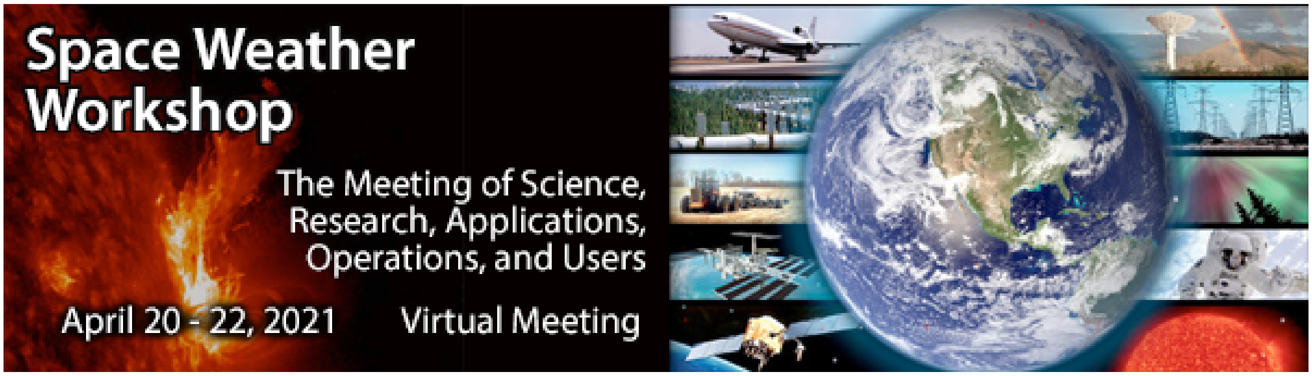

2021 Space Weather Workshop Poster Abstracts
Held Virtually
Lightning Talks from 5:00 - 5:30 pm EDT with Poster viewing from 5:30 - 6:30 pm EDT

Tuesday April 20 Poster Session: Solar and Interplanetary Research and Applications

Berger, Thomas (Space Weather TREC, University of Colorado at Boulder)
Progress in Application of Machine Learning to Solar Flare Prediction
Co-Author(s): V Deshmukh, N Flyer

As part of the NASA Space Weather O2R grant program, we report our recent progress on the application of machine learning techniques to the prediction of solar flares using Convolution Neural Network architectures (CNNs). Although the ultimate goal of the grant is to produce an accurate and reliable 3 - 12 hour probabilistic flare forecasting system using a multi-stage CNN, here, we present results from optimizing the first stage of the architecture which is critical to predictive performance tuning. Items to be discussed are the effect of 1) input vector dimensionality, 2) image resolution variability, 3) dataset augmentation with cross-entropy weighting for highly imbalanced datasets, 4) how thresholding the softmax probability output effects performance metrics, 5) temporally stacking images when using CNNs, and lastly 6) comparing how CNNs perform alone versus a CNN plus LSTM architecture. Results are presented for both 24 hour and 12 hour forecasts, showing what items significantly reduce false positives (false alarm) and frequency bias (overprediction) while maintaining low false negative (missed forecasts).

Bilenko, Irina (Sternberg Astronomical Institute, Moscow State University, Moscow, Russia)
Influence of Cycle Variations of the Polar and Nonpolar Magnetic Fields of the Sun on the Parameters of the Solar Wind

Since the solar corona is not in hydrostatic equilibrium, this leads to the constant propagation of coronal plasma into interplanetary space and the formation of solar wind streams that determine space weather in the Earth's orbit. Solar magnetic fields are a superposition of constantly changing different-scale magnetic structures. These fields are carried out by the solar wind streams, forming an interplanetary magnetic field (IMF). Based on the data from ground-based and space

observatories, the regularities of the time-spatial cycle variation in the different-scale solar magnetic fields and their influence on solar wind parameters and IMF in cycles 21–24 are studied. The plasma parameters are calculated at different distances from the Sun and the time dependencies of their variations at different phases of solar activity are revealed. The calculation results are compared with direct observations. The dependencies of plasma parameters on the magnitude and structure changes of the magnetic field are investigated taking into account the cycle variations of the contribution of the polar and nonpolar magnetic fields, which are a manifestation of the poloidal and toroidal components of the global magnetic field of the Sun. The influence of the observed decrease in the polar and nonpolar magnetic fields on the parameters of the solar wind and the differences in their dependencies on magnetic fields in high and low cycles at different phases of solar activity are analyzed.

Boerner, Paul (Lockheed Martin Solar and Astrophysics Laboratory)
EUV Extended Coronal Observations for Space Weather
Co-Author(s): N Hurlburt, L Shing, G Slater, M Shaw-Lecerf, R Seguin, D Seaton

Monitoring the dynamics of the solar corona at 1.5-3.5 RSun (above the field of view of current solar disk imagers, but inside the occulting region of coronagraphs) offers the potential to greatly improve the identification and characterization of coronal mass ejections beyond what is currently possible. SUVI has performed a number of extended coronal imaging experiments demonstrating the ability to trace coronal structures out to 3 RSun. These results demonstrate that EUV imaging telescopes can observe this critical region with excellent cadence, resolution, and signal-to-noise, along with the diagnostic capabilities of multi-spectral imaging. We present the SUVI results and discuss how future instruments could maximize the power of extended coronal observations for space weather monitoring.

Bruno, Alessandro (NASA Goddard Space Flight Center and Catholic University of America)
A New Empirical Model of 10 – 130 MeV Solar Energetic Particle Spectra at 1 AU
Co-Author(s): I Richardson

We present a new empirical model (SEPSTER-2D) to predict solar energetic particle (SEP) event-integrated and peak spectra between 10 and 130 MeV at 1 AU, based on multi-point spacecraft measurements from the Solar TErrestrial RElations Observatory (STEREO), the Geostationary Operational Environmental Satellites (GOES) and the Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA) satellite experiment. The model is developed using 32 SEP events in 2010-2014 including protons in excess of a few tens of MeV that were unambiguously recorded at three spacecraft locations. The spatial distributions of SEP intensities are parameterized using an energy-dependent 2D Gaussian functional form that accounts for the correlation between the intensity and the speed of the parent coronal mass ejection (CME), and the magnetic field line connection angle. The CME measurements used are from the Space Weather Database Of Notifications, Knowledge, Information (DONKI). The model performance is tested by comparing with the spectra of 20 SEP events not used to derive the model parameters. Despite the simplicity of the model, the observed and predicted event-integrated and peak and intensities at Earth and STEREO for these events show remarkable agreement, both in the spectral shapes and their absolute values. The model is currently running in near-real time and providing predictions for the CCMC SEP Scoreboard (https://sep.ccmc.gsfc.nasa.gov/intensity/).

Casillas, Lizet (California State University Northridge, Advanced Heliophysics)

Predicting Magnetic Chirality and Potential Geo-effectiveness of Coronal Mass Ejections

Co-Author(s): O Panasenco

Coronal Mass Ejections (CMEs) can create powerful magnetic storms that can have devastating effects on earth environment as they affect satellites, power grids and electronics. The ability to predict CMEs that can be geo-effective early as possible would help to alleviate the effects of solar storms on earth. It is important to forecast the direction of the magnetic field of a CME when it interacts with the earth's magnetosphere as it the key determinant of the effectiveness of the CME in creating geomagnetic storms. In this work it is our purpose to verify if CMEs and the filament channels from where they originated will be geo-effective by analyzing the chirality of the filament channels to determine the direction of the axial magnetic field inside channels and in the flux ropes of the corresponding CMEs and compare with the existing data bases. Chirality of CME source regions can be determined days and weeks before the eruptions, making this a better early warning compared to existing observations from satellites that indicate field direction only 10-60 minutes before the CME arrival. We will use python to find the statistical likelihood of geo-effective CMEs based on their chirality and geometry. We will create boundary data set that can be used for data-driven propagation of magnetized CMEs in heliospheric models and AI models to predict the magnetic configuration of CMEs at 1 AU and the potential geo-effectiveness of the solar storm.

Caspi, Amir (Southwest Research Institute)

The CubeSat Imaging X-ray Solar Spectrometer (CubIXSS)

Co-Author(s): A Shih, H Warren, A Winebarger, PS Athiray, T Woods, M Cheung, C DeForest, J Klimchuk, G Laurent, J Mason, S Palo, D Seaton, M Stęślicki, S Gburek, J Sylwester, T Mrozek, M Kowaliński, M Schattenburg

The CubeSat Imaging X-ray Solar Spectrometer (CubIXSS) is a 6U CubeSat proposed to study a compelling science question: what are the origins of hot plasma in solar flares & active regions? CubIXSS will make sensitive, precise measurements of abundances of key trace ion species, whose spectral signatures reveal the chromospheric or coronal origins of heated plasma over a broad ~1 to >30 MK range. These measurements address longstanding inconsistencies from prior studies with limited, differing temperature & composition sensitivities. CubIXSS comprises two co-optimized instruments to fill a critical observational gap: (1) MOXSI, a novel diffractive spectral imager using a pinhole camera and X-ray transmission diffraction grating for spectroscopy from 1 to 55 Å (0.29-0.37 Å & 29"-39" FWHM spectral & spatial resolution); and (2) SASS, a suite of four spatially-integrated off-the-shelf spectrometers for high-cadence, high-sensitivity spectroscopy from 0.5 to 50 keV (0.06-0.5 keV FWHM resolution). CubIXSS would launch in late 2023 for a 1-year prime mission during the rising phase of the solar cycle, and is a pathfinder for next generation Explorer-class missions with improved SXR imaging spectroscopy. We present the CubIXSS science background, its suite of instruments & expected performances, & other highlights from the Concept Study Report, including novel analysis techniques to fully exploit the rich data set of spectral observations of intense flares & active regions.

Chamberlin, Phillip (U. of Colorado/Laboratory for Atmospheric and Space Physics (CU/LASP))
The Flare Irradiance Spectral Model - Version 2 (FISM2)
Co-Author(s): FG Eparvier, V Knoer, H Leise, A Pankratz, M Snow, B Templeman, EMB Thiemann, DL Woodraska, TN Woods

The Flare Irradiance Spectral Model (FISM) is an important tool for estimating solar variability for a myriad of space weather research studies and applications, and FISM Version 2 (FISM2) was recently released in Nov 2020 (Chamberlin et al., Space Weather, 2020), and can be downloaded from the LASP LISIRD interface (https://lasp.colorado.edu/lisird/). FISM2 is an empirical model of the solar ultraviolet irradiance created to fill spectral and temporal gaps in the satellite observations. FISM2 estimates solar ultraviolet irradiance variations due to the solar cycle, solar rotations, and solar flares. The major improvement provided by FISM2 is that it is based on multiple new, more accurate instruments that have now captured almost a full solar cycle and thousands of flares, drastically improving the accuracy of the modeled FISM2 solar irradiance spectra. Specifically, these new instruments are SDO EVE, SORCE XPS, and SORCE SOLSTICE. FISM2 is also improved to 0.1 nm spectral bins across the same 0-190 nm spectral range, and is already being used in research to estimate space weather changes due to solar irradiance variability in planetary thermospheres and ionospheres. This poster will present example FISM2 spectra and time series, as well as compare these to the measurement datasets for which it was based on.

DeForest, Craig (Southwest Research Institute)
Space Weather Monitoring in 3D with PUNCH and QuickPUNCH: Mission Status
Co-Author(s): S Gibson, R Killough, T Case, A Henry, M Beasley, G Laurent, R Colaninno, The PUNCH Mission Development Team

The Polarimeter to UNify the Corona and Heliosphere (PUNCH) is a NASA Small Explorer mission to understand the processes which connect the corona and inner heliosphere, including space weather. During its two year mission, PUNCH will image the entire outer solar corona and inner heliosphere routinely on a 4-minute cadence, using polarization data to infer 3D structure and propagation of space-weather-relevant events such as CMEs and CIRs. PUNCH comprises four identical smallsats that will deploy from an ESPA ring into a Sun-synchronous 6am/6pm polar orbit. One carries the "Near Field Imager" (NFI), a compact coronagraph design that approximately matches the LASCO C-3 field of view; the other three carry copies of the "Wide Field Imager" (WFI), a heliospheric imager design that extends the field of view to 45°. The four cameras have overlapping fields of view, and are synchronized and matched in wavelength, to ensure a single seamless data stream. QuickPUNCH is an initiative by NOAA/SWPC to enable rapid

near-real-time downlink, early processing, and distribution of PUNCH data as a backup to other operational data and to evaluate polarized imaging - both as a forecast tool for CMEs arrival, and to infer CME chirality -- a key step toward data-based forecasting of CME Bz. PUNCH is in Phase B (preliminary design), with mission PDR scheduled for the week of 18-May-2021 and a transition to Phase C/D anticipated in early July 2021. Science data flow commences in 2024.

Fleming, Rhiannon (Millersville University of Pennsylvania)
A Review of Measuring Total Solar Irradiance and Solar Observation Remote Sensing Methods

Sun interaction observations began in 1957, with Sputnik 2, and are now recognized as an important set of observational data for both ground and orbital infrastructure. This study will focus on the evolution of instruments which have had an impact on the ability to measure Total Solar Irradiance and additional space weather phenomena. An understanding of the instrumentation and methods of measurement are key for identifying the evolution of data collection, analysis, and applications of the retrieved data. Focusing on the history of solar measurements, this study will review the use of remote sensing in the context of space weather phenomena through the present. Furthermore, the potential gaps in the current observing system will be investigated including the availability of this data for their applications in climate studies including their integration in climate models will be investigated.

Flores-Soriano, Manuel (Universidad de Alcalá)
SMOS Mission: from Earth Explorer Satellite to Space Weather Asset
Co-Author(s): C Cid

ESA's SMOS mission was originally conceived to map the concentration of salt in the oceans and the moisture of the soil. However, not only Earth, but also the Sun appears in the wide field of view of its 1.4GHz antenna, making it possible to use SMOS as a 24h solar radio telescope able to provide data in near real-time with full polarization. In this presentation we show how SMOS sees the Sun and its response to different types of solar events. We compare the 1.4GHz solar radio signals from flares depending on if they are associated with a coronal mass ejection or not. We also show the correlation between the radio bursts fluence and the speed, angular width and kinetic energy of the CMEs. Finally, we show how SMOS can help monitoring solar interferences affecting GNSS, radar and L-band wireless communications.

Hassler, Don (Southwest Research Institute)
The Solaris Solar Polar MIDEX Mission: Improving our Understanding for Space Weather Research and Prediction
Co-Author(s): S Gibson, J Newmark

Solaris is an exciting and innovative mission of discovery to reveal the mysteries of the Sun's poles. Solaris was selected for Phase A development as part of NASA's MIDEX program.   Solaris will be the first mission to image the poles of the Sun from ~75 degrees latitude and provide new insight into the workings of the solar dynamo, which is at the foundation of our understanding of the solar cycle, as well as the first simultaneous, 360 degree longitudinal views of coronal structure, variability and CME eruption, providing new insight into our understanding of space weather. Specifically, Solaris will: *Provide time series of polar magnetograms, EUVI and coronagraph images with complete longitudinal coverage to enable monitoring of developing structures. *Provide the first global view of the 3D structure of the solar corona, solar activity, CME eruption and propagation, and distinguish directionality of "Halo CMEs".   *Provide co-temporal stereo-graphic observations with those from the identical coronagraphs at L1 and L5. *Enable improved modeling & monitoring of Earth-intersecting transients. *Provide the first line-of-sight measurements of southward directed B-field. In summary, Solaris is a Research-to-Operations (R2O) opportunity that will improve our understanding for Space Weather Research, as well as improved space-weather & geomagnetic storm prediction.

Hegde, Dinesha Vasanta (The University of Alabama in Huntsville)
Solar Wind Simulations along the Parker Solar Probe Trajectory
Co-Author(s): T Kim, N Pogorelov

Solar wind (SW) modeling is a vital component for space weather predictions. It describes the propagation of solar coronal disturbances, such as coronal mass ejections (CMEs) and energetic particles, towards the Earth orbit. Space weather forecasting through better understanding of the physical processes occurring in the SW plasma is essential. On the other hand, Parker Solar Probe (PSP), launched on 2018 August 12, provides us with a unique set of in situ SW measurements at distances as close as the critical surface around the Sun. This can help validate numerical models of the solar corona and inner heliosphere. We perform simulations of the 3D global heliosphere using an empirically driven MHD model developed within the frameworks of the Multi-Scale Fluid-Kinetic Simulation Suite (MS-FLUKSS) using the photospheric magnetograms as input. We compare our SW simulations in the inner heliosphere with in situ measurements along the PSP trajectory for the completed orbits. We also compare our simulations with the near-Earth SW properties which are closely monitored and stored at the OMNI database. This study provides us with better constraints for our semi-empirical data-driven MHD model and helps understand the SW acceleration.

Hurlburt, Neal (Lockheed Martin Advanced Technology Center)
Future Architectures for Space Weather Magnetographs
Co-Author(s): T Berger

The ability to accurately measure the magnetic field at the solar surface is a critical space weather requirement as laid out in multiple mission studies. As we move to the next generation of space weather observing systems, a key driver is the optimal architecture for photospheric (and possibly chromospheric or coronal) field measurements. In particular, should they be acquired from ground-based or space-based instruments, or both? Here we argue that space-based instruments are the best solution, not only due to the well-established fact of their superior data quality, but also to the lesser understood role they play in providing a more cost effective, more flexible and more operationally efficient solution. Using existing operational observing systems as the starting point for our comparison, we project what the next generation of ground- and space-based systems will offer, and compare estimates for their total cost of ownership, system performance, reliability and operational efficiency.

Illarionov, Egor (Moscow State University)
Machine-Learning Framework for Synoptic Maps Construction and Coronal Holes Segmentation
Co-Author(s): D Sitdikov, A Kosovichev, A Tlatov

Fast and reliable automatic pipelines for data processing and interpretation are an essential part in space weather prediction models. We present an open-source framework https://github.com/observethesun/helio for convenient pipelines construction, training and prediction with machine learning models. In particular, we demonstrate a construction of solar synoptic maps from SDO/AIA, SOHO/EIT and GONG/SUVI data, training a coronal holes (CHs) segmentation model from daily solar disk images and model application to CHs identification in synoptic maps. The continuously updated catalogue of solar synoptic maps built from SDO/AIA images is available at https://sun.njit.edu/coronal_holes starting from the very beginning of SDO observations. At the moment we prepare an extension of the catalogue based of SOHO data archive. In the presentation we also discuss a correlation between SDO and SOHO synoptic maps over a common period of observations as well as physical properties of CHs identified.

Kim, Tae (The University of Alabama in Huntsville)
Predicting the Solar Wind Using the Multi-scale Fluid-kinetic Simulation Suite (MS-FLUKSS)
Co-Author(s): T Singh, D Hegde, N Pogorelov,

The Sun emits a stream of charged particles called the solar wind, which is the primary driver of space weather and geomagnetic disturbances. Modeling and observations complement each other to help us identify and understand the physical processes governing the solar wind dynamics on different scales. Numerical models of the solar wind have greatly improved in recent years with advances in computational infrastructure and by employing data-driven or data-assimilative approaches. Multi-scale Fluid-kinetic Simulation Suite (MS-FLUKSS) is arguably one of the most sophisticated numerical codes designed primarily for modeling the partially ionized plasma throughout and beyond the heliosphere using adaptive mesh refinement technique on Cartesian or spherical grids. To inform potential users and interested members of the space community, we provide a brief description of MS-FLUKSS and the current state of the solar wind models developed in its framework, with an emphasis on heliospheric models driven and constrained by remote and in situ observations. We also discuss potential scientific and operational applications of MS-FLUKSS on prediction of space weather throughout interplanetary space.

Kooi, Jason (U.S. Naval Research Laboratory)
Advantages of Multiple Line-of-Sight Measurements of Faraday Rotation through a Coronal Mass Ejection
Co-Author(s): M Ascione, L Reyes-Rosa, S Rier, M Ashas

The orientation of a coronal mass ejection's magnetic field is a key factor in determining its geoeffectiveness. Faraday rotation (FR) measurements are proving to be an effective means for inferring the strength and orientation of coronal mass ejections (CMEs). FR is measured by calculating the rotation of the plane of polarization when linearly polarized light propagates through a magnetized plasma (e.g. a CME). Most modern observations of CME FR have been limited to a single line of sight and, therefore, limited to measuring the strength of the axial magnetic field of the occulting CME, with little or no information concerning the CME's orientation. We report the first triggered Karl G. Jansky Very Large Array (VLA) observations of CME FR using multiple lines of sight (LOS). These VLA observations were made at 1-2 GHz frequencies in the A-array configuration on July 31, 2015. The primary advantage of using multiple LOS is that we not only recover the strength of the axial magnetic field (assuming a force-free flux rope magnetic structure), but also the helicity and orientation. Multiple LOS also provided the data necessary to resolve ambiguities such as whether or not a particular LOS was occulted by one or both legs of the CME. We explored three models for the CME plasma structure: a constant density model and two types of shell model (thin-shell and thick-shell). The constant density and thin-shell models were clearly favored by the observed FR data.

Larrodera, Carlos (University of Alcalá)
Estimation of Extreme Events in the Solar Wind
Co-Author(s): L Nikitina, C Cid

Large space weather events can cause technological problems in modern society. Assessment of extreme space weather events can help to understand and mitigate risks to technology from these hazardous events. The solar wind is the driver of space weather effects on the Earth so it is important to identify extreme variations in solar wind parameters. In this work, extreme value theory is used to characterize extreme variations in the interplanetary magnetic field and speed of protons in the solar wind. This is done by applying an extreme value distribution to the data above a certain threshold for each parameter. Analysis demonstrates that these thresholds are around 900 km/s for the proton speed and around 30 nT for the interplanetary magnetic field. Based on 20 years of solar wind data, estimations of extremes in the interplanetary magnetic field and solar wind proton speed have been made for return periods 44 and 66 years, corresponding to 4 and 6 solar cycles. For 6 solar cycles the extreme values with the 99% confidence interval are 6350 km/s ± 1350 km/s for the proton speed and 105 nT ± 10 nT for the interplanetary magnetic field.

Lavasa, Eleni (Department of Physics, National and Kapodistrian University of Athens, 15784 Athens, Greece)
Predicting the Occurrence of Solar Energetic Particles With Machine Learning Techniques
Co-Author(s): A Papaioannou, A Anastasiadis, IA Daglis, A Aran, D Pacheco, B Sanahuja

We investigate the prediction of the occurrence of Solar Energetic Particles (SEPs) under a high-level Machine Learning (ML) pipeline, based on flare and coronal mass ejections (CME) characteristics. Addressing the problem at hand as an inherently imbalanced binary classification task, an extensive search for solutions is performed across several ML algorithms and wide hyper-parameter spaces. The employed methods are: logistic regression (LR), support vector machine (SVM), neural network (NN) in the fully connected multi-layer perceptron (MLP) implementation, decision tree (DT) and tree ensembles random forest (RF), extremely randomized trees (XT) and extreme gradient boosting (XGB). We present a thorough experimental evaluation that supports RF being the best performing and most robust solution identified for our setting. In particular, utilizing both flare and CME data, RF achieves a Probability of Detection (POD) = 0.76(±0.06), a False Alarm Rate (FAR) = 0.34(±0.10), true skill statistic (TSS) = 0.75(±0.05), and Heidke skill score (HSS) = 0.69(±0.04). CME speed, width and flare soft X-ray (SXR) fluence stand out as the features with the highest discriminatory power in our sample.

LeRoy, Anita (University of Alabama Huntsville / NASA SPoRT)
The MAG4 Flare Forecast Tool and Iterative O2R2O
Co-Author(s): G Fry, C Hain, K Lee, D Falconer

Anticipating solar flares and subsequent particle events and their intensity is a forecast challenge to operational space weather groups like NOAA's Space Weather Prediction Center and NASA Space Radiation Analysis Group. To address this need, a probabilistic forecast model called MAG4 was developed by Dr. David Falconer at the University of Alabama in Huntsville, in collaboration with NASA Marshall Space Flight Center. MAG4 predicts the likelihood of X and M class flares, CMEs, and fast CMEs by Active Region and full disk for the upcoming 24 hour time period using a database of magnetograms and the prior activity from them. In 2018, the NASA Earth Science SPoRT project (Short-term Prediction Research to Transition Center) partnered with SWPC and SRAG to investigate the possibility of using SPoRT's terrestrial weather research to operations paradigm as a framework for R2O in space weather. Those activities were summarized in two assessment reports for SPoRT. A main takeaway from those reports is the iterative nature of O2R2O activities, in which end users provide feedback regarding a product's latency, display, and capabilities, and the research and development team attempts to address those suggestions to help the product provide greater value in the operational environment. Herein, we will describe the SPoRT methodology of O2R2O, using the MAG4 product's evolution at SWPC and SRAG as our example.

Malagoli Thereza, Raphael (Mackenzie Radio Astronomy and Astrophysics Center (CRAAM), School of Engineering, Mackenzie Presbyterian University, São Paulo, Brazil)

Simulations of Nuclear De-Excitation Gamma-Ray Line Spectra from Solar Flares with the Monte Carlo Package FLUKA

Co-Author(s): CG Giménez de Castro, AL MacKinnon; PJA Simões

The modelling of gamma-ray emission spectra observed in solar flares is generally carried out via the best-fit of data using a set of independent templates and functions for the several spectral components produced by the relevant physical processes (bremsstrahlung of electrons and positrons, nuclear de-excitation, neutron capture, positron annihilation and decay of pions). In recent works (Tusnski et al., 2019; MacKinnon et al., 2020), we have demonstrated the potential of the Monte Carlo package FLUKA as an effective tool for the simulation of nuclear processes in the context of solar flares, as well as its capability to implement a self-consistent treatment of the several spectral components in the energy range from 100's keV to 100's MeV. In this work we use FLUKA to calculate nuclear de-excitation gamma-ray line spectra expected from solar flare accelerated ion distributions. We implement a simulation strategy which allows to synthesize photon spectra for primary accelerated ions with arbitrary energy distributions and chemical abundances. We show model spectra obtained from a range of assumed primary accelerated ion distributions which exhibit reliable statistics and energy resolution and are in good agreement with those obtained using the code developed by Murphy et al. (2009).

Munoz-Jaramillo, Andres (Southwest Research Institute)

Cross-Calibration, Super-Resolution, and Uncertainty Estimation of the Conversion of MDI and GONG to HMI Full-Disk Magnetograms Using Deep Learning

Co-Author(s): A Jungbluth, X Gitiaux, P Wright, C Shneider, S Maloney, A Kalaitzis, A Baydin, Y Gal, M Deudon

Over the past 50 years, a variety of instruments have obtained images of the Sun's magnetic field (magnetograms) to study its origin and evolution. While improvements in instrumentation have led to breakthroughs in our understanding of physical phenomena, differences between subsequent instruments such as resolution, noise, and saturation levels all introduce inhomogeneities into long-term data sets. This has proven to be an insurmountable obstacle for research applications that require high-resolution and homogeneous data spanning time frames longer than the lifetime of a single instrument. Here we show that deep-learning-based super-resolution techniques can successfully up-sample and homogenize solar magnetic field images obtained both by space and ground-based instruments. In particular, we show the results of cross-calibrating and super-resolving MDI and GONG magnetograms to the characteristics of HMI. We also discuss the importance of agreeing on a standardized set of training, validation, and test data, as well as metrics that enable the community to benchmark different approaches to collectively and quantitatively identify the best practices. This includes distributing test data within the broad heliophysics community. Finally, we discuss our approach for making an empirical estimation of uncertainty and the importance that uncertainty estimation plays in the credibility and usefulness of deep learning applications in heliophysics.

Napoletano, Gianluca (Università degli studi di Roma "Tor Vergata")
Investigating the DBM Parameters Distributions Through Statistical Methods
Co-Author(s): D Del Moro, G De Gasperis, J Teunissen, AM Tiwari, E Camporeale

Interplanetary Coronal Mass Ejections (ICMEs) are violent phenomena of solar activity,responsible of the major Space Weather effects in the heliosphere.Due to the high risks for our technology, predicting in advance their impact on our planet is the primary goal of any Space Weather forecasting service. Basing on the observation of CMEs initiations at the Sun and in-situ measurements,several forecasting techniques have been developed to combine forecast accuracy and short computational time.The Drag-Based Model is a widely employed model which is based on a simple equation of motion for the ICME, defining its acceleration as $a=-\Gamma(v-w)v-w$, where w is the ambient solar-wind speed and Γ is the so-called drag parameter (Vršnak+2013).Due to its effectiveness in predicting the ICME transit time and impact speed, this model has been investigated and refined by several authors by introducing 'Ensemble approaches' (Dumbovich+2018;Napoletano+2018),allowing to quantify the uncertainty on the forecasting results.In this framework, Probability Distribution Functions (PDFs) account for initial conditions variability and uncertainty on parameters.Particularly,the PDF for the Γ is still poorly defined.Here we employ a list of past ICMEs,and apply a statistical approach to measure the parameters Γ and w.The solution to this inverse problem,with known transit time and arrival speed, allows to obtain more reliable PDFs parameters to be used in future forecasts.

Pankratz, Chris (Laboratory for Atmospheric and Space Physics (LASP) / University of Colorado Boulder)
A New Interactive 3-Dimensional Data Viewer for the Enlil Solar Wind Model
Co-Author(s): G Lucas, J Knuth, D Odstrcil, J Craft, TE Berger

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 visualize the CME expansion out of the plane of the Earth that is designed to give forecasters the full view of the heliosphere. We will discuss our initial progress in deploying and running the Enlil model in a Cloud-based Testbed and will also describe the process of interacting with space weather forecasters in designing a new interactive 3D visualization tool that meets their needs.

Pogorelov, Nikolai (University of Alabama in Huntsville)
SWQU: Improving Space Weather Predictions with Data-Driven Models of the Solar Atmosphere and Inner Heliosphere
Co-Author(s): CN Arge, CD Fry, J Linker, L Upton, B Van Straalen, P Colella, R Caplan, C Downs, TK Kim, MS Yalim

Predicting space weather with quantified uncertainties (SWQU) is a national priority program jointly supported by the NSF and NASA. Funded by this program, we are developing a new, free-access software to support data-driven models of the solar atmosphere and heliosphere suitable for real-time predictions of extreme events at Earth and further in the interplanetary space. (1) A new solar magnetic field flux transport model which will evolve information to the back side of the Sun and its poles and update the model flux with new observations using data assimilation methods. (2) A new potential field solver (POT3D) combined with the output from the WSA model, and with remote coronal and in situ solar wind observations. Both will be validated with the maps from the new flux transport model. (3) A parallel, adaptive mesh refinement solver for the Reynolds-averaged MHD equations describing the solar wind flow in the inner heliosphere in the presence of CMEs. These are accompanied by the description of the turbulence transport. We are building on the Multi-Scale Fluid-Kinetic Simulation Suite developed using the Chombo framework for adaptive solution of differential equations. Our new software will be built on Chombo v.4 and allow us to perform simulations with the fourth order of accuracy in time and space, and use cubed spheres to generate meshes around the Sun for code speedup. Modern computer architectures will be used. We describe the software and new results.

Sadykov, Viacheslav (Georgia State University)
Prediction of Solar Proton Events with Machine Learning: Comparison with Operational Forecasts and “All-Clear” Perspectives
Co-Author(s): A Kosovichev, I Kitiashvili, V Oria, G Nita, E Illarionov, Y Jiang, P O’Keefe, S Fereira

Solar Energetic Particles (SEPs) are among the most dangerous transient effects of solar activity. Representing hazardous radiation, SEPs may adversely affect the health of astronauts in outer space and therefore can endanger current and future space exploration. In this work, we consider the important problem of developing “all-clear” forecasts of Solar Proton Events (SPEs). 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. Second, we construct daily forecasts of Solar Proton Events based on the properties of magnetic fields in Active Regions (ARs), preceding soft X-ray and proton fluxes, and statistics of solar radio bursts. Machine learning (ML) is applied as an artificial neural network of custom architecture designed for whole-Sun input. The predictions of the ML model are compared with the SWPC NOAA operational forecasts of SPEs. Our preliminary results indicate that 1) for AR-based predictions, it is necessary to take into account ARs at the western limb and on the far side of the Sun, 2) characteristics of the preceding proton flux are the most important for prediction, 3) daily median properties of ARs may be excluded from the forecast without significant performance loss, and 4) ML-based forecasts outperform SWPC NOAA forecasts in situations in which failing to predict an SPE event is very undesirable.

Shin, Junho (Kyung Hee University (KOREA))
Comparison of the Off-Axis Imaging Characteristics of Japanese Space Solar Telescopes
Co-Author(s): R Kano, T Sakurai, YH Kim, YJ Moon

Japanese space solar telescopes, the Yohkoh Soft X-ray Telescope (SXT) and the Hinode X-Ray Telescope (XRT) have made contributions to our research on the coronal magnetic field structures. One of the purposes of these instruments is to study the variation of physical quantities of coronal plasma and interpret the mechanism of solar activities. Coronal holes, the regions of low density associated with open magnetic fields, are important because they are known as the sources of fast solar winds. Nevertheless, the mechanism of coronal heating leading to the solar wind acceleration is still unknown. Detailed studies on the physical state of coronal plasma in the polar coronal holes and near the off-limb areas will therefore help us to understand the mechanism of energy transfer processes from the photosphere to the upper coronal region. The Sun is, however, a large astronomical object and thus the targets near the off-limb area are located in the periphery of the full FOV. For this reason, the off-axis artefacts should be calibrated carefully in order for the data to be properly interpreted. In our presentation, the optical characteristics of Hinode/XRT and Yohkoh/SXT, especially the scattered lights and the vignetting effect, will be discussed in detail. The methods of analysis using highly saturated in-flight images to estimate the amount of scattered lights will be introduced. The vignetting effects in the telescopes will also be compared thoroughly.

Shneider, Carl (Dutch National Center for Mathematics and Computer Science (CWI))
Pipeline for Generating Machine-Learning-Ready Data Sets from the SOHO and SDO Missions for Space Weather Readiness
Co-Author(s): A Hu, AK Tiwari, MG Bobra, K Battams, J Teunissen, E Camporeale

We present a flexible framework that allows user-defined input selection criteria and a range of pre-processing steps, for generating ready-to-use machine-learning Solar and Heliospheric Observatory (SOHO) and Solar Dynamics Observatory (SDO) image product data cubes. The framework utilizes SunPy's Federated Internet Data Obtainer (Fido) interface with the Virtual Solar Observatory (VSO) tool as well as the Data Record Management System (DRMS) to interface with the Stanford Joint Science Operations Center (JSOC). Using ML-ready images for forecasting space weather parameters is a potentially valuable resource for the community. We illustrate the use of this data with an application of a deep convolutional neural network (CNN) to the SOHO data set insubset of an effort to provide a 3-5 day-ahead forecast of the north-south component of the of the interplanetary magnetic field (IMF) observed at L1. Baselines for future model comparison are also provided.

Singh, Talwinder (The University of Alabama in Huntsville)
Subjective Uncertainties in 3-D Coronal Mass Ejection Fittings and their Consequences for Space Weather Prediction
Co-Author(s): N Pogorelov, T Kim

Coronal Mass Ejection (CME) direction, tilt and speed play an important role in determining its arrival time and magnetic signature at 1 AU. Graduated Cylindrical Shell (GCS) model is a widely used tool to determine these properties of the CME using multi-viewpoint observations from SOHO and STEREO A\&B coronagraphs. In this study, we estimate the subjective uncertainties typically seen while deriving these CME properties by comparing the GCS model results reported in multiple

studies and catalogs for 56 CMEs. We find that the GCS estimates of latitude, longitude, and tilt show an average uncertainty of 5.7, 11.2, and 24.7 degrees with standard deviation of 5.5, 12.7, and 19.7 degrees respectively. We found that the uncertainties in estimated latitudes are correlated with uncertainties in estimated longitude, tilt, and speed, showing that some CMEs are inherently difficult to fit than others. We then introduced these uncertainty values in our 3-D MHD flux rope based modified spheromak CME model to figure out their consequences for space weather prediction. We find that much better CME observations are required to reliably predict magnetic field of CMEs at 1 AU using flux rope based models, since the uncertainties in the estimated GCS values can result in large differences in 1 AU signatures, especially for CMEs launched away from the Sun-Earth line.

Tenishev, Valeriy (University of Michigan)
Toward Developing Integrated Model for the SEPs, GCRs, and Alfven Wave Turbulence in the Inner Heliosphere
Co-Author(s): I Sokolov

The more advanced human technology becomes, the danger of Solar Energetic Particle (SEP) events greatly increase. Most vulnerable are human exploration missions. Galactic Cosmic Rays (GCRs) are thought to be accelerated in supernova remnants from which they diffuse throughout the galaxy. The flux of GCRs at 1 AU is highly dynamic. Particularly, a decrease in the GCRs flux, commonly referred to as Forbush decrease (FD), may last for about one day until it reaches a minimum, and then it gradually recovers to the pre-FD values within several days. The project presented here is focused on characterizing SEP and GCR populations in the inner heliosphere. The goal of the presented work is to model the energetic particles' dynamics as they move along a time-varying set of magnetic field lines. To achieve that, we have implemented a procedure that couples Solar Corona (SC), Inner Heliosphere (IH), and the Particle Tracker (PT) components of the Space Weather Modeling Framework (SWMF). The Particle Tracker (PT) component uses the Adaptive Mesh Particle Simulator (AMPS) to model particle transport and acceleration. The latter is an advanced Monte Carlo kinetic code previously used in a range of planetary and heliophysics studies. Here we present the preliminary results of modeling SEPs transport obtained using this combination of the model.

Tiwari, Ajay (Centrum Wiskunde and Informatica)
Predicting Arrival Time for CMEs: Machine Learning and Ensemble Methods
Co-Author(s): E Camporeale, J Teunissen, R Foldes, G Napoletano, D Del Moro

Coronal mass ejections (CMEs) are arguably one of the most violent explosions in our solar system. CMEs are also one of the most important drivers for space weather. CMEs can have direct adverse effects on several human activities. Reliable and fast prediction of the CMEs arrival time is crucial to minimize such damage from a CME. We present a new pipeline combining machine learning (ML) with a physical drag-based model of CME propagation to predict the arrival time of the CME. We evaluate both standard ML approaches and a combination of ML + probabilistic drag based model (PDBM, Napoletano et al. 2018) on the database of more than 200 CMEs. We analyzed and compared various machine learning algorithms to identify the best performing algorithm for this database of the CMEs. We also examine the relative importance of various features such as mass, CME propagation speed, and height above the solar limb of the observed CMEs in the prediction of the arrival time. The model is able to accurately predict the arrival times of the CMEs with a mean square error of 8.8 hours. We also explore the differences in prediction from ML models and ensemble predictions method namely P-DBM model. We also present a way to predict the distribution of the parameters of the PDBM model just using the physical properties of the CMEs.

Tiwari, Chandramani (A.P.S. University, India)
Relation between Solar Activity and near the Earths Environment
Co-Author(s): S Kaur, PR Singh

Abstract: The effects of the sun's variability are evident in various physical and chemical processes in the earth's upper atmosphere. The variability interaction of the solar outputs on the earth environment, Kp-Index, AE- Index, and Temperature Index, shows correlation with Sunspot number (SSN) and Total Solar Irradiance (TSI) in solar cycle 24 is more than solar cycle 23. The effect of these parameters on earth's climate is very minimal.

Tsinamdzgvrishvili, Tamar (Abastumani Astrophysical Observatory, Ilia State University, Tbilisi, Georgia)
Regular and Oscillatory motion of Coronal Bright Points
Co-Author(s): B Shergelashvili, B Chargeishvili, I Mghebrishvili, T Mdzinarishvili, D Japaridze

Long-term automatic tracking of coronal bright points has made it possible to study their proper motions using data from the AIA 193 Å channel of SDO/AIA. Fits files for 95 visually long-lived bright points uniformly distributed in latitude have been chosen for processing. A specially developed program automatically fixes the heliographic coordinates of the centroid of the chosen coronal bright points in a series of Fits files. It was found that the proper motions of all the coronal bright points studied here have a distinct oscillatory character. The periods of the oscillations range from 5 to 60 h with an average of 20 h. Some tendencies in the latitudinal dependence of the oscillatory characteristics have been found. A possible explanation of these oscillations in terms of the propagation of helical waves along the magnetic loops that form the structure of the coronal bright points is pointed out. Linear trends in the latitudinal and longitudinal components of the motion of the coronal points are used to determine the rotational velocity and meridional migration of the coronal bright points. An analysis of the rotational velocities confirms the differential character of the latitudinal dependence. The problem of determining the direction and magnitude of the meridional migration is discussed.

Venkataramanasastry, Aparna (Georgia State University)
Coronal Sigmoids & Chromospheri Filaments
Co-Author(s): M Georgoulis, PC Martens

Sigmoids are forward (S-shaped) or inverse (Z-shaped) features on the Sun that are seen at coronal heights in X-ray or high temperature extreme ultraviolet (EUV) wavelengths. The sharpest and brightest of them are highly eruptive. They usually deform or disappear via coronal mass ejections. This makes it important to understand X-ray sigmoids because of their relevance for space-weather forecasting purposes. Chromospheric filaments are generally observed as absorption features in H-alpha wavelengths. In this work, we observe chromospheric filaments underlying the sigmoids to correlate the helicities of the two features. We also compare the helicities obtained using photospheric vector magentograms to that found in the chromosphere and the corona. We have conducted a joint survey of the sigmoids and the underlying filaments between 2007 and 2017. The results of the comparison between the signs of helcities obtained from photospheric calculations, chromosphere and the corona are presented. The cases that have the same signs for all three features are similar in number to that do not. An attempt is made to explain this curious result.

West, Matthew (Southwest Research Institute)
The Influence of the Middle Corona on Space Weather Events
Co-Author(s): D Seaton, N Alzate, C Downs, A Higginson, J Mason, L Rachmeler, K Reeves, S Savage, N Viall, D Wexler

The Middle Corona is a region of the solar atmosphere, under-observed but highly influential in shaping space weather events, between roughly 1.5 and 6 solar-radii. New EUV evidence and WL observational strategies are changing this paradigm. Observations of this region are important for space weather forecasts because the region determines the connection between the sun and heliosphere, influencing the structure of outflow into the solar wind, and governing the physical processes that control the early evolution of Coronal Mass Ejections (CMEs) and the formation of shocks. Historically, this region has been difficult to observe because it is difficult to detect scattered light close to the sun with white-light (WL) observations, while extreme ultraviolet (EUV) emission in this region was believed to be too weak to observe. Here we present an overview of the Middle Corona and its importance for space weather forecasts. We review current and proposed instruments and observations that will help close the gap in our understanding of this region, and clarify its role in determining space weather. This includes PROBA2/SWAP, GOES/SUVI, STEREO/COR1 and EUVI, the upcoming PUNCH mission, a variety of radio observations and proposed instrument concepts such as LUCI, COSIE, SunCET, and the ground-based COSMO coronagraph.

Yalim, Mehmet (The University of Alabama in Huntsville)
Overview of a Data-driven MHD Simulation Model for CME Generation and Propagation
Co-Author(s): A Prasad, N Pogorelov, Q Hu, G Zank, Y Liu

Coronal mass ejections (CMEs) are major drivers of extreme space weather conditions, hence a matter of serious concern for our modern, technologically dependent society. The development of models that simulate CME generation and propagation through the interplanetary space is an important step toward our capability to predict CME arrival times at Earth and their geoeffectiveness. CME generation models of varying complexity and accuracy have been developed for decades from over-pressured plasmoid models to flux rope-based models with or without the necessity of energy build-up before eruption. In almost all cases, they have model parameters that need adjustment from one event to another. In this work, we present an overview of a data-driven MHD simulation model for CMEs extending from the lower chromosphere to 1 AU which is recently developed. It is entirely based on first principles with minimum setup effort and free model parameters. It consists of local and global simulation models that are to be coupled. Our local model driven by vector magnetograms on the photosphere will track the evolution of active regions that will yield the formation of flux ropes near polarity inversion lines and eventually their eruptions resulting from ideal and non-ideal instabilities. The propagation of the erupted CME will then be followed to 1 AU through the global corona and inner heliosphere allowing the results to be validated with near-Earth spacecraft data.

Wednesday April 21 Poster Session: Ionosphere and Thermosphere Research and Applications and General Space Weather Services

Azeem, Irfan (ASTRA LLC)
Taking Ionospheric Measurements to the Oceans
Co-Author(s): G Crowley, A Reynolds, J Hughes, E Stromberg

Our ability to monitor the geospace environment from open and coastal ocean waters is a technological challenge. This is a problem because the oceans cover about 70% of the Earth's surface. This leaves a large swath of the Earth's surface inaccessible for persistent ionospheric measurements and without ocean-based measurements, the global synoptic measurements of the space physics systems will remain incomplete. ASTRA has developed a science-grade GPS receiver capable of providing ionospheric Total Electron Content (TEC) and scintillation measurements from mobile and moored buoys. Since September 2018, ASTRA has operated two of its GPS receivers on the NOAA Tropical Atmosphere Ocean (TAO) buoys located at 5.03° N, 169.98° W and 1.97° N, 153.70° W. In this study, we present initial results of TEC from these systems in the Pacific Ocean. We also show a design of an All-Sky Imaging (ASI) system, called Ocean Stabilized Ionospheric Remote Imaging Sensor (OSIRIS), for ionospheric remote sensing from ocean buoys. This new class of sensors that are capable of operation from the ocean surface will enable new and innovative scientific measurements of the ionosphere. Taking ionospheric measurement to the open water will address the gap in our current observational capability and contribute uniquely to the heliophysics community's effort of characterizing global ionospheric variability and its response to solar and terrestrial inputs.

Bernstein, Valerie (University of Colorado Boulder)
Interactive Tool To Visualize Space Weather Scenarios
Co-Author(s): K Wahl, D Knipp

Space weather forecasters, satellite operators, trainees and students could all benefit from an interactive tool designed to map out space weather storms and impacts. We have developed a Space Weather Scenario Toolkit, a web-based resource for users to map out sequences of space weather

events. The toolkit draws connections between space weather storms and the different engineering problems they can cause. The educational and practical tool distinguishes between physical drivers of space weather, intermediate observations and signals, and human/technology impacts. Thus far, one major space weather active period has been reviewed to populate the majority of the events and impacts included in the interactive tool: the storms of December, 2006. The tool is designed using D3 JavaScript as an interactive tree map, which users can click through to trace different space weather sequences of events from space weather activity origins to potential communication, hardware, and human impacts. Characteristics of the events, like duration and intensity, are included as well as general information about the likelihood of the possible effects produced. Prior and ongoing conversations with space weather forecasters from the United Kingdom have deeply informed the direction of the toolkit development based on the practical needs of forecasters. As such, this work contributes to space weather research-to-operations, visualization, and educational goals.

Butler, Elizabeth (University of Colorado Boulder)
R2O2R Improvements Identified by US Space Weather Forecasters
Co-Author(s): J Keller

A communication deficit exists between the space weather forecast and research communities in the research-to-operations-to-research (R2O2R) pipeline, leading to a transition process that can take decades to make research operational. To begin explicitly filling this gap, we formally surveyed a group of US space weather forecasters on their needs or wishes for improvement, via a combination of questionnaire and focus group discussions. Nineteen needed improvements were identified, clustering into four categories: Scientific Understanding (5 items), Access to Data (4 items), Forecast Office Tools (6 items), and Instrumentation (4 items). The participants had difficulty determining a priority ranking for these improvements, as they felt strongly that “they’re all things we need [and] what it boils down to is at this point, we’ll take whatever we can get.” We also took the opportunity to investigate the frequency and manner forecasters are being included in the forecast tool development process. Uniformly, participants want to be included in tool development more often and earlier in the process as they felt they were “seldom listened to when it comes to what [they] actually need.”

Chakraborty, Shibaji (Virginia Tech)
A Framework for Estimating Ionospheric HF Absorption in Response to a Solar Flare
Co-Author(s): JM Ruohoniemi, RAD Fiori, JBH Baker, KA Zawdie

The first space weather impact of a solar flare is radio blackout across the dayside of the Earth. The operation of HF systems is often completely suppressed due to anomalous HF absorption. Our current monitoring capability is based on modeling the ionospheric impacts based on observations of solar fluxes. We present a technique to characterize and model the radio blackout following solar flares using HF radar and the first principal-based model framework, respectively. The new framework first uses irradiance models incorporating high-resolution solar flux data from the GOES satellite X-ray sensors to compute the enhanced ionization produced during a flare event. Then it uses dispersion relation and collision frequency formulations to estimate the enhanced HF absorption. The modeled HF absorption is then validated with riometer observation. The future extension of this work is to develop an early warning system to identify, monitor, and forecast radio blackouts using HF radars currently deployed for space research. Networks of such radars operate continuously in both hemispheres. Recent studies have shown that radio blackout (also known as shortwave fadeout) is easily detected and characterized using radar observations. We will combine realtime observations from the North American suite of SuperDARN radars to specify the occurrence of radio blackouts. In this study, however, we present investigation, recognition, and modeling techniques of shortwave fadeouts in HF instrument.

Cilliers, Pierre (South African National Space Agency)
Estimation of ROTI Thresholds for Ionospheric Scintillation Over the African Sector
Co-Author(s): T Matamba

The Rate of Change of TEC Index (ROTI) is one of the ionospheric scintillation indices required by the International Civil Aviation Organization (ICAO) to be included in air navigation advisories on space weather conditions that may indicate the degradation of GNSS-based navigation and surveillance. The ROTI index can be derived from data from the GNSS receivers of the International GNSS Service (IGS) of which there are more than 40 deployed in Africa and the Trignet network of more than 60 receivers in South Africa. Due to the paucity of other instruments for measuring ionospheric scintillation in Africa, the ROTI may serve as a useful proxy for ionospheric scintillation. ROTI thresholds are derived to match the ICAO thresholds for "Low", "Moderate" and "Severe" levels of ionospheric scintillation, by comparison with the amplitude scintillation index S4, for which ICAO established the following thresholds S4<0.5 (low), 0.5<S4<0.8 (moderate) and S4>0.8 (severe). The relevance of the thresholds is evaluated by comparison with the associated range of position errors in dedicated scintillation receivers and IGS dual-frequency GPS receivers.

Craft, James (University of Colorado, Laboratory for Atmospheric and Space Physics)
SWx TREC Model Staging Platform: Facilitating Model/Algorithm R2O and O2R Development within a Cloud Computing Environment
Co-Author(s): G Lucas, CK Pankratz, E Sutton, T Berger

The Space Weather Technology, Research and Education Center (SWx TREC) is an emerging national center of excellence in cross-disciplinary research, technology, innovation, and education, intended to facilitate evolving space weather research and forecasting needs. Within this center, we are developing a Space Weather Model Staging Platform (MSP) to facilitate the R2O and O2R pipelines. The MSP leverages cloud computing to provide a managed computational environment for independent science teams to deploy their processing software into an operational-like system. Using cloud computing for the environment enables traditional defined-cadence (daily, hourly) model runs to be scheduled while also providing the ability to submit on-demand runs during storm times with no additional bulk hardware purchases that would otherwise sit idle most of the time. In this poster, we demonstrate the ways that the MSP is being utilized. First, in the R2O pipeline, we have implemented code from the USGS to produce electric field maps at a set cadence to demonstrate that the code can be run in an operational mode. Second, in the O2R pipeline, we are

taking an operational code, the NOAA Whole Atmosphere Model (WAM), and enabling researchers to investigate new data assimilation techniques that can supplement and enhance current operational code capabilities. Finally, we demonstrate the use of cloud resources to generate automatic flare forecasts from satellite images.

Debczak, Charles (United States Military Academy)
Initial Results From the Poker Flat Incoherent Scatter Radar Global Positioning System Five-Beam Mode
Co-Author(s): D Loucks

The Poker Flat Incoherent Scatter Radar (PFISR) collects data on ionospheric parameters in Earth's ionosphere including electron density. This data can give insights into scintillation effects observed on trans-ionospheric Global Positioning System (GPS) signals. Initial results from geomagnetic storms occurring on 26 August 2018, 10 November 2018, 28 February 2019, and 20 April 2020 will be presented to show the viability of the GPS five-beam PFISR mode for ionospheric conditions analyses as they pertain to GPS scintillation studies. Electron density data are interpolated spatially and temporally during periods of known GPS scintillation. Future analyses will evaluate electron density data sets in conjunction with GPS scintillation, all sky imagery, local magnetometer, and other available data sets to visualize and interpret ionospheric conditions leading to E-region sourced GPS scintillation.

Elias, Ana G. (Laboratorio de Ionosfera, Atmosfera Neutra y Magnetosfera, LIANM, FACET-UNT & INFINOA (CONICET-UNT))
Ionospheric Long-Term Trends and Its Relevance to Space Weather
Co-Author(s): BS Zossi, M Fagre, Z Saavedra, FD Medina, MG Molina

The Earth's ionosphere presents long-term trends that have been of interest since a pioneering study in 1989 suggesting that long-term increase of greenhouse gases concentration would produce a global cooling in the upper atmosphere in addition to the global warming in the troposphere. Since then, investigation of long-term changes in the upper atmosphere and ionosphere has become a significant topic in global change research. Even though anthropogenic forcing seems to be the main trend driver, there are other ionospheric long-term change forcings. Among them is the secular variation of Earth's magnetic field, which affects not only the electron density, but currents flowing in the ionosphere and magnetosphere, ionospheric conductivity, and radio wave propagation as well. The ionosphere, as a part of the space weather environment, plays a crucial role through the modulation of the global electrodynamic circuit, its coupling to the magnetosphere and as a key medium for communication, sounding and navigation. Certainly it could be said that space weather cannot be fully understood without reference to the ionosphere. Thus, a thorough understanding of its variability in all time scales becomes crucial. In this work, ionospheric trends are analyzed linked to their relevance for space weather. These trends, although weak, are steady and may become significant in the future and of importance for long-term space weather forecasts.

Fiori, Robyn (Natural Resources Canada (NRCan))
Canadian Aviation Services Related to High Frequency Radio wave Communication
Co-Author(s): D Boteler, L Trichtchenko, L Nikitina, L Nikolic

The Canadian Space Weather Forecast Center (CSWFC), operated by Natural Resources Canada, is a member of the Australia-Canada-France-Japan consortium providing global space weather services for the International Civil Aviation Organization. Canada is ideally located for observing the ionospheric impact of space weather having infrastructure, including a geomagnetic observatory, riometer, and high frequency transmitter network, distributed over a wide geographic area spanning polar cap, auroral, and sub-auroral latitudes. The CSWFC is therefore in a unique position to monitor and model a wide range of phenomena impacting high frequency radio wave communication (HF COM), and to use this information to provide ionospheric services. This poster presents Canada's monitoring and alerting services for space weather impacts to HF COM relied on by aviation.

González, Gilda (Universidad Nacional de Tucumán)
Spread-F Occurrence During Geomagnetic Storms Near the Southern Crest of the EIA in Argentina

We present the analysis of the occurrence of ionospheric irregularities during geomagnetic storms at Tucuman, Argentina (26.9°S, 294.6°E; magnetic latitude 15.5°S) near the southern anomaly crest in South America. Three geomagnetic storms occurred on May 27, 2017 (a month of low occurrence rates of spread-F), October 12, 2016 (a month of transition from low to high occurrence rates of spread-F) and November 7, 2017 (a month of high occurrence rates of spread-F) are analyzed using Global Positioning System (GPS) receivers and ionosondes. The rate of change of total electron content (TEC) Index (ROTI), GPS Ionospheric L-band scintillation, the virtual height of the F-layer bottom side (h'F) and the critical frequency of the F2 layer (foF2) are considered. Each ionogram is manually examined for the presence of spread-F. We observed that, for the events studied, geomagnetic activity creates favorable conditions for the initiation of ionospheric irregularities, manifested by ionogram spread-F and TEC fluctuation. Postmidnight irregularities may have occurred due to the presence of eastward disturbance dynamo electric fields (DDEF). For the May storm, an eastward over-shielding prompt penetration electric field (PPEF) is also acting. A possibility is that the PPEF is added to the DDEF and produces the uplifting of the F region that helps trigger the irregularities. During October and November, strong GPS L band scintillation is detected associated with strong range spread F (SSF).

Goodwin, Lindsay (New Jersey Institute of Technology; University Corporation for Atmospheric Research)
Resolving High-Latitude Ionospheric Plasma Density Structures With Novel Geospace Sensor Techniques
Co-Author(s): G Perry

Earth's high-latitude ionosphere is filled with plasma density structures that are generated and altered through a variety of mechanisms. These structures have properties different from their surroundings and can impact radio wave propagation (disrupting vital communication). Although these structures are a critically important space weather effect, their dominant drivers, characteristics, formation mechanism(s), and scale-sizes, remain unclear. Additionally, studies that directly relate changes on the sun with changes in the high-latitude ionosphere are lacking. Advanced Modular Incoherent Scatter Radars (AMISRs) provide the opportunity to collect volumetric measurements of the high-latitude ionosphere beset with plasma irregularities. By leveraging phased array ISR technology and using the facts that F-region cross-field plasma diffusion is slow at scales greater than 10 km, and geomagnetic field lines are nearly vertical at high-latitudes, we have developed a novel technique for resolving high-latitude ionospheric irregularity spectra at a high spatial-temporal resolution using AMISRs. From the resulting spectra, we can quantify the abundance and scale-sizes of plasma structures in the high-latitude ionosphere, and examine their connections to geomagnetic drivers. This presentation will motivate the newly developed technique, give preliminary results that connect high-latitude ionospheric plasma density structuring to solar parameters, and discuss future directions.

Harris, Ezra (United States Military Academy, Department of Physics and Nuclear Engineering)
Exploring the Validity of the KHI-GDI Two Step Mechanism For Instability Propagation in the Ionosphere
Co-Author(s): J Tyrrell, M Tran, N Scribner, F Czerniakowski, J Brady

Enhancements in plasma densities can cause Gradient Drift Instability (GDI) indicated by the phase scintillation of GPS signals in the polar cap region. Phase scintillation is the largest contributor to data loss during radio wave transmission, so we hope to explore novel causes of GDI to gain a better understanding of why it occurs. Previous research has suggested a new, two-step mechanism for the propagation of GDI during flow channel events. This theory states that Kelvin Helmholtz instability (KHI) occurring in flow channel events creates a plasma enhancement that causes GDI. This plasma enhancement is created by two fluids moving across their interface at differing velocities. When there is a disturbance at the interface, KHI grows uncontrollably due to the Bernoulli effect. For this paper we will analyze flow channel events occurring in the E-region of the ionosphere, namely Flux Transfer Events (FTE) due to magnetic reconnection events and coronal mass ejections. We will use data from the Madrigal database to correlate these flow channel events with phase scintillation indices in order to draw a connection between GDI and KHI.

Knuth, Jenny SWx TREC, CU Boulder, LASP)
SWx TREC's Space Weather Data Portal: A Tool for Accessing Diverse Space Weather Data
Co-Author(s): G Lucas, C Pankratz, T Berger, the LASP Web Team

The Space Weather Data Portal (Data Portal) provides an easy way to access, organize, and visualize data relevant to space weather (SWx) events. SWx data is diverse by nature and housed in disparate repositories, each with its own organizational system. Accessing this diverse data typically is laborious and comes with a steep learning curve. To address this challenge, CU Boulder's Space Weather Technology, Research, and Education Center (SWx TREC)and LASP have developed a new

Space Weather Data Portal (https://lasp.colorado.edu/space-weather-portal). The Data Portal makes it easy to display and correlate a variety of SWx data all in one place. The website aims to reduce the effort spent accessing data in order to facilitate SWx research and education. After the user selects a time range or event of interest on a timeline, the event's entire life cycle, from the moment it occurs on the Sun to its impact at the Earth, can be explored. SDO AIA imagery can be plotted alongside NOAA's GOES X-ray flux and ACE solar wind or the USGS's ground-based magnetometer data. With practically no learning curve, the Data Portal does the work of accessing the data while the user can freely explore a SWx event all on one screen. This poster intends to introduce the Space Weather Data Portal, highlight the ways it can be used to speed SWx research, education, and communication, and solicit feedback from the SWx community to expand the datasets and features available in the tool.

Lanabere, Vanina Universidad de Buenos Aires (FCEyN-DCAO-LAMP))
An Operative Space Weather Service in Argentina
Co-Author(s): N Santos, B Dorsch, A Niemelä-Celeda, C Gutiérrez, A Gulisano, V López, S Dasso

Since 2016, the Argentine space weather laboratory (in Spanish Laboratorio Argentino de Meteorología del esPacio, LAMP) started to carry out daily monitoring of real-time information (space and ground-based instruments) on space weather conditions. LAMP also set up a Space Weather Laboratory in the Antarctic peninsula, in the Argentine Marambio base, where a Water Cherenkov radiation Detector was installed during the Argentinean Antarctic campaign (January-March of 2019). Furthermore, since January 2020 LAMP is the Argentine regional warning center of the International Space Environment Service (ISES). In this work we present the latest operative space weather products developed by LAMP that are offered publicly at spaceweather.at.fcen.uba.ar.

Ledvina, Vincent (New Mexico Consortium, Aurorasaurus, Los Alamos, NM, United States, University of North Dakota, Grand Forks, United States)
The North Dakota Dual Aurora Camera (NoDDAC), a Student-Led Citizen Science Project: Presentation of First-Light Images, Future Developments, and Scientific Potential
Co-Author(s): E Macdonald, M McCormack, S Collins, W Barkhouse, T Young

The North Dakota Dual Aurora Camera (NoDDAC) is a unique student initiative based at a university observatory, focusing on dual cameras with COTS equipment and low resource computing, emphasizing open data, a responsive community resource, and citizen science. NoDDAC uses the Sony a7s ii camera and Sony 24mm f/1.4GM lens as a north-facing aurora video camera. A less expensive all-sky camera uses a Canon T6 paired with a Sigma 4.5mm f/2.8 circular fisheye lens continuously capturing 60-second images every two minutes. The cameras are stationed at UND's Martens Observatory (48.1N). The LiveAuroraNetwork hosts the image streams from both cameras on their website and mobile app, controlling the cameras with IPTimelapse software. When aurora is detected by IPTimelapse, the NoDDAC twitter account will post a short clip of the display to alert aurora chasers. These cameras will be shown on the Aurorasaurus auroral oval map along with other citizen scientist observations. Image data are archived and made open source, abiding by the FAIR data use principles. NoDDAC serves as a vital resource for aurora chasers and enables a growing technology-driven movement of aurora citizen science. In 2021 alone, the cameras have detected aurora over 20 times, including overhead aurora and STEVE. This presentation will present first-light images, outline a timeline for NoDDAC and its capability to answer science questions, and explore collaborations with other citizen science efforts.

Lucas, Greg (Laboratory for Atmospheric and Space Physics)
Pushing the Frontiers of Geoelectric Hazard Modeling
Co-Author(s): A Kelbert, EJ Rigler, W Carande

In this new NASA-funded O2R project, we focus on improving the spatial resolution of geoelectric field maps by upgrading the solid Earth conductivity models and the respective magnetotelluric (MT) impedances. The joint NOAA-USGS operational geoelectric field map product was released by the Space Weather Prediction Center to the public in September 2019, and this was upgraded to use 3D-MT impedance tensors in September 2020. These products combine geospatially sparse time-varying geomagnetic vector field observations - interpolated to a uniform grid by inverting for a Spherical Elementary Current System (SECS) - with MT impedances, to generate a regular grid of geoelectric vector fields at Earth's surface. Specifically, we leverage MT data obtained through the NSF EarthScope project and subsequent acquisition elements sponsored by NASA and the USGS. We use an existing physics-based MT inversion code (ModEM) to create an electrical conductivity model for the entire contiguous United States, from which we derive surface impedance at a 0.1-degree spatial resolution. Real-time magnetic field data interpolated to the same 0.1-degree resolution still needs to be validated. Here, we present preliminary impedance maps, and, additionally, we demonstrate a new method to handle real-time magnetic field observatory data dropouts based on an exponentially weighted temporal filter to reduce anomalous "jumps" in the spatial magnetic field interpolations.

Matamba Tshimangadzo, Merline (South African National Space Agency (SANSA))
The Ionospheric Response Due to High Intensity Long Duration Continuous AE Activities (HILDCAA)
Co-Author(s): JB Habarulema

The ionospheric responses to High-Intensity Long Duration Continuous Auroral Electrojet Activity (HILDCAA) event that occurred following the Corotating Interaction Region (CIR)-driven storm were studied over the African mid-latitude region. The HILDCAA events are ionospheric or magnetospheric events that occur during High-Speed Solar Wind Streams (HSSWS) and mainly occur during the declining phase of solar activity. They also happen following the Interplanetary Coronal Mass Ejections (ICME)-driven storms but for shorter periods. The 10-17 April 2005 event was analyzed to understand some of the mechanisms responsible for the ionospheric changes during the HILDCAA event. The ionosonde critical frequency of the F2 layer (foF2) and Global Navigation Satellite System (GNSS) Total Electron Content (TEC) were used to analyze the ionospheric responses. The ionospheric responses and some physical processes will be discussed.

Roarick, Riley (United States Military Academy)
Space Radiation Effects on Commercial Microprocessors
Co-Author(s): J Gittemeier, A Roberts, F La Torre

Low earth orbits above 900 km experience a large increase in the radiation environment due to the first Van Allen Radiation Belt. This research attempts to address the viability of commercial-off the-shelf electronics in this region. During recent testing, it was determined that for the Raspberry Pi 3 Model B (RPi), there was a near simultaneous failure of six RPis tested during a total ionizing dose (TID) test after 400 greys of exposure to a Cobalt-60 radiation source. The first component that failed was the USB interface. 7.0mm of aluminum shielding will be placed over the USB component as well as on the back side of the RPi and a TID test will be conducted. The results of the TID test will be compared to the previous study to see if the slight modification can allow for the RPi to function in LEO.

Rodriguez, Juan (Ball Aerospace)
Auroral Imager on a Tundra Satellite for Space Weather
Co-Author(s): P Oakley, J Hardaway, E Mrkvicka, D Gallagher, R Warden, S Mitchell, R Schindhelm, A Harwit, J Lumpe, S Evans, H Knight

Auroral imagery provides situational awareness for users of technologies affected by auroral phenomena, including power grids, satellites, and aviation. Real-time imagery can be used to identify regions in which the risks of spacecraft charging, radio frequency scintillation, and geomagnetically-induced currents are elevated. The Space Platform Requirements Working Group (SPRWG) Report for the NOAA Satellite Observing Systems Architecture (NSOSA) study identified Auroral Imaging from a highly elliptical orbit (HEO) as fifth priority for improvement out of 19 Space Weather objectives. HEO has long been recognized and used as a vantage point for global auroral imaging, including the NASA Dynamics Explorer-1, Polar, and IMAGE missions. We report on a concept for a far-ultraviolet auroral imager in a Tundra orbit that images the auroral oval simultaneously in three spectral bands. We address the demanding requirements of such an observation, including rapid refresh rate, large dynamic range, and stringent out-of-band rejection. We present orbital and auroral radiance scene simulations, instrument modeling results, and data product retrievals through which the quality of the auroral data products is predicted. This work has been funded in part by the National Oceanic and Atmospheric Administration under contract 1332KP20CNEEO0079 to Ball Aerospace. This presentation does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

Sapundjiev, Danislav (Royal Meteorological Institute of Belgium)
Space Weather Event Signatures From Ionosonde Observations
Co-Author(s): SM Stankov

Ground based ionosondes provide detailed information about the bottom side structure of the ionosphere. Besides the standard ionospheric characteristics, a number of other measurements like ionospheric tilt, drift velocities, and sky maps are derived. These characteristics measured at different time instances give insight into the dynamic processes taking place in the ionosphere. A space weather event can additionally increase the gradients in the observed data. The large number of measured parameters provides the possibility to identify complex ionospheric traits and distinguish between the characteristics of the incentive conditions. In this work, modern ionosonde measurements are analyzed during several space weather events. The latter have been selected from different event classes (radio, geomagnetic and solar radiation) in order to create a set of space weather event fingerprints(SWEF) based on the entire set of measured ionospheric parameters. The results from the analysis are then applied to create a unique SWEF database for the different space weather events and classify them accordingly. The real-time measurements are then mapped to the existing SWEF database. The occurrence of an event can be identified by its fingerprint which in turn can be used for space weather conditions nowcast and to forecast the event development based on the historic data.

Sutton, Eric (University of Colorado / SWx TREC)
Ionosphere-Thermosphere Data Assimilation with WAM-IPE
Co-Author(s): G Lucas, M Pilinski, J Thayer, T Fang, A Kubaryk, T Berger

Providing accurate knowledge of the state of the ionosphere-thermosphere system is a key function of NOAA/SWPC. This information is used by customers such as the International Civil Aviation Organization (ICAO) to specify and forecast impacts to navigation and communication services. In the past few years, data assimilative methods have matured to the point of estimating corrections to the external drivers in a self-consistent manner with physical, coupled models of the upper atmosphere and ionosphere. Our project seeks to bring the recent modeling, data-assimilative, and observational advances to bear on operational Space Weather products by developing a physical, data-assimilative framework to specify the global ionosphere-thermosphere system. This talk will provide an update on these efforts, including the challenges encountered thus far and the path ahead.

Thiemann, Edward (Laboratory for Atmospheric and Space Physics, University of Colorado Boulder)
Measurements of Thermospheric Density and Temperature from SUVI Solar Occultations
Co-Author(s): R Sewell, D Seaton, C Peck, E Sutton, M Pilinski

Direct observations of the thermospheric state can provide direct indicators of space weather activity for constraining models of the thermosphere-ionosphere system. However, no such measurements are currently made in real-time for use in space weather operations, and few have been historically collected for research purposes. In this study, we present first results from a NASA Operations to Research project to develop unprecedented operational measurements of the thermospheric state using the Solar UltraViolet Imager (SUVI) onboard the GOES-R series constellation. SUVI images the Sun at extreme ultraviolet (EUV) wavelengths with a primary objective to characterize and track the Sun’s morphology as it relates to the source of geoeffective space weather. Since EUV radiation is strongly absorbed in the thermosphere, it can be used to probe the thermosphere via solar occultations. The wavelengths measured by SUVI provide sufficient constraints to distinguish the three major species of the thermosphere: N_2, O_2 and O. We focus observations made on 15 September 2019 near 18:00 local time over northern mid-latitudes in order to present algorithms for retrieving number density (both total and composition resolved), exospheric temperature and altitude resolved temperature. Results are shown to illustrate how EUV images are converted to solar occultation light curves, and how density and temperature are derived from these light curves.

Voss, Hank (NearSpace Launch (NSL))
Space-Weather CubeSat Array for Prompt Global Coverage Experiment (SWAP-E)
Co-Author(s): WK Tobiska

Merit: SWAP-E addresses NASA R2O/O2R Strategic Action Plan for S5.06 SBIR area: Space Weather Instrumentation. A Space Weather (SW) array of 4 dual CubeSats released from a standard 6U deployer are linked through the Globalstar constellation to provide near real-time ionospheric forecasting for 1000's of satellites. Each CubeSat provides low-latency connections via space-space links in a redundant, time-ordered, and common database (O2R) for prompt 24/7 data with a delay of seconds.   The SBIR Phase 1-2 effort provides a new satellite platform to improve sensors in space with compact innovative instrumentation designed to validate SW models: energetic particle suite, plasma probes, sensors, and GPS. Each CubeSat string includes foldouts that separate the relatively noisy ThinSat Bus section from the quiet and cooled ThinSat Payload section to improve sensor performance. The SWAP-E 6U array of 4 CubeSats give pole-to-pole orbit data every 12 minutes in the underexplored SW region 100 to 400 km. Prompt and multipoint SW sensors improve rapid forecasting and understanding new energy transfer with the goal to deliver end-user action.
Feasibility: Currently most of the SWAP-E Bus subsystems and sensors are manifested on two SpaceX rideshare flights in 2021 for SWAP-E risk reduction and radiation testing. NSL has flown 450 commercial subsystems in orbit with 100% success. The SWAP-E Prototype will be completed through TRL =5- 7 for orbit demonstration in 2022.

Thursday April 22 Poster Session: Geospace/Magnetosphere and Aviation Radiation Research and Applications

Albert, Dennis (Institute of Electrical Power System, Graz University of Technology)
Geomagnetically Induced Currents and Space Weather Prediction in Austria
Co-Author(s): P Schachinger, R Bailey

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 7 self developed measurement systems running in parallel in different transformer stations in Austria. In order to investigate the transformer behaviour under GIC bias transformer laboratory tests and simulation models were set up. The developed network 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 simulations 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. Initial results show good forecasting abilities, and the model is currently being optimised for real-time use.

Axelrod, Artem (Mission Space)
The Feasibility Study of a New Short-Term Warning System for Approaching CME's
Co-Author(s): V Petrov

Solar activity is a threat we have to be ready to deal with. Moreover, the dependence of the modern civilization on electricity and new technologies makes this threat even more evident and dangerous. We propose a new and advanced near real-time hazard warning system for solar coronal mass ejections (CMEs) approaching the Earth, based on the constant monitoring and correlational analysis of the cosmic rays fluxes in midday and midnight areas of the Earth magnetosphere. There is a wide-known Forbush-effect - an occasional decrease in the intensity of cosmic rays as observed on Earth, attributed to magnetic effects produced by solar flares, which are disturbances on the Sun, with CME causing geomagnetic storms several days after. The partial scattering of cosmic rays particles by magnetic field perturbations during CME have a direct impact on the Earth's magnetosphere. The study of this effect is generally done after the occurrence, but what if we can see or predict the effect before it even happens? Mission Space equips its constellations of nano, pico, and femto sats with advanced space weather monitoring detectors that can provide a live data of solar and galactic cosmic rays (SCR and GCR) fluxes from low near-Earth orbit, measured in an exact field of view, giving us an opportunity to measure an anisotropy value from to-the-Sun and from-the-Sun directions. This anisotropy should highlight the shadow of approaching CME, though the reaction time will be rather short.

Benton, Eric (Radiation Physics Laboratory, Oklahoma State University)
Atmospheric Ionizing Radiation Tissue Equivalent Dosimeter (AirTED)
Co-Author(s): T Lee, B Hayes, B Gersey

The Atmospheric Ionizing Radiation Tissue Equivalent Dosimeter (AirTED) is a compact tissue equivalent proportional counter (TEPC) adapted from the Active Tissue Equivalent Dosimeter (ATED) instrument designed by the Oklahoma State University Radiation Physics Laboratory (OSU RPL). A unique capability of TEPCs, in addition to measuring absorbed dose in tissue, it is capable of estimating the average quality factor (Q) of the complex, mixed and changing radiation field in the space environment and therefore may be used to determine the radiation protection quantity dose equivalent. ATED was originally designed to provide space radiation dosimetry aboard manned and unmanned spacecraft, and was first flown in space during a mission aboard the International Space Station (ISS) in 2018. AirTED is a smaller version of ATED specifically designed for use aboard

aircraft, UAVs, high altitude balloons and sub-orbital rockets, and which makes use of a new spherical ionization cavity designed to minimize the influence of microphonic noise on the measured lineal energy spectra. Low cost and the use of COTS parts has been prioritized in the design of AirTED in order to ensure that the instrument can be made in relatively large numbers to enable deployment on multiple airborne platforms. The prototype of AirTED has been calibrated using the Los Alamos Neutron Science Center's 30L spallation neutron source that simulates the secondary neutron energy spectrum encountered at aviation altitudes.

Benton, Eric (Radiation Physics Laboratory, Oklahoma State University)
Atmospheric Ionizing Radiation Environment Code (AIREC)
Co-Author(s): P Inman, K Copeland, B Gersey

As part of our laboratory's ongoing effort to better understand the steady state atmospheric ionizing radiation environment and its effects, we are developing the Atmospheric Ionizing Radiation Environment Code (AIREC), a compact, stand-alone computer model for 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. Particle species include primary and secondary protons, alpha particles and heavy ions of charge up to Z=26, and secondary neutrons, charged pions, muons, electrons and positrons and x/gamma rays. AIREC is based on the MCNP Monte Carlo simulations of GCR incident on the atmosphere originally carried out as part of the development of the CARI-7 aviation dosimetry model. Like CARI-7, incident GCR flux is based on the 2004 ISO model, while geomagnetic field dependence is based on the IGRF model. AIREC is valid for altitudes from sea level to 100 km. The AIREC model can be used to systematically investigate how energy spectra and flux of various particle species changes as functions altitude and location. In addition, the output of the AIREC code, together with an appropriate model of a particular instruments radiation response, can be used to simulate particular high altitude experiments. We illustrate the use of AIREC in modeling a 2005 high altitude balloon flight over New Mexico.

Bortnik, Jacob (UCLA)
A Machine Learning Based Specification and Forecast Model of the Inner Magnetospheric Radiation Environment
Co-Author(s): X Chu, D Ma, WK Tobiska, D Bouwer, A Cruz

The field of space physics is currently in a remarkable position where it enjoys a large volume of high quality data which only promises to grow and in fact accelerate its growth in the near future. Traditional analysis techniques often do not exploit the data to their fullest potential, and will likely not be able to keep pace with the large volumes of data returned by current and future missions that will likely be on the order of petaBytes. A new approach is needed, which will inevitably involve developments in the rapidly growing field of data science. In this talk, we present the initial results from our NASA/SWO2R project which uses ML techniques to model radiation belt fluxes over a range of energies, based only on geomagnetic indices and solar wind inputs. These models give high

out-of-sample accuracy and can be run in nowcast or forecast modes. We show our efforts in serving our model results to the scientific and space weather community, through our collaboration with our industry partner Space Environment Technologies and the interaction between operations and research.

Caraballo, Ramón (Universidad Nacional Autónoma de México, Laboratorio Nacional de Clima Espacial)

GIC Monitoring in the Mexican 400kV Power Grid

Co-Author(s): JA González-Esparza, M Sergeeva, CR Pacheco

Geomagnetically Induced Currents (GIC), can pose a potential threat to power grids at low-to-mid latitudes. The National Space Weather Laboratory (LANCE) of México and the Mexican Electricity Operator (CFE), established a collaboration to study SW induction effects on their main power utility. First, to estimate GIC level along the 400 kV power grid we developed a numerical model. Second, we start the installation of GIC sensors at some particular substations. Currently, this is the only GIC monitoring project ongoing in Latin America. We present the analysis of GIC data collected at Querétaro during six months (June - November 2020). According to the results by our initial model, coastal substations and those located at the end-points of the power grid are the most vulnerable in terms of GIC hazard. Experimental and modelled data were compared for the Querétaro substation. Preliminary analysis shows that geomagnetically induced currents are a non-negligible phenomenon even during solar minimum conditions. The differences between the experimental and modelling results are ascribed to inaccuracies in the ground conductivity and coast effects at locations close to the shorelines. We are improving the numerical model to consider these effects. We are improving the numerical model to consider these effects. In addition, we are expanding the sensor network to improve the model validation and monitoring coverage.
Keywords: GIC, Space Weather, EM Induction, Power Grids.

Chu, Xiangning (Laboratory for Atmospheric and Space Physics, University of Colorado Boulder)

Forecasting Relativistic Electrons in the Outer Radiation Belt Using Neural Network Approach

Co-Author(s): D Ma, J Bortnik, WK Tobiska, F Set, D Bouwer, H Zhao, Q Ma, D Baker, H Spence, G Reeves

The relativistic electrons in the outer radiation belt are significant hazards to human-made satellites, space stations, and astronauts. We have developed a machine learning-based empirical model of the relativistic electron fluxes. The FRENA model serves two purposes: scientific research and real-time forecast. The FRENA model uses only upstream solar wind parameters supplemented with geomagnetic activity indices. The FRENA model has been trained and validated using electron flux data from the REPT instrument onboard Van Allen Probes. The model performance was demonstrated on the test dataset and an out-of-sample dataset of a geomagnetic storm in March 2017. The Pearson correlation coefficient is reasonably high (~0.90 of the variations), and the modeled electron fluxes have an error of a factor of ~2.0. The model can reproduce the transport, acceleration, decay, and dropout of the outer radiation belt electron fluxes during geomagnetic

storms and account for solar cycle variations. The FRENA model has excellent values and broad applications in the space physics community and space weather industry.

Foldes, Raffaello (University of L'Aquila)
A Machine Learning Approach for Estimating Equatorial Plasmaspheric Mass Density Using ULF Wave Measurements
Co-Author(s): A Del Corpo, E Pietropaolo, M Vellante

Monitoring the plasmasphere is an important task to achieve in the Space Weather context. A consolidated technique consists of remotely inferring the equatorial plasma mass density in the inner magnetosphere using Field Line Resonance (FLR) frequency estimates which can be obtained via cross-phase analysis of ULF magnetic signals recorded from pairs of latitude separated stations. In the last years, machine learning (ML) has been successfully applied in Space Weather, but this is the first attempt to estimate FLRs with these techniques. Here we employ XGB for identifying FLR frequencies by using measurements of the European quasi-Meridional Magnetometer Array (EMMA). Our algorithm takes as input the 30-min cross-phase spectra of magnetic signals and returns the FLR frequency as output by using data from four different station pairs from L=2.4 to L=5.5. Results show that XGB algorithm can be a robust and accurate method to achieve this goal. Its performances slightly decrease with increasing latitude and tend to deteriorate during nighttime. However, at high latitudes, the error increases during highly disturbed geomagnetic conditions such as the storm's main phase. Finally, we compare the equatorial plasmaspheric mass density obtained by XGB estimates with the density profiles by Del Corpo et al. (2019) for the geomagnetic storm of the 1st June 2013. Our approach may represent a prominent space weather tool included in an automatic monitoring system of the plasmasphere.

Gil, Agnieszka (Siedlce University & Space Research Centre)
Analysis of Strong Geomagnetic Storms and Electrical Grid Failures in Poland Using the Geoelectric Field as a GIC Proxy
Co-Author(s): M Berendt-Marchel, R Modzelewska, S Moskwa, A Siluszyk, M Siluszyk, L Tomasik, A Wawrzaszek, A Wawrzynczak

We study strong geomagnetic storms during the first half of the solar cycle 24, which appeared only several times during the studied period. These storms were mostly associated with southwardly directed heliospheric magnetic field Bz. Using various methodology as self-organizing maps, statistical and superposed epoch analysis, we show that during and right after intense geomagnetic storms, growth in the number of transmission lines failures, which might be of solar origin, appeared. We also examine the temporal changes in the number of failures during 2010-2014 and found the growing linear tendency of electrical grid failures occurrence possibly connected with solar activity. We confront these results with the geoelectric field calculated for the first time for the Poland’s region using a 1-D layered conductivity Earth model.

Haiducek, John (NRC postdoctoral fellow, resident at US Naval Research Laboratory)
Substorm Dynamics in MHD: Statistical Validation Tests and Paths for Improvement
Co-Author(s): D Welling, S Morley, A Mukhopadhyay, X Chu, J Helmboldt, J Huba, N Ganushkina

Magnetohydrodynamic (MHD) models have been used for nearly four decades to study the dynamics of magnetospheric substorms. However, until recently no demonstration has been made that MHD models can consistently reproduce substorm onset times in a statistical sense. To test whether MHD can reproduce observed substorm onset times, we developed a procedure for identifying substorm onsets that can be applied both to observational data and to MHD output. Our substorm identification procedure aims to improve upon existing methods of substorm identification by using multiple types of observations to corroborate each identified substorm. Using this procedure, we identified over 100 substorms from the period 1-31 January 2005. Using this list of substorm onset times, we show that the MHD model has weak, but statistically significant skill in predicting substorm onset times. We explore paths to improving the ability of the MHD model to predict substorm dynamics by testing different configurations of the MHD model.

Hartinger, Michael (Space Science Institute)
Simultaneous Observations of Geoelectric and Geomagnetic Fields Produced by Magnetospheric ULF Waves
Co-Author(s): X Shi, G Lucas, B Murphy, A Kelbert, J Baker, J Rigler, P Bedrosian

Geomagnetic perturbations (BGEO) related to magnetospheric ultralow frequency (ULF) waves induce electric fields within the conductive Earth-geoelectric fields (EGEO)-that in turn drive geomagnetically induced currents. Though numerous past studies have examined ULF wave BGEO from a space weather perspective, few studies have linked ULF waves with EGEO. Using recently available magnetotelluric impedance and EGEO measurements in the contiguous United States, we explore the relationship between ULF waves and EGEO. We use satellite, ground‐based radar, BGEO, and EGEO measurements in a case study of a plasmaspheric virtual resonance (PVR), demonstrating that the PVR EGEO has significant spatial variation in contrast to a relatively uniform BGEO, consistent with spatially varying Earth conductivity. We further show ULF wave EGEO measurements during several moderate storms of ~1-2 V/km; in some of these storms, magnetospheric ULF waves are the source of the largest amplitude EGEO. We use both results to highlight the need for more research characterizing ULF wave EGEO.

Honkonen, Ilja (Finnish Meteorological Institute)
Towards Global Magnetohydrodynamic Simulation of All ACE Data
Co-Author(s): M van de Kamp

We present our approach to modeling over 20 years of the solar wind-magnetosphere-ionosphere system using version 5 of the Grand Unified Magnetosphere-Ionosphere Coupling Simulation (GUMICS-5). As input we use 16 s magnetic field and 1 min plasma measurements by ACE satellite starting from 1998. The modeled interval is divided into 28 h simulations including 4 h overlap. We use a maximum magnetospheric resolution of 0.5 Earth radii (Re) up to about 15 Re from Earth and decreasing resolution further away. In ionosphere we use a maximum resolution of approximately

100 km poleward of +-58 magnetic latitude and decreasing resolution towards equator. We have parallellized the magnetosphere of GUMICS-5 using the Message Passing Interface and have made several improvements which have e.g. decreased its numerical diffusion. Currently we have simulated over 8 years of ACE data: 2001-2004, 2010, 2015-2017. On average we obtain new results at a rate of perhaps 30 times faster than real-time and expect to have simulated ACE data from 1998 to 2018 or later by end of this year or early next year. Results for one day and overlap require approximately 15 GB of disk space and final requirement is expected to be about 100 TB. We describe some of the challenges of working with such a large data set. Initial results indicate that GUMICS reproduces the solar cycle in magnetospheric and ionospheric parameters when compared to empirical models.

Kitiashvili, Irina (NASA Ames Research Center)
Solar Radiation in the Earth Environment (SREE) Data Portal
Co-Author(s): VM Sadykov, WK Tobiska, G Madhulika, SS Ranjan, RC Spaulding, DG Deardorff

The impact of solar radiation dramatically increases at high altitudes in the Earth's atmosphere and in space. Therefore, continuous monitoring of the radiation environment and tracking of space-weather originated disturbances is critical for aircraft and spacecraft crew safety. The Solar Radiation in the Earth Environment (SREE) Data Portal is an interactive web-based application for convenient search and visualization of in-flight radiation measurements and exploration of various properties related to the radiation environment. The web application contains a comprehensive search form with built-in filters, allowing the user to customize flight selection and other search parameters and to access visualization tools. The search procedure is supported by dynamic histograms of flight parameters implemented with the Google Charts API. The database includes (1) data from the Automated Radiation Measurements for Aerospace Safety (ARMAS) experiment obtained during more than 780 airplane flights, which are accompanied by the Nowcast of Atmospheric Ionizing Radiation for Aviation Safety models (NAIRAS); (2) measurements of solar soft X-ray radiation in the 0.5-4A and 1-8A wavebands from GOES; and (3) measurements of solar proton fluxes in various energy channels from GOES. The SREE data environment is publicly available at https://data.nas.nasa.gov/helio/portals/rdp/ and is part of the Helio Portal (https://data.nas.nasa.gov/helio/), which serves to share models and data tools.

Lejosne, Solene (University of California, Berkeley)
Operational High-Definition Description of Radiation Belt Radial Diffusion

An increasing number of spacecraft operate through or within the terrestrial radiation belts, a region where charged energetic particles are trapped in the Earth's magnetic field. Computer codes simulate this dynamic radiative environment, with the objective of improving spacecraft design and understanding spacecraft anomalies. These codes are physics-based models. That is, they solve a master diffusion equation using a series of inputs that summarize the effects of different physical processes on particles. One of the key inputs to these codes is the radial diffusion coefficient. Yet radial diffusion quantification is currently limited: its formulation is an average, obtained by interpolating a few experimental data points, and the time resolution is no better than 3 hr. On the other hand, even though the importance of using event‑specific radial diffusion coefficients to improve model accuracy is now well-accepted, their determination is seemingly incompatible with operational models. This work provides a physics-based method to build operational, event‑specific, electromagnetic diffusion coefficients via an analysis of the immediate time history of the solar wind (1 hr worth of data). That way, the time resolution is improved, and the coefficient variability is enhanced. The fact that the resulting radial diffusion coefficients vary around the standard values provided by the current reference adds credibility to the method.

Mertens, Christopher (NASA Langley Research Center)
NAIRAS Operational Improvements to SEP Aviation Radiation Dose Predictions
Co-Author(s): G Gronoff, S Nandan, P Mehta, Y Zheng

The Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) model is a real-time, global, physics-based model that predicts human radiation exposure from galactic cosmic rays (GCR) and solar energetic particle (SEP) events from the surface of the Earth to free-space. The NAIRAS model addresses the need in the aerospace industry to provide reliable dose estimates to quantify the cumulative health risks from GCR exposure to commercial aviation and commercial spaceflight passengers and crew, by providing a decision-support tool to facilitate the implementation of the as low as reasonably achievable (ALARA) principle in radiation protection. Furthermore, the NAIRAS model addresses the need to have reliable, real-time SEP dose predictions to make actionable grounding/re-routing flight decisions prior to and during a solar storm event and quantify and document the radiation exposure received during such events. Thus, recent efforts are focused on improving nowcasts and forecasts of atmospheric SEP dose. The NAIRAS model has been recently transitioned to prototype operations at the NASA Goddard Space Flight Center's Community Coordinated Modeling Center (CCMC). This presentation will summarize these recent activities.

Mooney, Margaret (NOAA's Cooperative Institute for Meteorological Satellite Studies)
The SatCamAurora Citizen Science Project
Co-Author(s): W Straka, K Strabala

The SatCamAurora project plans to collect, develop and archive multiple case studies pairing Aurora Borealis photos captured by citizen scientists with satellite images acquired at the same time and location. A repository of this sort became possible in 2011 with the launch of the Suomi-NPP satellite carrying the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument and the Day Night Band (DNB) sensor. The DNB is the only satellite sensor that routinely reveals the Aurora Borealis. The November 2017 launch of NOAA's JPSS-1 (NOAA-20) satellite doubled the VIIRS DNB database and inspired this citizen-science project. The platform envisioned is a progressive web app that leverages the VIIRS Today site (https://ge.ssec.wisc.edu/viirs-today/)from NOAA's Cooperative Institute for Meteorological Satellites (CIMSS), extending coverage northward for a "VIIRS Tonight" view of the central Canadian Provinces. This would enable, for the first time, routinely available DNB images of the Aurora Borealis with spectacular detail for locations near and north of the U.S./Canadian border from Washington to Maine. To date, proof-of-concept matches have only been made by happenstance. However, CIMSS is waiting proposal notification to leverage public enthusiasm with the Aurora to pair, catalog and archive citizen science photographs paired with concurrent DNB imagery. If funded, we will develop multiple case studies freely available to the broader space weather community.

Radhakrishnan, Rajeswaran (Faraday Technology Inc)

Improved Satellite Robustness through Application of Erosion Resistant and High Emissivity Coatings

Co-Author(s): TD Hall, D Liu, M Inman, E Jennings Taylor, ST Snyder, JR Dennison, M Finckenor

National Space Weather Strategy and Action plan calls for the need to enhance Protection of National Security, Homeland Security, and Commercial Assets and Operations against Effects of Space Weather. Extreme space weather event like solar flares, cosmic rays, and radiation belts cause ionizing radiation that can damage electronics, solar arrays, and optical systems on satellites reducing their functionality and lifetimes, by inducing an ionic charge on the spacecraft's surface, when a spacecraft fly in and out of the ionosphere. This negative charge buildup can lead to ion sputtering/arcing, and producing irreparable damage in spacecraft components. Therefore, the local application of materials systems that can passively mitigate the negative charge build up by emitting the electron back into space, while improving resistance to erosion during ion sputtering is of interest. In this presentation, we will discuss the feasibility of a low-cost, efficient and scalable manufacturing process for the deposition of lightweight passive highly emissive and erosion resistant coating onto spacecraft viable substrates that can mitigate charging and erosion effects from ionizing radiation. This composite coating showed a 140% increase in maximum total electron yield over the noncoated Al, as well as substantially extending by 4x the range of electron yields between crossover energies >1, and maintained nominal emission properties in modeled ISS plasma erosion.

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Patterns of CALIPSO Laser Energy Drops and NOAA-19 Energetic Charged Particle Fluxes

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The Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) mission was launched on 28 April 2006. Originally planned for a 3-yr mission, CALIPSO is still making high-quality lidar measurements. It has operated at 705 km and, after 28 September 2018, at 688 km altitudes. The primary payload is the Cloud–Aerosol Lidar with Orthogonal Polarization (CALIOP). At launch, the laser canisters were filled with dry air at atmospheric pressure. The canister pressure has dropped gradually during the mission. In June 2016, after the pressure reached a third of an atmosphere, the laser energy started to drop on individual shots in regions of enhanced energetic charged particle fluxes. As the pressure has dropped, the average magnitude of the energy drops has increased. To identify the associated radiation, we have compared maps of energy drops and of charged particle fluxes observed by the NOAA-19 Medium Energy Proton and Electron Detector (MEPED) omnidirectional charged particle detectors. The energy drops are associated with three populations: (1) 10's of MeV proton fluxes in the inner belt (South Atlantic Anomaly), (2) galactic

cosmic rays, whose fluxes increase towards the poles, and (3) MeV electrons in the outer belt. (The laser was turned off at the onset of the July and September 2017 solar energetic particle events, so an evaluation of the effect of these events is not possible.) The size of the energy drops is related in part to the flux levels.

Tobiska, W. Kent (Space Environment Technologies)

Building an Industrial Strength Global Aviation and Suborbital Radiation Monitoring Capability

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The aviation radiation monitoring community has made significant strides in building an industrial strength, global aviation radiation monitoring capability. We describe efforts in three major areas that are enabling a dose exposure hazard from the surface of the Earth to the top of the atmosphere to be provided for the current epoch and forecast time frames. These include: 1) data collection in multiple altitude, magnetic latitude and time scale domains; 2) data assimilation into physics-based models and quantifying the uncertainty through ensemble and machine-learned modeling; and 3) dose parameter and related space weather information distribution, publicly and widely, via the ARMAS iOS app. We identify the metrics (goals and thresholds) that are needed for global aviation and suborbital radiation monitoring and discuss the existing state-of-art in characterizing this environment for commercial and government users. Finally, we provide an update to unique science issues related to better understanding the sources of observed excessive radiation at high latitudes but unconnected to traditional galactic cosmic ray (GCR) or solar energetic particles (SEP) activity.

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Small Scale dB/dt Fluctuations: Resolving and Exploring Spikes in Global Models

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Geomagnetic Disturbances (GMDs) on Earth's surface can be highly localized and of large amplitude, causing disruptions in ground conducting systems. Because the source of localized GMDs is unresolved, we are prompted to model these effects, identify the physical drivers of GMDs, and improve our prediction of GMDs. We run a high-resolution simulation using the Space Weather Modeling Framework (SWMF) of the September 7, 2017 event. This configuration combines the Block Adaptive Tree Solar-wind Roe Upwind Scheme (BATS-R-US), the Ridley Ionosphere Model (RIM), and the Rice Convection Model (RCM). The configuration mirrors that which is used in operations, however, the higher grid resolution used can reproduce mesoscale structure in the tail and ionosphere. We use Regional Station Difference (RSD) and Regional Tail Difference (RTD) to quantify the success of the model against observations. RSD is a metric calculated using dB/dt or geoelectric field to pinpoint when a single magnetometer station records a significantly different value than others within a given radius. RTD is a metric calculated using relevant variables along the field lines connecting the magnetometer stations to the magnetosphere. Our results support a new hypothesis that there are two causes of localized GMDs - those associated with small scale structures in the tail and those associated with divergent magnetic field line mapping of the stations into the magnetosphere.

Xu, Wei (University of Colorado Boulder)
Atmospheric Radiation Production by Relativistic Electron Precipitation
Co-Author(s): RA Marshall, WK Tobiska

Radiation safety in the Earth's atmosphere is of particular importance to our living environment, especially at aviation altitudes. Aviation radiation has been long known to originate primarily from the galactic and solar system: galactic cosmic rays (GCR) and solar energetic protons (SEP) [Vainio et al., Space Sci Rev, 147, 187, 2009]. Recent flight measurements by the Automated Radiation Measurements for Aerospace Safety (ARMAS) experiment have uncovered another potential source for aviation radiation: Relativistic Electron Precipitation (REP) from the Van Allen radiation belts [Tobiska et al., Space Weather, 16, 1523, 2018]. REP can induce radiation at aviation altitudes through bremsstrahlung X-ray production, which carries radiation down to the stratosphere and even the troposphere. In this study, using a suite of physics-based Monte Carlo models, we characterize the effective radiation dose produced at altitudes between ground and low-Earth-orbit by relativistic precipitation electrons with energies between 100 keV and 10 MeV. We produce a lookup table of atmospheric radiation production that calculates the expected radiation dose for a given precipitation flux, spectrum, and pitch angle distribution. This lookup table provides results that are consistent with X-ray measurement during radiation belt precipitation by balloon-borne instruments in the stratosphere. Moreover, we analyze the ARMAS measurement on October 3, 2015 using space-borne measurements of REP fluxes.