2022 Space Weather Workshop Poster Abstracts
Held Virtually
Lightning Talks from 5:00 - 5:30 pm EDT with Poster viewing from 5:30 - 6:30 pm EDT

Tuesday April 26 Poster Session: Solar and Interplanetary Research and Applications

Ali, Aatiya (Georgia State University)
Predicting Solar Proton Events of Solar Cycles 22-24
Co-Author(s): Viacheslav Sadykov, Georgia State University

Solar energetic particles (SEP) 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 predict Solar Proton Events (SPEs). 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 properties (start and end times, peak flux, fluence, etc.) spanning through Solar Cycles 22-24. We successfully compare the developed catalog to others; like those by NOAA's Space Environment Services Center, to aid in the validation of data processing. The analysis of flux ratios as a proxy for spectral hardness during proton events is explored along with the fluence distributions across various energy channels ranging from 1 MeV to 100 MeV. These are also used to inspect any possible relevance of SPEs to the formation of ground level enhancement (GLE) events. The catalog of daily proton and soft X-ray fluxes' statistical properties is also constructed for extending the SPE prediction effort presented by Sadykov et al. (2021) to solar cycles 22 and 23, providing a possibility to build a more robust and substantiated machine learning-driven effort. We discuss our progress on the development of the forecasting attempt, including its extension to "all-clear" forecasts.

Bautista Torres, **Carlos Andrés** (Santander)
Magnetohydrodynamics Waves Propagation in the Solar Atmosphere on the MHD Equations with Radiative Losses
Co-Author(s): Fabio Duvan Lora Clavijo, Universidad Industrial de Santander

Many phenomena occur in the solar atmosphere, such as coronal mass ejections, coronal heating, or solar flares, and the MHD waves propagation plays an essential role in their behavior. On the other hand, radiation coming from the Sun's core and the plasma itself is not negligible, especially in the solar photosphere. Hence, it is crucial to understand the energy transport process and losses through the solar atmosphere due to MHD waves and radiation transfer. In order to do so, we incorporated the radiation transfer equation (RTE) into the system of MHD equations for partially ionized fluids. Furthermore, we applied an opacity model pondered by a Rosseland mean using the bound-free and the scattering opacities. We coupled this new equation with the energy conservation equation, and the total system is called the radiation magnetohydrodynamics (Rad-MHD) equations. This modification refines the model by adding the photon-matter interaction and gives us a chance to use the observational data of the radiation from the Sun. We solved the RTE numerically and analytically to test this new algorithm for a monochromatic intensity. Moreover, we simulated an MHD wave propagating along z-direction in the solar atmosphere, calculating the heat loss by radiation emission.

Cobos Maestre, Mario (Universidad de Alcalá)
An Autoregressive Solar Wind Speed Forecasting Deep Learning Model
Co-Author(s): Manuel Flores-Soriano, Universidad de Alcalá David F. Barrero, Universidad de Alcalá

High speed streams of solar wind can impact Earth's magnetic environment. Currently, state of the art geomagnetic effect forecasting methods can predict perturbations up to two hours in advance by using solar wind measurements made in the L1 Lagrange poin. By forecasting these solar wind parameters, it should be possible to extend the time range for which said methods can be used. We present an autoregressive model for the forecasting of daily average bulk speed values. Our model aims to be a first step in providing a larger predictive time horizon for geomagnetic effect forecasting methods. We discuss its performance when compared to a baseline and results obtained by previously published similar models.

Elliott, Heather (Southwest Research Institute, San Antonio)
Space Weather Applications for Statistical Relationships Between Solar Wind, and IMF Parameter

Plasma properties a solar wind parcel observed near Earth depends on the region of the Sun that emitted it, and how the parcel evolved on its journey to Earth. The slow wind with speeds less than ~450 km/s has more variable plasma properties and associated with coronal streamers and/or the edges of coronal holes. The fast wind emitted from coronal holes is steadier, has a lower density, and has a higher temperature than the slow wind. The large polar coronal holes and their extensions emit wind ranging from 700 to 800 km/s, and smaller equatorial coronal holes emit wind with speeds from 500 to 700 km/s. At a given time a slow wind emitting streamer will align with Earth and then later owing to solar rotation a coronal hole emitting fast wind will align with Earth. The solar wind travels along a radial line from which it was emitted. Therefore, as the fast wind parcels run into slow wind parcels emitted earlier, compression regions are formed with enhanced density, temperature, and field strength. Since different types of source regions emit wind with different plasma properties and those properties are altered in systematic ways owing to the interactions between different speed parcels, this produces relationships between solar wind speed and other solar wind and IMF properties and the Kp index. We discuss how these relationships can be used as metrics and tools for space weather forecasting.

Flores-Soriano, Manuel (University of Alcalá, Space Weather Group)
Simplified CME Monitoring and Characterization by Summarizing Time Series of Coronagraph Images

This poster presents a simple but effective way of boiling a time series of coronagraph images down to a single image. Originally conceived as an aid to the operational real time CME monitoring, the summary image contains information about CME occurrence, their relative importance, and their sky plane angular width and direction. Combining it with a detection algorithm, the product can also estimate the sky plane velocity of the CME. Besides their operational functionality, the summary images are useful for post-event analyses helping to identify the solar sources of space weather disturbances and for machine learning applications reducing the amount of input data. The real-time summary plots for the last five days are made available in the web page of the Spanish Space Weather Service (SeNMEs) http://www.senmes.es/pub/ACME/acme_resumen.png

Isham, Brett (Interamerican University of Puerto Rico, Bayamón, Puerto Rico, USA)
An Advanced Low-band VHF Radar for Atmospheric, Space, and Solar Research
Co-Author(s): Jason Kooi, Naval Research Laboratory, Washington, DC, USA Namir Kassim, Naval Research Laboratory, Washington, DC, USA Joseph Helmboldt, Naval Research Laboratory, Washington, DC, USA Jorge Chau, Leibniz Institute for Atmospheric Physics, Kühlungsborn, Germany Juha Vierinen, University of Tromsø, Tromsø, Norway Marco Milla, Pontifical Catholic University of Peru, Lima, Peru Michael Nolan, University of Arizona, Tucson, Arizona, USA Michel Blanc, Midi-Pyrénées Observatory, Toulouse, France Wlodek Kofman, Institute of Planetology and Astrophysics, Grenoble, France and Space Research Center of the Polish Academy of Sciences, Warsaw, Poland

The construction of a low-band VHF radar observatory -- for research spanning the solar corona and solar wind; the moon, the planets, asteroids, and meteors; and the magnetosphere, ionosphere and neutral atmosphere -- has been a decades-long dream of space scientists. Studies of exoplanets, interplanetary scintillation, and other passive radio astronomical observations would also be possible. The development of techniques for tracking cislunar objects and hypersonic vehicles are recent defense-related additions to this list. Over the years our awareness of what might be gained by such an observatory has increased, and the techniques that can be used have dramatically improved, making this an opportune time for the design and construction of a powerful and capable modern radar observatory. Possibilities for solar radar observations will be presented as an example of the potential of the proposed system for achieving selected science goals. Solar radar will be a game changer for solar physics research and space weather prediction and monitoring, including early warning of earth-directed coronal mass ejections. Space weather is a critical factor in communication, navigation, power distribution, and for both manned and unmanned aircraft and spacecraft. The incorporation of a low-band VHF radar as part of a renewed Arecibo Observatory would benefit the American ISR chain, the 60W/120E great circle initiative, and heliospheric, planetary, and geospace science.

Jaimes Gonzalez, Daniela (Industrial University of Santander)
Magnetic Reconnection of Two Twisted Magnetic Flux Tubes in the Sun
Co-Author(s): Fabio Duván Lora Clavijo, Industrial University of Santander

Observations show that the magnetic field of the Sun occurs in flux-tube bundles in the solar atmosphere, so flare models commonly invoke two or more flux-tube collisions as the trigger for flares. In these models, the collision of the flux tubes brings magnetic field lines into contact, and the subsequent reconnection releases energy stored in the flux-tube configuration, resulting in a flare. Therefore, through 2.5D numerical simulations performed with the MAGNUS code, which solve the system of nonlinear partial differential equations of resistive magnetohydrodynamics, we evolve the emergence of two twisted magnetic flux tubes initially in mechanical equilibrium. The domain of interest extends from the upper convective zone to the lower solar corona, and the temperature distribution depends only on the vertical coordinate. In this work, we consider two models: the first where the magnetic flux tubes are initially located at the same height and the second where the magnetic flux tubes are located at a slightly different height between them. Particularly in this work, we study the morphology of wave propagation in the solar atmosphere, as well as the dynamics of the two emerging tubes. Additionally, we show the formation of symmetric and antisymmetric current sheets, depending on the model. Finally, we measure the magnetic, kinetic, and internal energy at two different heights of the solar atmosphere to analyze the contribution of each type of energy in these areas.

Kooi, Jason (U.S. Naval Research Laboratory)
FETCH Instrument Concept: Spacecraft-to-Spacecraft Faraday Rotation Observations to Enhance Future Space Weather Forecasting
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The Faraday Effect Tracker of Coronal and Heliospheric structures (FETCH) is a new instrument concept being developed to probe interplanetary (IP) magnetic field structures, stream interaction regions, and coronal mass ejections (CMEs) as they evolve in the inner heliosphere upstream from Earth. FETCH is one of the instruments that constitute the Multiview Observatory for Solar Terrestrial (MOST) science mission. FETCH will measure spacecraft-to-spacecraft Faraday rotation (FR) at frequencies of <100 MHz along four lines of sight (LOS) provided by the four MOST spacecraft: two large spacecraft deployed at Sun-Earth Lagrange points L4 and L5 and two smaller spacecraft, one ahead of L4 and the other behind L5. FR is the rotation of the plane of polarization when linearly polarized radiation propagates through a magnetized plasma. FR is proportional to the LOS-integrated product of electron number density and LOS-projected magnetic field strengths. An important feature of spacecraft-to-spacecraft FR measurements is that the entire sensing path remains in interplanetary space, thus avoiding the complications of trans-ionospheric observations. While spacecraft-to-spacecraft FR has been successfully demonstrated in the Earth's magnetosphere, FETCH would be the first instrument to accomplish this in the solar wind. Simulated FETCH detections of CME FR showcase FETCH's potential to enhance space weather forecasting capabilities by providing CME parameters in the IP medium.

Kumari, Anshu (University of Helsinki, Finland and Indian Institute of Astrophysics, India)
Solar Radio Specto-Polarimetry (50 - 500 MHz)
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A radio spectro-polarimeter was developed at the Gauribidanur radio observatory (Longitude: 77◦27′07″; Latitude : 13◦36′12″) to study the characteristics of the polarized radio waves that are emitted by the impetuous solar corona in the 50 - 500 MHz frequency range. The instrument has three major components: a Cross-polarized Log-Periodic Dipole Antenna (CLPDA), an analog receiver, and a digital receiver (spectrum analyzer). Here, we elaborate the design and developmental aspects of the CLPDA, its characteristics and briefs about the configurations of the analog and digital receivers, setting up of the spectro-polarimeter, stage-wise tests performed to characterize it, etc. To demonstrate the instrumental capability, the estimation of the solar coronal magnetic field strength (B vs heliocentric height), using the spectral data obtained with it, is exemplified. Throughout the above band, the CLPDA has a gain, return loss and polarization cross-talk of ≈ 6.6 dBi, .-10 dB, and .-27 dB, respectively. The design constraints, the procedure to tune its impedance and to minimize its dimension, etc. are elaborated. The analog receiver has a noise figure of ≈3 dB and a receiver-noise-temperature (Trcvr) of about 290 K. The digital receiver can sweep and cover the above bandwidth in 4 ms (instantaneous bandwidth of ≈1.1 MHz). The spectral data acquired for ten successive sweeps are integrated (for 100 μs) and averaged onboard.

Lowder, Chris (Southwest Research Institute)
Coronal Hole Observer and Regional Tracker for Long-term Examination

Manifesting as regions of decreased emission in extreme ultraviolet (EUV) and x-ray wavelengths, coronal holes are the observational signatures of the roots of open solar magnetic field. Coronal plasma

within these regions is free to flow outward along open magnetic field lines, resulting in reduced density and emission. Identifying and characterizing these coronal hole regions provides useful insights into their connection with open magnetic field, their evolution over the solar cycle, and impacts on space weather as a source of fast solar wind. The Coronal Hole Observer and Regional Tracker for Long-term Examination (CHORTLE) provides an automated and adaptive tool for coronal hole detection, using an intensity thresholding technique combined with a consideration of enclosed magnetic flux. Utilizing EUV data from a variety of sources including SOHO/EIT, SDO/AIA, and STEREO/EUVI A&B, coverage extends from solar cycle 23 to present, with multi-instrument merged observations providing enhanced polar and far-side coverage where available. Coronal hole depth maps are generated at a variety of cadences, are assembled to provide coronal hole latitudinal distributions and enclosed open magnetic flux measurements over the span of solar cycles, yielding a description of coronal hole evolutionary patterns and a long-term set of data for comparison with both models and observations.

Marble, Anthony (CU/CIRES, NOAA/SWPC)
GONG Near-Real-Time SWx Data Processing
Co-Author(s): John Britanik, National Solar Observatory

The GONG network is operated by NSF/NSO with financial support from NOAA/SWPC and provides continuous observations of the Sun from six ground-based sites distributed around the world. GONG data are used to drive the WSA-Enlil model for propagation of the solar wind and CMEs, monitor solar flares and other dynamic activity on the Sun, and provide additional situational awareness for space weather forecasting. In 2021, the near-real-time processing of GONG space weather data was transitioned from NSO to SWPC's operational environment, where it runs today with collaborative support from SWPC and NSO.

Nascimento, Luís (National Institute for Space)
LSTM MultiLabel Ntwork to Predict Solar Flares from SHARP Parameters
Co-Author(s): Tardelli Stekel - Federal Institute of Sao Paulo (IFSP)

The interplanetary space is dominated by several magnetic field topologies that control the confinement and particle flux of the interplanetary plasma. Disturbances in space weather can easily damage communication systems, power distribution, equipment, and satellite reliability. Solar flares, one of the most common magnetic structures in this environment, are eruptions on the surface with a high concentration of high-velocity particles and intense radiation, usually caused by changes in the interplanetary magnetic field. In this work, artificial neural networks are implemented as a method of forecasting solar flares, using LSTM (Long-Short Term Memory) models and multivariate time series dataset of SHARP (SpaceWeather HMI Active Region Patch) parameters.

Nishimoto, Shohei (Japan Air Self-Defense Force)
Statistical Analysis for EUV Dynamic Spectra and their Impact on the Ionosphere During Solar Flares
Co-Author(s): Kyoko Watanabe, National Defense Academy of Japan Hidekatsu Jin, NICT Toshiki Kawai, ISEE Nagoya University Shinsuke Imada, University of Tokyo Tomoko Kawate, NIFS Yuichi Otsuka, ISEE Nagoya University Atsuki Shinbori, ISEE Nagoya University Takuya Tsugawa, NICT Michi Nishioka, NICT

The X-rays and extreme ultraviolet (EUV) emitted during solar flares can rapidly change the physical composition of Earth's ionosphere, causing space weather phenomena (Dellinger 1937). It is important to develop an accurate understanding of solar flare emission spectra to understand how it affects the ionosphere. We reproduced the entire solar flare emission spectrum using the empirical model and physics-based model (Kawai et al., 2020; Nishimoto et al., 2021), and input it into the Earth's atmosphere model to calculate the total electron content (TEC) enhancement due to solar flare emission. We compared the statistics of nine solar flare events and calculated the TEC enhancements with the corresponding observed data. The model used in this study was able to estimate the TEC enhancement due to solar flare emission with a correlation coefficient greater than 0.9. The results of this study indicate that the TEC enhancement due to solar flare emission is determined by soft X-ray and EUV emission with wavelengths below 35 nm. The TEC enhancement is found to be largely due to the change in the soft X-ray emission and EUV line emissions with wavelengths such as Fe XVII 10.08 nm, Fe XIX 10.85 nm and He II 30.38 nm.

Ökten, Mehmet Baran (TÜBİTAK MAM Polar Research Institute, Turkey
Optimization Between 2020 and 2030 with Regard to the Space Weather
Co-Author(s): Furkan Ali Küçük,TÜBİTAK MAM Polar Research Institute, Turkey

The space environment is very harsh for satellite electronics. The trapped particles in the Earth's radiation belts and cosmic rays and also solar storms are decreased the system's performance are gradually Total induced dose (TID) reduce the system's lifetime. In this study; TID analysis with regard to the space environment is reported. For 5 mm aluminum shielding thickness, we also show TID's value is 25 krads for launch dates between 2020 and 2030 for different mission durations and altitudes.

Peck, Courtney (CIRES/University of Colroado, NOAA NCEI)
Improving Operational Solar EUV Irradiance Modeling Using Physics-Based Differential Emission Measure Techniques
Co-Author(s): Daniel Seaton, SWRI, CIRES/University of Colorado, NOAA NCEI Christian Bethge, CIRES/University of Colorado, NOAA NCEI Janet Machol, CIRES/University of Colorado, NOAA NCEI Ed Thiemann, LASP/University of Colorado Mark Cheung, Lockheed Martin

Solar Extreme Ultraviolet (EUV) irradiance incident on Earth's upper atmosphere varies by a factor of 2 to 10, which impacts atmospheric drag experienced by satellites in low-earth orbit. Recent work suggests that solar EUV measurements and models must be accurate to much better than 25% in order to benefit operational satellite collision avoidance (Emmert et al. 2014; Emmert et al. 2017; Vourlidas & Bruinsma, 2018). However, this accuracy is not met by most existing EUV measurements and models including the operational EUV spectral model used by SWPC. We present work from a NASA Operations to Research project to develop a physics based operational EUV spectral model from 5-127 nm with 1 nm resolution and 1 minute cadence to within 10% relative error. The model will utilize the full suite of operational solar data from the GOES-R satellites by using solar image data from the Solar Ultraviolet Imager (SUVI) to model solar corona emission using physics-based differential emission measures (DEMs) and solar irradiance data from the Extreme Ultraviolet and X-ray Irradiance Sensor (EXIS) to model chromospheric and continuum emission. We present preliminary results using simulated GOES-R data from the Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA) and EUV Variability Experiment (EVE) which show that the model achieves the proposed 10% relative error at 1 nm spectral resolution across a majority of the 5-127 nm range.

Petersen, Alicia (Air Force Research Laboratory / National Research Council)
Quantifying the Impacts of Interplanetary Propagation and Transient Events on Solar Energetic Particle Intensity-Time Profiles
Co-Author(s): Stephen M. White, Air Force Research Laboratory, Kirtland AFB Stephen W. Kahler, 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.

Ratliff, J. Martin (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA)
Assessing Space Weather for Mars Missions
Co-Author(s): Allen J. Andersen, Jet Propulsion Laboratory

A central characteristic of a well-designed robotic spacecraft is that it does not need constant human monitoring and intervention. For this it is key that the spacecraft be designed to handle a fair degree of adverse space weather (SWx) conditions. For missions to locations beyond the vicinity of Earth, we typically have limited knowledge of the current SWx conditions, and a limited ability to do near-term forecasting. However, if useful SWx information can be obtained, there are ways in which SWx information can be used to reduce mission risk in the lead-up to critical spacecraft operations. Examples include landing the Mars-2020 rover on Mars, and flying the Ingenuity helicopter over the Mars surface. The poster will provide reasons for determining SWx conditions for these missions, and some methods for doing so; and will note additional monitoring and forecasting capabilities that would help future missions to Mars.

Redmon, Robert (NOAA/NCEI)
NCEI's Planned Space Weather Follow On Science Center - Powering Space Science Discovery
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The US National Centers for Environmental Information (NCEI) is dedicated to observing and characterizing the natural environment from Sun to Earth. NCEI's Solar and Terrestrial Physics group expertly stewards all of NOAA's and several partner space science data sets, from before the 1957/1958 International Geophysical Year to present. NOAA's Space Weather Follow On (SWFO) Program will place new advanced solar, charged particle and magnetic field observing capabilities into critical locations along the sun-earth line (Lagrange Point L1) and in geostationary orbit. NOAA instrumentation to be flown on the SWFO-L1 spacecraft includes the Compact Coronagraph (CCOR-2), Solar Wind Plasma Sensor (SWiPS), SupraThermal Ion Sensor (STIS) and the Magnetometer (MAG) to collectively observe coronal mass ejections and solar wind bulk and energetic plasma properties impinging on our geospace system. A second coronagraph (CCOR-1) will be flown on the GOES-U geostationary platform. Our suite of roles for the SWFO program build on NOAA's multi-decadal investment in developing and applying expertise to numerous past missions including GOES-R and the Deep Space Climate Observatory (DSCOVR). This presentation describes NCEI's SWFO activities, which include calibrating/validating products, developing operational & retrospective algorithms, and creating the new NOAA SWFO Science Center; collectively empowering the future of data-rich near-Earth space science discovery from operational capabilities.

Righini, Simona (INAF)
Mapping the Sun with the Italian radio telescopes
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The Italian radio telescopes, managed by the National Institute for Astrophysics (INAF), are carrying out a new solar radio imaging project, implemented through specific upgrades of these large - and general-purpose - single-dish instruments. More than 170 radio continuum maps in the 18-26 GHz band were achieved in the commissioning and early science phases of the project (2018-2020), and more have so far been produced on an almost weekly basis. As such frequencies are presently not employed by other radio telescopes for solar mapping, these observations provide a meaningful insight for solar and space weather studies. The typical resolution lies in the 0.7-2.0 arcmin range, while the brightness temperature sensitivity is lower than 10 K. The Supernova Remnant Cas A was chosen as a flux reference for absolute calibration, yielding typical errors of less than 3% in the estimation of the flux density measurements of both the quiet-Sun level components and the active regions. The maps allowed the multi-wavelength identification of active regions, their brightness and spectral characterization. The project aims at producing useful outcomes both for solar physics, such as the analysis of the chromospheric network dynamics, and space weather applications, for example flare precursors studies.

Riley, Pete (Predictive Science Inc.)

What Machine Learning Algorithms Teach us about Which Explanatory Variables Matter Most in Predicting Bz within Coronal Mass Ejections

Co-Author(s): M. A. Reiss, Space Research Institute of the Austrian Academy of Sciences Christian Möstl, Space Research Institute of the Austrian Academy of Sciences

Accurately predicting the z-component of the interplanetary magnetic field, particular during the passage of an interplanetary coronal mass ejection (ICME) is a crucial objective for space weather predictions. Currently, only a handful of techniques have been proposed and they remain limited in scope and accuracy. Recently, a robust machine learning (ML) technique was developed for predicting the minimum value of Bz within ICMEs based on a set of 42 'features', that is, variables calculated from measured quantities upstream of the ICME and within its sheath region. In this study, we investigate these so-called explanatory variables in more detail, focusing on those that were (1) statistically significant; and (2) most important. We find that number density and magnetic field strength, as well as the minimum value of IMF By accounted for a large proportion of the variability. Taken together, these features capture the degree to which the ICME compresses the ambient solar wind ahead. Intuitively, this makes sense: Energy made available to CMEs as they erupt is partitioned into magnetic energy density and kinetic energy. Thus, more powerful CMEs are launched with larger flux-rope fields (larger Bz), at greater speeds, resulting in more sheath compression (increased number density, By, and total field strength).

Rotti, Sumanth (Georgia State University)

An Integrated Catalog of Geostationary Solar Energetic Particle (GSEP) Events

Co-Author(s): Berkay Aydin, Georgia State University Manolis K. Georgoulis, Academy of Athens Petrus Martens, Georgia State University

Solar Energetic Particle (SEP) events are radiation storms of particle fluxes that originate in large solar eruptions. They are essential to understand and forecast. In space weather research, the motivation to use machine learning (ML) is that the models can learn and make decisions based on observational data and issue quicker forecasts to improve upon the existing results of statistical models. But, it is crucial to establish basic needs such as reliable data collection & analysis, feature engineering, and infrastructure. In this view, this work highlights a new dataset of SEP events. We have integrated a comprehensive list of SEP events with reference to their parent flares and CMEs. The catalog consists of 342 events from 1986

to 2017 and helps users explore more SEP events with parameters of interest for various statistical studies and ML exercises. Also, it provides a reference to multiple parameters for each event, allowing researchers to understand if the event satisfies the criteria for case studies. We use the Geostationary Operational Environmental Satellite (GOES) integral solar proton flux data. We have cleaned the dataset and homogenized it across the GOES missions. The time intensities of fluxes define and characterize SEP events and are useful to distinguish the source event as the temporal behavior differs. Furthermore, we have generated time series slices of the SEP events, which are helpful to perform ML experiments on SEP event forecasting.

Sadykov, Viacheslav (Georgia State University)
Prediction of Solar Proton Events with Machine Learning: Comparison with Operational Forecasts and "All-Clear" Perspectives
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Robust prediction of Solar Energetic Particle (SEP) events is among the key priorities of the space weather community. In this presentation, we report our progress on the project "Machine Learning Tools for Predicting Solar Energetic Particle Hazards" supported by NASA's Early Stage Innovation program. First, we highlight our progress in developing an online-accessible database that integrates a variety of solar and heliospheric data, metadata, and descriptors related to SPEs. Specifically, we discuss the current data sources collected in the database, the ways to request the data via the Application Programming Interface (API), and the search and visualization capabilities of the web front-end. Second, we accent on a problem of the "all-clear" forecasts of Solar Proton Events (SPEs) and our contribution to this problem conducted within the project. Specifically, we discuss (1) the main outcomes of our study of the daily probabilistic prediction of > 10 MeV > 10 pfu proton events for the solar cycle 24 (2010-2020) and its comparison with the operational forecasts, (2) the approach to extend this study to the solar cycles 22-23 based on the statistical properties of soft X-ray and proton fluxes, and the McIntosh and Hale classes of solar active regions, and (3) the development of flare-driven SPE forecasts based on the GOES soft X-ray measurements during the solar flares.

Shaikh,Zubair (Indian Institute of Geomagnetism India)
Super-adiabatic Heating and Cooling of Alfvenic plasma
Co-Author(s): Anil N. Raghav: University Department of Physics, University of Mumbai, Vidyanagari, Santacruz (E), Mumbai, India, Geeta Vichare: Indian Institute of Geomagnetism, New Panvel, Navi Mumbai, India

Alfv\'enic fluctuations are widespread and crucial in various physical processes of space \& astrophysical plasma. However, their role in heating and work remains unexplored. Here, we examined 12 distinct Alfv\'enic regions using polytropic analysis. We found the average polytropic index $\alpha = 2.64 $, associated effective degree of freedom $f = 1.26$ and $\frac{\delta w}{\delta q} = -0.68$. It implies that alfv\'enic regions show super-adiabatic expansion, where 68 percent of the supplied heat is utilized to accomplish work by the system, and the remaining is used to increase internal energy. The protons in the examined region are heated for $f < 1.26$, but it cools for $f>1.26$. As a result, we assume that some small-scale process exists that may modify or change the f for a given α and contribute to the heating/cooling of plasma proton.

Singh, Talwinder (The University of Alabama in Huntsville)
Forecasting Solar Flares Using the Time Evolution of Active Regions and Machine Learning Techniques
Co-Author(s): Nikolai Pogorelov, The University of Alabama in Huntsville, AL , Timothy Newman, The University of Alabama in Huntsville, AL, Bernard Benson, McLeod Software Corporation, Birmingham, AL, Syed Raza, The University of Alabama in Birmingham, AL

Accurate forecasting of solar flares is an area of active research due to their adverse impact on near-Earth space weather. Due to the availability of a large amount of solar data gathered over the years, machine learning (ML) can serve as an important tool for predicting solar flares. Physical properties of active regions (ARs) obtained from their magnetic field observations or AR's magnetic, white-light, and EUV images are used as training data sets for ML algorithms. However, the majority of the ML-based studies that have been performed so far use time snapshots of various AR properties to do predictions. Solar flares are very dynamic events. Several pre-flare processes have been identified over the years, which means that some pre-flare trends can be used for flare forecasting. Therefore, it should be beneficial to train ML models using the observed time evolution of ARs. In this presentation, several pre-flare dynamics will be discussed along with the appropriate ML techniques that can be used to utilize these pre-flare dynamics for flare forecasting.

Tenishev, Valeriy (University of Michigan)
Integrated Model for the Solar Energetic Particles and Alfven Wave Turbulence in the Inner Heliosphere
Co-Author(s): Igor Sokolov, University of Michigan Lulu Zhao, University of Michigan

Understanding the radiation environment due to solar energetic particles in the heliosphere and the Earth's magnetosphere is a challenging task. Exposure to energetic particles often leads to malfunctions and unexpected failures of electronics onboard spacecraft. Geomagnetic field deflects SEPs moving through geospace though some of these particles propagate to LEO and have a high penetrating capability, thus producing significant radiation hazard for human spaceflight. Numerical modeling of the radiation environment due to SEPs in the inner heliosphere and geospace is a multifold problem. That includes simulating 1) dynamics of solar wind and the interplanetary magnetic field, 2) global modeling of the Earth's magnetosphere, and 3) modeling transport and acceleration of SEPs in the inner heliosphere and geospace. In the presented work, we combined the results of modeling different parts of SEPs propagation in the inner heliosphere and geospace. First, we solve the Focused Transport equation to simulate the transport and acceleration of SEPs as they propagate in the inner heliosphere. Then, the results of that modeling are used for simulating the transport of SEPs in geospace using a realistic geomagnetic field. This presentation discusses the integrated modeling approach employed in this study and summarizes the results.

Vievering, Juliana (Johns Hopkins University Applied Physics Laboratory)
Concept for Real-Time Solar Flare Predictions
Co-Author(s): Brent Smith, Johns Hopkins Applied Physics Laboratory 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 Säm Krucker, Space Sciences Laboratory at the University of California Berkeley Janet Machol, CIRES at the University of Colorado Boulder Courtney Peck, CIRES 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 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. 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. 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.

Wang, Nai-Yu (NOAA/NESDIS/OPPA

NOAA's Solar Coronagraph Instrument on L5 and Plan for Sustaining CME Observations

Co-Author(s): Doug Biesecker, NOAA/NESDIS/OPPA Irfan Azeem, NOAA/NESDIS/OPPA Jim Silva, NOAA/NESDIS/OPPA Richard Ullman, NOAA/NESDIS/OPPA Elsayed Talaat, NOAA/NESDIS/OPPA Damien Chua, Naval Research Lab Arnaud Thernisien, Naval Research Lab

One of the major drivers of space weather is coronal mass ejections (CMEs). NOAA/National Environmental Satellite, Data, and Information Service (NESDIS) is developing the next-generation coronagraph instrument, called the Compact Coronagraph (CCOR). Three state of the art CCOR instruments are being developed for NOAA by the U.S. Naval Research Laboratory (NRL). The first CCOR (CCOR-1) instrument will be flown in a Geosynchronous Earth Orbit (GEO) on NOAA's GOES-U spacecraft, scheduled for launch in 2024. The second CCOR (CCOR-2) instrument will be flown on the Space Weather Follow On (SWFO) mission to the Sun-Earth Lagrange Point 1 (SWFO-L1) to be launched 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 2027-2028 timeframe. CCOR-3 is currently in phase-A requirement definition stage to achieve the desired goal of maintaining the same cadence and angular resolution of CCOR-2. Observations from CCOR-3 in conjunction with those from CCOR-2 are expected to improve the 3D characterization of CMEs.

Wanliss, Grace (Presbyterian College)

Cosmic Rays, Space Weather, and Human Chronobiology

Co-Author(s): Germaine Cornelissen, University of Minnesota James Wanliss, Presbyterian College

There is a strong connection between space weather and fluctuations in technological systems. Some studies also suggest a statistical connection between space weather and subsequent fluctuations in the physiology of living creatures. This connection, however, has remained controversial and difficult to demonstrate. Here we present support for a response of human physiology to forcing from the explosive onset of the largest of space weather events—space storms. We consider a case study with over 16 years of high temporal resolution measurements of human blood pressure (systolic, diastolic) and heart rate variability to search for associations with space weather. We find no statistically significant change in human blood pressure but a statistically significant drop-in heart rate during the main phase of space storms. Our empirical findings shed light on how human physiology may respond to exogenous space weather forcing.

Zhu, Brian (Jet Propulsion Laboratory)
Comparison of JPL and ESP Solar Proton Fluence Models Using the Background Subtracted RDSv2.0 Dataset
Co-Author(s): Insoo Jun, Jet Propulsion Laboratory Martin Ratliff, Jet Propulsion Laboratory

High energy protons from solar energetic particle (SEP) events are a hazard to spacecraft systems and instruments. For interplanetary and geosynchronous spacecraft, a mission's cumulative SEP fluence is an important consideration for hardware design. The total solar proton fluence for a mission can be dominated by a small number of very high-fluence events. Because of the sporadic and unpredictable nature of these large events, data sets collected over multiple solar cycles are needed to construct a statistical model that can predict a mission's risk of seeing a given fluence exposure during its mission. Several statistical models have been developed, including the JPL model and the Emission of Solar Protons (ESP) model. The models produce somewhat different results, which could be due in part to the different data sets from which they were derived. To understand the sensitivity of predicted mission fluence to the choice of data set and to the statistical distribution to which that data set is fit, we present a comparison of the JPL and ESP cumulative fluence models as reformulated from the same SEP data set, a background-subtracted version of the Reference Data Set Version 2.0 based on data from IMP-8 and GOES, covering 41 years of SEP events from 1974 to 2015 with proton energies between 5 to 289 MeV. The comparisons show that different modeling approaches can produce a factor >2 difference in the mission fluences even when the same data set is used for model development.

Wednesday April 27 Poster Session: Ionosphere and Thermosphere Research and Applications and Space Weather Policy and General Space Weather

Aa, Ercha (MIT Haystack Observatory)
Developing 4-D Ionospheric Specification Over U.S. with a New TEC-based Ionospheric Data Assimilation System (TIDAS)
Co-Author(s): Shun-Rong Zhang, MIT Haystack Observatory Wenbin Wang, NCAR HAO Philip J. Erickson, MIT Haystack Observatory Anthea J. Coster, MIT Haystack Observatory William Rideout, MIT Haystack Observatory

Accurately imaging the 4-D spatial-temporal variation of the Earth's ionosphere has always been a challenging task in the space weather community, since the ionosphere is a highly variable system which exhibits not only remarkable climatological variations but also significant weather disturbances. In the past decades, with the ever-increasing availability of GNSS measurements from ground-based receivers and space-borne radio occultation data, remarkable progress has been made in the data assimilation technique to improve the overall accuracy of ionospheric nowcast and forecast. However, there still exists a strong need to provide retrospective specification of the storm-time sophisticated four-dimensional electron density gradient with high spatial-temporal resolution so that detailed localized ionospheric variability and weather disturbances could be better reproduced and understood. Recently, we have developed a new TEC-base ionospheric data assimilation system (TIDAS) to issue high-resolution (1 deg× 1 deg× 20 km × 5 min) four-dimensional electron density products over the continental US, which is built upon the massive GNSS line-of-sight TEC data, COSMIC radio occultation data, Millstone Hill incoherent scatter radar measurements, and JASON TEC data. TIDAS is a powerful tool to better reproduce the storm-time localized ionospheric morphology, which helps further understand the underlying mechanism of storm-enhanced density and related midlatitude density gradients.

Camporeale, Enrico (NOAA)
How Machine Learning is Reinventing Space Weather

In the last few years machine learning techniques have proven capable of forecasting space weather events with a much higher accuracy than traditional empirical and physics-based models. In this presentation, we give an overview of the multitude of new products that the University of Colorado is developing, spanning from forecasting of geomagnetic indices and ground magnetic perturbations, to solar wind forecasting, coronal mass ejection arrival times, solar flares predictions, and auroral electron precipitation. In particular, we will focus here on a new Dst machine learning model that is able to accurately predict 1 to 6 hours ahead and to estimate reliable uncertainty levels, outperforming all other operational models. The new model is currently being transitioned to operations by the University of Colorado and will become open and available to the international space weather community.

Chingarandi, Frank (National Institute for Space Research, São José dos Campos, SP, Brazil)
Ionosphere Response to Moderate Geomagnetic Storm Over Equatorial & Low Latitude During Deep Solar Minimum
Co-Author(s): F. Becker-Guedes, National Institute for Space Research, São José dos Campos, SP, Brazil C. M. N, Candido , National Institute for Space Research, São José dos Campos, SP, Brazil O. O, Taiwo , National Institute for Space Research, São José dos Campos, SP, Brazil S.P, Moraes-Santos , National The The period 2018-2019 was characterised by unusually low solar activity and has been classified by many as "Deep Solar Minimum". We investigate the response of equatorial and low latitude ionosphere to a moderate G2 (min Sym-H~-60nT) geomagnetic storm which occurred on 24 October 2019 driven by a High-Speed Solar Wind Streams/ Co-rotating interaction regions (HSSWS/ CIR) using multiple ground and space-based observations. A Positive ionospheric storm from the main phase with maximum positive deviation of ~174% associated with large positive Interplanetary Eastward Electric Field and negative of ~79 % both over the Southern low latitudes of Brazil. However, there was low variability in plasma density over the equatorial sector. Storm-enhanced fountain effect in the presence of prompt-penetration electric fields resulted in the intensification and latitudinal expansion of the Equatorial Ionisation Anomaly (EIA). Furthermore, initial suppression and thereafter enhancement in irregularities during the main and recovery phase respectively were observed. For the first time over South America, the GOLD Far-Ultraviolet (FUV) imager is used to investigate the disturbed post-sunset ionosphere. Maps of 135.6nm irradiance were used to analyse the post-sunset EIA evolution and morphology of plasma irregularities.

Codrescu, Stefan (Vector Space LLC)
Assimilative Specification of Neutral Density in Low Earth Orbit
Co-Author(s): N/A

Accurate neutral density specification is a critical component of situational awareness for satellite operators in Low Earth Orbit. The recent loss of SpaceX satellites is a timely warning as we enter solar cycle 25. Data assimilation in a physics-based model combines the predictive strength of physics-based models with an anchor to reality through observational data. Results are presented showing the impact of assimilating CHAMP, GRACE-A, and GRACE-B neutral density observations on global neutral density specification during several large geomagnetic storms. During the 2003 Halloween storm, orbit maximum neutral density increases by a factor of 2.5x within several hours. Along track neutral density specification during this extreme event is better than 22% NRMSD in all experimental setups.

González, Gilda de Lourdes (Universidad Nacional de Tucumán)
Characterization of Ionospheric Irregularities Near the Southern Crest of the Equatorial Ionization Anomaly in South America During Quiet and Disturbed Geomagnetic Conditions
Co-Author(s): N/A

We analyse the occurrence of spread-F (range spread-F and frequency spread-F) and plasma bubbles near the southern crest of the Equatorial Ionization Anomaly in Argentina (Tucumán, 26.8°S, 65.2°W;magnetic latitude 15.5°S) during the descending phase of solar cycle 24. Also, we examined the effects of four geomagnetic storms of different solar sources in the generation/suppression of irregularities. We used data from an ionosonde, a GPS receiver and magnetometers. The height of the F-layer bottom side, the critical frequency of the F2-layer, the ROTI and the S4 index were analysed. The data show that spread-F and plasma bubble occurrence rates peak in summer and are minimum in equinox and winter. Geomagnetic activity suppresses the generation of spread-F in equinox and summer and enhances it in winter. Plasma bubble occurrence is higher on disturbed days, but under medium solar activity summer months register more plasma bubbles on quiet days. Range spread-F and moderate TEC depletions were detected in one of the four storms: 27 May 2017. We suggest that eastward disturbance dynamo electric field and over-shielding prompt penetration electric fields may create favourable conditions for developing irregularities. Whereas westward storm time electric fields might inhibit the growth of irregularities during the other geomagnetic storms considered. During CIR-driven storms, the westward disturbance dynamo electric field may be associated with the non-occurrence of irregularities.

Gross, Nicholas (Boston University)
Providing the Next Generation of Space Physicists and Space Weather Professionals with a Holistic View of the Sun-Earth System and the Processes in the Space Environment: A Tale of Two Summer Schools.
Co-Author(s): Mark Moldwin, Univ. of Michigan, Asher Pembroke, Ensemble Consultancy

For space physics as a discipline, as well as its adjacent disciplines of space weather and Heliophysics, a broad and holistic knowledge of the system is beneficial to researchers, forecasters, and other professionals. However, many graduate programs in space physics have only a few or just one faculty member who trains graduate students. Thus, it is difficult for these students to gain a broad exposure to the whole system-science. Graduate students will become experts in a narrow portion of the discipline but may not appreciate its context in the broader Sun-Earth system. There are two annual summer schools that partially fill this gap by providing a broad and holistic understanding of the space environment and its drivers. - The Boulder Space Weather Summer School (BSWSS). https://www2.hao.ucar.edu/SWSS) takes a conceptual understanding of the space weather system from Sun to Mud and provides context for each of the sub disciplines of space physics. - The Heliophysics Summer School (HSS). https://cpaess.ucar.edu/heliophysics/summer-school/recruitment-announcement) focuses on the physics of core processes, such as magnetic reconnection or MHD modeling, that describe the domains of the heliosphere (solar interior and corona, solar wind, magnetospheres, ionospheres, and the heliosphere boundary). This summer school emphasizes the unifying concepts between these domains. Both of these summer schools draw upon world recognized experts in the field to provide lectures and lead discussions. In addition, each summer school makes use of state-of-the-art simulation results from the NASA Community Coordinated Modeling Center (CCMC), located at the Goddard Space Flight Center. Summer school participants engage in activities that use these simulation results, along with ground based and spacecraft data, to explore the fundamental concepts in the field. The summer schools also provide opportunities for professional development, community building among the participants, and networking with the instructors. These summer schools play a key role in the development of the future workforce in space physics.

Harris, Ezra (United States Military Academy)
The Application of Finite Volume Methods to the Two Fluid Plasma Model to Understand Atmospheric Instabilities and Their Effect on Radio Wave Propagation in The F-Region of the Ionosphere
Co-Author(s): Isaac Escapa, Alexis Komisza, COL Diana Loucks, United States Military Academy (All)

Gradient Drift Instability is a major cause of irregular plasma structuring in the F-region of the ionosphere. Irregular plasma structures can cause radio wave scintillation because they create varied optical densities in the path of electromagnetic signals. As the radio wave passes through these varied optical densities the radio wave is altered due to the index of refraction of the region. This creates inaccuracies in global positioning, and interference with communication systems. Conditions in the high latitudes enable instability development and propagation. The two fluid plasma model captures the two fluid effects required to simulate the instability and the subsequent structuring. Finite volume methods are used to explore the evolution of plasma density in the F-region to determine the index of refraction at different points along a plane wave's path through the ionosphere. Using an approximate Riemann solver, we determined the density of the plasma, from which we were able to determine the relative permittivity of the layers of the medium. Current modeling efforts use characteristic solvers to resolve ionospheric structuring. Our efforts seek to use an approximate Riemann solver to model plasma structuring caused by Gradient Drift Instability to more accurately understand the effects on radio wave propagation.

Isham, Brett (Interamerican University of Puerto Rico, Bayamón, Puerto Rico, USA)
A High-frequency Array for Radar and Radio Imaging of the Ionosphere
Co-Author(s): Terence Bullett, University of Colorado, Boulder, Colorado, USA Björn Gustavsson, University of Tromsø, Tromsø, Norway Emil Polisensky, U.S. Naval Research Laboratory, Washington, DC, USA Vasyl Belyey, Private researcher, Oslo, Norway Arturs Stramkals, Uppsala University, Uppsala, Sweden Christiano Brum, Arecibo Observatory, Arecibo, Puerto Rico, USA

We are developing a 2 to 25 MHz, medium and high frequency (MF/HF) antenna array, for radar and radio imaging of the ionosphere. The array will consist of multiple active crossed antenna elements arranged in a partly ordered and partly random pattern providing a good distribution of baseline vectors, with 7 and 400 meter minimum and maximum spacing, respectively. The proposed location for the array is at the site of the former U.S. Air Force Ramey Solar Observatory (RSO), in Aguadilla in northwest Puerto Rico. Radar imaging will be done in collaboration with the University of Colorado and NOAA HF radar system located at the USGS San Juan Observatory in Cayey, 110 km from Aguadilla. Relocatable cable-less antenna elements will also be included, with phase maintained through the use of GPS-disciplined rubidium clocks. These elements may be used independently, or together with the main array for improved imaging resolution. Science goals include the study of space weather, ionospheric structure and dynamics, meteors, lightning, radio propagation, and plasma physics. Radio imaging is ideal for the study of stimulated ionospheric radio emissions, such as those induced by the Arecibo Observatory high-power HF radio transmitter, which may be restored to operation in 2024. Observations of meteor tails could be used as a proxy for the development of detection and tracking techniques for hypersonic vehicles, a current defense priority.

KÜÇÜK, Furkan Ali (TÜBİTAK MAM Polar Research Institute)
Estimating Ionospheric Slab Thickness during 11 August 2018 Solar Eclipse for Different Locations
Co-Author(s): Dr.Ceyhan Kahya, Istanbul Technical University, Faculty of Aeronautics and Astronautics, Department of Meteorological Engineering, İstanbul

The purpose of the work is to describe the chancing ionospheric slab thickness of August 11, 2018, the relationship between TEC and TAU in Tromsø, Kiruna, and Moscow. The solar eclipse of August 11, 2018 was a partial solar eclipse that was visible in the north of North America, Greenland, Northern Europe, and north-eastern Asia. In the study, Ionospheric slab thickness variation was calculated using TEC and foF2 data from inosonde stations and wavelet graphs. The thickness, the ratio of the total electron content (TEC) to the F2-layer peak electron density (NmF2), is closely related to the shape of the ionospheric electron density profile Ne (h) and the TEC. The data were taken from global ionosphere radio observatory. The ionospheric slab thickness is a substantial parameter representative of the ionosphere. TAU variation in these three stations during the solar eclipse was estimated and compared.

Therefore, while there was no severe mobilization and peak change in the Moscow station, approximately similarity was found in the ionospheric thickness changes observed at the Tromsø and Kiruna Stations. TAU value increased from 138.24 to 402.31 km in the time interval of maximum eclipse at Tromsø station. Also, The TAU value ranged from 270.42 to 402.31 km in the period of maximum eclipse at Kiruna station. As a result, the ionospheric effect of the solar eclipse that took place on August 11, 2018, was seen more clearly by Tromsø and Kiruna than at the Moscow station.

Kursinski, Rob (PlanetIQ)
PlanetiQ GNSS RO Measurements of the Ionosphere
Co-Author(s): Jonathan Brandmeyer, PlanetIQ Ryan Gooch, PlanetIQ Aaron Botnick, PlanetIQ, Mark Leidner, AER Craig Oliveira, AER Stephen Leroy, AER Christian Alcala, AER

PlanetIQ's first operational satellite launched June 2021 into a 525 km, 2 pm sun synchronous polar orbit. Our next satellite launches April 1, 2022 into an 11 AM 650 km SSO. Our new Pyxis GNSS RO receiver on each satellite tracks GPS, GLONASS, Galileo and BeiDou satellites to acquire 2800 daily ionospheric occultations, with pole-to-pole coverage. The number of ionosphere occultations from 2 PlanetIQ satellites is comparable to that from COSMIC-2's 6 satellites. Pyxis measures total electron content (TEC) along all available signal paths through the ionosphere for assimilation into space weather specification/forecasting systems. We also derive electron density profiles, including using 50 Hz data to characterize sporadic E layers with very high vertical resolution. We measure amplitude and phase scintillations at 50 Hz and downlink the full complex signal to locate ionospheric turbulence along the signal paths via backpropagation. Using two high latitude ground stations, we deliver space weather data with a median latency of 29 minutes. With additional ground stations, we can reduce median latency to < 15 minutes. We plan to deploy 20+ satellites by end of 2025 to acquire 60,000+ daily ionospheric occultations, with full global and diurnal coverage, delivering 1250 occultations every half hour, and an unprecedented, continuous, 4D characterization of the global ionosphere. We will present a summary of initial measurement, calibration and validation results.

Lee, I-Te (Central Weather Bureau)
Applications of FORMOSAT-7/COSMIC-2 to Space Weather at CWB/SWOO
Co-Author(s): Jyun-Ying Huang, Central Weather Bureau, Taiwan Hsu-Hui Ho, Central Weather Bureau, Taiwan Mark Cheng, Central Weather Bureau, Taiwan

The FORMOSAT-7/COSMIC-2 (F7/C2) mission was successfully launched on June 25, 2019 and deployed into a lower inclination orbits about 24 degrees around 520 km altitude. It can provide near 4,000 soundings per day of the Earth's ionosphere over the magnetic equatorial region and lower latitude by the TriG GNSS Radio occultation System (TGRS) to receive US GPS and Russian GLONASS signals. These dense observations not only can shorten the data accumulation period to reproduce three-dimensional ionospheric structure, but also assimilate into numerical model to improve ionospheric weather prediction. Thus, the Space Weather Operational Office (SWOO) of Central Weather Bureau (CWB) in Taiwan collaborated with the National Space Organization (NSPO) and sciences teams to develop and operate numerous applications with F7/C2 observations for near real-time monitoring and forecasting of ionospheric conditions. More detail information for these applications of SWOO/CWB will been explained to illustrate that the F7/C2 are suitable and valuable for ionospheric space weather operations.

Mangla, Sarvesh (Indian Institute of Technology Indore, India)
Equatorial ionosphere Study Using the Giant Metrewave Radio Telescope (GMRT)
Co-Author(s): Abhirup Datta, Indian Institute of Technology Indore India

Radio interferometers initially built to observe distant astronomical sources in the universe. In recent times, they also used to study the Earth's ionosphere with greater precision than any conventional ionospheric probes like the Global Navigation Satellite System (GNSS). Interferometers require calibration procedures to remove the effects of the ionosphere, especially at low radio frequency observation. Therefore, the calibration data contain information about the ionosphere and may be used to study and characterize the same. Square Kilometer Array (SKA) pathfinder GMRT is one of the largest sensitive radio telescopes that observe the sky at low-frequency regimes. The geographical location and configurations of the GMRT make this telescope unique to explore the equatorial ionosphere region at different spatial scales. By observing a bright radio source with GMRT, we achieved a precision of ~mTECU to measure ionospheric variation, which is an order of magnitude higher sensitivity than current GNSS-based measurements. We tracked wave patterns associated with medium scale traveling ionospheric disturbances (MSTIDs) by performing spectral analysis. We can also calculate the speed and direction of individuals and groups of waves. Our new focus is to simultaneously study the ionosphere at frequencies below 400 MHz and with different array configurations. Upcoming new telescopes like SKA can conduct a similar analysis to probe the Earth's ionosphere.

Moreland, Kimberly (University of Texas at San Antonio/Southwest Research Institue)
A Machine-learning Oriented Remote and In-situ Dataset for Forecasting SEP Occurrence and Properties
Co-Author(s): Maher Dayeh, Southwest Research Institue, University of Texas at San Antonio Subhamoy Chatterjee, Southwest Research Institute Andres Munoz-Jaramillo, Southwest Research Institute Hazel Bain, CU Bouler CIRES, NOAA SWPC Samuel Hart, University of Texas at San Antonio

We present a new parameter-rich dataset using over 18,000 flare events from the NOAA/SWPC GOES flare event list extending from 1998 to 2013. Each event in the dataset includes remote images, along with spacecraft measured X-ray, radio, proton, electron, upstream interplanetary (IP) plasma, magnetic field properties, and, when available associated IP coronal mass ejection and IP shock parameters. In situ data comes from multiple instruments onboard the GOES (XRS, EPS, EPEAD) and ACE (EPAM, ULEIS, SWEPAM, MAG) spacecraft. The remote sensing data, also from various instruments (SDO, SOHO), comprises of full disc magnetograms, EUV, and coronagraph images. Selection criteria for flare event classification are described and methods for calculating important SEP properties such as peak flux and fluence are explained, as well as the methods and time windows for calculating the solar wind plasma and magnetic field properties, are detailed. The purpose of this work is to provide a validated dataset with parameters specifically tailored for forecasting the occurrence and subsequent properties of SEP events at 1 au. Special consideration is given to data that is currently available in operational real-time or will be available in real-time on upcoming missions.

Ökten, Mehmet Baran (Yildiz Technical University)
Latitudinal Variation of the Relationship of Ionospheric Slab Thickness with the Height of the Peak Electron Density of F2 Layer
Co-Author(s): Zehra Can (Yildiz Technical University)

The Earth's ionosphere, a natural plasma, is formed by extreme ultraviolet radiation from the Sun and particle precipitation and is affected by time, season, latitude, and geomagnetic storms. The ratio of the total electron content (TEC) to the peak electron density (NmF2) of the F2 layer is called ionospheric slab thickness (τ), which is affected by various ionospheric parameters, gives us the variation in the vertical direction of the ionosphere. In this study, with ionosondes with URSI codes IF843, PA836, BC840, AU930, PRJ18, and BVJ03 located at the equatorial latitudes of the Northern and Southern Hemispheres of North and South America, the τ change between 1-14 February 2022 by dividing the TEC by NmF2 was investigated locally. By comparing τ with the peak height of the F2 layer (hmF2), two clusters were detected around two different 12-hour curves that varied from region to region. It was found that the correlation between them was higher during the day and weaker at night. By calculating the angle between the curves, the diurnal variation of the relationship between τ and hmF2 in that region is shown, and it is seen that the angle difference increases from the equator to higher latitudes. Developing this research to cover all latitudes on Earth and a longer period will improve our understanding of space weather.

Osborne, Anastasia (United States Military Academy)

Correlating Solar Wind Variations to the Timing of Field Aligned Current Flow

Co-Author(s): Loucks, United States Military Academy Espenshade, United States Military Academy Dear, United States Military Academy

This research attempts to better our prediction of aurora by examining lag time, and whether field aligned (Birkeland) currents increase in flow upon subsolar magnetic merging, or from night-side reconnection. A cross correlation analysis between solar wind data and auroral intensity data was conducted including dates in 2014, 2015, and 2017. Criteria used to select dates include the presence of red emission lines and dates with detectable aurora at a normal level. An average lag of approximately two hours was calculated through the cross-correlation analysis, with shorter lag times corresponding to higher bulk solar wind speed. Initial analysis reveals field aligned currents increase in flow upon night-side reconnection. The importance of this research lies in being able to better predict space weather events, specifically, refining auroral prediction by first determining the conditions for their occurrence and the lag time between the detection of those conditions by satellites and auroral detection on Earth. Satellite-based communication, PNT capabilities, and things such as GPS are reliant on our abilities to predict and protect from space weather events.

Ostroy, Joanne (NOAA/NESDIS/OPPA)

Space Weather Next (SW Next): Formulation Activities

Co-Author(s): E. Talaat NOAA/NESDIS R. Ullman NOAA/NESDIS S. Jacobs NOAA/NESDIS I. Azeem NOAA/NESDIS L. Palardy NOAA/NESDIS F. Chaudhry NOAA/NESDIS M. Devaney NOAA/NESDIS K. Jensen NOAA/NESDIS E. Lynch NOAA/NESDIS S. Schnee NOAA/NESDIS D. Vassiliadis NOAA/NESDIS

As part of the formulation of NOAA's Space Weather Next (SW Next) Program, the agency will require a detailed assessment of the economic and societal benefits for the justification cost of providing program capabilities. The cost versus benefits is a key component for the justification and scoping of a program. NOAA is therefore conducting an Analysis of Alternatives (AOA) as a standard process for any major program. The analysis requires tracing the potential program capabilities to the economic and societal benefits. This is a complex process involving close collaboration with operational centers like the Space Weather Prediction Center (SWPC), NASA, and other stakeholders. It also includes feedback from the end users who are affected by the economic and societal outcomes. The AOA process includes other aspects to evaluate architectures, but the focus here will be on the Effectiveness Analysis (EA), The EA is crucial to weigh against the cost of the program capabilities for decision makers for program scope and approval.

Pankratz, Christopher (University of Colorado, Boulder)

A New Interactive 3-Dimensional Data Viewer for the Enlil Solar Wind Model

Co-Author(s): Greg Lucas, Laboratory for Atmospheric and Space Physics (LASP) / Univ. of Colorado Jenny Knuth, Laboratory for Atmospheric and Space Physics (LASP) / Univ. of Colorado Dusan Odstrcil, George Mason University James Craft, Laboratory for Atmospheric and Space Physics (LASP) / Univ. of Colorado Thomas E Berger, University of Colorado, Space Weather Technology, Research, and Education Center

One of the critical models in space weather forecasting is the Enlil solar wind prediction model that can inform space weather forecasters the direction and speed of coronal mass ejections CMEs. The Enlil code calculates the propagation of the solar wind throughout the 3D heliosphere, but current visualization capabilities in the forecasting offices are restricted to 2D planes intersecting Earth. This limits forecasters to only be able to view CME properties that are traveling directly in the plane of the Earth. Here, we present a new visualization capability being developed to take advantage of the full Enlil 3D data volume and interactively visualize the CME expansion out of the plane of the Earth. This is designed to give forecasters and researchers the full view of the heliosphere in a manner that can be tailored to these different types of users. To accomplish this, we are deploying the Enlil solar wind model into a scalable Cloud-based model staging platform computing environment, which will allow the full 3D Enlil output to reside in-situ with the visualization engine. We will discuss our progress in deploying and running the Enlil model in the Cloud-based testbed environment, the process of interacting with space weather forecasters to design a new interactive 3D visualization tool that meets their needs and will demonstrate use of the visualization tool itself.

Patterson, Cameron (Lancaster University)
Modelling Space Weather Impacts on UK Railway Signalling Systems
Co-Author(s): Jim Wild, Lancaster University

Track circuits are widely used signalling systems that use electrical currents to detect the presence or absence of a train in predefined sections of a railway network, as such, they are susceptible to interference from geomagnetically induced currents. This work aims to determine the impact space weather has on realistic track circuits across geologically different regions of the UK under various storm conditions by using the Spherical Elementary Current System method of geomagnetic field interpolation, a ground conductivity model of the UK, a 1D-layered model to provide estimations of the geoelectric field and track circuit modelling techniques developed by Boteler (2021). Early results of modelled rail sections in Northwest England and Scotland will be presented.

Sievers, Klaus (VC - German Airline Pilots´ Association)
ICAO Space Weather Advisories for Aviation
Co-Author(s): Ralf Parzinger, VC German Airline Pilots´ Association

A poster is proposed on the introduction of ICAO Space Weather Advisories. They became operational 2019 and should be generally known to researchers and aviators alike. However, the now on-going process of their adoption in Europe (and elsewhere) has shown that knowledge about their existance could be more widespread. The poster is intended to further spread basic knowledge about the advisories, along the lines of this article: https://www.eurocockpit.be/news/space-wx-icao-radar-screen

Sur, Dibyendu (CIRES, University of Colorado Boulder, Boulder, Colorado, US)
Performance Comparisons of the Global Ionospheric Electrodynamics from WAM-IPE during St. Patrick’s Day Geomagnetic Storm (March 17-18, 2015)
Co-Author(s): Tzu-Wei Fang, NOAA Space Weather Prediction Center, Boulder, Colorado, US Timothy J. Fuller-Rowell, CIRES, University of Colorado Boulder, Boulder, Colorado, US Daniel T. Welling, University of Texas at Arlington, Arlington, Texas, US Mariangel Fedrizzi, CIRES, University of Colorado Boulder, Boulder, Colorado, US and NOAA Space Weather Prediction Center, Boulder, Colorado, US Roderick A. Heelis, William B. Hanson Center for Space Sciences, University of Texas at Dallas, Richardson, Texas, US

The paper presents a version of the coupled Whole Atmosphere Model - Ionosphere Plasmasphere Electrodynamics (WAM-IPE) driven by the Michigan Geospace Model (MGM). The intensities of the potentials of MGM are generally higher than those from Weimer during the 2015 St. Patrick’s Day

geomagnetic storm. The simulated Total Electron Content (TEC) agrees well with the global TEC observations. The zonal plasma drifts from these runs show promising results compared with measurements from the Defense Meteorological Satellite Program (DMSP) satellites at 850km. The drift values are also compared with several locations where ground-based measurements are available. The way how these models were coupled and validation results from these comparisons will be described in the poster.

Taiwo, Osanyin (National Institute for Space Research)
Performance of a Locally Adapted NeQuick-2 model During 2014 Solar Maximum Over the Brazilian Equatorial Region
Co-Authors(s): Frank Chinuarandi, National Institute for Space Research

Considering the unique geometry of the geomagnetic fields near the magnetic equator and low-latitude regions, the satellite communication systems such as GNSS (Global Navigation Satellite System) and other related radio systems in the Brazilian sector are strongly affected by the effects of the solar and geomagnetic activities. The first-order delay caused by the ionosphere is proportional to the Total Electron Content (TEC) along the signal path between the satellite and the receiver. As a result, precise modeling of the ionospheric TEC is very important and remains a challenge for positioning and navigation systems such as GNSS. Hence, this study investigates the performance of the NeQuick 2 model for the prediction of TEC variation during the solar maximum (2014). GPS data from a station located at the magnetic equator has been ingested in the NeQuick model for ionospheric correction over this region. The results of the diurnal and seasonal variations have been presented considering both equinoxes and solstices. The diurnal variation in both observation and model presents the day-to-night variation with higher values of VTEC during the day and lower values at night. Seasonal variation showed a peak in equinox and a minimum in the solstice. The comparison between the GPS-TEC and NeQuick 2 model revealed a great improvement in the model after data ingestion.

Tang, Genevieve (United States Military Academy)
Isolating Confounding Variables Associated with Ionospheric Navigation Solution Parameters
Co-Author(s): Dominic Rudakevych, United States Military Academy COL Diana Loucks, United States Military Academy Dr. Mai Tran, United States Military Academy MAJ Noah Scribner, United States Military Academy CPT Frank Czerniakowski, United States Military Academy

The question of ionosphere scintillation and its effects on GPS functionality at high latitudes becomes increasingly pertinent with rising global temperatures and decreased sea ice extent in the Arctic Ocean. Through correlative analyses ran on data gathered from the Illinois Institute of Technology, our team sought to increase modern understanding of ionosphere storms and how increased solar activity affects the precision of satellite-based navigation tools. This process began by collecting and managing large data files from multiple sources. Afterward, the data was cleaned to a format ready for analysis. In order to isolate the effects of scintillation, manipulation was also necessary to account for the effects of other precision-harming processes, such as errors due to satellite configuration (GDOP). Once appropriately cleaned and filtered, the data was then analyzed within RStudio under multiple correlative models to identify where meaningful relationships do and do not exist

Urbář, Jaroslav (Istituto Nazionale di Geofisica e Vulcanologia, Italy)
Identification of Scale-dependent Lags and Application to Ionospheric Weather
Co-Author(s): Luca Spogli, Istituto Nazionale di Geofisica e Vulcanologia, Italy & SpacEarth Technology, Italy Antonio Cicone, University of L'Aquila, Italy & Istituto Nazionale di Geofisica e Vulcanologia, Italy Claudio Cesaroni, Istituto Nazionale di Geofisica e Vulcanologia, Italy Lucilla Alfonsi, Istituto Nazionale di Geofisica e Vulcanologia, Italy

The Intrinsic Mode Cross Correlation (IMXC): a novel scale-wise signal lag measurement identifies scale-dependent lags. The IMXC relies on non-linear non-stationary signal decomposition provided by the novel Multivariate Fast Iterative Filtering (MvFIF) technique, which identifies the common scales embedded in the signals. The lags are then obtained scale-wise, enabling the identification of the lag dependence on the involved spatio/temporal scales for the artificial data set (even in presence of high levels of noise), and to estimate them in a real-life signal. The method performance is evaluated first on known artificial signals. To show the usability of the technique in the Space Weather context, in scenario assuming cause-effect relationship, we use the closely separated measurements of the European Space Agency's Swarm satellites by comparing the leading and trailing satellite (Swarm A-C pair) in the high latitude topside ionosphere, where we evaluate lags of the intensifications in the common scales between the electron density measurements and the field-aligned current measurements from Swarm FAC dataset. This can pave the way to future uses of this technique in contexts in which the causation chain can be hidden in a complex, multiscale coupling of the investigated features. This work is performed within the Swarm Variability of Ionospheric Plasma (Swarm-VIP) project, funded by ESA in the "Swarm+4D-Ionosphere" framework (ESA Contract No. 4000130562/20/I-DT).

Vassiliadis, Dimitrios (NOAA/NESDIS)
OSSEs and Other Numerical Studies in Support of the Space Weather Next (SW Next) Program
Co-Author(s): Irfan Azeem, NOAA/NESDIS/OPPA Mihail Codrescu, NOAA/NWS/SWPC Tim Fuller-Rowell, NOAA/NWS/SWPC Adam Kellerman, UCLA Tomoko Matsuo, University of Colorado Terry Onsager, NOAA/NWS/SWPC Joanne Ostroy, NOAA/NESDIS/OPPA Eric Sutton, University of Colorado Nai-Yu Wang, NOAA/NESDIS/OPPA Title: OSSEs and other numerical studies in s

In 2020, NOAA initiated planning for a number of space weather observation activities to continue and expand the current Program of Record 2025. The Space Weather Next (SW Next) Program is one of these activities with planned capabilities to include solar imagery in the visible, UV, and X-ray wavelength ranges as well as solar wind plasma, particle flux, and interplanetary magnetic field measurements as a continuation of the POR 2025. The program will also include magnetospheric particle and magnetic-field measurements from geostationary and off-equatorial orbits, and ionospheric/thermospheric imagery and in situ measurements. The presentation will discuss the development of observing system simulation experiments (OSSEs) to identify optimal parameter ranges for instruments, orbits, and other architectural elements considered in the first stage of the program definition. Three such studies were kicked off starting in October 2021 focusing on ionospheric electron density, thermospheric neutral density, and radiation belt electron flux and based on advanced environmental models for the corresponding geospace regions. The presentation will discuss the goals, systems approach and parameters for each study as well as the expected results for improved mission planning. We will also go over the relevance to the categories of space weather information users. We invite feedback from the user and science community on the application of these new approaches to mission planning.

Wang, Houjun (CIRES, University of Colorado at Boulder)
Development of a Discontinuous Galerkin Ionosphere-Plasmasphere Model
Co-Author(s): N/A

The objective of this study is to explore the application of high-order numerical methods in ionosphere-plasmasphere modeling. Specifically, the nodal discontinuous Galerkin method is chosen to solve the multifluid dynamical equations along the magnetic field lines. A general curvilinear magnetic field-line-following coordinate system is also used in the model. Numerical simulations with different combinations of number of elements (K) and polynomial orders (N) show the converging results, indicating the robustness of the algorithms and implementation. The model also captures the dawn terminator effect very well in the He+ field. References: Wang, H. (2022a), A general curvilinear magnetic field-line-following coordinate system for ionosphere-plasmasphere modeling, J. Geophys. Res. Sp. Phys., p. 13, doi:10.1029/ 2021JA030017. Wang, H. (2022b), Development of a discontinuous Galerkin ionosphere-plasmasphere model, J. Geophys. Res. Sp. Phys., p. 19, doi:10.1029/2021JA030047.

Willis, Jacob (United States Military Academy)
Detection of High-latitude Ionspheric Plasma Conditions Leading to GPS Scintillations Using a Novel Poker Flat Incoherent Scatter Radar Mode
Co-Author(s): COL Diana Loucks; USMA Professor and research advisor

The Poker Flat Incoherent Scatter Rader (PFISR) located in Fairbanks, Alaska, provides data on ionospheric conditions. 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. This research project analyzes data collected on August 26, 2018, 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. Methods for isolating chaotic conditions within the ionosphere to quantitatively detect structures before disintegration and quantifying the strength of correlation between beams are addressed. Additionally, a three-dimensional approach to the visualization of plasma structure movement is explained. 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 shearing of plasma structures within the ionosphere and enhance the utility of ISRs in detecting GPS scintillation.

Zou, Shasha (University of Michigan)
Innovative Global Ionospheric Total Electron Content (TEC) Map Reconstruction and Forecasting Using Machine Learning
Co-Author(s): Hu Sun, University of Michigan Zihan Wang, University of Michigan Yang Chen, University of Michigan Yurui Chang, University of Michigan

In the current era, the ionospheric total electron content (TEC) derived from multi-frequency Global Navigation Satellite System (GNSS) receiver is arguably the most utilized dataset in the ionospheric research area, and also has essential practical importance, as it is the largest naturally occurring error source for GNSS positioning, navigation, and timing (PNT) accuracy. The potential of using the GNSS data as a backbone of the space weather observational system has been demonstrated in the last decade with the GPS system, and as we are moving into the multi-GNSS era, we are at the forefront of a new chapter by combining the traditional space science and the modern optimization and machine learning (ML) algorithms to make a leap forward in the specification and forecasting of ionosphere state and variability. We use state-of-the-art video imputation and optimization algorithm VISTA to specify the global ionosphere TEC and its variability and construct a global TEC database. Advanced ML tools, including a modified U-net architecture and an interpretable matrix auto-regressive model, are developed to forecast the TEC map. Performance of the new forecasting models are then compared with the forecasting model developed using traditional IGS maps and validated against real TEC observations.

Thursday April 28 Poster Session: Geospace/Magnetosphere Research and Applications, and Aviation Radiation Research and Applications

Ala-Lahti, Matti (Department of Climate and Space Sciences and Engineering, University of Michigan)
Fine Structure of Geoeffective Solar Wind Transients Complicating Space Weather Predictions
Co-Author(s): Andrew P. Dimmock - Swedish Institute of Space Physics Tuija I. Pulkkinen - Department of Climate and Space Sciences and Engineering, University of Michigan; Electronics and Nanoengineering Engineering, Aalto University Simon W. Good - Department of Physics, University of

Helsinki Emilya Yordanova - Swedish Institute of Space Physics Lucile Turc - Department of Physics, University of Helsinki Emilia K. J. Kilpua - Department of Physics, University of Helsinki

Spacecraft measurements upstream Earth's magnetosphere at L1 are used as a monitor when trying to understand magnetospheric dynamics. The precise conditions driving the magnetosphere are not however always captured because of the fine structure of solar wind and its transients. We report the transmission of temporal southward magnetic fields within a sheath region driven by interplanetary coronal mass ejection (ICME) to Earth's magnetosheath, and we show that the correlation of observations from a solar wind monitor and a spacecraft in the magnetosheath depends on spacecraft alignment, demonstrating that choosing the monitor has to be practiced carefully. Observing these fields is important to understand the various dynamics and prompt responses of the magnetosheath and magnetosphere during an ICME passage, and to recognize the causality of geomagnetic disturbances.

Benton, Eric (Oklahoma State University, Dept. of Physics)
Atmospheric Ionizing Radiation Environment (AIRE) Institute
Co-Author(s): Kyle Copeland, U.S. Federal Aviation Administration, Civil Aerospace Medical Institute, Oklahoma City, OK USA Brad Gersey, Oklahoma State University, Department of Physics, Stillwater OK USA Tristen Lee, Oklahoma State University, Department of Physics, Stillwater OK USA Martin Yang, Oklahoma State University, Department of Physics, Stillwater OK USA

The Atmospheric Ionizing Radiation Environment (AIRE) Institute, headquartered at Oklahoma State University, is the first research and education institute in the US focused primarily on the study of the on the Steady State Atmospheric Ionizing Radiation Environment (SSAIRE), its effects on life, on our technological infrastructure and on the environment. In addition to furthering our understanding of the fundamental physics underlying the SSAIRE, our research emphasizes development of ionizing radiation detectors for use in the atmosphere and on the ground, and on developing and refining computer models of the SSAIRE. Our educational mission is focused on informing the scientific community, the aviation community and general public about the SSAIRE and its effects on life, the larger environment and technology. In addition to low-cost ground-based detectors to measure the fluxes of secondary cosmic ray neutrons and muons, the AIRE Institute is developing a range of instrumentation suitable for atmospheric dosimetry including the Atmospheric Ionizing Radiation Tissue Equivalent Dosimeter (AirTED). The institute has also developed AIREC, a compact, stand-alone computer model capable of estimating the energy spectra and flux of the major species of ionizing radiation produced in galactic cosmic ray (GCR) induced atmospheric air showers as functions of altitude, geographic (geomagnetic) coordinates and solar epoch.

Capannolo, Luisa (Boston University)
Association Between the Spatial Characteristics of Relativistic Electron Precipitation Observed at LEO and its Magnetospheric Drivers
Co-Author(s): Wen Li, Boston University Robyn Millan, Dartmouth College David Smith, University of California Santa Cruz Nithin Sivadas, NASA GSFC John Sample, Montana State University Sapna Shekhar, Auburn University Sheng Huang, Boston University

Precipitation of relativistic electrons from the outer radiation belt into the Earth's atmosphere is an important mechanism occurring in the magnetosphere. On one hand, it can lead to significant depletion of the energetic population in the outer radiation belt, thus changing the near-Earth radiation environment. On the other hand, the interaction between the precipitating relativistic electrons and the neutral atmosphere can alter the chemistry and ionization of the atmosphere itself. Both of these outcomes are important for Space Weather. In this work, we focus on identifying the specific driver of the relativistic precipitation observed by the POES/MetOp satellites at low-Earth-orbit. We find that plasma waves are responsible for the spatially isolated relativistic electron precipitation, while current sheet scattering (CSS) drives an energy-dependent precipitation pattern. We focus our attention on the nightside electron precipitation and highlight that, over 22-02 MLT, waves and CSS are co-existing mechanisms. Furthermore, we show how deep learning techniques can be used to automatically identify and classify events between those driven by waves and those due to current sheet scattering. This deep learning model is useful to obtain statistically large datasets to comprehensively understand in which MLTs and L shells waves dominate over CSS and to estimate their respective contribution to the total relativistic electron precipitation.

Chauhan, Prithika (Hamilton High School, Chandler, AZ)
Flying Through the Aurora: A Pilot's Guide
Co-Author(s): Jinni Meehan, National Oceanic and Atmospheric Administration, Washington D.C., USA

The Sun's warmth and light sustain all life on earth, but every now and then it blasts us with its magnetic and nuclear energy. Aurora, solar flares, geomagnetic storms are a few examples of Space weather conditions that can force flights to be rerouted. In this project, I want to understand space weather and help pilots decide when to reroute flights in case of any space weather event. In the past, many times flights were rerouted due to space weather events. I reviewed the space weather events using websites like NASA, NOAA, FAA, etc. These sites contain data from satellites which needs to be converted into a user-friendly interface for pilots. I also compared data of past Space weather events like the Halloween storm and correlated it with an impact, particularly on the Aviation industry. A simulation of the Aurora experiment was also conducted on Simulator C172. This was done at the CAP center where I go to learn how to fly a plane. In the end, my suggestion is to add a space weather app on the pilot's dashboard which can indicate different levels of severity of storms and let pilots know when to reroute the plane and to fly at which altitude. I also would like to suggest that pilots get brief information about the space weather ahead from FAA specialists.

Albert, Dennis (Institute of Electrical Power Systems, Graz University of Technology)
Geomagnetically Induced Current Measurements and Space Weather Prediction in Austria
Co-Author(s): Philipp Schachinger, Institute of Electrical Power Systems, Graz University of Technology; Rachel L. Bailey, Zentralanstalt für Meteorologie und Geodynamik Austria.

Unusually high transformer sound levels triggered the GIC research in Austria. The measurements revealed DC currents highly correlated with geomagnetic field variations. There are currently 9 self-developed measurement monitoring transformer neutral point currents in the Austrian transmission grid. The developed GIC-grid-simulation tool calculates the currents in the power grid from the measured magnetic field data. The calculation is based on an earth subsurface conductivity model combined with a model of the electrical transmission grid. The comparison between continuous measurements and calculations results in constantly improved calculation methods. We wish to provide forecasts of future GICs using the incoming solar wind measured at the Earth-Sun Lagrange point 1 (L1) as a basis. We aim to predict the two horizontal geoelectric field components, Ex and Ey, with the ground truth being the geoelectric field modelled from geomagnetic variations. The forecasting is carried out using a recurrent neural network (LSTM), which takes solar wind speed, density and magnetic field, as well as recent geomagnetic variations, as input and then outputs the maximum expected geoelectric field in the next 30-40 minutes, assumed to be homogenous across Austria. The fit of simulation to measurement will be shown with recent solar events of 2021.

Graf, Sophie (University of Texas at Arlington)
Effects of Upstream Small Scale Structure on Predictive Performance of the Space Weather Modeling Framework
Co-Author(s): Daniel Welling, University of Texas at Arlington Steve Morley, Los Alamos National Lab

Numerical models of the geospace environment, such as the operational configuration of the Space Weather Modeling Framework, require the solar wind and interplanetary magnetic field to be specified at the upstream boundary. For both science and operations, this boundary condition is usually taken from a solar wind monitor near L1, such as ACE or DSCOVR, and specified at 1-minute cadence or better. However, there are a number of circumstances in which this temporal resolution is not available, such as data gaps due to instrumental effects; historical events that do not have complete solar wind coverage; and synthetic events used for benchmarking and hypothesis testing, which are often specified as idealized drivers. In each of these cases, small-scale structure is missing from the upstream boundary condition driving the model. The extent to which the sub-hourly solar wind structure impacts the predictive performance of geospace models has not previously been examined. Using a set of 5 events that have been the basis of previous validation efforts, we simulate each event multiple times, progressively filtering and downsampling the driver time series to 1-, 15-, 30-, and 60-minute cadences. We quantify the reduction in predictive skill and use a comprehensive validation suite to assess the change in model performance at high- and mid-latitude regions, as well as in local time.

Hartinger, Michael (Space Science Institute)
Underestimates of ULF Geomagnetic and Geoelectric Fields: Revisiting the 29 October 2003 Geomagnetic Storm
Co-Author(s): Xueling Shi, Virginia Tech Josh Rigler, USGS Craig Rodger, University of Otago Ikuko Fujii, Kakioka Observatory Karl Kappler, UC Berkeley Juergen Matzka, GFZ-Postdam Joseph Baker, Virginia Tech Daniel MacManus, University of Otago Michael Dalzell, Transpower New Zealand Tanja Petersen, GNS Science

Past studies have linked magnetospheric Ultra Low Frequency (ULF) waves to Geomagnetic Fields (BGEO), Geoelectric Fields (EGEO), and Geomagnetically Induced Currents (GIC). The largest wave intensities were associated with wave periods >~4 minutes occurring at magnetic latitudes >~60 degrees, with comparatively smaller intensities reported at lower latitudes and shorter wave periods. We use BGEO, EGEO, and GIC measurements sampled at 0.1-1 Hz to show that waves with periods of ~1-2 minutes were present during and after the Storm Sudden Commencement (SSC) on 29 October 2003 at several locations <60 degrees magnetic latitude. At these locations, the waves led to BGEO with amplitudes of ~100 nT, EGEO with a range of values depending on local ground conductivity (~0.1-0.6 V/km peak values at locations with measurements available), and GICs in New Zealand with sustained variations of +/- 5 A. We compare these results to measurements sampled at 0.0167 Hz (1 minute), demonstrating that the use of 1-minute data removes the contributions of these waves to BGEO and EGEO and alters conclusions concerning the source of the GICs in regions where the waves were present.

Landinez, Gabriela (Universidad Industrial de Santander)
Impact of the Hall Effect on the Reconnection rate: MHD Simulation of the Earth's Magnetotail
Co-Author(s): Fabio Lora, Universidad Industrial de Santander

Physical processes in the magnetosphere determine how space weather affects Earth, therefore, the study of the magnetosphere and its coupling with the solar wind is essential. Part of the coupling occurs because of the magnetic reconnection process that takes place in the magnetotail. In this zone, the reconnection rate is of particular interest because it is associated with the amplitude of geomagnetic disturbances. Unfortunately, the reconnection rate inferred from observations is much faster than predicted by theory. In addition, we do not know which phenomenon is responsible for the reconnection rate having the same value in all astrophysical reconnection events. To address this problem, we have taken a single fluid approach with the hall term in the resistive MHD equations. The system of equations was solved numerically using MAGNUS, in which a subroutine with initial conditions for the magnetotail and another for the calculation of the reconnection rate were implemented. Finally, a systematic comparison between the resistive Hall-MHD and the resistive MHD simulations allows us to determine the impact of the Hall effect on the reconnection rate.

Ozturk, Dogacan (University of Alaska Fairbanks)
MAGICIAN Project: Machine Learning, Data Collection, Education and Outreach for Space Science Research
Co-Author(s): Victor Pinto, University of New Hampshire Hyunju K. Connor, NASA Goddard Space Flight Center Austin Cohen, University of Alaska Fairbanks Matthew Blandin, University of Alaska Fairbanks Jeremiah Johnson, University of New Hampshire Chuck Smith, University of New Hampshire Amy Keesee, University of New Hampshire and the MAGICIAN team

With over 34 participants, the Machine Learning Algorithms for Geomagnetically Induced Currents in Alaska and New Hampshire (MAGICIAN) is a joint team between the University of Alaska Fairbanks and the University of New Hampshire, that applies Machine Learning techniques to the ever-growing space science data for improving our understanding and prediction of hazardous geomagnetic activity. Primarily focusing on geomagnetically induced currents, which can cause significant damage to the power grids, the MAGICIAN team studies various different phenomena that occur as a result of the dynamic interaction between the solar wind and the Earth's magnetosphere. The diverse efforts of the MAGICIAN team include developing machine learning models to predict and classify various space weather related phenomena, as well as promoting education, outreach, and citizen science activities through the Space Weather UnderGround (SWUG) project across Alaska, New Hampshire, and the United States. This presentation will showcase the machine learning models developed by the MAGICIAN team and introduce the SWUG Project.

Pettit, Joshua (Laboratory for Atmospheric and Space Physics)
Long-Term Impacts on the Middle and Upper Atmosphere from Energetic Electron Precipitation
Co-Author(s): Cora Randall: University of Colorado/Laboratory for Atmospheric and Space Physics Lynn Harvey: Laboratory for Atmospheric and Space Physics

Energetic particle precipitation (EPP) can have large influences on the chemistry of the middle and upper atmosphere. Solar protons have large impacts on NOx, HOx, and ozone in the mesosphere and stratosphere; however, they occur relatively infrequently, maximizing near solar cycle maximum. Auroral electrons, which have energies < 30 keV, precipitate continuously but deposit their energy in the thermosphere. Electrons with energies > 30 keV, on the other hand, precipitate regularly to altitudes ranging from the lower thermosphere through the upper stratosphere. The long-term contribution to the chemistry of the middle atmosphere from these higher energy electrons could therefore exceed that of other forms of EPP. This work investigates the long-term impacts on the stratosphere, mesosphere and lower thermosphere from EPP, with a focus on the higher energy precipitating electrons. Simulations including solar protons, auroral electrons and higher energy electrons were performed using the Whole Atmosphere Community Climate Model. The newly derived Medium Energy Proton and Electron Detector Precipitating Electron (MPE) data set was used to specify the higher energy electron precipitation. The forced simulations are compared to a baseline WACCM6 simulation that excluded the higher energy electrons of > 30 keV. The simulations included the time frame from 1 January 2001 through 1 January 2019. The simulations are compared with available satellite observations to validate the results.

Schultz, Adam (Oregon State University)
An ML Approach to Forecasting Space Weather Impacts on Critical Infrastructure from Ground-Based Arrays
Co-Author(s): Rolando Carbonari, Hebrew University of Jerusalem

For the past sixteen years under the support of NSF, NASA and most recently the US Geological Survey, we have been systematically measuring electric and magnetic field time series from moving arrays of magnetotelluric (MT) instrumentation spanning the conterminous US and the interior of Alaska. While originally motivated by questions of the structure and evolution of the North American continent, the resulting 3-D electrical conductivity structure of the Earth's crust and upper mantle, and the electromagnetic impedance data derived from this work on have in recent years proved of considerable importance to mitigating risk to critical infrastructure (most notably, the power grid) from geomagnetically induced currents caused by space weather and electromagnetic pulse events. Under current NSF support we are exploring how to combine real-time magnetic observatory data streams with this information and with power flow simulations of the power grid to provide real-time alerting information of GIC impacts on high-voltage transformers to electric utilities. In the present work we go beyond real-time and present preliminary results of our efforts to train neural networks to assimilate data from dense arrays of ground-based MT stations in Alaska to provide forecasts of ground electric and magnetic field time series that could in future, with installation of permanent MT arrays, provide actionable intelligence to utilities ahead of GICs impacting their networks.

Wiltberger, Michael (NCAR/HAO)
Multiscale Atmosphere Geospace Environment Model
Co-Author(s): Viacheslav Merkin - JHU/APL CGS Tea - Various

The physical complexity of geospace makes predicting space weather a major challenge. A major source of this challenge originates from the fact that geospace is inherently multiscale and heterogenous. The different regions within geospace evolve on a vast array of spatial and temporal scales and accurate simulations must include both the coupling between these regions as well as the capability to resolve the mesoscale physics that play a fundamental role in governing the global response of the space weather system. The team at the recently selected NASA Drive Center for Geospace Storms is developing the Multiscale Atmosphere Geospace Environment (MAGE) model to address both of these challenges and to fulfill the the Center's vision to "transform our understanding and predictability of space weather" by innovating community space weather modeling capabilities, empowering the academic and operational communities, and discovering how the different parts of geospace work together during storm times to shape the response to space weather drivers from the Sun. In this presentation we highlight the capabilities of the model framework to predict the multiscale plasmasheet and ring current and their impacts, the mesoscale ionospheric structure and global mass circulation, and coupling between atmosphere, ionosphere, and magnetosphere across different scales during storms.