
**2023 Space Weather Workshop Poster Abstract Booklet**
**Boulder, CO**

*Organized by day and poster number, with virtual-only posters at the end of the booklet.*

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## Tuesday April 18 Posters

## *Solar and Interplanetary Research and Applications*

Posters can be viewed all day, with dedicated times from 9:35 AM - 10:35 AM and 2:45 PM - 3:45 PM

Poster Lightning Talks are from 5:00 - 5:30 pm MDT (see listing in Meeting Program)

**1 Wu, Chin-Chun** (US Naval Research Laboratory)
**Evolution of a Coronal Mass Ejection from 2.5 Solar Radii to the Earth and Beyond**
**Co-Author(s):** Keiji Hayshi, George Mason University, Fairfax, USA; Kan Liou, Applied Physics Laboratory, Laurel, USA

Currently, there are two general approaches in magnetohydrodynamic (MHD) simulations of the global solar wind (with or without a coronal mass ejection, CME) in the heliosphere: (1) initiating a coronal model from the surface of Sun and merging the model result with a solar wind model at ~0.1 AU and (2) initiating the solar wind MHD model at ~0.1 AU with empirical and theoretical boundary conditions. The first approach can be cumbersome and impractical in space weather operation, whereas the second approach does not provide information about the CME and its driven shock within 0.1 AU (e.g., first ~4 hours, assuming Vcme = 1000 km/s). Here, we present a new modeling capability aiming for space weather. The model propagates a flux-roped coronal mass ejection from the source surface (2.5 Rs) to ~1 AU in a single model. This model is based on our G3DMHD solar wind model with three improvements: (1) extending the inner boundary from 18 Rs to 2.5 Rs, (2) adding the characteristic-based boundary treatment (Nakagawa et al., 1987; Wu and Wang, 1987) at the inner boundary to improve the model stability, and (3) injecting a self-contained magnetic flux-rope model (Chen, 1996) into the system at 2.5 Rs. We will demonstrate this new capability by simulating background solar wind in July 2007, and the CME event on July 12, 2012. Detailed results will be presented and compared with observation obtained at 1 AU.

**2 West, Matthew** (Southwest Research Institute)
**Resolving CME Characteristics with Polarized White Light Data**
**Co-Author(s):** Sarah E Gibson, National Center for Atmospheric Research, High Altitude Observatory; James Marcus Hughes, Southwest Research Institute; Ritesh Patel, Southwest Research Institute; Chris

Lowder, Southwest Research Institute; Craig DeForest, Southwest Research Institute; Daniel B Seaton, Southwest Research Institute; Anna V Malanushenko, National Center for Atmospheric Research, High Altitude Observatory

The line of sight propagation of coronal mass ejections (CMEs) throughout the heliosphere can be determined directly from total and polarized brightness measurements with instruments such as the LASCO, COR, and future PUNCH imagers. By using the physics of Thomson scattering applied to synoptic polarized images, and a symmetric three-polarizer measurement and representation system, the Stokes parameters can be derived, which in turn can be used to derive distances of structures. To accurately determine the position of structures measurements require relative photometric accuracy at a few percent precision, which is undermined by instrument and photometric noise, which redistributes measured polarization angles.

In this presentation the ability to accurately measure the 3D structure of imaged objects in the heliosphere, using polarized brightness measurements is assessed. ""Clean"" synthetic data produced with the Gamera model, forward modeled to look like white light coronagraph data using the HAO FORWARD algorithms, is used with a polarization resolver to determine the line of sight distance of synthetic CMEs. Additionally, realistic photometric (poisson) and instrument noise is applied to the data to assess the impact on the estimated positions of structures. The noisy data is subsequently ""noise-gated"" to reduce noise and mitigate its impact. The impacts of noise reduction, and how it can improve estimates of 3D position are assessed.

**3 Wang, Nai-Yu** (Office of Space Weather Observations (SWO), NESDIS, NOAA)
**NOAA's Compact Coronagraph Instrument for the ESA VIGIL Mission to Lagrange Point 5**
**Co-Author(s):** Eugene Guerrero-Martin, Goddard Space Flight Center, NASA; Jim Silva1, Irfan Azeem, Office of Space Weather Observations (SWO), NESDIS, NOAA; Rich Ullman, Office of Space Weather Observations (SWO), NESDIS, NOAA; Elsayed Talaat, Office of Space Weather Observations (SWO), NESDIS, NOAA; Damien Chua, US Naval Research Laboratory; Arnaud Thernisien, U.S. Naval Research Laboratory

One of the major drivers of space weather is coronal mass ejections (CMEs). NOAA/NASA Space Weather Observations (SWO) Programs Division is supporting development of the next-generation coronagraph instrument, called the Compact Coronagraph (CCOR). The CCOR is designed to detect halo coronal mass ejection that is Earth-directed. Coronagraph images are essential inputs to current operational numerical models that predict the arrival of a CME at Earth.

Three state of the art CCOR instruments are being developed for NOAA by the U.S. Naval Research Laboratory (NRL). The first CCOR instrument (CCOR-1) will be flown in a Geosynchronous Earth Orbit (GEO) on NOAA's GOES-U spacecraft, scheduled for launch in 2024. The second CCOR instrument (CCOR-2) will be flown on the Space Weather Follow On mission to the Sun-Earth Lagrange Point 1 (SWFO-L1) to be launched as a rideshare with NASA's Interstellar Mapping and Acceleration Probe (IMAP) mission in 2025. A third CCOR (CCOR-3) will be deployed as a NOAA contribution to the European Space Agency's (ESA) Vigil mission to the Sun-Earth Lagrange Point 5 (L5) in the 2029 timeframe. CCOR-3 is currently in phase-A requirement definition stage to achieve the desirable comparable performance characteristics with regard to cadence and angular resolution as CCOR-2 on SWFO-L1. Coordinated and concurrent coronagraph observations from L1 and L5 vantage points will improve the 3D characterization of CMEs.

In this presentation, we will describe the CCOR-3 instrument design, expected performances, and the potential space weather modeling and forecasting benefits from L5 vantage point.

**4 Vievering, Juliana** (Johns Hopkins Applied Physics Laboratory)
**Concept for Real-Time Solar Flare Predictions Using Early Flare Signatures**

**Co-Author(s):** P. S. Athiray, University of Alabama Huntsville; Juan Camilo Buitrago-Casas, Space Sciences Laboratory at the University of California Berkeley; Phillip Chamberlin, Laboratory for Atmospheric and Space Physics at the University of Colorado Boulder; Lindsay Glesener, University of Minnesota Twin Cities; Sam Krucker, Space Sciences Laboratory at the University of California Berkeley; Janet Machol, CIRES at the University of Colorado Boulder; Courtney Peck, Laboratory for Atmospheric and Space Physics at the University of Colorado Boulder; Marianne Peterson, University of Minnesota Twin Cities; Katharine K. Reeves, Harvard-Smithsonian Center for Astrophysics; Sabrina Savage, NASA Marshall Space Flight Center; Amy Winebarger, NASA Marshall Space Flight Center

Understanding when and where extreme solar flares and eruptive events will occur continues to be an important goal for the heliophysics community, from both fundamental science and space weather perspectives. Currently available flare forecasts typically fall into two main categories: (1) long-term probabilistic forecasts (e.g., probability that a flare of a certain magnitude is going to occur over the next 24 hours), and (2) flare alerts (e.g., notification when GOES X-ray flux reaches a high threshold). For a wide variety of operations and research purposes, there is an additional need for flare predictions that are more actionable than long-term forecasts and provide earlier notice of extreme events than current flare alerts do. To address this need, we seek to develop a tool using machine learning that rapidly aggregates near-real-time signatures of flare onset, including X-ray and EUV irradiance measurements, to provide early prediction of the magnitude and duration of ensuing solar eruptive events. In particular, real-time chromospheric and transition region measurements from GOES EUVS provide a direct measure of impulsive phase heating and energy deposition in the low solar atmosphere as an early indication of flare onset. Such a tool will provide crucial notice (~minutes) prior to the arrival of harmful radiation in near-Earth space to mitigate effects on astronauts and radio communications and will enable triggered observations of scientifically interesting events. Here we present our concept for real-time solar flare predictions and preliminary analysis of real-time EUV irradiance data from GOES EUVS for this application.

**5 Vassiliadis, Dimitris** (NOAA/NESDIS/SWO)
**Developing New and Updated Solar and Heliospheric Data Products for NOAA's Upcoming Space Weather Follow On (SWFO) Program**

NOAA's Space Weather Follow On (SWFO) program is planned to provide coronal imagery and heliospheric time series data to users of space weather information including the Space Weather Prediction Center's (SWPC) forecasters. To a large extent, the SWFO data products are a significant improvement over those of the DSCOVR mission as well as over several of the measurements of NASA's Solar and Heliospheric Observatory (SOHO) and Advanced Composition Explorer (ACE) missions. They include coronal imagery from 3 to 22 solar radii; solar wind plasma (esp. velocity and density) and magnetic field data, and suprathermal ion and electron fluxes. We will discuss the data levels and features for these products. We will also present the SWFO ground segment and its elements. One of the elements, Product Generation and Distribution, will be used to implement functions such as algorithm development, product generation and distribution, and data stewardship. The SWFO Science Center developed by NOAA's National Centers for Environmental Information (NCEI) and leveraging the NOAA Common Cloud Framework (NCCF) run by the Office of Common Services (OCS) will serve as the portal through which the community will be able to access the data. We will discuss the quality control process for algorithms and data products based on long-standing NCEI and SWPC practices and legacy from earlier missions.

**6 Singh, Talwinder** (University of Alabama in Huntsville)
**Solar Flare Forecasting using Machine Learning and SDO/HMI Data: A Comparison of Multiple ML Models and AR Parameter Time Series**
**Co-Author(s):** Christian Hall, University of Alabama in Huntsville; Timothy Newman, University of Alabama in Huntsville; Bernard Benson, McLeod Software Corporation; Syed Raza, University of Alabama in Huntsville; Nikolai Pogorelov, University of Alabama in Huntsville

Solar flares are explosive events that release massive amounts of energy, particles, and radiation into the space environment. Accurate forecasting of these events is crucial for space weather prediction and mitigation efforts. In this presentation, we will discuss the results of our study on solar flare forecasting using machine learning (ML) models and SDO/HMI data. We will compare the performance of multiple ML models, including K-Nearest Neighbors (KNN), Random Forest Classifier (RFC), Logistic Regression (LR), and Support Vector Machines (SVM), in predicting solar flares. Additionally, we will examine the difference in forecasting accuracy between Active Regions (ARs) that have flared before and ARs that have not flared yet.

Furthermore, we will show the improvement in forecasting metrics when a time series of AR parameters is used in training instead of point in time parameters. Specifically, we will investigate the use of AR parameters such as magnetic field strength, area, and complexity as features in our ML models. We will also discuss the potential of this approach to improve the overall accuracy of solar flare forecasting. Our study provides insights into the effectiveness of ML models for solar flare forecasting and the importance of AR parameter time series in improving the accuracy of such forecasts.

**7 Seaton, Daniel** (Southwest Research Institute)
**Space Weather Forecasting of Solar Eruptions and Solar Wind Outflow using Wide-Field EUV Images**
**Co-Author(s):** Amir Caspi, Southwest Research Institute; Craig DeForest, Southwest Research Institute; Ed DeLuca, Center for Astrophysics | Harvard & Smithsonian; Leon Golub, Center for Astrophysics | Harvard & Smithsonian; Alexander Krimchansky, NASA; James Mason, Johns Hopkins University Applied Physics Lab; Ritesh Patel, Southwest Research Institute; Kathy Reeves, Center for Astrophysics | Harvard & Smithsonian; Yeimy Rivera, Center for Astrophysics | Harvard & Smithsonian; Sivakumara Tadikonda, Science Systems & Applications Inc.; Matthew West, Southwest Research Institute

Traditional approaches to tracking solar outflows for space weather forecasting rely primarily on coronagraph images, which generally observe the solar corona above a minimum height of about 2.5 solar radii. EUV images have been widely used to characterize features on the solar disk, but only recently have instruments and imaging techniques been developed that provide views of the EUV middle corona - out to heights exceeding 5 solar radii. Here we present some recent highlights from the GOES Solar Ultraviolet Imager (SUVI) and Solar Orbiter' Extreme-Ultraviolet Imager (EUI) Full Sun Imager that illustrate the potential for these new types of EUV observations to contribute to space weather forecasting applications. We discuss how such images are useful for characterizing the early onset of eruptive events and outflow into the solar wind. They also reveal the origins of shocks that are known to accelerate particles and drive solar energetic particle (SEP) events. Because CMEs generally experience the bulk of their acceleration below the height of coronagraphic observations, these images provide information about the origins of these events that has not been available traditionally. Together with coronagraphic measurements, EUV images provide the continuous views needed to connect CMEs back to their source regions. We also highlight new and proposed missions that will further enable heliophysics and space weather science, including the Sun' Coronal Ejection Tracker (SunCET) CubeSat and the proposed EUV CME and Coronal Connectivity Observatory (ECCCO) Small Explorer, as well as opportunities for observations from the L5 Lagrange point via a hosted instrument on the Vigil mission.

**8 Sachdeva, Nishtha** (University of Michigan)
**Ensemble modeling to reconstruct remote and in-situ CME observations**
**Co-Author(s):** Gabor Toth, University of Michigan; Chip Manchester, University of Michigan; Bart van der Holst, University of Michigan; Aniket Jivani, University of Michigan; Hongfang Chen, University of Michigan; Zhenguang Huang, University of Michigan

Accurate space weather impact predictions require high-fidelity and high-skill modeling of solar transients like Coronal Mass Ejections (CMEs). The Space Weather Modeling Framework (SWMF) includes MHD modeling of the solar wind and CMEs from the Sun to the Earth and beyond. The Alfven Wave Solar atmosphere Model (AWSoM) is a 3D extended-MHD solar corona model within SWMF that

reproduces the solar wind background into which CMEs can propagate. The Eruptive Event Generator (EEG) module within SWMF is used to obtain flux-rope parameters to model realistic CMEs within AWSoM using different flux-rope configurations.

It is important to improve the models and tools using uncertainty quantification and data assimilation techniques to reconstruct CMEs. This is done by validating simulation results with multi-viewpoint observations of the solar corona and the inner heliosphere at various heliospheric distances.

In this work supported by the NSF SWQU and LRAC programs, we perform an ensemble of solar wind background simulations to obtain the best plasma environments into which CMEs can be propagated. We vary the flux-rope parameters to do an ensemble of CME simulations and compare the model reconstructed results with remote coronagraph observations near the Sun (LASCO C2/C3 and STEREO COR1/COR2) as well as with in-situ observations of solar wind plasma at 1 au. The ensemble modeling is a step forward towards improving the accuracy of the tools that provide flux-rope parameter estimates as well as quantifying the uncertainty in CME modeling.

**9 Pogorelov, Nikolai** (University of Alabama in Huntsville)
**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; Cooper Downs, Predictive Science Inc.; Christopher Gebhard, Lawrence Berkeley National Laboratory; Carl Henney, Air Force Research Laboratory; Shaela Jones, NASA Goddard Space Flight Center; Tae Kim, University of Alabama in Huntsville; Jon Linker, Predictive Science Inc.; Andrew Marble, University of Colorado, Boulder; Talwinder Singh, University of Alabama in Huntsville; James Turtle, Predictive Science Inc.; Lisa Upton, Southwest Research Institute; Brian Van Straalen, Lawrence Berkeley National Laboratory; Mehmet Yalim, University of Alabama in Huntsville; Dinesha V. Hegde, University of Alabama in Huntsville; Syed Raza, University of Alabama in Huntsville; Miko Stulajter, Predictive Science Inc.

To address Objective II of the National Space Weather Strategy and Action Plan 'Develop and Disseminate Accurate and Timely Space Weather Characterization and Forecasts' and US Congress PROSWIFT Act 116-81, our team has been developing a new suite of open-source software that would ensure substantial improvements of Space Weather (SWx) predictions. On the one hand, the focus is on the development of data-driven models. On the other hand, each individual component of our software is aimed to have higher accuracy with a substantially improved performance. This is done by the application of new computational technologies and enhanced data sources. The development of such software paves way for improved SWx predictions accompanied with an appropriate uncertainty quantification. This will make it possible to forecast hazardous SWx effects on the space-borne and ground-based technological systems, and on human health. Our models involve (1) a new, open-source solar magnetic flux model (OFT), 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) associated with the Wang-Sheeley-Arge coronal model, and (3) a new adaptive, 4-th order of accuracy solver (HelioCubed) for the Reynolds-averaged MHD equations implemented on mapped multiblock grids (cubed spheres). We describe the software and results obtained with it, including the application of machine learning to modeling coronal mass ejections, which makes it possible to improve SWx predictions by decreasing the time-of-arrival mismatch. The tests show that our software is formally more accurate and performs much faster than its predecessors used for SWx predictions.

**10 Mothersbaugh III, James** (NOAA National Centers for Environmental Information (NCEI) and University of Colorado Cooperative Institute for Research in Environmental Sciences (CIRES))
**50 Years of GOES XRS Science-Quality Data**
**Co-Author(s):** Janet Machol, NOAA NCEI and University of Colorado CIRES; Courtney Peck, University of Colorado Laboratory for Atmospheric and Space Physics (LASP); Erika Zetterlund

Rodney Viereck, NOAA Space Weather Prediction Center (SWPC); Ann Marie Mahon, NOAA NCEI and University of Colorado CIRES

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 through GOES-18. We are currently reprocessing the GOES-8 through -12 XRS data to create a science-quality data set. This reprocessing removes the incorrect "SWPC scaling factor" adjustment to the GOES-1 through -15 irradiances, corrects the bandpass calibration, sets data quality flags, smooths the calibrations, standardizes file formats, and fills in data gaps, all of which have already been done for the science-quality GOES-13 through -18 data sets. Additionally, we present plans for completion of the GOES-1 through -7 XRS science-quality data, and for future new XRS data products.

**11 McDonald, Samuel** (Department of Computer Science, Georgia State University)
**A Machine Learning Ecosystem for Filament Analysis - Phase I: A Manually Annotated Dataset of Filaments**
**Co-Author(s):** Rohan Adhyapak, Department of Computer Science, Georgia State University; Kartik Chaurasiya, Department of Computer Science, Georgia State University; Laxmi Alekhya Nagubandi, Department of Computer Science, Georgia State University; Apaar Bawa, Department of Computer Science, Georgia State University; Patrick Copeland, Department of Computer Science, Georgia State University; Aya Abdelkarem, Department of Computer Science, Georgia State University; Aparna Venkataramanasastry, Bay Area Environmental Research Institute; Petrus C. Martens, Department of Physics and Astronomy, Georgia State University; Azim Ahmadzadeh, Department of Computer Science, Georgia State University

Detecting and classifying solar filaments is critical in forecasting Earth-affecting transient solar events, including large solar flares and coronal mass ejections. Undetected, these space weather events can cause catastrophic geomagnetic storms resulting in substantial economic damage and  death. A network of ground-based observatories, named the Global Oscillation Network Group, was created to provide continuous observation of solar activity. However, parsing the large volume of image data continuously streaming in from GONG tests the limitations of human analysis and presents challenges for space weather research. To address this, we proposed the Machine Learning Ecosystem for Filament Detection (MLEcoFi), an NSF-funded, multiyear project that will produce an open-source collection of filament data and computer vision software for space weather research. In cooperation with NSO, MLEcoFi will assist in automatically detecting, classifying, localizing, and segmenting solar filaments in full-disk H-alpha images. The present phase of research aims to produce a dataset of thousands of GONG H-alpha images, with all filaments chirality, bounding box, and segmentation mask manually annotated following strong quality assurance standards, advancing research of filaments and filament-related topics. This dataset, as the first MLEcoFi product, will aid in ongoing and future development of products, including a chirality-aware filament data augmentation engine, high-precision image segmentation loss function, deep neural network segmentation and classification model, and filament detection module that is planned for deployment into NSO' live infrastructure for the research community. The MLEcoFi team is eager to present its progress and future milestones to obtain valuable feedback from the future users of this ecosystem.

**12 Massa, Paolo** (Department of Physics & Astronomy, Western Kentucky University)
**Solar Flare Nowcasting Using Multi-wavelength SDO/AIA Data**
**Co-Author(s):** A. Gordon Emslie, Department of Physics & Astronomy, Western Kentucky University; Ivan Novikov, Department of Physics & Astronomy, Western Kentucky University;  Jake Boils, Department of Physics & Astronomy, Western Kentucky University; Jarrett Packwood, Department of Physics & Astronomy, Western Kentucky University; Sabrina Guastavino, Department of Mathematics,

University of Genova (IT); Francesco Marchetti, Department of Mathematics “Tullio Levi Civita” University of Padova (IT); Michele Piana, Department of Mathematics, University of Genova (IT)

We consider the development of machine learning models to forecast the occurrence of solar flares a few tens of minutes in advance. Such results can be used to support projects such as the NASA Solar Flare Sounding Rocket Campaign in Spring 2024, during which three rocket-borne instruments will be launched near-simultaneously to observe the evolution of a flare. Accurate advance prediction of the flare will enhance the chances of observing the flare in its impulsive/rise phase. We have trained Convolutional Neural Networks (CNNs) on images of active regions recorded by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory (SDO/AIA) in seven EUV wavelengths at several consecutive timesteps, forming four-dimensional (x,y,Œª,t) "datacubes". These datacubes contain information on both morphological and thermodynamic changes within the active regions, both of which are likely precursors of flaring activity, and hence have an enhanced predictive capability compared to the magnetograms that are usually employed. We show preliminary results obtained by training CNNs on a dataset of active region datacubes recorded between 2010 and 2018. We also discuss Fourier-based data compression techniques that can be used to significantly reduce the size of the dataset while retaining its essential morphological and thermodynamic information. We also describe the training of CNNs on Differential Emission Measure (DEM) datacubes that are constructed from the original (x,y,Œª,t) datacubes by means of a novel Regularized Maximum Likelihood inversion algorithm.

**13 Lindsey, Charles** (NorthWest Research Associates)
**Machine Learning Utilities for Helioseismic Maps of Solar Activity**
**Co-Author(s):** Kiran Jain, National Solar Observatory/Global Oscillations Network Group; Andrés Asensio Ramos, Instituto de Astrofísica de Canarias (IAC); Tobias Felipe, IAC; Elena Garcia-Broock, IAC

Direct comparisons by McDonald et al. of helioseismic and magnetic observations of active regions in the Sun's near hemisphere in solar cycle 24 were useful in magnetically calibrating signatures of active regions in helioseismic maps of the Sun's far hemisphere. The near-hemispheric maps are distinctive in having sufficient spatial resolution to discriminate large sunspot umbrae from their penumbrae and surrounding plages. This offers enormous advantages in statistical weight and accuracy of the calibration curves derived. We will outline a collaboration between the Global Oscillations Network Group (GONG) at the National Solar Observatory (NSO) in Boulder, NorthWest Research Associates (NWRA), also in Boulder, and Instituto de Astrofísica de Canarias (IAC) on Tenerife in the Canary Islands, Spain, to develop machine-learning (ML) technology for recognition of new aspects of the helioseismic/magnetic relation that could be of interest to space weather forecasting.

**14 Leka, KD** (NWRA and Nagoya University / ISEE)
**Properties of Flare-imminent versus Flare-quiet Active Regions from the Chromosphere through the Corona**
**Co-Author(s):** Karin Dissauer, NWRA; Graham Barnes, NWRA; Eric L. Wagner, NWRA

We investigate whether parameters describing the state of the solar upper atmosphere can differentiate an active region that will imminently produce a solar flare from one that will not (Leka+2023). Using the AIA Active-Region Patches dataset (AARPs; Dissauer+2023) we construct 160 parameters from AIA brightness images and running-difference images that characterize the dynamics and heating of the upper solar atmosphere, including the temporal (time-series) evolutionary behavior. These new "AARP parameters", parallel to the HMI "SHARP parameters" (and also publicly available, see Leka+2023) were examined for all HARP patches June 2010--December 2018 (over 32,000 "HARP-day" samples) in the context of event definitions of C1.0+ and M1.0+ flare activity in the subsequent 6hr and subsequent 24hr. Using the NWRA Classification Infrastructure (NCI), a well-established statistical classifier system based on Non-Parametric Discriminant Analysis, we find top Brier Skill Scores in the 0.07 - 0.33 range, True Skill Statistics in the 0.68 - 0.82 range (both depending on event definition), and Receiver Operating Characteristic Skill Scores above 0.8. Classification success using higher-order moments of running

difference images indicates enhanced levels of short-lived brightenings in flare-imminent active regions. A high temperature ``memory" of flare activity is also found. The 94 A filter data provides the most parameters with discriminating power with indications that it benefits from sampling multiple physical regimes. This research was made possible by funding primarily from NASA/GI Grant 80NSSC19K0285 with some initial exploration through AFRL SBIR Phase-I contract FA8650-11-M-1147, and some final support from NASA/GI Grant 80NSSC21K0738 and NSF/AGS-ST Grant 2154653.

**15 Leamon, Robert** (UMBC/ NASA GSFC)
**F10.7, EUV Flux, Geoeffective CMEs, and Forecasts for Cycle 25**
**Co-Author(s):** Scott McIntosh, NCAR

The Sun's variability is controlled by the progression and interaction of the magnetized systems that form the 22-year magnetic activity cycle (the "Hale Cycle") as they march from their origin at ‚àº55¬∞ latitude to the equator, over ‚àº19 years. We will discuss the end point of that progression, dubbed "terminator" events, and our means of diagnosing them. Recently (https://doi.org/10.3389/fspas.2022.886670) we expanded on the Extended Solar Cycle framework to construct a new solar activity "clock" which maps all solar magnetic activity onto a single normalized epoch based on the terminations of Hale Magnetic Cycles. Defining phase 0*2œÄ on this clock as the Terminators, then solar polar field reversals occur at ‚àº 0.2*2œÄ, and the geomagnetically quiet intervals centered around solar minimum start at ‚àº 0.6*2œÄ and end at the terminator, thus lasting 40% of the cycle length. At this onset of quiescence, dubbed a "pre-terminator," the Sun shows a radical reduction in active region complexity and, like the terminator events, is associated with the time when the solar radio flux crosses F10.7 = 90 sfu.

We use this terminator-based clock to predict F10.7, X-Flares and EUV flux for the rest of Cycle 25. That cessation of activity at the 0.6 cycle point is currently predicted to be in early-mid 2027, and that prediction will be revised and made more precise at the solar polar field reversal, currently predicted to be in mid-2024.

**16 Landeros, Jaime** (California State Polytechnic University Pomona)
**Visualization of WSA Coronal and Solar Wind Forecasts**
**Co-Author(s):** Daniel E. da Silva, NASA Goddard Space Flight Center, Laboratory for Atmospheric and Space Physics, University of Colorado Boulder; C. Nick Arge, NASA Goddard Space Flight Center; Shaela I. Jones, NASA Goddard Space Flight Center

The Wang-Sheeley-Arge (WSA) Model has stood as an essential pillar in the realm of solar wind forecasting for more than a decade, but it has lacked an intuitive, centralized, and publicly accessible method for visualizing its empirical and physics-based corona and solar wind predictions. The development of a browser-based dashboard is well suited to fill this gap. It will provide forecasters with the ability to juxtapose recent in situ and full disk satellite observations and model predictions to assess model performance, as well as to allow scientists to investigate the model's detailed ensemble predictions from various satellite perspectives and compare them with observations. Visualized data include time series plots of solar wind speed and interplanetary magnetic field (IMF) polarity, as well as projected maps of derived coronal holes overlayed on EUV coronal hole observations, the heliospheric current sheet location at 5 solar radii, and probabilistic predictions of satellite-footpoint connectivity. Predictions are available for satellites dispersed throughout the Heliospheric System Observatory, including ACE, STEREO-A, PSP, and SolO. The project has been developed with maintainability and ease of deployment in mind with the Plotly Dash framework in Python, targeted JS functions to reduce latency, Git version control, and Docker containerization.

**17 Kubo, Yuki** (National Institute of Information and Communications Technology, Japan)
**Ground stations for Solar Wind Observation Satellites in Japan**

Monitoring a solar wind in real-time 24/7 is important for space weather forecasting. Deep Space Climate Observatory (DSCOVR) has observed a solar wind at L1 point since 2015. Because the DSCOVR is

located at L1 point, a downlink of the observed data in real-time in 24/7 is not possible by only one country. So, an international collaboration named Real-time Solar Wind Net (RTSWNet) is performed. We, NICT, are a member of RTSWNet, and operate a ground station of DSCOVR satellite.
As it has taken almost 8 years since DSCOVR was launched, NOAA has planned to launch DSCOVR follow-on satellite (hereafter, called SWFO-L1), and NICT has been approached by NOAA to be a partner of SWFO-L1 ground station network. We accepted the approach and started installing a ground station. In this poster, we introduce our ground stations for DSCOVR and STEREO satellites and current status of preparation of SWFO-L1 ground station.

**18 Krista, Larisza** (University of Colorado/CIRES, NOAA/NCEI)
**A DEFT way to forecast flares**
**Co-Author(s):** Matthew Chih, Marietta College; Paul Lotoaniu, University of Colorado/CIRES, NOAA/NCEI

Solar flares have been linked to some of the most significant space weather hazards at Earth. These hazards, including radio blackouts and energetic particle events, can start just minutes after the flare onset. Therefore, it is of great importance to identify and predict flare events. The Detection and EUV Flare Tracking (DEFT) tool identifies flare signatures and their precursors using high spatial and temporal resolution extreme-ultraviolet (EUV) solar observations from the Solar Ultraviolet Imager instrument aboard the GOES-R satellite. The unique advantage of DEFT is its ability to identify small but significant EUV intensity changes that may lead to solar eruptions. The tool can also identify the location of the disturbances and distinguish events occurring at the same time in multiple locations. In a study of 61 flares observed in 2017, the "main" EUV flare signatures (those closest in time to the X-ray start time) were identified on average 6 minutes early. The "precursor" EUV signatures (second-closest EUV signatures to the X-ray start time) appeared on average 14 minutes early. Our goal is to develop an operational version of DEFT which could significantly improve space weather forecast times.

**19 Krista, Larisza** (University of Colorado/CIRES, NOAA/NCEI)
**Solar Events During the STEREO-SOHO Quadrature**
**Co-Author(s):** Drew Manning, Colorado College

Between 2010 December and 2011 August the STEREO-A and B satellites were approximately at right angles to the SOHO satellite. This alignment was particularly advantageous for determining CME properties, since the closer a CME propagates to the plane of sky, the smaller the measurement inaccuracies are. Our primary goal was to study dimmings and their relationship to CMEs and flares during this time. We identified 53 coronal dimmings using STEREO/EUVI 195 √Ö observations, and linked 42 of the dimmings to CMEs (observed with SOHO/LASCO/C2) and 23 to flares. Each dimming in the catalog was processed with the Coronal Dimming Tracker (CoDiT) which detects transient dark regions in extreme ultraviolet images directly, without the use of difference images. This approach allowed us to observe footpoint dimmings: the regions of mass depletion at the footpoints of erupting magnetic flux rope structures. Our results show that the CME mass has a linear, moderate correlation with dimming total EUV intensity change, and a monotonic, moderate correlation with dimming area. Hence, the more the dimming intensity drops and the larger the erupting region is, the more plasma is evacuated. These results indicate that observing dimming properties has the potential to aid space weather forecasting efforts.

**20 Knuth, Jenny** (SWx TREC, University of Colorado, Boulder)
**New Space Weather Data Mashups: Collections and Correlations Using SWx TREC's Space Weather Data Portal Catalog**
**Co-Author(s):** Greg Lucas, SWx TREC University of Colorado Boulder; Thomas Berger, SWx TREC University of Colorado Boulder; Christopher Pankratz, SWx TREC University of Colorado Boulder

Investigating a space weather event's impacts across the heliosphere requires finding and comparing diverse observational data products and models from multiple data repositories and learning each repository's unique organizational structure.

SWx TREC's Space Weather Data Portal at https://lasp.colorado.edu/space-weather-portal is a tool that does this work for you by correlating diverse space weather data by date. The Portal organizes data held in disparate repositories by the date range of an event and then requests the selected data from the data's source, in real time, for display and downloading. This makes it easy to trace a solar event as it travels from the Sun to the Earth.

The reusable data catalog underlying the Portal makes it easy to present different collections of space weather data for different applications. For example, space weather now can be viewed at https://lasp.colorado.edu/space-weather-portal/now. Models such as Dst Live (swx-trec.com/dst) , MSIS (swx-trec.com/msis) , and Enlil (swx-trec.com/h3lioviz) can use data from the Portal catalog as inputs as well as to visualize observed data alongside predicted data.

The ability to quickly correlate diverse space weather data by event is essential to advancing space weather science. The SWx TREC Space Weather Data Portal is an example of a nimble, evolving technology that can bring together data on an axis of interest. In the case of space weather data, organizing the data by event makes it quick and easy to discover, display, and download relevant space weather data.

**21 Dhiren, Kataria** (Southwest research institute)
**Techniques to Improve the  Accuracy of Solar Wind Measuresurements with Electrostatic Analyzers**
**Co-Author(s):** Heather Elliot, Southwest Research Institute, San Antonio,  TX, USA; Rob Ebert, Southwest Research Institute , San Antonio,  TX, USA; Roman Gomez,  Southwest Research Institute, San Antonio,  TX, USA

Measurements of solar wind particle densities and velocities are crucial for space weather monitoring. These measurements are typically carried out with electrostatic analyzers, particularly with the top-type, tri-quadrispheric design. Top-hats provide considerably higher geometric factors relative to other electrostatic analyzer designs,  providing higher sensitivity and accuracy during quite wind conditions. However, during extreme space weather events, e.g., during CMEs, 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 and present techniques to improve measurement accuracies across all solar wind conditions using a combination of charged particle optics techniques and detector rate handling enhancements.

**22 Jackson, Bernard** (Center for Astrophysics and Space Sciences, University of California, San Diego)
**ASHI: The All Sky Heliospheric Imager: August 25-26 2022 Balloon Flight and Data Reduction Progress**
**Co-Author(s):** Matthew Bracamontes, Center for Astrophysics and Space Sciences, University of California; Stephen White, Air Force Research Laboratory, AFRL/RVBXD; Mario M. Bisi, Rutherford Appleton Laboratory Oxfordshire, United Kingdom; Andrew Buffington, Center for Astrophysics and Space Sciences, University of California, San Diego; Stuart Volkow, Center for Astrophysics and Space Sciences, University of California, San Diego; Ed Stephan, Stephan Design-Build, Haslet, TX; Philippe Leblanc, Stephan Design-Build, Haslet, TX; Ron Quillin, Stephan Design-Build, Haslet, TX

We have conceived, designed, and have evaluated components for an All-Sky Heliospheric Imager (ASHI), suitable for flight on future space missions. ASHI was tested last summer on a NASA-sponsored topside balloon flight; this presentation highlights the images taken and the current state of the image data reduction by this instrument on its successful overnight flight. ASHI is currently being promoted as a hosted payload on a DoD Space Test Program satellite. As a simple, light weight (~6kg), and relatively

inexpensive instrument, the ASHI system 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's unique optical system is designed to view a hemisphere of sky starting a few degrees from the Sun. A key photometric specification for the spacecraft ASHI is better than 0.05% differential photometry in one-degree sky bins at 90 degrees elongation that enables the three dimensional (3-D) reconstruction of heliospheric density extending outward from the Sun. The ASHI system, unlike coronagraphs or other planned heliospheric imagers, is intended to maximize the analysis of heliospheric structures that pass the spacecraft. This is especially important where recent high-resolution Solar Mass Ejection Imager (SMEI) and STEREO Heliospheric Imager (HI) analyses have shown CMEs have an evolving and corrugated structure when they pass nearby. A successful space-borne flight will have an order of magnitude more throughput than SMEI or the STEREO HI instrumentation, and thus provide a far better science and forecast capability than possible before.

**23 Hurlburt, Neal** (Lockheed Martin Advanced Technology Center (LMATC))
**IPSOS, the Imaging Photonic Spectropolarimeter for Observing the Sun**
**Co-Author(s):** Gopal Vasudevan, LMATC; Georgios Chintzoglou, LMATC

The Imaging Photonic Spectropolarimeter for Observing the Sun (IPSOS) demonstration mission develops and matures the technology developed MICRO, the Magnetograph using Interferometric and Computational imaging for Remote Observations - a disruptive imaging technology developed with NASA HTIDS and LM IRAD support. MICRO collapses the optical elements of an Imaging Spectro-Polarimeter (ISP) into a single, multilayer wafer, thus reducing the size and weight by orders of magnitude. And instead of painstaking manual assembly, these wafers are printed using photolithographic methods, leading to a dramatic reduction in cost with improved reproducibility. These revolutionary properties expand hosting opportunities and enable the formation of novel constellations combining traditional and non-traditional platforms for monitoring solar oscillations and magnetic fields.
We lack global measurements of the Sun, in part, due to the cost, which is driven by the expensive, high-mass ISPs needed to measure the Sun's magnetic field and surface velocity. IPSOS removes this impediment, enabling cost-effective global measurements. These measurements are best made in both the photosphere and chromosphere. IPSOS includes both with minimal additional impact to cost or mass. IPSOS enables cost-effective constellations that can provide complete solar coverage of magnetic and Doppler measurements at cadences and resolutions required for space weather research and forecasting and for global helioseismology.

**24 Hegde, Dinesha** (Department of Space Science & Center for Space Plasma and Aeronomic Research (CSPAR), University of Alabama in Huntsville)
**Modeling of the Coronal Mass Ejection that Triggered the Third-Largest Geomagnetic Storm of Solar Cycle 24**
**Co-Author(s):** Talwinder Singh, CSPAR, University of Alabama in Huntsville; Tae Kim, CSPAR, University of Alabama in Huntsville; Nikolai Pogorelov, Department of Space Science & CSPAR University of Alabama in Huntsville

Coronal mass ejections (CMEs) are powerful explosions on the Sun that can have a significant impact on the interplanetary medium and our planet. On August 26, 2018, during the declining phase of solar cycle 24, the third-strongest geomagnetic storm of the cycle occurred due to a CME that erupted from the Sun on August 20, 2018. Remarkably, this particular event was caused by a slower and smaller CME, which is unusual as fast and large CMEs are typically responsible for geomagnetic storms. Previous studies had reported that the flux rope associated with this CME had a complicated rotation in the interplanetary medium before it reached Earth, and the high-density structure in the magnetic cloud observed at Earth. In this study, we employ a constant-turn flux rope-based magnetohydrodynamic model to simulate the propagation of this CME through a time-dependent, data-driven ambient solar wind (SW). We utilize parameters from a graduated cylindrical shell model to constrain the flux rope model, which was obtained by fitting coronagraphic observations of the CME, including data from the Heliospheric Imager (HI) on

STEREO-A. Our research highlights the significance of modeling CME propagation to gain a better understanding of the dynamics of these events and their impact on the Earth's space environment.

**25 Greatorex, Harry** (Queen's University Belfast)
**The Inter-Flare Variability of Lyman-alpha Emission in Equivalent Magnitude Solar Flares**
**Co-Author(s):** Ryan Milligan, Queen's University Belfast; Phillip Chamberlin, Laboratory for Atmospheric and Space Plasma

The chromospheric Lyman-alpha line of neutral hydrogen (LyŒ±; 1216 A) is the most intense emission line in the solar spectrum and is believed to constitute a considerable portion of the total radiated energy in solar flares. Here, we present a multi-wavelength study of three M3 flares that were simultaneously observed by RHESSI, GOES, and SDO. Despite having identical X-ray magnitudes these flares show significantly different LyŒ± responses. The peak LyŒ± enhancements above quiescent background for these flares were 1.5 %, 3.3 %, and 6.4 %. However, the predicted LyŒ± enhancements from FISM2 were consistently

**26 Goodwin, Griffin** (Georgia State University)
**Exploring Performance Trends of Simulated Real-time Solar Flare Predictions**
**Co-Author(s):** Viacheslav Sadykov, Georgia State University; Petrus Martens, Georgia State University

In this study, our goal is to explore the factors that influence machine learning-based predictions of solar flares in a simulated operational environment. Using Georgia State University's Space Weather Analytics for Solar Flares benchmark dataset (doi:10.7910/DVN/EBCFKM), we investigate the impact of training window type, solar cycle, and solar X-ray background flux on support vector machine, decision tree, and feed-forward neural network model performance.

We train classifiers using three window types: stationary, rolling, and expanding. The stationary window utilizes a single set of data available before the forecasting instance, which remains constant throughout the testing period. The rolling window utilizes data from a constant time interval before the forecasting instance, which moves with the testing period. Finally, the expanding window utilizes all available data before the forecasting instance. To our surprise, skill scores were comparable across all window/classifier combinations. We can conclude that training with more than 1.75 years' worth of data does not significantly improve the quality of predictions.

Additionally, a moderate positive correlation exists between the X-ray background flux and the percent of non-flaring false positive predictions. Likely related, a moderate negative correlation exists between a model's true skill statistic score and the number of sunspots present. This suggests that the X-ray background flux and solar cycle phase have a large influence on forecasting.

Lastly, to gain better intuition about our results, we present a novel visualization that provides insightful analysis into the temporal performance of a classifier.

**27 Frascella, Francesco** (University of Turin/National Institute of Astrophysics)
**Solar corona from SolO/Metis and SOHO/LASCO : observations and comparison with MAS code simulations**
**Co-Author(s):** Fineschi Silvano, National Institute of Astrophysics (INAF) Turin, Italy; Susino Roberto, INAF; Bemporad Alessandro, INAF; Giordano Silvio, INAF; Abbo Lucia, INAF; Burtovoi Aleksandr, INAF; Romoli Marco, University of Florence, Italy; Lionello Roberto, Predictive Science Inc., Boulder, USA; Lamy Philippe, Laboratoire Atmosphères Milieux et Observations Spatiales, Guyancourt, France; Messineo Rosario, ALTEC S.p.A., Turin, Italy

Understanding how coronal mass ejections (CMEs) originate and evolve is of the uppermost importance for Space Weather as they are one of the most energetic events in our Solar System and may severely impact technological assets (e.g., power grids) and affect human space exploration. In this study, we use data sets of total and polarized broadband visible-light brightness (pB) of the solar K-corona acquired by two space coronagraphs: Metis (on board the Solar Orbiter, SolO) and LASCO-C2 (on board the Solar and Hemispheric Observatory, SOHO). For both instruments, we retrieved data images from December 2021 to the first SolO perihelion in March 2022. From these data sets, we derived a side-by-side temporal sequence, showing the evolution of the solar corona and the occurrence of several CMEs as seen from the two different lines of sight.

Starting from these preliminary results, we aim at performing a comparison with simulations derived from the MAS (Magnetohydrodynamic Algorithm outside a Sphere) model developed by the Predictive Science Inc. group. This model is frequently used, for instance, to forecast the magnetic structures of the solar corona during total solar eclipses. In particular, we aim at comparing the magnetic-field topology derived from the MAS model with the magnetic configuration that can be inferred from the visible-light images before the onset of the CMEs events. The goal is to investigate how possible differences between those magnetic configurations could be correlated with the subsequent CMEs evolution.

**28 Elliot, Heather** (Southwest Research Institute)
**Extending Forecast Lead Time of the Solar Wind and Interplanetary Magnetic Field**
**Co-Author(s):** F. G. Eparvier, W. E. McClintock, A. R. Jones, T. Woods, and D. L. Woodraska University of Colorado, Boulder; J. L. Machol and J. Mothersbaugh
National Centers for Environmental Information, Boulder CO; M. Snow South African National Space Agency, Hermanus, South Africa

We analyze the residual errors for the Wang-Sheeley-Arge (WSA) solar wind speed forecasts as a function of the photospheric magnetic field expansion factor (fp) and the minimum separation angle (d) in the photosphere between the footpoints of open field lines and the nearest coronal hole boundary. We find the residual errors are systematic when examined as a function of fp and d. We use the array of average residual errors as a function of fp and d to apply a correction to the model speeds based on the corresponding model fp and d values. Here, we test this approach for improving the speed forecast.The solar wind density, temperature, and the interplanetary magnetic field strength all correlate well with the solar wind speed. Therefore, improving the accuracy of solar wind speed forecasts enables forecasting other quantities that correlate with the speed and the speed profile. Using these relationships and the WSA corrected speeds, we examine some initial forecasts of the solar wind density, temperature, and interplanetary field strength, and Kp geophysical index.

**29 Eden, Thomas** (University of Colorado, Boulder)
**Solar Oscillations as Measured by the GOES-R Series EXIS EUVS-C Sensor**
**Co-Author(s):** F. G. Eparvier, W. E. McClintock, A. R. Jones, T. Woods, and D. L. Woodraska, University of Colorado, Boulder; J. L. Machol and J. Mothersbaugh, National Centers for Environmental Information; M. Snow, South African National Space Agency

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 spectrograph, called EUVS-C, that covers a narrow band in the ultraviolet between 277-283 nm, where it can measure the Magnesium-II emission doublet at 280 nm. The primary goal of the EUVS-C data is to construct the well-known Mg-II index. This index is often used as a tracer for chromospheric activity. Because of the high temporal and spectral resolution of the EUVS-C measurements, the data can be used for more than just generating the Mg-II index. For example, the signals contain waves that have definite signatures of three and five-minute oscillation periods. The frequency response of the signals is dependent on what part of the spectrum is analyzed (e.g., the Mg-II emission lines). With the recent increase in solar activity for Solar Cycle 25, these waves exhibit enhanced amplitudes and phase shifts during the impulsive phase of strong solar flares. This poster will

show the technique for extracting these waves, results from a quiet sun, and results from several X-class solar flare events.

**30 Dissauer, Karin** (NorthWest Research Associates (NWRA))
**Does "Precursor Activity" Really Foretell Solar Energetic Events?**
**Co-Author(s):** Graham Barnes, NWRA; KD Leka, NWRA and Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan; Eric L. Wagner, NWRA

Small-scale activity in EUV and soft X-rays have been reported prior to the onset of solar energetic events. This includes transient brightenings (TBs) that result from plasma heating and particle acceleration, and pre-flare coronal dimmings (PCDs) indicating early filament activation or the rise of overlying fields prior to coronal mass ejections (CMEs). The physical role of precursors in the initiation of solar flares and CMEs is unclear, in part due to limited single-event studies. We investigate the uniqueness and causal relationship of precursor activity to flares and CMEs for a statistically significant sample. The signatures' temporal behavior, magnetic context, coronal dynamics, temperature and density prior to events is analyzed and compared against the characteristics of similar phenomena during activity-quiet epochs (testing uniqueness). We also check if pre-event activity occurs at locations favorable to reconnection (locations of open field, magnetic null points) as determined by the topology of a Potential Field Source Surface model (testing causal relationship). For these reported preliminary results, time-series images from the Atmospheric Imaging Assembly (AIA) and vector magnetograms from the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO) are used. The importance of this work's outcome is two-fold: if uniqueness/causal relationship can be proven, results will elucidate which, and when, proposed event-triggering mechanisms are involved. If pre-event TBs and PCDs cannot be differentiated from randomly-occurring phenomena, then they cannot be considered physically involved in the event initiation. Both outcomes are highly relevant for forecasting solar energetic events and space-weather related research. This work is supported by NASA/HGI 80NSSC21K0738 and NSF/AGS-ST 2154653.

**31 Dissauer, Karin** (NorthWest Research Associates (NWRA))
**AIA Active Region Patches (AARPs): an ML-ready dataset for Coronal-Informed Event Prediction**
**Co-Author(s):** KD Leka, NWRA and Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan; Eric Wagner, NWRA

NWRA has released a machine-learning-ready dataset of E/UV timeseries images and parametrizations covering most of Solar Cycle 24. We present here the AIA Active-Region Patches ("AARPs"; Dissauer+2023), presently curated and hosted at the NASA Solar Data Analysis Center, that are constructed from the Solar Dynamics Observatory Atmospheric Imaging Assembly data in coordination with the SDO/Helioseismic and Magnetic Imager Active Region Patches ("HARPs"). Down-selection in the spatial domain is solely from full-disk to active-region size; the native spatial sampling is retained. Down-selection in the temporal domain is more severe (but could be augmented), yet allows for both short-lived dynamic features and longer-term evolutionary trends to be evaluated. All AARP files are calibrated for instrument degradation, tracked, coaligned, and ready for, e.g., Differential Emission Measure analysis (Emission Measure, Temperature, and Density maps are a forthcoming data product). Of note, all HARPs are included, without bias for active region size, activity level, location, or evolutionary stage; additionally, the bounding-boxes are extended beyond the HARP boxes in order to better capture the extended active-region coronal structures. A total of over 256k samples are thus provided. This AARP database has provided the first results of potential solar flare forecasting diagnostics from the chromosphere, transition region, and corona (Leka+2023), but is ready for additional scientific research relating to active region coronal heating, evolution, and energetic events. This work was funded primarily from NASA/GI Grant 80NSSC19K0285 with some final support from NASA/GI Grant 80NSSC21K0738 and NSF/AGS-ST Grant 2154653.

**32 DeForest, Craig** (Southwest Research Institute)
**Polarimeter to Unify the Corona and Heliosphere: Status & Path to Flight**

The Polarimeter to Unify the Corona and Heliosphere (PUNCH) is a NASA Small Explorer mission that will image space weather relevant phenomena in 3-D, capable of tracking CMEs and SIRs across the solar system from the Sun to Earth. In addition to advancing the science of space weather, PUNCH has the capability to aid forecasting directly. Under a NOAA-sponsored augmentation to the science mission, PUNCH is working to produce "QuickPUNCH" data products with low latency suitable for real-time forecasting; these products will be made available to NOAA for use in the Space Weather Prediction Center. PUNCH is on-track to co-launch with the SPHEREx mission from Vandenberg Space Force Base in April of 2025. We present current status of the mission and the QuickPUNCH project, upcoming meetings, and anticipated space weather impacts.

**33 DeForest, Craig** (Southwest Research Institute)
**Space-weather Solar Coronagraph (SwSCOR): Concept and Path Forward**
**Co-Author(s):** Steve Osterman, SwRI; Matt Beasley, SwRI; Nicholas Erickson, SwRI

We present a preliminary concept design for a novel coronagraph, SwSCOR, optimized for space weather forecasting. SwSCOR is a short externally-occulted coronagraph with a novel 1.5-stage occultation scheme that enables darker (hence wider-field) imaging than a single multi-disk occulter alone. SwSCOR includes a single-piece, blunt-edged occulter, and a current design trade considers multiple disks vs. a smooth profile to better eliminate Fresnel scattering. A secondary "Arago spot suppressor" in front of the optical prime focus redirects the major source of diffracted stray light -- the Arago spot formed by the occulter itself. This enables imaging closer to and/or farther from the Sun, by expanding the stray-light trade space relative to comparably sized instruments with conventional occultation. The instrument is designed with polarimetry in mind, to enable 3-D tracking of space weather relevant solar structures, including CMEs and SIRs. We present the preliminary concept, prototyping status, and path forward for SwSCOR.

**34 Corti, Claudio** (NASA GSFC/CCMC)
**Comparison of Real-Time and Historical Solar Flare Catalogs**

Timely forecasts of solar energetic particles (SEPs) at various locations are crucial to improve the protection of astronauts from radiation hazards during deep space missions. Solar flare properties are one of the key input to SEP forecast models. For this reason, prompt flare detection and characterization are needed to ensure astronauts have enough time to take shelter in their spacecraft/habitat before the bulk of the SEPs reach their location. In this work, we review and compare various publicly accessible services providing near real-time flare alerts and summaries. We analyze the delay between the time of the flare occurrence and the time its information is published. We also study the accuracy of various flare properties required for SEP forecasting, such as peak flux intensity and location on the solar surface, by comparing their near real-time estimates derived from operational-ready data with measurements performed on science-quality data.

**35 Chaturmutha, Varun** (Georgia State University)
**Flare Precursor Signatures in Acoustic Waves**
**Co-Author(s):** Bernhard Fleck, NASA-GSFC; Stuart Jefferies, Georgia State University

The field of helioseismology was heralded by the detection of acoustic waves in the solar atmosphere. Acoustic waves, which have traditionally been used to probe the solar interior, can also be used to map the solar atmosphere which is home to solar eruptive events. Predicting such events represents one of the most prominent outstanding questions in heliophysics. In our work, we will employ our recently developed acoustic wave analysis to search for predictive information on solar eruptive events. The analysis involves modeling travel time measurements of waves in the Sun's atmosphere using a plane wave propagation model and estimating atmospheric properties such as acoustic cutoff frequency, radiative cooling time, and sound speed. Measurements by Finsterle et al. (2004) suggest that the acoustic cutoff frequency may experience changes in the hours leading up to the flare from changes in the magnetic field inclination due to the ramp effect. Moreover, the temporal evolution of the travel time measurements of the 6.5 mHz waves by Venkataramanasastry (2022) has shown strong variance in flaring regions when compared to non-flaring regions of similar magnetic field strengths. These results suggest that acoustic waves could carry strong flare precursor signatures. To this end, we will capitalize on the wealth of SDO/HMI data that has recorded 8000+ flares during Solar Cycle 24. By studying the flaring and non-flaring datasets in HMI through our acoustic wave analysis, we will look to verify if measurements of the acoustic wavefield in the Sun's atmosphere provide a flare precursor signal.

**36 Burkepile, Joan** (National Center for Atmospheric Research (NCAR)/ HAO)
**Near-real-time Coronal Mass Ejection Alerts as part of an Early Warning Forecasting System for Solar Energetic Particle (SEP) events**
**Co-Author(s):** Michael Galloy, NCAR/HAO; Ben Berkey, NCAR/HAO; Lisa Perez-Gonzalez, NCAR/HAO; Marc Cotter, NCAR/HAO; Chris St. Cyr, NASA/GSFC (retired); William Thompson, NASA/GSFC; Leila Mays, NASA/Community Coordinated Modeling Center (CCMC); Joycelyn Jones, NASA/CCMC; Philip Quinn, NASA/Space Radiation Analysis Group (SRAG); Ricky Egeland, NASA/SRAG; Ian Richardson, NASA/GSFC

The NCAR Mauna Loa Solar Observatory (MLSO) COSMO K-Coronagraph (K-Cor) issues near-real-time coronal mass ejection (CME) alerts 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 was designed to study CME onset and dynamics. It's field-of-view is 1.05 to 3 Rsun at 15-second cadence. 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 processing, combine to provide an early warning CME detection as part of a SEP forecasting system, as pointed out by St. Cyr et al. (2017). Most of the K-Cor alerts were issued before the CME entered 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 LAvarunSCO at the Space Weather Prediction Center (SWPC).
We discuss the CME detection system and present statistics on performance. We discuss ongoing work to improve performance and highlight the benefit of a ground-based coronagraph network (ngGONG mission).

**37 Afanasiev, Alexandr** (University of Turku, Finland)
**Towards Advanced SEP Forecasting with the PARA-SOL model**
**Co-Author(s):** Nicolas Wijsen, NASA Goddard Space Flight Center, USA; Rami Vainio, University of Turku, Finland; Seve Nyberg, University of Turku, Finland; Angels Aran, Universitat de Barcelona, Spain; David Lario, NASA Goddard Space Flight Center, USA; Stefaan Poedts, KU Leuven, Belgium

Solar energetic particle (SEP) events constitute one of the crucial aspects of space weather. Of particular importance are gradual SEP events, which are associated with shock waves driven by coronal mass ejections, as they often provide the highest intensities at MeV energies. Substantial effort has been addressed worldwide to develop reliable methods to forecast such SEP events, using empirical or physics-based modeling approaches. The latter approach includes simulations of particle acceleration at shocks, which are computationally demanding if done self-consistently, i.e., if the effect of the turbulence amplification by accelerated particles is included. This currently prevents such models from being directly used in an operational SEP forecasting framework.

Here we present a new particle acceleration and transport model, PARA-SOL, which is based on the SOLar Particle Acceleration in Coronal Shocks (SOLPACS) model simulating proton acceleration at shocks, coupled with Alfv√©n wave generation, and the PArticle Radiation Asset Directed at Interplanetary Space Exploration (PARADISE) model simulating 3-D particle transport in the heliosphere. The key point of PARA-SOL is that the computationally demanding self-consistent simulations of particle acceleration are substituted with an analytical description of the foreshock region, which is derived from fitting the results of the SOLPACS simulations.

The PARA-SOL model has been developed as a part of the European Union's EUHFORIA 2.0 project aimed at advancing our space weather forecasting capabilities. As such, the PARA-SOL model is coupled with the EUHFORIA solar-wind magnetohydrodynamics model. Here we show and discuss first results of simulating SEP events using EUHFORIA and PARA-SOL.

**38 Upton, Lisa** (Southwest Research Institute)
**Polar field precursors, geomagnetic precursors, and curve fitting: The outlook for Solar Cycle 25**
**Co-Author(s):** David Hathaway, Stanford University

The strength of the polar fields and the geomagnetic precursors (e.g., the aa index) at solar minimum are established predictors of the amplitude of the solar cycle. Surface Flux Transport (SFT) models describe the process by which magnetic flux from active regions is transported to the poles and are used to estimate the polar field strength well before minimum. The state-of-the-art Advective Flux Transport (AFT) model was designed with the intent of creating the most realistic SFT model possible. AFT has proven successful at predicting active region evolution and decay, as well as the evolution of the Sun's polar fields. In 2016 and 2018, AFT was used to create forecasts of the Sun's polar field and predict the strength of Solar Cycle 25 - predicting a weak cycle. During solar minimum (December 2019) the polar field and geomagnetic precursors both indicated that Cycle 25 would indeed be a small cycle, with the geomagnetic prediction being slightly higher than the prediction from the polar fields. We present an update on the current state of the solar cycle and show how the observations compare with the AFT predictions. Now that we are well into the cycle, we can use curve fitting to provide an additional prediction for the amplitude of Solar Cycle 25. We find that the curve fitting results are consistent with the geomagnetic precursor prediction (slightly larger than the polar fields). Finally, we provide an update on the outlook for Solar Cycle 25.

**39 Taylor, Wesley** (Millersville University of Pennsylvania Department of Earth Sciences)
**Project Halo: An Effort to Provide Continuous Meteorological Observation of the April 8th 2024 Total Solar Eclipse**
**Co-Author(s):** Allison Krantz, Millersville University of Pennsylvania Department of Earth Sciences Alex Colgate, Millersville University of Pennsylvania Department of Earth Sciences; Joshua Kinsky, Millersville University of Pennsylvania Department of Earth Sciences; Nichole Behrenhauser, Millersville University of Pennsylvania Department of Earth Sciences; Melodie Martinez-Manahan, Millersville University of Pennsylvania Department of Earth Sciences

Project HALO aims to provide continuous meteorological monitoring of the total solar eclipse on 8 April 2024. The project's preliminary goals are to determine whether the boundary layer temperature inversion generated by the eclipse can be considered a function of latitude. To complete this endeavor, we seek to create a network of observation teams to collect data on the day of the eclipse. We plan to provide a space for a discussion on interest, logistics, and the possibility of expanding the scope of the project to potentially include the monitoring of the solar corona, atmospheric compositional dynamics, and other topics of interest. Since the project will still be in its planning phase, not all details will be determined by the time of the conference, but this poster will provide a to-date status report on the ongoing initiative.

**40 Jones, Shaela** (NASA GSFC / CUA)
**Quantitative Testing of Photospheric Synoptic Map Improvements**
**Co-Author(s):** Luca Bertello, NSO; C. Nickolos Arge, NASA GSFC; Gordon Petrie, NSO; Vadim Uritsky, CUA; Nathalia Alzate, NASA GSFC; Chris Rura, CUA

Assembly of global photospheric flux maps is necessary for accurate modeling of the solar corona and heliosphere. However, it is a tricky problem. Disk measurements of magnetic flux - themselves a modeled quantity - vary from source to source. Also, such measurements are typically only available from a single point of view, while we often wish to know the state of the entire photosphere at an instant in time. Finally, the photosphere is highly a dynamic place, which complicates the combination of non-concurrent measurements. In the absence of reliable testing, it is possible to invent many reasonable ways of constructing surface flux maps with no clear way of knowing which is (are) best. This variability of the boundary condition complicates coronal modeling and can lead to significant uncertainty in space weather forecasting. Here we will present an example using quantitative comparisons with real-world data to assess the value of a proposed enhancement to existing photospheric flux maps.

## Wednesday April 19 Posters

### *Solar and Interplanetary Research and Applications; Ionosphere and Thermosphere Research and Applications; Aviation Radiation Research and Applications*

10:05 AM -11:00 AM and 2:30 PM - 3:15 PM

Lightning Talks 4:30 - 5:00

**1 Williams, Anthony** (Millersville University)
**A Statistical Analysis of Heliobiology: Exploring Connections Between Space Weather and Human Health**
**Co-Authors(s):** Dr. Tamitha Skov, Millersville University; Dr. Christopher Stieha, 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. The purpose of this study is to take a statistical approach to understand if there are any correlations between significant space weather events and human health. This will be accomplished by collecting data of solar activity from the solar cycle 23 minimum, and the maximum period of solar cycle 24, and comparing this data to cases of acute myocardial infarction (AMI) across regions of differing latitudes in the United States. Space weather data will be focused on periods of high KP and AE index, as well as the specific dates significant space weather events. The results of this study will be used to further investigate multiple variables and time frames to attempt to understand any correlations between space weather and human health that may exist.

**2 Sawant, Sailee** (University of Alabama in Huntsville)
**Driving the SEPCaster Model with an Automated AR Identification and Characterization Module**
**Co-Authors(s):** Gang Li, University of Alabama in Huntsville; Meng Jin, Lockheed Martin Solar and Astrophysics Laboratory

Solar flares and coronal mass ejections (CMEs) can cause disruptive space weather conditions, including geomagnetic storms and solar energetic particle (SEP) events, which may severely damage ground- and space-based technological systems and affect our daily lives. Therefore, we require state-of-the-art forecasting models to accurately predict space weather phenomena. This research aims to develop a physics-based operational SEP Forecast model, SEPCaster, for the energetic particle radiation environment in the inner solar system and Earth's magnetosphere.

SEPCaster is based on two advanced research models: the Alfv\'en Wave Solar Model (AWSoM) and the improved Particle Acceleration and Transport (iPATH) model. It operates in two distinct modes: an automated forecasting mode and a user-interactive mode. In the automated mode, SEPCaster runs with minimal human interaction, while in the interactive mode, users can modify the inputs and analyze specific events in greater detail.

This presentation focuses on a new automated module for identifying and characterizing active regions (ARs). We start by using real-time National Solar Observatory/Global Oscillation Network Group (NSO/GONG) magnetograms as our raw inputs and apply an image segmentation technique to detect regions of interest (ROIs) with positive and negative polarities. Next, we implement and refine a hierarchical clustering algorithm to identify potential ARs from these ROIs. We then calculate a set of parameters to characterize these ARs, including our newly defined area-based AR complexity index. Based on these parameters, we also compute potential CME eruption speeds, which are incorporated into SEPCaster.

**3 Petersen, Alicia** (University of Florida)
**Quantifying the Impacts of Interplanetary Propagation on Solar Energetic Particle Intensity-Time Profiles**
**Co-Authors(s):** Stephen White, Air Force Research Laboratory, Kirtland AFB

Solar energetic particle events (SEPs) that are produced in the solar corona and propagate through the inner heliosphere and interplanetary space may encounter intervening magnetic obstacles such as interplanetary coronal mass ejections (ICMEs) or the heliospheric current sheet (HCS). Such encounters impact SEP acceleration and propagation. SEP propagation speed and intensity are factors that impact SEP forecasting. We investigate the extent to which unusual in-situ measurements of the rise phase and Weibull fit shape parameters of SEP intensity-time profiles at 1 AU are correlated with interactions with intervening structures in the inner heliosphere. In a multi-year survey using Geostationary Operational Environmental Satellites (GOES) and Advanced Composition Explorer (ACE) observations we quantitatively compare correlations between potential ICME and HCS interactions with features of SEP intensity-time profiles and determine their significance via a resampling test.

**4 Martens, Petrus** (Georgia State University)
**The Space Weather Prediction Effort at GSU: Many Projects in Parallel Within a Unified Architecture**
**Co-Authors(s):** Rafal Angryk and the GSU Astro-informatics Cluster, Georgia State University

The Georgia State University Astro-informatics Cluster is a strongly integrated interdisciplinary research group between the departments of Computer Science and Physics & Astronomy. Since its foundation in 2014 the cluster has been solely focused on space weather prediction.

Our current research program consists of over a dozen projects, each carried out in parallel by faculty and their graduate and undergraduate students. Each project forms a building block for a comprehensive and unique space weather data mining and forecasting using cutting edge machine learning and modeling approach. Several of these projects are presented at this meeting in more detail here in posters by our graduate students.

In my contribution I will present the overall design and architecture of our prediction system, the place of each individual effort within it, and describe future projects to complete the system.

A partial list of efforts underway or completed is:
- Thoroughly verified, complete, connected, and machine learning ready data bases of flares, CME's, and SEP's (benchmarks), made publicly available
- A Systematic search for flare precursors in magnetic and spectral data, including use of GSU's South Pole Observatory data, polarity inversion line morphology, and GONG H-alpha filament observations
- A computer science study of the machine learning method and data requirements for optimal space weather prediction
- Mitigation of solar limb limitation of the quality of magnetic field data for machine learning
- Integration of SoHO EIT and MDI data labels with those from HMI and AIA on SDO
- Flare prediction from time series data rather than static snapshots
- Constructing synthetic time series data for improving forecasting
- Simulated real-time predictions

This is merely a sample of projects going on. None of this work would be possible without the dedication and persistence of our standing army of students.

**5 Heffern, Lena** (Southwest Research Institute)
**RAD Observations on Mars During the Progression to Solar Maximum**
**Co-Authors(s):** Bent Ehresmann, Southwest Research Institute; Donald M. Hassler, Southwest Research Institute; Cary Zeitlin, NASA; Robert Wimmer-Schweingruber, Christian-Albrechts-University Kiel and The MSL RAD Team

The Radiation Assessment Detector (RAD) on the Mars Science Laboratory (MSL) Curiosity rover is capable of measuring the dose rate and particle distribution at the surface of Mars during solar particle events (SPEs). SPEs are powerful eruptions of particles and radiation from the sun that can have significant impacts on the surface of Mars. These events can be caused by solar flares or coronal mass ejections (CMEs), and their effects can range from short-term disruptions of the Martian atmosphere to long-term changes in the planet's surface environment. Often, as a CME propagates through space, it creates a shock wave that sweeps up and scatters cosmic rays, which can cause a decrease in the observed number of particles at the surface of Mars, this is called a Forbush decrease (FD). We will present on RAD measurements taken since the beginning of the progression to solar maximum and compare these measurements with that of other heliocentric spacecraft and other MSL instruments. We will discuss detection of large SPEs, FDs, and changes in dose rate due to topography during MSL's journey across Gale Crater while approaching solar maximum.

**6 Dayeh, Maher** (SwRI, San Antonio, Texas, USA/UTSA, Texas, USA)
**MEMPSEP: A Multivariate Ensemble of Models for Probabilistic forecast of SEP Occurrence and Properties**
**Co-Authors(s):** Subhamoy Chatterjee, SwRI, Boulder, CO; Andres Munoz-Jaramillo, SwRI, Boulder, CO; Kim Moreland, CU Boulder/CIRES, CO; Hazel Bain, CU Boulder/CIRES, NOAA SWPC, USA

Solar flares, Coronal Mass Ejections (CMEs), and Solar Energetic Particles (SEPs) are among the key drivers of space weather in the near-Earth environment and beyond. While some CMEs and flares are associated with intense SEPs, some show no or little SEP association. Furthermore, there is no clear and consistent connection between the properties of SEPs observed at 1 au and their progenitors at or near the Sun. The latter is due to the complex environment that dominates SEP origin, acceleration, and transport in the interplanetary space. To date, robust long-term (hours to days) forecasting of SEP properties does not effectively exist and the search for such development continues.

In this work, we present an ensemble of neural networks that uses both remote and in-situ data from multiple sources to predict the true probability of SEP occurrence and its properties such as peak intensity within different energy pass-bands, event onset time, and duration. We show that incorporating the SEP occurrence probability as a weighting factor into the regression can tighten the prediction of event properties on the test set. We also show how the uncertainty estimated through the ensemble of models enables robust forecasting decisions for unseen data. This work is fully supported by the O2R program (Grant no. 80NSSC20K0290).

**7 Zhan, Weijia** (Space Weather Technology, Research and Education Center, University of Colorado Boulder)
**Uncertainty Quantification of the Ionosphere-Thermosphere with WAM-IPE for Varying Solar Wind Conditions**
**Co-Authors(s):** Alireza Doostan, University of Colorado Boulder; Eric Sutton, University of Colorado Boulder; Tzu-Wei Fang, NOAA Space Weather Prediction Center

One of the most frequent space weather events in the ionosphere-thermosphere (IT) system, equatorial and low latitude ionospheric irregularities can have a significant effect on radio transmission in the ionosphere. In order to narrow down the input parameters and identify the most crucial external drivers, it is necessary to quantify the uncertainty in the IT system. In this study, the uncertainties of the IT conditions simulated by the Whole Atmosphere Model-Ionosphere Plasmasphere Electrodynamics

(WAM-IPE) forecast system for verying solar wind drivers will be estimated. Using an advanced multichannel variational autoencoder ((MCVAE), the historical solar wind density, velocity, and interplanetary magnetic field (IMF) data are gathered to generate synthetic data for driving the model. We drive WAM-IPE and produce an ensemble of simulations using the synthetic solar wind parameters. Then, polynomial chaos expansion (PCE) is used to approximate the quantities of interest (QoI) and to estimate the statistical metrics of the QoI based on the expansion coefficients. Using the PCE-based UQ and Sobol index, we show the uncertainties and global sensitivity analysis results of the electron density, plasma flow, and neutral winds. Details regarding the universal time, local time, and vertical variances are provided.

**8 Zayed, Gamal** (Cairo University; Electronics and Communications Engineering)
**Evaluation of Global Ionospheric TEC Using Simultaneous Observations from Amateur Radio Networks, International Space Station, and NeQuickG Model for Space Weather Prediction**
**Co-Authors(s):** Marcin Lesniowski, Independent researcher, Rzeszow, Poland; Pasumarthi Babu Sree Harsha, SONDRA, CentraleSupelec, Paris, France; Matthew Downs, Independent researcher, Chelmsford, England, United Kingdom; Daniel Metcalfe, University of Huddersfield, Harrogate, England, United Kingdom; Sila Kardelen Karabulut, BallSquad, Warsaw, Poland

Evaluation of Global Ionospheric TEC Using Simultaneous Observations from Amateur Radio Networks, International Space Station, and NeQuickG Model for Space Weather Prediction, Ionospheric electron density plays a significant role in long-distance communications and sky-wave propagation. Prediction of the accurate state of the ionosphere is necessary to understand the accurate signal perturbations thereby estimating the critical parameters for better signal transmission. The space weather impacts on such trans-ionospheric technological systems are evident. In this work, a web application is developed to represent the global day-to-day electron density variations from the NeQuickG model. Also, the ground-based HAM radio broadcast network hop data with different wavelengths (eg. 10 m and 20 m) and simultaneous top-side electron density with space-based International Space Station (ISS) probe data from floating point measurement units are examined. The electron density variations for the year 2017 are clearly represented. Optimization techniques are necessary to frame a denser spatial grid-based ionospheric electron density map from all the observations. It is essential to estimate the optimal weight function that can distribute the observation influence over empty grid bins with minimum error variance through a probabilistic approach. User-understandable metrics development exclusively for Amateur radio operators and civil aviation sectors is focused. In the near future, the developed web-based application could serve as a better visualization platform for space weather forecasting.
This project, Fellowship of the Ionosphere, is a Global Finalist in the 2022 NASA Space Apps Challenge. NASA Space Apps 2022 had 31,400+ registered participants from 162 countries and territories, with over 3000 submissions from 5327 teams. Global Finalists are ranked as one of the top 35 projects from all submissions.

**9 Willis, Jacob** (United States Military Academy)
**Detection of the Apparent Motion of High-latitude Ionospheric Plasma Leading to GPS Scintillations Using a Novel Poker Flat Incoherent Scatter Radar Mode and Supporting All Sky Imagery**
**Co-Authors(s):** COL Diana Loucks, USMA; Dr. Rodger Varney, UCLA; CPT Nicholas Deschenes, USMA; Dr. Don Hampton, UAF

The Poker Flat Research Range located in Fairbanks, Alaska, provides data on ionospheric conditions. The Poker Flat Incoherent Scatter Radar (PFISR) detects plasma densities along the line of sight of conjunctive GPS signals in the E and F regions of the ionosphere through a novel mode using five independent radar beams. All Sky imagery detects narrow band electron precipitation in a wide field of view. This research project analyzes data collected on August 26, 2018 from PFISR and all sky imagery to show how plasma structures displace both spatially and temporally. Cross-correlation methods in this study compare electron densities reported along each of five PFISR beams to detect when and where plasma structure patterns reoccur. The PFISR statistical analysis is then compared to apparent auroral

motion captured by 557.7 nm all sky imagery. The three-dimensional characterization of apparent auroral motion captured by PFISR is within an order of magnitude of the two-dimensional apparent auroral motion captured by all sky imagery. Initial results indicate that this analysis technique can successfully be applied across data spanning four Arctic winters. This study has the potential to quantify the three-dimensional auroral motion within the ionosphere and enhance the utility of ISRs in detecting GPS scintillation.

**10 Tshisaphungo, Mpho (**South African National Space Agency**)**
**Re-examining Ionograms for Space Weather Monitoring**
**Co-Author(s):** Tshimangadzo Merline Matamba, South African National Space Agency
Donald Danskin, South African National Space Agency

Traditional measurements for ionosondes such as foF2 and hmF2 are often used to characterize the state of the ionosphere. Often autoscaling methods are employed to provide a real-time stream of the ionospheric parameters. Under certain ionospheric conditions, the ionosphere may be underestimated due to observational bias. A comparison of TEC from GPS receivers and ionosondes shows at times that the ionosonde TEC is often underestimated during the daytime. Using data from South African Ionosondes and GPS receivers, clear examples of underestimation are presented and discussed.

**11 Thiemann, Edward** (LASP, University of Colorado)
**Real-Time Operational Measurements of the Thermospheric State: Recent Advances and Future Possibilities**
**Co-Authors(s):** Robert Sewell, LASP, University of Colorado; Marie Dominique, Royal Observatory of Belgium; Marcin Pilinski, LASP, University of Colorado; Eric Sutton, SWxTREC, University of Colorado; Courtney Peck, LASP, University of Colorado; Dan Seaton, SWRI

The Earth's thermosphere is the neutral region of the upper atmosphere, playing a critical role in the Earth's response to space weather and satellite drag in particular. The relationship between thermospheric variability and satellite drag is relatively straightforward: A hotter thermosphere results in higher densities at all altitudes, directly increasing satellite drag. Despite its crucial role in space weather, there are presently no operational direct measurements of the thermospheric state. Instead, today, the thermospheric state can only be estimated by driving numerical models with known space weather drivers, or by assimilating spatiotemporally averaged satellite drag data into such models.

This is soon to change with the arrival of real-time operational measurements of thermospheric density between 150 and 350 km from solar occultations measured by the SUVI solar telescope on-board the latest-generation GOES-R series satellites. These thermospheric data are currently undergoing validation, with an anticipated public release time-frame of mid-2023. The question then becomes: What will the space weather community do with these data and how will their availability change fore- and now-casting of space weather in the ionosphere and thermosphere?

SUVI measurements are made twice daily, due to the GOES-R Geostationary orbit, seeing only one eclipse period per day, limiting their use in tracking the rapid changes during geomagnetic storms. On the other-hand, the LYRA instrument onboard the PROBA2 satellite measures solar occultations of the thermosphere every 100 minutes, owing to its LEO orbit, and can rapidly track storm-induced changes in density and temperature from 150 to 350 km. The drawback for LYRA is its data have a latency of four hours and its thermospheric data processing is not automated.

In this presentation, we review the SUVI and LYRA measurements and show the technology can be readily miniaturized and optimized for thermospheric density measurements. We make the case that model developers and space weather forecasters need to determine how these data should be used, and mission planners should request funding agencies to invest in targeted instruments for measuring thermospheric density via solar occultations.

**12 Thayer, Jeffrey** (University of Colorado)
**Thermosphere Density Retrievals from Low Earth Orbiting Spacecraft**
**Co-Authors(s):** Zachary Waldron, Space Weather Technology, Research, and Education Center at University of Colorado; Eric Sutton, Space Weather Technology, Research, and Education Center at 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 University of Colorado

There is a critical need for improved space environment specification and forecast at low Earth orbit (LEO) so that more reliable and accurate trajectories of resident space objects (RSO) can be provided to reduce risk of collisions or costly maneuvers. The uncertainty in forecasting thermosphere mass density produces the largest uncertainty in predicting future positions of RSOs. Perpetuating this uncertainty is the lack of thermosphere observations, both globally and in frequency. Properly equipped LEO spacecraft offer a data source that, once merged with a utilization technique, can provide extensive information about the thermosphere mass density at high cadence and across the globe. These data can then serve to feed models to improve forecasts. This poster presents on techniques to extract thermosphere mass density using LEO satellite precision orbit determination (POD), and associated methods. Specific examples will discuss the utility of using the GEODYN II POD software along with ICESAT-2 and Spire satellites to assess approaches in extracting neutral density estimates from such platforms.

**13 Tang, Genevieve** (United States Military Academy)
**Analysis of Navigation Solution Parameters Affected by High-latitude Ionospheric Scintillation**
**Co-Authors(s):** COL Diana Loucks, PhD: United States Military Academy Professor; Dr. Mai Tran: United States Military Academy Professor; CPT Nicholas Deschenes: United States Military Academy Professor; CDT Natane Randall: United States Military Academy Junior; CDT Claudia Brodsky: United States Military Academy Freshman

The question of ionosphere scintillation and its effects on GPS functionality at high latitudes becomes increasingly essential with rising global temperatures and decreased sea ice extent in the Arctic Ocean. Through correlative analyses performed on data gathered from high-resolution Connected Autonomous Space Environment Sensor (CASES) GPS receivers, our team sought to increase modern understanding of ionospheric storms and how increased solar activity affects the precision of satellite-based navigation tools. To isolate the effects of scintillation, we sought to remove the effects of other precision-harming processes such as errors due to satellite configuration like geometric dilution of precision (GDOP). Multiple correlative models were run to identify where meaningful relationships do and do not exist. In comparing the position solution accuracy between CASES and Continuously Operating Reference Stations (CORS) GPS receivers, we hope to see CORS receivers exhibiting greater magnitudes of error. We also hope to that controlling for GDOP will reveal a meaningful relationship between scintillation and magnitude of error.

**14 Taiwo, Osanyin** (National Institute for Space Research)
**Validation of Data Ingestion in NeQuick 2 Model over South America by Means of Ionosonde and COSMIC Data**
**Co-Authors(s):** Claudia N. Candido, National Institute for Space Research; Fabio Becker-Guedes, National Institute for Space Research; John Bosco Habarulema, South African National Space Agency; Yenca Migoya-Orue, Abdus Salam International Centre for Theoretical Physics; Nyassor Prosper, National Institute for Space Research

In this paper, an investigation of a technique for data ingestion in the NeQuick 2 model is introduced. This method involves binning data in spatial resolution and subsequence indexing to find the median or nearest points in each cell grid.¬† The effectiveness of this technique depends on the geographical region as well as the availability of data in both space and time. The South American sector has been considered a case study due to the deployment of more GNSS (Global Navigation Satellite System) receivers over the years, thereby enabling further validation of the NeQuick 2 model for a near-real-time description of the low and middle latitude ionosphere. Our results showed that NeQuick is able to describe the evolution of the

Equatorial Ionization Anomaly during both quiet and disturbed geomagnetic conditions. Validation with both ionosonde and COSMIC electron density profiles showed significant improvement after data ingestion.

**15 Surco Espejo, Teddy M** (Institute for Scientific Research, Boston College)
**Estimation of Ionospheric Scintillation Index S4 from Rate of Change of Total Electron Content Index (ROTI) in Low Latitudes**
**Co-Author(s):** Charles Carrano, Institute for Scientific Research, Boston College; Keith Groves, Institute for Scientific Research, Boston College; Theodore Beach, Institute for Scientific Research, Boston College

Ionospheric scintillations are fluctuations in the phase and amplitude of the signals from GNSS satellites occurring when they cross regions of electron density irregularities in the ionosphere and hence can cause significant errors in positioning based on Global Navigation Satellite System (GNSS). Scintillation is usually characterized by amplitude and phase scintillation index (S4 and œÉœÜ). However, the specialized receivers that can generate the scintillation indices are not available all around the world, which limits the application of these approaches. In spite of that, there are numerous inexpensive geodetic receivers that are capable of measuring the Total Electron Content (TEC) and Rate of TEC (ROTI). In order to overcome this problem, the relationship between ROTI and scintillation indices (S4 and œÉœÜ) has been studied. In this work is applied a quantitative theoretical model developed for ROTI related to the phase structure function. This theoretical model is a scaled version of the structure function of phase fluctuations imparted to the wave by the irregularities and relates the statistical measures of TEC fluctuations and ionospheric irregularities of associated scintillations. This model for ROTI accounts for the dependence on the sampling interval, satellite motion, propagation geometry and the spectral shape, strength, anisotropy and drift of ionospheric irregularities. The focus of this work is to estimate the ROTI based on data from GNSS receivers located in low latitudes then, the S4 index is calculated using the relationship of ROTI/S4. In addition, this study evaluates the S4 index estimated using a climatological RISA model for drift, different sampling rates (Œ¥t =1 s and Œ¥t =10 s), GPS frequency (L1, L2C and L5).

**16 Raeder, Joachim** (UNH Space Science Center)
**Polar Cap Boundary Expansion During Geomagnetic Storms**
**Co-Author(s):** B. Tulegenov, UNH; W. D. Cramer, UNH; B. Ferdousi, UNH; T. J. Fuller-Rowell, NOAA; N. Maruyama, CU Boulder; R. J. Strangeway, UCLA

The polar cap, delineated by the Open Closed field line Boundary (OCB), responds to changes in the Interplanetary Magnetic Field (IMF). The boundary moves equatorward when the IMF turns southward and contracts poleward when the IMF turns northward. Observations of the OCB are spotty and limited in local time, making more detailed studies of its IMF dependence difficult. Here, we simulate five solar storm periods with the coupled OpenGGCM-RCM-CTIM model to estimate the location and dynamics of the OCB. For these events, polar cap boundary location observations are also obtained from Defense-Meteorological Satellite Program (DMSP) precipitation spectrograms and compared with the model output. There is a large scatter in the DMSP observations and in the model output. However, we generally find good agreement between the model and the observations. On average, the model overestimates the latitude of the open-closed field line boundary by 1.61 degrees. Additional analysis of the simulated polar cap boundary dynamics across all local times shows that the MLT of the largest polar cap expansion closely correlates with the IMF clock angle; that the strongest correlation occurs when the IMF is southward; that during strong southward IMF the polar cap shifts sunward; and that the polar cap rapidly contracts at all local times when the IMF turns northward.

**17 Pilinski, Marcin** (University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics)
**Evaluating Thermospheric Nowcast and Forecast Performance of an Assimilative Density Specification Tool**

**Co-Author(s):** M. Pilinski, E. Thiemann, University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics; R. Blay , G. Crowley, C. Fish, G. Thompson, J. Wilson, C. Johnstone, K. Underwood, Orion Space Solutions; K. Tobiska, Space Environment Technologies

A significant increase in orbital congestion in low Earth orbit (LEO) is motivating research into enhanced orbit prediction and conjunction analysis (CA) capabilities. In LEO, this includes improvements in the specification and prediction of a perturbing force called 'satellite drag', caused by the satellite moving through the Earth's Thermosphere. Satellite drag perturbations are proportional to the atmospheric neutral density (ND) which is highly variable and difficult to predict, degrading the accuracy of orbital forecasts.

Accordingly, the specification of the current and future neutral density environment in the thermosphere is a vital capability for the sustainable continuation of commercial, government, and military space operations. Recently developed data assimilation (DA) techniques such as IRIDEA (Sutton et al., 2018), and Dragster (Pilinski et al., 2016) have the ability to determine atmospheric model forcing and (in the case of Dragster) density corrections that are most compatible with the observed satellite drag, effectively making a 'model driver correction' at each time step. The atmospheric model drivers or 'forcing' include solar and geomagnetic indices/proxies that attempt to capture the amount of energy flowing into the Thermosphere. Because the Thermosphere is a strongly forced system, these drivers are critical to determining its state including the distribution of neutral density. The techniques above use ensembles of atmospheric models to assimilate satellite drag data and have been shown to significantly reduce ND specification errors. However, it is not clear at the present time how existing forecasts of Thermospheric forcing should be correlated with the corrected drivers estimated by DA techniques. One approach is to compute the offset between each estimated forcing parameter and its zero-day forecast then to apply that offset to the predictions at each step of the forecast. Another method involves the linear regression between the zero-day forcing forecasts and the DA estimates over a moving analysis window. The results of the regression are then applied to subsequent forecasts. The latter approach also results in an estimate of uncertainty in the mapping parameters between the available forecasts of model drivers and their DA estimates. This uncertainty can be used to generate an ensemble of ND forecasts leading to an estimate of the evolving errors in satellite drag that are necessary for improved CA.

In this poster, we focus on evaluating Orion Space System's Dragster nowcast and forecasts and comparing their performance to nowcasts and forecasts generated using other models. The models include the Space Force's High Accuracy Satellite Drag Model (HASDM) which is also an assimilative tool. Non-assimilative approaches will also be compared and include the Jacchia-Bowman 2008 empirical model. Dragster assimilated orbital drag data from over 60 satellites archived by the Space Force. Forcing indices and proxies, as well as an archive of their forecast are provided by Space Environment Technologies. For validation, we use POD-derived data products from the European Space Agency's Swarm satellite (not assimilated).

References:
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Sutton, E. K. (2018), A new method of physics‚Äêbased data assimilation for the quiet and disturbed thermosphere, Space Weather, 16, 736‚Äì753, https://doi.org/10.1002/2017SW001785

**18 Pettit, Joshua** (GMU/NASA GSFC)
**Modeling the Thermospheric Response to Solar and Geomagnetic Drivers during the Feb 2022 Starlink Incident**
**Co-Author(s):** Katherine Garcia-Sage, NASA GSFC; Philip Chamberlin, LASP; Tzu-Wei Fang, NOAA SWPC

In early February of 2022, moderate solar and geomagnetic activity caused increased neutral densities at altitudes where SpaceX satellites were initially launched. The increased densities prevented the satellites from reaching their final orbit and as a result, 38 Starlink satellites were destroyed. The following study investigates this time period from a research modeling perspective. Here we use the Global Ionosphere/Thermosphere Model (GITM) to compare with recent simulations from NOAA's Space Weather Prediction Center's operational Whole Atmosphere Model (WAM-IPE). We use the second version of the Flare Irradiance Spectral Model (FISM2) as short wavelength radiative forcing using 58 wavelength bins in GITM. To estimate electron precipitation, we use the AE auroral model. Four simulations were completed. The first includes all forcings (electron and radiative), while the second and third isolate the radiative and precipitating electron forcing separately. The last simulation acts as a baseline simulation and does not include either of the forcings. We then compare the simulations with both observational data and the WAM-IPE model output to understand what the most important driver was for the Starlink incident and how well GITM performs for the time period of investigation.

**19 Njendu, Gikonyo** (United States Military Academy)
**Modeling the Auroral Ionosphere - a Nuclear Perspective**
**Co-Author(s):** CDT Catherine Brodsky; COL Diana Loucks, Ph.D.; CDT Lauren Coleman; Dr. Mai Tran; CPT Nicholas Deschenes

GPS signal distortion is a frequent occurrence within the high-latitude ionosphere, with known contributions in the auroral E region. Few models can recreate plasma density with the resolution required to understand the cause of these disturbances. We are creating a 3D ionospheric model by utilizing existing nuclear code platforms and data from digital all-sky imagery. A nuclear model perspective is a very novel approach as it focuses on particle interactions that occur. An iterative development process will occur whereby each cycle will feature an expanded model with increased complexity than its predecessor. Between each cycle, a series of tests will occur to discover both the model's and code platform's limits. Although nascent in development, long-term expected outcomes include a complete model of the auroral E region that processes present data and creates a 3D visualizer reactive to given inputs and accurate regarding scale, plasma physics, and composition.

**20 Nikitina, Lidia** (Natural Resources Canada)
**Development of Forecast Model for Ionospheric Scintillation in Canadian High Latitudes.**
**Co-Author(s):** Robyn Fiori, Natural Resources Canada; Quinn Ciardelli, Natural Resources Canada; Raymond Langer, Natural Resources Canada

Small-scale disturbances in the ionosphere related to space weather activity cause phase and amplitude scintillation of a radio-frequency signal and can lead to degrading of accuracy and availability of GNSS service. Natural Resources Canada (NRCan) is developing an operational service for aviation to provide monitoring and forecast of scintillation activity in the auroral zone for safe operation of aviation including trans-arctic flights. Phase scintillation activity is often observed in high latitude ionosphere, and this work presents an analysis of scintillation activity at high latitudes across Canada together with local geomagnetic activity. Analysis of scintillation activity is based on 15 years of data, 2008-2022, from the Canadian High Arctic Ionosphere Network (CHAIN) http://chain.physics.unb.ca/chain/. This was combined with geomagnetic data recorded by NRCan https://www.spaceweather.gc.ca/data-donnee/geomag/mp-en.php?type=magnetic. A comparison of these datasets demonstrates that the ionospheric scintillations are strongly related to local geomagnetic activity. Regression models were established between ionospheric scintillation and geomagnetic activity, separately for scintillation intensity and duration. To include the daily and seasonal variability of scintillation activity, the solar zenith angle has been added to the regression model. Analysis of this regression model, its stability and statistical significance will be used for further development of NRCan operational ionosphere scintillation service providing space weather advisories.

**21 Matzka, Jürgen** (GFZ German Research Center for Geosciences, Germany)

**New Developments with Kp and the New Hourly and Half-hourly, Kp-like Geomagnetic Index Hpo (Hp60, Hp30)**

**Co-Author(s):** Guram Kervalishvili, GFZ German Research Center for Geosciences, Germany; Jan Rauberg, GFZ German Research Center for Geosciences, Germany; Yosuke Yamazaki, IAP Leibniz Institute of Atmospheric Physics, Germany

GFZ Potsdam provides the international Kp index as a near real-time (NRT) version for operational services and as a definitive version for post event analysis and scientific studies. The index is now available through a new portal, kp.gfz-potsdam.de, from where all previously existing data streams and new data distribution channels (e.g. web service, https, ftp) are linked. The new Hpo indices are very similar to Kp. They correlate well with Kp during both quiet and storm times, they have very similar statistical properties and they correlate slightly better with solar wind parameters (see other abstract by Matzka et al.). However, due to their higher temporal resolution (hourly Hp60, half-hourly Hp30) they are for example better suited to describe substorm activity or the onset timing of geomagnetic activity. Apart from that, the Hpo indices are open-ended and thus describe extremely large space weather events much more nuanced than Kp, which is capped at 9 and is assigning the value 9 to all extreme events. From an operational point of view, the Hpo indices are produced in the same way as Kp, and should thus be equally robust and reliable.

**22 Malhorta, Garima** (University of Colorado Boulder)

**Medium-scale thermospheric gravity waves simulated by high-resolution Whole Atmosphere Model**

**Co-Author(s):** Timothy Fuller-Rowell, CIRES, University of Colorado Boulder, CO and National Oceanic and Atmospheric Administration, CO; Tzu-Wei Fang, National Oceanic and Atmospheric Administration, CO; Christopher Heale, Embry-Riddle Aeronautical University, FL; Valery Yudin, Catholic University of America, DC; Erich Becker, Northwest Research Associates, CO; Adam Marshall Kubaryk, CIRES, University of Colorado Boulder, CO and National Oceanic and Atmospheric Administration, CO; Svetlana Karol, CIRES, University of Colorado Boulder, CO and National Oceanic and Atmospheric Administration, CO; Raffaele Montuoro, National Oceanic and Atmospheric Administration, CO

Gravity waves (GWs) propagate vertically and horizontally away from their source regions and play an important role in coupling of energy and momentum between different regions of the Earth's atmosphere. Even though GWs have been widely observed at higher altitudes, there is still a lack of understanding of their characteristics in the ionosphere and thermosphere (IT) region because of lack of direct observations and their broad spatial and temporal spectrum. The improvement in computing resources has led to the development of high-resolution space weather models, enabling the investigation of much larger spectrum of GWs and comparison with observations. In this study, we use the high-resolution Whole Atmosphere Model, WAM (T254), with horizontal resolution of ~0.5o, to investigate the climatology and characteristics of quiet-time medium-scale thermospheric GWs with scale lengths between ~150-620 km. WAMT254 displays a rich spectrum of waves and reproduces medium-scale GWs (~155- 620 km) that resemble GOCE observations of GWs at mid-high latitudes, especially in the Andes, Antarctic peninsula in the winter hemisphere, and high latitudes. When observed at around noon local time, a 4-peak maxima is observed in all the seasons at low-mid latitudes. This feature is most prominent in September. This is due to modulation of vertical propagation of secondary GWs in the MLT by DE3 tide at low-latitudes. We provide evidence for this process using 2D MAGIC simulations where GWs generated from a convective plume are propagated through WAMT254 background atmosphere. Thus, we show that the high-resolution GCM, WAMT254 is able to realistically simulate the generation, propagation, dissipation, and non-linear wave interaction of medium-scale GWs and the resulting variability in the IT region.

**23 Lay, Erin** (Los Alamos National Laboratory)

**Using new lightning-derived vertical total electron content data to calibrate GNSS absolute TEC**

**Co-Author(s):** Jeffery D. Tippmann, Los Alamos National Laboratory, Los Alamos, NM; Sarah E. McDonald, Space Science Division, Naval Research Laboratory, Washington, DC.; Anthony J. Mannucci, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA; Xiaoqing Pi, Jet

Propulsion Laboratory, California Institute of Technology, Pasadena, USA; Anthea Coster, MIT Haystack Observatory, Westford, USA

A newly-released, novel ionospheric dataset of global gridded vertical total electron content (VTEC) has recently been released. This VTEC dataset is derived from very-high frequency (VHF; defined as 30-300 MHz) broadband radio-frequency (RF) measurements of lightning RF emissions made by U.S. Department of Defense sensing systems on board Global Positioning System (GPS) satellites. The VTEC dataset has compared favorably to Jet Propulsion Laboratory's Global Ionospheric Model (JPL GIM), the CEDAR community's Open Madrigal VTEC gridded measurements of L-band GNSS (global navigation satellite systems) TEC, and JASON altimetry measurements. Because this technique uses a completely different methodology to determine TEC, the sources of errors are distinct from the typical ground-based GNSS L-band (GHz) TEC measurements. Also, because it is derived from impulsive RF lightning signals, this dataset provides measurements in regions that are not well covered by ground-based GPS measurements, such as over oceans and over central Africa. We will conduct case studies comparisons of the new data set with JPL GIM and Madrigal VTEC at low TEC to better calibrate absolute biases.

**24 Hughes, Joseph** (Orion Space Solutions)
**The Observation System Simulation Experiment Tool (OSSET) for Global Ionospheric Electron Density**
**Co-Author(s):** Geoff Crowley, Orion Space Solutions; Ian Collett, Orion Space Solutions; Adam Reynolds, Orion Space Solutions; Irfan Azeem, NOAA

Decision makers are often tasked with choosing how many sensors to deploy, of what types, and in what locations to meet a given operational or scientific outcome. An Observing System Simulation Experiment (OSSE) is a numerical experiment which can provide critical decision support to these complex and expensive choices. There are three simulation steps in an OSSE:

(1) An observation system consisting of any combination of instruments such as ionosondes, GPS ground stations, satellite-based RO is specified, and the measurements are simulated using the truth model which contains the electron density at every location and time.

(2) These simulated measurements are provided to an assimilator which uses them to update a background model and create an analysis.

(3) The analysis and the background model are compared to the truth model. The degree to which the analysis improves relative to the background indicates the value of those measurements. This process can be repeated for multiple combinations of instruments to compare the relative impact of different data sets. The impact of a given sensor or group of sensors can be assessed, and the value of that impact can be compared with the cost of acquiring these datasets to estimate the ‘bang for the buck’ in terms of improving ionospheric specification.

Orion Space Solutions has developed the OSSE Tool (OSSET) which is a software system used to perform ionospheric OSSEs. To our knowledge, it is the first such tool of its kind. This presentation has two parts. First, we describe OSSET's basic operation and what data sets it can simulate. Second, we compare OSSET's predictions of the impact of adding Radio Occultation TEC data to the real impact of adding RO data.

**25 Dandenault, Patrick** (JHU/APL)
**Data-Driven First-Principles Modeling of the SpaceX Starlink Satellite Loss Event in February 2022**
**Co-Author(s):** Rafael Luiz Araujo de Mesquita, JHU/APL; Robert Schaefer, JHU/APL

A series of Coronal Mass Ejections (CMEs) erupted on January 29th, 2022, and then propagated toward Earth, making them geoeffective. The solar wind plasma traveled away from the Sun with an elevated speed of around 500 km/second. A few days later, on February 3rd, the CMEs arrived at Earth with a strong southward interplanetary magnetic field (IMF Bz) producing a geomagnetic storm in the near-Earth environment which generated significant perturbations in the thermosphere and ionosphere.

Also on February 3rd, SpaceX launched 49 Starlink satellites into eccentric orbits with 210 km perigee, 350 km apogee, and 53¬∞ inclination. The final altitude for the satellites was set for 550 km. The maneuver and thrusting for orbit raising typically occurs within 2 days of the launch date, but the satellites experienced an unexpectedly large increase in atmospheric drag due to a sharp increase in thermospheric densities. The Starlink team was able to command 11 of the 49 satellites into a 'safe' orbit but the remaining 38 satellites could not overcome the increased drag and reentered Earth's atmosphere just days later.

The response of Earth's thermospheric neutral density varies as a function of altitude, geomagnetic activity, and solar activity. Even though the February 3rd global Kp index indicated that the geomagnetic storm was moderate, the nonlinear response of the thermosphere was very strong. This effort will use global ionosonde observations taken before and during the storm period to constrain the Field Line Interhemispheric Plasma (FLIP) model to simulate the response of the ionosphere and thermosphere to the storm. The variability of ionospheric hmF2 and NmF2, local F-region neutral winds, and relative changes of the neutral species (O, O2, N2, NO, O/N2) will be discussed.

**26 Collett, Ian** (Orion Space Solutions)
**Validating and Improving a Realistic Ionospheric Truth Model for Observing System Simulation Experiments of HF Propagation**
**Co-Author(s):** Joseph Hughes, Orion Space Solutions; Walter ""Junk"" Wilson, Orion Space Solutions; Geoff Crowley, Orion Space Solutions; Jonah Colman, AFRL; Russell Landry, AFRL

The US Air Force Coverage and Analysis Program (AFCAP) experiments 1, 2, and 3 have all been multimillion dollar campaigns to perform detailed Observing System Experiments (OSEs) of the ionosphere. Much of that expense has been dedicated to collecting enough observations of the ionosphere to be capable of post processing a 'truth' ionosphere. Even after such great expense, significant limitations exist in the breadth of available truth data. The ability to conduct an OSE without having to deploy sensors and personnel would vastly expand research opportunities. Such "virtual" OSEs are called Observing System Simulation Experiments (OSSEs) and require a synthetic truth model. For the HF propagation environment relevant to AFCAP, the synthetic truth model must accurately represent small-scale structures not present in smooth climatological or physics-based models. We present a synthetic truth model and a path of further development which we believe will achieve this objective.

Our synthetic truth model is constructed from the smooth physics-based TIE-GCM model by incorporating spatial and temporal electron density variations informed by two years of ionosonde measurements at mid-latitudes. Recently, using data from AFCAP experiment 2, we have performed validation of the truth model's representation of the HF propagation environment (E, F1, and F2 layers). Improvements to the truth model are also being explored. For example, using a N-dimensional Lomb-Scargle Periodogram is a more consistent treatment among spatial and temporal correlations, allowing the truth model to capture phenomena that are coherent in space and time, such as traveling ionospheric disturbances and sporadic E.

**27 Codrescu, Stefan** (Vector Space LLC)
**Data Assimilation in the Thermosphere-Ionosphere: Assimilative Specification of Neutral Density in Low Earth Orbit**

Accurate Neutral Density specification is critical for orbit prediction in Low Earth Orbit due to the impact it has on satellite trajectory through drag. Data assimilation in a physics based model combines the predictive strength of a physics based models with an anchor in reality through observational data. We assimilate different combinations of Neutral Density measurements from CHAMP and GRACE satellites during several large geomagnetic storms to demonstrate that assimilating data from even a single accelerometer results in improved global specification. During the 2003 Halloween storm, orbit maximum Neutral Density increased by a factor of 2.5x within several hours. We reproduce along track Neutral Density specification during this extreme event with better than 22% NRMSD in all experimental setups.

**28 Chakraborty, Shibaji** (Virginia Tech)
**Viability of Nowcasting Solar Flare-driven Radio-blackouts Using SuperDARN HF Radars**
**Co-Author(s):** J. Michael Ruohoniemi, Virginia Tech; Joseph B. H. Baker, Virginia Tech

The first space weather impact of a 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 HF systems are often completely suppressed due to anomalous absorption, while many RF systems suffer some degradation. While the onset of blackout is very rapid (‚àº 1-minute), the recovery takes tens of minutes to hours [3]. Furthermore, severe solar flares can disrupt emergency HF communications that support humanitarian aid services, including amateur radio and satellite communication systems. Our current monitoring capability is based on modeling the ionospheric impacts based on GOES satellite observations of solar fluxes. We present a technique to characterize radio blackout following solar flares using HF radar. The future extension of this work is to develop an now-casting system to identify and monitor radio blackouts using HF radars 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. Recent studies have shown that radio blackout (also known as shortwave fadeout) is easily detected and characterized using radar observations. We will combine real-time observations from the North American suite of SuperDARN radars to specify the occurrence of radio blackouts in near real-time.

**29 Cantrall, Clayton** (Johns Hopkins University Applied Physics Laboratory)
**Bayesian Estimation of the Thermosphere Vertical Structure from Nadir-viewing Measurements of Far Ultraviolet Airglow**
**Co-Author(s):** Tomoko Matsuo, CU Boulder Aerospace Engineering Sciences

Space-based, nadir-viewing measurements of far ultraviolet (FUV) airglow radiances are one of the few sources of direct, global-scale information of thermosphere composition and temperature in the (Very) Low Earth Orbit (V/LEO) regime (100-300 km). Despite their information content, these measurements are not utilized in operational specification and forecasting of the thermosphere due to complexities in converting the radiances into useable information for the space weather community. Here we demonstrate a Bayesian estimation approach to infer vertical profiles of the thermosphere, i.e., composition, temperature, and mass density, between 100-500 km from nadir-viewing measurements of FUV radiances. The efficacy of the approach is tested in the context of an observing system simulation experiment (OSSE). The OSSE implements the retrieval approach to invert synthetic radiance observations by NASA's GOLD mission that are generated from a 'true' upper atmosphere state specified by the model output of NCAR's Specified Dynamics (SD) WACCM-X. The results indicate promise for such an approach to extract critical information of the thermosphere's vertical structure that can be readily utilized for space operations in V/LEO. Limitations of the approach will be discussed, along with future directions for extension toward the 3-dimensional specification of the thermosphere.

**30 Cameron, Taylor G.** (Canadian Hazards Information Service, Natural Resources Canada)
**Statistical Analysis of Off-Great Circle Radio Wave Propagation in the Polar Cap**
**Co-Author(s):** R. A. D. Fiori, Canadian Hazards Information Service, Natural Resources Canada; G. W. Perry, Center for Solar-Terrestrial Research, New Jersey Institute of Technology; A. Spicher, Department of Physics and Technology, UIT the Arctic University of Norway; T. Thayaparan, Defence Research and Development Canada

High Frequency radio waves propagating in the polar cap are often deflected to off-great circle paths by localized ionospheric electron density structures such as polar cap patches and arcs. These off-great circle deflections can reduce signal quality for communications, and lead to large errors in positioning for over-the-horizon radar. In this study, nearly 2.5 years of multi-frequency transmissions from Qaanaaq, Greenland to Alert, Canada are used to perform a statistical analysis of the occurrence and impacts of off-great circle propagation in the polar cap. Off-great circle deflections are shown to be very common in the polar cap. For example, averaged over one year, 11.1 MHz signals experienced deflections > 30 degrees from the great circle direction 70.7% of the time. The occurrence of off-great circle deflections is shown to be at a maximum in the winter and close to zero in summer, and higher in the morning sector than the evening sector for frequencies < 14.4 MHz. A comparison of the angle of arrival of signals with relevant signal parameters shows that off-great circle deflections are associated with increased time-of-flights, a larger range of possible Doppler shifts, increased Doppler spreads, and lower signal-to-noise ratios. These results are discussed and explained in the context of space weather-related ionospheric phenomena in the polar cap. Implications for over-the-horizon radar operation at high latitudes are also discussed.

**31 Barjatya, Aroh** (Space and Atmospheric Instrumentation Lab, Embry-Riddle Aeronautical University)
**Low-cost In-situ Simultaneous Multi-point Plasma Density Observations**
**Co-Author(s):** Robert Clayton, Embry-Riddle; Shantanab Debchoudhury, Embry-Riddle; Henry Valentine, Embry-Riddle; Nathan Graves, Embry-Riddle

Spatial and temporal variability of absolute plasma density and plasma density fluctuations are a critical set of measurements to characterize most space weather events. Among the various methods to perform in-situ plasma density measurements is a simple Langmuir probe. This poster presents design and performance of a miniaturized planar Langmuir probe suitable for small satellite and sounding rocket platforms. We discuss the CubeSat implementation of the instrument that is part of the NASA LLITED dual CubeSat mission slated to launch in April 2023. The poster also presents results from the NASA SpEED Demon sounding rocket launch that did the first simultaneous multipoint in-situ measurements of a Sporadic-E layer using the miniaturized Langmuir probe. Finally, we also present the instrumentation and mission plans for the upcoming Apophis sounding rocket mission that is expected to launch a similar set of rockets as SpEED Demon with multi-pint measurements in the upcoming annular eclipse in 2023 and total eclipse in 2024.

**32 Purohit, Yagya** (Indian Institute of Science Education and Research Tirupati, India)
**Study the Effect of Different Space Weather Conditions on the Ionosphere**
**Co-Author(s):** P.K.Purohit, National Institute of Technical Teachers' Training and Research, Bhopal, India

There is a strong correlation between ionospheric variability and space weather conditions. When there is a geomagnetic storm, it is disrupted. They also affect satellite navigation and communications systems. We present here the responses of six intense geomagnetic storms (-100 nT > Dstmin> -250 nT) at low, mid, and high latitudes that develop during the solar cycle of 24 years. We have retrieved GPS-VTEC dual-frequency data in Receiver Independent Exchange Format (RINEX) from the Scripps Orbits and Permanent Array (SOPA) database of the International GNSS Service (IGS). Additionally, we consider the solar Dst index and the Bz component of the IMF. VTEC values are enhanced at all three latitudes (low-latitude, mid-latitude, and high-latitude). Compared to previous or quiet days, VTEC values changed most at low latitudes, then at mid and high latitudes.

**33 Sadykov, Viacheslav** (Georgia State University)
**Understanding Space Radiation in Earth Environment with Radiation Data Portal**
**Co-Author(s):** Zachary Watkins, Georgia State University; William Jones, Georgia State University; Dustin Kempton, Georgia State University; Xiaochun He, Georgia State University; W Kent Tobiska, Space Environment Technologies; Christopher Mertens, NASA Langley Research Center; Shubha Ranjan, NASA Ames Research Center; Irina Kitiashvili, NASA Ames Research Center; Ryan Spaulding, NASA Ames Research Center; D Glenn Deardorff, NASA Ames Research Center

Continuous monitoring and analysis of the radiation environment in the Earth's lower atmosphere are critical for the safety of aircraft and spacecraft crews and passengers. Addressing the problem requires a complex approach of integrating different data sources and enhancing the visualization and search capabilities. This work highlights the progress of expanding the Radiation Data Portal (RDP) database. Currently, the RDP allows the users to explore the measurements obtained from the Automated Radiation Measurements for Aerospace Safety (ARMAS) device and soft X-ray and proton fluxes from Geostationary Orbiting Environmental Satellite (GOES). The RDP expansion includes the incorporation of new sources (the measurements of the cosmic rays, solar wind, energetic particles, and geomagnetic activity) and upgrades of the portal visualization capabilities. Using the RDP, we examine the properties of the ARMAS flights taken during the enhanced Solar Proton (SP) fluxes and compare them to the flights of similar time and location taken during SP-quiet periods. We also compare the radiation dose rates measured by ARMAS and predicted by Nowcast of the Atmospheric Ionizing Radiation for Aerospace Safety (NAIRAS V2) model for different geographic locations, phases of the 11-year solar activity cycle, and the presence of significant space weather events.

**34 Mertens, Christopher** (NASA Langley Research Center)
**NAIRAS Model Updates and Improvements to the Prediction of Ionizing Radiation from Earth's Surface to Cislunar Environment**
**Co-Author(s):** Guillaume Gronoff, SSAI, Inc.; Yihua Zheng, NASA Goddard Space Flight Center Janessa Buhler, NASA Kennedy Space Center; Emily Willis, NASA Marshall Space Flight Center; Maksym Petrenko, NASA Goddard Space Flight Center; Daniel Phoenix, SSAI, Inc.; Insoo Jun, Jet Propulsion Laboratory; Joseph Minow, NASA Marshall Space Flight Center

The Nowcast of Aerospace Ionizing RAdiation System (NAIRAS) predicts dosimetric quantities for assessing human radiation exposure and differential and integral flux quantities for assessing single event effects from galactic cosmic rays, trapped inner belt protons, and solar energetic particles (SEP) from the Earth's surface to the space environment. NAIRAS is composed of coupled physics-based models that transport ionizing radiation through the heliosphere, Earth's magnetosphere, the neutral atmosphere, and aircraft or spacecraft shielding. Recent updates to NAIRAS include the transition to prototype operations at the Community Coordinated Modeling Center (CCMC) where the model now operates in two modes: (1) real-time global predictions of the atmospheric radiation environment (0-90 km) and (2) a run-on-request (RoR) service allowing the user to select a specific time period for the global dosimetric calculations, or to upload an aircraft, balloon, or spaceflight trajectory file to provide predictions of the dosimetric and flux quantities along the flight path. The trapped proton model and the differential and integral flux quantities are also recent updates to NAIRAS. The NAIRAS model improvements include a more accurate atmospheric ionizing radiation transport method and more robust and reliable SEP predictions. The NAIRAS model updates and improvements are described, and results are shown for aircraft, high-altitude balloon, low-Earth and medium-Earth orbits, and the NASA Artemis 1 cislunar flight. The range of flights examined occurred during both quiescent and solar-geomagnetic disturbed conditions. Model comparisons with measurement data are also shown.

**35 Lee, Dong-Hee** (National Meteorological Satellite Center, Korea Meteorological Administration)
**Estimation of Radiation Dose Rates at the Aviation Flight Levels during Episodic Solar Proton Events**
**Co-Author(s):** Jiyoung Kim, National Meteorological Satellite Center, Korea Meteorological Administration

Radiation monitoring can help aircrew to identify and minimize the risk of high-altitude ionizing radiation. And the risk assessment of episodic space weather events is critical to planning and updating contingency flight plans. But, every commercial aircraft can not embed a radiation dose rate instrument, and the records of radiation dose observations at past flight altitudes are insufficient. Accordingly, using the Korean Radiation Exposure Assessment Model for aviation route dose (KREAM), we estimated the enhancement of dose rates at the flight levels during episodic solar proton events (SPE) since 1976 (the first GOES proton data is available). The maximum dose rate during the study period appeared on October 20, 1989, with 161.5 uSv/hr at the flight level of 12 km. The SPE was associated with the X13 flare on October 19 (GOES proton flux > 10 MeV reached 40,000 pfu). Usually, a region with a severe dose rate level of the International Civil Aviation Organization space weather advisory (> 80 uSv/hr) was in North America and distributed at a latitudinal area higher than 60 degrees North. In addition, the estimated dose rates at 12km of the top 10 events are severe levels. The events occurred during solar cycles 22 and 23, concentrating at the maximum phase except for only one case (February 21, 1994). In this study, we presented the estimated dose rates for the episodic SPE events during the study period. And we will discuss the scientific implications of the operational space weather service.

**36 Helpling, Braden** (US Air Force Academy)
**Characterizing Electron Flux in Geosynchronous Orbit with the Falcon Solid-state Energetic Electron Detector**
**Co-Author(s):** Isaac Hanley, US Air Force Academy; R. Anthony Vincent, US Air Force Academy; John D. Williams, US Air Force Academy; M. Geoff McHarg, US Air Force Academy

Continuous monitoring and analysis of the radiation environment in the Earth's lower atmosphere are critical for the safety of aircraft and spacecraft crews and passengers. Addressing the problem requires a complex approach of integrating different data sources and enhancing the visualization and search capabilities. This work highlights the progress of expanding the Radiation Data Portal (RDP) database. Currently, the RDP allows the users to explore the measurements obtained from the Automated Radiation Measurements for Aerospace Safety (ARMAS) device and soft X-ray and proton fluxes from Geostationary Orbiting Environmental Satellite (GOES). The RDP expansion includes the incorporation of new sources (the measurements of the cosmic rays, solar wind, energetic particles, and geomagnetic activity) and upgrades of the portal visualization capabilities. Using the RDP, we examine the properties of the ARMAS flights taken during the enhanced Solar Proton (SP) fluxes and compare them to the flights of similar time and location taken during SP-quiet periods. We also compare the radiation dose rates measured by ARMAS and predicted by Nowcast of the Atmospheric Ionizing Radiation for Aerospace Safety (NAIRAS V2) model for different geographic locations, phases of the 11-year solar activity cycle, and the presence of significant space weather events.

**37 Fernandez Gomez, Isabel** (German Aerospace Center (DLR), Germany)
**Quantifying Uncertainty in Thermospheric Mass Density From Satellite Measurements via Data Assimilation with CTIPe Model**
**Co-Author(s):** Stefan Codrescu, Vector Space LLC, US; Timothy Kodikara, German Aerospace Center (DLR), Germany; Frank Heymann, German Aerospace Center (DLR), Germany; Claudia Borries, German Aerospace Center (DLR), Germany

This study proposes a method for estimating the uncertainty of thermospheric mass density derived from satellites, which is a crucial parameter that characterizes the upper atmosphere. The accuracy of satellite trajectory calculations is heavily influenced by the accuracy of this parameter, and uncertainty in neutral density can lead to significant errors in such calculations, particularly in situations that require collision avoidance measures. The proposed method combines measurements of thermospheric neutral density with a physics-based Coupled Thermosphere Ionosphere Plasmasphere with Electrodynamics (CTIPe) model. We analyze data from two different satellite missions, CHAMP and Swarm, during periods of quiet geomagnetic conditions. By analyzing the effect of different uncertainties on the assimilation result, we can estimate the uncertainty in the neutral density measurements. The results for both satellites are presented.

## Thursday April 20 Posters

### *Geospace/Magnetosphere Research and Applications; Space Weather Policy and General Space Weather Contributions*

9:40 AM - 10:30 AM and 2:55 PM - 3:40 PM
Lightning talks: 5:30 PM - 6:00 PM

**1 Young, Shawn** (Air Force Research Laboratory)
**Testing the Liouville Theorem Based SEP Flux Mapping Method with Multiple Cutoff Models at High Altitudes and Off the Magnetic Equator**
**Co-Authors(s):** Christian M. Alcala, Atmospheric and Environmental Research
The accurate determination of the local level of radiation exposure to satellites during a solar energetic particle (SEP) event is essential for satellite and instrument protection and for anomaly resolution. Local flux levels can be estimated through the use of rigidity cutoff models and the application of the Liouville theorem. However, the Earth's magnetic field complicates this computation because its location-dependent radiation shielding varies depending on the field's configuration and activity level.

Geomagnetic cutoff models have been developed to address this issue using both empirical and numerical methods. However, these approaches have limitations, the former method is usually restricted to LEO orbits because data are limited elsewhere, while the latter method can require significant computational resources. Fortunately, approaches to reduce these constraints exist, allowing the creation of models that are operationally feasible and valid for all of geospace.

Here we test both empirically and numerically based models against HEO satellite data. However, while cutoffs are important to determining the hazard, they are not operationally useful in and of themselves. It is the local fluxes that are the important quantity, thus we will not test the cutoff models directly. Instead we will use them as part of a method, based on Liouville's theorem, to map interplanetary fluxes inside of geospace. We will then compare the specified fluxes to those observed on the HEO satellite. Similar work has been done using CRRES observations, but the HEO satellite will provide a test of these models off of the geomagnetic equator.

**2 Welling, Daniel** (University of Michigan)
**A New Community-Focused GIC Workshop**
**Co-Authors(s):** Bang Nguyen, NREL; Hannah Parry , U. Alberta; Liying Qian, NCAR; Surja Sharma, U. Maryland

End-to-end research and research-to-operations efforts on the issue of geomagnetically induced currents (GICs), from space weather physics to power grid impacts, is fraught with unique challenges. It requires a wide range of experts to come together using a common language to communicate needs, capabilities, and next steps. Currently, major obstacles exist preventing progress in this field. No community exists to bring together all GIC-relevant disciplines on a consistent basis. Talent and knowledge pipelines that should bridge communities over the long term are either ‚Äúleaky‚Äù (high workforce attrition rate) or non-existent.

In this poster, we introduce a new community dedicated to advancing interdisciplinary GIC research and collaboration. Our long term mission is to Integrate the effort and resources of all relevant disciplines to build talent & knowledge pipelines and develop sustained support mechanisms for combined GIC research and mitigation efforts. An inaugural workshop will be held this fall with the goal of developing a true GIC-dedicated community. We invite those interested to discuss participation opportunities.

**3 Vandegriff, El** (University of Texas at Arlington)

**Localized Geomagnetic Disturbance Forecasting: Evaluating Physics and Numerics in Global Models**
**Co-Authors(s):** Daniel Welling, University of Michigan; Agnit Mukhopadhyay, Mapping and RF Propagation, The MathWorks Inc.; Andrew Dimmock, Swedish Institute of Space Physics (IRF); Steven Morley, Los Alamos National Laboratory; Ramon Lopez, University of Texas at Arlington

One of the prominent effects of space weather is the formation of rapid geomagnetic field variations on Earth's surface driven by the magnetosphere-ionosphere system. These Geomagnetic Disturbances (GMDs) cause Geomagnetically Induced Currents (GICs) to run through ground conducting systems. A subset of this phenomena is localized GMDs (LGMDs) which are high amplitude, small scale sizes (~100 kilometers). LGMDs are both hazardous to the power grid and difficult to predict. Modeling LGMDs is therefore a critical step for risk mitigation, but is complicated due to the dynamic and sometimes highly localized nature of the phenomena. At present, LGMD forecasting is performed by the operational version of the Space Weather Modeling Framework (SWMF). In this study, we evaluate the ability of the SWMF to reproduce LGMDs in the September 7, 2017 event. We compare various metrics to quantify the success of the model against observation, we examine features of the model that help us identify drivers of LGMDs, we analyze shortcomings of the model, and we plan for model improvements that will have a direct effect on the ability of the SWMF to reproduce LGMDs.

**4 Tenishev, Valeriy** (University of Michigan)
**Dynamics of Solar Energetic Particles in Geospace**

Penetrating radiation by energetic particles significantly affects human technology in the altitude range above that used by commercial aviation in the troposphere. In space, exposure to energetic particles often leads to malfunctions and unexpected failures of electronics onboard manned and unmanned spacecraft and poses a severe health risk for astronauts.

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

**5 Shprits, Yuri** (GFZ German Research Centre for Geosciences, DE)
**Prediction of Adverse effects of Geomagnetic storms and Energetic Radiation (PAGER)**
**Co-Authors(s):** Dedong Wang, GFZ German Research Centre for Geosciences, DE; Michael Wutzig, GFZ German Research Centre for Geosciences, DE; Stefano Bianco, GFZ German Research Centre for Geosciences, DE; Ruggero Vasile, GFZ German Research Centre for Geosciences, DE; Bernhard Haas, GFZ German Research Centre for Geosciences, DE; Hayley Allison, GFZ German Research Centre for Geosciences, DE; Tony Arber, University of Warwick, UK; Keith Bennett, University of Warwick, UK Mike Liemohn, University of Michigan, USA; Bart van der Holst, University of Michigan, USA; Ondrej Santolik, Czech Academy of Sciences, Institute of Atmospheric Physics, CZ; Ivana Kolmasova, Czech Academy of Sciences, Institute of Atmospheric Physics, CZ; Ulrich Taubenschuss, Czech Academy of Sciences, Institute of Atmospheric Physics, CZ; Julien Forest, Artenum SARL, FR; Arnaud Trouche, Artenum SARL, FR; Benoit Tezenas du Montcel, Artenum SARL, FR

Geomagnetic perturbations related to various phenomena in the near-Earth space environment can induce The PAGER project provides space weather predictions initiated from observations on the Sun to predict radiation in space and its effects on satellite infrastructure. Real-time predictions and a historical record of the dynamics of the cold plasma density and ring current allow for the evaluation of surface charging, and predictions of relativistic electron fluxes allow for the evaluation of deep dielectric charging. The project provides a 1-2 day probabilistic forecast of ring current and radiation belt environments, which allow satellite operators to respond to predictions that present a significant threat. As a backbone of the project, we use the most advanced codes that currently exist and adapt existing codes to perform ensemble simulations and uncertainty quantifications. This project includes a number of innovative tools including data assimilation and uncertainty quantification, new models of near-Earth electromagnetic wave environment, ensemble predictions of solar wind parameters at L 1, and data-driven forecast of the geomagnetic Kp index and plasma density. The developed codes may be used in the future for realistic modeling of extreme space weather events. The PAGER consortium is made up of leading academic and industry experts in space weather research, space physics, empirical data modeling, and space environment effects on spacecraft from Europe and the US.

**6 Shi, Xueling** (Virginia Tech)
**Intense Geoelectric Field Perturbations Driven by Magnetospheric Ultra-low Frequency Waves**
**Co-Authors(s):** Michael Hartinger, Space Science Institute, Boulder, CO, USA; Joseph Baker, Virginia Tech, Blacksburg, VA, USA

Geomagnetic perturbations related to various phenomena in the near-Earth space environment can induce geoelectric fields within the electrically conducting Earth. In turn these geoelectric fields drive geomagnetically induced currents (GIC) that can cause potential damage to technological infrastructure. Ultra-low frequency (ULF: 1 mHz - several Hz) waves have recently been reported to be a common driver of intense geoelectric fields during geomagnetic storms. Though numerous past studies have examined ULF wave related geomagnetic fields from a space weather perspective, few studies have linked ULF waves with geoelectric fields due to limited direct measurements of these fields. Using 1-second cadence geoelectric field measurements made at recently available magnetotelluric survey sites distributed widely across the United States, we explore the relationship between ULF waves and intense geoelectric field perturbations. Detailed case studies demonstrate that the ULF wave driven geoelectric fields have significant spatial variation in contrast to relatively uniform geomagnetic field perturbations, consistent with spatially varying Earth conductivity. We further show that geoelectric fields driven by magnetospheric ULF waves during geomagnetic storms have comparable amplitudes to once-per-century geoelectric hazard maps. Our results highlight the need for more research characterizing geoelectric fields driven by ULF waves.

**7 Mubashir, Arfa** (Georgia State University)
**Muon Flux Variation in Real-time and its Correlation with Space Weather Activity**
**Co-Authors(s):** Xiaochun He, Georgia State University; Ashwin Ashok, Georgia State University; Anu Bourgeois, Georgia State University; Yang-Ting Chien, Georgia State University; Megan Connors, Georgia State University; Ernesto Potdevin, Georgia State University; Petrus Martens, Georgia State University; Armin Mikler, Georgia State University; Unil Perera, Georgia State University; Viacheslav Sadykov, Georgia State University; Murad Sarsour, Georgia State University; Deepali Sharma, Georgia State University; Chetan Tiwari, Georgia State University

We present a comparison of the measured cosmic ray (CR) muon fluxes from two identical detectors at different geolocations and their sensitivity to space weather events in real time. The first detector is installed at Mount Wilson Observatory, CA, USA (geomagnetic cutoff rigidity Rc~4.88 GV), and the second detector is running on the downtown campus of Georgia State University in Atlanta, GA, USA (Rc~3.65 GV). The variation of the detected muon fluxes is compared to the changes of the interplanetary solar wind parameters at L1 Lagrange point and geomagnetic indexes. We have also investigated the muon flux behavior during major interplanetary shock events and geomagnetic disturbances. To validate the interpretation of the measured muon signals, the muon fluxes are compared to the neutron flux measurement from the Oulu neutron monitor (NM) in northern Finland (Rc~0.8 GV). The results of this analysis show that the cosmic ray flux percentage changes from all stations are significantly correlated with each other and with solar wind parameters at L1, and the decreases of the muon fluxes can sometimes be observed several hours ahead of the onsets of the interplanetary shock arrivals at L1 and geomagnetic disturbances. Although this is yet an initial effort of building a global network of cosmic ray muon detectors for monitoring the space and earth weather in real time, the study provides evidence that

muon network detection efficiency can be a diagnostic and forecasting tool for geomagnetic storms hours before they hit the Earth.

**8 Moraga, Gabriel** (University of Colorado at Boulder)
**Pushing the Frontiers of Operational Geoelectric Hazard Modeling**
**Co-Authors(s):** Dr. Greg Lucas, Laboratory for Atmospheric and Space Physics, Boulder, Colorado, United States; Maxine Hartnett, Laboratory for Atmospheric and Space Physics, Boulder, Colorado, United States; Matthew Bourque, Matthew Bourque; Dr. Wendy Carande, Maxar Technologies, Westminster, Colorado, United States

Space weather, and its effects on Earth, is a trending topic. Geoelectric fields are influenced by geomagnetic field variation caused by Earth's surrounding space weather environment. Geoelectric hazards from space weather can critically affect infrastructure, and the aftermath is economically costly. It is essential to enhance geoelectric hazard modeling by implementing a combination of research and machine learning. This will determine where and when geomagnetically induced currents (GICs) may impact critical infrastructure.

Organizations such as NOAA, USGS, NASA, NSF and international partners (NRCan) have contributed to an operational geoelectric field map data product. Currently, ground based stations across North America measure real-time surface geomagnetic field data, which is driven by natural-time ionosphere conductivities within the thermosphere. The current geoelectric field maps use the Spherical Elementary Current System (SECS) interpolation method, based on physical constraints of the magnetic field. Currently there is no machine learning method in place to fill missing data and flag outliers in real-time. Our team created an algorithm in Python, using real-time data, which interpolates missing values and detects anomalies outside a standard deviation of 3 sigma. With the Seasonal Auto-Regressive Integrated Moving Average (SARIMA) anomaly detection model as the base, the newly created model will fill data gaps and flag anomalies. We generate more accurate geoelectric field maps using machine-learning algorithms that identify and replace missing data within the real-time data streams. The final machine learning model will be run in the CU's Space Weather Technology Research and Education Center's (TREC) cloud-based Testbed environment.

**9 Matzka, Jürgen** (GFZ German Research Center for Geosciences, Germany)
**Relation to Solar Wind and Index Prediction for the New Kp-like Hpo Indices (Hp30, Hp60)**
**Co-Authors(s):** Yosuke Yamazaki, IAP Leibniz Institute of Atmospheric Physics, Germany; Yuri Shprits, GFZ German Research Center for Geosciences, Germany; Stefano Bianco, GFZ German Research Center for Geosciences, Germany

The new Kp-like Hpo indices consist of the hourly Hp60 and half-hourly Hp30 and their linear versions ap60 and ap30 (for more information, see other abstract by Matzka et al.). They not only have a time resolution, which is higher than that of Kp, they are also open-ended. We compare the new indices to the open-ended Newell (2007) and Kan and Lee (1979) coupling function as well as other open-ended geomagnetic indices (auroral electrojet index AE and polar cap index PC) that indicate the energy transfer from the solar wind to geospace. We find that, firstly, the Hpo indices correlate slightly better with solar wind and geospace parameters than Kp itself. Secondly, the relationship between Hpo and the other open-ended parameters works follows simple polynomial functions also for Hpo > 9. A 72 hour lead time prediction of Kp and Hp60 is published and updated hourly on spaceweather.gfz-potsdam.de. The machine-learning algorithm is based on L1 solar wind and interplanetary magnetic field measurements as well as on historic index values. An additional prediction of L1 conditions from solar observations and solar wind ensemble predictions (see www.spacepager.eu) is in preparation. This will significantly improve the forecast quality for lead times exceeding a few hours and it will also provide uncertainties in the form of confidence levels.

**10 Leonard, Trevor** (CIRES, CU Boulder)
**The GOES-R SEISS Magnetospheric Particle Sensor - Low Energy**

**Co-Authors(s):** Brian Kress, Cooperative Institute for Research in Environmental Sciences, CU Boulder; NOAA National Centers for Environmental Information; Athanasis Boudouridis, Cooperative Institute for Research in Environmental Sciences, CU Boulder; NOAA National Centers for Environmental Information; Juan Rodriguez, Cooperative Institute for Research in Environmental Sciences, CU Boulder; NOAA National Centers for Environmental Information

The Magnetospheric Particle Sensor - Low Energy (MPS-LO) is NOAA‚Äôs first plasma instrument on a Geostationary Operational Environmental Satellite (GOES) measuring 30 eV - 30 keV ions and electrons. MPS-LO observations can help identify spacecraft surface charging which is associated with thermal particle populations,

**11 Keebler, Timothy** (University of Michigan)
**Stormtime Geomagnetic Disturbance Events - Impact of High-Resolution Grid and Adaptive Kinetic Physics**
**Co-Authors(s):** Daniel Welling, University of Michigan, Gabor Toth, University of Michigan
Xiantong Wang, University of Michigan

Rapidly-changing surface geomagnetic fields as a result of space weather can create harmful impacts to electrical systems via induced currents. These Geomagnetic Disturbances (GMDs) are critical to understand using numerical modeling as a predictive tool to forecast and help mitigate impacts. The Michigan Geospace model is used operationally by the Space Weather Prediction Center to produce forecasts of potentially harmful events. However, this model uses magnetohydrodynamic equations in the global magnetosphere physics domain, and a relatively coarse grid in the magnetotail. Magnetic reconnection in this domain has a large impact on GMDs by initiating substorms and associated magnetic perturbations.

To explore the impacts of model grid and physics on GMDs, we run the Michigan Geospace model in the operational configuration as a baseline for several storm-time events. Geospace is then altered to have higher grid resolution in the magnetotail, impacting resistive nightside reconnection. Finally, we compare these with the MHD with Adaptive Embedded Particle-In-Cell (MHD-AEPIC) model, which couples the FLEKS particle code with the SWMF in the magnetotail. This code features an adaptive grid that dynamically activates to cover only the plasma sheet and reconnection locations. By adding particle physics for tail reconnection, the reconnection physics changes with impacts to substorm formation and surface magnetic perturbations. Comparison between the model configurations shows the importance of magnetotail grid resolution and adaptive kinetic physics on GMDs in the Geospace model.

**12 Hu, Andong** (CIRES, CU Boulder)
**One-Hour-Ahead Horizontal Geoelectric Fields Forecast Using Multi-Fidelity-Based Machine Learning Method**
**Co-Authors(s):** Enrico Camporeale, CIRES, University of Colorado, Boulder, NOAA Space Weather Prediction Center; Greg Lucas, SWX-TREC, LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS (LASP)

Geomagnetically Induced Currents (GICs) are electrical currents induced at the Earth's surface by rapid changes in the geomagnetic field caused by space weather events, and the currents can flow through conductive infrastructure such as power grids and pipelines. Hence, a significant but still unresolved problem in the Geospace environment is forecasting the occurrence of GICs, not just nowcasting.

GIC is calculated by horizontal geoelectric fields (including Ex and Ey). Instead of dB/dt, we develop a new model to directly forecast Ex and Ey 1-hour-ahead using a newly developed multi-fidelity machine learning method, magnetometer data, and Magnetotellurics (MT) survey data. We forecasted the maximum Eh to within 10% of the observed Eh with an hour lead time during storm events.

**13 - Poster moved to last poster on Wednesday.**

**14 Fillion, Martin** (CIRES, University of Colorado Boulder)
**Modeling the Local Time Asymmetry of the Near-Earth Magnetospheric Field**
**Co-Authors(s):** Arnaud Chulliat, CIRES, University of Colorado Boulder; Patrick Alken, CIRES, University of Colorado Boulder; Mikhail Kruglyakov, Department of Physics, University of Otago, New Zealand; Alexey Kuvshinov, Institute of Geophysics, ETH Zurich, Switzerland

Data-based modeling of the near-Earth magnetospheric field is challenging due to the highly dynamical nature of magnetospheric currents and to the sparse available data. One important characteristic of this field is the so-called local time asymmetry, which can be clearly observed during the main phase of geomagnetic storms. Modeling this asymmetry requires a dataset with a good spatial coverage at a high time resolution. The network of ground magnetic observatories provides the only magnetic data that meet these criteria. In this study, we present a data-based model of the near-Earth magnetic field produced by electric currents in the inner magnetosphere. Using vector magnetic data from ground observatories, we take advantage of the spatiotemporal coverage of the full dataset to model the local time asymmetries with a one-hour timestep. The magnetospheric field is modeled with spherical harmonics in the Solar Magnetic coordinate frame and its external and induced parts are separated using a time-domain approach. The model is validated by comparing it to satellite data from Swarm, Oersted and CHAMP. The resulting model allows to study the local time asymmetries for all geomagnetic conditions over a period of 24 years. In particular, storm-time asymmetries can be observed for numerous storm events.
The asymmetry during quiet times is subtle and is discussed within the scope of the separation of the ionospheric and magnetospheric fields in magnetic data, which remains a major challenge in geomagnetism. It is believed that this model can provide constraints for the study of geomagnetic storms and substorms.

**15 Espenshade, Matalyn** (United States Military Academy)
**Correlating Solar Wind Variations to the Timing of Field-Aligned Current Flow**
**Co-Authors(s):** Nathan Lampshire, United States Military Academy; Anastasiya Ryabenko, United States Military Academy

The current state of research into field-aligned currents is primarily concerned with the causation of the increase in field-aligned current flows. Field-aligned currents, also known as Birkeland currents, flow along geomagnetic field lines and increase strength in response to changes in the interplanetary magnetic field (IMF). Researchers debate whether field-aligned currents are caused by magnetic merging or the convection of plasma in the magnetosphere following night-side reconnection. Currents are categorized by region: Region 1 at the magnetopause where currents are driven by charge separation, and Region 2 where currents are connected to the equatorial ring and originate from charge separation. Region 2 currents dominate in auroral electrojets that connect to the magnetosphere, drift eastward, and cause the diffuse aurora. Current systems are interconnected, and recent analysis focuses on the lag between solar wind conditions for the aurora and detection of the aurora. Both are used to determine whether reconnection is responsible for field-aligned current flow. The end state of this project is to determine the timing of either Region 1 or Region 2 currents with diffuse aurora. Initial analysis of non-geomagnetically active times with southward IMF polarity and the presence of diffuse aurora reveals a lag of approximately two hours, indicating Region 2 currents are responsible.

**16 Doublestein, Kaitlin** (Department of Climate and Space Science and Engineering, University of Michigan)
**Impact of Single Fluid and Multifluid MHD on GMD Forecasting: An Inner Boundary Condition Sensitivity Study**
**Co-Authors(s):** Michael Liemohn, Department of Climate and Space Science and Engineering, University of Michigan; Daniel Welling, Department of Climate and Space Science and Engineering, University of Michigan

Altering global MHD model inner boundary conditions, such as temperature, parallel velocity, and ion composition can impact ground magnetic disturbances (GMD) by changing the geospace response to solar drivers. As solar and magnetospheric activity increases, we see an increase in light and heavy ion densities in Earth's magnetosphere. These additional ions impact physical processes, including reconnection rates, ring current development, and wave environments. Many of the physical mechanisms responsible for additional ion outflow are not included in the idealized magnetohydrodynamic (MHD) equations. The Space Weather Modeling Framework (SWMF) using a passive static inner boundary condition [e.g., Welling & Liemohn, 2014] approximates outflow magnitude with ideal MHD equations, but does not accurately show the outflow pattern. To better reflect the ion composition this requires us to switch from ideal MHD equations to a multifluid MHD equation set, allowing for multiple ion species to be present, solving for separate momentum and energy equations. Changing between these two equation types results in higher computational costs and diverges from real-time analysis, but may improve simulated ground-based magnetometer results by reflecting an accurate ion outflow pattern. We compare the ground magnetic response as a function of ion outflow type, exploring the importance of mass outflow on GMD. Both single and multifluid MHD equation sets are exercised. The overall effect of inner boundary conditions on GMD forecasting is summarized.

**17 Davis, Aspen** (University of Colorado/CIRES;  NOAA/NCEI, Boulder, United States)
**Observations of Relativistic Electron Wave-Particle Interactions at Geostationary Orbit by the new NOAA GOES-16, GOES-17 and GOES-18 Satellites**
**Co-Authors(s):** Paul T M Loto, University of Colorado/CIRES, NOAA/NCEI, Boulder, United States; Alison Jarvis, University of Colorado/CIRES, NOAA/NCEI, Boulder, United States; Alessandra Abe Pacini, University of Colorado/CIRES, NOAA/NCEI, Boulder, United States; Fadil Inceoglu, University of Colorado/CIRES, NOAA/NCEI, Boulder, United States

We present two examples of relativistic electron enhancements by the GOES satellites. On April 2nd, 2022 the new NOAA Geostationary Operational Environmental Satellite (GOES) 16 and 17 Space Environment In Situ Suite (SEISS) particle instruments measured large increases in relativistic electron particle fluxes that were accompanied by Ultra Low Frequency (ULF) plasma waves detected by the onboard magnetometers. A second event of relativistic electron flux enhancement and ULF waves was observed by GOES-16, 17 and the recently operational GOES 18 on February 28th, 2023, following a sustained (~1hr) magnetopause crossing on February 26th, 2023. During both events, the >2MeV particle flux increased by a factor of 100, rising above the operational limit for NOAA Space Weather Prediction Center (SWPC) alerts. Particle fluxes showed a permanent increase for a number of days before beginning to drop. On board magnetometers observed Pc5 ULF waves (1-10mHz frequency range) lasting from minutes to hours and were present in the data for a number of days before wave duration decreased to minute time scales. We estimate wave spectral properties, calculate electron radial diffusion rates and compare diffusion timescales to relativistic electron flux enhancement times. We present wave spectral properties and discuss diffusion rate estimates, the role of ULF wave-particle interactions in relativistic electron enhancements and the possibility of developing future operational radiation belt products using estimates of relativistic electron radial diffusion timescales. The February 2023 event is the first observation of a magnetopause crossing and permanent particle flux enhancement accompanied by ULF waves by the newly operational GOES-18 instruments and the last observation from GOES-17 before entering storage.

**18 Chu, Xiangning** (Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, Boulder, Colorado, USA)
**Imbalanced Regression and Large Event Prediction: Application on Whistler-mode Chorus Using a Neural Network**
**Co-Authors(s):** Jacob Bortnik, Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, California, USA; Wen Li, Center for Space Physics, Boston University, Boston, Massachusetts, USA; Xiao-Chen Shen, Center for Space Physics, Boston University, Boston, Massachusetts, USA; Qianli Ma, Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, California, USA; Donglai Ma, Department of Atmospheric and Oceanic

Sciences, University of California, Los Angeles, California, USA; David Malaspina, Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, Boulder, Colorado, USA; Sheng Huang, Center for Space Physics, Boston University, Boston, Massachusetts, USA

Real-world data sets often exhibit imbalanced distributions, which have significantly more data or observations in a specific range of values than the other ranges. For example, space physics data sets, such as geomagnetic indices, relativistic electron fluxes in Earth's radiation belt, and the occurrence and amplitude of solar flares, are typically imbalanced. This is the too-often-too-quiet challenge, one of the fundamental problems in space physics and space weather, and is also a general problem in machine learning. For example, the electron density and plasma fluxes in the Earth's radiation belts can be accurately modeled in our previous studies [Bortnik et al.,  2016, 2018; Chu et al., 2017a,b; 2021; Ma et al., 2022a, b]. However, the ML-based models of the plasma waves are usually biased due to the too-often-too-quiet problem both in numerical simulations and observations [Ma et al., 2018; Camporeale et al., 2019; Guo et al., 2021].

We developed a method to solve this problem and applied it to the whistler-mode chorus waves in the Earth's radiation belt. The ML-based wave model used a neural network approach, which takes geomagnetic indices as input and prediction the wave power. As a result, the model can predict not only the quiet time values but also large events. The fact demonstrates that the model provides reliable and stable predictions when the too-often-too-quiet problem is solved. This method of imbalanced regression has wide applications in space physics/weather and a wider field of machine learning techniques.

**19 Chakraborty, Shibaji** (Virginia Tech)
**SCUBAS: A Python-Based Numerical Model To Estimate GMD-Driven Electrical Surges in Submarine Cables**
**Co-Authors(s):** D. Boteler, Natural Resources Canada, Canada; M. Hartinger, Space Science Institute; X. Shi, Virginia Tech/HAO, NCAR

Submarine cables have become a vital component of our modern infrastructure. They carry a significant amount of international internet traffic, so any disruption to their operation would have wide-ranging consequences. However, it is uncertain how modern submarine cables systems would behave in an extreme (1 in 100 years) space weather event. Thus, submarine cables, like other critical infrastructure, need to consider space weather as High Impact, Low Frequency (HILF) events which require an assessment of risk and preparation of mitigation action if necessary. The aim of this study is to build a computational model of geomagnetic induction to calculate the induced voltages produced in submarine cables during geomagnetic disturbances. We present the theory for estimating the induced voltages experienced by the submarine cables during geomagnetic disturbances and then describe  implementation of a Python-based software model to be used by end-users, such as researchers or cable engineers. The model requires the specification of a number of parameters, such as Earth-water conductivity structure, depth, length of cable sections, and earth conductivity model, and then uses magnetic observatory data to estimate the induced cable voltages. As part of the demonstration of the capabilities of the software and validation of the model, we describe several applications and examples of the software. In conclusion, we will discuss the various capabilities and limitations of the current computational model and the potential extensions of the software in the near future.

**20 Brenner, Austin** (University of Michigan Climate and Space Sciences and Engineering Department)
**Using Energy Dynamics to Track Magnetospheric Perturbations**
**Co-Authors(s):** Tuija Pulkkinen, University of Michigan Climate and Space Sciences and Engineering Department; Qusai Al-Shidi, University of Michigan Climate and Space Sciences and Engineering Department

The space environment near our planet is dominated by the intrinsic dipole field. Energetic plasma from the solar wind is able to reach near the planet and cause rapid fluctuations in the geomagnetic field during space weather events. These variations can cause serious impacts to human infrastructure on ground and in space. In order to better understand the origin and causal linkage of magnetic perturbations in the magnetosphere, we rigorously track energy flow in a 3D simulation using the Space Weather Modeling Framework. By quantifying the amount of energy that passes through the dynamically varying 3D volumes in the simulation domain, we pinpoint the origins of the largest magnetic perturbations for a real storm event on February 2, 2022.

The conventional picture of energy transport can be explained through the Dungey Cycle, where magnetic field lines merge with solar wind on the dayside, are dragged tailward, and merge again on the nightside in the plasma sheet. This process brings solar wind plasma into the inner magnetosphere, where it is trapped on closed drift paths and forms the ring current. Our analysis shows how the open field line magnetotail lobes take part in a continuous energy exchange with the closed field line region both on the tail interface between the lobe and the plasma sheet and the dayside interface at the cusp separating open and closed field lines. These new results provide a more detailed and quantitative sequence than the classic Dungey Cycle picture.

**21 Ardakani, Akhtar** (University of New Hampshire)
**Impacts of the Heavy Ions on the Earth's Magnetotail Dynamics in Different Scales**
**Co-Authors(s):** C. G. Mouikis, University of New Hampshire, USA; L. M. Kistler, University of New Hampshire, USA

During disturbed times, the amount of O+ in the plasma sheet and the inner magnetosphere can be comparable to the levels of the H+ ions. Because of the oxygen larger mass, such a population of O+ in the near Earth magnetotail has the potential to modify the plasma sheet dynamics. Plasma sheet dynamics has an important role on connecting the solar wind to Earth space weather by that could affect the near-Earth space weather. Observations have shown that in the presence of more oxygen compared to protons, the substorm triggers at a higher total tail pressure, and then for the same events the tail unloading rate becomes faster (global scales). These effects of O+ ions on the substorm development, could indicate a faster reconnection rate in the presence of high O+ abundance (local micro-scales), or a wider reconnection site in the cross-tail direction GSM-Y (meso-scales), or totally different dynamics of the whole system during the events with higher oxygen ion density (global-scales). Using Cluster and MMS data, we investigated how the local reconnection rate is affected in events with a higher ratio of O+ to H+. Our results show that the high density of oxygen ions changes the dynamics of the system at each scale, differently.

**22 Al Shidi, Qusai** (University of Michigan)
**Geomagnetic Indeces and Ground Magnetometer Uncertainties in Forecasting with the SWMF**
**Co-Authors(s):** Tuija Pulkkinen, University of Michigan; Daniel Wellington, University of Michigan

We show and quantify the uncertainties with trying to predict geomagnetic indices and ground magnetometer perturbations with the Space Weather Modeling Framework (SWMF). Geospace simulations' inputs are usually solar wind parameters propagated from L1 to the magnetosphere's bow shock nose (BSN). In this study, it can be seen that simulations are more sensitive to the solar wind drivers of energy conversion into the magnetosphere than uncertainties that can arise in the solar wind, like oblique shock phase front normals before propagating to the BSN, which can cause a lot of uncertainty in arrival time and solar wind parameters. We also do a multivariate analysis of what factors causes more uncertainty in the output of the simulations.

**23 Sharma Paneru, Prashanna** (Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT, USA)
**Modeling Criteria for applying the FDTD methods to GICs**
**Co-Authors(s):** Yisong Zhang, Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT, USA; Dallin R. Smith, Air Force Research Laboratory/Geospace Environment Impacts and Applications Branch, Kirtland AFB, NM, USA; Mark B. Moldwin, University of Michigan,

Ann Arbor, MI, USA; Jamesina J. Simpson, Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT, USA.

In the interest of maintaining both civilian and military infrastructure, it is important to protect electric power grids, smart grids, low-voltage internet of things, and other electrotechnologies from known and possibly as-of-yet unknown space weather hazards. The finite-difference time-domain (FDTD) method is a robust and versatile method that has already been applied to the study of geoelectric fields and geomagnetically induced currents. The advantages of FDTD over other methods are that it can account for more geometrical complexities and realistic time waveforms. For example, it can account for the 3-D variations of the lithosphere composition and ocean-continent boundaries. It can also account for complex 3-D ionospheric currents. Previously, when applied to GICs, FDTD grids with relaxed grid resolutions in the horizontal direction were utilized for computational efficiency, since Snell's Law predicts that any electromagnetic waves should be propagating straight downwards into the low resistivity ground even when the electromagnetic waves are incident from a grazing angle with the ground. We investigate whether this assumption is correct and find that for accuracy, the horizontal (not just vertical) grid resolution should be.

**24 Goldstein, Jerry** (Southwest Research Institute)
**Weather Imaging by the EPIC Small Explorer Mission**
**Co-Authors(s):** Philippa Molyneux, Gregory Fletcher

Exploration of Plasma Interactions and Circulation (EPIC) is a Heliophysics imaging mission to reveal the life cycle of core magnetospheric plasma. Core plasma is a fundamental magnetospheric population comprising the majority of the magnetosphere's mass, 100 to 1,000 metric tons. Core plasma is initially cold (<10 eV) within the plasmasphere and oxygen torus. During storms it is transported throughout geospace and heated to 100 eV – keV energies.

EPIC is the first mission to target the critical core plasma life cycle (CPLC), by imaging four fundamental geospace populations: plasmasphere, dense oxygen torus, neutral hydrogen exosphere, and ring current. Continuous, multi-species, multi-region imaging from EPIC's high (>70º) inclination 20 RE circular orbit achieves a coordinated system-level view of the CPLC, including imaging of core plasma circulated to both dayside and nightside outer magnetosphere.

This continuous, multi-region imaging is also extremely well suited to space weather monitoring/backcasting that can greatly improve predictive models. Continuous 30.4 nm EUVHe plasmaspheric He+ imaging provides a global monitor of the cold plasma, a population with several big space weather effects: (1) it controls the waves that can increase or decrease the outer radiation belt, (2) it reduces spacecraft charging, and (3) it enables estimation of inner magnetospheric convection. The first-ever 83.4 nm EUVO oxygen ion imaging will finally observe the formation and global distribution of the dense oxygen torus whose mass loading controls the Alfven speed that is fundamental to magnetosphere-ionosphere coupling, and reconnection. A high-resolution (200 km) geocoronal imager (GCI) captures the neutral H exosphere that affects atmospheric escape. Low-energy neutral atom (LENA) imaging captures the macroscale dynamics of ENA spectra to measure how core ion recirculation feeds storms.

Core plasma is an essential and central component of geospace weather. EPIC improves prediction of extreme conditions driven by the many CPLC-affected plasmas and phenomena throughout geospace. EPIC's science and space weather impacts are cross disciplinary (both ""Ionosphere and Thermosphere"" and ""Geospace/Magnetosphere"" categories), targeting a plasma population whose origin is ionospheric, whose home is the inner magnetosphere, and whose fate is to be circulated to the outer magnetosphere, both dayside and nightside.

**25 Sokolova, Olga** (Sirin Orbital Systems AG, Switzerland)
**Towards industry Resiliency to Space Weather Effects**

**Co-Authors(s):** Vadim Uritsky, Catholic University of America/NASA Goddard Space Flight Center; Léa Feuillet, Catholic University of America; Robert Robinson, Catholic University of America/NASA Goddard Space Flight Center; Steve Kraemer, Catholic University of America/NASA Goddard Space Flight Center

For us on Earth, solar activity manifestations can range from the beauty of an aurora borealis to the potentially damaging impacts of space weather and the significant risk they pose to our modern society, heavily dependent as it is on technology. The growing appreciation of space weather problems brings the need for the proper modeling of its effects on modern society's well-being. Industry preparedness heavily depends on the sector and the previous negative experience. The level of preparedness is one of the escalating factors in the crisis. Overall, the general approach can be underpinned by three elements: designing mitigation where possible, developing the ability to provide alerts and warnings, and having response plans.

Multiple events over the past decades demonstrated a global lack of preparedness for high-impact low-probability events. It showed the need for a change from a risk-oriented approach to a resilience-focused framework for managing such disruptions. In the past years, the field of resilience analytics has conceptualized resilience frameworks within the context of infrastructure development. While critical infrastructure operators, owners and governments agree on the need for resilience building, the views on the levels of resilience may differ. The government philosophies and policy documents vary significantly in resilience assessment. The resilience matrix framework for comparing temporal and spatial scales of resilience across published legal documents by governments and infrastructure operators is introduced in this presentation.

Moreover, the concept of assessing space weather effects as the perfect storm is proposed. Risk engineers characterize devastating space weather impact on critical infrastructure as a super-storm (black swan). The author proposes to classify it as a perfect storm. In the case of a perfect storm, multiple forces join to create a disaster greater than the sum of its parts. These forces can be assessed in a systematic way before the event, since they have been observed in the past, though they are rare. The critical infrastructure vulnerability to space weather avenues is determined by interrelated critical factors.

**26 Poh, Gangkai** (Catholic University of America/NASA Goddard Space Flight Center)
**A comprehensive Applied Space Weather Research Graduate Program for Professionals to Meet Academia and Commercial Needs for Space Weather Expertise**
**Co-Authors(s):** Vadim Uritsky, Catholic University of America/NASA Goddard Space Flight Center; Léa Feuillet, Catholic University of America; Robert Robinson, Catholic University of America/NASA Goddard Space Flight Center; Steve Kraemer, Catholic University of America/NASA Goddard Space Flight Center

Space weather is the study of the changes in Earth's space environment with solar activities that impact technical systems, such as communication, navigation, aviation, satellite command and control, and electric power. With the increasing human presence in space and the blossoming of the New Space industry, understanding the physics of the heliosphere and the ability to accurately predict space weather events became essential to government agencies and private industry. The need for "in-house" professional experts on space weather becomes important for agencies/businesses to understand the potential implications of upcoming space weather events and make informed decisions to protect equipment, infrastructure and ensure health and safety. The Catholic University of America Physics department (CUA-Physics) has developed one of the U.S. first M.S. program in Applied Space Weather Research (ASWR), taught by faculty in the Dept. of Physics, researchers from our NASA/PHaSER cooperative agreement, and NASA civil-servant scientists. The CUA Master's Degree program in Applied Space Weather Research is designed to provide graduate students the knowledge that will be needed in government and industry to confront the increasing impacts of space weather as human presence in space expands. In addition to core courses in thermodynamics, electromagnetism, and statistical mechanics, the program includes three new courses that cover the fundamental physical processes of space weather from the surface of the Sun to Earth's atmosphere, in addition to courses in plasma physics and numerical methods for space weather. The technical and health impacts of space weather are integrated into these courses and also taught as part of a space weather seminar series. The program is open to students from any of the sciences, mathematics, and engineering disciplines, and is designed to teach students from diverse backgrounds the fundamentals of space weather. The program makes use of models and data streams available through CUA's on-going partnership with NASA Goddard Space Flight Center. A key goal of the program is to provide our students with ample opportunity to learn both the scientific and practical aspects of space weather that will position them for jobs in academia, government and industry through active mentorship with scientists and researchers at Catholic University, NASA, and university partners. With emphasis on both the applied and research aspects of space weather, the program provides the unique interdisciplinary education needed to address the challenges of understanding, forecasting, and mitigating the threats from space weather.

**27 Ostroy, Joanne** (MITRE/NOAA/NESDIS/SWO)
**Formulation of the NESDIS Space Weather Next Program**
**Co-Authors(s):** Elsayed Talaat, NOAA/NESDIS/SWO; Rich Ulman, NOAA/NESDIS/SWO; Dimitrios Vassilliadis, NOAA/NESDIS/SWO; Susan Jacobs, NOAA/NESDIS/SWO; Erin Lynch, NOAA/NESDIS/SWO

In support of the “Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act” (PROSWIFT Act) of 2020 and space weather observational continuity, the National Environmental Satellite, Data, and Information Service (NESDIS) has been formulating the new Space Weather Next (SW Next) Program under the joint National Oceanic and Atmospheric Administration (NOAA)/National Aeronautics and Space Administration (NASA) Space Weather Observations (SWO) Programs Division . SWO is now  a third pillar of NESDIS space-based observations along with terrestrial observations from Geostationary (GEO) and Low Earth Observations (LEO. As a loosely-coupled program, SW Next will be able to adapt to meet users’ needs as those needs evolve. For example, the renewed emphasis on space exploration and surge in satellite congestion has increased the public attention to the impacts of space weather. The formulation of the SW Next program has focused on how to address these emerging needs as well as providing continuity in existing assets. The program is near final approval in the next month.

The focus of this poster is to illustrate the formulation of the SW Next Program and how this emphasis on user needs has shaped the recommended architecture and program plans. The SW Next formulation plans to continue work hand in hand with the operational centers (e.g. National Weather Service’s  Space Weather Prediction Center), the science community, and partners such as the European Space Agency (ESA) and European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), to optimize the implementation of the recommended architecture. Continuing evaluation and integration of the forecast product needs and improvements that scientists, forecasters and end users, like the electrical power grid operators, use in operational decisions that impact society and the economy are a crucial part of the planning and implementation of future projects. As influential advancements in technologies and algorithms materialize, the SW Next Program plan is to infuse them as much as possible.

**28 Muehlbauer, Sebastian** (Federal Agency for Cartography and Geodesy)
**Ground-based infrastructure for space weather observation at the BKG**
**Co-Authors(s):** Torben Schueler, Federal Agency for Cartography and Geodesy

The Federal Agency for Cartography and Geodesy (BKG) is a German higher federal authority in the portfolio of the Federal Ministry of the Interior and Community. With the Geodetic Observatory Wettzell (GOW), the BKG operates one of the world's most important fundamental geodetic stations, which is recognized as a GGOS Core Site. Currently, in addition to the existing responsibilities in geodesy, ground-based measurement infrastructure for space weather observation is being established with a focus on the potential impact on satellite navigation.

The planned measurement infrastructure includes sensors for direct solar observation as well as for detecting the influence of the sun on the Earth's ionosphere and magnetic field. The Solar Flux Telescope is scheduled to go into operation at the end of 2023. This telescope will directly observe the sun's radiation intensity in the radio wave spectrum. One of the frequency bands considered will be at 2.8 GHz to measure the F10.7 index. In order to be able to link solar activity with variations in the Earth's magnetic field, magnetometers have been installed in the vicinity of the observatory. Further magnetometers at selected locations will follow. To directly characterize the state of the ionosphere, the Total Electron Content (TEC) and ionospheric scintillations will be monitored. This poster gives an overview of current and future capabilities of the BKG in the field of ground-based space weather observation.

**29 Lynch, Erin** (NOAA/NESDIS/SWO)
**User Engagement in Support of NOAA's Space Weather Next Sensors-to-Benefits Traceability Study**
**Co-Authors(s):** Nai-Yu Wang, NOAA/NESDIS/SWO; Joanne Ostroy, MITRE; Dimitrios Vassiliadis, NOAA/NESDIS/SWO; Scott Schnee, Aerospace Corp.

As part of the formulation of NOAA's Space Weather Next (SW Next) Program, the Office of Space Weather Observations (SWO) is conducting a detailed study to identify the economic and societal benefits associated with planned SW Next observations. Space weather poses a threfat to a number of industries including electric power grid, satellite operations, and civil aviation. Economic and societal benefits are derived from the ability of these end-user communities to mitigate detrimental space weather impacts by utilizing timely and accurate space weather information in their operational decisions. To understand these processes, value chains have been constructed by tracing how SW Next sensors impact downstream products and services and ultimately user decisions. This trace is key to understanding the value of a program and key to tracing user needed improvements back to model and sensor performance.

The most difficult part of this trace is capturing the utility of end-users' uses of space weather products. User engagements with key user communities including civil aviation, satellite operators, and the electric power grid support this effort. User engagements are supported by close collaboration with operational centers like the National Weather Service (NWS) Space Weather Prediction Center (SWPC), National Aeronautics and Space Administration (NASA), and other stakeholders to understand their needs for space weather data to support end-users. The collection and understanding of user needs also feeds back into the National Environmental Data and Information Service (NESDIS) enterprise portfolio management; thus, these efforts are also undertaken in close collaboration with the Office of Architecture and Advanced Planning (OSAAP) within NESDIS who maintains that portfolio. Over the course of the SW Next program, user engagement focus will also include ensuring the readiness of users for SW Next data products, and finally the sustainment of support to those user communities.

**30 Lee, I-Te** (Central Weather Bureau)
**Current State of Space Weather Operation in Taiwan**
**Co-Authors(s):** Pei-Yun Chiu, Central Weather Bureau; Jyun-Ying Huang, Central Weather Bureau Hsu-Hui Ho, Central Weather Bureau; Tzu-Wei Fang, NOAA Space Weather Prediction Center, Mark Chia-Ping Cheng, Central Weather Bureau

Based on the geolocation of Taiwan, higher plasma density during the day time period overhead are recorded associated with the equatorial ionization anomaly, and to easier observe plasma bubbles/irregularities in the evening to midnight period. These phenomena related ionospheric space weather significantly influence high-frequency and satellite communication as well as navigation and positioning services. Therefore, the Central Weather Bureau (CWB) has established the Space Weather Operational Office (SWOO) since 2015 to play the role of providing space weather information and forecasts locally. With the assistance of the National Space Organization and scientific research teams, routine operations have become more stable and reliable. SWOO provides real-time observations of solar images, regional GNSS-TEC, ionosonde and geomagnetic disturbance as well as the global ionospheric electron density structure, scintillation index, in-situ ion composition and temperature and radio frequency interference index by using FORMOSAT-7/COSMIC-2 measurements. Meanwhile, a data assimilated ionosphere and thermosphere coupled model is operated by SWOO since 2018 to provide a 6-hour forecast of ionosphere and thermosphere hourly. More detailed information for those SWOO/CWB products and evaluation of the assimilated foresting system will be presented and discussed.

**31 Kotten, Brooke** (University of Wisconsin-Madison, Department of Astronomy, Madison, WI, NOAA National Centers for Environmental Information (NCEI), Boulder, CO, University of Colorado Boulder, Cooperative Institute for Research in Environmental Sciences (CIRES), Boulder)
**Accuracy of the Real-Time GOES-R XRS Solar Flare Location Data Product**
**Co-Authors(s):** Courtney Peck, University of Colorado Boulder, Laboratory for Atmospheric and Space Physics (LASP), Boulder, CO; Janet Machol, NOAA National Centers for Environmental Information (NCEI), Boulder, CO, University of Colorado Boulder, Cooperative Institute for Research in Environmental Sciences (CIRES), Boulder, CO; Ann Marie Mahon, NOAA National Centers for Environmental Information (NCEI), Boulder, CO, University of Colorado Boulder, Cooperative Institute for Research in Environmental Sciences (CIRES), Boulder, CO; Laurel Rachmeler, NOAA National Centers for Environmental Information (NCEI), Boulder, CO; Stefan Codrescu, NOAA National Centers for Environmental Information (NCEI), Boulder, CO, University of Colorado Boulder, Cooperative Institute for Research in Environmental Sciences (CIRES), Boulder, CO

Solar flares impact high-frequency radio communications on Earth and can be correlated with geoeffective, or Earth-directed, coronal mass ejections which cause a variety of terrestrial space weather effects. To assess these risks, the X-Ray Sensors (XRS) instrument on Geostationary Operational Environmental Satellites - R Series (GOES-R) monitors solar X-ray irradiance to provide early warnings of solar flares. Additionally, XRS quadrant photodiode measurements are used to determine accurate real-time solar flare locations. Both the X-ray irradiance and the flare locations data products are used operationally by SWPC. This poster will discuss the flare location algorithm, which can locate C-class and larger flares on the solar disk within 1 arcminute for GOES-16 and -17. Multiple consecutive flares make up 12% of flare events; an upcoming revision to the algorithm's background correction will result in a 28% improvement in the location accuracy of the second or third consecutive flare after a C-class or above flare. The updated flare locations data product is available at www.ngdc.noaa.gov/stp/satellite/goes-r.html.

**32 Kim, Jiyoung** (Korea Meteorological Administration)
**KMA’s Satellite-based Space Weather Observation: Current Status and Future Plan**
**Co-Authors(s):** Dae-Hueon Oh Korea Meteorological Administration

The geostationary earth orbit (GEO) is one of the ideal orbital locations for satellite operation, including telecommunications, broadcasting, weather, and environment monitoring, as it provides a constant view of a fixed region on the Earth. However, the GEO is also subject to dynamic space weather phenomena that can impact satellites. Satellites in GEO, expected to have an operational lifetime of 10 years or more, can be vulnerable to extreme space weather events, such as strong magnetic storms or solar energetic particle events, which can cause malfunctions, data loss, and communication disruptions. In particular, energetic particle exposures could increase satellite anomalies. Satellite-based in-situ observations of the near-Earth space environment have significantly advanced our scientific understanding of space weather phenomena. In this context the Korea Meteorological Administration (KMA) launched the GeoKompsat-2A (GK2A) satellite on December 4, 2018, which features the Korean Space Weather Monitor (KSEM) as a secondary payload. The KSEM mission aims to provide real-time in-situ monitoring of space weather from the geostationary orbit with a longitude of 128.2¬∞E. The KSEM instrument suite includes the particle detector, a magnetometer, and a charging monitor. In this workshop, main results of KSEM data analysis as well as inter-comparison among sensors at the GEO orbit since July 2019 will be presented. And the development plan of GK2A follow-on satellite (GK5) will be briefly introduced.

**33 Kempton, Dustin** (Georgia State University)
**Synthetic Time Series Generation to Mitigate the Class-imbalance Problem in Flare Forecasting**
**Co-Authors(s):** Yang Chen, Georgia State University; Rafal Angryk, Georgia State University

The problem of solar flare forecasting suffers greatly from the issue of class imbalance which can severely hinder the predictive power of classification algorithms. Attempts to overcome this issue, either at the classification algorithm-level or data-level have seen limited success. In the algorithm-level methods, either a problem-specific classifier or ensemble approach tend to be utilized, while data-level methods are classifier-independent and offer greater flexibility. Data-level methods include sampling strategies such as random undersampling and oversampling, or value interpolation methods that are performed in the input space to generate synthetic samples (e.g., SMOTE). However, the typical value interpolation method is based on local information of minority classes, as opposed to the data distribution. In this study, we investigate the use of the conditional generative adversarial network (CGAN) as an algorithm to generate informative synthetic samples by approximating the distribution of existing data. The CGAN is used as a class-imbalance remedy to generate synthetic time series data on the SWAN-SF benchmark dataset for flare forecasting. To validate the similarity between real and generated minority class samples, two methods of verification are employed. We assess the effectiveness of the generated samples as a class-imbalance remedy for training a traditional, supervised machine learning algorithm and test the trained model on unseen, real data. The results demonstrate that the classifier trained on data augmented with synthetic samples performs significantly better than in the absence of augmentation, demonstrating the utility of CGAN-based data generation for complex tasks like flare forecasting.

**34 Halford, Alexa** (NASA/GSFC)
**An update on the Use and Usability of the Application Usability Levels.**
**Co-Authors(s):** Jeff Klenzing NASA/GSFC; Katie Garcia-Sage NASA/GSFCL; Sean Elvidge University of Birmingham; Michael Liemohn University of Michigan; Daniel Welling University of Michigan Sophie Murray Dublin Institute for Advanced Studies; Adam Kellerman University of California Los Angeles

In 2019, Application Usability Levels (AULs) were presented to the space weather community to address the need for a new, flexible framework to track the progress of a project. The AUL framework was developed to be general enough that all types of projects could comfortably use it while calling out the important milestones to be met for advancement. Alongside other frameworks such as the NOAA Readiness Levels and Technology Readiness Levels, AULs provide a way to assess a project or team's productivity, progress, and usability as it advances over time (e.g. see the new sami2py paper out at https://www.frontiersin.org/articles/10.3389/fspas.2022.1066480/full, or validating and development of LDi and LCi indices as described in https://www.swsc-journal.org/articles/swsc/full_html/2021/01/swsc200053/swsc200053.html and https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022SW003092) These frameworks can help determine the success of a program, identify where roadblocks exist, and help plan for future directions and resources needed. The AUL framework takes the lessons learned and best practices identified from other tracking frameworks while working with and keeping in mind the range of potential users. On an individual project level, the AULs can help ensure that the project/tool developed is useable by the end user whether that is a forecaster at NOAA, an industry partner, or another researcher. Thus, the AULs have been designed to help bridge the valley of death ensuring a clear path with aliment of the goals and outcome from the research to operation sides. Within this paper, we will take a retrospective look to show how the AULs have been implemented and used with current projects.

**35 Dayeh, Maher** (Southwest Research Institute)
**Space Weather Center of Excellence: FIRE-Forecasting the Interplanetary Radiation Environment**
**Co-Authors(s):** The FIRE team

Overview: FIRE is a Space Weather Center of Excellence (SWxC) aimed at advancing Space Weather Forecasting (SWF) capabilities through interdisciplinary cutting-edge science and technology. It integrates ten institutions and ensures trackable flow of information, decision implementation, and coordination among FIRE science and technology factions. FIRE continuous innovative research and infusion of technology ushers in a new era of probabilistic SWF and streamlines Research-to-Operations-to-Research (R2O2R) process. A dedicated FIRE Consortium facilitates continuous collaboration and development through regular feedback and implementation from all members involved.

Science Objectives: (1) Understand the conditions of quiet solar periods to improve All-Clear forecasts. (2) Advance the understanding of active region evolution and the likelihood of transient events emergence. (3) Advance interplanetary magnetic field and solar wind lead-time forecasts and short term (< 60 min) forecasts of solar wind structures near 1 au. (4) Utilize operational physics-based models to provide probabilistic predictions of key SWx driving properties of coronal mass ejections. (5) Understand acceleration and transport of solar energetic particles over broad energies and provide continuous assessment of energetic particle levels near 1 au.

Technology Objectives: (1) Transform deterministic into probabilistic forecasts and improve the estimation of forecast uncertainties using tailored machine learning algorithms. (2) Develop an R2O2R platform to streamline SWF. (3) Assess the science-technology-users chain and develop an effective feedback process for community engagement.

**36 Clark, Richard** (Millersville University)
**Ch...Ch...Ch...Changes in Space Weather Activities at Millersville University: An Update**
**Co-Authors(s):** Sepideh Yalda, Millersville University

Space Weather programs continue to be strong academic options for both undergraduate and graduate students at Millersville University. At the undergraduate level, the academic minor in Heliophysics and Space Weather (H&SW) continues to draw about 10% (10/100) of students that matriculated with majors in meteorology. This minor is sufficiently rigorous such that a student graduating with a B.S. in meteorology with a minor in H&SW can gain admission to graduate programs in solar/space physics at major R1 institutions with full graduate assistance. Several graduates from this program have gone on to earn their Master of Science or Doctorate in solar/space physics/science. In addition to the undergraduate minor, students who already have a BS/BA in a physical science or science communication can earn a graduate certificate in Space Weather and Environment: Science, Policy, and Communication. The graduate certificate is a stand-alone program of 5 courses, 15 credit hours, that can be completed in one year and is intended to bring knowledge, understanding, and skills to those who want to engage with, or themselves become, decision-makers and/or communicators on space weather issues. Finally, the Millersville University Space Weather group is leading the development of a certificate program for incorporation into the American Meteorological Society's (AMS) Certificate in Broadcast Meteorology (CBM) with the intention of helping to inform BMs in a disciplinary area that is not typically taught as part of their prior educational training. This poster will report on these activities.

**37 Brandt, Daniel** (Michigan Tech Research Institute)
**Generalized Additive Models for Solar Irradiance Forecasting**
**Co-Authors(s):** Erick Vega, Michigan Tech Research Institute; Aaron Ridley, University of Michigan Ann Arbor

A significant number of upper atmospheric models used for space situational awareness, satellite orbit prediction, and satellite collision avoidance rely only on the F10.7 solar radio flux as a proxy for solar EUV input into the upper atmosphere. Methods to forecast F10.7 routinely employ persistence and climatology, but the limitations of these methods, in addition to the inability of F10.7 to comprehensively capture the dynamics of solar EUV at all wavelengths, lead to non-trivial uncertainties in atmospheric models, constraining their effectiveness for use in orbit prediction, especially over timescales on the order of a week or greater. Additionally, continued development of the aforementioned atmospheric models has seen their reliance not merely on F10.7 as a solar EUV driver, but on the solar irradiance in multiple wavelength bands in order to more comprehensively capture the multifaceted solar effects on the upper atmosphere. Forecasting the solar irradiance accurately in multiple bands thus has become of paramount importance for increased space situational awareness. To address this concern, we propose a new and statistically grounded method for forecasting solar irradiance in 59 wavelength bands using Generalized Additive Models (GAMs) parameterized not only on F10.7, but additionally on Lyman-Alpha solar index and sunspot number. We demonstrate the capacity of this approach for short (2-3 days) and medium-term (5-days) irradiance forecasting, and compare the results of the approach to operational paradigms including EUVAC, NEUVAC-59 (an improved version of the solar flux driven by F107), and measured solar irradiance from TIMED/SEE.

**38 Zanetti, Lawrence** (NOAA/NESDIS)

**Input into NOAA's Space Weather Observations Program: the IMF Bz Issue**

**Co-Authors(s):** Elsayed Talaat, NOAA NESDIS; Dimitrios Vassiliadis, NOAA NESDIS; Joanne Ostroy NOAA NESDIS; Carrie Black, NSF Astronomy Directorate/Facilities Section; Terrance Onsager, NOAA Space Weather Prediction Center (SWPC)

The National Academies of Science, Engineering and Medicine (NASEM) has conducted the Space Weather Operations and Research Future Infrastructure Workshop (https://www.nationalacademies.org/our-work/space-weather-operations-and-research-infrastructure-workshop) in 2020 to maintain and improve critical observations as input to the space weather prediction and notification system. The workshop was conducted in two parts:
Part 1 - June 16-17, 2020 (held virtually; records, presentations on NASEM website)
Part 2 - September 9-11, 2020 (held virtually; records, presentations on NASEM website)

The workshop final report is published on the NASEM website.
Results are input to the future NESDIS Space Weather Observations and Space Weather Next Programs. Prime workshop issues are the forecasts of Geomagnetic Storm Watches, Warnings and Alerts of varying time scales. The Interplanetary Magnetic Field (vertical Bz) at Earth's magnetosphere, both projected by improved CME transport code through the heliosphere as well as the local parameters observed at L1 by space weather platforms are crucial.

## Virtual Poster Session: Geospace/Magnetosphere Research and Applications

**Capannolo, Luisa** (Boston University)
**Characterizing the EMIC-driven Electron Precipitation and its Effects in the Upper Atmosphere**
**Co-Author(s):** Wen Li, Boston University; Qianli Ma, Boston University, UCLA; Murong Qin, Boston University; Xiao-Chen Shen, Boston University; Vassilis Angelopoulos, UCLA
Anton Artemyev, UCLA; Xiao-Jia Zhang, University of Texas at Dallas, UCLA
Miroslav Hanzelka, Boston University; Robert Marshall, University of Colorado Boulder; Grant Berland, University of Colorado Boulder

Plasma waves can be excited in the near-Earth environment and interact with energetic electrons populating the Earth's radiation belts. Through wave-particle interactions, electrons can be pushed into the loss cone and be lost into the Earth's atmosphere (electron precipitation), where they deposit their energy. Electron flux variations in the radiation belt environment and the atmospheric impact of particle precipitation are important for predicting and mitigating space weather. Charged particles in the radiation belts can potentially damage satellite electronics or instrumentation leading to anomalies or failures, whereas precipitating electrons enhance ionospheric conductance and indirectly facilitate ozone reduction in the atmosphere. Therefore, it is crucial to characterize the wave-driven electron precipitation and its effects in the upper atmosphere. Here, we focus on precipitation driven by Electromagnetic Ion Cyclotron (EMIC) waves and we analyze it with high energy and pitch-angle resolution using the ELFIN CubeSats, orbiting at ~450 km. Our analysis shows that precipitation is latitudinally localized, most efficient for ~MeV electrons and accompanied by weaker low-energy precipitation down to ~100-200 keV. We also find that the loss cone is filled up with increasing energy and pitch-angle, and overall agrees with quasilinear theory predictions. Finally, we model the atmospheric ionization rates due to EMIC-driven precipitation using the BERI (Boulder Electron Radiation to Ionization) model. We show that the peak of ionization depends on the energy and pitch-angle distribution of precipitating electrons and on average occurs at ~50-60 km.

## Virtual Poster Session: Solar and Interplanetary Research and Applications

**Ali, Aatiya** (Georgia State University)
**Predicting Solar Energetic Particle Events & Understanding Their Relation to Dynamic Coronal Features**
**Co-Author(s):** Dr. Viacheslav Sadykov, Georgia State University; Dr. Alexander Kosovichev, New Jersey Institute of Technology

"Solar Energetic Particle (SEP) events and their major subclass, Solar Proton Events (SPEs; defined by stark increases in proton flux with energies >=10 MeV), and their propagation through the heliosphere and interactions with the Earth's atmosphere result in unfavorable consequences to numerous aspects of life and technology. Given the rare nature of these events, it is crucial to study data from the Sun at different solar cycles to develop the ability to reliably forecast them.

In this work we report the completion of a catalog of > 10 MeV > 10 pfu SPEs observed by GOES satellites/detectors with records of their statistical properties spanning through Solar Cycles 22-24. We report an additional catalog consisting of daily proton and SXR flux statistical properties for extending the SPE prediction effort presented by Sadykov et al. (2021). Using these catalogs, we discuss the application of machine learning using a Support Vector Machine for prediction of SPEs across these solar cycles. We emphasize effects of cycle-to-cycle differences in event statistics and feature importance. Further, by considering MHD models of the solar corona, we investigate the relevance of plasma conditions in regions of CME generation to the production of SPEs. We also discuss future work combining FORWARD emission modeling and uCOMP observations."

**Kosovich, Paul** (New Jersey Institute of Technology)
**Time Series of Magnetic Field Parameters Extracted from Merged Space-Weather MDI/HMI Active Region Patches as Potential Tool for Solar Flare Forecasting**

Space-Weather MDI Active Region Patches (SMARPs) and Space-Weather HMI Active Region Patches (SHARPs) are two recently developed data products, which have been used for solar flare prediction studies. The present work is an effort to expand the application of SMARP and SHARP summary heliomagnetic parameters to the forecasting of solar flares. A new data product was derived by filtering, rescaling, and merging the SMARP and SHARP summary parameter data series, which were further converted into two-dimensional arrays by selecting time slices corresponding to R-value maxima, where R-value is a measure of the unsigned magnetic flux near polarity inversion lines. The resulting combined MDI-HMI time series currently span the period between April 4, 1996 and December 13, 2022, and can be extended to a more recent date, providing an opportunity to correlate and compare them with other solar activity parameters, such as the daily solar flare index, which is computed as a sum of the product of GOES X-ray flare magnitude and flare duration, for all M- and X-class flares during a day. Preliminary results demonstrate a significant overall correlation, with Pearson coefficients between 0.339 and 0.627. In addition, an oscillating pattern is seen in the daily-averaged sliding-window correlation coefficient. Time-lagged cross-correlation indicates that a leader-follower dynamic exists in some parameters, especially R-value, where they lead the flare index by at least several days, which may have potential for further application in space weather forecasting.

**Kosovichev, Alexander** (New Jersey Institute of Technology)
**Development of Solar Energetic Particle Prediction Portal (SEP3)**
**Co-Author(s):** Viacheslav Sadykov, Georgia State University; Vincent Oria, New Jersey Institute of Technology; Irina Kitiashvili, NASA Ames Research Center; Patrick O'Keefe, New Jersey Institute of Technology; Aatiya Ali, Georgia State University; Chun-Jie Chong, New Jersey Institute of Technology; Fraila Francis, New Jersey Institute of Technology; Russell Marroquin, University of California San Diego; Paul Kosovich, New Jersey Institute of Technology; Gelu Nita, New Jersey Institute of Technology

Robust prediction of Solar Energetic Particle (SEP) events is among the key priorities of the space weather community. In the framework of NASA's Early Stage Innovation Program, we develop the Solar Energetic Particle Prediction Portal (SEP3 https://sun.njit.edu/SEP3), which hosts web applications that allow the users to retrieve the database records. In particular, SEP3 lists the API examples to query each data source potentially important for the SEP prediction. The Portal has a search page for browsing the events from the most widely used catalogs (https://sun.njit.edu/SEP3/search.php) and a dedicated space to share the most recent achievements of the team. In addition, we have added a CDAW SEP catalog and a LASCO/SOHO CME catalog and introduced the possibility of displaying the properties of the connected events (parental solar flares and CMEs for SEPs) on the search page. The interactive widget has the capability to display GOES soft X-ray and proton flux time series from different satellites with the GOES flare records on top of them. The data portal has been used to evaluate the forecasts of the solar proton events based on the statistical properties of the GOES soft X-ray and proton fluxes and investigate machine-learning approaches to the SEP prediction.

**O'Keefe, Patrick** (New Jersey Institute of Technology)
**Predicting Solar Proton Events with Random Hivemind Models: An Application of Ensemble Deep Learning**
**Co-Author(s):** Viacheslav Sadykov, Georgia State University; Alexander Kosovichev, New Jersey Institute of Technology; Irina Kitiashvili, NASA Ames Research Center; Vincent Oria, New Jersey Institute of Technology; Gelu Nita, New Jersey Institute of Technology; Fraila Francis, New Jersey Institute of Technology; Chun-Jie Chong, New Jersey Institute of Technology; Paul Kosovich, New Jersey Institute of Technology; Aatiya Ali, New Jersey Institute of Technology; Russell D. Marroquin, University of California San Diego

Deep learning has become a popular method of predicting solar proton events (SPEs) due to its malleability and its adaptability to new data. However, a series of parameters passed to a conventional neural network (CoNN) may be rather arbitrary, especially if there is no surefire way to decide how to program hyperparameters for a given dataset and the chaotic nature of neural networks. The random hivemind (RH) addresses this concern by having multiple neural network estimators with random permutations of features take part in decisions. Learning rates and the maximum numbers of epochs may be boosted or attenuated depending on how important all features used by a given estimator are, but all other hyperparameters remain the same across estimators. This allows one to quickly see whether consistent class decisions can be made by multiple neural networks with the same sets of hyperparameters, with random subsets of features chosen to force variation in how data are predicted by each, placing the quality of the data and hyperparameters into focus. The effectiveness of RH in the predictions of SPEs is demonstrated by comparing it to that of using both CoNN and the traditional committee-based approach used in ensemble deep learning through experimentation. Our results demonstrate that RH is capable of meeting or outperforming the CoNN and the identical neural network committees, and demonstrates promising results with respect to the "all-clear" prediction of SPEs.

**Rotti, Sumanth** (Georgia State University)
**Understanding Important Source Solar Eruption Features Leading to SEP Events.**
**Co-Author(s):** Petrus Martens, Georgia State University

Reliable predictions of SEP events are vital to mitigate and avoid space weather hazards, including high energy particle exposure of astronauts and spacecraft equipment outside the Earth's magnetosphere. As SEP events are often associated with solar eruptions such as flares and coronal mass ejections (CMEs), understanding the precursors and their various parameters that dictate the SEP acceleration is of crucial importance. We have identified over 400 SEP events between 1986 and 2018, and developed an extensive, publicly available catalog carefully associating each event with a solar source, wherever possible. We made use of existing catalogs of flares, CMEs and radio bursts to obtain the necessary features associated with SEP events. We considered the proton fluxes from the Geostationary Operational Environmental Satellites (GOES) and inspected each individual event in detail to extract the event statistics. Following up on this we are analyzing the relationships of different solar source parameters associated with SEP events and the correlations between these quantities. Furthermore, we are undertaking feature importance studies using tree-based machine learning (ML) models useful for predicting SEP events. In this poster, we experiment with decision trees (DT), random forests (RF) and extreme gradient boosting (XGBoost) classifiers in a binary classification problem domain. The motivation behind this is that the ML models can learn and make decisions based on data and issue quicker forecasts to improve upon existing statistical models.

**Svoboda, Filip** (University of Cambridge)
**A Federated Distributed Learning Benchmark for solar wind speed forecasting using solar EUV images**
**Co-Author(s):** Gianluca Mittone, Edward Brown, Nicholas Lane, Pietro Lio

Distributed training is the future of on-board computation in space as it offers scalability, resilience, and flexibility that can not be matched by a centralized setup. In the communication space it trades-in the cost of a full-dataset aggregation for that of an intermittent exchange of training messages. This work first explores the resource cost landscape of centralized training and a number of distributed variants. Federated learning, we observe, greatly lowers the communication cost of message passing relative to its distributed peers. It is, therefore, chosen for closer examination in the second part of this work. When used on the state of the art transformer model for solar wind speed prediction (Svoboda, Brown et al., 2022) and the Extreme UV images taken by the Solar Dynamics Observatory (OmniWeb, 2023) it retains the performance of the centralized model under both IID and non-IID conditions, while offering significant communication savings. Our extensive battery of experiments shows that the observed results are robust to a wide array of changes in the client count and the degree of data distribution heterogeneity. Furthermore, our results give materially significant recommendations relevant to the design of future missions as they identify a substantial trade-off between the benefits of adding new data, and the cost of adding more clients.

## Virtual Poster Session: Space Weather Policy and General Space Weather Contributions

**Sievers, Klaus** (Vereinigung Cockpit, Germany)
**ICAO Space Weather Advisories**
**Co-Author(s):** Ralf Parzinger

The advisories are providing the most up to date information on space weather effects on shortwave radio communications, Global Navigation Satellite System (e.g. GPS) -based navigation, and radiation impacting humans.The advisories are distributed via the meteorological information transmission networks that carry traditional, terrestrial meteorological information and advisories, and thus, the ICAO Space-weather advisories are available globally. Note that the service is available 24 / 7, and provides information on current conditions as well as a forecast for up to 24 hr ahead. The advisories appear quite rarely, compared to advisories for volcanic ash, tropical cyclones and the like. The poster provides examples as well as links to more information