
# 2024 Space Weather Workshop Poster Abstract Booklet
# Boulder, CO

*Organized by day and poster number.*

*Poster Lightning talks for:*

*Tuesday Posters: Tuesday April 16 11:45 AM - 12:15 PM*

*Wednesday Posters: Tuesday April 16 5:00 PM - 5:30 PM*

*Thursday Posters: Wednesday April 17 5:00 PM - 5:30 PM*

# Tuesday, 16 April

## *Solar and Interplanetary Research and Applications*

## *Aviation Radiation Research and Applications*

*Posters can be viewed all day, with dedicated times from 9:50 AM - 10:45 AM and 2:45 PM - 3:45 PM*

**1. Bibhuti Kumar Jha** (Southwest Research Institute)
**AFT 2.0: Incorporating Sun's far-side observation in Advective Flux Transport Model**
**Co-Author(s):** Lisa Upton, Southwest Research Institute, Boulder, CO; Cooper Downs, Predictive Science Inc., San Diego, CA; Emily Mason, Predictive Science Inc., San Diego, CA; Jon A Linker, Predictive Science Inc., San Diego, CA

The Advective Flux Transport (AFT) models the global solar magnetic field and its evolution. The full Sun magnetic maps produced by AFT can be used as the boundary condition for time-dependent coronal modeling. However, AFT heavily relies on near-side observations of the Sun. This presents a challenge for these studies because the lack of far-side information in the AFT maps can significantly affect the magnetic field topology in the coronal models. To overcome this limitation, we investigate multiple proxies for obtaining information about far-side active region (AR) emergence and growth. This includes data from the 304Å channel of the EUVI instrument aboard the STEREO spacecraft and far-side helioseismic acoustic maps from HMI/SDO and GONG/NSO. We evaluate the strengths and weaknesses of each proxy. Finally, we develop a composite method for incorporating proxy data into AFT. This method relies on far-side proxies for identifying the time and location of far-side emergence. The proxy information is used to provide an initial estimate of the magnetic flux, but this is constrained by the HMI/SDO magnetic field observations when the AR returns to the near-side. The HMI/SDO observations are also used to determine far-side ARs' properties, such as tilt. Preliminary results on the inclusion of far-side ARs into AFT using this combined approach will be presented.

**2. Amr Hamada** (National Solar Observatory)
**Far-Side Active Regions Based on Helioseismic and EUV Measurements: Toward a Global Index**
**Co-Author(s):** Kiran Jain, National Solar Observatory, Boulder, CO; Charles Lindsey, North West Research Associates, Boulder, CO; Mitchell Creelman, National Solar Observatory, Boulder, CO; Niles Oien, National Solar Observatory, Boulder, CO

Active Regions (ARs) are regions of strong magnetic field flux in the solar photosphere. Understanding the global evolution of ARs is critical for solar magnetism as well as for accurate space weather forecasting applications. We used the brightening of the solar corona in extreme ultraviolet (EUV) 304 Å images as a proxy for the magnetic ARs. In this study, we examine different AR datasets to investigate the relationship between the helioseismic signatures and EUV source distributions of strong magnetic regions in the Sun's far hemisphere. For the EUV component of the study, we use synchronic EUV maps at 304 Å comprised of observations from the Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA) with Solar TErrestrial RElations Observatory/Extreme UltraViolet Imager (STEREO/EUVI) instruments. For the far-side helioseismic observations, we used seismic phase-shift maps of the Sun’s far hemisphere, computed from the National Solar Observatory/Global Oscillation Network Group’s (NSO/GONG) Dopplergrams. We present the first global EUV/AR catalog of the whole Sun, providing several basic parameters: location, area, tilt angle, EUV flux, and latitudinal and longitudinal extent of the identified ARs. We also present a similar catalog for the far-side GONG/ARs where the helioseismic phase shift parameters are included. Helioseismic far-side GONG/ARs are examined and their success at predicting far-side strong ARs is assessed. We finally discuss the ARs temporal and spatial evolution of the global EUV/ARs and far-side GONG/ARs during the maxima of Solar Cycle 24 (May 2010 - May 2016).

**3. Nikolai Pogorelov** (The University of Alabama in Huntsville, Department of Space Science)
**Improving Space Weather Forecasts Improving Space Weather Predictions with Data-Driven Models of the Solar Atmosphere and Inner Heliosphere**
**Co-Author(s):** Charles N. Arge, NASA Goddard Space Flight Center; Ronald Caplan, Predictive Science Inc.; Phillip Colella, Lawrence Berkeley National Laboratory; Chris Gebhart, Lawrence Berkely National Laboratory; Jon Linker, Predictive Science Inc.; Talwinder Singh, The University of Alabama in Huntsville, AL; Brian Van Straalen, Lawrence Berkeley National Laboratory; Lisa M. Upton, Southwest Research Institute, Boulder, CO; Ralf Attie, Predictive Science Inc.; Cooper Downs, Predictive Science Inc.; Dinesha Vasanta Hegde, The University of Alabama in Huntsville, AL; Shaela Jones, NASA Goddard Space Flight Center; Tae K. Kim, The University of Alabama in Huntsville, AL; Andrew Marble, University of Colorado, Boulder, CO; Syed Raza, The University of Alabama in Huntsville, AL Miko Stulajter, Predictive Science Inc.; James Turtle, Predictive Science Inc.

We describe a newly-developed software suitable for near real-time predictions of the SW properties at Earth’s orbit and in the interplanetary space. It involves the following components.
1. A new Open surface Flux Transport (OFT) model which evolves information to the back side of the Sun and its poles and updates the model flux with new observations using data assimilation methods.

2. A new potential field solver (POT3D) combined with the output from the traditional WSA model, and with remote coronal and in situ solar wind observations. WSA and the new potential field solver (PFSS and PFCS) are both validated using the maps from the OFT. Due to its efficiency and versatility, it is especially efficient for ensemble modeling.
3. A highly parallel, adaptive mesh refinement (AMR) code (HelioCubed) for the Reynolds-averaged, ideal MHD system of equations between 0.1 au and 1–3 au. This system also involves equations describing the transport of turbulence. HelioCubed is built on Chombo 4 framework and makes it possible to perform simulations with the fourth order of accuracy in time and space, and use cubed spheres to generate meshes around the Sun.
4. The developed software runs on both GPUs and CPUs and is being made publicly available.
5. We also apply machine learning techniques and demonstrate that their application is critical for accurate predictions of coronal mass ejection arrival at Earth.

**4. Jussi Lehti** (Aboa Space Research Oy (ASRO), Finland)
**Pioneers in Space Weather Monitoring: ASRO's Radiation Monitor Family**
**Co-Author(s):** Osku Raukunen, ASRO, Finland; Philipp Oleynik, ASRO and University of Turku, Finland; Deepa Anantha Raman, ASRO, Finland; Pasi Virtanen, ASRO and University of Turku, Finland; Tero Säntti, ASRO and University of Turku, Finland

With 25 years of experience in space weather instrumentation, Aboa Space Research Oy (ASRO) has developed a novel suite of four Radiation Monitors. These instruments are specifically designed for comprehensive space weather monitoring, a critical aspect of understanding the near-Earth environment and ensuring the safety and functionality of space missions tailored to the New Space era.

Each instrument in ASRO's product family has a compact design suitable for nanosatellite platforms, with weights between 0.5 and 1.2 kilograms. Their detection capabilities include X-rays between 1 and 30 keV, electrons between 3.5 keV and 8 MeV, protons above 1 MeV, and alpha particles above 7 MeV/n with effective separation of particle species. ASRO's product family shares the unique benefits of a common back-end design based on flight proven heritage, and the possibility of merging two instruments into a 1U instrument. Furthermore, the instruments have tuneable sensor heads for different energy ranges, viewing angles and fluxes, making them suitable for a wide range of missions and orbits from Low Earth Orbit to interplanetary space.

ASRO provides these off-the-shelf instruments along with data analysis support services for various space weather service providers, scientific missions and research institutes. The data produced by these instruments is pivotal for elucidating space weather phenomena which helps scientists and engineers in predicting and mitigating potential repercussions on space travel, satellite operations and critical ground infrastructure.

**5. Guifre Molera Calves** (University of Tasmania, Australia)
**Deep Space Weather Radio Sounding Observations of the Solar Corona by VLBI Radio Telescopes**
**Co-Author(s):** Jasper Edwards, University of Tasmania, Australia; Giuseppe Cimo, Joint institute for VLBI in Europe

The University of Tasmania (UTAS) operates five large radio telescopes (Hobart-12m, Katherine-12m, Yarragadee-12m, Hobart-26m, and Ceduna-30m) as part of its VLBI-based geodetic, astronomic, and spacecraft tracking activities. We expanded our interplanetary spacecraft tracking capability by conducting radio sounding experiments for the European Space Agency missions. These experiments are conducted within the framework of the Planetary Radio Interferometry and Doppler Experiment on board of the Jupiter Icy Moons Explorer (JUICE) mission, launched in April 2023.

Using the University of Tasmania's VLBI radio telescopes, we monitored the X-band radio downlink signals from Mars Express, Tianwen-1, BepiColombo, Solar Orbiter, and the JUICE missions throughout 2023. Particularly, Mars Express and BepiColombo experienced solar conjunction between October and December. During this campaign, we collected data on phase and frequency scintillation, and the spectral broadening of the carrier signals. Additionally, we observed the transit of a Coronal Mass Ejection across the radio propagation path while both spacecraft. At the time of observation, the angular separation between Mars and the Sun was approximately 4.5 degrees (9 solar radii).

These measurements are essential for characterising turbulent fluctuations in the solar wind at various solar elongations. Very Long Baseline Interferometry (VLBI) observations allow for the measurement of phase fluctuations over the baselines, enabling the inference of plasma parameters including bulk velocity and axial ratio.

In this presentation, we will discuss the results of the solar conjunction and CME transit observations, including their implications for CME structure. We will also present preliminary observations of JUICE and outline plans for this year's campaign.

**6. Larisza Krista** (University of Colorado/CIRES, NOAA/NCEI)
**Identifying Solar Flare Precursors in a Forest of EUV Signatures**

It is widely accepted that solar flares are powered by free magnetic energy built up in the corona. However, this energy alone might not be sufficient to initiate an eruption. Flare initiation and onset mechanisms are one of the most debated subjects in solar physics. A large-scale statistical study is crucial to investigate the evolution of flare precursors and their link to flare initiation. The Detection and EUV Flare Tracking (DEFT) tool can identify flare precursors in high temporal and spatial resolution extreme-ultraviolet (EUV) solar observations (e.g. SDO/AIA and GOES/SUVI). DEFT is a fast and robust tool that can identify and track the location, magnitude and change in EUV signatures from one observation to the next. Using a comprehensive differentiation technique, it can detect potential flare precursors in a vast number and variety of EUV signatures. In a study of over 1500 flares, we found that EUV signatures are consistently observable before B, C, M and X class flares. We hypothesize that the EUV flare precursors we observe are small-scale ongoing reconnection events produced by the increasing magnetic complexity in regions that later produce flares.

**7. Pierre-Simon Mangeard** (University of Delaware)
**The Neutron Monitor Network's Role in Space Weather Monitoring**
**Co-Author(s):** John Clem, University of Delaware; Paul Evenson, University of Delaware; James Ryan, University of New Hampshire; Surujdeo Seunarine, University of Wisconsin River Falls; Hazel Bain, CIRES/University of Colorado

The Neutron Monitor Network is integral in monitoring Ground-Level Enhancements (GLEs), sudden increases in cosmic ray intensity typically triggered by solar energetic particle events. These events pose significant challenges to space weather forecasting and infrastructure protection.

GLEs can have profound effects on infrastructure, particularly in space-based systems and technologies. High levels of cosmic ray flux during GLEs can disrupt satellite operations, leading to communication glitches, navigation errors, and even hardware damage. Furthermore, increased radiation exposure poses risks to astronauts during spacewalks or long-duration missions, necessitating careful planning and shielding measures.

On Earth, GLEs can affect aviation and power grids. Airlines may need to reroute flights to lower altitudes to minimize radiation exposure to passengers and crew.

The Neutron Monitor Network's role in detecting GLEs is critical for understanding and mitigating their impacts on infrastructure. By providing early warnings and data on cosmic ray flux enhancements, the network enables stakeholders to take proactive measures to safeguard space-based assets, ensure astronaut safety, and protect terrestrial systems from the disruptive effects of GLE-induced space weather events.

In this poster, we give an update on the American operating Simpson Neutron Monitor Network (SNMN). We present the real-time monitoring of the cosmic ray radiation by the SNMN. We present the current GLE alert system based on SNMN data. Finally, we discuss future upgrades to optimize the data products for space weather applications.

**8. Lisa Upton** (Southwest Research Institute)
**The COFFIES DRIVE Science Center: A United Quest to Unlock the Mysteries of the Sun's Solar Cycles**
**Co-Author(s):** J. Todd Hoeksema, Stanford University; The COFFIES Team

The solar cycle and its variability are Consequences of Fields and Flows in the Interior and Exterior of the Sun (COFFIES). The COFFIES DRIVE Science Center, funded by NASA's Heliophysics Division, is dedicated to unraveling how the Sun generates periodic magnetic cycles that cause space weather and influences the entire heliosphere. The initiative seeks to understand the drivers behind large-scale plasma motions, their interaction with magnetic fields to create solar activity cycles, the emergence of active regions, and how these solar processes can inform stellar studies. The COFFIES team is comprised of experts from 14 institutions, skilled in helioseismology, dynamo modeling, solar convection, and surface flow observations. Bringing together experts from these diverse fields, we unite to collaboratively tackle three major cross-cutting science themes: the Tachocline, the Near Surface Shear Layer, and Flux Transport and Emergence. By leveraging our varied expertise, COFFIES is primed for rapid advancement in these areas, with the ultimate goal of improving cycle forecasting capability by developing data-driven physical models of solar activity. The center is dedicated to enhancing science knowledge while also inspiring STEM students and sharing the thrill of solar physics with the wider community. COFFIES holds a strong commitment to Diversity, Equity, Inclusion, and Accessibility, creating a supportive atmosphere for collaboration between scientists, students, postdocs, and those at the early stages of their research careers. External collaborations are encouraged, with resources available to facilitate such partnerships. For more information about COFFIES and how to get involved, visit us at coffies.stanford.edu.

**9. Robert Leamon** (UMBC/NASA Goddard Space Flight Center Code 672)
**What activity levels may we expect for the rest of Cycle 25?**
**Co-Author:** Scott McIntosh, National Center for Atmospheric Research, Boulder, CO

We discuss How Solar Cycle 25 is going, and implications for both crewed and uncrewed spacecraft operations for the rest of the cycle.

The Leamon-McIntosh Terminator-based unit cycle prediction for the amplitude of Solar Cycle 25 is looking pretty good as of the time of writing, and certainly tracking better than the NOAA/NASA consensus panel forecast, with a peak which is both significantly lower and significantly later...

This is not meant to gloat, but rather to address a recurring theme of criticism against not just our model, but *any* cycle forecast, namely "they just got lucky this time," or "that's just one cycle; wait 11 years or so to be sure they're right."

Here, in an attempt to help shift that narrative, we argue that a fixation on solar max is a distraction. It is also a science communication issue, with many millions of dollars at stake for spacecraft operations, and lives on the line as the Artemis program returns to the moon *after* the peak of Cycle 25.

We also discuss how the Leamon-McIntosh Terminator-based prediction for the shape of Solar Cycle 25 is as least as important as the amplitude. There are real-world (economic) consequences for F10.7 (under)-prediction. In addition to landmark levels of activity, we attempt to show the quasi-annual surges of activity driven by Rossby-type waves in the solar interior may be predicted on the downslope of Solar Cycle 25.

**10. Irfan Azeem** (National Oceanic and Atmospheric Administration)
**Establishing Continuity of NOAA's Operational Space Weather Observations from the Sun-Earth Lagrange 1 Point**
**Co-Author(s):** Space Weather Next L1 Team

The Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act integrates national space weather activities. National Oceanic and Atmospheric Administration (NOAA) is implementing the PROSWIFT Act by fulfilling existing program responsibilities and data continuity requirements, as well as standing up new programs to advance critical operational space weather capabilities. The NOAA Office of Space Weather Observations (SWO) is developing the Space Weather Follow-On (SWFO) mission to Lagrange 1 (L1) point, planned for launch in 2025 as a rideshare. It will serve as NOAA's first space weather dedicated observatory, to succeed NOAA's Deep Space Climate Observatory. In parallel, SWO is embarking on implementing the Space Weather Next (SW Next) program that will provide continuity of space weather observations from L1 and Geosynchronous orbits, as well as other relevant orbits. The SW Next program developed its reference space architecture and concept for the collection of data to meet its observational requirements. The program is currently formulating the SW Next L1 Series project that will provide continuity of observations beyond SWFO. The project will consist of two observatories that are near-derivative of SWFO-L1. The first SW Next L1 Series mission (L1-A) is planned to be launched in 2028, and the second SW Next L1 Series mission (L1-B) in 2031. In this presentation, we will describe observational requirements from the L1 vantage point to support different space weather products and services. We will present the notional SW Next architecture and discuss the status SW Next L1-A observatory development.

**11. Thomas Eden** (University of Colorado, Laboratory for Atmospheric and Space Physics (CU/LASP))
**Solar-flare Induced Atmospheric Waves as Measured by the GOES-R Series EXIS EUVS-B Instrument**
**Co-Author(s):** Frank Eparvier, CU/LASP; Andrew Jones, CU/LASP; Bill McClintock, CU/LASP; Don Woodraska, CU/LASP; Janet Machol, NOAA National Center for Environmental Information

The Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) instrument onboard the GOES-R Series satellites is part of its solar-pointed payload. The EXIS instrument contains two full-disk instruments: The EUVS (Extreme Ultraviolet Sensor) and XRS (X-ray Sensor). Of particular interest, the EUVS contains a normal-incidence, interference filtered spectrograph, called EUVS-B. This instrument measures four individual emission lines between 115-141 nm. These emission lines are formed in the chromosphere and transition region. When a large eruptive solar-flare occurs, these emissions exhibit oscillations in response to the energetics of the flare. This poster will illustrate the analysis methodology used to derive these waves, and examine these waves for all Solar Cycle 25 X-class flare events.

**12. C. Nick Arge** (NASA/Goddard Space Flight Center)
**Measuring the Variation in Asymptotic Solar Wind Speed and Magnetic Field Strength Between Two WSA Implementations**
**Co-Author(s):** Shaela I. Jones, NASA Goddard Space Flight Center, Greenbelt, MD; Ronald M. Caplan Predictive Science Inc., San Diego, CA; Jon Linker, Predictive Science Inc., San Diego, CA; Carl J. Henney, Air Force Research Laboratory Kirtland AFB; Cooper Downs, Predictive Science Inc., San Diego, CA; Lisa Upton, Southwest Research Institute Boulder, Boulder, CO; Bibhuti Kumar Jha, Southwest Research Institute Boulder, Boulder, CO; James Turtle, Predictive Science Inc., San Diego, CA; Raphael Attie, NASA Goddard Space Flight Center, George Mason University, Greenbelt, MD; Tae K. Kim, University of Alabama in Huntsville, CSPAR, Huntsville, AL; Nikolai Pogorelov, University of Alabama in Huntsville, CSPAR, Huntsville, AL

The Wang-Sheeley-Arge (WSA) model is widely used within the heliophysics community. It can be used to determine the location of open flux regions on the photosphere, provide inner boundary conditions for heliospheric models, forecast solar wind speed and IMF polarity, and/or determine the coronal sources of solar wind observed in situ. Given its wide acceptance, fairly simple physics, and low computational cost, multiple versions of the model exist. Here we present the results of a detailed comparison between two such models: the CORona-HELiosphere (CORHEL) WSA implementation based on the POT3D numerical magnetic field solver, and the traditional WSA model code that makes use of spherical harmonics. While the two codes solve the same problem, multiple small differences exist in the implementations which we describe. To understand the impact of these small differences, we compare the asymptotic solar wind speeds and magnetic field at the outer boundaries of the two models, the separation between the footpoints of their magnetic field lines, and the locations of open flux at the photosphere. While the differences are usually quite small, there are some conditions where the WSA empirical equation for solar wind speed is quite sensitive and produce large differences in the asymptotic wind speed, or where small differences in the position of the magnetic neutral line result in dramatic differences in magnetic field footpoint locations. Finally, we compare the differences between these two models to the variability of the models themselves in the presence of small perturbations in the model parameters.

**13. Daniel Seaton** (Southwest Research Institute)
**QuickPUNCH: Observations for Space Weather Operations and Research**
**Co-Author(s):** Craig DeForest, Southwest Research Institute; Gabriel Dima, Cooperative Institute for Research in Environmental Sciences & NOAA NCEI; Marcus Hughes, Southwest Research Institute; Jeff Johnson, Cooperative Institute for Research in Environmental Sciences & NOAA SWPC; Sarah Kovac, Southwest Research Institute; Chris Lowder, Southwest Research Institute; Ritesh Patel, Southwest Research Institute; Jillian Redfern, Southwest Research Institute; Nai-Yu Wang, NOAA NESDIS Office of Space Weather Observations; Matthew West, Southwest Research Institute

PUNCH is a coronagraphic and heliospheric imaging NASA Small Explorer composed of four spacecraft: three Wide Field Imagers (WFI) and one Near Field Imager (NFI), which generates polarization-resolved observations of the corona and heliosphere between 5.5–180 solar radii. In addition to its science mission, PUNCH makes low-latency observations of the corona and heliosphere that can support space weather forecasting operations: the QuickPUNCH project, whose initial goal is to develop and demonstrate the required data products, pipeline, and low-latency capabilities.

We describe the space weather applications for QuickPUNCH observations, including tracking coronal mass ejections (CMEs) and solar wind outflow. We discuss the specific low-latency QuickPUNCH data products for space weather, PUNCH's more general science products, and end-user data access. We provide an overview of research-to-operations opportunities provided by these data, including the uses of polarized coronal measurements for space weather, tracing of CMEs in 3D, and the use of PUNCH data as a constraint for numerical forecasting models. We conclude with a look at potential synergistic opportunities between PUNCH and planned and proposed operational space weather missions such as NOAA's Space Weather Follow-On mission, the European Vigil mission to the L5 Lagrange point, and ground-based observations from observatories such as the COronal Solar Magnetism Observatory (COSMO).

**14. Yuta Kato** (Fujitsu Limited)
**Predicting Solar Energetic Particle Event Occurrences Using Explainable AI**
**Co-Author(s):** Kanya Kusano, Nagoya University; Chihiro Mitsuda, Fujitsu Limited; Yasuhide Ishihara, Fujitsu Limited

Solar Energetic Particle (SEP) Events, which occur in conjunction with solar flares (SFs) and coronal mass ejections (CMEs), have effects on both humans and space systems.

We conduct a classification task using Wide Learning, an explainable AI developed by Fujitsu, to explore the conditions of SFs with/without SEP Events. Wide Learning which is based on emerging pattern mining algorithms was originally developed in the field of Discovery Science, enables us to conduct classification tasks with exhaustive conditions.

We created 57 features from GOES and SDO satellites data and the physics-based three-dimensional extrapolated magnetic fields developed by Kusano et al. (2020). We classified SFs that meet > 10 MeV, > 10 pfu in the NOAA SWPC database during Solar Cycle 24 as positive samples, and all other SFs as negative samples. Due to the class imbalance, we fixed the positive flares and under-sampled the negative flares to achieve a 1:3 ratio for each Flare class.

We conducted 100 trials with random replacements and our model demonstrates a True Skill Statistic (TSS) approximately about 0.4. For positive flares, we identified multiple useful conditions with numerical ranges which consist of the longitude, duration time, and history of SFs. These results suggest the potential for predicting SEP Event occurrences with real-time step-by-step alerts, and the ability to reference past cases that align with identified conditions. We also discuss the potential for SEP event forecasting using these conditions and future prospects.

**15. Robert Redmon** (NOAA National Center for Environmental Information (NCEI) and NOAA Center for Artificial Intelligence (NCAI - noaa.gov/ai))
**NOAA National Centers for Environmental Information (NCEI) - Space Weather Follow On (SWFO) Science Center Activities**
**Co-Author(s):** Brian Kress, NOAA/NCEI and University of Colorado - Cooperative Institute for Research in Environmental Sciences (CU/CIRES); Paul Loto'aniu, NOAA/NCEI and CU/CIRES; Nazila Merati, NOAA/NCEI; Alessandra Pacini, NOAA/NCEI; Laurel Rachmeler, NOAA/NCEI; Josh Riley, NOAA/NCEI and CU/CIRES; Juan Rodriguez, NOAA/NCEI and CU/CIRES; William Rowland, NOAA/NCEI; Donald Schmit, NOAA/NCEI and CU/CIRES

We present an overview and current status of the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI) activities for the Space Weather Follow On (SWFO) Program and discuss the importance of SWFO's data products for the Heliophysics community. SWFO Program will ensure continuity of space weather operational data in the solar wind, providing advanced heliospheric observing capabilities from the Lagrange Point L1 and geostationary orbit. The SWFO-L1 spacecraft will be launched in 2025, hosting a Solar Wind Plasma Sensor (SWiPS), a Magnetometer (MAG), a SupraThermal Ion Sensor (STIS) and a Compact Coronagraph (CCOR-2), enabling continuity of Coronal Mass Ejection and solar wind observations from NOAA's Deep Space Climate Observatory (DSCOVR), NASA's Advanced Composition Explorer (ACE) and NASA-ESA Solar and Heliospheric Observatory (SOHO) which are well past their designed lifetime. An additional coronagraph (CCOR-1) will fly on the next Geostationary Operational Environmental Satellite to be launched in 2024 (GOES-U) and will add operational resilience to the CME imagery necessary for space weather monitoring and forecasts. NCEI's primary roles include leading the calibration working group to help ensure performance of the operational products produced by NOAA's Space Weather Prediction Center (SWPC), as well as optimal scientific data stewardship and advanced data services for the research community, through the NCEI SWFO Science Center in development.

**16. Rob Ebert** (Southwest Research Institute/The University of Texas at San Antonio)
**The Solar Wind Plasma Sensor for the SWFO-L1 Mission: Flight Model Performance**
**Co-Author(s):** Prachet Mokashi, Southwest Research Institute; Heather Elliott, Southwest Research Institute/The University of Texas at San Antonio; C. Elder, Southwest Research Institute; S. Escobedo, Southwest Research Institute; M. Fortenberry, Southwest Research Institute; R. Gomez, Southwest Research Institute; G. Grubbs, Southwest Research Institute; K. Llera, Southwest Research Institute; K. Persson, Southwest Research Institute; R. Perryman, Southwest Research Institute; P. Valek, Southwest Research Institute; J. Carey, ASRC Federal Holdings Corporation; G. Comeyne, NOAA/NESDIS/OPPA; D. Vassiliadis, NOAA/NESDIS/OPPA

The Solar Wind Plasma Sensor (SWiPS) is an instrument on the upcoming joint NOAA/NASA Space Weather Follow On-Lagrange 1 (SWFO-L1) mission. The SWFO-L1 mission objectives are to establish operational capability and continuity of space weather observational requirements and enable space weather watches, warnings, forecasts, and predictions from the Sun-Earth Lagrange 1 point over a 5-year period starting in 2025. The SWiPS sensor design contains two sensors capable of measuring ions from ~0.17 – 32 keV/q to provide solar wind velocity measurements up to 2500 km/s during potential extreme space weather events. SWiPS data products include solar wind ion velocity, temperature, density and dynamic pressure. These are provided in near real-time to NOAA’s Space Weather Prediction Center and used to characterize Space Weather causing events such as CMEs, interplanetary shocks, corotating interaction regions, and high-speed flows associated with coronal holes. In this presentation, we describe the SWiPS flight model performance through environmental testing and final ion beam calibration.

**17. Bernard Jackson** (University of California, San Diego (UCSD), La Jolla, CA - Department of Astronomy and Astrophysics)
**All Sky Heliospheric Imager (ASHI) NASA Balloon Flight Image Data Analysis**
**Co-Author(s):** Matthew Bracamontes, UCSD - Department of Astronomy and Astrophysics, San Diego, La Jolla, CA; Benjamin Pieczynski, UCSD - Department of Astronomy and Astrophysics, San Diego, La Jolla, CA; Paul Hick, UCSD - Department of Astronomy and Astrophysics, San Diego, La Jolla, CA; Andrew Buffington, UCSD - Department of Astronomy and Astrophysics, San Diego, La Jolla, CA; Stuart Volkow, UCSD - Department of Astronomy and Astrophysics, San Diego, La Jolla, CA; Stephen White, Air Force Research Laboratory, Kirtland AFB, NM; Mario M. Bisi, United Kingdom Research and Innovation – Science & Technology Facilities Council - Rutherford Appleton Laboratory, RAL Space, Harwell Campus, Oxfordshire, United Kingdom; Ed Stephan, Stephan Design-Build, Haslet, TX; Philippe Leblanc, Stephan Design-Build, Haslet, TX; Ron Quillin, Stephan Design-Build, Haslet, TX

The All-Sky Heliospheric Imager (ASHI) instrument's unique optical system views a hemisphere of sky starting a few degrees from the Sun out to 180 degrees from this. ASHI is a simple, light weight (~6kg), and relatively inexpensive spacecraft instrument. This has the principal objective of providing a minute-by-minute and day-by-day near real time acquisition of precision Thomson-scattering photometric maps of the inner heliosphere. The instrument is designed to 3-D reconstruct the heliospheric solar wind that extends outward from the Sun and passes 1.0 AU. ASHI was tested in summer 2022 on a NASA-sponsored topside balloon flight; this presentation highlights the images taken and our data reduction from this instrument’s successful overnight flight. This data reduction includes stellar identification and instrument pointing, and subsequently, the removal of atmospheric glows, starlight, and

zodiacal light. This process produces hemispheric images to a brightness level a factor of 10 lower than heliospheric electron Thomson-scattering about 45 degrees from the Sun-Earth line and beyond. As has never before been possible, the ASHI balloon analysis provides a characterization of the imaged background heliospheric solar wind structures from a few degrees to over 20 degrees in size as they pass the Earth.

**18. George Millward** (University of Colorado - Cooperative Institute for Research in Environmental Sciences, (CU/CIRES), Boulder, CO and NOAA Space Weather Prediction Center (SWPC))
**PyCAT: A Next-Generation development of the Space Weather Prediction Center CME Analysis Tool (SWPC_CAT)**
**Co-Author(s):** Mark Miesch, CU/CIRES, Boulder and NOAA/SWPC; Manasi Gopala, NOAA/SWPC Charlotte Martinkus, CU/CIRES, Boulder and NOAA/SWPC; Anders Englyst, UK Met Office; Mike Marsh, UK Met Office; Francois-Xavier Bocquet, UK Met Office

The first operational numerical model to leverage high-performance computing (HPC) resources at NOAA's Space Weather Prediction Center (SWPC) was WSA-Enlil, a three-dimensional, time dependent, MHD model of the Heliosphere. WSA-Enlil, in operations at SWPC since 2011, provides a 5 day forecast of solar wind conditions at Earth. A critical issue for this forecast is the estimation (and subsequent input into the model) of any Coronal Mass Ejections (CMEs) in terms of their size/width, direction of propagation, and speed. After much trial and tribulation, an IDL-based software tool, the CME Analysis Tool (SWPC_CAT) was developed which calculates these parameters by utilizing concurrent coronagraph images from SOHO (LASCO C2/C3) and STEREO (COR-2). The CAT tool has proved very successful as a critical part of the WSA-Enlil system and is a daily aspect of SWPC forecasters' predictions for the incoming solar wind at Earth, particularly Geomagnetic storms. Fast-forward to 2023/24 and there is a need to modernize CAT by leveraging state-of-the-art web-based software technologies. The new model, PyCAT, under development as a collaboration between SWPC and the UkMet Office, features an interactive browser-based front-end, a Python back-end and an event database managed by MongoDB. After initial development and deployment, we plan to make PyCAT, not only a full replacement for the existing CAT tool, but also to be available as an open-source application to promote Research to Operations and Operations to Research (R2O2R). In this vein, we describe the motivation, design, and expected use of pyCAT and encourage the community to participate as users and potentially contributors. The goal is a modern, containerized, user-friendly, extensible application for modeling CME events that can be progressively improved to leverage future advances in multi-perspective observing platforms and numerical modeling. To that end, whilst continuing to work with existing coronagraph images from SOHO and STEREO-A, PyCAT will also support the new generation of operational coronagraphs, notably CCOR-1 on the upcoming GOES-U satellite, CCOR-2 on SWFO-L1, coronagraphs on the PUNCH mission and CCOR-3 to be flown to the L5 point on the VIGIL satellite.

**19. Matthew West** (Southwest Research Institute)
**Overcoming the Front-Back Polarization Ambiguity by Tracking CMEs in 3D Over Time**
**Co-Author(s):** James Marcus Hughes, Southwest Research Institute Boulder; Daniel B Seaton, Southwest Research Institute; Sarah E Gibson, National Center for Atmospheric Research; Craig DeForest, Southwest Research Institute; Ritesh Patel, Southwest Research Institute; Elena Provornikova, Johns Hopkins APL

The Polarimeter to UNify the Corona and Heliosphere (PUNCH) mission will explore the largely unexplored region of the heliosphere from the middle corona out to 1 AU: i.e., the "young solar wind", through direct, global, spatially continuous, and 3D deep-field imaging. This is achieved through Brightness (B) and polarized brightness (pB) measurements, which is analogous to the Stokes system in solar observing coordinates. PUNCH will be able to study the propagation of coronal mass ejections

(CMEs) throughout the heliosphere, and in particular the chirality of CMEs, which can be determined directly from physics of Thomson scattering applied to synoptic polarized images.

In this presentation the Velocity And POsition Reconstruction (VAPOR) tool is presented, which is capable of using polarization measurements from PUNCH (and any analogous data sets: STEREO, LASCO, kCOR, etc) to derive the 3D structure of imaged objects in the heliosphere.

To demonstrate VAPORs capabilities both STEREO observations, and ”Clean" synthetic data generated from the Gamera model, forward modeled using the HAO FORWARD algorithm, are used to determine the position of observed and synthetic CMEs. Emphasis is given to the determination of the front-back ambiguity about the Thomson surface.

**20. Nguyen, Ryan** (Orion Space Solutions)
**Exploring the Re-Creation of the McIntosh Archive with Deep Learning**
**Co-Author(s):** Jack Ziegler, Orion Space Solutions; Ryan Kelly, Orion Space Solutions; Ian Hewins, Orion Space Solutions; David Webb, Boston College; Michael Kirk, NASA Goddard Space Flight Center; Geoff Crowley, Orion Space Solutions /Arcfield

The McIntosh Archive stands as a remarkable collection of hand-drawn solar Carrington maps meticulously crafted by Patrick McIntosh spanning from 1964 to 2009. McIntosh ingeniously amalgamated data from H-alpha, He-II 10830 Å, and photospheric magnetic measurements obtained from ground-based observatories and NASA satellites to create maps of the evolution of solar features during four solar cycles. In response to the gap left by the passing of Patrick McIntosh and the discontinuation of his solar Carrington maps, we have employed Machine Learning methods to replicate his map generation process. We discuss the utilization of Supervised Learning through a variational autoencoder (VAE), Unsupervised Learning via K-means clustering, and a novel Reinforcement Learning (RL) approach. Excitingly, the Supervised Learning model developed for Coronal Hole identification exceeded our performance expectations when validated against hand-drawn maps created by trained cartographers. It appears to yield results that are as good or better than previous machine learning approaches.

We have also used the same Supervised Learning approach to identify the PILs, filaments, and sunspots with the remaining two out of three solar image types, and obtained similar high quality results. The Supervised Learning approach is important because it could increase the speed at which Carrington Rotation maps can be generated, yet with minimal sacrifice in performance. This may mean they could be generated in real-time for use in Space Weather operations.

Results from a Reinforcement Learning approach will also be discussed, together with a concept for the fusion of both methods (Supervised Learning and Reinforcement Learning).

**21. Kartik Chaurasiya** (Georgia State University)
**A Statistical Anomaly Detection Algorithm for GONG’s H-Alpha Observations**
**Co-Author(s):** Rohan Adhyapak, Georgia State University; Eugene Kang, Harrison High School; Aparna V, Bay Area Environmental Research Institute; Azim Ahmadzadeh, University of Missouri-St. Louis

The Global Oscillation Network Group (GONG) comprises a network of six telescopes positioned around the globe. Collectively, these telescopes achieve an average duty cycle of 93%, with a cadence of 30 seconds. Despite the overall high quality of the images, a small fraction exhibit corruption due to various degrees and types of noise. Although this fraction is minimal, their unforeseen presence, and the fact that they may occur in consecutive batches, can significantly disrupt research and operational efforts. This issue is especially critical for automated tasks processing a continuous stream of image data captured by GONG, where even minor anomalies can lead to substantial inaccuracies. Currently, to the best of our

knowledge, the community lacks a known algorithm that can reliably identify and exclude these anomalous observations. In this study, we empirically identify anomalies in H-Alpha observations of the Sun and design a statistical algorithm to detect images exhibiting these anomalies. While our primary emphasis is on the interpretability and efficiency of the anomaly detection algorithm, we assess its performance relative to more resource-demanding approaches, specifically auto-encoders. Recently, auto-encoders have demonstrated considerable success in general-purpose anomaly detection tasks. So, our comparison aims to balance the algorithm's lightness (in terms of the number of parameters) and interpretability (in terms of justifying the detections). We show that taking advantage of the low variance in macroscopic scale and high-variance in microscopic scale of the observations, an optimized region-based statistical model can reliably identify regional anomalies.

**22. Espen Fredrick** (University of Texas at Arlington)
**Examining the Accuracy of The OMNI Data in Representing ICME Observations Near Earth and the Effect on Global Modeling**
**Co-Author:** Ramon Lopez, University of Texas at Arlington

Global models of the geospace environment, including those used in the prediction of space weather phenomena, rely on a set of upstream solar wind conditions outside the bow shock to drive the model. Generally, these data are provided by the OMNI dataset, a set of observations of the solar wind typically collected near the L1 Lagrange point and ballistically propagated to Earth's bow shock nose. The actual solar wind conditions outside the bow shock may differ from the OMNI data, leading to erroneous model inputs. Erroneous model inputs will lead to erroneous model outputs, hence erroneous predictions of space weather phenomena. Interplanetary Coronal Mass Ejections (ICMEs) are the drivers of the strongest magnetic storms. In this case study, we examine the accuracy of the OMNI data in representing ICMEs near Earth. This presentation will include examples of global magnetosphere simulations driven with the OMNI data and data near Earth to illustrate potential uncertainties in global simulation output during ICME events.

**23. Berhe Tewelde Teklhaimanot** (University of Vale do Paraíba)
**Analyzing Magnetic Reconnection Exhausts in the Solar Wind Heliospheric Current Sheet**
**Co-Author:** Arian Ojeda-González, University of Vale do Paraíba

Magnetic reconnection stands as a fundamental occurrence in space and laboratory plasmas in which magnetic energy is converted into kinetic energy, released in the form of accelerated particles, flows, and heating. Although the process itself is highly localized, it eventually leads to a global change in the magnetic field topology. In this paper, we present the investigation of solar wind reconnection exhausts with an anti-sunward orientation by employing in-situ measurements from multiple spacecraft. Through a statistical analysis of reconnection exhausts, we ascertain their average properties and reveal that the plasma density and temperature of the reconnection exhaust are influenced by the plasma beta and reconnection guide field. By comparing measurements across multiple spacecraft for different distinct events, we observe changes in the structure of the reconnection current sheet with increasing distance downstream from the reconnection site. Furthermore, variations in measurements of solar wind exhausts between different events are notable, and we attribute much of this variability to differing inflow region conditions and the magnetic shear across the current sheet. In this talk, I will review this narrative in detail and point to the detection and analysis of halo electrons, considered distinctive markers of magnetic reconnection events, the energy spectra and distributions of the tilt angles of these particles, and the importance of simultaneous IMF analysis to gain insights into its role in characterizing the solar wind.

**24. Matthew Lennard** (Department of Automatic Controls and Systems Engineering, The University of Sheffield, UK)
**Understanding Plasma Flows in Solar Active Regions: A Neural Network Based Method for the Recovery and Analysis of Coherent Plasma Structures in Magnetically Dominated Environments**
**Co-Author(s):** Suzana de Souza e Almeida Silva, Department of Automatic Controls and Systems Engineering, The University of Sheffield, UK; Benoit Tremblay, High Altitude Observatory/University Corporation for Atmospheric Research, USA; Andrés Asensio Ramos, Instituto de Astrofísica de Canarias, Spain; Hideyuki Hotta, Institute for Space-Earth Environmental Research, Nagoya University, Furocho, Chikusa-ku, Nagoya, Aichi 464-0814 Japan; Haruhisa Iijima, Institute for Space-Earth Environmental Research, Nagoya University, Furocho, Chikusa-ku, Nagoya, Aichi 464-0814 Japan; Sung-Hong Park, Korea Astronomy and Space Science Institute, Republic of Korea; Gary Verth, School of Mathematics and Statistic, The University of Sheffield, UK; Viktor Fedun, Department of Automatic Controls and Systems Engineering, The University of Sheffield, UK

High-energy solar events such as solar flares (SFs) and coronal mass ejections (CMEs) are the result of the build up of strong magnetic fields in active regions (ARs). Identifying plasma flows in ARs and understanding their structure and evolution are still challenging. Recently, a number of realistic simulations of sunspots have appeared, in particular, the R2D2 code has been used to simulate the evolution of a flux tube in its entirety in a box covering the whole convective region (see Hotta and Iijima 2020). What remains is the assimilation of data in models to support our understanding of observed transient solar phenomena.

In this work we train the neural network (NN) DeepVel (DV, see Asensio Ramos 2017) on R2D2 simulation data to reconstruct subgranular transverse flows in photospheric ARs. We then present a method for analysing these detailed DV estimated flows by seeking coherent structures in the flow by identifying flow barriers defined to be the most repelling and attracting structures in the flow, described by the finite-time Lyapunov exponent (FTLE, see e.g., Haller 2014).

We have found that DV is able to estimate transverse flows on length scales <1Mm. Flow structures surrounding pores have been found to be consistent with Evershed flows that have been identified in observations and that coherent structures, defined by FTLE ridges may be used to identify flows that are indicative of the presence of an AR emerging.

**25. Gabriella Araujo** (University of Florida)
**Exploring Small Satellite Resilience: Material Testing Against Solar Energetic Particles**
**Co-Author:** Alicia Petersen, University of Florida

Space weather is defined as anything that can influence the performance and reliability of space-borne and ground-based technological systems from conditions on the Sun, magnetosphere, ionosphere, and thermosphere. Solar-energetic particles (SEPs) are high energy charged particles, protons and electrons, that originate from the sun. Currently, as single-event upsets, and or anomalies occur, the main focus is generally on the next necessary steps that should be taken to immediately address the issue and try to get operations back up and running. A better understanding as to why that upset occurred and preventative and predictive measures that could have been placed can result in higher success rates as well as minimal damage with ongoing particle interactions. It is currently an area within the space weather and aerospace engineering community that is not as well studied but having a better understanding of it can be crucial to future mission success. The goal of this research is to study the physical impacts of space weather, specifically with solar energetic particles (SEPs) on different materials common in small satellites to better understand what results from these interactions and how we can help minimize the impacts using different materials. Most small satellites are not designed to last and their materials have not been as well tested. Further testing would allow for satellites to be able to be designed to last longer and withstand

more conditions in the space environment. In regards to material testing against space weather, very general conditions have been looked at. Testing specifically against SEP protons in a plasma chamber would allow for more accurate data with regards to a very specific scenario to allow us to better understand the impact this event truly has on different materials. The initial goal is to determine factors such as what region of space we might want to look at, the conditions in those regions, relevant fluxes and energies of SEP ground-level enhancement (GLE) events in low earth orbit (LEO), and the materials used in small satellites. This research is currently ongoing and initial results will be presented.

**26. Aniket Jivani** (University of Michigan)
**Towards Predictive Uncertainty Quantification in Space Weather Simulations Through Surrogate Models for Dynamical Systems**
**Co-Author(s):** Hongfan Chen, University of Michigan; Nishtha Sachdeva, University of Michigan Zhenguang Huang, University of Michigan; Xun Huan, University of Michigan; Bart van der Holst, University of Michigan; Ward Manchester, University of Michigan; Shasha Zou, University of Michigan; Gabor Toth, University of Michigan

Uncertainty Quantification (UQ) is critical in the Space Weather domain, where predictive models are built from first principles e.g. the Space Weather Modeling Framework (SWMF) to simulate phenomena such as CMEs (coronal mass ejections) and forecast their arrival time and geomagnetic impact accurately. Given the high cost of simulating Sun-to-Earth propagation of CMEs for a new event, we usually perform only a limited number of simulations based on varying flux rope parameters that describe the strength and shape of the CME. In this setting, surrogate models or emulators for approximating the true dynamics are valuable tools to provide improved extrapolation of the training data at arbitrary timesteps. These have the potential to accelerate forward UQ to propagate uncertainty from the free parameters to the QoIs and other downstream inference tasks.. Here, we compare the performance of different emulators, including parametrized Neural Ordinary Differential Equations (NODEs). These are constructed using data from synthetic white light images generated in the SWMF. The final surrogate model can be useful for generating the evolution of the leading edge based on unseen initial conditions and also supply predictive uncertainties on the test simulations.

**28. David Galarza** (University of Florida)
**HelioSTET: Modeling Suprathermal Electron Transport in the Heliospheric Magnetic Field**
**Co-Author(s):** Alicia Petersen, University of Florida; Nicholas Furioso, University of Florida; Luke Morris, University of Florida; James Fairbanks, University of Florida

Heliophysics is deeply rooted in the heliospheric magnetic field (HMF) complexities. The HMF interacts with charged particles and, in large part, is responsible for the dynamics that go into simulating their transit through the heliosphere. Heliophysics is studied to further understand the laws governing the Sun and Earth. Modeling suprathermal electron transport through the solar wind and HMF will build upon research done that mapped suprathermal electron transport (STET) within the Earth's magnetosphere. The proposed research extends beyond this and works by building upon an adaptation of STET called Heliospheric STET (HelioSTET), which models transport under different parameters. This model specializes in analyzing pitch angle scattering and could potentially measure and model electron strahl due to forces induced by the HMF. The current model needs to be developed to expand its capabilities in executing the goal of a complete HMF model. This will be accomplished by implementing two new frameworks. The first is Fluxon, a 3-D time-dependent MHD simulation that renders magnetic field lines based on topology fitting. The second framework is DECAPODES, a discrete exterior calculus differential equation evaluator that simultaneously allows building a visual interface to facilitate variable relationships and operators. DECAPODES will be added to HelioSTET to apply the kinetic equation and significantly boost computational efficiency. With the proposed model development, HelioSTET could offer insight into the connection between the Sun and Earth, and strengthen our understanding of its complex dynamics.

**29. Harshita Gandhi** (Aberystwyth University)
**Deep Learning-Based Analysis of Near-Real-time Single-Viewpoint Coronagraph Images Using Neural Networks**
**Co-Author(s):** Cory Thomas, Aberystwyth University; Huw Morgan, Aberystwyth University

This study tackles the significant challenge of space weather forecasting by detecting Coronal Mass Ejections (CMEs), critical solar events with profound impacts on Earth's technological infrastructure. We introduce a deep learning framework to identify CMEs in C2 and C3 coronagraph imagery efficiently. Our methodology is structured into three phases: dataset compilation, model training, and performance evaluation. Initially, we utilized web scraping to compile an 11-year dataset of C2 images from Solar Cycle 23, tailored for deep learning analysis. We then assessed the performance of three state-of-the-art convolutional neural network (CNN) models to determine the most effective approach for CME detection. This evaluation led to a detailed comparison of the models, highlighting the challenges and limitations inherent in dataset curation and the training process. Our findings culminate in developing an automated pipeline for detecting CMEs, employing CNN models to streamline the process and enhance space weather forecasting accuracy.

**30. Dimitrios Vassiliadis** (NOAA National Environmental Satellite, Data, and Information Service (NESDIS) - Space Weather Office (SWO))
**NOAA's SWFO Program Launching in 2024: Science Objectives and Data Products**
**Co-Author(s):** Matthew Argall; John Carey; Gus Comeyne; Matthew Devaney; Rob Ebert; Heather Elliott; Steven Hill; Michael Honaker; Jacob Inskeep; Jeff Johnson; Brian Kress; Natsuha Kuroda; Davin Larson; Paul Loto'aniu; Nazila Merati; Cynthia Merrow; Alessandra Pacini; Christopher Pagan; Laurel Rachmeler; Ali Rahmati; Robert Redmon; Juan Rodriguez; William Rowland; Donald Schmit; Charles Smith; Errol J. Summerlin; and Roy Torbert

NOAA's Space Weather Follow On (SWFO) program will provide coronal and heliospheric measurements to replace those of ACE, DSCOVR, and SOHO. In 2024, SWFO's Compact Coronagraph-1 (CCOR-1) will be launched onboard the GOES-U geostationary satellite. In 2025, CCOR-2 and three state-of-the-art in situ instruments will start operating at the Lagrange 1 point on the SWFO-L1 observatory.

Level 0-3 data products are developed collaboratively by instrument developers, NCEI, and SWPC. NCEI is implementing Archive and Access (A&A) functions at the NOAA Common Cloud Framework (NCCF). Product distribution is implemented in the SWFO Science Center featuring rich metadata and a web dashboard with interactive search and plotting capabilities. Also, SWFO is developing user readiness in meetings like this workshop (see presentations on user readiness for NOAA Program of Record 2025 missions given on April 15 in this workshop).

For solar/heliospheric science, SWFO will enable progress in several areas: coronal imagery will be used to track the propagation of transient structures, and their time evolution will be used in modeling the energy pathways between corona and L1. Other topics include CME acceleration in the middle and outer corona, CME precursors, and the relations to solar flares and SEP events. Measurements of plasma moments, the IMF, and suprathermal spectra will have several uses including solar wind characterization and modeling, and application of AI/ML methods. Time series data will be used in validating heliospheric models and driving magnetospheric and ionospheric models. Progress in these areas is expected to contribute to the Research to Operations (R2O) pipeline.

**31. Heather Elliott** (Southwest Research Institute)
**Statistical Relationships Between Solar Wind Parameters: Implications for Space Weather Forecasts**
**Co-Author(s):** C. Nickolos Arge, NASA Goddard Space Flight Center, Greenbelt, MD; Carl. J. Henney; Air Force Research Laboratory, AFB, NM; Maher A. Dayeh; Southwest Research Institute, San Antonio, TX; Joerg-Micha Jahn; Southwest Research Institute, San Antonio, TX; Craig E. DeForest; Southwest Research Institute, Boulder, CO

The solar wind density, temperature, and the interplanetary magnetic field strength all correlate well with the solar wind speed. By combining these relationships Wang-Sheeley-Arge (WSA) corrected speed forecasts, we can produce multi-day forecasts of the solar wind density, temperature, and interplanetary field strength, and the Kp geophysical index. First, we quantify how well these relationships can work using solar wind speed observations from near Earth in the OMNI data. This establishes a baseline for developing a skill score since the measured upstream Earth are the most accurate estimate of the solar wind speed that encounters Earth. Then, we determine how well the relationships perform at forecasting density, temperature, field strength and Kp index when using multi-day WSA speed forecast relative to when using the measured speeds.

**32. Michael Cook** (MITRE)
**Assessment of Vulnerability of U.S. National Airspace System to Space Weather**
**Co-Author(s):** William Bauman, MITRE; Matt Fronzak, MITRE; Michael Robinson, MITRE; David Strand, MITRE; Samantha Carlson, Federal Aviation Administration

Space Weather can negatively impact civil aviation's ability to navigate, communicate, and protect people and systems from radiation. Geomagnetic storms can create ionospheric disturbances causing inaccurate Global Positioning System (GPS)/Global Navigation Satellite System (GNSS) positioning of aircraft within the National Airspace System (NAS). These inaccuracies can affect commercial aircraft precision landing as well as high fidelity navigation of Unmanned Aircraft Systems (UAS) at all altitudes. A digitally-based, highly connected and distributed Info-Centric NAS (ICN), more reliant on space-based assets to operate, could be vulnerable to disruptions caused by solar storms. Radio blackouts caused by Solar Flares can block radio communications at multiple frequencies, thereby limiting frequencies available to aircraft for Air Traffic Control and Aeronautical Operational Control communication. These same energetic protons can penetrate deep into objects they collide with causing damage to biological DNA or electronic circuits putting people and avionics in high flying aircraft at risk to radiation exposure. Several models that assess and predict Solar Energetic Particle (SEP) event onset, duration, and severity may be utilized to improve aviation safety and efficiency during solar radiation events.

This paper will share assessment results summarizing potential NAS vulnerabilities to space weather, as currently operated and as it advances towards ICN, supporting more diverse and potentially susceptible commercial space, UAS, and Advanced Air Mobility (AAM) operations. This assessment will include investigations into potential vulnerabilities of precision operations reliant upon GPS/GNSS, of radiation effects on biologics and avionics in commercial flights, supersonic aircraft operations, and space tourism, and FAA and stakeholder decision-making preparedness and available space weather information that may be needed to mitigate civil aviation and aerospace operational impacts. It will also highlight what SEP models perform well with regards to important aviation parameters and where the models still need improvement.

**33. Alex Hands** (TRIUMF, Vancouver, BC, Canada)
**System-level Avionics Testing for Extreme Space Weather Conditions**
**Co-Author(s):** Camille Bélanger-Champagne, TRIUMF; Michael Trinczek, TRIUMF; Ewart Blackmore, TRIUMF

A subset of space weather events known as ground level enhancement (GLE) events can lead to very large enhancements in the atmospheric radiation environment experienced by commercial aircraft. GLEs occur when solar energetic particle (SEP) events have sufficient intensity in the high energy proton spectrum to cause spallation reactions with molecules in the upper atmosphere, leading to high energy neutron cascades all the way to ground level. In extreme cases, neutron fluxes may increase by several orders of magnitude at aircraft altitudes, leading to equivalent increases in single event effect (SEE) rates in aircraft electronics (avionics). Such events cannot be predicted, shielded against or circumvented, therefore the best option for building resilience to their effects is through testing via recreation of the enhanced neutron environment. Although such testing is routine to account for SEE caused by background galactic cosmic rays (GCR), there is currently no regulatory requirement for manufacturers to demonstrate survivability in GLE environments.

Canada's TRIUMF laboratory has proton and neutron accelerated test facilities for studying SEE and other radiation effects in spacecraft and aircraft electronics. These are being developed for the specific purpose of enabling the study of SEE in avionics during extreme GLEs. Avionics equipment manufacturers will be able to perform system-level tests in a realistic atmospheric neutron spectrum over a wide flux range covering small 1-in-10-year GLEs through to the most extreme 1-in-10,000-year GLEs. This capability will help the aviation industry develop resilience to the most extreme space weather events.

**34. Kai Schennetten** (Institute of Aerospace Medicine, German Aerospace Center (DLR))
**Does the South Atlantic Anomaly Affect Radiation Exposure at Flight Altitudes?**
**Co-Author(s):** Matthias M. Meier, Institute of Aerospace Medicine, German Aerospace Center (DLR); Thomas Berger, Institute of Aerospace Medicine, German Aerospace Center (DLR); Thomas Jahn, Lufthansa German Airlines; Daniel Matthiä, Institute of Aerospace Medicine, German Aerospace Center (DLR); Mona C. Plettenberg, Institute of Aerospace Medicine, German Aerospace Center (DLR); Markus Scheibinger, Lufthansa German Airlines; Michael Wirtz, Institute of Aerospace Medicine, German Aerospace Center (DLR)

The South Atlantic Anomaly (SAA) is a geographical region over the South Atlantic Ocean where the inner Van Allen radiation belt extends down particularly close to Earth. This leads to highly increased levels of ionizing radiation and related impacts on spacecraft in Low Earth Orbits, e.g., correspondingly increased radiation exposure of astronauts and electronic components on the International Space Station. According to an urban legend, the SAA is also supposed to affect the radiation field in the atmosphere even down to the altitudes of civil aviation. In order to identify and quantify any additional contributions to the omnipresent radiation exposure due to the Galactic Cosmic Radiation at flight altitudes, comprehensive measurements were performed crossing the geographical region of the SAA at an altitude of 13 km in a unique flight mission—Atlantic Kiss.

**35. W. Kent Tobiska** (Space Environment Technologies)
**Mud to Moon radiation monitoring – Automated Radiation Measurements for Aerospace Safety (ARMAS) n Aircraft, the Aeronautical Regional Geospatial Observer System (ARGOS), the ISS, and IM-2 Lunar Lander**
**Co-Author(s):** Justin Bailey, Space Environment Technologies; Leonid Didkovsky, Space Environment Technologies; Seth Wieman, Space Environment Technologies; Kevin Judge, Space Environment Technologies; Ben Hogan, Space Environment Technologies; Brad Gersey, Space Environment Technologies; Gary Baum, Space Environment Technologies; Greg Glenn, Space Environment Technologies; James Hall-Prior, Space Environment Technologies; Benjamin Sullivan-Douglass, Space Environment Technologies; Dave Bouwer, Space Environment Technologies; Kaiya Wahl, Space Environment Technologies; Kai Drumm, Space Environment Technologies; Vikki Wong, Space Environment Technologies

Radiation hazards at commercial aviation altitudes up to suborbital space have been known for decades including those from galactic cosmic rays (GCRs), solar energetic particles (SEPs), and more recently phenomena associated with radiation belt particle precipitation (RBPP). The complex radiation field that derives from these primary particle sources creates safety concerns for aerospace crew and passengers. Because of this safety hazard, the Automated Radiation Measurements for Aerospace Safety (ARMAS) program was developed to provide global aerospace radiation environment monitoring. The ARMAS operational system has now achieved monitoring from the surface of the Earth into Low Earth Orbit (LEO) with aircraft, high altitude balloon, suborbital vehicle, satellite and ISS flights over the past year. We present the latest results from i) the various flight domains (ISS in 2022 with 24 underflight aircraft conjunctions); ii) the calibrations of the ARMAS system with the Tissue Equivalent Proportional Counter (TEPC); iii) the ongoing real-time data assimilation of ARMAS data into the RADIAN system using NAIRAS v3 baseline global data and CARI-7 verifications; and iv) the development of an online ARMAS global database for scientific research. We also describe progress towards 24/7 atmospheric monitoring from both the perspective of new sensor development as well as new stratospheric monitoring platforms. We present this talk in the context of validation and performance assessment for radiation monitoring and its transition to operations.

**36. Eric Benton** (Oklahoma State University, Department of Physics)
**Progress on the Atmospheric Ionizing Radiation Tissue Equivalent Dosimeter (AirTED)**
**Co-Author:** Kyle Copeland, U.S. Federal Aviation Administration, Civil Aerospace Medical Institute, Oklahoma City, OK

The Atmospheric Ionizing Radiation Tissue Equivalent Dosimeter (AirTED) is a low cost, compact ionizing radiation detector for use aboard aircraft, UAVs, high altitude balloons and suborbital rockets currently being developed at Oklahoma State University with support from NASA SWR2O2R program. The detector consists of a tissue equivalent proportional counter (TEPC) to measure high LET radiation including secondary neutrons, and primary and secondary protons and heavy ions, and a Si PIN Photodiode to measure low LET radiation including x-/gamma-rays, electrons and positrons. Low cost and the use of COTS parts has been prioritized in the design of AirTED in order to ensure that the instrument can be made in relatively large numbers to enable deployment on multiple airborne platforms. A prototype of AirTED has been calibrated using the Los Alamos Neutron Science Center's 30L spallation neutron source that simulates the secondary neutron energy spectrum encountered at aviation altitudes. SpaceTED, a NASA space-qualified version of AirTED, is currently operating on the International Space Station. Preliminary results from SpaceTED demonstrate that the detector is working as designed. The less expensive AirTED version will soon be deployed on various aircraft including NASA's WB-57 high altitude research aircraft.

**37. Naoto Nishizuka** (National Institute of Information and Communications Technology)
**Operational Solar Flare Predictions and Evaluations using Deep Flare Net**
**Co-Author(s):** Yuki Kubo, National Institute of Information and Communications Technology; Komei Sugiura, Keio University; Mamoru Ishii, National Institute of Information and Communications Technology; Takuya Tsugawa, National Institute of Information and Communications Technology

We have developed an operational solar flare prediction model using deep neural networks, named Deep Flare Net (DeFN), which is used in daily space weather forecast meetings in NICT (Nishizuka et al. 2018 ApJ, 2021 EPS). The DeFN model can predict occurrence probabilities and the largest level of flares occurring within the next 24 hr. We used magnetograms and EUV images taken by HMI and AIA onboard SDO during 2010-2015. DeFN can automatically detect active regions from magnetograms, extract 79 physical features from each region, and input them into deep neural networks to predict flares occurring in the next 24 hours. We evaluated the prediction results by TSS, and we found that DeFN succeeded in predicting flares with TSS=0.80 for >=M-class flares and 0.63 for >=C-class flares, which is better than human forecasting. Furthermore, we have operated DeFN since 2019, and it has been used for daily forecasting. We evaluated the operational prediction results in the period of 2019/1-2020/7, and we found that DeFN achieved TSS=0.82 for >=C-class flare predictions. Recently, we have evaluated the prediction results again in the period of 2019/1-2023/6, and we found that DeFN achieved TSS=0.70 (0.72) for >=M(C)-class flare predictions. In this presentation, we would like to introduce our DeFN model and operational results for five years.

# Wednesday, 17 April

## *Ionosphere and Thermosphere Research and Applications*

## *Geospace/Magnetosphere Research and Applications*

## *Space Weather Policy and General Space Weather Contributions*

*Posters can be viewed all day, with dedicated times from 10:05 AM -10:55 AM and 2:30 PM - 3:20 PM*

**1. Joe Hughes** (Orion Space Solutions)
**Impacts of Small Scale Structures on Observation System Simulation Experiments for HF Propagation**
**Co-Author(s):** Ana Newheart, Orion Space Solutions; Ian Collett, Orion Space Solutions; Cami Nasr, Orion Space Solutions; Junk Wilson, Orion Space Solutions

Observation System Simulation Experiments (OSSEs) are simulation experiments that quantitatively assess different sensor architectures for how well they meet science or operational metrics. Such assessments can be coupled to a pricing model to perform cost-benefit analyses. Many OSSEs use smooth physics-based nature runs or truth models, but these models typically lack small-scale structure that is present in the real ionosphere. This limitation can lead to overly optimistic estimates of the performance of an observation system. This is because the real-life ionosphere is not often well-modeled by a linear interpolant. Recent work has developed methods for generating 'noisy truth models' (NTMs) which have realistic small-scale structure to remedy this problem. OSSEs performed with a NTM ought to be more accurate since it is impossible to know how well a sensor system can resolve small-scale features if there are no small-scale features to find in the truth model.

This work will investigate the impact of the truth model on OSSE results with a High Frequency (HF) propagation metric relevant for Over The Horizon (OTH) Radar. Two OSSEs will be performed: one with a smooth truth model and one with a NTM. Both OSSEs will sample their respective truth models with the same sensors, and will use an identical assimilator. The improvement of both of the analyses over the background will be quantified and compared.

**2. Zachary Waldron** (Space Weather Technology, Research, and Education Center at the University of Colorado)
**Thermospheric Neutral Density Extraction from Low Earth Orbiting Spacecraft**
**Co-Author(s):** Jeffrey Thayer, Space Weather Technology, Research, and Education Center at the University of Colorado; Eric Sutton, Space Weather Technology, Research, and Education Center at the University of Colorado; Vishal Ray, Kayhan Space Inc.; Katherine Garcia-Sage, NASA Goddard Space Flight Center; Marcin Pilinski, Laboratory for Atmospheric and Space Physics at the University of Colorado

As low Earth orbit (LEO) becomes increasingly crowded, the risk of collision continues to grow. Effective mitigation of this risk requires more reliable and accurate predicted trajectories of resident space objects, which in turn requires improved specification and forecasting capabilities of the earth space environment via upper atmospheric models. A primary source of this chain of uncertainties is the dearth of observation of the thermospheric neutral density, in both coverage and frequency, preventing effective validation of the thermospheric density models over a variety of periods, conditions, and altitude regimes. GNSS-equipped LEO satellites are precisely tracked and can serve as "data of opportunity" to provide additional observations of the thermospheric density. This work demonstrates using the GEODYN-II precision orbit determination software along with precise science orbit ephemeris to extract high-cadence neutral density estimates along the orbit of the ICESat-2 satellite. We demonstrate the usefulness of this method to identify errors in the thermospheric density models via scaling factors and to produce the estimated neutral density observations. Results are compared against the coplanar GRACE-Follow On satellite's accelerometer-derived densities, and plans to extend this methodology to the Spire constellation are explored.

**3. Ryan Kelly** (Orion Space Solutions)
**AI-Based Ionospheric Scintillation Impact Prediction**
**Co-Author(s):** Ryan Nguyen, Orion Space Solutions; Jack Ziegler, Orion Space Solutions; Ian Collett, Orion Space Solutions

Ionospheric scintillation, characterized by rapid fluctuations in radio signal phase and amplitude, presents significant challenges to ground-to-space communication links, particularly in the low-latitude ionosphere. The lack of reliable tools for forecasting or nowcasting scintillation can impact the reliability of communication with GNSS satellites. In response to these limitations, we have built Ionospheric Scintillation Impact Prediction AI (ISIP.AI), a novel tool that leverages machine learning (ML) to enhance the accuracy of nowcasting and forecasting ionospheric scintillation in the low-latitude ionosphere. ISIP.AI utilizes observations of ionospheric irregularities and scintillation along satellite-to-satellite links to estimate scintillation for space-to-ground links.

ISIP.AI attempts to predict the maximum amplitude scintillation (S4) over specified time spans at ground-to-space links. Key inputs for the model include transmitter and receiver positions and operational data products from the COSMIC-2 mission, which provides GNSS radio occultation measurements of the ionosphere. We have implemented several ML architectures including classical ML models, Convolutional Neural Networks and Graph Neural Networks. We then evaluated these models against results from the established Wide Band MODel (WBMOD) climatological software tool.

**4. Huei-Wen Siao** (Central Weather Administration)
**Validation of the Location of Equatorial Plasma Bubbles Around Taiwan Using FORMOSAT-7/COSMIC-2 and GNSS Ground Receivers**
**Co-Author(s):** Lee, I-Te, Central Weather Administration, Taiwan; Jan-Peter Weiss, COSMIC Data Analysis and Archive Center, UCAR; Jyun-Ying Huang, Central Weather Administration, Taiwan; Hsu-Hui Ho, Central Weather Administration, Taiwan

Equatorial plasma bubbles (EPBs) are the regions with lower plasma density compared to the background ionosphere. Besides, EPBs are one of the sources that alter both the phase and amplitude of signals from GNSS (Global Navigation Satellite System) satellites, leading to significant errors in positioning accuracy, commonly referred to as ionospheric scintillations. Given Taiwan's unique geographic location, it is particularly easier to observer EPBs. However, determining the precise positions of equatorial plasma bubbles poses a significant challenge on both regional and global scales.

To address this challenge, the Space Weather Operational Office (SWOO), established by the Central Weather Administration (CWA), has the primary task of providing and improving space weather information as well as local space weather forecasts. For ionospheric products, SWOO utilizes data obtained from both space-based and ground-based observations. The verification of plasma bubble positions relies on bubble geolocation products retrieved from FORMOSAT-7/COSMIC-2 measurements and ionospheric scintillations using GNSS ground receivers installed by the CWA/Seismological Center. It is noteworthy that under certain conditions, there may be slight differences in the positions of plasma bubbles between these two monitoring methods.

SWOO also provides global ionospheric electron density structures, scintillation indices, in-situ ion composition and temperature data, radio frequency interference indices, and radio occultation (RO) profiles retrieved from FORMOSAT-7/COSMIC-2 measurements, enhancing the monitoring of local space weather conditions.

**5. Shaylah Mutschler** (Space Environment Technologies)
**Assessing Upper Atmosphere Models for Navigating a Crowded LEO Environment**
**Co-Author(s):** Eric Sutton, SWx TREC at University of Colorado, Boulder; Sean Bruinsma, CNES (DTM); Kent Tobiska, Space Environment Technologies; Marcin Pilinski, University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics; Delores Knipp, University of Colorado, Boulder; Brandon DiLorenzo, Space Environment Technologies; Christian Siemes, TU Delft; Steve Casali, Omitron; Tzu-Wei Fang, NOAA Space Weather Prediction Center; Tim Fuller-Rowell, NOAA Space Weather Prediction Center

The Low Earth Orbit (LEO) regime is becoming more congested as the number of satellites continues to grow with the rising popularity and establishment of SmallSat constellations. In addition to a congested LEO space environment, the rapid rise of this solar cycle suggests that the current solar maximum occurring between 2024-2027 will be higher than the previous solar maximum, thus causing higher perturbations due to drag from atmospheric density on LEO satellites. Despite these increasingly hazardous conditions, there is still no consensus among agencies and companies on how to quantify and predict the thermospheric environment through which these objects are orbiting. This poster outlines

current state-of-the-art thermospheric density models, describing their performance, computation time, required operational space weather input parameters, and notes for implementation. We include models that are at a technology readiness level of eight or nine, meaning that the model is currently being run on an operational system or the model has validated performance under operational conditions.
The models that are assessed in this work are as follows: DTM2020, HASDM, JB2008, MSIS2.0, TIE-GCM2.0, and WAM-IPE. An analysis is provided in which each model's performance is compared during quiet and storm conditions during the month of April 2023. Models are evaluated globally against HASDM densities and locally against GRACE-FO satellite accelerometer-derived density data. A propagation analysis is also included in which satellites are propagated through each model's density field during the April 2023 storm and quiet conditions. Overall, this presentation provides a comparison between state-of-the-art density models to identify possible areas of improvement for particular models and for thermospheric density modeling as a whole.

**6. Ian Collett** (Orion Space Solutions)
**ReflecTEC: A Concept Satellite Sensor for Measuring Vertical Total Electron Content**
**Co-Author(s):** Joe Hughes, Orion Space Solutions; Jack Ziegler, Orion Space Solutions; Nathan Tipton, Orion Space Solutions; Erich Hoover, Orion Space Solutions; Adam Reynolds, Orion Space Solutions

Characterizing global ionospheric electron density is critical for understanding and mitigating effects on, for example, radio communication and satellite navigation systems. Yet measurements of the ionosphere are often too sparse to specify electron density to the fidelity necessary. This is especially true over the open ocean because of the gap in ionosonde and ground GNSS receiver observations. To help fill this critical data coverage gap, we have developed the concept for a novel spaceborne sensor called ReflecTEC. ReflecTEC estimates vertical total electron content (TEC) of the ionosphere below the satellite altitude by transmitting VHF signals at multiple frequencies and measuring the differential delay of their reflections from the ocean surface. The signal frequency and measurement geometry make ReflecTEC highly complementary to existing measurement types. VHF signals are more sensitive to TEC and are more coherently reflected from the ocean. Furthermore, in this measurement geometry, vertical TEC can be measured directly (rather than approximated from slant TEC) and combining the vertical rays with the typically near-horizontal TEC rays of GNSS radio occultation will improve the results of data assimilation or tomographic inversion. Here, we present the results on our initial feasibility study of ReflecTEC, which involved a simulation study of signal transmission, propagation and surface scattering effects, receiver signal processing, and TEC estimation. Additionally, we share a notional system design and comment more specifically on how ReflecTEC measurements could be used to improve electron density specification.

**7. Camella Nasr** (Orion Space Solutions)
**Methods and Outcomes for Recent Evaluations of Commercial Radio Occultation Total Electron Content**
**Co-Author(s):** Joe Hughes, Orion Space Solutions; Ian Collett, Orion Space Solutions; John Noto, Orion Space Solutions; Geoff Crowley, Orion Space Solutions

Global Navigation Satellite System (GNSS) Radio Occultation (RO) is a remote sensing technique that uses GNSS signals of opportunity to estimate parameters of the Earth's atmosphere such as the total

electron content (TEC). Currently, near real time RO measurements are provided by the COSMIC-2 mission and an increasing number of commercial providers. The data available from commercial providers has significant scientific and operational potential, especially given their coverage of higher latitudes that are not visited by COSMIC-2. Orion Space Solutions (OSS) has a long history of evaluating commercial RO data utility, from Spire, GeoOptics, and PlanetiQ. As part of the US Air Force's Commercial Weather Data Pilot (CWDP), we assessed the quality of ionospheric TEC data collected by PlanetiQ's GNOMES-2 satellite beginning in late 2021. We investigated quality with respect to the elevation angle, minimum altitude, geographic coverage, and receiver performance statistics, comparing those to COSMIC-2 and other commercial providers. The data was also compared to ionosondes, incoherent scatter radars (ISRs), the international reference ionosphere (IRI) climatological model, and an assimilative model: IDA4D. We performed an Observing System Simulation Experiment (OSSE) to compare the resulting analysis to the original truth model. In all aspects of overall data evaluation, PlanetiQ data was found to be accurate and high quality. For NASA's Commercial Smallsat Data Acquisition New Vendor Onramp Evaluation (CNVOE) program, we evaluated whether GeoOptics ionospheric data supports NASA's earth science research goals. We will present several methods and outcomes of these past and current evaluations.

**8. Jeong-Heon Kim** (Korea Astronomy and Space Science Institute)

**Deep Learning-Based Solar Irradiance Prediction Model using the FISM2 Dataset During the Solar Flare Events**

**Co-Author(s):** Young-Sil Kwak, Korea Astronomy and Space Science Institute; Sung-Hong Park, Korea Astronomy and Space Science Institute; Junmu Youn, Kyung Hee University; Seungwoo Ahn, Kyung Hee University; Kangwoo Yi, Kyung Hee University

In this study, we address the challenge of predicting solar irradiance changes triggered by solar flares, which are crucial for understanding the ionospheric disturbances that affect the stratified regions of Earth's atmosphere. Solar flares markedly amplify the Sun's radiance, leading to increased photo-ionization within the ionosphere, particularly affecting the D and E layers, and disrupting ground-to-satellite communications. Current space weather surveillance systems are inadequate in providing timely predictions of these changes in irradiance following flare incidents. Our approach involves developing a predictive model based on deep learning techniques that estimate solar irradiance across the spectrum from X-ray to EUV wavelengths, targeting a prediction window of about three hours following a solar flare event. We utilize observational data reconstructed since 2003, based on the FISM2 model framework. We have curated a dataset of solar flare events classified as M-class and above, spanning from 2003 to the current day, collecting 964 events. For training, the model processes 90 data points at one-minute intervals, starting 1.5 hours before the flare's peak, focusing on the 0.1nm to 0.8nm X-ray wavelength range. The output comprises 180 data points with one-minute intervals, from the flare's peak to three hours into the recovery phase, across four wavelength bins, including X-ray and EUV spectra. Our dataset, divided in an 8:1:1 ratio for training, validation, and testing sets, employs a simple multi-layer perceptron (MLP) for initial deep learning methodology. This research is a part of KASI's SpaceAI project. In this presentation, we will share our preliminary findings, discuss challenges faced, and outline future directions for this predictive model's development.

**10. Chris Watson** (University of New Brunswick)
**Space Weather Ionospheric Network Canada**
**Co-Author(s):** Thayyil Jayachandran, University of New Brunswick; Anton Kashcheyev, University of New Brunswick; David Themens, University of New Brunswick; Richard Langley, University of New Brunswick; Anthony McCaffrey, University of New Brunswick; Torsten Reuschel, University of New Brunswick; Karim Meziane, University of New Brunswick; Abdelhaq Hamza, University of New Brunswick; Alex Koloskov, University of New Brunswick; Richard Chadwick, University of New Brunswick; Philippe Trottier, University of New Brunswick

Space Weather Ionospheric Network Canada (SWINCan) is a pan-Canadian remote sensing network that will provide continuous, real-time ionospheric monitoring spanning polar, auroral, and sub-auroral regions. SWINCan is an expansion and modernization of the Canadian High Arctic Ionospheric Network (CHAIN), operated by the Radio and Space Physics Laboratory (RSPL) at the University of New Brunswick (UNB) and currently one of the world's largest ionospheric observation networks. New deployments include 100 state-of-the-art global navigation satellite system (GNSS) receivers (100 Hz scintillation monitors) and 10 specialized modular ionospheric sounder (MODIS) systems, adding to the 39 GNSS and 9 ionosonde systems currently installed as part of CHAIN. MODIS systems developed by RSPL are next generation, high-frequency (HF) sounders, which take advantage of the latest developments in software defined radio and signal processing technology. SWINCan capitalizes on Canada's geographic expanse and proximity to the northern magnetic pole, which provides a unique natural laboratory for the fundamental study of solar-terrestrial interactions. This network will observe the multi-scale structure and dynamics of the high-latitude ionosphere with unprecedented detail, providing essential measurements to resolve the internal and geospace coupling processes that drive this complex behaviour. SWINCan will also provide essential input for enhancing 3D modeling capabilities of ionospheric plasma density, and for mitigating the effects of space weather on modern technological systems such as position, navigation, and timing (PNT), radio communication, and over-the-horizon-radar, services critical to social, military, science, and major economic sectors.

**11. Paul Straus** (The Aerospace Corporation)
**Radio Occultation (RO) Effective Coverage/Refresh Assessment for Low Latitude Ionospheric Scintillation Monitoring**
**Co-Author:** JJ Cabrera-Guzman, The Aerospace Corporation

The Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC-2) program has demonstrated a near-real time capability for monitoring ionospheric scintillation. However, the sensitivity of individual RO events to ionospheric irregularities depends on highly variable RO geometry and its relationship to the earth's magnetic field that guides irregularity formation and extent. Initial studies of effective COSMIC-2 coverage and refresh indicate that simple theoretical models may significantly over-estimate performance. We describe a more detailed analysis approach to investigate the reasons behind this disconnect. These studies are important because a good understanding of RO system coverage/refresh performance is critical to the design of future RO sensing systems.

**12. Katherine Garcia-Sage** (NASA Goddard Space Flight Center)
**Geospace Dynamics Constellation: The Mission We Need for the New Era of Access to LEO**
**Co-Author(s):** Greg Lucas, University of Colorado, Boulder; Rebecca Bishop, The Aerospace Corporation; Jeff Thayer, University of Colorado, Boulder; Bob Robinson, Catholic University of America/NASA Goddard Space Flight Center; Doug Rowland, NASA Goddard Space Flight Center; Larry Kepko, NASA Goddard Space Flight Center

Society's increasing dependence on space for defense and commercial needs requires a new, comprehensive examination of the ionosphere-thermosphere (IT) region, in order to improve our fundamental understanding of space weather processes. Further, we need to determine the most crucial real-time space weather quantities required for expanded activities and maintaining leadership in LEO. The Geospace Dynamics Constellation (GDC) Mission will provide this understanding through multiscale measurements of energy input from the magnetosphere to the ionosphere-thermosphere, its effects in the IT region, and internal processes throughout the IT system. GDC's six satellites will characterize the IT system and its geomagnetic drivers from ~375 km altitude. This mission will make unprecedented multi-point orbital measurements of ionospheric and thermospheric density, composition, and temperature, magnetic and electric fields, and ionospheric variability. The measurements and science advancements will inform our understanding of the processes that change atmospheric densities, cause ionospheric scintillation, and drive ionospheric currents, with effects on satellite drag, navigation/communication, and geomagnetically induced currents.

Data from GDC's six science instruments plus a set of dosimeters onboard each of six spacecraft will be available for operational use. GDC is a crucial pathfinder for future space weather observations and pipelines that will contribute to the prioritization of data needs for future operational platforms. This poster will present details of the draft data products and request feedback on optimizing operational impact. The GDC mission also encourages applied research that will help ensure the maximum space weather impact of these data.

**13. I-Te Lee** (Central Weather Administration, Taiwan)
**Integrated Ionospheric Irregularity Observations Over Taiwan**
**Co-Author(s):** Tung-Yuan Hsiao, National Tsing Hua University, Taiwan; Hui-Wen Hsiao, Central Weather Administration, Taiwan; Jyun-Ying Huang, Central Weather Administration, Taiwan; Hsu-Hui Ho, Central Weather Administration, Taiwan

In general, higher plasma density during the day time period overhead is recorded associated with the equatorial ionization anomaly over Taiwan, and to easier observe plasma bubbles/irregularities in the evening to midnight period. Such phenomena would significantly influence high-frequency and satellite communication as well as navigation and positioning services. In order to provide near real-time information of ionospheric electron density distribution for associated users, the Central Weather Administration conducts an integrated observation network together with the Taiwan Space Agency and domestic scientific research teams. These observational instruments including Ground-based GNSS receivers, self-developed all-sky camera, and radio occultation taken by the FORMOSAT-7/COSMIC-2 to conduct the regional map of total electron content (TEC), scintillation index (S4), and rate of TEC index change (ROTI). Recently, many cases reveal ionospheric irregularities via optical and radio measurements, simultaneously. To cross check those observations also give a good chance to analyze the algorithm of data processing. Therefore, it would provide a good dataset to monitor irregularities and quality of positioning signal as well as to have more detailed studies.

**14. Marcin Pilinski** (University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics)
**Leveraging Data Assimilative Models for Enhanced Satellite Drag Predictions**
**Co-Author(s):** Weijia Zhan, Space Weather Technology, Research, and Education Center at the University of Colorado; Eric Sutton, Space Weather Technology, Research, and Education Center at the University of Colorado; Jenny Knuth, Space Weather Technology, Research, and Education Center at the University of Colorado; Shaylah Mutschler, Space Environment Technologies; W. Kent Tobiska, Space Environment Technologies; Ryan Blay; Geoff Crowley, Orion Space Solutions

Low Earth Orbit (LEO) satellite drag is a persistent Space Weather (SWx) challenge requiring urgent and immediate attention. One of the main impediments to accurate satellite drag predictions results from uncertainties in the air density of the highly-variable upper atmosphere, also known as the thermosphere. In-turn, this thermospheric variability is primarily driven through forcing by dynamic solar wind and extreme ultraviolet radiation. Drag-validated data assimilation (DA) techniques such as IDEA [Sutton 2018], and Dragster [Pilinski et al. 2016] now have the ability to determine the thermospheric model forcing that is most compatible with the observed satellite drag, effectively making a "driver correction" to the atmospheric models at each time step. These methods have been the only ones so far shown to match or outperform the current state of the art in density specification, which is the High Accuracy Satellite Drag Model (HASDM) used by the Department of Defense.

As promising as these driver corrections are, it is not clear how well DA driver corrections persist into the forecast window nor how best to combine them with existing operational driver forecasts. Determining this "driver-mapping" and delivering it to the broader community can enable broader access to forecasts that are tied to our best estimates of the present drag environment. To achieve this outcome, our team is performing a driver-mapping evaluation that tests various approaches for mapping DA-estimated geomagnetic and solar drivers to forecast products. The mapping algorithms that are being evaluated include linear and non-linear regression as well as autoregressive neural network models. The overall goal is to determine how best to make ND forecasts using the best validated and most operationally ready DA techniques.

**15. Daniel Gillies** (NOAA National Environmental Satellite Data, and Information Services GEO)
**GOES Data Collection System RF Data as a Space Weather Data Source**
**Co-Author:** William Dronen, NOAA National Environmental Satellite Data, and Information Services, Office of Satellite and Product Operations

The GOES Data Collection System (DCS) is a NOAA operated radio frequency relay system which collects environmental data transmitted in the Ultrahigh Frequency (UHF) band by Data Collection Platforms (DCPs) across the western hemisphere. The GOES East and West spacecraft collect the UHF transmissions and relays them via a bent-pipe architecture down to NOAA receiving stations in L-Band at Wallops Island, VA and Fairmont, WV. DCP transmissions have been known to experience suspected scintillation effects, particularly for South America sites, which to date have not been quantitatively characterized. Due to the large number (approximately 30,000 UHF DCP transmitters) and distribution (coverage ellipses down to 5 degrees elevation from GOES-East and West) of UHF transmitters and the geostationary nature of the bent-pipe relay, DCS may offer a unique opportunity to contribute a massive, open dataset that could be applied to HF scintillation topics relevant to space weather and aviation communities. Scintillation effects on DCS UHF transmissions may also serve as a closer proxy to scintillation effects on HF transmissions than the L-Band GNSS transmissions. This poster provides an overview of DCS, its geographic distribution, and technical characteristics to promote further discussion on the potential for use of this RF data within the space weather community.

**16. Richard Eastes** (University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics)
**Real Time Satellite Drag Prediction using Global-scale Observations of the Limb and Disk (GOLD) Mission Images**
**Co-Author(s):** Fazlul Laskar, University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics; William McClintock, University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics; Timothy Plummer, University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics; Stephane Beland, University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics; J. Scott Evans, Computational Physics, Inc.; Jerry Lumpe, Computational Physics, Inc.

Thermospheric neutral densities depend directly on the temperature and composition. The thermosphere can be closely modeled as an ideal gas, for which the relationships between the density of the gas is directly derivable from the temperature, composition and a constant. NASA's GOLD mission images temperature and composition, the key variables, concurrently at coincident locations on Earth's dayside disk. Comparisons of observations during the recent Space-X storm confirm that neutral densities can be well specified using observations of the neutral temperatures, a current empirical model of the thermosphere and the ideal gas law relationship between densities and temperature. Using only the GOLD disk measurements of temperatures to guide/nudge MSIS model temperatures, the resulting neutral densities extrapolated to higher altitudes were in excellent agreement with GRACE-FO (500 km) and SWARM-C (460 km) observations of densities. Using the neutral composition (O/N2 ratio) data from GOLD should further improve the ability to specify and even predict neutral and ionospheric densities because GOLD has shown that the composition changes slowly, with perturbations persisting for days. Since it has been previously demonstrated that a real-time version of the GOLD data is possible and agrees closely with the publicly released (but higher latency) science products, real-time neutral densities could readily be made available for operational use.

**17. Shibaji Chakraborty** (Virginia Tech)
**Viability of Monitoring Solar Flare-Driven Radio-Blackouts Using SuperDARN HF Radar**
**Co-Author(s):** J. M. Ruohoniemi, Virginia Tech; J. B. H. Baker, Virginia Tech

The first space weather impact of a strong solar flare is radio blackout across the dayside of the Earth. At a delay of just 8 minutes, the arrival of enhanced X-ray and EUV radiation leads to a dramatic increase in ionization density in the lower ionosphere. Operation of high-frequency (HF: 3-30 MHz) systems is often completely suppressed due to D-region absorption, also known as shortwave fadeout or radio blackout. Severe solar flares can disrupt emergency HF communications that support humanitarian aid services, including amateur radio and satellite communication systems. Recent studies have shown that radio blackout is easily detected and characterized using SuperDARN HF radar observations. Statistical studies reported that the onset of blackout is very rapid (~ 1-minute) while recovery takes tens of minutes to hours. Our current predictive capability is based on modeling the ionospheric impacts using solar flux measurements from GOES sensors and an empirical model named D-Region Absorption Prediction (DRAP). We present a technique to characterize radio blackout following solar flares using HF radar. We have developed a monitoring system to identify and monitor radio blackouts using HF radars (over North American Sector) that are currently deployed to support space science research. Networks of such radars operate continuously in the northern and southern hemisphere as part of the SuperDARN collaboration. We have devised a tool that integrates data obtained from the array of North American SuperDARN radars to identify instances of daily radio blackouts and relate them to GOES X-ray irradiance. We also employ a novel empirical model named the X-ray Irradiance-driven D-region Absorption Prediction (X-RAP) model, which generally predicts higher levels of absorption than the DRAP model.

**18. Qian Wu** (High Altitude Observatory/National Center for Atmospheric Research)
**Multi-platform thermospheric wind observation at HAO/NCAR**

Thermospheric winds are one of the critical parameters for understanding the ionosphere from high to low latitudes. NCAR HAO has been building and deploying Fabry Perot interferometers (FPI) to various locations around the world and high altitude balloons to measure thermospheric winds. In addition, HAO/NCAR is also developing a CubeSat version of the FPI to measure the thermospheric winds. Each of the platforms (ground, balloon, and CubeSat) offer a different perspective of the thermosphere. Recently, NCAR deployed a sub-auroral FPI in Athabasca, Canada and another at low latitudes in Korhogo, Ivory Coast. These two FPIs will contribute the space weather research at NCAR and help validate NCAR ionosphere and thermospheric wind models. NCAR also plans to fly a balloon borne-FPI in New Zealand in 2025. We will give an overview of the NCAR FPI programs and possible applications to space weather research.

**19. Katekile Shivambu** (South African National Space Agency)
**The Ionospheric Response to Geomagnetic Storm of 23-24 April 2023 Over Southern Africa**

The Earth's ionosphere responds to perturbations caused by solar activities such as coronal mass ejections (CMEs), solar flares, coronal hole high-speed streams, corotating interactive regions, and solar energetic particles. This study will focus on the ionospheric response to a geomagnetic storm that occurred on April 23rd to 24th, 2023. The key ionospheric parameters such as the critical frequency of the F2 layer (foF2) and the Total Electron Content (TEC) are analyzed over South African stations located in Hermanus (19.22°E, 34.42°S) and Grahamstown (33.31°S, 26.52°E). The disturbance storm time (Dst) index reached a minimum of -180 nT with a maximum planetary K index (Kp) of 8. The Hermanus and Grahamstown stations both experienced a significant decrease in the foF2 and TEC during the storm period. This distinct decrease is an indication of the negative ionospheric storm effect.

**20. John Emmert** (Space Science Division, U.S. Naval Research Laboratory)
**Advances, Updates, and Future Developments of the NRLMSIS® Atmospheric Empirical Model**
**Co-Author(s):** McArthur Jones Jr., Space Science Division, U.S. Naval Research Laboratory; Douglas Drob, Space Science Division, U.S. Naval Research Laboratory; Manbharat Dhadly, Space Science Division, U.S. Naval Research Laboratory; Michael Stevens, Space Science Division, U.S. Naval Research Laboratory; J. Michael Picone, Voluntary Emeritus Program, Space Science Division, U.S. Naval Research Laboratory

NRLMSIS® is an empirical atmospheric model that extends from the ground to the exobase and describes the average behavior of temperature, composition, and mass density, as a function of day of year, time, location, solar and geomagnetic activity. Over the last ten years the MSIS model has undergone major upgrades, including the assimilation of extensive new data sets, reformulation to couple species densities to the entire temperature column, and the addition of nitric oxide. As part of the development team's continuing efforts to enhance the MSIS model for scientific and space weather applications, we are currently working on incorporating non-migrating tidal variations in temperature in the middle and upper atmosphere, as well as formulating an empirical model of carbon dioxide (the tenth species to be represented in the model); both of these efforts require upgrades to the model software. Prospective future developments of the MSIS model include major revision of the thermosphere using more recent neutral temperature and density observations, incorporation of long-term trends, reformulation of geomagnetic and solar terms, and the addition of ozone and water vapor. This presentation will provide an overview of the MSIS model, its history, highlight recent model releases and scientific results, describe progress on incorporating non-migrating tidal variations and carbon dioxide, and motivate upcoming model developments.

**21. Xavier Gaefke** (United States Air Force Academy)
**Static Charging of the International Space Station**

Static charging of spacecraft is a phenomenon that occurs for a multitude of reasons while in the space environment. The hazards encountered due to static charging produce a necessity to predict and mitigate the charging. In the case of the International Space Station (ISS), three major factors are the photoelectric effect, photovoltaic charging, and electron flux from the ionosphere. In this project, we will analyze data collected by an instrument on the ISS, which is highly susceptible to static charging due to its size and large solar array. By filtering out and analyzing patterns in the data, our research could lead to a better understanding and prediction of satellite static charging. Using Matlab, STK, and other software, we will glean insight into the causes and magnitudes of each mode of static charging. Data will be compared to events such as periodic solar exposure and geomagnetic storms. The final product of the research is an understanding of factors for static charging of the ISS, with hopeful applications to other spacecraft.

**22. Natalie Wirth** (Air Force Institute of Technology)
**Assessing the  Relationship Between the Quasi-Biennial Oscillation and  D-Region Electron Density**
**Co-Author(s):** Kyle Fitch, Air Force Institute of Technology; Daniel Emmons, Air Force Institute of Technology; Dong Wu, National Aeronautics and Space Administration; Jae Lee, National Aeronautics and Space Administration; Cornelius Salinas, National Aeronautics and Space Administration

High-frequency (HF) communication plays a crucial role in military operations, heavily dependent on ionospheric conditions. The D-region, the lowest layer of the ionosphere, significantly influences HF signals due to variations in electron density. While research often delves into the impact of space weather on the upper ionosphere, particularly its higher layers, the D-region remains relatively understudied. Despite its proximity to the troposphere and stratosphere, the D-region is intricately linked to solar events and terrestrial weather patterns. This study addresses the gap in scientific literature by employing Fast Fourier Transforms (FFT), Continuous Wavelet Transforms (CWT), and Cross Wavelet Transforms (XWT). These analyses investigate the relationship between the stratospheric Quasi-Biennial Oscillation (QBO) and the ionosphere D-Region electron density. The FFT analysis reveals a significant association between QBO pressure levels and electron density frequencies, particularly at .33 yr^-1, prevalent across latitudinal bins. The QBO's influence on electron density is statistically significant, particularly during daytime and at lower latitudes. Notably, a consistent phase relationship of approximately -.61 months for the QBO frequency .33 yr^-1 suggests a significant connection, potentially indicating QBO propagation from the upper stratosphere to the lower ionosphere with an 18-day time lag. This newfound understanding holds potential implications for strategic planning and operational adjustments in HF communications reliant upon D-region conditions.

**23. Natane Randall** (United States Military Academy)
**The Analysis of the Impacts that Scintillation Activity has on GPS Receivers at High-Latitudes**
**Co-Author(s):** Stephen Litterini, United States Military Academy; Mason Bay, United States Military Academy

With the upcoming solar maximum, users may find themselves unable to navigate in high-latitude regions due to a higher likelihood of geomagnetic storm activity combined with the limited number of satellites in view of high latitude receivers. By analyzing data from high-resolution Connected Autonomous Space Environment Sensor (CASES) GPS receivers located in Poker Flat, Alaska Research Range during a geomagnetic storm that occurred on August 26, 2018, we are studying the effects that satellite configurations have on position solution error. The project aims to determine the relationship between the configuration of the satellites in view of the receiver and the direction in which the deviation between the known receiver location and the flawed position solution occurs. We want to understand why the position solution error deviates in a specific direction given the levels of scintillation activity that are affecting each of the satellites in the configuration. We are conducting this analysis during times when all satellites in view of the receiver have nominal STEC values in order to isolate the variable of configuration. The results of this analysis will be used to contribute to the development of an index to categorize the severity of geomagnetic storms and the effects they have on the operational use of GPS receivers at higher latitudes.

**24. Arunima Prakash** (Space Weather Technology, Research, and Education Center at the University of Colorado)
**Navigating Space Weather: Examining Ionospheric and Thermospheric Responses to the August 2018 Geomagnetic Storm**
**Co-Author:** Luis Navarro, Space Weather Technology, Research, and Education Center at the University of Colorado

The loss of 38 out of 49 Starlink satellites due to a minor geomagnetic storm (February 2022) is a perfect example highlighting the dire need for understanding the dynamics of the Ionosphere and Thermosphere (I-T) system during the main and recovery phase of a geomagnetic storm. While it is recognized that the neutral density composition and electron density in the I-T system undergo enhancements during and after a storm - causing variations in satellite drag, the extent of their variation with respect to different storm magnitudes remains ambiguous. This work investigates the Thermospheric – Ionospheric response to the August 2018 geomagnetic storm. The energization of the upper atmosphere due to high-speed coronal streams and a minor coronal mass ejection which triggered this storm, is analyzed with respect to plasma drifts, neutral wind disturbances, and electron density changes. Using the data from Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC-1) satellite, the electron density profiles from 24th August to 27th August 2018, are investigated to establish the I-T response, the extent of plasma depletion and the role of the ionospheric disturbance dynamo in the I-T response during the main and recovery phase of the storm.

**25. Larry Bolt** (United States Military Academy)
**Constructing a Model in GEANT 4 to Quantify the Uncertainty of GNSS PNT Transmission**
**Co-Author(s):** Kiran Goldstein, United States Military Academy; Joshua Upton, United States Military Academy; Luke Welcher, United States Military Academy; Clement Horak, United States Military Academy

Aurora seen in the polar regions are indicative of varying ionospheric plasma density gradients facilitated by incident high-energy particles propagating along Earth's magnetic field lines. Much work has been done attempting to characterize these density gradients in the polar regions and understanding the intricacies of the physics dictating the behavior of the environment. Little however has been done to understand how this dynamic environment affects the uncertainty of Position, Navigation, and Timing (PNT) signals transmitted by Global Navigation Satellite Systems (GNSS). Additionally, the research that has been done focuses on the F-Region of the ionosphere and does not produce high horizontal spatial resolution.

The Polar Latitude Atmospheric Space Measurement and Analysis (PLASMA) team at the United States Military Academy (USMA), seeks to remedy this by constructing a model that classifies and characterizes the plasma in the E-region of the ionosphere to determine a margin of error of GNSS solutions that can be forecasted with respect to solar actively on demand. Utilizing GEANT 4, a particle focused software platform, PLASMA intends to construct a simulation of the E-region of the ionosphere under such conditions to compare our in-situ data collected. Preliminary data will be obtained using scintillators situated within a particle accelerator emulating E-Region conditions. Scintillators function using an enclosed crystal that when excited, will convert energized particles into visible light, allowing us to get a

profile of the particles passing through. This profile will be the basis of the model we will compare to our GEANT 4 simulation, allowing us to verify the accuracy of our numbers and providing us with a valuable tool in our pursuit to quantify the uncertainty of GNSS PNT transmissions.

**26. Mason Bay** (United States Military Academy)

**Correlation of Navigation Solution Parameters Affected by High-Latitude Ionospheric Scintillation Through Allsky Imagery**

**Co-Author(s):** Steve Litterini, United States Military Academy; Natane Randall, United States Military Academy

With the upcoming solar maximum, users may find themselves unable to navigate in high-latitude regions due to a higher likelihood of geomagnetic storm activity combined with the fewer high elevation satellites in view of high latitude receivers. Through analyzing data from high-resolution Connected Autonomous Space Environment Sensor (CASES) GPS receivers and simulations run on SkyDel Global Navigation Satellite System (GNSS) simulator, we have aimed to develop an index to categorize the severity of geomagnetic storms and the effects they have on the operational use of GPS receivers at higher latitudes. Our results are based on a geomagnetic storm on August 26th of 2018 as observed by a CASES receiver located at the Poker Flat Research Range.
The visible aurora is an obvious indicator of plasma-dense regions of the ionosphere. Plasmas contribute to the high total electron content (TEC) in the range between the receiver and the GPS satellite. This high TEC can cause delays in the reception of GPS signals, affecting the pseudorange measurement that the receiver calculates. Therefore, a relationship can be established between GPS pseudorange measurements and the discrete aurora found in AllSky imagery. This study's purpose is to visualize the real-time effects of GPS scintillation during dynamic auroral events. Currently, this research takes a simplified approach to understanding this relationship by focusing solely on the pseudorange offset due to ionospheric activity. The future of this research is to contextualize GPS scintillation in visible dynamic aurora that can be used in an operational impacts index.

**27. Qinglang Lao** (United States Military Academy)

**Collecting and Analyzing High Spatial Resolution, Polar Latitude, E-Region Ionospheric Plasma with Langmuir Probes aboard a CubeSAT**

**Co-Author(s):** Carlee Casteel, United States Military Academy; Madeline Edwards, United States Military Academy; Maleeya Sanders, United States Military Academy

As human activity in the Arctic increases, so too has the reliance on Global Navigation Satellite Systems (GNSS) to traverse the inhospitable and often featureless terrain. The increased commercial and geopolitical competition has placed a premium on the accuracy of space-based navigation systems; however, these systems are often uniquely disrupted by interference due to the effects of solar activity in the Earth's upper atmosphere. While it is understood that increases in particle activity can significantly degrade the reliability of GNSS solutions, few existing tools boast both the precision and horizontal resolution to quantify the effects of these ionospheric disturbances. As such, it remains impossible to accurately forecast the severity of GNSS inaccuracies given a solar event.

The long-term objective of the United States Military Academy (USMA) Polar Latitude Atmospheric Space Measurement and Analysis (PLASMA) Team is to develop a high-resolution model of the E-region ionosphere that has the capability to predict and quantify scintillation effects on GNSS when solar activity impacts the atmosphere. A precondition of the model is high fidelity data of the ionospheric environment during a solar storm. As such, the PLASMA team is developing a cylindrical Langmuir Probe capable of measuring the internal parameters of ionospheric plasma. It will be integrated onto a CubeSat and maneuvered to such an orbit that maximizes the horizontal fidelity of collected data. This paper will discuss the team's progress in payload design and testing parameters.

**28. Stephen Litterini** (United States Military Academy)
**Analysis of Navigation Solution Parameters Affected by High-Latitude Ionospheric Scintillation Through Simulation**
**Co-Author(s):** Natane Randall, United States Military Academy; Mason Bay, United States Military Academy

With the upcoming solar maximum, users may find themselves unable to navigate in high-latitude regions due to a higher likelihood of geomagnetic storm activity combined with the fewer high elevation satellites in view of high latitude receivers. Through analyzing data from high-resolution Connected Autonomous Space Environment Sensor (CASES) GPS receivers and simulations run on SkyDel Global Navigation Satellite System (GNSS) simulator, we have aimed to develop an index to categorize the severity of geomagnetic storms and the effects they have on the operational use of GPS receivers at higher latitudes. Our results are based on a geomagnetic storm on August 26th of 2018 as observed by a CASES receiver located at the Poker Flat Research Range. Manipulating CASES receiver files and importing them to Skydel allowed us to isolate the effects of scintillation. We calibrated our system by running a model void of external precision-harming processes, like tropospheric delays. We have been able to use simulated position navigation solutions to explore correlations in the raw data with the goal of finding a variable that strongly correlates to a directionless offset from the actual receiver location.

**29. Daniel Klotz** (United States Military Academy)
**Distributed CASES Array for Mid-Latitude Ionospheric Characterization**
**Co-Author(s):** Joanna Halfhill, United States Military Academy; Aaron Jeronimo-Monarca, United States Military Academy

In ionospheric research, GNSS receivers and sensors are commonly used to measure the effects of space weather and solar events on space and ground systems. The primary areas that have been studied are polar and equatorial regions, while far less work has been done in the mid-latitude regions. For this project, a distributed network of CASES receivers is being deployed to three sites located within 2 km across the West Point Military Reservation in New York to gain visibility into mid-latitude space weather effects. From GPS observations, total electron content, amplitude scintillation, and phase scintillation will be inferred. Ground magnetometers will be utilized to acquire information about the ground-induced currents, field-aligned currents (if any), and local magnetic perturbations. This data will then be used to characterize structures in the regional ionosphere that cause signal offsets and are characterized in terms of density, velocity, and decay rate. At the time of the workshop, any collected data on solar events and a solar eclipse using collocated receivers will be presented. This data will be used to inform future analysis

of the expected phenomena to be recorded with the distributed operational system. At the conclusion of this project, valuable ionospheric data and analysis will be added to the body of work on the mid-latitudes, a method for creating a relatively low-cost receiver network will be documented, and a distributed laboratory will be established for use in future GPS coursework at the United States Military Academy.

**31. Vincent Ledvina** (University of Alaska Fairbanks)
**Agile Collaboration: Citizen Science as a Transdisciplinary Approach to Heliophysics**
**Co-Author(s):** Elizabeth, MacDonald, NASA Goddard Space Flight Center, Greenbelt, MD, and Aurorasaurus, New Mexico Consortium, Los Alamos, NM; Laura Brandt Edson, NASA Goddard Space Flight Center, Greenbelt, MD, and Aurorasaurus, New Mexico Consortium, Los Alamos, NM; Don Hampton, University of Alaska-Fairbanks, Fairbanks, AK

Citizen science connects scientists with the public to enable discovery, engaging broad audiences across the world. There are many attributes that make citizen science an asset to the field of heliophysics, including agile collaboration. Agility is the extent to which a person, group of people, technology, or project can work efficiently, pivot, and adapt to adversity. Citizen scientists are agile; they are adaptable and responsive. Citizen science projects and their underlying technology platforms are also agile by utilizing beta testing and short timeframes to pivot in response to community needs. As they capture scientifically valuable data, citizen scientists can bring expertise from other fields to scientific teams. The impact of citizen science projects and communities means citizen scientists bridge scientists and the public, facilitating the exchange of information. These attributes of citizen scientists form the framework of agile collaboration. In this seminar, we will contextualize agile collaboration with a primary focus on aurora chasers—a group of citizen scientists actively engaged both in projects and independent data gathering—using the NASA citizen science project Aurorasaurus as an example of successful collaboration. Ways in which citizen science may be applied to many areas of heliophysics will be presented. Solving current Heliophysics grand challenges will require novel and innovative methods, and agile collaboration with citizen scientists is integral to such solutions.

**32. Tesfay Tesfu** (Universidade do Vale do Paraíba (UNIVAP))
**The Response of Solar Flares to VTEC Anomalies during the December 2013 Solstices over Ethiopia**
**Co-Author(s):** Gebregiorgis Abraha, Department of Physics, Mekelle University, Mekelle, Ethiopia; Virginia Klausner, UNIVAP; Claudia Nicoli, Instituto Nacional de Pesquisas Espaciais; Brazilian Ministry of Science, Technology and Innovations; Netsanet Gebrezgher, Samara University, Samara, Russia; Mahder Tesfu, Axum University, Tigray, Ethiopia

We studied the impact of solar flares during the 2013 Total Electron Content (TEC) anomaly over Ethiopia. Our study utilized one year of solar flare data from Hinode Flare Catalogue and Vertical Total Electron Content (VTEC) data recorded by two SCINDA (Scintillation Network and Decision Aid) GPS receivers located at Addis Ababa (9.034◦N, 38.67◦E, geomagnetic 0.9◦N, 110.5◦E) and Bahir Dar (11.37◦N, 37.10◦E, geomagnetic 2.64◦N, 108.94◦E). The one-year dataset was categorized into three seasons: D-season (January, February, November, and December), E-season (March, April, September, and October), and J-season (May, June, July, and August). Our analysis revealed a total of 1158 solar flare

events occurring on the day side out of 2045 total events (day and night side). The selection of day side flare events was based on local daytime over Ethiopia, where Ethiopian Local Time (LT) is equivalent to Universal Time (UT) plus 3 hours. The highest number of flare events of X, M, and C classes was observed during the D-season. Specifically, in the D-season, 39.3% of C class, 45.6% of M-class, and 50% of X-class events were observed, while in the E-season, 32.4% of C-class, 36.8% of M-class, and 33.3% of X-class events were observed. During the J-season, 28.3% of C-class, 17.7% of M-class, and 16.66% of J-class events were observed. Furthermore, we found that the majority of flare events originated from heliographic sources located between 30◦ South and 30◦ North. The D-season exhibited the highest frequency of events, followed by the E-season, with the J-season observing the fewest events. In comparing the hourly diurnal variation, we observed that VTEC was highest during November, followed by October and December. Equatorial ionization anomaly was clearly observed over the two stations, with TEC over Bahir Dar station being slightly dominant than the TEC observed over Addis Ababa station. The average VTEC during D, E, and J-seasons was observed to be around ~ 42 TECU, ~ 35 TECU, and ~ 26 TECU, respectively.

**33. Nicholas Furioso** (Self)
**Utilizing Discrete Exterior Calculus for Particle Transport from the Heliosphere to the Ionosphere**
**Co-Author(s):** David Galarza, SWIFT Lab; Luke Morris, GATAS Lab; Dr. James Fairbanks, GATAS Lab

Our research aims to efficiently model the trajectory of radiative particles and their impact on spacecraft throughout the environments near the Earth and the Sun. We plan to create models using a unique approach that is grounded in discrete exterior calculus. Opposed to typical models that are based within continuous calculus, this method expects to work better within applicable space environments that tend to be less continuous. This proposal plans to exploit the efficient nature of discrete exterior calculus in complex space environments to calculate accurate outputs quickly. Our main objectives include predicting the impact of damaging solar events for spacecraft and ground-based electronics, decreasing computational time of particle transport models, and after verification and validation of our increased capability models, analyzing the respective Sun and Earth environments and their convoluted physics. This is especially true near the Sun, as we will compare Parker Solar Probe (PSP) observational data to our validated model to look at any differences we see, and analyze why those differences occur. To predict solar event impacts, we have chosen to verify our model with the Nowcast of Aerospace Ionizing Radiation System (NAIRAS), a particle transport model that specializes in dosage rates of radiation for spacecraft, aircraft and its passengers. This research ultimately aims to explore which aspects of the underlying physics can be improved to better model particle transport.

**35. Matalyn Espenshade** (United States Military Academy)
**Correlating Dayside Reconnection to Nightside Region 2 Field-Aligned Currents during Auroral Substorms**
**Co-Author(s):** Connor Chang, United States Military Academy (current co-author); Anna Maria Dear, United States Military Academy (previous co-author); Anastasia Osborne Black, United States Military Academy (previous co-author)

The increase in the prevalence of Region 2 Field-Aligned Currents (R2 FACs), or Birkeland currents, connecting the magnetosphere and ionosphere are correlated to a previous strong southward magnetic field component in the solar wind. The question remains whether we can predict the timing of these events during non-storm time substorms to help predict lag, outages, and scintillation. We assume that since the solar wind magnetic field turns southward and transfers energy through frozen-in plasma across the polar region, we can cross-correlate the two to determine the lag leading to an accurate prediction of aurora and substorms. Initially, solar wind data from the Advanced Composition Explorer (ACE) satellite and auroral intensity data collected by a meridian spectral photometer at Poker Flat Research Range (PFRR) in Fairbanks, Alaska were collected. Cross-correlations between the data sets were performed to determine the lag between the detection of southward solar wind magnetic field and their appearance to determine the cause of R2 FACs in relation to when reconnection happens. In the initial study, three dates in 2014 were selected for a cross-correlation analysis and it was determined that diffuse auroral intensity (inferred from meridian spectral photometers) detection lags the southward turning of the solar wind by approximately two hours, which is approximately the time of a substorm expansion phase. Our updated study in 2024 narrows dates from a code directory to select non-storm time substorms and subsequently performs a time-lagged cross-correlation between the nightside R2 FACs and the day-side reconnection. Updated datasets also include summary plots from AMPERE to show magnetospheric activity as well as SuperMAG and ground magnetometer datasets from Poker Flat, AK to focus on the activity and timing of R2 FACs. Although refinement of the analysis is required, the ability to accurately determine the lag between southward solar wind magnetic field and their occurrence can help refine auroral prediction, which in turn can help mitigate issues for satellite-based communications, protection of the power grid, and position, navigation, and timing system errors caused by ionospheric scintillation.

**36. Eric Rodriguez** (United States Military Academy)
**Arctic Sensing and Forecasting**
**Co-Author:** Jack Brewster, Furman University

This project focuses on Arctic Sensing and forecasting, particularly concerning geomagnetic substorms and storms. This project is unclassified. There are no restrictions on the distribution of this presentation. This project supports several other projects as it is expected to be further used as an open-source service for the space weather community and essentially focuses on 'big data' collection for more straightforward analysis. The primary effort concerns ionospheric activity quantification and data collection and display, sourcing all data to one table. This also allows a user to specify a particular value that a variable must meet, allowing for quick filtering through many data points. This prevents the user from manually sifting through databases, saving time. Secondarily, this project focuses on analyzing the geomagnetic substorm indices IMF BZ, IMF |B|, Kp, Dst, SuperMag index, auroral electrojet index, and polar cap index, how they relate to one another, and when they become essential concerning one another. The experiment data provided through the query in this project is from the Poker Flat Research Range (PFRR), NOAA, and Madrigal database and is open to more sources in the future. This data is collected using the PFISR, Poker Flat Incoherent Scatter Radar, and previous sounding rocket experiments conducted at PFRR and indices. In the future, in addition to using PFISR data, this project will also incorporate data and images from NASA's network of All Sky Imagers located across North America, providing valuable optical data on auroral activity.

# Thursday, 18 April

## *Solar and Interplanetary Research and Applications*

## *Geospace/Magnetosphere Research and Applications*

## *Space Weather Policy and General Space Weather Contributions*

*Posters can be viewed all day, with dedicated times from* 9:45 AM -10:45 AM and 2:30 PM - 3:30 PM

**1. Robert Albarran** (University of California, Los Angeles)
**Kinetic Modeling of Ionospheric Outflows in Pressure Cooker Environments**
**Co-Author(s):** Matthew Zettergren, Department of Physical Sciences, Embry-Riddle Aeronautical University, Daytona Beach, FL; Doug Rowland, NASA Goddard Space Flight Center, Greenbelt, MD; Jeff Klenzing, NASA Goddard Space Flight Center, Greenbelt, MD; James Clemmons, Physics Department, The University of New Hampshire, Durham, NH

Plasma escape from the high-latitude ionosphere (ion outflow) serves as a significant source of heavy plasma to the magnetospheric plasma sheet and ring current regions. Outflows alter mass density and reconnection rates, hence global responses of the magnetosphere. A new fully kinetic and semi-kinetic model, KAOS (Kinetic model of Auroral ion OutflowS), is constructed from first principles which traces large numbers of individual O+ ion macro-particles along curved magnetic field lines, using a guiding-center approximation, in order to facilitate calculation of ion distribution functions and moments. Particle forces include mirror and parallel electric field forces, a self-consistent ambipolar electric field, and a parameterized source of ion cyclotron resonance (ICR) wave heating, thought to be central to the transverse energization of ions. The model is initiated with a steady-state ion density altitude profile and Maxwellian velocity distribution and particle trajectories are advanced via a direct simulation Monte Carlo (DSMC) scheme. This outlines the implementation of the kinetic outflow model, demonstrates the model's ability to achieve near-hydrostatic equilibrium necessary for simulation spin-up, and investigates L-shell dependent wave heating and pressure cookers scenarios. This paper illustrates the model initialization process and numerical investigations of L-shell dependent outflows and pressure cooker environments and serves to advance our understanding of the drivers and particle dynamics in the auroral ionosphere

**2. Luisa Capannolo** (Boston University)
**Preliminary Results on the Ionospheric Effects of Relativistic Electron Precipitation and the Solar Wind Conditions**
**Co-Author(s):** Wen Li, Boston University; Andrew Staff, Boston University; Robert Marshall, University of Colorado, Boulder; Grant Berland, Johns Hopkins University Applied Physics Laboratory; Qianli Ma, Boston University, University of California, Los Angeles; Vassilis. Angelopoulos, University of California; Nithin Sivadas, NASA Goddard Space Flight Center; Anton Artemyev, University of California; Xiaojia Zhang, University of Texas, Dallas; Xiaochen Shen, Boston University; Murong Qin,

Boston University; Miroslav Hanzelka, Helmholtz-Zentrum Potsdam; Katharine Duderstadt, University of New Hampshire; Drew Turner, Johns Hopkins University Applied Physics Laboratory

The Earth's outer belt is populated by energetic particles, including relativistic (>700 keV) electrons. When geomagnetic activity is induced by solar wind (SW) fluctuations, plasma waves are excited and often scatter the outer belt electrons into the atmosphere. Relativistic electron precipitation (REP) affects the atmospheric chemical composition and ionization, possibly contributing in disrupting communications and altering the radiative balance through ozone depletion.
We collected precipitation events from the ELFIN CubeSats and found that REP is primarily observed on the duskside, most efficient at high-energies (>~MeV), but also observed at ~200 keV. We also quantified the average atmospheric ionization due to REP and found that relativistic electrons can affect the atmosphere over a broad range of altitudes, peaking in the mesosphere – a region where energy deposition is often overlooked.

To advance our knowledge on the distribution and flux intensity of REP, we are currently extending the dataset of events using the POES/MetOp constellation and analyzing the precipitation depending on SW conditions, with the ultimate goal of predicting REP occurrence (location and intensity) from the L1 monitors. Our preliminary work shows that REP from 14 to 4 MLT occurs during dayside reconnection, while REP from 4 to 14 MLT might be associated with a closed and compressed magnetosphere.
This research is crucial for improving our understanding of the SW-REP relationship, the dynamics of the Earth's radiation environment, and the energy input into the atmosphere.

**4. Anna Kelbert** (U.S. Geological Survey)
**Validation of Geoelectric Field Estimation using Measurements from Magnetotelluric Surveys**
**Co-Author(s):** Christopher Balch, University of Colorado - Cooperative Institute for Research in Environmental Sciences (CU/CIRES) and NOAA Space Weather Prediction Center (SWPC); Greg Lucas, University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics; E. Joshua Rigler, U.S. Geological Survey); Jordan Guerra Aguilera, CU/CIRES and NOAA SWPC

During geomagnetic disturbances, quasi-direct (DC) currents are induced along electric power transmission lines and flow from the bulk power grid into the ground through transformer windings. This can result in operational difficulties as the transformers enter an abnormal condition called half-cycle saturation, which increases reactive power demand on the grid, generates abnormal harmonics in the current and voltage waveforms, and can cause heating in and around the transformers. Assessing the impact of a geomagnetic storm on the operations of an electric power grid requires knowledge of the geoelectric field at the Earth's surface, a phenomenon that in turn is caused by the interaction of the time varying geomagnetic field and the conductivity properties of the solid Earth in the footprint of the power grid.

One approach for estimating the geoelectric field at the surface has been to combine information from ground-based magnetic observatories with magnetotelluric (MT) impedance tensors as derived from MT surveys, to generate a near-real-time estimate of the ground-level geoelectric field over contiguous United States (CONUS), as has been done in the joint NOAA-USGS Geoelectric Field Maps 3D empirical operational data product [https://www.swpc.noaa.gov/products/geoelectric-field-models-1-minute]. The local magnetic field time series between the magnetic observatories is estimated using the method of spherical elementary currents (SECS) [Rigler et al., 2019 and references therein]. The MT impedances are time-stationary, frequency-domain transfer functions that relate the time variations in Earth's geoelectric field to time variations in Earth's geomagnetic field. These data reflect the local and regional electrical conductivity of the Earth and allow for accurate estimation of ground-level geoelectric field. Since 2006, continuous MT surveying of CONUS was supported through the National Science Foundation's (NSF's) USArray and the NASA, then US Geological Survey's (USGS) USMTArray projects. These efforts have provided a quasi-regular 70 km grid of long-period (10-10,000 sec) MT impedance observations covering most of CONUS.

The empirical tensors are also used by the MT community to obtain three-dimensional (3D) electrical conductivity models of various regions in CONUS. We collected these regional models in a coherent 3D electrical conductivity compilation for the entire CONUS, covering depths up to 250 km [Kelbert et al, 2019; Murphy et al, 2023]. We then developed a spherical-coordinate variant of ModEM 3D [Kelbert et al., 2014], a parallelized Fortran MT modeling and inversion code and employed that for high-resolution continental-scale forward modeling of MT impedances to create a gridded national impedance map, as detailed in the USGS Geomagnetism Program Research Plan [Love et al., 2020]. We compute and analyze the gridded MT impedances modeled at 0.1-degree resolution, and predicted at the Earth's surface at a range of frequencies for our composite CONUS 3D electrical conductivity model.

In this work, we compare ground measurements with simulated geomagnetic fields produced by the SECS model, simulated electric fields generated using 3D empirical MT impedances, and simulated electric fields generated using MT impedances derived from a high-resolution 3D earth conductivity model inverted from empirical MT impedances. We select geomagnetically disturbed time periods and compare the model outputs with electric field and magnetic field measurements that were obtained from surveys carried out during those disturbances.

**5. John Spritzer** (U.S. Geological Survey)
**Signal Enhancement of Ground-Based Magnetometer Data**
**Co-Author:** Claudia Rossavik, U.S. Geological Survey

Ground-based magnetic data are critical to space physics and geomagnetic observatory research. However, the quality of the recorded data is often affected by various external factors, including localized disturbances, weather conditions, and instrument noise. Signal enhancement techniques like normalized least mean squares adaptive filtering (NLMS) can be used to improve the data quality. We have developed a new algorithm integrating scalar and vector magnetometer data into an NLMS filter to enhance the signal-to-noise ratio significantly. Our new algorithm estimates the signals' correlation to determine the filter coefficients that can minimize the error between noisy and reference signals. By adjusting the filter weights based on the correlation estimate, NLMS removes uncorrelated noise and improves the signal quality of the noisy magnetometer. Our test setup includes five vector magnetometers aligned to true north and one scalar magnetometer. The five vector magnetometers are arranged in proximity so that the predominant uncorrelated noise between the sensors is inferred as instrument, and very localized, noise. We compare three different combinations of scalar and vector magnetometers simultaneously, where one magnetometer is the control, and the other two are test magnetometers for NLMS. We calculate the power spectral density of each dataset to analyze the noise floor and compare the normalized data's signal-to-noise ratio to assess the best noise reduction performance. The result is a significant improvement to noise reduction and removal from magnetometer data, making NLMS a powerful tool for signal enhancement of ground-based magnetometer data.

**6. Athanasios Boudouridis** (University of Colorado - Cooperative Institute for Research in Environmental Sciences (CU/CIRES) and NOAA National Centers for Environmental Information (NCEI))

**Background Removal for the High Energy Electron Channels of the Magnetospheric Plasma Sensor – High Energy, and its Connection to Galactic Cosmic Rays**

**Co-Author(s):** Juan Rodriguez, CU/CIRES and NOAA NCEI; Brian Kress, CU/CIRES and NOAA/NCEI; Trevor Leonard, CU/CIRES and NOAA/NCEI

The Space Environment In-Situ Suite (SEISS) on NOAA's GOES-16/-17/-18 satellites includes the Magnetospheric Particle Sensor – High Energy (MPS-HI), an instrument designed for measuring radiation belt electrons and protons that have energies responsible for charging of internal spacecraft elements that can lead to disruptive or damaging electrostatic discharges. The four high energy electron channels, two differential channels with effective energies ~1970 keV (E9) and ~2900 keV (E10), and two integral channels with threshold energies ≳2000 keV (E11) and ≳4100 keV (E10A), require background removal due to penetrating high energy protons. This is conducted in real-time for the operational Level 1b (L1b) product. The operational L1b product for channel E11 is used for real time alerts of an enhanced radiation environment by the Space Weather Prediction Center (SWPC). The background removal is essential for accurate flux specification of the high energy electron channels. The first step in this process is the assumption that the high energy protons responsible for the elevated electron backgrounds are due to Galactic Cosmic Rays (GCRs). We use high energy GCR proton fluxes from the Solar and Galactic Proton Sensor (SGPS) instrument (also onboard the GOES satellites), to estimate the level of contamination of the MPS-HI E9-E11 channels. We show 7 years of MPS-HI E11 electron fluxes and SGPS P11 (>500 MeV) proton fluxes from the GOES-16 spacecraft (2017-2023), in order to evaluate the connection between the GCRs and the E11 backgrounds. We calculate the E11 background fluxes by modeling the peak of the electron distribution and the counts below the peak (the background counts) with a Gaussian distribution. We do the same for the SGPS P11 counts, and use the means of the two distributions to estimate the "background removal coefficients" that are used in real time to remove the GCR background counts from the MPS-HI E9-E11 electron channels. We perform this process periodically, every a few months, for the entire GOES-16 mission, to assess the stability of the resulting "background removal coefficients" over time, and thus evaluate the validity of our methodology in which the E9-E11 backgrounds, assumed to be due to the GCR fluxes, are accurately captured by the SGPS P11 (>500 MeV) fluxes.

**7. Jordan Guerra** (University of Colorado - Cooperative Institute for Research in Environmental Sciences (CU/CIRES) and NOAA Space Weather Prediction Center (SWPC))
**Estimating the Impact of the Magnetometer Network on the SWPC Geoelectric Field Model**
**Co-Author:** Chris Balch, CU/CIRES and NOAA/SWPC

We performed a leave-one-out analysis in order to study the impact of the operational network of magnetometers on the SWPC geoelectric field model. The geoelectric field model has two main components: 1) the magnetic interpolator (MI), which uses geomagnetic data from the magnetometer network and the Spherical Elementary Currents (SECS) method to evaluate the magnetic field disturbance everywhere, and 2) the geoelectric field calculator, which combines the SECS model output with information about the ground conductivity. In this study we create an ensemble of SECS and geoelectric field model runs: one reference run in which all magnetometers are included, and many test runs in which one magnetometer is excluded from the SECs interpolation. The main goal of this study is to compare geomagnetic and geoelectric response time series at the test location and characterize the differences between the reference run and the test runs. This methodology only accounts for the uncertainties introduced by the SECS model due to the geographical configuration of the magnetometer network. Our results indicate that both geomagnetic and geoelectric field vector correlations are higher when the distance to the closest station is smaller. In particular, SWPC geomagnetic and geoelectric Fields appear to produce vector fields with high reliability (i.e., correlation values > 0.8) for grid points located within ~200-300-km radius from a magnetometer. However, these results display some dependence with the test site's geographical location – the correlation-distance relation decreases faster for stations located northern than 50 degrees in latitude. Furthermore, taking into account the locations of all magnetic stations (not just the closest to the test site) shows that beyond this ~200-300 km radius, the angular distribution of stations (relative to the test site) might play an important role. This implies that locations inside the network (e.g., surrounded by stations) might have more accurate fields than points in the periphery. The magnetometer network currently used in the nowcasting (operational) SWPC geoelectric field model – a combination of US Geological Survey (USGS) and Natural Resources Canada (NRCan) stations – is in a configuration such that any given model grid point over north america (up to 60 degree north) is, on average, 484 km to the nearest magnetometer. Our results suggest the addition of magnetic observatories to the operational network is needed.

**8. Natalia Ganushkina** (University of Michigan)
**Unique and Unpredictable 1-100 keV Electrons in the Earth's Inner Magnetosphere**

Electrons with energies of 1-100 keV constitute a significant part of the inner magnetosphere population. These electrons are the seed population for the radiation belts, being accelerated to MeV energies by various processes in the Earth's inner magnetosphere. Electrons within 10-50 keV energy range that surround spacecraft can cause surface charging. At present, the behavior of keV electrons is a puzzle in many ways. Their fluctuations occur on a time scale of minutes and their fluxes are local time-dependent. Increasing geomagnetic activity does not necessarily lead to the enhancements of their fluxes. Changes of 2-3 orders of magnitude in fluxes have been observed during smaller disturbances (e.g., isolated substorms) but without any clear dependence on the substorm strength. Accurate specification of 1-100 keV electrons at different orbits is of a key importance. Operational model in the inner magnetosphere, Inner Magnetosphere Particle Transport and Acceleration model (IMPTAM) provides the keV electron flux at all L-shells and at all satellite orbits (imptam.engin.umich.edu). It is driven by the real time solar wind and IMF parameters and by the real time Dst index but no matter how well it may predict, it is not a valid tool for effectively testing hypotheses about physical drivers.

We investigate the drivers of 1–100 keV electron flux in the inner Earth's magnetosphere employing statistical analysis of GOES 13/15/17/18, Van Allen Probes and THEMIS data, SWPSNN (Solar Wind Plasma Sheet Neural Network) model, and using autoregressive moving average transfer functions (ARMAX) multiple regression models which remove the confounding effect of diurnal cyclicity and allow assessment of each parameter independently.

**9. Michael Hartinger** (Space Science Institute)
**Including Ultra Low Frequency Waves in Space Weather Models and Statistical Analyses: Lessons Learned From Recent Studies**
**Co-Author(s):** Xueling Shi, Virginia Tech; Joseph Baker, Virginia Tech; Terry Liu, University of California, Los Angeles; Dong Lin, High Altitude Observatory, National Center for Atmospheric Research; Martin Archer, Imperial College London

Due in part to their large amplitudes and long event durations, magnetospheric Ultra Low Frequency (ULF) waves have been linked to several space weather phenomena, including geomagnetic/geoelectric field variations and ionospheric heating. Past studies show they can lead to significant space weather impacts, for example driving geomagnetically induced currents that are among the largest ever reported at some mid-latitude locations. However, because of the spatial and temporal dependence of these waves, they are often attenuated, eliminated, and/or not accounted for in space weather models and statistical analyses. We highlight lessons learned from several recent studies and related recommendations for properly accounting for ULF waves in space weather models and statistical (or hazard) analyses: (1) use of uniform 10-s or 1-s samples at mid- and low-latitude locations to capture expected wave frequencies, (2) using power spectra rather than time series when conducting superposed epoch analysis to avoid averaging out wave activity with arbitrary frequency/phases, (3) using geoelectric field dynamic power spectra rather than geomagnetic field time series to avoid obscuring contributions from ULF variations to geomagnetically induced currents, (4) use of sufficient grid resolution (~<1/8 Re cells) upstream of the Earth’s magnetosphere when simulating ULF waves in space weather models. More work is needed to quantify the contribution of ULF waves to, for example, overall ionospheric heating rates and overall geomagnetic/geoelectric hazard analyses. However, general conclusions concerning the contributions of ULF waves to these phenomena should be avoided if the above recommendations aren’t followed.

**10. Ilja Honkonen** (Finnish Meteorological Institute)
**Current Status and Future Outlook of Global Space Weather Models at Finnish Meteorological Institute**
**Co-Author:** Riku Jarvinen, Finnish Meteorological Institute

Space weather has been modeled at Finnish Meteorological Institute (FMI) for over 40 years, starting with geomagnetically induced currents since 1980s, global magnetohydrodynamic (GMHD) modeling of Earth since 1990s and global hybrid particle-in-cell (GHPIC) modeling of several solar system planets, moons and smaller bodies since early 2000s. We describe the current status and future outlook of space plasma modeling at FMI, concentrating on global space weather models of Earth, Mercury and other celestial bodies.

The GMHD model GUMICS developed at FMI has been utilized for nearly 30 years, and was recently parallelized and used to simulate over 20 years of the interaction of solar wind measured by ACE with Earth's magnetosphere and ionosphere. We present an update to this work which includes a few years of results with higher magnetospheric resolution than used originally. The GHPIC model HYB developed at FMI has been used for over 20 years, with its parallel version RHybrid developed during the past decade. Solar system bodies modeled with GHPIC at FMI include, for example, Mercury, Venus, Mars, Moon and comets. We show examples of latest analysis concentrating on induced magnetospheric processes, solar wind driven atmospheric erosion and physics of comparative planetary space weather.

Global space plasma models of FMI are based on modular libraries and modern C++ using an object-oriented template architecture. A parallel grid and other libraries shared between models provide synergy in developing and coupling different plasma descriptions. We demonstrate a staggered magnetic field solver under development for improved robustness and parallel efficiency of GUMICS magnetospheric solution. To our knowledge this is the first time that such a solver includes support for cell-based run-time adaptive mesh refinement and temporal substepping. We also discuss current development efforts which includes adding support for both parallel run-time adaptive mesh refinement and electron physics with full kinetic plasma description to GHPIC.

**11. Shibaji Chakraborty** (Virginia Tech)
**SCUBAS: A Python-Based Numerical Model to Estimate Electrical Surges in Submarine Cables During Geomagnetic Disturbances**
**Co-Author(s):** X. Shi, Virginia Tech; M. D. Hartinger, Space Science Institute; D. Boteler, Natural Resources Canada

Submarine cables are crucial for global internet connectivity, but their vulnerability to extreme space weather events remains uncertain. Understanding and mitigating this risk is essential for maintaining reliable communication infrastructure. This study aims to develop a computational model to assess the induced voltages in submarine cables during geomagnetic disturbances. The model, implemented in Python, utilizes parameters such as ocean and Earth conductivity, cable length, and magnetic observatory data to estimate induced voltages. By providing a user-friendly software tool, researchers and engineers can evaluate the impact of geomagnetic events on submarine cables. Through theoretical explanations and practical demonstrations, this study enhances our understanding of submarine cable behavior under extreme space weather conditions. Ultimately, this research contributes to the preparation and mitigation of potential disruptions to submarine cable systems, ensuring the resilience of global communication.

**12. Fadil Inceoglu** (University of Colorado - Cooperative Institute for Research in Environmental Sciences (CU/CIRES) and NOAA National Centers for Environmental Information (NCEI))
**Correcting Arcjet Contamination in GOES MAG Using Various AI Methods**
**Co-Author(s):** Alison Jarvis, CU/CIRES and NOAA/NCEI; Paul T. M. Loto'aniu, CU/CIRES and NOAA/NCEI; Aspen Davis, CU/CIRES and NOAA/NCEI; Sarah Auriemma, CU/CIRES and NOAA/NCEI

The Geostationary Operational Environmental Satellite (GOES) missions have been continuously measuring the Earth's magnetic field at geostationary orbit for the past 40 years, covering nearly 4 solar cycles. The data obtained from these missions are used in operational settings by National Oceanic and Atmospheric Administration's Space Weather Prediction Center for detecting geomagnetic storms, substorms and motion of the magnetic field through magnetopause crossings. In addition to the operational use of the magnetic field data from GOES missions, scientists all around the world use these data to study the geospacer, radiation belt dynamics, magnetosphere, and geomagnetic storms in detail.

These studies require high-quality and continuous data. Unfortunately, the magnetic field measurements from the GOES-R spacecraft shows some contamination, which sometimes reach about 20 nT, which is quite significant considering the average geomagnetic field is around 100 nT. These contaminations are observed to be caused by the Arcjet firing, which use hydrazine thrusters, for periodic orbital maneuvers to stay in the planned geostationary orbit.

In this work, we used 4 different AI methods, which are XGBoost, LightGBMs, LSTMs, and Transformer Networks. The former two methods are tree-based regressors, while the latter two are based on Neural Networks. The results show that the tree-based methods provide better results compared to those that are based on neural networks.

**13. Weichao Tu** (West Virginia University)
**Revamping Models of Energetic Electron Precipitation Based on Realistic NOAA/POES Response Functions**
**Co-Author(s):** Zhi Gu Li, West Virginia University; Richard Selesnick, Retired

Accurately quantifying the global precipitation of energetic electrons is critical for assessing electron loss from the inner magnetosphere and its effects on magnetosphere-ionosphere coupling and atmospheric chemistry. Modeling the energetic electrons at low altitudes also has important space weather applications, e.g., for the proliferated low-Earth orbit constellations. The electron fluxes measured by multiple NOAA/POES and MetOp satellites near and inside the loss cone have been extensively used in studies of global electrons precipitation. However, nominal field-of-view (FOV) response of the MEPED particle telescopes on POES and MetOp has been most used in the literature. In our recent published work, we found that the 0-degree MEPED telescope, intended to measure precipitating electrons, instead usually measures trapped or quasi-trapped electrons as the 90-degree telescope, except during times of fast pitch angle diffusion. Consequently, using a nominal FOV response of MEPED could lead to an overestimation of the electron precipitation by orders of magnitude. In this work, we will implement the realistic angular response of MEPED into a drift-diffusion model to create a revamped model for the global precipitation of energetic electrons. The model includes the physics of pitch angle diffusion, azimuthal drift, and atmospheric backscatter and will be used to simulate the low-altitude electron distributions observed by multiple POES and MetOp satellites. The newly modeled global precipitation maps of energetic electrons will be compared with the ones that were generated by assuming nominal FOV response functions to illustrate the significance of using the realistic MEPED response functions in the precipitation quantification.

**14. Sanele Lionel Khanyile** (South African National Space Agency)
**Geomagnetic Jerks Observed in Geomagnetic Observatory Data Over Southern Africa Between 2017 and 2023**
**Co-Author:** Dr. Emmanuel Nahayo, South African National Space Agency

Geomagnetic jerks are jumps observed in the second derivative of the main magnetic field that occur on annual to decadal timescales. Understanding these jerks is crucial as they provide valuable insights into the complex dynamics of the Earth's outer liquid core. In this study, we investigate the occurrence of geomagnetic jerks in geomagnetic observatory data collected at southern African magnetic observatories, Hermanus (HER), Tsumeb (TSU), Hartebeesthoek (HBK) and Keetmanshoop (KMH) between 2017 and 2023. The observatory data was processed and analyzed by retaining quiet night-time data recorded during quiet geomagnetic activities with the help of Kp, Dst and ring current RC indices. Results confirm the occurrence of 2019-2020 geomagnetic jerk in the region and identify the recent 2021 jerk detected with V-shaped secular variation changes in X and Z components at all four observatories. The highest estimated 2021 jerk secular acceleration amplitudes in X and Z components were found at HBK, 12.7 nT/year^2 and 19. 1 nT/year^2, respectively. Notably, the global CHAOS-7 model aptly identifies this 2021 jerk in the Z component at all magnetic observatories in the region.

**15. Hongfan Chen** (Department of Mechanical Engineering, University of Michigan)
**Global Geomagnetic Perturbation Forecasting with Quantified Uncertainty using Deep Gaussian Process**
**Co-Author(s):** Gabor Toth, Department of Climate and Space Sciences and Engineering, University of Michigan; Yang Chen, Department of Statistics, University of Michigan; Shasha Zou, Department of Climate and Space Sciences and Engineering, University of Michigan; Xun Huan, Department of Mechanical Engineering, University of Michigan

Accurately predicting the horizontal component of the ground magnetic field perturbation (dBH), as a proxy for Geomagnetically Induced Currents (GICs), is crucial for estimating the impact of geomagnetic storms and remains a topic under active investigation. The current state-of-the-practice Geospace model is computationally expensive for fine-grid global simulations, while existing machine learning methods consistently tend to underestimate dBH. Additionally, these models either lack uncertainty quantification (UQ) or provide UQ that lacks calibration. In this work, as part of the NextGen SWMF project funded by NSF, we develop a data-driven, grid-free global model using deep Gaussian process (DGP), a Bayesian non-parametric approach that forecasts the maximum dBH in 20-minute temporal bins for the full surface of Earth with calibrated uncertainty. The model uses solar wind measurements and the Dst index as input, and it is trained based on ground magnetometer station data provided by SuperMAG over the period 2003-2013 to estimate the spatial-temporal correlation of dBH on the full surface of Earth. The model's predictions are evaluated based on the Heidke skill score (HSS) for a total of 23 storms with a SYM-H

index < -50 nT in 2015. The results demonstrate that our model outperforms the state-of-the-art model, with predictions exhibiting high accuracy in mid-latitudes and high-latitude regions in the northern hemisphere.

**16. Arfa Mubashir** (Georgia State University)
**Correlation Study and Time-Lag Analysis Between Cosmic Ray Intensity and Solar Activity Parameters at Different Geomagnetic Cutoff Rigidities**
**Co-Author(s):** Ashwin Ashok , Georgia State University; Ernesto Potdevin, Georgia State University Enosh Herath Mudiyanselage, Georgia State University; Tharindu Hettiarachchi, Georgia State University; Viacheslav M Sadykov, Georgia State University; Xiaochun He, Georgia State University

Variations in solar activity cause cosmic ray flux changes at different temporal scales and geopositions. Our aim is to determine the correlation and cross-correlation time lag between various space parameters and cosmic ray muon counts from two detectors installed at different geomagnetic positions (one in Atlanta, Georgia and the other at Mt Wilson, California, USA). These two detectors are part of the worldwide network of low-cost and portable cosmic ray muon detectors which is under development at Georgia State University for monitoring the space and terrestrial weather at a global scale. To validate our findings, we compare the muon flux measurements with measurements from the Oulu neutron monitor at low cutoff rigidity. The parameters under consideration include sunspot number, solar wind plasma, the Bz component of the interplanetary magnetic field, the Kp index, and the Dst index. Our results indicate significant correlations between cosmic ray intensities at different geomagnetic cutoff rigidities and the space activity parameters. Additionally, our time-lag analysis, employing cross-correlation techniques, aligns well with previously reported findings.

**17. Estacio, Ben** (Johns Hopkins University, Applied Physics Laboratory (JHU/APL))
**Applied Space Weather at JHU/APL**
**Co-Author(s):** John Hicks, Johns Hopkins University, Applied Physics Laboratory; Pat Dandenault, Johns Hopkins University, Applied Physics Laboratory; Joe Comberiate, Johns Hopkins University, Applied Physics Laboratory; Matt Zuber, Johns Hopkins University, Applied Physics Laboratory

At the Johns Hopkins University Applied Physics Laboratory (JHU/APL) we are well known for our space and space weather science missions such as the Van Allen Probes and Parker Solar probe. Missions such as these have advanced understanding of space weather in our solar system. In addition to the science work, we at JHU/APL have interests in the application of space weather to spacecraft hardware, spacecraft operations, and working with/around space weather to enable novel missions. These applications encompass both Civil and National Security Space interests. They range from operations that take place in very Low Earth Orbit (vLEO) to missions to the edge of the sun's influence. Our software has enabled tool transition from research to operations for multiple end users, with more capabilities on the way. We research the effects of space weather on hardware, no matter the distance from the Sun, engineering better systems and enabling more robust spacecraft with more capabilities. Through laboratory experiments, modeling, and analysis we are working to enable future technologies such as on orbit manufacturing, sustained vLEO, and novel power systems in orbit or on the lunar surface taking into account or exploiting space weather. We will present the breadth of applications that JHU/APL is considering, the resources JHU/APL has, and how the work being done on space weather applications may be of interest to the broad space weather community.

**18. José Miguel Espinoza Acosta** (University of Santiago de Chile)
**Plasma Pressure Gradients in the Dynamics of the Earth's Magnetosphere During Geomagnetic Storms**
**Co-Author(s):** Rodrigo López, University of Santiago de Chile; Marina Stepanova, University of Santiago de Chile; Elizaveta Antonova, Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University and Space Research Institute RAS, Moscow, Russia

The balance between the solar wind's dynamic pressure and the Earth's magnetosphere, known as magnetostatic equilibrium, is a fundamental aspect of space physics and is crucial for understanding space weather phenomena. Both historical and contemporary data have underscored the significance of this balance, which is described by the Grad-Shafranov equation. This equation provides a nuanced correlation between plasma pressure gradients and fluctuations in the geomagnetic field. In this study, we introduce an advanced model employing a dipolar approximation of the magnetic field, integrated with specific conditions derived from magnetohydrodynamic equations in order to obtain a self-consistent solution between plasma pressure profiles and the geomagnetic field during strong geomagnetic storms. Our methodology incorporates numerical and mathematical techniques, with a focus on finite difference discretization for solving partial differential equations. We compare our results with empirical data from space missions such as RBSP and THEMIS. Our preliminary results offer a more comprehensive insight into the modulation of the geomagnetic field by plasma pressure gradients, ultimately leading to more accurate models of the Earth's magnetosphere dynamics based on the Dst index.

**19. Kathryn Wilbanks** (University of Michigan)
**Multi-model Ensemble Forecasts of Ground Magnetic Perturbations**
**Co-Author:** Daniel Welling, University of Michigan

In our dynamic space weather environment, there are several impacts of space weather to our current infrastructure. Notably, ground magnetic disturbances (GMDs) that can interrupt and damage power grids. As such, it's paramount to provide actionable space weather forecasts of GMDs. Meteorological forecasting has already shown the robust uses of ensemble forecasting. However, a multi-model ensemble forecast for GMDs has yet to be implemented.

In this work, we present results from a first-of-its-kind multi-model ensemble for forecasting GMDs. Utilizing the open data set from Pulkkenin et al. 2013, we combined five models to produce different configurations of a multi-model ensemble forecast. Analysis of these ensembles were compared to results from the operational Space Weather Modeling Framework, the state-of-the-art in deterministic GMD forecasting. It was found that some ensemble combination strategies are able to improve forecast performance, while others lower predictive skill. The main obstacle to improving skill via multi-model ensembles is the predilection of all models towards underprediction. Being able to show feasibility of ensemble models in space weather forecasting is an important next step for the community as we explore new methodologies and applications.

**20. Valeriy Tenishev** (NASA Marshall Space Flight Center)
**Dynamics of Solar Energetic Particles in Geospace**

Solar energetic particles (SEPs) penetrate deep into the geospace and the Earth's atmosphere, initiating nuclear and chemical reactions. These reactions produce secondary hadrons, leptons, and photons, posing radiation hazards at commercial aviation altitudes, particularly during high-latitude flights. During solar particle events, protons with energies above 10 MeV can reach below 100 km altitude, causing ionization that disrupts HF communication and navigation in polar regions.

Galactic Cosmic Rays (GCRs) and Solar Energetic Particles (SEPs) pose radiation risks to satellites, astronauts, and ground infrastructure. High-energy particles can lead to single-event effects in spacecraft electronics, such as upsets, latch-ups, and burnouts. These particles also interact with the Earth's atmosphere, generating ionization and secondary particles like hadrons, leptons, and photons, creating hazards for astronauts, especially during extravehicular activities.

The work presented in the paper is focused on characterizing the SEP population in geospace in the altitude range starting from that of LEO through MEO and GEO, and up to the magnetopause accounting for the realistic geomagnetic field. The dynamics of SEPs are studied during quiet and geomagnetically active times using Monte Carlo simulations. The paper discusses the variability of the SEP population in geospace in response to geomagnetic activity.

The former manifests in the temporal trapping of SEPs in geospace and the suppression of rigidity cutoff during geomagnetic storms.

**21. Carina Alden** (NASA Goddard Space Flight Center (GSFC)/Catholic University of America (CUA))
**The Moon to Mars (M2M) Space Weather Analysis Office: Overview of Support, Validation, and Outreach Activities**
**Co-Author(s):** Michelangelo Romano, NASA GSFC / CUA; Teresa Nieves-Chinchilla, NASA GSFC Anna Chulaki, NASA GSFC / CUA; Mary Aronne, NASA GSFC / CUA; Mattie Anastopulos, NASA GSFC / CUA; Hannah Hermann, NASA GSFC / CUA; Tony Iampietro, NASA GSFC / CUA; Melissa Kane, NASA GSFC / CUA; Mary Keenan, NASA GSFC / ADNET Systems, Inc.

The Moon to Mars (M2M) Space Weather Analysis Office, located within the Heliophysics Science Division at NASA’s Goddard Space Flight Center, provides real-time space weather assessments in support of NASA human and robotic missions. As an integral part of NASA’s in-house R2O2R pipeline, M2M serves as a proving ground for new capabilities that can be transitioned to operational entities while also populating the Community Coordinated Modeling Center’s (CCMC) Database Of Notes, Knowledge, Information (DONKI) with real-time space weather analysis in support of the research community. Additionally, M2M collaborates with NASA Johnson Space Center’s Space Radiation Analysis Group (SRAG) and NOAA’s Space Weather Prediction Center (SWPC) to analyze space weather and characterize the space radiation environment in support of the Artemis program. M2M’s impact extends beyond analysis and model validation with the group’s activity within the broader heliophysics community through international educational and outreach activities. In this poster, we highlight M2M’s space weather analysis work, validation efforts, and outreach/educational activities.

**22. Anthony DeStefano** (NASA Marshall Space Flight Center)
**Solar Cycle 25 Model Prediction Comparisons: An Engineering Perspective**
**Co-Author:** Ronnie Suggs, NASA Marshall Space Flight Center

The solar cycle 25 progression is ramping up, prompting satellite operators to provide estimates of propellent usage over the next several years. Drag due to atmospheric heating from solar activity is the main driver to satellite lifetime decay, especially for those in low-Earth orbit destinations. In this poster, several model predictions of the sunspot number are compared and discussed with comments on applicability to engineering programs.

**23. James Mothersbaugh III** ((University of Colorado - Cooperative Institute for Research in Environmental Sciences (CU/CIRES) and NOAA National Centers for Environmental Information (NCEI))
**50 Years of GOES XRS Science-Quality Data**
**Co-Author(s):** Janet Machol, CU/CIRES and NOAA/NCEI; Ann Marie Mahon, CU/CIRES and NOAA/NCEI

The X-Ray Sensor (XRS) instrument has flown on every Geostationary Operational Environmental Satellite (GOES) mission since GOES-1 launched in 1975. XRS measures solar irradiance in the X-ray region in 2 bandpasses, at 0.05-0.4 nm (short channel) and 0.1-0.8 nm (long channel). The GOES XRS data is used by the NOAA Space Weather Prediction Center (SWPC) to forecast the effects of space weather phenomena on Earth, and is also used by solar scientists to understand the statistics and dynamics of solar flares. This poster discusses science-quality data from GOES 1-18. The GOES 8-12 XRS science-quality data is complete. This reprocessing removes the incorrect "SWPC scaling factor" adjustment, sets data quality flags, and fills in data gaps, all of which have already been done for the science-quality GOES 13-18 data sets. In the last year, the average irradiance, daily background irradiance, flare summary, and flare detection products have been reprocessed and completed for GOES 8-12. Additionally, we present plans for completion of the GOES 1-7 XRS science-quality data, and the GOES 1-15 composite flare report product.

**24. Dhirendra Kataria** (Southwest Research Institute)
**Cross-Calibration of Solar Wind Instruments for Space Weather and Science**
**Co-Author:** Heather Elliott, Southwest Research Institute

Measurements of solar wind particle densities and velocities are crucial for space weather monitoring. Several plasma instruments are currently in operation within the inner solar system, e.g., Stereo, Solar Orbiter, PSP, ACE and Wind and several others e.g., Aditya, IMAP and VIGIL, are or will be making their way to L1 and L5 over the next few years. Plasma instruments are also an important part of the GOES, GOES-Next and Hermes platform. Calibration and cross calibration of these assets will be a crucial aspect for efficient exploitation of the data for space weather as well as for science of the heliosphere. In addition, plasma instruments exhibit considerable performance variability over their lifetimes and under different solar wind conditions. During extreme space weather events for example, the electron multiplier detectors used for detection of the incoming plasma tend to saturate, providing large errors in the measurements. In this paper, we discuss several aspects that result in performance variability of these instruments and discuss techniques that are typically employed to correct for these variations. We also discuss potential techniques that can be used to calibrate in-flight and cross-calibrate these different assets at their different heliospheric locations.

**25. Zachary Marsh** (Teledyne Brown Engineering)
**Compact Sensor Package Provides Adaptable Solution to Space Weather Awareness**
**Co-Author(s):** Jeff King, Teledyne Brown Engineering; Byron Bonds, Teledyne Brown Engineering

The ECP-Lite Space Radiation Sensor is a space-worthy device that can be hosted on satellite platforms to provide in situ sensing of the space weather environment. Collecting space weather information on-board the host satellite provides situational awareness of the radiation environment and hazards such as surface charging or single event effects (SEEs) that operators or algorithms can use to adjust the operating parameters of other instruments (e.g., switching to "safe mode"). The data also can be leveraged to explain anomalies in telemetry or unusual spacecraft behavior. Collected data can be used on board the spacecraft, at a dedicated ground station, or shared with a central database maintained by a Government agency to contribute to improved knowledge of the natural/ambient radiation environment in orbit regimes of operational relevance to satellite operators. This could be a "one stop shop" for space weather analysis data to complement observations from the Space Weather Prediction Center operated by the National Oceanic and Atmospheric Administration (NOAA).

The device contains 6 micro-sized radiation detectors, 2 photodiodes, an electrostatic discharge recorder, surface charging plate, and 1 surface dosimeter which measures plasma currents in a 2.5 kg, 1667 cc package. Each dosimeter will measure the total-ionization-dose (TID) behind a specified shield thickness. Shield thicknesses are chosen to create electron and proton integral energy channels that are used to derive a dose-depth curve data product for long-term assessment of total ionizing dose and near-instantaneous dose rates (and equivalent integral proton and electron flux) at various depths for shorter-term hazard assessments.

**26. Iver Cairns** (University of Sydney)
**Towards An Australian Centre of Excellence in Space Weather**
**Co-Author(s):** David Pontin, University of Newcastle; Melanie Johnston-Hollitt, Curtin University; Suelynn Choy, RMIT University; Brad Carter, University of Southern Queensland; Michael Wheatland, University of Sydney; Brett Biddington, Biddington Research; Alina Donea, Monash University; Richard Marshall, Bureau of Meteorology; Hannah Schunker, University of Newcastle; Daniel Baker, University of Colorado at Boulder, CO; Gary Zank, University of Alabama at Huntsville, AL; Nick Pogorelov, University of Alabama at Huntsville, AL; Yu Lin, University of Auburn, AL; The Bid Team

A group of Australian, American, British, Indian, and Japanese colleagues are developing a bid for an Australian-based but internationally linked Centre of Excellence in space weather research. The Centre is intended to be broad and to complement existing international efforts. It currently aims to understand, predict, and verify space weather observationally from the Sun to the ground in time for benefit and mitigation. Research program titles are presently Sun & interplanetary, Earth system, stellar-solar, and end-user applications, with cross-cutting themes of risk & policy, workforce development, education, and outreach. At the workshop we seek to learn from and of international efforts, identify complementary programs, and find additional partners for mutual benefit.

**27. Bent Ehresmann** (Southwest Research Institute)
**MSL/RAD Radiation Measurements on the Surface of Mars During Solar Maximum**
**Co-Author(s):** Don Hassler, Southwest Research Institute; Cary J. Zeitlin, Leidos Innovations Corporation; Robert F. Wimmer-Schweingruber, University of Kiel, Germany

Mars possesses only a thin atmosphere with a few tens of g/cm^2 of vertical column depth. Thus high-energy particles (for example, protons with energies > 150 – 170 MeV) can penetrate deep into the atmosphere and ground. Thus, the radiation environment on the surface of Mars consists mainly of Galactic Cosmic Radiation (GCR) and their secondary particles created by interactions in the atmosphere or soil. Additionally, spontaneous Solar Energetic Particles (SEPs), emitted from the Sun during solar storms, can dominate the Martian surface radiation field on short time scales of hours to days. Protecting future human astronauts from exposure to this radiation remains one of the major challenges for the exploration of Mars.

To understand this radiation environment and how it changes over time, the Radiation Assessment Detector (RAD) has been measuring the radiation environment on the Martian surface aboard the Curiosity rover since landing in August 2012. The RAD measurements, thereby, provide vital information on the radiation exposure and potential health risks for future human explorers of Mars. As a space weather monitor on Mars at 1.5 AU, RAD measurements also provide valuable information for the space weather and heliophysics communities. For example, they provide insight into the intensity and timing of the arrival of SEPs, in particular their high-energy component.

Here, we present updated measurements of the evolution of the Martian surface radiation environment over the last few years during the rising phase of the current solar maximum. Thereby, we mainly focus on measurements of the absorbed radiation dose, and calculations of the dose equivalent based on the quality factor derived from RAD LET (Linear Energy Transfer) measurements. Furthermore, we present updated measurements of SEP events and other relevant solar features, such as Forbush decreases, that RAD was able to detect.

**28. Joan Burkepile** (High Altitude Observatory (HAO), National Center for Atmospheric Research (NCAR))
**Near-real-time Coronal Mass Ejection Alerts as part of an Early Warning Forecasting System for Solar Energetic Particle (SEP) Events**
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The NCAR Mauna Loa Solar Observatory (MLSO) COSMO K-Coronagraph (K-Cor) issues near-real-time coronal mass ejection (CME) alerts (when MLSO is operating) to the community and to

NASA's Community Coordinated Modeling Center Solar Energetic Particle (SEP) scoreboard for use by the NASA Space Radiation Analysis Group in support of the Artemis mission. K-Cor has a field-of-view from 1.05 to 3 solar radii with 15-second cadence images to study CME onset and dynamics in the low and middle corona. Data are fully processed in less than 2 minutes using a fully automated pipeline that includes CME detection. The K-Cor field-of-view, high time cadence and low latency data, combine to provide an early warning CME detection capability as part of a SEP forecasting system, as pointed out by St. Cyr et al. (2017). Most of the K-Cor alerts are issued before the CME enters the LASCO field-of-view. When LASCO data latency is included, we show that K-Cor alerts can provide the first warning of in-progress CMEs tens of minutes to an hour before the CME can be seen in available LASCO data. Data latency will be lower for the upcoming CCOR coronagraph, however the inner field-of-view of CCOR is 3.6 solar radii (vs LASCO 2.1 solar radii) requiring more time for the CME to travel to be visible in CCOR images. K-Cor CME alerts provide early detection of CMEs along with speed and location information that can be combined with CME measurements from CCOR images to improve forecasts.

We discuss the CME detection system and performance statistics. We present characteristics of CMEs in the low and middle corona that are associated with SEP events. We discuss ongoing work to improve performance and highlight the benefit of a ground-based coronagraph network (I,e. ngGONG mission).

**29. Erin Lynch** (NOAA National Environmental Satellites, Data, and Information Services, Office of Space Weather Observations)
**User Engagement for NOAA's Space Weather Next Program**
**Co-Author:** Nai-Yu Wang, NOAA National Environmental Satellites, Data, and Information Services, Office of Space Weather Observations

The National Oceanic and Atmospheric Administration (NOAA) is implementing the Space Weather Next (SW Next) program to provide continuity of critical space weather observations and enhancements beyond current capabilities. In formulating the SW Next program, the Office of Space Weather Observations (SWO) within NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) relies on user engagement to support mission milestones. This poster describes the SWO framework for user engagement and recent user engagement work. User engagement for SW Next consists of three phases: (1) understanding user needs, (2) ensuring user readiness, and (3) user sustainment. Currently, SWO is assessing user needs to understand how operational space weather users, such as NOAA's Space Weather Prediction Center (SWPC), end users impacted by space weather like power grid and satellite operators, and the science community, rely on space weather observations. The information collected will inform the development of requirements, architecture and instrument selection, and planning for its next generation satellite missions and data products.

As launches of SW Next observatories approach, focus will shift from identification of user needs to ensuring the readiness of users to incorporate SW Next data products into their applications and optimizing the transition to operations. The final phase of user engagement focuses on sustainment. NOAA plans to achieve this by ensuring that SW Next products continue to meet user needs through calibration and algorithm adjustments, the development of new products, and the identification of new data sources. User engagements are supported by close collaboration with operational centers like SWPC, National Aeronautics and Space Administration (NASA), and other stakeholders. The collection and understanding of user needs also feeds back into NESDIS enterprise portfolio management. Therefore, these efforts proceed in close collaboration with the NESDIS Office of Systems Architecture and Engineering (SAE).

**30. Laurel Rachmeler** (NOAA National Centers for Environmental Information (NCEI))
**NOAA Space Weather Products: User Input & Feedback**
**Co-Author(s):** Howard Singer, NOAA Space Weather Prediction Center; Erin Lynch, NOAA National Environmental Satellites, Data, and Information Services, Office of Space Weather Observations

NOAA solicits your feedback on any and all NOAA products! What do you think of what we create and share with you? We would like to know if you have suggestions, comments, feedback, or requests on any and all of our products. Examples of 'products' may include satellites & measurements, data products, models and model output, forecasts, alerts, warnings, data access, etc. Please submit your input via this simple Google Form (https://forms.gle/CfzaHJJHenpduR8h8).

**31. Laura Sandoval** (University of Colorado, Boulder (CU), Laboratory for Atmospheric and Space Physics (LASP))
**I-ALiRT System for Forecasting Space Weather**
**Co-Author(s):** Greg Lucas, CU/LASP; Evan Brookens, CU/LASP; Steve Monk, CU/LASP; Kristopher Larson, CU/LASP; Eric R. Christian, NASA Goddard Space Flight Center; Christina O. Lee, University of California, Berkeley; David J. McComas, Princeton University; Arik Posner, NASA Headquarters

The Interstellar Mapping and Acceleration Probe (IMAP) mission includes the Active Link for Real-Time (I-ALiRT) system to forecast Space Weather phenomena. IMAP I-ALiRT will continually broadcast data 24/7 from the IMAP observatory, facilitated by NASA's Deep Space Network (DSN) of ground stations as well as antennae partners across the globe. The IMAP Science Data Center (SDC) at the Laboratory for Atmospheric and Space Physics (LASP) will play a critical role in this architecture, receiving I-ALiRT data from ground stations and implementing a real-time, low-latency processing pipeline. I-ALiRT will utilize AWS cloud resources to facilitate efficient data ingest and processing. Data products will be made available through the IMAP Science Data Center. We will present the Cloud Architecture plans, emphasizing how we intend to leverage cutting-edge technology to provide real-time space weather data products to the public and forecasting centers.

**32. Phillip Chamberlin** (University of Colorado, Boulder (CU), Laboratory for Atmospheric and Space Physics (LASP))
**Near Real-Time Flare Monitoring at Mars from MAVEN EUVM**
**Co-Author(s):** Rita Borelli, CU/LASP; Frank Eparvier, CU/LASP; Ed Thiemann, CU/LASP; Gina Dibraccio, NASA Goddard Space Flight Center; Christina Lee, University of California, Berkeley

Space Weather has traditionally explored the Sun's immediate influence on the Earth system and its technology, including the direct impact on humans. With increasing missions to Mars and beyond, as well as future plans to send humans to Mars, space weather has recently expanded to include not only Mars, but also the entire heliosphere. One critical asset that has made studying space weather at Mars possible is NASA's Mars Atmosphere and Volatile Evolution mission (MAVEN). MAVEN has instruments on board to not only study the solar irradiance, solar wind, and energetic particles, but also the in-situ and remote sensing instruments to directly measure the Sun's impact, and its variability, on the Martian environment. This presentation focuses on the near real-time products from the EUV Monitor (EUVM), providing flare timing and magnitude/class similar to what is provided by the NOAA/GOES/XRS channels at Earth. The three near real-time space weather data products from EUVM will be presented and discussed. Additionally, the well-established personnel, tools, and methods of NASA's Community Coordinated Modeling Center (CCMC) and Moon-to-Mars (M2M) Space Weather Analysis Office make a perfect pairing to provide the assets capable of real-time space weather monitoring and data serving of the space weather at Mars, and this Space Weather Collaboration will also be presented.

**33. Janelle Shank** (Millersville University)
**Using Geospatial Technology to Identify High Risk Areas In Precision Farming**
**Co-Author:** Tamitha Skov (Millersville University)

Idaho has the second largest population growth in the United States as of 2023. The current population growth in Idaho is taking farmland at a rapid pace and there are currently no policies to correct it. Because of the reduced availability of land, farmers are searching for land elsewhere and being pushed further to the mountains. Idaho is located at higher magnetic latitude than the majority of states in the USA. At these latitudes GPS is at a higher risk for signal disruption from space weather events during geomagnetic storms. Since there are mountainous areas in Idaho, these regions are already at risk for GPS signal disruptions due to the blockage of signals by the mountains themselves, which increase multi-path signal reception errors. Therefore, farmers scouting for new land to develop need new tools that can both capture and quantify the unique problems associated with GPS-enabled precision farming in both mountainous and high magnetic-latitude terrain. One such tool that will aid farmers is a custom GIS tool. The purpose of this project is to outline the development and application of a new GIS tool designed to enhance how precision farming planning is undertaken. Furthermore, this new approach employs GIS tools to develop methodologies in the creation of a new, space-weather-sensitive metric by determining "risk zones" for the degradation of GPS signal reception, especially in regions where space weather susceptibility is high.

**34. Anthony Williams** (Millersville University)
**A Statistical Analysis of Heliobiology: Exploring Connections Between Space Weather and Human Health**
**Co-Author(s):** Christopher Stieha, Millersville University; Tamitha Skov, Millersville University

Solar storms are highly complex and powerful phenomena that have a significant impact on the Earth and the solar system at large. As scientists are learning more about the interaction of the sun and the Earth, some are turning their attention to the impacts that space weather might have on human health. This discipline of research on how the sun can directly affect biological organisms is called Heliobiology. Along with driving space weather events during its 11 year solar cycle, the sun also has a direct influence on the amount of Galactic Cosmic Rays (GCR) that the Earth receives. The purpose of this study is to take a statistical approach to understand if there are any correlations between significant space weather events, GCR, and human health.

**35. Steven Meloney** (Napa Valley College)
**Cosmic Ray Project**
**Co-Author(s):** Suhail Mohammed, Napa Valley College; Jorge Alejandre, Napa Valley College

Cosmic rays are high energy particles that rain down on Earth from outer space at the speed of light. The objective of the Cosmic Ray Project was to introduce ourselves to the field of Particle Physics by constructing a cloud chamber which would allow us to observe particle tracks firsthand, and by analyzing datasets from the Cosmic Ray e-Lab to measure the lifetime of a muon. A cloud chamber has a supersaturated vapor cloud inside that is just on the verge of condensing. When a cosmic ray enters the chamber, it causes a small disturbance in the vapor cloud which can be seen with the naked eye. Muons decay into smaller particles such as the muon neutrino, the electron neutrino, and the electron. Using an array of scintillators we are able to measure the amount of time this decay takes. Muons decay randomly, so a statistically meaningful number of decays must be recorded in order to produce a reliable muon lifetime value. We calculated a mean muon lifetime of 2.1943 microseconds with a standard error of +-0.23 microseconds. Our mean value is within a hundredth of a microsecond of the accepted average lifetime of 2.1969 microseconds. Understanding cosmic rays is important because they help us to understand more about the cosmos; from our own stellar neighborhood to the edges of the visible universe.

**36. Jorge Padial** (Vanderbilt University)
**Automatically Labeled EUV and X-Ray Incident Solarflare Catalog**
**Co-Author(s):** Kelly Holley-Bockelmann, Department of Physics and Astronomy, Vanderbilt University; Eric Jonas, Department of Computer Science, University of Chicago

Large solar flares and events associated with them, like Coronal Mass Ejections, are rare but highly destructive phenomena that can impact social, economic, and digital infrastructure on Earth. Attempts have been made to use different machine learning (ML) algorithms tasked with predicting which Active Regions (AR) will erupt within a predetermined time frame. Regardless of model complexity or the amount of data being fed into these classifiers, >10 years of ML applied to flare prediction yield similar evaluation metrics (TSS ~ 0.7). We hypothesize that this stagnation is a result of incorrect labeling of AR's as flare producing or non-flare producing, which is being fed into these models. Evidence stems from the incomplete localization of historical solar flares compiled from canonical databases. In order to test this hypothesis, we have developed the Automatically Labeled EUV and X-Ray Incident SolarFlare (ALEXIS) catalog.

Solar flare locations, peaks, magnitudes, and associated AR are learned by ALEXIS by recreating the full-disk X-Ray flux from XRS as a weighted linear combination of discrete regions as observed by multi-pixel images. This is possible by applying contemporary computer vision techniques coupled with clustering, differential time-series analysis, and convex optimization to the full resolution and cadence of the XRS, AIA and SXI data. A proof of concept run of ALEXIS was run locally parsing through 14 TB of data in search of 1057 solar flares of C-class magnitudes and above, randomly selected between March 2010 - May 2020. Comparison of ALEXIS's catalog with the catalogs produced by SWPC and SolarSoft show that these databases incorrectly localize 56% and 18% of the flares, respectively. Additionally, ALEXIS increased the amount of flares in this subsample by 34%, has provided the first observational

evidence for synchronous flares, and has proved that the flare durations (start, peak, end) and X-Ray labels as compiled by SWPC are misleading. ALEXIS has been granted 200 TB of storage and 20,000 node hours at the Argonne Leadership Computing Facility to run this pipeline on ~ 8,300 flare entries compiled by SWPC from March 2010 to May 2020. The ALEXIS catalog will compete with canonical databases and can also be modified to return near-real time flare detection.

**37. Nai-Yu Wang** (NOAA National Environmental Satellites, Data, and Information Services, Office of Space Weather Observations (SWO))
**NOAA Uses, Needs, and Plans for Off Sun-Earth Line at Lagrange Point 5 Observations**
**Co-Author(s):** Irfan Azeem, NOAA SWO; Jim Silva, NOAA SWO, Richard Ullman, NOAA SWO; Elsayed Talaat, NOAA SWO; V. Pizzo, NOAA Space Weather Prediction Center (SWPC); Eric Adamson, NOAA SWPC; Robert Steenburgh, NOAA SWPC

The launch of the National Aeronautics and Space Administration (NASA) Solar Terrestrial Relations Observatory (STEREO) in 2006 demonstrated the utility of off Sun-Earth line observations to improve space weather forecasting. The National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center (SWPC) uses STEREO data in real-time to model coronal mass ejections (CMEs) for improved Wang-Sheeley-Arge (WSA)-Enlil predictions of CME arrival at Earth. STEREO in-situ solar wind, interplanetary magnetic field, and energetic particle data are used to monitor the evolution of co-rotating structures with lead times of days before any potential impact on Earth. As a result, the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) will be supplying the Naval Research Laboratory (NRL) Compact Coronagraph 3 (CCOR-3) to the European Space Agency's (ESA) Vigil mission to the Lagrange 5 (L5) point mission. Additionally, research has shown pathways to using particle data and heliospheric imaging data to further improve forecasting of space weather. NOAA is also interested in the planned Vigil magnetograph for improved solar wind modeling and for the longer lead time solar flare predictions it will enable. We will present the NOAA current uses of STEREO data and plans for future observations and space weather product improvements.

**38. Greg Lucas** (University of Colorado, Boulder (CU), Laboratory for Atmospheric and Space Physics (LASP) and Space Weather Technology, Research, and Education Center (SWx TREC))
**SWx TREC Tools for Forecasting, Nowcasting, and Verification**
**Co-Author(s):** Jennifer Knuth, CU LASP and SWx TREC; Chris Pankratz, CU LASP and SWx TREC Thomas Berger, SWx TREC

The Space Weather Technologies Research and Education Center (SWx TREC) at the University of Colorado, Boulder has a growing suite of tools and applications designed for the critical tasks of space weather forecasting, nowcasting, and verification.

We will provide a live demonstration of some of these data-driven tools (publicly available at https://swx-trec.com) which provide real-time information about rapidly changing space weather conditions. SWx TREC's tools combine predictions and observational data for validation and in order to foster continuous improvement.

SWx TREC leverages pioneering space weather data access methodologies to drive state-of-the art computational models and analysis tools. These agile, easy-to-use visual applications are designed to improve space weather forecasts and understanding—capabilities vital for safeguarding critical infrastructure such as satellite communication systems, GPS networks, and power grids from the adverse effects of solar and geomagnetic storms.

SWx TREC is committed to sharing its knowledge and expertise with the broader community through education and outreach initiatives. Our applications are built on platform of reusable components and we are able to respond quickly to user requests. SWx TREC hopes this growing suite of tools will contribute to space weather awareness in our increasingly interconnected and technologically reliant world.

**39. Dale Gary** (New Jersey Institute of Technology (NJIT), Center for Solar-Terrestrial Research)
**A Solar-Dedicated Instrument for Real-Time Meterwave Radio Spectral Imaging**
**Co-Author(s):** Bin Chen, NJIT Center for Solar-Terrestrial Research; Surajit Mondal, NJIT Center for Solar-Terrestrial Research; Gregg Hallinan, California Institute of Technology, Pasadena, CA; OVRO-LWA Team, California Institute of Technology, Pasadena, CA

The Owens Valley Radio Observatory Long Wavelength Array (OVRO-LWA), an all-sky imager operating in the range 13-88 MHz, is now operating with longer baselines and a new solar-dedicated backend to provide commensal daily solar imaging observations. The 352 antenna elements provide baselines to 2.6 km (5 arcmin resolution at 80 MHz). Modes include (1) a solar-dedicated beam with 3072 frequencies (24 kHz resolution) measured simultaneously over 13-88 MHz at 1 ms time resolution, (2) a slow-visibility interferometric imaging mode with 10 s time resolution on all baselines for extremely sensitive imaging of slowly varying emission, and (3) a fast-visibility interferometric imaging mode at 0.1 s time resolution on baselines of 48 selected antennas for stronger bursts of more rapid variability. A near-real-time pipeline producing ultra-high-sensitivity spectrograms and images within minutes is now operational at https://ovsa.njit.edu/status.php. Even lower-latency data products are feasible with more computing resources, if determined to be useful for operational purposes.

**40. Ian Cohen** (Johns Hopkins University, Applied Physics Laboratory (JHU/APL))
**Space Weather Science at JHU/APL**
**Co-Author(s):** Alex Chartier, Johns Hopkins University, Applied Physics Laboratory; Matina Gkioulidou, Johns Hopkins University, Applied Physics Laboratory; Juliana Vievering, Johns Hopkins University, Applied Physics Laboratory; Pat Dandenault, Johns Hopkins University, Applied Physics Laboratory; Drew Turner, Johns Hopkins University, Applied Physics Laboratory

The Johns Hopkins University Applied Physics Laboratory (APL) boasts a broad array of capabilities relevant to space weather (SWx). This starts with a broad array of world-class researchers with significant experience studying every aspect of relevant space weather phenomena spanning the sun, solar wind, radiation belts, cislunar space, and the ionosphere-thermosphere-mesosphere region. Across these various research domains, APL has the science and engineering capability to design, test, build, and operate an equally broad range of in-situ and remote sensing instrumentation to obtain the scientific and operational measurements necessary to understand and monitor space weather phenomena. Finally, APL also features a deep bench of scientists, researchers, and engineers skilled at applying a diverse set of experience and analytical tools – including cutting-edge machine learning techniques - to address the unique computational and engineering problems presented by space weather. In the coming decade, APL plans to accelerate its leadership in the area of solar and space physics with a new focus on space weather. APL looks to unite a diverse set of government, commercial, and public stakeholders to enable a national and cross-agency space weather initiative that includes opportunities for research, technology, and a new line of missions to study the Sun–Earth system.