eruptions, which comprise coronal mass ejections (CMEs), flares, and filament/prominence eruptions. The state of the art of this area of solar research will be introduced, starting from the conjectured (and debated) magnetic source region structures – magnetic flux rope vs. sheared magnetic arcade – and addressing in detail the (also debated) initiation and driving processes – ideal MHD instability vs. magnetic reconnection. Although solar eruptions are large-scale processes operating at active-region scales, both the evolution toward eruption and the eruption itself involve processes at much smaller scales. Some aspects of such cross-scale coupling will also be addressed. Finally, the effects of the largest eruptions on the Sun and on stars on the respective space climate will be briefly reviewed.
The subsequent hands-on session will introduce some analysis tools that are useful in evaluating the results of MHD simulations of solar eruptions.

Interplanetary disturbances as space weather drivers **S2-1**

Spiros Patsourakos [1]
[1] *Department of Physics, Section of Astrogeophysics, University of Ioannina, Greece*

Space weather refers to variable conditions in space that can affect the near-space environment and upper atmosphere of Earth, as well as other bodies in the solar system, and under certain circumstances influence high-technology human activities and assets both in space and on Earth. The interplanetary medium is shaped by the solar wind slow and its interactions with the interplanetary magnetic field. Large-scale disturbances of the background solar wind, in the form of coronal mass ejections (CMEs) and high-speed solar wind streams originating at the Sun and propagating through interplanetary space, are main drivers of space weather.
In this lecture, we will outline the basic properties of these large-scale heliospheric disturbances, discuss the physics governing their propagation, and review current efforts to predict their key characteristics in the near-Earth space environment. A hands-on activity focused on predicting the time of arrival of a CME at near-Earth space environment will also be included.

Cross-scale coupling processes of the solar wind, magnetosphere, and ionosphere **S3-1**

Rumi Nakamura [1]
[1] *Space Research Institute, Austrian Academy of Sciences*

A number of in situ measurements performed in the past decades from space missions and outcome from the computer simulations and theories led to a significant advancement of understanding of the fundamental plasma processes, such as magnetic reconnections, shocks, and turbulence acting at the various boundaries or regions throughout the magnetospheres and ionosphere. Yet, complex interaction processes among the different scales of plasma governing their energization and transport are still not fully understood. The importance of understanding the cross-scale coupling of the solar wind with the magnetosphere and ionosphere are not only for Earth, but also for other planets and moons where the solar wind coupling with induced magnetospheres or with surface are relevant.
In this lecture the cross-scale coupling of plasma processes in the solar wind-magnetosphere-ionosphere systems are discussed in particularly highlighting magnetic reconnection that are one of the key processes leading to plasma transport and energization. Recent spacecraft observations from multi-point measurement and analysis of these data to study different temporal and spatial scales of magnetic reconnection will be introduced that advanced our understanding of the complex coupling problems of magnetic reconnection with support also by global/local computer simulations. The handson assignments will enable participants to experience further the ongoing research of this cross-scale coupling process in the solar wind/magnetosphere/ionosphere systems.

Storms, substorms and energetic particles in geospace **S4-1**

Ioannis A. Daglis [1]
[1] *National and Kapodistrian University of Athens*

This lecture focuses on the two main eruptive geospace weather phenomena and the associated energetic particle populations. The input of magnetic energy into the terrestrial magnetosphere during magnetic reconnection of the geomagnetic field with the interplanetary magnetic field at the dayside magnetopause leads to the occurrence of magnetospheric substorms and magnetic storms. The ring current is the actual engine of magnetic storms: its growth defines the storm main phase, while its decay leads to storm recovery. The Earth's outer radiation belt, consisting of relativistic electrons, represents one of the most dynamic and challenging particle populations in space, exhibiting flux variations spanning multiple orders of magnitude on timescales from seconds to weeks. We will review the intricate feedback between the ring current and energetic electron populations, which plays a crucial role in the variability of the outer radiation belt.
The hands-on session will introduce on-line tools for nowcasting and forecasting of substorms, storms, and the outer radiation belt.

Vertical Coupling in Earth's Middle and Upper Atmosphere **S5-1**

Nicholas M. Pedatella [1]
[1]*High Altitude Observatory, NSF National Center for Atmospheric Research, USA*

The Earth's middle and upper atmosphere (mesosphere, thermosphere, and ionosphere) are driven by a combination of processes, including waves propagating upwards from the lower atmosphere (troposphere-stratosphere) and from solar/geomagnetic variations. The effects from the lower atmosphere are primarily driven by different types of waves propagating upwards from the lower atmosphere, including gravity waves, atmospheric tides, and planetary waves. These waves ultimately drive spatial and temporal variations in the mesosphere, thermosphere, and ionosphere. This lecture will provide an overview of the different wave processes that couple the lower atmosphere to the middle and upper atmosphere. The physical mechanisms by which atmosphere waves generate spatial and temporal variations in the ionosphere will also be reviewed. Students will additionally learn about extracting wave properties from observations and simulations during hands on exercises.

External impacts on the thermosphere-ionosphere system and their effects **S6-1**

Astrid Maute [1]
[1]*Leibniz Institute of Atmospheric Physics, Kühlungsborn, Germany*

The thermosphere–ionosphere (TI) system is continuously influenced by multiple external forcings that vary in strength, spatial scale, and timescale. Its response depends both on the nature of the forcing and on the background state of the TI system. Solar radiation is a persistent driver, varying among others with season and the solar cycle. During active solar periods, solar flares can abruptly increase X ray and EUV radiation, producing rapid changes in ionization and heating. The TI system is also shaped by dynamical forcing from the lower atmosphere, including tides, planetary waves, and gravity waves. These vary with season and meteorological conditions and contribute significantly to day to day TI variability.
A major source of rapid TI change is solar wind and magnetospheric forcing. The associated energy is deposited in the high latitude upper atmosphere, partitioned into auroral particle precipitation, Joule heating, and kinetic energy. TI effects are enhanced ionization and heating, generated pressure gradients and winds. Although the energy is deposited at high latitudes, the resulting disturbances can be global. The mean circulation can be disturbed and the composition changed which then affects the plasma distribution. In addition, sudden intense energy input can lead to large scale travelling atmospheric disturbances (LSTADs) and travelling ionospheric disturbances (TIDs) which can propagate around the globe.
Ionospheric electrodynamics plays a crucial role in shaping the thermosphere–ionosphere (TI) system's response to external forcing and in coupling high and low latitudes. During geomagnetic storms, penetration electric fields and disturbance wind dynamo processes can significantly alter low latitude vertical plasma drifts and the overall plasma distribution. Predicting the variability of the TI system during storm conditions, as well as under influences from the lower atmosphere, remains challenging because of the highly variable forcing and the complex interactions among dynamical, chemical, and electrodynamic processes.
Participants will work with existing TI model simulations and observational datasets to investigate system behaviour during both quiet and disturbed conditions. Activities include:

- Comparing TI structure during nominal solar radiation and during periods of enhanced solar wind forcing.
- Examining the relationship between solar wind parameters, high latitude ion convection, and field aligned currents during various solar wind conditions.
- Using simulations to analyse Joule heating during a geomagnetic storm and its effects on neutral temperature, winds, and composition.
- Investigating storm time responses at low latitudes using ion drift measurements and magnetic perturbations to assess the timing and magnitude of the storm response.