2019 Space Weather Workshop Draft Agenda with Abstracts, Some Abstracts Pending
Embassy Suites Hotel
Boulder, Colorado

Monday, April 1

8:00-10:00 **UN International Civil Aviation Organization (ICAO) Coordination Discussion – by invitation** – Brent Gordon – Foothills Meeting Room
8:30-10:00 **US Air Force and US Federal Agency Collaboration – by invitation –** Major Janelle Jenniges, Michael Starks & James McCollough – Royal Arch Meeting Room
10:00-12:00 **UN International Civil Aviation Organization (ICAO) Coordination Discussion – by invitation** – Brent Gordon/Bill Murtagh – Royal Arch Meeting Room
12:00-1:30 Lunch
1:30 – 4:30 **UN International Civil Aviation Organization (ICAO) Discussion** – **Open -** Brent Gordon/Bill Murtagh – Royal Arch Meeting Room
3:00 - 4:30 **Student Networking Session – by invitation** – Carina Alden – Foothills Meeting Room
5:00 - 7:00 **Networking Session for Space Weather Workshop Participants –** NCAR Mesa Lab – Busses Provided from/to Hotel

Tuesday, April 2

8:30 **Workshop Opening Remarks**
Bill Murtagh, NOAA/SWPC

8:45 – 9:00 **Special Presentation: Update from the Executive Office of the President**
Aaron Miles, Office of Science and Technology Policy

9:00 – 9:45 **Operational Space Weather Services – Latest Developments**
Chair: Bill Murtagh, NOAA/SWPC

9:00 **SWPC Update to the 2019 SWW**
Brent Gordon, NOAA/SWPC

SWPC has continued to make exciting advances in its capabilities over the past 12 months since the 2018 Space Weather Workshop. We continue to focus our efforts on our existing and upcoming space weather models to support our operations. Key to this progress is to continue to increase our R2O2R through growing relationships with public, private, and educational institutions. Our work with NASA and NSF in this area have resulted in four joint announcements of opportunity in the past year and a half that are targeted at applied space weather topics. We continue to focus our efforts on provided the best products and services to support our mission. Our forecast mission recently grew with our designation as a Global Space Weather Services Provider by the International Civil Aviation Organization at the end of 2018. These are truly exciting times, with many exciting opportunities, for the Space Weather Prediction Center!

9:15 **Current Mission and Future plans for the USAF Space Weather Operations Center**
Major Eric Cercone, US Air Force/557th Weather Wing

9:30 **Contributions to Space Weather Services from the Commercial Sector**
Conrad Lautenbacher, American Commercial Space Weather Association

9:45 – 10:45 **Break and Poster Session (Solar and Interplanetary Research and Applications)**

10:45 - 12:15 **<u>Panel Session: Space Weather and ICAO: Meeting Needs for Global Aviation Services</u>**
Chair: Brent Gordon, NOAA/SWPC

10:45 **Regulatory Group/Policy Perspective**
Bill Bauman, Federal Aviation Administration

This presentation will provide an over view of the status and background of the ICAO Space Weather Provision for designating ICAO Space Weather Centers.

11:00 **Space Weather: An Airline Perspective**
Mike Stills, United Airlines

11:10 **A Practitioner's Perspective on Integrating ICAO Requirements into Operations**
Rob Steenburgh, NOAA/SWPC

NOAAs Space Weather Prediction Center (SWPC) was one of three entities chosen to provide space weather advisories in support of the International Civil Aviation Organization members. This new mission represents a monumental step in global collaboration for the provision of space weather services. This endeavor carries equally significant challenges and opportunities. This talk will present an overview of the Space Weather Prediction Center's efforts to assimilate these new requirements into our operations and the center-wide collaboration needed to overcome obstacles and capitalize on opportunities.

11:20 **Service Center – Pan-European Consortium for Aviation Space Weather User Services**
Ari-Matti Harri, Finnish Meteorological Institute

11:30 **Service Center – Australia-Canada-France Japan Consortium**
David Boteler, Natural Resources Canada

11:40 **Commercial Sector Space Weather Support for ICAO**
W. Kent Tobiska, Space Environment Technologies, LLC

The International Civil Aviation Organization (ICAO), a UN specialized agency managing the administration and governance of the Convention on International Civil Aviation (Chicago Convention), is considering a number of actions related to management of space weather effects on global civil aviation. Standards and Recommended Practices (SARPs) are being developed for HF communication, GPS navigation, and radiation risks in order to permit aviation’s global network an ability to operate safely and reliably in every region of the world. The U.S., as a state-member of ICAO, participates through an FAA representative. While not formally part of the ICAO SARP process, the commercial space weather sector has begun considering technical recommendations to ensure continued future civil aviation safety in areas relevant to space weather risks for aviation. This presentation will overview several of the outstanding commercial sector recommendations.

11:50-12:15 **Panel/Audience Discussion**

12:15 – 1:45 **Lunch & SWPC Tour** ***(Please Note: Tour participants must have signed up and will miss early afternoon session talks, Tour bus departs the Embassy Suites Lobby at 12:30 PM and returns at 3 PM)***

1:45 – 2:00 **Keynote: Satellite Anomalies and the Radiation Belts**
Daniel Baker, University of Colorado Boulder

Measurements of energetic electron (E >0.8,> 2 and > 4 MeV) fluxes have been made for many years by sensor systems on board the Geostationary Operational Environmental Satellite (GOES) series of geostationary orbit spacecraft. These long-term data have become a mainstay for monitoring the state of the Earth's radiation belts. This information, in turn, has been used often for assessing spacecraft operational anomalies. We have been interested in directly comparing the scientific radiation belt particle measurements from the NASA dual-spacecraft Van Allen Probes (Radiation Belt Storm Probes) sensor systems with the GOES operational data. The Van Allen Probes as part of the Living with a Star Program have measured the fluxes, energy spectra, and pitch angle properties of radiation belt electrons virtually continuously from September 2012 to the present time. In this study we make statistical comparisons of Van Allen Probes electron data near L=6 with concurrent daily averages of equivalent GOES flux values. We also are able to compare Van Allen Probes data at various other L-values and at a much broader range of particle energies with the baseline GOES values. These comparisons inform us about the relative calibrations of the scientific and operational systems and allow us to assess how well GOES data correlate with overall radiation belt behavior away from the geostationary orbit location. We believe this knowledge will help to provide a broader and more useful basis for overall space weather situational awareness.

2:00 - 3:15 **<u>Satellite Impacts and Anomaly Support</u>**
Chair: Janet Green, Space Hazards Applications

2:00 **The Wave of Sensitive Systems**
Jonny Dyer, Lyft

In the last 10 years there has been an explosion in the number of small commercial satellite missions, a trend expected to continue or even accelerate. The vast majority of these missions derive from cubesat heritage and philosophy where largely off-the-shelf commercial technologies are used. While successful to-date, there is no experience in this community for truly harsh space weather conditions. Furthermore there are a growing number of terrestrial systems whose design and implementation has been successfully executed in a historically mild solar weather climate.

2:15 **A 60-satellite Space Weather Constellation with Real-time 24/7 Globalstar Coverage**
Hank Voss, Nearspace Launch, Inc.

NSL has recently developed and delivered 60 Thin CubeSats (ThinSats) as a demonstration project that are manifested for launch April 17, 2019 on an NG11 rocket to the ISS from Wallops Island, VA. The research grade constellation of satellites will be released at about 300 km altitude with the new capability to explore the lower ionosphere down to 100 km, an important region for space weather fine structure measurements and modeling. With smart phone technology these small ThinSats (10 by 10 by 1.7 cm) can include energetic particle detectors, plasma probes, booms for magnetic and electric fields, camera imagers, IR sensors, GPS, and much more. Larger ThinSats are also available up to 30 by 30 by 5 cm for release of six ThinSats from a 27U CSD launcher. The lifetime for the April launch is about 1 week but ThinSats can be placed into any LEO orbit with much longer lifetimes. Twiggs Space Lab and Virginia Space have funded this work and supported many of the ThinSat educational payloads. Another constellation of 84 satellites is planned for spring of 2020. The ThinSats have a 3-hinge solar array foldout and can also be connected in strings.

The recently proven satellite-to-satellite NSL/Globalstar EyeStar link is ideal for a time ordered constellation database with dashboard for comparing data in the existing ground segment (TRL 9). The professional and commercial Globalstar network does not require a project ground station so that data is available from anywhere and anytime in the world within seconds for rapid announcement and response to space weather changes.

NSL has a 100% success with 7 of 7 NSL FastBus satellites in orbit and 27 of 27 NSL Globalstar communication systems in orbit. Because of robotic assembly and testing we can build a research grade constellation with flight mil-spec parts at significantly reduced cost. Real-time in situ and remote space weather constellation satellite data, especially in the underexplored 100-400 km region, in concert with ground-based measurements and modeling data will likely be a leap forward in understanding and predicting Sun-Earth connections.

2:30 **SpaceWx and UK SKYNET Operations and Exercises**
Ewan Haggerty, Airbus Defense and Space

This talk will highlight the cooperative work that has been done between the USAF 557th Weather Wing 2nd Space Weather Squadron, Met Office Space Weather Operations Centre, [dstl], BLOS MOD and led by Airbus DS. Key focus will be on the real activities of Sep 17 where SpaceWx was a comms limiting factor in OP RUMAN, effectively mitigated by the developed SKYNET SpaceWx procedure. A top-level description of means to include SpaceWx impacts in training and development exercises will be provided.

2:45 **Spwx Correlations to Abnormal Satellite State of Health**
Chris Bowman, Data Fusion and Neural Networks

We detect abnormal satellite State of Health (SOH) and abnormal space weather events then discover correlations to improve prediction of space weather effects on satellites. This is based on DF&NN intelligent software tools including: ANOM (Anomaly) Detection, Smoking Gun, and Abnormality Detection Classification Viewer (ADCV). These tools are applied to historical Geostationary Operational Environmental Satellite (GOES) 11 State of Health (SOH) and Space Environment data to include the Spacecraft Environmental Anomalies Expert System (SEAES) data for GOES 11.

3:00 **Roadmaps from the Space Environment Engineering and Science Applications Workshop**
Paul O'Brien, The Aerospace Corporation

On 5-8 September 2017 NOAA SWPC and NCEI hosted the Space Environment Engineering and Science Applications Workshop (SEESAW). The workshop was sponsored by the IEEE Nuclear and Plasma Sciences Society and by the National Science Foundation. It had approximately 70 attendees from the US and international institutions. As part of the workshop, the attendees constructed a set of roadmaps, addressing surface charging, internal charging, single event effects, total dose, nowcast/forecast and special topics. These roadmaps provide guidance to the scientific and engineering communities in moving forward with research and applications to further improve the design and operation of space and launch vehicles.

3:15 - 4:15 **Break and Poster Session (Solar and Interplanetary Research and Applications)**

4:15 - 5:30 **<u>Space Weather Support for the Arctic Region</u>**
Chair: Rodney Viereck, NOAA/SWPC

4:15 **Policy Perspective**

4:30 **Arctic Marine Navigation and Communication Support**
Captain David Zezula, NOAA

4:45 **Arctic Research at the Geophysical Institute**

Bob McCoy, University of Alaska Geophysical Institute

The Geophysical Institute (GI) at the University of Alaska Fairbanks performs research across the Arctic in multiple geophysical disciplines. The GI was created by Congress at the end of WWII because of the aurora and space weather effects on HF communication, but since then its research portfolio has expanded to include the complex and diverse geophysical phenomena in Alaska including: volcanoes, earthquakes, snow, ice and permafrost, sea ice, Arctic weather and glaciers. In support Arctic research the GI manages multiple research facilities (many 24/7) including: Poker Flat Research Range (PFRR); High-frequency Active Auroral Research Program (HAARP); Alaska Satellite Facility (ASF); Alaska Volcano Observatory (AVO); Alaska Earthquake Center (AEC); Alaska Center for Unmanned Aircraft System Integration (ACUASI) and the Wilson Alaska Technical Center (WATC). WATC uses infrasound and seismic sensors to monitor volcanic activity but is also funded by the DoD to for nuclear test ban treaty verification and has become the newest DoD University Affiliated Research Center (UARC) for Global Detection of Nuclear Proliferation. Space weather remains a primary competence of the GI and its location in the subarctic, and the multiple optical and RF sensors (owned by the GI and others) make Alaska an ideal location to observe and study space weather.

5:00 Analytic and Experimentation Capabilities for Arctic Communications and Operations
Jennifer Forsyth, The MITRE Corporation

Arctic situational awareness is increasingly important as arctic ice decreases and maritime transits increase. Key challenges include, as the DoD arctic strategy calls out, vast distances, obsolete or deteriorating polar communications architecture, limitations of geostationary communications satellites, harsh weather conditions, high-latitude ionic disturbances, and geomagnetic storms. These combine to make reliable, secure communications in the Arctic difficult.

Arctic users have reported that current modeling tools for High Frequency (HF) communications are not consistently accurate in the arctic. The auroral oval relative to the refraction point has an impact on HF communications outages. This makes it difficult to operate reliably and to look forward to defining requirements for communications systems of the future.

This presentation reviews operational needs and challenges for HF communications and proposes future work for a geographically diverse, multi-point HF network to provide reliability in the arctic. It introduces recent work that compares existing HF models' performance in the arctic, using several publicly available HF models as well as data from University of Massachusetts Lowell Digisonde database. The intent is to improve arctic HF communication definitions for current capabilities, provide insight into arctic HF communications limitations, and drive decisions for investments and test planning especially around opportunities to improve reliability through a multi-point network.

5:15 Space Weather in the NWS Alaska Region
David Kochevar, NOAA/NWS Alaska Region

While most may first think of brilliant auroral displays, extreme Space Weather events can have significant impacts to the everyday life of Alaskans. These impacts are felt most often by the marine and aviation communities through the degradation or loss of HF communications and GPS navigation, however they can be much more far-reaching and concerning. Disruptions to the vulnerable power grid can create immediate concerns for life and property due to seasonal lack of sunlight and extreme winter weather. Marine and aviation traffic also continue to increase in very high latitude areas (north of 70 degrees) as diminishing sea ice creates new navigable routes and aircraft become more fuel efficient. This increased traffic is increasing the need for additional support for search and rescue or disaster operations during hazardous weather events in extremely rural areas with limited communications and observations, which can be further complicated by space weather.

This trend of additional activity through the arctic will continue to increase the reliance of HF communications and GPS navigation, and the need for enhanced Impact-based Decision Support Services for Space Weather in Alaska Region. For this reason, the NWS Alaska Region is enhancing its long standing partnership with the Space Weather Prediction Center to explore using the arctic as a proving ground for new Space Weather forecast products. This partnership, will better position the NWS to provide customers and stakeholders with superior Decision Support Services in Alaska not only for terrestrial but also for space weather.

5:45 - 8:00 **13th Annual NOAA - Commercial Space Weather Interest Group (CSWIG)/American Commercial Space Weather Association (ACSWA) Summit Meeting – by invitation**

<u>Wednesday, April 3</u>

8:30 - 8:45 **Keynote:** Overview of NASA's Exploration Campaign
Steve Clarke, National Aeronautics and Space Administration

8:45 – 10:00 **<u>Panel Session: Space Weather Support for Human Expansion Across the Universe</u>**
Chair: Linda Parker, Universities Space Research Association

8:45 **Operational Space Weather Forecasting Needs for Manned Exo-LEO Missions**
Eddie Semones, NASA Johnson Space Center

As human spaceflight goals extend from Low-Earth Orbit (LEO) missions like the International Space Station to the moon, Mars and beyond, the Space Radiation Analysis Group (SRAG) at Johnson Space Center will need to update their approach for mitigation of crew radiation exposure due to large Solar Particle Events (SPEs). Complications for exo-LEO missions include the lack of protection from the Earth's geomagnetic field employed by the ISS as well as limited communication capability between the crew and the ground. Although vehicle shielding is an important aspect of radiation exposure protection, there is also a continued requirement to monitor and predict the space weather environment in case of a need for the crew to take corrective action (i.e., seek shelter); to this end, SRAG maintains a console position in Mission Control with 24/7 mission support capability. SRAG's concept of operations for exo-LEO missions will transition from nowcasting to an emphasis of improving forecasting capabilities, providing the Flight Control Team with more information when responding to a space weather event. The Integrated Solar Energetic Proton Event Alert/Warning System (ISEP) represents a collaboration between SRAG and the Community Coordinated Modeling Center (CCMC) at Goddard Space Flight Center to bring state-of-the-art space weather models from research and development at universities and small businesses to operational use at NASA (R2O). These models will have a user interface in the form of a model Scoreboard that will allow the SRAG console operator to view and compare the results from several different models simultaneously; this approach also encourages the console operator to understand the background and associated caveats of each model in order to formulate the best crew response to changes in the space weather environment. The ISEP team is incorporating an R2O approach to improve space radiation exposure mitigation capabilities in the exo-LEO mission era.

8:55 **Air Force Research Laboratory's Solar Energetic Particle Forecasting Needs**
Rachel Hock-Mysliwiec, Air Force Research Laboratory

Predicting solar energetic particle (SEP) spectral and temporal evolution remains an important part of space weather operations. This talk will outline the Air Force Research Laboratory's needs for SEP forecasting for the development of next-generation space environment models and impact tools.

9:05 **ESA Space Weather Activities in Space Safety Programme**
Juha-Pekka Luntama, European Space Agency

European Space Agency's (ESA) Space Situational Awareness (SSA) Programme has been developing since 2009 the European Space Weather (SWE) System for the capability to provide operational space weather services to support protection of European space and ground based assets against adverse effects from space weather. This system is based on use of European space weather assets through a federated network consisting of thematic Expert Service Centres (ESCs) and SSA Space Weather Service Coordination Centre (SSCC). Many European space weather centres of excellence in academia, research institutes and industry are already part of the network and inclusion of additional groups in the framework of coming ESA space weather activities. In parallel, SSA Programme has been developing European space weather monitoring capability.

This presentation will address the status and achievements of the space weather activities in the framework of ESA's SSA Programme and show the prospects for the coming activities and developments after 2020 when the Programme will evolve into Space Safety Programme with expanded scope and additional objectives.

9:15 **Solar Energetic Particle Forecasting: Current Capabilities and Future Directions**
Hazel Bain, NOAA/SWPC

Radiation storms consisting of solar energetic particles (SEPs) are a major component of space weather. SEP events can result in spacecraft malfunction; disrupt high frequency radio communications; pose a radiation risk for passengers and crew on polar flight routes; and, most importantly for human space exploration, significantly increase the radiation dose for astronauts going beyond low earth orbit. Therefore, an essential aspect of space weather forecasting is to predict the occurrence and properties of an SEP event before it occurs.

Physics-based numerical models are not yet at the level where they can provide the robust, real-time forecasts required in an operational setting. However, there exists a number of empirical and semi-empirical models which use observations of SEP associated signatures and phenomena, to generate forecasts which indicate the probability of an SEP event occurrence, onset time, peak intensity, duration etc. In this talk I will give an overview of the current state of SEP forecasting, of the models currently available in the research community and the current forecast skill of these models. I will talk about future requirements for SEP forecasting at the NOAA Space Weather Prediction Center and areas we need to work on in order to meet those requirements.

9:25 **Active Dosimeter-Based Estimate of Astronaut Acute Radiation Risk from Solar Energetic Protons**
Chris Mertens, National Aeronautics and Space Administration at Langley

Radiation exposure from solar energetic particle events (SEP) becomes a much greater concern as human exploration extends beyond low Earth orbit and the protective geospace environment. Exposure to SEP events in deep space have an increased impact on mission planning and operations, as preventative actions may be necessary to avoid exceeding astronaut permissible exposure limits and acute radiation syndrome. Operational analysis tools are needed to assess acute radiation effects during SEP events in order to determine courses of action during the mission. A methodology has been developed to meet this need for NASA's upcoming Exploration Missions (EM-1 and EM-2). The operational tool utilizes onboard vehicle dosimeter measurements, combined with a pre-computed database of dose quantities, to estimate organ doses at astronaut crew locations. The estimated dose quantities, in turn, provide the necessary inputs to acute biological response models that predict radiation induced performance decrement and other acute radiation effects. The statistical characteristics of dose to the blood-forming organs of crew inside the spacecraft are presented for historical SEP events, and the methodology of the new active dosimeter-based SEP acute radiation risk tool is presented.

9:35-10:00 **Panel/Audience Discussion**

10:00 - 11:00 **Break and Poster Session (Ionosphere and Thermosphere Research and Applications and General Space Weather Services)**

11:00 - 12:00 **<u>Agency Vision on Implementation of Space Weather O2R2O</u>**
Chair: Tamara Dickinson, Office of Science and Technology Policy

11:00 **NOAA O2R2O**
Mary Erickson, Deputy Director of the National Weather Service

11:15 **Heliophysics at NASA and the Science of Space Weather**
Nicola Fox, National Aeronautics and Space Administration

NASA is a mission driven agency whose science mission is focused on discovering the secrets of the universe, looking for life elsewhere, and safeguarding and improving life on Earth. Heliophysics plays a key role in every aspect of the NASA science mission, including understanding the drivers of and enabling the prediction of space weather. Heliophysics has an established research program that motivates and funds solar and space physics, which is the essence and foundation of space weather research. Recently, the Heliophysics Division established a Space Weather Science and Applications Program, SWxSA. The objective of this competed program is to enable the transition of the knowledge and understanding of space weather to operation environments, by partnering with sister agencies, the commercial sector, and academia. SWxSA leverages relevant NASA capabilities to reach this objective. This talk provides an overview of space weather research and SWxSA in the NASA Heliophysics Division.

11:30 **NSF Space Weather Activities**
Michael Wiltberger, National Science Foundation

NSF's primary role in developing space weather readiness for the nation is in the support of basic research that advances fundamental understanding of space weather and related processes, specifically, the generation of solar storms, their propagation through the interplanetary medium, and the generation of disturbances in the near-Earth space environment and atmosphere. NSF supports the development of models for space weather processes, observations of the space weather system from a variety of ground and space-based platforms ranging from advance ionospheric radars to magnetometers. The goal of these research activities is further refining our understanding of the space weather system. These research activities are to benefit because they contribute to the achievement of specific, desired societal outcomes, such as improving space weather predictive capability.

11:45 **USAF Space Weather O2R2O Efforts**
Michael Farrar, US Air Force Directorate of Weather

The USAF provides space weather forecasts, watches, warnings, and alerts for Department of Defense and Intelligence Community operations. The National Security mission and future operating environment drive the O2R process through warfighter collaboration and prioritization of requirements. Based on these requirements, modernization of ground and space-based observation networks and the USAF space weather modeling and forecasting architecture are planned. The USAF Space Weather Enterprise will achieve these modernization efforts through deliberate O2R and R2O work and by energizing relationships with labs, academia, industry and continued collaboration with civil agencies to transition research capabilities to operations.

12:00 **UK R2O Activities**
Mark Gibbs, United Kingdom Met Office

The Met Office will present a summary of space weather activities in the UK focused on R2O work both underway and planned.

The Met Office Space Weather Operations Centre has been delivering space weather forecast services to the UK for almost five years. The Met Office currently work with individual universities, government bodies and operational centres to bring individual space weather research through into operations but have found getting across the ‘valley of death’ challenging. The software languages and standards governing an operational setting, mean significant rewriting of model code slowing down operational implementation. This demand on resources has resulted in operational centres working together to share the rewriting of code and validation of models.

The picture in the UK has been further complicated as research funding is provided by multiple research councils. With a new space weather strategy being developed in the UK it is anticipated that co-ordination of research and transition into operations will improve over the coming years.

12:15 - 1:35 **Lunch**

1:35 - 2:50 <u>**Extreme Space Weather Benchmarks**</u>
Chair: Geoffrey Reeves, Los Alamos National Laboratory

1:35 **Benchmarks for Induced Geo-Electric Fields**
Pete Riley, Predictive Sciences, Inc.

Severe geomagnetic storms can generate geo-electric fields of sufficient magnitude to drive potentially damaging quasi-direct currents within electric power grids. In ‘Space Weather Phase 1 Benchmarks,’ a report published in June 2018 by the Space Weather Operations, Research, and Mitigation (SWORM) Subcommittee on behalf of the National Science and Technology Council (NSTC), the ‘Induced Geo-electric Fields’ working group (WG) summarized their objectives to: (1) assess the feasibility of establishing functional benchmarks for induced geo-electric fields using currently available storm data sets, existing models, and published literature; and (2) use the existing body of work to produce benchmarks for induced geo-electric fields for specific regions of the United States. To address this, they focused on developing a statistical product that captured maps of geo-electric hazard. In this presentation, I summarize the main findings of this Phase 1 report, identify some of the advances that have occurred in the intervening two years, and solicit comments from the Space Weather community, as our working group begins to update the current state-of-knowledge with respect to improved benchmarks for induced geo-electric fields.

1:50 **Space Weather Impacts of Solar Radio Bursts**
Dale Gary, New Jersey Institute of Technology

2:05 **Next Steps in Determining Space Weather Benchmarks for Ionizing Radiation Hazards**
Christina Cohen, California Institute of Technology

The 2018 report from the National Science and Technology Council on Space Weather Benchmarks described results from phase one of the effort to determine benchmarks (1-in-100-year levels and theoretical upper limits) for five phenomena connected with extreme space weather events. Among those examined was the increase in ionizing radiation near Earth resulting from solar energetic particle events, galactic cosmic rays, and the Earth’s radiation belts. Such radiation is a significant hazard to satellites and humans in space as well as crews on polar-routed airlines. This talk reviews the methodology used and the resulting benchmarks for ionizing radiation in phase one and discusses the plans for the next steps that will be taken in preparation of phase two.

2:20 **National Benchmarks for Ionospheric Disturbances**
Susan Skone, University of Calgary

Preparing for space weather events is critical to national security, infrastructure services, space missions, and technology innovations. Threats are often directly related to physical phenomena such as induced geo-electric fields, ionizing radiation, solar radio bursts, upper atmospheric expansion and ionospheric disturbances. To improve national preparedness, The U.S. National Science & Technology Council released phase 1 space weather benchmarks associated with these phenomena in June 2018. Such benchmarks are intended to capture an event's ability to affect the Nation, and provide clear and consistent descriptions of space weather events. The approach provides input for creating engineering standards, developing vulnerability assessments, establishing thresholds for action, understanding risk, and developing more effective mitigation, response and recovery procedures. A subsequent phase 2 effort will more rigorously define benchmarks of sufficient precision for their intended uses.

To support phase 2 efforts, opportunities for feedback and community engagement are underway via online consultation, public forums and working group activities. This presentation focuses on the status of benchmarking for ionospheric disturbances and next steps in reviewing, integrating public feedback and developing working groups recommendations to inform phase 2 efforts.

2:35 **Upper Atmosphere Expansion**
Eric Sutton, University of Colorado, Boulder

2:50 - 3:45 **Break and Poster Session (Ionosphere and Thermosphere Research and Applications and General Space Weather Services)**

3:45 – 4:00 **Modernizing the Power Grids and Understanding Potential Impacts from Solar Weather**
Ben Kroposki, National Renewable Energy Laboratory

Grid modernization is increasingly important to address a range of challenges and enable future energy systems to maintain affordability and reliability while increasing security, resilience, and the ability to integrate energy in all forms. The rapidly growing penetration of smart devices at all levels (e.g. power electronics converters for wind and solar energy, smart controllers for bulk and distribution systems, EV charging/discharging interface with power systems, smart appliances with adjustable electrical loads) have potentials to support a scalable, reconfigurable, and self-organizing information and control infrastructure. However, they also present increased risk from all forms of disturbances. Space weather can impact the operations of electrical power systems since it can impact the conditions of the earth's atmosphere which can induce electro-magnetic reactions in the electrical grid and its components. These geomagnetically induced currents can overload the electrical power equipment and cause disruptions in operations. This presentation will discuss the impacts that the solar wind, interplanetary magnetic fields, coronal mass ejections, and other space weather can induce on the structure and operations of electrical power systems on earth and offer potential solutions to deal with these effects. Solar weather can cause geomagnetic storms that can change the time-varying magnetic fields and electrical current in electrical power grids on earth.

4:00 – 5:15 **Panel Session: Space Weather Services for the Electric Power Grid**
Chair: Seth Jonas, Science and Technology Policy Institute

4:00 **Integrating Space Weather and Ground-based Magnetotelluric Data with Powerflow Solutions for Real-time Assessment of Risk to the Power Grid**
Adam Schultz, Oregon State University

The National Space Weather Action Plan, NERC Reliability Standard TPL-007-1,2 associated FERC Orders 779, 830 and subsequent actions, emerging standard TPL-007-3, as well as Executive Order 13744 have prepared the regulatory framework and roadmap for assessing and mitigating the impact on critical infrastructure from space weather. These actions have resulted in an emerging set of benchmarks against which the statistical probability of damage to critical components such as power transmission system high-voltage transformers can be assessed; for the first time the impacts on the intensity of geomagnetically induced currents (GICs) due to the spatial variability of the geomagnetic field and of the Earth's electrical conductivity structure can be examined systematically.

While at present not a strict requirement of the existing reliability standards, there is growing evidence that the strongly three-dimensional nature of the electrical conductivity structure of the North American crust and mantle (heretofore 'ground conductivity') has a first-order impact on GIC intensity, with considerable local and regional variability. The strongly location dependent ground electric field intensification and attenuation due to 3-D ground conductivity variations has an equivalent impact on assessment of risk to critical infrastructure due to HEMP (E3 phase) sources of geomagnetic disturbances (GMDs) as it does for natural GMDs.

From 2006-2018, Oregon State University (OSU) under NSF EarthScope Program support, installed and acquired ground electric and magnetic field time series (magnetotelluric, or MT) data on a grid of station locations spaced ~70-km apart, at 1161 long-period MT stations covering nearly 2/3 of CONUS. The US Geological Survey completed 47 additional MT stations using functionally identical instrumentation, and the two data sets were merged and made available in the public domain. OSU and its project collaborators have also collected hundreds of wider frequency bandwidth, more densely-spaced MT station data under other project support, and these have been or will be released for public access in the near future.

NSF funding was not available to make possible collection of EarthScope MT data 1/3 of CONUS in the southern tier of states, in a band from central California in the west to Alabama in the east and extending along the Gulf Coast and Deep South. OSU, with NASA support just received, plans to complete MT station installation in the remainder of California this year, and with additional support both anticipated and proposed, we hope to complete the MT array in the remainder of CONUS. For this first time this will provide national-scale 3-D electrical conductivity/MT impedance data throughout the US portion of the contiguous North American power grid. Complementary planning and proposal efforts are underway in Canada, including collaborations between OSU, Athabasca University and other Canadian academic and industry groups.

In the present work, we apply algorithms we have developed to make use of real-time streams of US Geological Survey, Natural Resources Canada (and other) magnetic observatory data, and the EarthScope and other MT data sets to provide quasi-real time predictions of the geomagnetically induced voltages at high-voltage transmission system transformers/power buses. This goes beyond the statistical benchmarking process currently encapsulated in NERC reliability standards. We seek initially to provide real-time information to power utility control room operators, in the form of a heat map showing which assets are likely experiencing stress due to induced currents. These assessments will be ground-truthed against transmission system sensor data (PMUs, GIC monitors, voltage waveforms and harmonics where available), and by applying machine learning methods we hope to extend this approach to transmission systems that have sparse or non-existent GIC monitoring sensor infrastructure. Ultimately by incorporating predictive models of the geomagnetic field using satellite data as inputs rather than real-time ground magnetic field measurements, a near-term probabilistic assessment of risk to transformers may be possible, ideally providing at least a 15-minute forecast to utility operators.

There has been a concerted effort by NOAA to develop a real-time geomagnetically induced ground electric field data product that makes use of our EarthScope MT data, which includes the strong impacts on GICs due to 3-D ground conductivity structure. Both OSU and the USGS have developed methods to determine the GIC-related voltages at substations by integrating the ground electric fields along power transmission line paths. Under National Science Foundation support, the present team of investigators is taking the next step, of applying the GIC-related voltages as inputs to quasi-real time power flow models of the power transmission grid in order to obtain realistic and verifiable predictions of the intensity of induced GICs, the reactive power loss due to GICs, and of GIC effects on the current and voltage waveforms, such as the harmonic distortion.
As we work toward integration of predicted induced substation voltages with power flow models, we've modified the RTS-GMLC (Reliability Test System Grid Modernization Lab Consortium) test

case (https://github.com/GridMod/RTS-GMLC) by moving the geographic location of the case to central Oregon. With the assistance of LANL we have the complete AC and DC network of the RTS-GMLC case, and we are working to integrate the complete case information into Julia (using the PowerModels and PowerModelsGMD packages of LANL), or into PowerWorld. Along a parallel track, we have performed GIC voltage calculations using our geophysical algorithm for a realistic GMD event (Halloween event) for the test case, resulting in GIC transmission line voltages that can be added into our power system model. We'll discuss our progress in integrating the geophysical estimates of transformer voltages and our DC model using LANL's Julia and PowerModelsGMD package, for power flow simulations on the test case, and to determine the GIC flows and possible impacts on the power waveforms in the system elements.

4:15 **NOAA's Development of Regional Geoelectric Field Modeling Capability: New Nowcast and Forecast Products to Improve Operational Decision Making of the U.S. Electrical Power Grid in Response to Geomagnetic Storms**
Christopher Balch, NOAA/SWPC

The impact of geomagnetic storms on the electrical power grid is a potential hazard to the nation's critical infrastructure. The most intense event in the era of modern bulk power grids dates back to March of 1989, about thirty years ago, which resulted in an extended blackout, equipment damage, and widespread operational anomalies. Since then, the power grid has continued to grow steadily, as has the dependence of modern society on reliable electrical power. A key parameter identified by the power grid industry to better characterize this effect is the regional geoelectric field. Nowcasts and forecasts of the regional geoelectric field comprise a major step forward in the description of space weather for this user community as the capability enables distinctions between high risk and low risk operating locations. In addition, the parameter provides a direct way to calculate the amount of geomagnetically induced current that is being imposed on a given power grid, which in turn enables an assessment of system vulnerability and can guide user responses so that they are cost-effective. NOAA, in partnership with USGS, NASA, and NRCAN has undertaken work to develop this capability. We describe in this talk highlights of the near real-time data flow and sample regional geoelectric product outputs which are available experimentally and nearing operational status.

4:30 **Magnetic-storm Geoelectric Hazard Maps and the Induction of Voltages on Power-grids**
Jeffrey Love, US Geological Survey

A summary is presented of recent research pursued by the U.S. Geological Survey (USGS) Geomagnetism Program undertaken in support of priorities established by National Space Weather Action Plan of the National Science and Technology Council's Space Weather Operations, Response, and Mitigation (SWORM) Working Group. Results are presented of analyses made of geoelectric fields that are induced in the Earth's electrically conducting interior during intense magnetic storms and their representation as maps and as voltages induced on electric-power grid networks. Estimates of geoelectric fields are obtained by convolution of geomagnetic time series (such as those provided by USGS observatories) with Earth-surface impedance tensors (such as those obtained by the EarthScope project of the National Science Foundation). Statistical analysis of long geoelectric amplitude time series gives estimates of extreme-values, such as those realized during rare but intense magnetic storms. Time-dependent maps of geoelectric vectors are constructed for individual magnetic storms, and voltages on power-grid lines are estimated by integrating the geoelectric vectors along the length of the transmission lines. Results inform studies of resilience of power-grid networks to geomagnetic disturbance as mandated by the Federal Energy Regulatory Commission (FERC), which is now being undertaken by utility companies within the North American Electric Reliability Corporation (NERC). Results also highlight the practical importance of both long-term geomagnetic monitoring and continental-scale magnetotelluric surveys.

4:45 **Using MT Data to Improve Regional Ground Response Models**
Jennifer Gannon, CPI Computational Physics, Inc.

Federal regulations for power utilities require transmission planners to evaluate system risk due to geomagnetic storms (GMD) and geomagnetically induced currents (GICs). Following the implementation of regulation TPL-007-1, the Federal Energy Regulatory Commission (FERC) ordered additional research into several key topics. One of the highest priority areas of study is evaluation of the accuracy of the conductivity models used to represent the ground response to changing magnetic fields. We present the latest updates from the team advancing ground response research in support of the science behind the regulatory effort, including the development of new regional response models based on Earthscope magnetotelluric (MT) measurements.

5:00-5:15 **Panel/Audience Discussion**

6:30 - 9:00 **Banquet Dinner at Pearl Street Ballroom**
Special Guest Speaker: Nicola Fox, Heliophysics Division Director, NASA

Thursday, April 4

8:30 - 10:00 **International Coordination on Space Weather Research**
Chris Cannizarro, US Department of State

8:30 **International Coordination**
Jean-Luc Bald, European Commission Delegation to the US

8:45 **Ensemble Flare Forecasting: Using Terrestrial Weather Prediction Techniques to Improve Space Weather Operations**
Sophie Murray, Trinity College of Dublin

One essential component of operational space weather forecasting is the prediction of solar flares. Whilst our understanding of the fundamental processes involved with flaring has advanced in recent years with the advent of high-resolution spacecraft imaging, accurate forecasting of these events remains elusive. Space weather researchers are increasingly looking towards methods used in terrestrial weather to improve operational prediction techniques. Ensembles have been used by weather forecasters for many years as a way to combine different predictions in order to obtain a more accurate result. Here we show the results of combining several operational flare forecasting methods currently available on the NASA/CCMC Flare Scoreboard to construct a 'best' ensemble forecast depending on what measure of performance is most important for the prediction. In this way space weather forecasters can choose the result that best fits the needs of different end-users who may be impacted by a severe space weather event in different ways.

9:00 **UN COPUOS – Long Term Sustainability Guidelines**
Peter Martinez, Secure World Foundation

9:15 **Space Weather initiatives in Latin America**
Joaquim E.R. Costa, National Institute for Space Research

This work will present some initiatives in Latin America based on a strong science existing in solar-terrestrial physics being structured to become international services for the space weather. Among the difficulties are unstable economic conditions, the lack of concrete policies in the administration of sciences and the creation, maintenance and renewal of qualified Human Resources. The local societies of the most active areas related to space weather have promoted meetings and discussions on initiatives in Space Weather, such as Latin American Space Geophysics Association (ALAGE), Argentinian Geophysical and Surveyors Society (AAGG), the Brazilian Astronomical Society (SAB), and the Brazilian Association for Space Geophysics and Aeronomy (SBGEA). Some services such as EMBRACE (Brazil) will be presented with its sensor's networks, forecast, and user watch, warnings and alert indexes, along with database distributed free of charge by the site. In Latin America, the ALAGE has recently played a very important role in coordinating local scientists and facilities to initiate space weather programs across the continent. However, four members of this society are the leaders of strong initiatives and are promoting space weather services in their countries cooperating to each other with expertise and data share. Argentina, Brazil, Chile and Mexico. Two of them have already a state mandate and is been set up internationally as regional warning centres (Brazil and Mexico), Argentine already has a web-service and discusses with the internal administration to be appointed as a national service. Chile is structuring his service and defining its scope of action. We will present the recent progress on the established services, growth of the network of sensors, public outreach and the news on international cooperation and opportunities.

9:30 **Modelling GICs in Australian Power and Pipeline Networks**
Jeanne Young, Australia Bureau of Meteorology

The Australian Bureau of Meteorology's Space Weather Services (SWS) has been working with power network and pipeline companies for a number of years on investigating the impact of Geomagnetic Induced Currents (GICs) on their networks (see Marshall et al., 2010 and 2017). This presentation will discuss two recent developments in this work: improved models for calculating geoelectric fields, and a new service that provides estimates of the impacts of GICs on power and pipeline networks via an application programming interface (API). The improved geoelectric field models are based on 3-D conductivity models of the Australian region (see Wang et al., 2016), which will lead to improved GIC estimates in coastal areas and areas with large conductivity anomalies. The new API service is available for registered users and can be used to model GICs or pipe-to-soil potentials (PSPs) on the user's assets. The modelling can be done with either near real-time magnetometer data, allowing the asset owner to monitor their network, or with historical data, for example to identify the effects of GICs on cathodic protection surveys. The API can also be used to explore the impact of different space weather event scenarios on networks using historical data.

9:45 **ESA Space Weather Activities in Space Safety Programme**
Juha-Pekka Luntama

European Space Agency's (ESA) Space Situational Awareness (SSA) Programme has been developing since 2009 the European Space Weather (SWE) System for the capability to provide operational space weather services to support protection of European space and ground based assets against adverse effects from space weather. This system is based on use of European space weather assets through a federated network consisting of thematic Expert Service Centres (ESCs) and SSA Space Weather Service Coordination Centre (SSCC). Many European space weather centres of excellence in academia, research institutes and industry are already part of the network and inclusion of additional groups in the framework of coming ESA space weather activities. In parallel, SSA Programme has been developing European space weather monitoring capability.

This presentation will address the status and achievements of the space weather activities in the framework of ESA's SSA Programme and show the prospects for the coming activities and developments after 2020 when the Programme will evolve into Space Safety Programme with expanded scope and additional objectives.

10:00 - 11:00 **Break and Poster Session (Geospace/Magnetosphere Research and Applications)**

11:00 - 12:00 **<u>Advances in Ground and Space-based Observations</u>**
Chair: Douglas Biesecker, NOAA/SWPC

11:00 **Commercial Weather Data Pilot: Update from Spire Global, GeoOptics and PlanetIQ**
Timothy Duly, Spire Global, Inc.
Conrad Lautenbacher Jr., GeoOptics, Inc.
Rob Kursinski, PlanetIQ

11:15 **Polarized Imaging for CME Tracking and 3D Structure**
Craig Deforest, Southwest Research Institute

We present a recent advance in the technology of 3D imaging and tracking of interplanetary CMEs as they cross the solar system: a validated measurement of CME location in 3D, together with its chirality (a direct indicator of leading-edge Bz), via polarized imaging. The result is an important step toward routine remote measurement of CME 3D properties and direct determination of leading-edge Bz from now-readily-obtainable measurements. Routine measurement of these properties could overcome the false-negative/false-positive/arrival-time problem for CME impact prediction, by tracking them in 3D across the solar system from a single near-Earth viewpoint. We describe how these now-demonstrated techniques can and should be validated for use in an operational context.

11:30 **NOAA's Current and Future Space Weather Architecture**
Elsayed Taalat, NOAA/NESDIS

NOAA observational responsibilities in support of space weather forecasting are in the context of significant, numerous, complementary international and domestic efforts. Each measurement plays a unique role at different phases of the forecasting or event characterization process. This paper overviews the current suite of observation that NOAA maintains and utilizes on various platforms, NOAA's forecasting capability, contributions to research efforts, and the status of the NOAA/NESDIS plan forward efforts for the Space Weather Follow-On (SWFO) program and COSMIC-2/FORMOSAT-7 mission to provide needed continuity. This paper will also brief the NOAA space weather goals within the NOAA Satellite Observing System Architecture.

11:45 **Space Weather Monitoring with the NOAA GOES-R Series Spacecraft: Instruments, Observations and Products**
Rob Redmon, NOAA/NCEI

Since their inception in the 1970s, the NOAA GOES satellites have monitored the sources of space weather on the sun and the effects of space weather at Earth. The GOES-16 and -17 spacecraft, the first two of four satellites as part of the GOES-R spacecraft series mission, were launched in November 2016 and March 2018, respectively. The space weather instruments on GOES-R have significantly improved capabilities over older GOES instruments. Solar instruments image the sun’s atmosphere in extreme-ultraviolet and monitor solar irradiance in X-rays and UV, while in-situ observations monitor solar energetic particles, magnetospheric energetic particles, galactic cosmic rays, and the Earth’s magnetic field. These measurements are important for NOAA Space Weather Prediction Center warnings, watches and alerts that are used by many worldwide customers; including satellite operators, airlines, power utilities, and NASA’s human activities in space. This presentation reviews the capabilities of the GOES-16 and -17 space weather instruments and presents initial observations along with a discussion of calibration activities and the current status of the instruments. We also describe the space weather Level 2+ products that are approaching operations for the GOES-R series including solar thematic maps, automated magnetopause crossing detection and spacecraft charging estimates. These new and continuing data products will be an integral part of NOAA space weather operations in the GOES-R era and will provide tremendous value to the research community.

12:00 - 2:00 **Lunch & SWPC Tour** ***(Please Note: Tour participants must have signed up and will miss early afternoon session talks, Tour bus departs the Embassy Suites Lobby at 12:30 PM and returns at 3 PM)***

2:00 – 2:15 **Keynote: NASA’s Parker Solar Probe – First Results**
Stuart Bale, University of California, Berkeley

2:15 - 3:30 **Research – Advances in Ground and Space-based Observations**
Chair: Tim Fuller-Rowell, University of Colorado Boulder

2:15 **New Observations from NASA's Global-scale Observations of the Limb and Disk (GOLD) Mission**
Richard Eastes, University of Colorado Boulder

The GOLD mission began routine observations in October, 2018. The mission's ultraviolet (UV), imaging spectrograph, hosted on the SES-14 satellite, observes the American hemisphere from a geostationary orbit located at 47.5 west longitude, near the mouth of the Amazon River. From there it repeatedly observes the same geographic locations over most of the hemisphere at a 30-minute cadence during the day and of more limited regions during the night at a 30 or 15 minute cadence. These data are well suited to understanding the spatial and temporal changes in the ionosphere and thermosphere due to geomagnetic storms, variations in solar radiation, and forcing from the lower atmosphere. Derived parameters, available at cadences of an hour or better, include the daytime composition ratio (O/N2) and temperature of the neutral atmosphere near 160 km. At night the peak electron densities and density depletions associated with scintillation of radio frequency signals in the low latitude, nighttime ionosphere are observable in real time. Such information is fundamental to better specification and prediction of space weather. This talk will discuss the early orbit observations, and describe a number of important new observations the mission has already produced.

2:30 **Space Weather Measurements from MACAWS: Monitors for Alaskan and Canadian Auroral Weather in Space (MACAWS)**
Anthea Coster, Massachusetts Institute of Technology

The MRI Collaborative: Development of Monitors for Alaskan and Canadian Auroral Weather in Space (MACAWS) is a sensor web network that provides both real-time and historical GNSS TEC and scintillation data products. The data are needed for geospace science and space weather monitoring in the auroral regions of northern Alaska and northwestern Canada that are currently not sampled or under-sampled. These regions are significant as they are the locations of origin for the majority of space weather events that affect the United States. At the end of the project, it is planned that 35 PolaRx5S Septentrio GNSS receivers will be installed across northern Canada and Alaska. In addition, smaller low-power low-cost GNSS total electron content receivers are planned to be installed at a few of the unmanned sites of the Alaskan Transportable Array. Currently, 15 receivers have been shipped and a subset of these have been installed. An additional receiver has been shipped to the Arecibo Observatory in Puerto Rico. Each receiver tracks both the GPS and GLONASS constellations. At every site, the data are collected to compute TEC and scintillation statistics for each satellite in track at every new station. All data are input to the Madrigal database and are available for near real-time processing. We report here on data collected from the recently installed sites. The new Madrigal database products will be highlighted. We focus on analysis of space weather events, and demonstrate the advantages of the additional data provided by the MACAWS system.

2:45 **GTOSat: A Pathfinder for a SmallSat-based Operational Space Weather Program**
Larry Kepko, National Aeronautics and Space Administration

GTOSat is a 6U CubeSat mission targeting a 2021 launch into a low inclination geosynchronous transfer orbit (GTO). From this orbit, GTOSat will measure energy spectra and pitch angles of ~hundreds keV - few MeV electrons and ions, with the primary science goal of advancing our quantitative understanding of particle acceleration and loss in Earth's radiation belts. Instrumentation includes a high-heritage Relativistic Electron Magnetic Spectrometer (REMS), a customized version of the MagEIS instrument onboard NASA's Van Allen Probes mission, and a boom-mounted fluxgate magnetometer to provide 3-axis knowledge of the local ambient magnetic field. The GTOSat bus consists of a 6U spin-stabilized structure with a Sun-pointing spin axis. Mitigation of radiation effects is accomplished through a multi-pronged systems approach consisting of spot shielding, parts selection, and a vault that utilizes a novel z-graded radiation shielding developed by NASA LaRC to reduce the total dose for 1 year on orbit to less than 25 krad. Communication is achieved via an S-band transceiver, enabling high data throughput through the Near-Earth Network (NEN) and low-latency radiation belt monitoring via the Tracking and Data Relay Satellite System (TDRSS), enabling nowcasting of the radiation belt environment. In addition to the compelling science objective, GTOSat will fly a new scalable radiation tolerant command and data handling (C&DH) system that could be used for future SmallSat missions. For just under $4.5M, and inside a 6U volume, GTOSat will provide continuity of radiation belt measurements in the post Van Allen Probes era, and serve as a pathfinder for a future SmallSat-based operational space weather program, of the type envisioned by the 2012 Heliophysics Decadal Survey.

3:00 **GOES-R Solar UltraViolet Imager Extended Coronal Imaging**
Gustave Comeyne, NOAA/NESDIS

GOES-16 and GOES-17 each hosts a Solar UltraViolet Imager (SUVI) that images the Sun in six extreme ultraviolet (EUV) wavelengths: 9.4 nm, 13.1nm, 17.1nm, 19.5nm, 28.4nm, and 30.4nm. The SUVI is nominally Sun-pointed and has a four-minute imaging sequence covering all the channels and meeting the dynamic range requirements. Based on the SUVI capabilities observed on-orbit, a campaign to image the extended solar corona was undertaken in 2018. This was performed by off-pointing the SUVI line-of-sight to the left and right of the Sun and producing a composite image by stitching together the off-pointed and the Sun-centered images. The imaging area in the composite is about three times the nominal image area in the East-West direction (about 5 RSun versus 1.8 RSun for nominal images). The campaign was conducted in February (4 hours), June (72 hours), and August-September of 2018 (5 weeks). Results from the campaign indicated the presence of solar corona to three solar radii, even in the quiet Sun part of the solar cycle. NOAA can operationalize this concept by tasking the SUVI on one of GOES-E and GOES-W. Such long-term operation will provide data that is needed to establish the much needed connectivity between the EUV and white light coronagraph data for the CME events.

3:15 **Seismic Monitoring of the Sun's Far Hemisphere**
Joe Werne, NorthWest Research Associates

For the past decade, NASA's twin STEREO spacecraft have provided us with EUV images of solar activity in the Sun's far hemisphere. By informing us of active regions gestating for up to two weeks before they rotate into direct view from Earth, these observations have considerably facilitated our ability to forecast space weather at Earth with lead times from about a day to two weeks. The STEREO spacecraft are now on the verge of losing their far-side vantage, as they gradually drift back into the Earth side of the solar system. Over the next decade, there will be significant periods during which coverage of the Sun's far hemisphere by spacecraft will be next to nil.

Since the turn of the century, analytic techniques applied to helioseismic observations of the Sun's near hemisphere have given us seismic maps of strong active regions in its far hemisphere. This facility promises to fill in the blanks in our awareness of solar activity when direct observations of the Sun's far hemisphere are not available.

We will review the development of far-side solar seismology from the 1990s to present. We will give an overview of what modern helioseismic monitoring of the Sun now gives us, capitalizing upon recent research under a NOAA SBIR grant on the relationship between helioseismic signatures and various aspects of solar activity. We will also show results of recent efforts to estimate signed magnetic-flux distributions from helioseismic signatures in the far hemisphere for applications in magnetic flux-transport projections and global coronal magnetic-field modeling. This work follows innovations introduced by C. Henney and N. Arge using the Hale Polarity Law for this purpose.

3:30 - 4:30 **Break and Poster Session (Geospace/Magnetosphere Research and Applications)**

4:30 - 5:40 **<u>Advances in Space Weather Research and Modeling</u>**
Chair: Michele Cash, NOAA/SWPC

4:30 **Research and Modeling at the Air Force Research Laboratory**
James McCollough, Air Force Research Laboratory

The Air Force Research Laboratory (AFRL) houses the US Air Force's core-funded space environmental science and technology (S&T) activities addressing defense requirements. The Laboratory executes an in-house and contract research effort spanning basic and applied research, as well as advanced technology development, focused on knowledge and technology gaps affecting the joint force. The service Laboratory's most critical role is to provide the bridge between the joint warfighter and the space weather research community, both to translate operational gaps into research needs and to translate research outcomes into tailored operational technologies. In this presentation we will discuss current efforts in space weather research and modeling at AFRL.

4:45 **CCMC-SWPC Partnership Aiming to Improve Operational Space Weather Products and Services**
Maria Kuznetsova, National Aeronautics and Space Administration

The Community Coordinated Modeling Center (CCMC) and the Space Weather Prediction Center (SWPC) have collaborated on several projects to transition research models to the operational forecasting community. These transition efforts that directly support the National Space Weather Strategy have been formalized with a NASA-NOAA MOU and an Interagency Annex. The first CCMC-SWPC Annex outline a 2-year efforts to assess improvements in CME arrival time forecasts using the new ADAPT model, and upgrades to the WSA, and ENLIL models. The presentation will overview the year-1 progress, discuss opportunities for extension and present ideas for new projects.

5:00 **Machine Learning in Space Weather**
Enrico Camporeale, NOAA/SWPC

The numerous recent breakthroughs in machine learning (ML) make necessary to carefully ponder how the scientific community can benefit from a technology that, although not necessarily new, is today living its golden age.

In this talk, I will give a short overview of possible applications of Machine Learning in Space Weather forecasting and nowcasting. In particular, I will highlight the powerful integration of physics-based models with data-driven approaches.

5:10 **The Performance Characteristics of Operational Flare Forecasting Systems**
KD Leka, NorthWest Research Associates

Solar flares can be considered the initiating event for many Space Weather phenomena and impacts; as such, they are tied to radiation storms and ionospheric-layer disruption as identified in the Space Weather Action Plan. Solar flares are perhaps themselves not the direct cause of other serious Space-Weather impacts, but do serve as an identified initiation to the related solar- and heliospheric-based processes that may more directly cause such problems. Predicting solar flare likelihood has thus long been a defined and required operational product, now with several facilities world-wide providing operational forecasts to a variety of customers. Evaluating the performance of operational forecasting methods was the subject of a recent workshop held at Nagoya University Institute for Space-Earth Environmental Research through its Center for International Collaborative Research. Using a variety of quantitative metrics, the team examined the overall performance (spoiler alert #1: generally better than 'no skill', but not great) -- but more importantly, we have sought to ask why certain methods and implementations perform better than others, and how to best evaluate this question in the first place. In this talk I will summarize the group's findings including performance differences resulting from both methodology and data, and especially highlight the findings that may improve operational performance in the future (spoiler alert #2: Human forecasters should not yet be worried).

5:20 **NASA's SPoRT Center: Progress in Extending Terrestrial Weather R2O/O2R to Space Weather**
Ghee Fry, National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) Short-term Prediction Research and Transition (SPoRT) Center is located at Marshall Space Flight Center in Huntsville, Alabama. Co-located with the Huntsville National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Forecast Office, SPoRT is a recognized leader in the transition of satellite datasets and modeling capabilities to the operational terrestrial weather community. For more than 15 years, SPoRT has collaborated with operational forecasters from NOAA/NWS Weather Forecast Offices and National Centers to transition and evaluate experimental data products in an effort to improve weather forecasts. These collaborations have followed a vetted and successful research-to-operations/operations-to-research (R2O/O2R) paradigm that includes forecasters as part of the problem-solving process, develops applications-focused training, integrates data into forecaster decision support tools, and performs targeted product evaluations to ensure that products meet forecaster needs. This same R2O/O2R paradigm can be applied as a unique approach to transitioning experimental products to the operational space weather community. This presentation will focus on a description of the SPoRT R2O/O2R paradigm and an example of how this paradigm has been tested in an operational space weather environment through the first iteration of the transition of the MAG4 (MAGnetogram Forecast) model to operational forecasters at the NOAA NWS Space Weather Prediction Center. MAG4 fills an operational need by generating full-disk solar magnetograms with computed active region parameters whose values determine forecast event rates and a 24-hour persistence forecast of those event rates for solar flares and coronal mass ejections. Additionally, we will share the outcome of a collective, collaborative experience between the research team and forecasters used to determine the optimal product representation, decision support tools, and training to enable transition success.

5:30 **Applied Artificial Intelligence for Science and Exploration**
Madhulika Guhathakurta, National Aeronautics and Space Administration

The recent advances in Artificial Intelligence (AI) capabilities are particularly relevant to NASA Heliophysics because there is growing evidence that AI techniques can improve our ability to model, understand and predict solar activity using the petabytes of space weather data already within NASA archives. This represents a strategic opportunity, since the need to improve our understanding of space weather is not only mandated by directives such as the National Space Weather Action Plan and the Presidential Executive Order for Coordinating Efforts to Prepare the Nation for Space Weather Events, but also because space weather is a critical consideration for astronaut safety as NASA moves forward with the Space Policy Directive to leave LEO and return to the Moon.

The Frontier Development Lab (FDL) is an AI research accelerator that was established in 2016 to apply emerging AI technologies to space science challenges which are central to NASA's mission priorities. FDL is a partnership between NASA Ames Research Center and the SETI Institute, with corporate sponsors that include IBM, Intel, NVidia, Google, Lockheed, Autodesk, Xprize, Space Resources Luxembourg, as well as USC and other organizations. The goal of FDL is to apply leading edge Artificial Intelligence and Machine Learning (AI/ML) tools to space challenges that impact space exploration and development, and even humanity.

The applied AI projects for space weather that are being undertaken by the Frontier Development Lab (FDL) represent an ideal opportunity for utilization of vast amount of NASA and other data to leverage the public-private partnerships of the FDL program in a manner that is highly complementary to ongoing efforts in space weather research. In this talk I will summarize the findings from two space weather topics, "Solar flare forecasting" and "A tool for exploring variability of Solar-Terrestrial interactions" that were part of FDL 2017/2018 summer program.

Friday, April 5

8:30 – 10:00 **Advances in Space Weather Research and Modeling: Solar Wind and CMEs**
Chair: James Spann, National Aeronautics and Space Administration

8:30 **Session Introduction**
James Spann, National Aeronautics and Space Administration

8:35 **Global Boundary Magnetic Field Optimization for Coronal and Solar Wind Models**
Graham Barnes, NorthWest Research Associates

Understanding and modeling the background solar wind is key for modeling the propagation of Coronal Mass Ejections (CMEs). To model the solar wind, it is common to first model the coronal magnetic field using potential field source surface (PFSS) type models driven by photospheric magnetic field data. From the outer boundary of the PFSS based model, assuming radial solar wind streams and a simple model for their interactions leads to predictions of the solar wind speed in the heliosphere. This approach forms the basis for the Wang-Sheeley-Arge (WSA) model.

Within this basic framework, there are a number of choices for how to generate the radial magnetic field boundary condition for the WSA model. Radial magnetic field observations are available, but are typically noisier than line of sight magnetic field observations, particularly in critical areas like the polar regions, and there is presently no operational data source for vector magnetograms. Several ways of estimating the radial component of the field from the line of sight component exist. The central objective of our investigation is to develop an algorithm to best meld these different methods; the quality of the results will be evaluated by comparing WSA predictions for open field regions to observed coronal holes, and comparing predicted wind properties with in-situ measurements of the solar wind. Although the validation will be performed using the WSA model, improved radial magnetic field maps will likely be of benefit to all solar wind and CME propagation models.

8:41 **Improving Magnetic Field Boundary Conditions for Solar Wind Models**
Thomas Berger, University of Colorado, Boulder

We briefly report progress on our NASA O2R grant to recalibrate the GONG full-disk photospheric magnetograms using comparisons to MHD simulations, SDO/HMI, and Hinode/SP data.

8:47 **A Higher-Accuracy Model of the Heliosphere with Improved Background Solar Wind and Coronal Mass Ejections**
Tae Kim, University of Alabama, Huntsville

The modern technologies and infrastructure are highly vulnerable to space weather events, which are primarily driven by solar activity. Consisting of charged particles emitted by the Sun, the solar wind carries the Sun's energy and magnetic field outward and interacts with the Earth's magnetosphere. Therefore, modeling the propagation of the solar wind (including transient structures) in the inner heliosphere between the Sun and the Earth is a significant component of space weather research. The main objective of this project is to improve the quality of our heliospheric simulations and forecasting abilities by building on the strengths of the Wang-Sheeley-Arge (WSA)-Enlil model, which is currently used by NOAA for operational forecasts of the solar wind and coronal mass ejection (CME) propagations to Earth. In this study, we propose to use Multi-Scale Fluid-Kinetic Simulation Suite (MS-FLUKSS), which is a package of physics-based computational codes that have been extensively used for heliospheric modeling, from just above the coronal region all the way out to the farthest reaches of the solar influence. Given accurate solar wind parameters to drive the model, MS-FLUKSS is capable of delivering realistic information about the physical properties of the solar wind around Earth and throughout interplanetary space. We will use a time-dependent, three-dimensional magnetohydrodynamics (MHD) solar wind model in MS-FLUKSS with boundary conditions from the Wang-Sheeley-Arge (WSA) coronal model. The basic idea to couple the WSA coronal model with a heliospheric MHD model with insertion of CMEs as determined by solar observations is similar to that of the existing WSA-Enlil+Cone model. However, there are clear differences in our approaches. Instead of using ad hoc prescriptions of density and temperature of the ambient solar wind at the inner boundary of the heliospheric MHD model as currently done by WSAEnlil, we will estimate those parameters from empirical correlations with velocity based on Ulysses and OMNI data. Furthermore, we will model interplanetary propagation of CMEs more realistically by releasing them into the improved background solar wind as flux ropes instead of oversimplified blobs as assumed by the WSA-Enlil+Cone model. We will evaluate our model for certain historical CME events for direct comparison with WSA-Enlil+Cone model and with in situ measurements at 1 AU.

8:53 Using Machine Learning to Validate Heliophysical Models
Michael Kirk, Catholic University of America

Independent model validation is critical feedback to understand where our forecast models are performing well and where they are unreliable. Scientifically, validating solar wind models is a necessary goal to improve the accuracy and understand where physics of the system is correctly captured. Heliospheric models are regularly updated with new physics incorporated, or improved definitions of empirical relationships, but with these improvements questions still remain: How accurately does a model reproduce observed solar wind conditions? When is the model accurate? How do models compare against each other?

We discuss how using machine learning (ML) algorithms can help answer these questions and talk give a specific example: using clustering to identifying physically similar groups in the measured and modeled solar wind and make a direct comparison between the model output and data.

8:59 Inner Heliosphere Modeling With the GAMERA MHD Model
Sasha Ukhorskiy, Johns Hopkins University

We present results from recent modeling efforts using the Grid Agnostic Magnetohydrodynamics (MHD) for Extended Research Applications (GAMERA) code in simulating the inner heliospheric environment, including the background solar wind and propagation of coronal mass ejections (CME). GAMERA is a newly developed MHD code which is a full rewrite of our high-heritage Lyon-Fedder-Mobarry (LFM) MHD code used extensively for solar wind simulations (known as LFM-helio) in the past. GAMERA has been written in modern Fortran, is highly flexible and portable. It features multiple improvements including: minimal external library dependence, high degree of optimization, OpenMP and MPI parallelism allowing use of heterogeneous architectures, and multiple upgrades to the underlying numerics. The background solar wind simulations are performed in a time-dependent fashion and build upon the technique we previously implemented in the LFM-helio code. Here, time-evolving photospheric magnetograms produced by the ADAPT model drive Wang-Sheeley-Arge (WSA) global corona solutions which, in turn, drive the global MHD solution of the inner heliosphere. As part of this recently commenced NASA O2R project, we will build a software pipeline to automate the process of producing such time-dependent simulations for long periods of time (e.g., years). These runs will be placed on a server at JHU/APL and made available to the community via an interactive web-interface. We will show examples of this prototype website in this presentation. For CME modeling, we initiate Gibson-Low (GL) flux-ropes in WSA-driven GAMERA background solar wind solutions. We will discuss some physical and algorithmical details of the process of GL insertion into GAMERA simulations and show results of CME propagation toward Earth along with comparisons with spacecraft at Earth's orbit.

9:05 Improving the Prediction Accuracy of CME Arrivals in the WSA-ENLIL-Cone Model
Dusan Odstrcil, George Mason University

The WSA-ENLIL-Cone model has been routinely used at NASA and NOAA to predict the arrival time of corotating and transient disturbances. Validation studies have found that arrivals of the coronal mass ejections (CMEs) can be predicted with an uncertainty of about 6-9 hours. This is probably the best performance that can be achieved for fixed values of the Cone model free parameters (like the ejecta radial extent and the density enhancement) that can be determined from calibration studies. To further improve the prediction accuracy of CME arrivals, we will enhance the model capacity through the flexible usage of the free parameters that can be constrained by existing observations.

9:11 **Using Magnetograms and Coronal Imaging to Improve Solar Wind Predictions**
Yi-Ming Wang, Naval Research Laboratory

Predictions of solar wind speed are often based on outward extrapolations of photospheric field measurements. We discuss a number of simple ways to constrain the predictions: (1) compare the predictions obtained from different photospheric field maps (e.g., GONG2 and HMI); (2) compare the predicted locations of coronal holes with EUV images; (3) compare the predicted locations of coronal streamers with coronagraph images. Future work should be focused on developing and automating procedures to modify the photospheric field maps so as to optimize the agreement with observed coronal holes and streamers.

9:17 **Reliably Inferring the Sun's Far-Side Magnetic Flux for Operations Using Time-Distance Helioseismic Imaging**
Shea Hess Webber, Stanford University

Solar wind models are highly dependent on global magnetic fields at the solar surface as their inner boundary condition, and the lack of global field data is a significant problem plaguing solar wind modeling. Currently, only near-side magnetic field observations exist and far-side approximations are incapable of predicting growth of existing active regions or new magnetic flux emergence. We therefore plan to develop a method that calibrates far-side helioseismic images, calculated using near-side Doppler observations, to far-side magnetic flux maps to fill this data gap. The calibration will employ machine-learning methods that use EUV 304 Angstrom data as a bridge: a relation will be sought 1) between the near-side AIA 304 Angstrom data and HMI magnetic field data, and 2) between STEREO 304 Angstrom data and far-side helioseismic images obtained from a newly developed time-distance helioseismic far-side imaging method. As an update, progress has been made in establishing the relation between the near-side 304 Angstrom data and magnetic flux data, and some previously-unknown systematics were identified and corrected in the helioseismic far-side images. These systematic-effect-corrected far-side images will then be used to establish a relation with the far-side EUV data.

9:23 **Metric-Based Assessment of New Solar Wind Forecast Models incorporating Data Assimilation**
Pete Riley, Predictive Sciences, Inc.

Accurate modeling of the ambient solar wind is a key component in NOAA/SWPC's present method for forecasting the arrival time at Earth of coronal mass ejections (CMESs) and fast solar wind streams. In this presentation, we describe an ongoing study to improve the accuracy of solar wind solutions through the use of data assimilation, ensemble modeling techniques, time-dependent modeling, and the application of rigorous metrics and skill score, using PSI's CORona-HELiosphere (CORHEL) framework. The pipeline begins with the processing of magnetograms from a variety of sources (e.g., AFRL/ADAPT, HMI, NSO/GONG and NSO/SOLIS), with the focus being on ADAPT maps, which provide time-dependent ensembles, and which, we anticipate, will lead to quantifiable improvements in forecast accuracy. These boundary conditions drive a model of the solar corona and inner heliosphere, the results of which are tested directly against NOAA and CCMC's currently implemented frameworks. We employ basic ensemble modeling methodologies in several ways, including the generation of multiple coronal solutions using a set of ADAPT realizations for each time period (as well as other observatories) and compare them with a range of observed outputs (e.g., coronal hole boundaries and in situ measurements). We also describe several refinements currently underway. For example, we are incorporating 'data assimilation' techniques by computing modeled-coronal hole boundaries and comparing them with automatically-determined boundaries from SDO observations, which will allow us to select the realizations with the highest likelihood of matching 1

AU measurements. Additionally, we are developing time-dependent solutions, driven by evolving ADAPT maps. This study, we believe, will help demonstrate the crucial role that an accurate specification of the background solar wind plays, and identify some of the key attributes that a successful operational forecasting model must possess.

9:29 **Space Weather O2R: Physics-Based Extension of the WSA Model Capabilities**
Igor Sokolov, University of Michigan

9:35 Interactive Tool for Modeling Multiple Solar Eruptions
Jon Linker, Predictive Sciences, Inc.

The main objective of this SBIR project is to develop CORHEL-AMCG, an interactive and highly automated tool that will allow non-expert users to routinely model multiple coronal mass ejections (CMEs) in a realistic coronal and heliospheric environment. CORHEL-AMCG will significantly extend the capabilities of currently developed CME-modeling tools, by including the complexity of pre-CME configurations, the slow initiation of CMEs, and their interaction in interplanetary space. CORHEL-AMCG builds on a previous tool that uses TDm flux ropes (Titov et al. 2014) to create the pre-eruptive configuration. CORHEL-AMCG employs RBSL flux ropes (Titov et al. 2018) that can be more easily applied to complex active regions, which are often the source of major CMEs. These advances will make our tool an extensible application that can be used by the broader scientific community and will constitute a major step towards more accurate operational space-weather forecasting.

During Phase I of the project, we have developed a prototype of CORHEL-AMCG that was delivered to the CCMC for testing. In this presentation, we briefly discuss the main properties of CORHEL-AMCG, how we plan to develop a fully functional version during Phase II of the project, and how the final framework could be transitioned into operational use for space-weather forecasting.

9:41 – 10:00 **Discussion**

10:00 - 10:30 **Break**

10:30 – 11:45 **<u>Advances in Space Weather Research and Modeling: Magnetospheric Energetic Particles and Plasma</u>**
Chair: Howard Singer, NOAA/SWPC

10:30 **Quantitative Forecasts and Specifications of Outer Radiation Belt Electrons Based on Solar Wind Conditions**
Xinlin Li, University of Colorado Boulder

Our current real-time forecasting models of MeV electron flux at geosynchronous (GEO) orbit and geomagnetic indices, e.g., AE and Dst, based on real-time solar wind measurements from ACE (previously) and DSCOVR (currently) are operating in real time. All results are publicly available on our website: http://lasp.colorado.edu/~lix/. It is a natural step to expand the forecasting and specification of relativistic electron fluxes inside and outside GEO, since we have accumulated more than six years of detailed measurements of charged particles in different energies, electric and magnetic fields, and various waves inside GEO by Van Allen Probes, as well as over 10 years of relevant data from the THEMIS mission covering inside and outside GEO. These rich data sets will enable us to build and validate our forecasting model of the relativistic electrons at almost any location inside magnetosphere. Our proposed model will incorporate energy diffusion, radial diffusion, and loss, providing a means of testing the relative importance and timing of these processes against data. The model will have realistic boundary conditions at the plasmapause and magnetopause and will be constrained by observations of precipitation loss and radial diffusion rates, and eventually provides the real-time forecast of the radiation belt electrons inside the magnetosphere based on real-time solar wind conditions.

10:36 Specifying High-altitude Electrons using Low-altitude LEO Systems (SHELLS)
Janet Green, Space Hazards Applications, LLC

This presentation provides a brief introduction to the SHELLS project that was recently funded as part of the joint NASA/NOAA Heliophysics Space Weather Operations to Research proposal call. The goal of the project is to deliver a purely data driven global specification of the high energy electron environment near Earth that includes retrospective, real time, and forecast outputs using machine learning techniques. The project will improve the existing SHELLS electron radiation belt model that was created to demonstrate the feasibility of the neural network technique. The demonstration model uses a neural network to learn the mapping from low altitude NOAA POES electron flux measurements to near equatorial Van Allen Probes measurements. Once the mapping is learned, the electron flux can be specified throughout the magnetosphere from L=2-6 using only the Kp index and measured POES electron fluxes. The project will build upon this initial success and expand the time, energy, and spatial coverage of the demonstration model. The work will update the model to use deep learning techniques that can capture more complicated relationships and the time cadence of the output will be increased. Most importantly, the architecture will be modified so that off equatorial regions can be modeled to provide a global flux mapping. The final improvement will be to add forecast capabilities. Once the model has been validated, the project will produce a publicly accessible long-term history of the environment driven by past POES and Kp data as inputs. Lastly, the project will create a real-time and forecast framework that can be implemented and run operationally that will include displays for some select orbits inside of GEO that could be used to drive alerts. The improved model and applications will fulfill the O2R objectives by giving satellite industry stakeholders a tool to more effectively diagnose and anticipate satellite anomalies related to internal charging. It will give NOAA the ability to assess and warn users of global space weather threats to the satellite infrastructure and establish data driven baseline performance metrics for evaluating current and future modeling efforts. Also, it will provide the scientific research community with a long term history of the electron radiation environment for analysis that complements in-situ data from the NASA Heliophysics Observatory.

10:42 PreMevE: A Neural Network Based Predictive Model for MeV Electrons inside Earth's Outer Radiation Belt
Yue Chen, Los Alamos National Security, LLC

Relativistic electrons with sustaining high flux levels inside the Earth's outer radiation belt present a space weather hazard to spaceborne electronics. These electrons, with kinetic energies up to multiple megaelectron-volt (MeV), manifest a dynamic and event-specific nature due to the delicate interplay of competing transport, acceleration and loss processes. Thus, forecasting outer belt MeV electrons has been long pursued by space weather community but remains an unresolved task. Recent studies have demonstrated the vital roles of electron resonance with waves (including such as chorus and electromagnetic ion cyclotron); however, it is still challenging for current diffusion radiation belt models to reproduce behaviors of MeV electrons during individual geomagnetic storms. Currently, we are working on a Heliophysics Space Weather O2R project that aims to develop a new, lightweight but reliable model called PreMevE to predict storm-time variance of MeV electrons within the whole outer radiation belt region. This neural network based model, taking advantage of the cross-energy, cross-L-shell, and cross-pitch-angle coherence caused by wave-electron resonant interactions, ingests observations mainly from belt boundaries including NOAA POES from low-Earth-orbits and upstream solar wind conditions to provide high-fidelity nowcast (multiple hour prediction) and forecast (> ~1 day) of MeV electron fluxes over L-shells between 2.8-7. Preliminary results from PreMevE exhibit high performance when assessed against long-term in situ data from one Van Allen Probe and a LANL geosynchronous satellite. As a first-of-its-kind, PreMevE can not only predict onsets of MeV electron enhancements during storms with 1-day forewarning time, but also reliably specify the evolving electron spatial distributions afterwards. This new model will enhance our preparedness for severe MeV electron events during post-RBSP era, and further add new science significance to existing and future LEO space infrastructure.

10:48 **A Machine Learning Based Specification and Forecast Model of the Inner Magnetospheric Radiation Environment**
Jacob Bortnik, University of California Los Angeles

We present a brief overview of our recently funded NASA/SWO2R project aimed at creating specification and forecast models of the energetic particles (~keV to ~MeV) and cold plasma in the Earth's magnetosphere, using data from a number of currently operational NASA and NOAA satellites. Our project will employ advanced machine learning techniques (neural networks) working either independently (for lower energies) or integrated with physics-based simulation models (for ultra-relativistic electrons). The work is to be performed in close collaboration between our research group at UCLA (having extensive radiation-belt theory and modeling experience) and a private-sector, commercial space weather operations provider (SET, with >17 years of space weather operational experience) that will inform the creation of our models, use our models to test-run as pilot operational models (giving us feedback in the process), and assist in the creation of long-range radiation forecasts (out to ~6 days) using SET's prediction/forecasting technology. As such, our proposed project is extremely relevant to the joint goals of NASA and NOAA, as articulated in the H-SWO2R focus, to improve specifications and/or forecasts of the energetic particle and plasma conditions encountered by spacecraft within Earth's magnetosphere.

10:54 **An ARIMAX Model of ULF Wave Power and Radial Diffusion for Space Weather Forecasting**
Kyle Murphy, University of Maryland, College Park

The Earth's outer radiation belt is comprised of highly energetic electrons which pose a hazard to both in-situ and ground-based infrastructure. Key to understanding the variability in the Earth's outer radiation belt is an accurate characterization of the wave-particle interactions which control the dynamics of these highly energetic electrons, including for instance, Ultra Low Frequency (ULF) waves. In this presentation we describe the scientific objectives and methodology of a new Space Weather Operations to Research project, the goal of which, is to develop and validate state-of-the-art near-real time models ULF wave power and radial diffusion coefficients for use in radiation belt forecasting. Utilizing an extensive data-base of ground-based ULF wave power and in-situ solar wind observations an Auto Regressive Integrated Moving Average with eXogenous variables (ARIMAX) model of ULF wave power will be developed and validated. The ARIMAX model of ULF wave power will subsequently be used to calculate radial diffusion coefficients for use in radiation belt simulations. To increase accuracy the ARIMAX model will rely on near-real time inputs of solar wind parameters available through NOAA and ULF wave power from the CARISMA magnetometer array. Initial results of the development and the validation of the ARIMAX model are presented along with a detailed outline of the project.

11:00 **Data-Augmented Forecasting Model for near-Earth Relativistic Electron Intensities**
Sasha Ukhorskiy, Johns Hopkins University

Geomagnetic storms can induce dramatic variability in the intensity of the outer radiation belt. The relativistic electron intensity often exhibits deep depletions during the main phase that is followed by a sharp increase during the recovery phase, potentially to levels significantly in excess of the prestorm value. To capture these processes, we have created a new radiation belt model CHIMP (Conservative Hamiltonian Integrator for Magnetospheric Particles) based on test particle and coupled 3-D ring current and global magnetohydrodynamic (MHD) simulations, and driven solely with solar wind and F10.7 flux data. Our approach differs from previous work in that we use MHD information to identify regions of strong, bursty, and azimuthally localized earthward convection in the magnetotail where test particles are then seeded.

Here we describe our model and the results of a sample application to the 17 March 2013 geomagnetic storm. We validate our model using in situ Van Allen Probe electron intensities over a multiday period and show that our model is able to reproduce meaningful qualitative and quantitative agreement on sub-hour timescales. We will describe our plans to extend and advance this approach over the duration of our NASA O2R project. These plans include transitioning to our new global magnetosphere model, Gamera, a reinvention of the LFM; closer integration of our test particle and MHD codes; and using spacecraft data to augment our first-principles modeling by providing localized flux-tube corrections to energetic particle phase space density.

11:06 Advanced Particle and Plasma Environment Specification Model for Spacecraft Impacts
Mei-Ching Fok, National Aeronautics and Space Administration

The main goal of our project is to develop an advanced particle and plasma environment specification model with the following objectives:
(1) To advance our understanding of the fundamental physics affecting the near-Earth particle and plasma environment, especially to investigate the roles of ionospheric conductance.
(2) To advance our existing space weather models to provide accurate predictions of the energetic particle and plasma environments that spacecraft will encounter.
(3) To output full energy spectrum of electron fluxes that is necessary for anomaly assessment. This capability is important especially for satellites that are without environment sensor.
(4) To assess the level of performance of our space weather models by using model validation and metrics studies.
(5) To provide an improved version of radiation belt model to iSWA and CCMC.

The main modeling tool is the Comprehensive Inner Magnetosphere-Ionosphere (CIMI) model integrated with the Space Weather Modeling Framework (SWMF). In the first year, we focus on improving the CIMI model. Two advancements are finished or near completion: (a) replacing (M-K) with (p-K) coordinates in the CIMI model; (b) implementing the IGRF model into the CIMI model. The improved CIMI provides better predictions on both the trapped population and particle precipitation into the ionosphere. These accomplishments pave the way to study the feedback of ionospheric conductance to the energetic particles in the magnetosphere. Our ultimate goal is to provide reliable specification and forecasting of the space environment for satellite operators and other customers to execute appropriate actions.

11:12 Development of a Predictive Inner Magnetosphere Model for Space Weather
Stanislav Sazykin, William Marsh Rice University

We describe a new effort to develop an inner magnetosphere first-principles numerical model capable of predicting geosynchronous electron fluxes substantially better than the currently available operational predictive models. The model is based on the latest version of the Rice Convection Model (RCM), and will be capable of retrospective flux specifications, with the real-time predictive capabilities based on input data availability. The focus is on predicting the electron fluxes of energies up to 50 keV near the geosynchronous orbits (L=4-7), which are thought to be the main factor in causing spacecraft surface charging. We will describe the methodology of targeted code modifications to the inputs to the RCM code and multi-phase testing and validation using geosynchronous particle data. Recent advances have provided us with sufficient insight into the physics of these phenomena that considerably improved specification and forecast should be possible. We anticipate having a predictive model of electron fluxes in the inner magnetosphere driven by real-time inputs that will incorporate the physics of the bi-modal transport in the plasma sheet and will be ready for further operational testing.

11:18 ARMAS Dual Monitor: Demonstrating an Operational Aviation Radiation Monitoring System
W. Kent Tobiska, Space Environment Technologies, LLC

The ‘Automated Radiation Measurements for Aerospace Safety’ (ARMAS) Dual Monitor (DM) project is funded by the NASA SBIR program through its Heliophysics Division. The objective of ARMAS DM is to demonstrate a capacity-building technology for cost-effective identification and management of risks from space weather radiation at aviation altitudes. ARMAS DM uses an ensemble of radiation detectors on long-duration, stratospheric balloons loitering over higher magnetic latitudes. Since the 1950's there have been three stages to manage radiation risks. They include discovering the risk with space measurements, developing and validating models with observational data, and monitoring the radiation environment, i.e., a stage now engaged by ARMAS DM. A fourth, soon-to-come stage will be forecasting the aviation radiation environment, which will require i) data assimilative modeling with physics-based global radiation models using abundant real-time observational data and ii) ensemble modeling with multiple models to estimate uncertainty inherent in the system. ARMAS DM directly supports stage 3 (monitoring) and lays the basis for data assimilative nowcasting and forecasting of the aviation radiation environment. An added contribution of ARMAS DM will be a unique science dataset 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. The ARMAS DM flights are anticipate for the summer of 2021 and will capture some of the highest levels of GCRs during solar minimum. This presentation will overview the status of the ARMAS DM project.

11:24 – 11:45 **Discussion**

11:45 – 12:00 **Solar Cycle 25 Predications**
Lisa Upton, High Altitude Observatory

12:00 <u>**Workshop Closing Remarks**</u>
Howard Singer, NOAA/SWPC