2018 Space Weather Workshop Agenda
Westin Westminster Hotel

Monday, April 16

8:30-9:30 **Satellite Anomaly Database –** Michael Bonadonna
The one-hour session will review progress being made by members of the SWORM Subcommittee on developing a Satellite Anomaly Database to address requirements of the National Space Weather Action Plan action 4.2.8.

9:30-11:30 **Air Force Meeting – by invitation** – Eric Sutton/Michael Starks
This Government-only session, coordinated by the Air Force Research Laboratory, will examine methods and mechanisms by which the DoD, NASA, NSF and NOAA can better communicate and coordinate to ensure maximum leveraging of basic research investments toward meeting civil and military operational space weather requirements.

11:30-1:00 Lunch

1:00 - 3:00 **Space Weather Policy –** Seth Jonas
Discussion of Federal space weather policies and activities.

3:00 - 5:00 **O2R-R2O Current Activities and Future Plans –** Terry Onsager/Howard Singer
This community discussion will provide a forum to hear about recent O2R-R2O accomplishments and opportunities, as well as to gather ideas about the most promising avenues for advancing the O2R-R2O process and outcomes.

3:00 - 4:30 **Student Workshop – by invitation** – Michael Cook and Alfredo Cruz
The Student Networking Session is geared to engage the students with professionals in the Space Weather Industry and learn about student opportunities, prior to the main networking session. Networking is a vital part of this workshop and we hope these conversations will carry on throughout the week.

5:00 - 7:00 **Networking Session for Space Weather Workshop Participants**

Tuesday, April 17

8:30 **Conference Welcome**
Bill Murtagh, NOAA/SWPC

8:45 - 10:00 **Space Weather 2018 – In the Spotlight**
Chair: Bill Murtagh, NOAA/SWPC

8:45 **SWPC – Always Moving Forward**
Brent Gordon, NOAA/SWPC

SWPC has continued to make exciting advances in its capabilities over the past 12 months since the last annual Space Weather Workshop. We are most proud of the developments we have attained to better support space weather customers with our Sun-to-Earth suite of models. In addition to upgrades to our Geospace model, SWPC has begun to make available output from experimental models such as the Geoelectric model and the Whole Atmosphere - Ionosphere Plasma Electrodynamics (WAM-IPE) model. An update to the WSA-Enlil model is also being readied which will become operational later this year. All of these new capabilities have been realized through partnerships with many organizations including the University of Michigan, USGS, NASA, Natural Resources Canada (NRCAN), USAF, and George Mason University (GMU). Closely related to our work to advance our modeling suite, SWPC is working with several partners as we enhance R2O and O2R capabilities across the entire enterprise. Our relationship with NASA continues to strengthen as SWPC partners with the NASA Community Coordinated Modeling Center (CCMC) on an evaluation of the ADAPT model for WSA-Enlil. In addition, we have released, with NASA Heliophysics, a joint Announcement of Opportunity to improve capabilities provided by our operational WSA-Enlil model. SWPC is working with both NOAA/NESDIS and NASA as we explore opportunities for a follow-on mission to L1, scheduled to launch in the 2024 time frame, as well as a future capability for operational coronagraph observations in that same time. Our operations are being prepared for the next generation of geostationary observations coming from GOES-16 & 17 and we continue to work with the NSF sponsored National Solar Observatory (NSO) to make operational its Global Oscillation Network Group (GONG) data processing system. SWPC is participating in NOAA's Commercial Weather Data Pilot where commercial providers will be asked to deliver space weather data obtained from radio occultation instruments, and we are working with several companies that have Small Business Innovative Research (SBIR) grants to foster potential commercialization of space weather products and services. New methods to disseminate our text products are also being explored which will allow us to move past older technologies such as email. Finally, SWPC is working closely with the new administration to continue the important work outlined in the National Space Weather Strategy.

9:00 **The USAF Space Weather Operations Center**
Lt. Col Justin Erwin, US Air Force

The Space Weather Operations Center (SpaceWOC) of the U.S. Air Force's 557th Weather Wing is undergoing several modernization efforts to meet future Department of Defense (DoD) and Intelligence Community (IC) demands. Aligned under the 2d Weather Squadron (2 WS) at Offutt Air Force Base, Nebraska, the SpaceWOC is the sole provider of 24/7 space weather analysis and forecasting information for DoD and the IC, relying on solar activity monitoring at five 2 WS-operated solar observatories located across the globe as the backbone of its space weather data. By fusing this data with observations from other DoD and civilian sources, the SpaceWOC generates and tailors space weather information into actionable, decision-quality intelligence for military and intelligence operations around the world. Additionally, the 2 WS coordinates on a daily basis with NOAA's Space Weather Prediction Center to ensure accuracy and consistency of applicable space weather information. Supported DoD mission areas include satellite launch, tracking, and orbital situational awareness as well as radar and radio frequency communications capabilities across all military services. The SpaceWOC works closely with research partners in DoD, civil service, academia, private industry, and the international community to guide and operationalize new capabilities employing the latest in scientific development and understanding. Its mission continues to grow and evolve as military and civil dependence on space-based assets increases. Current SpaceWOC modernization focus areas include product tailoring and integration with space weather users, training, and manning.

9:15 **MOSWOC – 4 years old! What have we achieved and where are we going?**
Mark Gibbs, United Kingdom Meteorological Office

The Met Office Space Weather Operations Centre (MOSWOC) is 4 years old. An overview of our focus and achievements over the past one to two years and our focus and ambitions for the next few years.

9:30 **The Space Weather Enterprise (SWE) - The Time Is Now!**
Conrad C.Lautenbacher, Jr., GeoOptics Inc.

The importance of Space Weather to world safety and enterprise continues to increase. The pieces needed to form a connected working environment for government, commercial, and academic space weather contributors are in place and their value increasing. Working together with common purpose and goals is the next vital step.

9:45 **Building Resilience against Space Weather Effects: An update from the Office of Science and Technology Policy**
Steven Clarke, Office of Science and Technology Policy

Space weather is a naturally occurring phenomenon that has the potential to cause substantial detrimental effects on the Nation's critical infrastructure, national security, economy and societal vitality. In response, the

White House Office of Science and Technology Policy, working within the Executive Office of the President, is coordinating activities to enhance national space-weather preparedness by coordinating, integrating, and expanding on existing policy efforts in the EOP and across the Federal Government. In this presentation I will share important new developments in our efforts to strengthen our Nation's capability to predict, protect, and respond to space weather events.

10:00 - 11:00 Break and Poster Session (Solar and Interplanetary Research and Applications)

11:00 - 12:15 <u>Panel Session: September 2017 Storm - Discussion on User Needs and Science Capabilities</u>

Chair: Howard Singer, NOAA/SWPC

The September 2017 solar and space weather activity is a reminder that space weather events and real-world consequences are always present, even as we head towards solar minimum. While these events were not in the "extreme" or superstorm category, they were strong to severe and provided an opportunity to exercise new tools used by forecasters, commercial services and the user community for monitoring and modeling space weather events. In this session you will hear about the September 2017 events and impacts, and about observations and model results that inform space weather forecaster warnings, watches and alerts. In addition, events such as the September storms prompt us to ask questions about what else is needed to provide customers with improved services? What are the customer needs and what are the research capabilities that can address those needs? Using the September 2017 storms as an example, this panel will explore how we can improve on our ability to cope with future extreme events by building on R20-O2R opportunities and strengthening the connections between user needs and research capabilities.

11:00 Overview of September 2017 Space Weather Period

Rob Redmon, NOAA/NCEI
Rob Steenburgh, NOAA/SWPC

Between September 6 and 10 of 2017, multiple solar eruptions occurred from active region AR2673. NOAA's well instrumented GOES and DSCOVR spacecraft observed the evolution of these eruptive events from their solar origin, through the interplanetary medium to their geospace impact. The September 6th eruption at X9.3 was the most intense X-class flare recorded since 2005 and the largest to date for the nearly finished solar cycle 24. The September 10th west limb eruption resulted in the first solar energetic particle (SEP) event with sufficient energy to yield a ground level enhancement (GLE) since 2012. DSCOVR observed the coronal mass ejections emitted by these eruptions just prior to their magnetosphere impingement. Strong compression and erosion of the dayside magnetosphere occurred, placing geosynchronous satellites in the magnetosheath. This period was geoeffective in several important ways, elevating hazards to technological systems. This presentation provides a space weather overview.

11:10 Overview of Impacts of the September 2017 Space Weather Period

Rob Steenburgh, NOAA/SWPC
Rob Redmon, NOAA/NCEI

During the September 2017 active space weather period, multiple X-class flares delivered by solar active region AR2673 resulted in rapid and comprehensive ionization of the equatorial upper atmosphere, disrupting HF communications in the Caribbean region while emergency managers were scrambling to provide critical recovery services to a region devastated by hurricanes. Through the lens of NOAA's space weather R-S-G storm scales, this event period increased hazards for systems susceptible to elevated "radio" (R3-strong), "solar radiation" (S3-strong), and "geomagnetic" (G4-severe) conditions. The purpose of this presentation is to provide an operations perspective of the events and an overview of HF and other technological system impacts.

11:20 The Effects of the 10 SEP 17 Solar Event on HF Voice Comms Over the Atlantic

Anthony Abate, Rockwell Collins

11:30 NOAA SWPC Operational Model Performance during the September 2017 Storms

Michele Cash, NOAA/SWPC

During the September 2017 Storms, both the WSA-Enlil solar wind and coronal mass ejection model and the

Geospace model were used by space weather forecasters at the NOAA Space Weather Prediction Center (SWPC) to provide guidance to inform their official forecasts. The WSA-Enlil solar wind model has been running in real-time operations since 2012 and is heavily relied on for by space weather forecasters for determining the likelihood that a Coronal Mass Ejection (CME) will interact with Earth, and if so, its time of arrival. The Geospace model was first transitioned into real-time operations in October 2016 and has been upgraded once since going operational. The Geospace model is a part of the Space Weather Modeling Framework (SWMF) developed at the University of Michigan, and the model simulates the full time-dependent 3D Geospace environment (Earth's magnetosphere, ring current and ionosphere), predicting both global and regional space weather parameters such as external and induced magnetic perturbations in space and on the surface of the Earth. In the operational mode, the Geospace model runs continually using real-time solar wind data from a satellite at L1, currently either DSCOVR or ACE. We present an analysis of the overall performance of these two operational models during the September 2017 storms. Using these results, we identity areas where improvements to the models and the current operational products could be made to more fully address the needs of SWPC customers.

11:40 **September 2017 Space Weather Impacts**
Capt John Ross, US Air Force

The briefing will cover unclassified communication, radiation, and satellite impacts reported to the Space Weather Operation Squadron during the September event.

11:50 **Panel/Audience Discussion**

12:15 - 2:00 **SWPC Lunch Tour** ***(Please Note: Tour participants must have signed up and will miss early afternoon session talks) *Tour bus departs the Westin Lobby at 12:30 PM and returns at 3 PM****

2:00 - 3:30 **Space Weather Policy**
Chair: Tamara Dickinson, Office of Science and Technology Policy

2:00 **EMP, Natural and Adversarial; A Policy Perspective**
Seth Jonas, Science and Technology Policy Institute

An electromagnetic pulse (EMP) is a burst of electromagnetic energy associated with nuclear explosions, pulse-power devices, or space weather events. Both high-altitude nuclear explosions (HANE) and geomagnetic disturbances (GMD), driven by space weather, can affect technology and infrastructure systems across wide geographic areas. Both HANE and GMD can induce currents in long power lines, destabilizing or damaging connected equipment. This presentation will discuss the similarities and differences between HANE and GMD, and will discuss recent policies focused on preparing for, responding to, recovering from, and managing the potential consequences of an EMP-related incident.

2:15 **Reducing GMD Risks to Reliability of the North American Electricity Grid**
Mark Olson, North American Electric Reliability Corporation

The 1989 geomagnetic disturbance (GMD) event that caused a blackout of the Hydro Québec system provided important lessons to the electricity sector. Since then, the sector has made significant progress in reducing vulnerability to geomagnetic storms. Most recently, in response to NERC's 2012 report, *Effects of Geomagnetic Disturbances on the Bulk Power System*, and the U.S. Federal Energy Regulatory Commission (FERC) May 16, 2013 order, NERC and industry have adopted two GMD standards to address risks to reliability caused by GMD.
The first stage standard (EOP-010-1 – Geomagnetic Disturbance Operations) took effect in April 2015. The standard requires entities throughout North America to have GMD operating procedures that can mitigate the potential impacts of GMD on the grid.

The second stage standard (TPL-007-1 – Transmission System Planned Performance for Geomagnetic Disturbance Events) was approved by FERC in September 2016. The new standard requires entities throughout North America to perform state-of-the-art vulnerability assessments of their systems and equipment for potential impacts from a severe 1-in-100 year benchmark GMD event and mitigate against identified impacts. When needed, mitigation could include changes in system or equipment design, or the installation of hardware to monitor or reduce the flow of geomagnetically-induced currents (GIC). Entities began implementing the new requirements in 2017 and must meet several steps leading to completion of the vulnerability assessments and mitigation plans by 2022.

In addition to developing and overseeing compliance with these reliability standards, NERC is engaged in an active GMD research effort with government, public, and private research organizations in the U.S., Canada, and other countries to advance understanding of GMD risks.

The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid. NERC develops and enforces Reliability Standards; annually assesses seasonal and long-term reliability; monitors the bulk power system through system awareness; and educates, trains, and certifies industry personnel. NERC is subject to oversight by the Federal Energy Regulatory Commission (FERC) and governmental authorities in Canada. NERC's jurisdiction includes users, owners, and operators of the bulk power system, which serves more than 334 million people.

2:30 **Provision of the Space Weather Advisory for International Air Navigation**
William Bauman III, Federal Aviation Administration

In November 2018, Space Weather Canters designated by the International Civil Aviation Organization (ICAO) will begin issuing the Space Weather Advisory product in support of international air navigation. The Space Weather Advisory is defined in Amendment 78 to Annex 3 of the Convention on International Civil Aviation which goes into effect in July 2018. Over 15 years will have elapsed from ICAO officially identifying space weather phenomena as posing potential risks to international air navigation to commencement of the operational production and dissemination of the Space Weather Advisory. This presentation will describe the process for developing the Space Weather Advisory, with an emphasis on the critical role of the ICAO Meteorology Panel, the information contained in the product, and the anticipated uses of the product by aviation decision-makers.

2:45 **Space Weather Services for Australia's Critical Infrastructure**
Richard Marshall, Australia Bureau of Meteorology

The Bureau of Meteorology's Space Weather Services is the national provider of space weather information to the Australian region and beyond. The Bureau collaborates with a number of national and international organizations and academic institutions to develop and deliver services to help mitigate the impacts of space weather on Australia's critical infrastructure. Services are developed in collaboration and consultation with industry sectors such as aviation, defense, positioning infrastructure, and the energy sector including pipeline and power network operators and owners. Such collaborations are aimed at improving our understanding of the impacts of space weather on critical infrastructure and/or improving our ability to forecast and mitigate its impact. Current service development projects include: development and delivery of products for aviation within the Australian region that meet the proposed ICAO standards for space weather, an ionospheric model that provides GNSS corrections to an accuracy of a few centimeters for a National Positioning Infrastructure, a model to calculate the flow of GICs in Australian power networks and pipelines, and models that improve space weather forecasting capabilities such as predicting the orientation of the solar wind IMF with CME impact and probabilistic solar flare forecasts. This paper will provide insight into some of these collaborative projects and the interactions with industry, recent results, and mitigating strategies for space weather that have been developed through the consultative process.

3:00 **Asia Oceania Space Weather Alliance (AOSWA)**
Yuki Kubo, Japan's National Institute of Information and Communications Technology

Asia Oceania Space Weather Alliance (AOSWA) was established in 2010 for encouraging cooperation and sharing information among institutes in Asia-Oceania region concerned with and interested in space weather. Asia-Oceania region has become one of the most important regions for space utilities and require close communication and cooperation. AOSWA has held some workshops in Asia-Oceania region like SWW in US and ESWW in Europa, and the workshop was held four times so far. The 5th AOSWA workshop will be held in Indonesia hosted by LAPAN in September this year. In this presentation, we will briefly introduce the activities of AOSWA.

3:15 **European Space Agency Space Situational Awareness Lagrange Mission to L5 Point**
Juha-Pekka Luntama, European Space Agency

ESA started analysis of an enhanced space weather monitoring system combining measurements from the Sun-Earth line and away from the Sun-Earth line with two parallel Phase 0 mission concept studies in 2014. These studies carried out by European aerospace industry and research organizations addressed space weather monitoring needs from both the Sun-Earth line and from the L5 point. The Phase 0 studies were completed by the end of 2016 and in 2017 ESA combined and consolidated the study results into mission and system requirements for space weather monitoring missions in L1 and in L5 points. With the mandate given by the Member States participating into the ESA Space Situational Awareness (SSA) Programme, ESA initiated two parallel Phase A/B1 mission system studies for a space weather monitoring mission to the L5 point in December 2017. These 18 month studies will be completed by June 2019 and they will pave the way for bridging phase and a mission Phase C/D/E proposal. The mission system studies are accompanied by two instrument pre-development studies addressing instrument packages for solar remote sensing and in-situ measurements, respectively.

This presentation will describe the Lagrange L5 space weather monitoring mission that ESA SSA Programme is currently developing. The presentation will show the baseline Lagrange mission concept including the observation requirements defined for the mission and the instrumentation that has been selected as the starting point based on the results of the Phase 0 studies. The first results from the recently started Phase A/B1 study and the considerations for the coordination of the Lagrange L5 mission and the measurements from the Sun-Earth line to build a comprehensive space weather monitoring system will be addressed. Finally the presentation will outline the next steps and the schedule for the mission implementation.

3:30 - 4:30 Break and Poster Session (Solar and Interplanetary Research and Applications)

4:30 - 5:15 Economic Impact Assessment

Chair: Chris Cannizzaro, US State Department

4:30 The Canadian Space Weather Socioeconomic Impact Study

Pierre Langlois, Canadian Space Agency

It was recommended by the United Nations that countries perform a space weather socioeconomic impact study. The methodology for the Canadian study will be presented, along with a progress status and future work.

4:45 The Social and Economic Impacts of Space Weather (US Project)

Susan Taylor, Abt Associates

The U.S. National Space Weather Action Plan (SWAP) calls for new research into the social and economic impacts of space weather and for the development of quantitative estimates of potential costs. In response to this call, NOAA’s Space Weather Prediction Center (SWPC) and Abt Associates worked together to identify, describe, and quantify the impacts resulting from both moderate and severe space weather events across four technological sectors: Electric power, commercial aviation, satellites, and Global Navigation and Surveillance Systems (GNSS) users. Our study involved an extensive literature review and conversations with ~50 stakeholders across these industries of diverse expertise from engineering to operations to end users. We also developed simple, tractable estimates of the potential costs of impacts that are apt to be largest and are also most plausible during moderate and more severe space weather scenarios. We hope that our systematic exploration of potential impacts provides a foundation for the future work that is critical for designing technologies, developing procedures, and implementing policies that can effectively reduce our known and evolving vulnerabilities to this natural hazard. This study concluded in October 2018. Our final report is publically available and can be downloaded at: https://www.weather.gov/news/171212_spaceweatherreport

5:00 Testing Realistic Scenarios for Space Weather: The Economic Impacts of Electricity Transmission Infrastructure Failure in the UK

Mark Gibbs, United Kingdom Meteorological Office

Following on from last year’s presentation by Edward Oughton, this continues the work in which a number of Realistic Disaster Scenarios due to failure in electricity transmission infrastructure are tested. We use regional Geomagnetically Induced Current (GIC) studies to identify areas in the UK high-voltage power system deemed to be high-risk. The potential level of disruption arising from a large geomagnetic disturbance in these ‘hot spots’ on local economic activity is explored. Electricity is a necessary factor of production without which businesses cannot operate, so even short term power loss can cause significant loss of value. We utilize a spatially disaggregated approach that focuses on quantifying employment disruption by industrial sector, and relating this to direct Gross Value Added loss. We then aggregate this direct loss into a set of shocks to undertake macroeconomic modelling of different scenarios, to obtain the total economic impact which includes both direct and indirect supply chain disruption effects.

5:15 **Special Presentation: Parker Solar Probe: A NASA Mission to Touch the Sun**
Nicola Fox, Johns Hopkins University Applied Physics Laboratory

The Parker Solar Probe (PSP) mission will be the first mission to fly into the low solar corona, revealing how the corona is heated and the solar wind and energetic particles are accelerated, solving fundamental mysteries that have been top priority science goals since such a mission was first proposed in 1958. The scale and concept of such a mission has been revised at intervals since that time, yet the core has always been a close encounter with the Sun. The primary science goal of the Parker Solar Probe mission is to determine the structure and dynamics of the Sun's coronal magnetic field, understand how the solar corona and wind are heated and accelerated, and determine what mechanisms accelerate and transport energetic particles. PSP uses an innovative mission design, significant technology development and a risk-reducing engineering development to meet the science objectives. In this presentation, we provide an update on the progress of the Parker Solar Probe mission as we prepare for the July 2018 launch.

5:45 - 8:00 **12th Annual NOAA - Commercial Space Weather Interest Group (CSWIG)/American Commercial Space Weather Association (ACSWA) Summit Meeting – by invitation**

Wednesday, April 18

8:30 - 8:40 **Special Presentation: Air Force Space Weather: The Way Ahead**
Col. Jeff Jarry, US Air Force
Mark Pesses, US Air Force

The U.S. Air Force provides operational space weather support to the Department of Defense and National Intelligence agencies utilizing a 24/7operations center supplying tailored products to the warfighter around the globe. This presentation will give the Air Force's way ahead for improving the accuracy, "shelf life" and geolocation specificity of its Space Weather forecasts. This way ahead effort is motivated by and the increasing need for Air Force and DoD space situational awareness in addition to the Air Force's role in the National Space Weather Strategy.

8:40 – 10:00 **Panel Session: Space Weather Action Plan Implementation – Challenges and Opportunities**
Chair: Steven Clarke, Office of Science and Technology Policy

In October 2015, the White House released the National Space Weather Strategy and the National Space Weather Action Plan (NSWAP). These two documents were developed by an interagency group of experts, with input from stakeholders outside the Federal government, to clearly articulate how the Federal government will work to enhance national space-weather preparedness. The Strategy identifies goals and establishes the guiding principles that will focus these efforts in both the near and long term, while the Action Plan identifies specific activities, outcomes, and timelines that the Federal government will pursue accordingly. In October 2016, the White House released Executive Order 13744 -- "Coordinating Efforts to Prepare the Nation for Space Weather Events". The Executive Order directs the implementation of necessary, high-level activities that were not included in the Action Plan, and reinforces the need to work with non-Federal entities to achieve national preparedness for space weather. We are now over two years into the execution phase of the NSWAP. This panel will look back, review achievements, share experience and challenges, and discuss the way forward in our efforts to enhance the resilience of critical infrastructure to the adverse effects of space weather.

8:40 **NASA's Role and Current Efforts for SWAP**
Jim Spann, NASA

8:50 **NSF's Contributions to SWAP Implementation**
Michael Wiltberger, National Science Foundation

9:00 **NOAA Progress on SWAP Activities**
Bill Lapenta, NOAA

9:10 **USAF SWAP Update**
Col. Jeff Jarry, US Air Force

9:20 **Goal 6: International Activities**
Chris Cannizzaro, US State Department

9:30 **USGS Role in SWAP Implementation**
Carol Finn, USGS

9:40 **Panel/Audience Discussion**

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

11:00 - 12:15 **Research and Services Supporting Satellite Operations**
Chair: Rob Redmon, NOAA/NCEI

11:00 **Spacecraft Anomalies and Failures Workshop 2017 Summary**
Alec Engell, NextGen Federal Systems

The 5th annual SCAF Workshop was attended by about 100 participants roughly equally split between government and industry. Over 20 presentations covering an equally diverse set of topics but with all discussions focused back on examining how people, processes, and technologies may be leveraged to identify, characterize, and attribute anomalies of spacecraft as being caused by manmade or natural effects. However, this year it was emphasized that attribution (determining the root cause by component/subsystem) is manifested in validation of environmental and failure models; feedback into design and parts selection; and insights into vulnerability models. In other words, it is not sufficient to document lessons learned; we must "transform" lessons learned into the new context to fully exploit previous experiences to achieve these multiple benefits. The mechanism of Keynote Listeners to create a "workshop" atmosphere was applied this year with three people assigned each day. The observations shared by them are included at the end of each day's technical presentations and contributed significantly to the key observations which will be presented.

11:15 **Summaries for the 2017 Applied Space Environments Conference (ASEC) and the Space Environment Engineering and Science Applications Workshop (SEESAW)**
Linda Neergaard Parker, Universities Space Research Association

Two specialty conferences were held in 2017 that attracted participants from the space environments engineering, applied space sciences, and space weather communities. In May, the first Applied Space Environments Conference (ASEC) was held in Huntsville, Alabama. With the theme of "Measurements, Modeling, Testing, and Tools," the conference brought together over 100 participants from industry, government, and academia to discuss the space environment disciplines' ability to support current space programs and to identify gaps in knowledge and technology needs required for future explorations goals. The conference program included contributions in contamination, meteoroids and orbital debris, atomic oxygen, radiation effects, solar array interaction, spacecraft charging, and space weather. In September 2017, the Space Environment Engineering and Science Applications Workshop (SEESAW) was held in Boulder, Colorado. Focusing on radiation and spacecraft charging effects, SEESAW was a specialty conference which provided an environment for space system design engineers, anomaly analysts, radiation effects scientists, space environment scientists, and others affected by the space environment to discuss space system design and anomaly resolution needs relating to the space environment. A main goal of the SEESAW workshop was to develop roadmaps for improved space radiation environment models and data. This presentation will summarize the conferences and discuss the primary points of interest and outcomes of the events.

11:30 **Tools for Understanding On-Orbit Satellite Anomalies**
Janet Green, Space Hazards Applications, LLC

Intense particle fluxes can damage electronic components on satellites, causing temporary malfunctions, degraded performance, or a complete system/mission loss. Understanding whether space weather is the cause of such problems expedites investigations and guides successful design improvements, resulting in a more robust satellite architecture.

Here we discuss our progress in developing tools for satellite designers, manufacturers, and decision makers to identify on orbit satellite anomalies related to space weather. We highlight two projects, the Satellite Charging Assessment Tool (SatCAT) and the Satellite Anomaly Driver Identification Tool (SANDI). The first is an online application that allows users to fly a satellite through the VERB electron radiation belt model and infer accumulated charge for user chosen shielding levels and materials. The second uses machine learning techniques to take a set of observed anomaly times and measured space particle fluxes and determines which, if any, is likely related to the observed anomaly.

11:45 **AE9/AP9/SPM (IRENE) Commercial Deployment and Use**
Richard Quinn, Atmospheric and Environmental Research

The AE9/AP9/SPM near-Earth statistical radiation environment model, soon to be renamed the International Radiation Environment Near-Earth (IRENE) model, is the new de-facto standard model for radiation design of spacecraft. Compared to the older AE8/AP8 models, IRENE provides better spatial resolution, quantification of uncertainty from both space weather and instrument errors and Monte-Carlo estimation of flux environments above percentile thresholds. Recent improvements include code parallelization for faster run-times on multi-processor computers or clusters. While the model, including source code, is freely available from the Air Force Research Laboratory, a case can be made for its integration into commercial products. For instance, while set up and execution of the model is reasonably straight-forward, the proper interpretation of the results in terms of satellite design or impacts on satellite or component lifetimes is not. For longer missions or multi-satellite constellations, trade space studies become more complex to set up and run-times can be computationally intensive. Based on a decade of experience developing and selling our Space Environment and Effects tool for STK, STK SEET, together with our business partner AGI, we feel a well-thought-out commercial offering can provide good business value to customers in this area. We discuss here the prospects and pitfalls for commercial deployment of the IRENE model.

12:00 **GPS Energetic Particle Data and their Use for Space Weather, Climatology, and Anomaly Assessment**
Steven Morley, Los Alamos National Laboratory

The Global Positioning System (GPS) satellites are distributed across six orbital planes in Medium Earth Orbit (MEO; ~20200km) and follow near-circular, inclined orbits with a 12 hour period. Energetic particle detectors have been flown on the GPS constellation for more than two decades; by February 2016 there were 23 GPS satellites equipped with energetic particle instrumentation. The Combined X-ray Dosimeter (CXD), which is flown on 21 GPS satellites, measures electrons from 120keV to >4MeV and protons above 6 MeV. The electron measurements have recently been cross-calibrated against data from the Van Allen Probes mission, demonstrating its utility for scientific research and radiation environment specification. The proton measurements were also cross-calibrated against the long-running GOES EPS measurements, demonstrating that CXD provides a high-quality specification of the proton flux above 20 MeV. Recently electron and proton data from these instruments, as well as from two BDD-IIR instruments, have been publicly released. The time period covered by this data release is approximately 16 years, which corresponds to more than 167 satellite years of data. The large number of GPS satellites, distributed over six orbital planes, provides important context for ongoing and historical science missions, as well as enabling new types of research not previously possible. We will describe the GPS constellation from the perspective of its use as a monitor for space weather, as a long-running data set for climatological modeling, and what measurements GPS makes that can be used in mission planning and anomaly assessment.

12:15 - 1:30 **Lunch**

1:30 - 2:45 **<u>Building Resilience to Geomagnetic Induced Currents on the Electric Power Grid</u>**
Chair: Christopher Balch, NOAA/SWPC

1:30 **Impacts of Extreme Space Weather Events on Power Grid Infrastructure: Physics-Based Modelling of Geomagnetically-Induced Currents (GICs) During Carrington-Class Geomagnetic Storms**
Michael G. Henderson, Los Alamos National Laboratory

Large geomagnetic storms can have devastating effects on power grids. The largest geomagnetic storm ever recorded -- called the Carrington Event -- occurred in 1859 and produced Geomagnetically Induced Currents (GICs) strong enough to set fires in telegraph offices. It has been estimated that if such a storm occurred today, it would have devastating, long-lasting effects on the North American power transmission infrastructure. Acutely aware of this imminent threat, the North American Electric Reliability Corporation (NERC) was recently instructed to establish requirements for transmission system performance during geomagnetic disturbance (GMD) events and, although the benchmarks adopted were based on the best available data at the time, they suffer from a severely limited physical understanding of the behavior of GMDs and the resulting GICs for strong events. To rectify these deficiencies, we are developing a first-of-its-kind data-informed modelling capability that will provide transformational understanding of the underlying physical mechanisms responsible for the most harmful intense localized GMDs and their impacts on real power transmission networks. This work is being conducted in two separate modes of operation: (1) using historical, well-observed large storm intervals for which robust data-assimilation can be performed, and (2) extending the modelling into a predictive realm in order to assess impacts of poorly and/or never-before observed Carrington-class events. Results of this work are expected to include a potential replacement for the current NERC benchmarking methodology and the development of mitigation strategies in real power grid networks. We report on progress to date and show some preliminary results of modeling large (but not yet extreme) events.

1:45 **CHARGED: An NSF-Funded Initiative to Understand the Physics of Extreme GICs**
Mike Liemohn, University of Michigan

The Comprehensive Hazard Analysis for Resilience to Geomagnetic Extreme Disturbances (CHARGED) project will develop, validate, and apply a state-of-the-art numerical model for studying and predicting Geomagnetically Induced Currents (GICs). GICs are driven by the induced geoelectric field, which is the result of solar storms interacting with the Earth's magnetic field, and an extreme GIC event could leave the United States without electricity for a month or more and cost trillions of dollars to fully recover. Studying and predicting these events is difficult because it requires a multidisciplinary approach that includes magnetospheric physics, ionospheric and atmospheric physics, and physics of the solid Earth. The CHARGED project will include every step of this interconnected system to create the world's first solar wind-to-lithosphere numerical model of the geoelectric field. This project was selected for funding by the NSF Prediction and Resilience of Extreme Events (PREEVENTS) program and is now in its first year of activity. This presentation will describe the project goals, members, and 5-year work plan. Note that other faculty at U-M led a second successful PREEVENTS proposal in extreme space weather modeling, and this project will be briefly discussed as well.

2:00 **GMD Vulnerability Assessment**
Emanuel Bernabeu, PJM Interconnection

The electric grid is arguably the most important critical infrastructure. Geomagnetic Disturbances pose unique reliability and resiliency challenges to the grid. It is argued that there is no "silver bullet" to address this risk. Dr. Bernabeu will cover the impact of GMDs on the power grid and PJM's actions to mitigate the risk (Operating Procedures and Transmission Planning Standards, NERC TPL-007).

2:15 **DOE's Recommended Monitoring Approach for GMDs *and* DOE's Pilot Program to Test and Evaluate Devices that can Mitigate GMD Impacts on the Grid**
John Ostrich, Department of Energy

Power Grid owners and operators are required to perform vulnerability assessments to evaluate whether their systems will likely collapse during a benchmarked GMD event sometimes called the "100-year storm." Data are needed to perform such assessments and evaluations. DOE will talk about its report that examined these data needs. If assessments show likely or possible voltage collapse or thermal damage, there are commercially available technologies that can mitigate and/or protect against these adverse consequences. DOE will also talk about its project to evaluate such technologies and plan to deploy such devices on the grid as a pilot project.

2:30 **Magnetic-Storm Geoelectric Hazard Maps and the Induction of Voltages on Power Grids**
Jeffrey Love, USGS

Research of the U.S. Geological Survey (USGS) Geomagnetism Program is pursued in support of priorities established by United States National Space Weather Action Plan of the National Science and Technology Council's Space Weather Operations, Response, and Mitigation (SWORM) Subcommittee. Recent Geomagnetism Program research projects have focused on the analysis and mapping of geoelectric fields that are induced in the Earth's electrically conducting interior during magnetic storms and which represent hazards for high-voltage electric-power grid networks. Realistic estimates of geoelectric fields can be accomplished 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 permits estimates of extreme-values, such as those realized during rare but intense magnetic storms. Time-dependent maps of geoelectric vectors can be constructed for individual magnetic storms, and voltages on power-grid lines can be estimated. Results inform resilience studies of power-grid networks mandated by the Federal Energy Regulatory Commission (FERC) and 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.

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

3:45 - 5:15 **Panel Session: Space Weather and Aviation - Making the Connection between Operations and Research**
Chair: Robert Rutledge, NOAA/SWPC

Space weather storms can result in lost or degraded communications, radiation hazards to crew and passengers, unreliable navigational equipment, and problems with flight-critical electronic systems. Forecasted growth in air travel, and particularly polar route operations, will require the continued need for space weather services. In addition, the UN International Civil Aviation Organization (ICAO) is in the process of formalizing the provision of space weather information to support international air navigation. ICAO recognizes that airlines require information on space weather events as part of their safety risk management program for flight planning for hazardous situations that could compromise the safety of flight. While the space weather community does provide useful products and services in support of aviation, there are still gaps between the services provided and the needs of the aviation industry for timely and understandable information. This panel will explore the current state of the science, the derived services to airlines, and the use of this information by the aviation community. The panel will explore ideas to improve the safety and operations of the aviation system through the integration of space weather information.

3:45 **United Airlines Space Weather Procedures and Needs**
Mike Stills, United Airlines

3:57 **Real-time Radiation Weather for Commercial Aviation on the Horizon**
W. Kent Tobiska, Space Environment Technologies

4:09 **The Effects of the 10 SEP 17 Solar Event on HF Voice Comms Over the Atlantic**
Anthony Abate, Rockwell Collins

4:21 **SWPC Challenges and Opportunities for Supporting Aviation**
Robert Rutledge, NOAA/SWPC
Bill Murtagh, NOAA/SWPC

4:33 **AFRL Next-Gen Dose Rate Specification and Prediction**
Shawn Young, Air Force Research Laboratory

The Air Force Research Laboratory is in the process of developing a next-generation atmospheric radiation dose rate specification and forecast capability for flight operations and planning. This new capability will draw on the best available dose rate specification and SEP forecast forecast models. I will discuss some of the considerations driving our development and describe the current status of the project.

4:45-5:15 Panel/Audience Discussion

6:00 - 9:00 Banquet Dinner at Westin Lake House
Special Guest Speaker: Thomas Zurbuchen,
Associate Administrator, NASA Science Mission Directorate
"Exploring as One"

Thursday, April 19

8:30 - 10:00 Space Weather Observations
Rodney Viereck, NOAA/SWPC

8:30 Status of the GOES-R Series Space Weather Observations
Juan Rodriguez, NOAA/NCEI

An era of expanded space weather observations from geostationary orbit started with the launch of GOES-R on November 19, 2016. Renamed GOES-16 once it successfully reached geostationary orbit, the first satellite has been returning data for nearly 1.5 years, and became the GOES-East operational satellite at 75.2 deg W on December 18, 2017. The second satellite (GOES-S, now GOES-17) was launched on March 1, 2018, and is scheduled to go into operations as GOES-West in late 2018. GOES-T and -U are currently scheduled to launch in 2020 and 2024, respectively.

The four satellites in the GOES-R series each carry four new space weather instruments: the Solar Ultraviolet Imager (SUVI), the Extreme Ultraviolet and X-Ray Irradiance Sensors (EXIS), the Space Environment In Situ Suite (SEISS), and the Magnetometer (MAG). Currently, the Solar Terrestrial Physics section in the NOAA National Centers for Environmental Information (NCEI) is conducting the post-launch product testing (PLPT) of the GOES-16 space weather products. NCEI's responsibilities include characterizing the on-orbit performance of the instruments, including cross-calibration with GOES 13-15; identifying issues in the first level of ground processing software; developing algorithm improvements to address instrument performance realities encountered on-orbit; and developing the second level of space weather products, which will be used by the Space Weather Prediction Center (SWPC) in its real-time operations.

In this presentation, we will address the current status of the GOES-R series satellites, provide an overview of the GOES-16 observations, and summarize NOAA plans for use and dissemination of the data.

8:45 The GOLD Mission – Real-time Imaging of the Space Weather in Earth's Ionosphere and Thermosphere from Geostationary Orbit
Richard Eastes, University of Colorado, Laboratory for Atmospheric and Space Physics

NASA's GOLD mission successfully launched an ultraviolet (UV), imaging spectrograph on January 25, 2018. The imager is a hosted payload on SES-14, a commercial communications satellite which is being placed into a geostationary orbit. The GOLD imager will begin a two-year science mission this Fall. SES-14's final orbit allows the imager to stay above one location, over eastern South America at 47.5 degrees west longitude, near the mouth of the Amazon River. From there, the imager will repeatedly observe the same geographic locations over most of the hemisphere at a 30-minute cadence, which is comparable to the time scale for changes in the ionosphere-thermosphere (I-T) system. The time resolution and spatial coverage will allow the GOLD mission to track the changes due to geomagnetic storms, variations in solar extreme ultraviolet radiation, and forcing from the lower atmosphere. In addition to providing a new perspective by being able to repeatedly observe the same hemisphere at a high cadence, GOLD's measurements will provide data essential for understanding how the Earth's ionosphere and thermosphere respond to forcing from both the Sun and the Earth's lower atmosphere. The imager will scan the full disk at a 30-minute cadence, making spectral images of Earth's UV emission from 132 to 162 nm, as well as observations of the Earth's limb. The data will be transmitted to the ground in real time. Fundamental parameters needed for better prediction and specification of the ionospheric space weather will be derived from the data, including the composition ratio (O/N2) and temperature of the neutral atmosphere on the dayside disk and, on the nightside disk, peak electron densities and density depletions in the low latitude ionosphere.

9:00 DSCOVR – Status Update and Comparing Data from L1
Doug Biesecker, NOAA/SWPC

NOAA/DSCOVR launched Feb 11, 2015 and became operational July 27, 2016. Since that time, the DSCOVR Magnetometer has performed flawlessly. However, the DSCOVR Faraday Cup and the DSCOVR spacecraft itself have at times, performed less than nominally. In spite of that, there are also improvements you may not be aware of. During nominal periods, the data quality is much improved relative to the NASA/ACE real-time solar wind plasma data. This has meaningful benefits for models that use these data as input, such as the Geospace model now in operations. In addition, outages in plasma data due to solar energetic proton events that impacted ACE during many severe and extreme geomagnetic storms will not affect DSCOVR. However, DSCOVR has entered Safehold 18 times since June 23, 2015. The Faraday Cup, which provides solar wind velocity, density and temperature data sometimes returns poor data during periods of low solar wind density. Various changes to the onboard software and to the ground processing have been made to ensure the Faraday Cup returns valid data most of the time and work continues to improve the data. We will discuss the value of improved data quality for improving forecasts; the spacecraft SafeHolds in more detail; and describe the issues with the Faraday Cup including the efforts to improve the data quality. In addition, we will show comparisons of data between NOAA/DSCOVR, NASA/ACE, and NASA/WIND all orbiting the L1 Lagrange point.

9:15 Activities of Korean Space Weather Center
Jinwook Han, Korean Space Weather Center

The Korean Space Weather Center (KSWC) of the National Radio Research Agency (RRA) is a government agency. RRA regulates the use of radio spectrum resources, oversees the convergences of radio communications, researches standardization issues and ensures the preservation of safe radio wave environments. RRA established KSWC in Jeju Island in 2011 with the increasing importance of space weather and to minimize the socio-economic damage from it. KSWC is the official source of space weather information for Korean Government and the primary action agency of emergency measure to severe space weather condition as the Regional Warning Center of the International Space Environment Service (ISES). KSWC's main role is providing alerts, watches, and forecasts in order to minimize the space weather impacts on both of public and commercial sectors of satellites, aviation, communications, navigations, power grids, and etc. KSWC is also in charge of monitoring the space weather condition and conducting research and development for its main role of space weather operation in Korea.

9:30 The FORMOSAT-7/COSMIC-2 Satellite Mission: Expanding the Observational Capabilities for the Space Weather Community
John Braun, University Corporation for Atmospheric Research

The FORMOSAT-7/COSMIC-2 (F7/C2) mission is a constellation of low earth orbiting satellites designed to support weather forecasting, space weather research, and atmosphere research. Six F7/C2-A satellites are scheduled to be launched in the second half of 2018 as part of the United States Air Force (USAF) Space Test Program -2 (STP-2) mission. Each satellite will support a single mission payload and two science payloads. The mission payload is a TriG GNSS Radio Occultation Receiver System (TGRS). From a space weather perspective, the TGRS will provide total electron content (TEC) and ionospheric scintillation data products from both GPS and GLONASS transmitters. The two science payloads are an Ion Velocity meter (IVM) and a Radio Frequency Beacon (RFB). The IVM will provide in-situ plasma measurements at spacecraft altitude including ionospheric density, ion composition, ion velocity and ion temperature. The RFB will transmit phase coherent signals in the UHF, L-Band and S-Band. These signals can be tracked by ground receivers to support the collection of scintillation and TEC data. This presentation will provide a summary of the current status of the mission and outline the improved observational capacity that these satellites are expected to provide to the broader space weather community.

9:45 Update from Spire Global, GeoOptics and PlanetIQ

Timothy Duly, Spire Global, Inc.
Rob Kursinski, PlanetIQ
Conrad Lautenbacher Jr., GeoOptics, Inc.

In this series of brief presentations, from three commercial satellite service providers, we will hear an update about their recent satellite programs and the high-quality measurements, either in progress or planned, that will provide key tropospheric and ionospheric data products.

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

11:00 - 12:00 <u>**Space Weather Observation Cont'd**</u>
Chair: Michael Bonadonna, Office of the Federal Coordinator for Meteorological Services and Supporting Research

11:00 Implementation of Solar Irradiance Measurements on the International Space Station (ISS): The TSIS-1 Mission of Total and Spectral Solar Irradiance Observational Continuity
Erik Richard, University of Colorado, Laboratory for Atmospheric and Space Physics

Solar irradiance is one of the longest and most fundamental of all data records derived from space-based observations. The continuous 40-year total solar irradiance (TSI) observational data record is the result of several overlapping instruments flown on many different missions where observational overlap is central to establishing a reliable composite solar radiation data record. The long-term, continuous measurements of the nearly full spectrum solar spectral irradiance (SSI) began with the Solar Radiation and Climate Experiment (SORCE) mission launched in 2003 and has provided continuous SSI observations for over 15 years. After nearly two decades of delays and programmatic changes, the first implementation of NASA's Total and Spectral Solar Irradiance Sensor (TSIS-1) launched on December 15th, 2017 and was integrated on the International Space Station (ISS). The TSIS-1 mission provides continuation of both the TSI and SSI observations with improved versions of the LASP Total Irradiance Monitor (TIM) and Spectral Irradiance Monitor (SIM), respectively, and will establish the long-term observational link to the SORCE end-of-mission solar data record. In this talk we present the very early TSIS mission results that marks the beginning of the new era of solar observations. We also address the operational and observational challenges of using the ISS as a scientific platform. Finally, based on lessons learned, we discuss an observational strategy for data overlap (both TSI and SSI) with a focus on future mission designs implementing redundant and overlapping small satellite concepts involving low-risk, cost efficient approaches to maintain critical long-term solar data records.

11:15 Deployment of Magnetic and Electric Field Sensors for GIC Hazard Mitigation
Jennifer Gannon, Computational Physics Inc.

Accurate, reliable, and secure magnetometers are a key component of hazard mitigation against geomagnetically induced currents (GICs) for power grid operators. Because of the highly localized nature of the GIC hazard, a transformer should be within 150 miles of a magnetometer for optimal hazard mitigation, yet there are sparse existing resources. In this talk we present a commercial magnetometer solution that is designed specifically for the GIC problem. We will discuss what is needed in terms of instrument spacing, installation and data characteristics, and show how magnetic field data can be used to understand and provide operational awareness of GIC conditions for the bulk power system.

11:30 OWS The Industrialization and Democratization of Space
Tony Gingiss, OneWeb

OneWeb Satellites (OWS) will shortly, and significantly, expand the low earth ecosystem. Beyond the mission of the OneWeb consortium to bring internet connectivity to the world, advancing the space weather enterprise is only one possible exploitation of the OWS constellation. Polar orbits, deployed with 10 degree separation in longitude our constellation could push the frontier of understanding the Geospace environment as never before. Beyond the initial generation of satellites we seek to form collaborative industrial, academic and government initiatives where science, technology, and a shared vision to advance the knowledge of Space Weather - through innovative dedicated constellations, collaborative hosted payloads and possibly the exploitation of embedded meta data within near term and future systems all become within the realm of possibility. With this presentation we'll give an overview of OWS update on space craft characteristics, provide access points for future collaboration, and give a few examples of possible applications.

11:45 **Five and One-Half Years of Radiation Belt Measurements: Space Weather in Earth's Neighborhood**
Daniel Baker, University of Colorado, Laboratory for Atmospheric and Space Physics

From their launch in August 2012 to the present time, the Van Allen Probes have made nearly continuous measurements of the highly- and ultra-relativistic electron populations in Earth's radiation belts. In this presentation, we focus on 1-20 MeV electron measurements made by the twin Relativistic Electron-Proton Telescope (REPT) instruments that were first turned on in early September 2012. We describe the morphological features seen repeatedly in the data (3-belt structures, "impenetrable" barrier properties, radial diffusion signatures) in the context of acceleration and loss mechanisms. We especially focus on solar wind forcing of the ultra-relativistic ($E \gtrsim 5$ MeV) electron populations. We present pitch angle resolved data and energy-spectral analyses for key events. The presentation also includes animated segments portraying the mission-long time variability of the out Van Allen belt emphasizing the remarkable dynamics of the system. These results give remarkable new insights into space weather issues in the Earth's magnetosphere.

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

2:00 – 2:15 Keynote: Alice Bunn - Director of Policy, UK Space Agency

2:15 - 3:30 Research to Operations

Chair: Terry Onsager, NOAA/SWPC

2:15 **University of Colorado Space Weather Technology, Research, and Education Center**
Jeffrey Thayer, University of Colorado

The University of Colorado at Boulder has launched a new academic center in the field of space weather called the Space Weather Technology, Research, and Education Center (SWx TREC). SWx TREC will serve as a national center of excellence in cross-disciplinary research, technological innovation and education. As an academic endeavor, SWx TREC provides new pathways for federal agencies, academia, commercial partners and industry to collaboratively address the nation's evolving space weather forecasting, mitigation and response requirements. SWx TREC seeks to improve current national space weather capabilities by advancing research-to-operations (R2O) and operations-to-research (O2R) functions through exchanges of models, data, technology, work force and information. Leveraging CU and Front Range nation-leading capabilities in space physics research, solar physics research, space instrumentation and mission design, aerospace engineering, CubeSat developments, astrophysical and planetary sciences, geospace modelling and data assimilation, and satellite and mission data management, SWx TREC has three main enterprises: Research Enterprise, Education Enterprise, and Modelling, Applications, and Data Technology (MAD Tech) Enterprise. We are excited to introduce to the space weather community this new resource and will present our vision and near-term activities.

2:30 **Space Weather Forecasting Advancements at the University of Michigan**
Daniel Welling, University of Michigan

The Center for Space Environment Modeling at the University of Michigan develops and maintains a suite of numerical modeling tools for space weather science and forecasting. Among these are the Space Weather Modeling Framework, a flexible software framework that executes, synchronizes, and couples many otherwise independent models of different regions of the Sun-to-Earth system. Through the SWMF, users can capture the multi-physics, multi-scale dynamics of the solar atmosphere, heliosphere, magnetosphere and upper atmosphere in a self-consistent manner. The models used within the SWMF include many developed outside of CSEM, making the SWMF a true community utility. The SWMF has become a standard tool for research and operations.

This presentation summarizes the efforts at the University of Michigan to expand the numerical modeling capabilities of the SWMF and the numerical models housed within.

New and ongoing projects are reviewed, including the transition of the SWMF to operations, sun-to-mud long-lead time forecasting for geomagnetically induced current applications, and development of advanced physics models. Progress towards instituting a new R2O-O2R testbed center at Michigan, the Building Research-to-operations Infrastructure in Diverse Geospace Environments (BRIDGE) center, will also be discussed.

2:45 Extending Terrestrial Weather R2O/O2R to Space Weather at NASA's SPoRT Center
Brad Zavodsky, NASA

NASA's Short-term Prediction Research and Transition (SPoRT) Center located at Marshall Space Flight Center in Huntsville, Alabama 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 National Oceanic and Atmospheric Administration (NOAA) National Weather Service (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 to transitioning experimental products to the space weather community, such as those at the NOAA NWS Space Weather Prediction Center. This presentation will focus on a description of the SPoRT R2O/O2R paradigm and an example of how this paradigm is being tested in an operational space weather environment through the transition of the MAG4 (MAGnetic forecasting) model, which produces measures of magnetograms whole 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.

3:00 Community Coordinated Modeling Center as a Hub for R2O and O2R: Capabilities, Challenges and Opportunities
Maria Kuznetsova, NASA GSFC, Community Coordinated Modeling Center

The Coordinated Modeling Center Modeling Center (CCMC, http://ccmc.gsfc.nasa.gov) serves as a space weather community R2O-O2R hub interconnecting key element of space weather capabilities ecosystem: understanding, modeling, observations, assessment, dissemination, and operations. The CCMC is hosting a rapidly growing collection of space weather models and applications. Models and data products ingested by the CCMC are served back to the community through Runs-on-request and other CCMC services. CCMC services and community-wide initiatives empowers researchers to engage in space weather analysis and evaluation of state of the art models and tools. In partnership with model developers, users of space weather information at NASA, and space weather services providers at NOAA and USAF, the CCMC develops actionable displays and space weather analysis and systems tailored for specific missions and user needs. Unbiased testing, evaluating and prototyping the hosted models and tools for potential transition to operational organizations (R2O) is one of the primary CCMC functions. The feedback from evaluations and from users of CCMC simulation services flows back to developers to fulfill the important O2R component. The presentation will overview the status of R2O-O2R capabilities and on-going activities. The presentation will also discuss challenges and opportunities for accelerated incorporation and evaluation of new scientific ideas with potential to improve space weather modeling capabilities into CCMC simulation services.

3:15 Air Force Research Laboratory Space Weather Open Standards and Data Repository Initiatives
Michael Starks, Air Force Research Laboratory

The Air Force Research Laboratory (AFRL) houses the US Department of Defense (DoD) core-funded space environmental science and technology (SandT) activities addressing defense requirements. The Laboratory executes a relatively small in-house and contract research effort spanning basic and applied research, and 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. These efforts are routinely hindered by two factors: uneven sensor observation standards, and the lack of environmental models designed to be run against the operationally-available sensor architecture. In general, many DoD operational space weather observations are either not archived or, if they are, are not released into the international research community once they are no longer of operational value. This limits the research community to the development of space environment specification and forecast models that can be constructed – and are often optimized to run – using a very limited subset of the operationally available data sources. This slows verification and validation efforts, complicates operationalization, and often artificially limits capability. AFRL is working to connect the DoD and civil communities to explore mechanisms by which historical military space weather observations may be made broadly available in standard formats, housed within open repositories. The definition and utilization of standard observation formats has the added advantage of enabling civil and military space weather operations to more easily exploit allied and commercial sensor networks with agility, providing a more authoritative and robust picture of the operating environment. Some of these ideas have already begun to take shape in nascent form through the National Space Weather Action Plan, such as the release of some DoD energetic charged particle data. Those efforts should be built upon to better serve the DoD, civil and international space weather research and operations communities.

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

4:30 - 5:30 <u>Space Weather Services for Human Space Exploration</u>

Chair: Scott McIntosh, National Center for Atmospheric Research, High Altitude Observatory

4:30 NASA's Near Term Human Exploration Plans

John Guidi, NASA

With changing national priorities in human spaceflight, NASA will leverage current human exploration systems and refocus exploration efforts toward the cislunar environment and lunar surface systems. This overview briefing will highlight the recent changes in space policy and elaborate on the redirection of human exploration efforts toward the Moon.

4:50 Space Radiation Protection for NASA Exploration Class Missions

Kerry Lee, NASA

The Space Radiation Analysis Group (SRAG) at the Johnson Space Center performs many functions with the overall objective of mitigating the effects of the natural radiation environment to the astronauts, while performing the missions set forth by NASA. NASA has set the near term goals of launching an unmanned mission designated as EM-1, followed by a manned mission called EM-2. Both of these missions have the intention to test all the systems on the new MPCV spacecraft while exploring in the vicinity of the Moon and returning safely back to Earth. The functions performed by SRAG to serve these missions include vehicle radiation protection analysis and design, definition of the needed capabilities for space weather forecasting and measurement, definition of operational concepts and flight rules, development of radiation sensors integrated into the spacecraft, and the development of active radiation dosimeters to monitor and manage individual crew radiation exposures. The work that has been performed by SRAG in preparation for these exploration missions will be presented here.

5:10 Update on the Worsening Particle Radiation Environment Observed by CRaTER and Implications for Future Human Deep-Space Exploration

Nathan Schwadron, University of New Hampshire

Over the last decade, the solar wind has exhibited low densities and magnetic field strengths, representing anomalous states that have never been observed during the space age. As discussed by Schwadron et al. (2014), the cycle 23--24 solar activity led to the longest solar minimum in more than 80 years and continued into the ``mini'' solar maximum of cycle 24. During this weak activity, we observed galactic cosmic ray fluxes that exceeded the levels observed throughout the space age, and we observed small solar energetic particle events. Here, we provide an update to the Schwadron et al (2014) observations from the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) on the Lunar Reconnaissance Orbiter (LRO). The Schwadron et al. (2014a) study examined the evolution of the interplanetary magnetic field, and utilized a previously published study by Goelzer et al. (2013) projecting out the interplanetary magnetic field strength based on the evolution of sunspots as a proxy for the rate that the Sun releases coronal mass ejections (CMEs). This led to a projection of dose rates from galactic cosmic rays on the lunar surface, which suggested a ~20% increase of dose rates from one solar minimum to the next, and indicated that the radiation environment in space may be a worsening factor important for consideration in future planning of human space exploration. We compare the predictions of Schwadron et al. (2014) with the actual dose rates observed by CRaTER in the last 4 years. The observed dose rates exceed the predictions by ~10%, showing that the radiation environment is worsening more rapidly than previously estimated. Much of this increase is attributable to relatively low-energy ions, which can be effectively shielded. Despite the continued paucity of solar activity, one of the hardest solar events in almost a decade occurred in Sept 2017 after more than a year of all-clear periods. These particle radiation conditions present important issues that must be carefully studied and accounted for in the planning and design of future missions (to the Moon, Mars, asteroids and beyond).

Friday, April 20

8:30 – 10:00 Ionosphere and Thermosphere Modeling and Prediction

Chair: Michael Wiltberger, NSF, Geospace Section

8:30 Why the WAM in WAM-IPE?

Tim Fuller-Rowell, University of Colorado, Cooperative Institute for Research in Environmental Sciences

In an effort to improve forecasts of space weather in the Sun to Earth system, NOAA is transitioning three separate physical model components. These include the WSA-ENLIL solar wind propagation model, the Michigan Geospace model of the magnetosphere, and a coupled model of the whole atmosphere and the ionosphere-plasmasphere-electrodynamics (WAM-IPE). The first two of these components have already been transitioned to operations at NOAA, and the third component is being tested in a real-time setting. We have known for a long time that waves from the lower atmosphere are a source of variability in the thermosphere and ionosphere, but it was very hard to quantify the impact and understand the physical processes. With the advent of whole atmosphere models we are able to probe the connection, begin to understand the physical processes, quantify the impact, and potentially be able to forecast the consequences on operational systems. When there is a geomagnetic storm, and a coronal mass ejection strikes Earth, it dominates space weather in the near-Earth environment. But space weather doesn't just occur during big geomagnetic storms. For instance, tides driven by the lower atmosphere create longitude ionospheric structure, sudden stratospheric warmings can increase total electron content by 50%, and ionospheric irregularities can disrupt satellite navigation and communication on any day. Whole atmosphere models can not only follow, but also forecast, the day-to-day variability and the longitude dependence of lower atmosphere wave sources driving the sporadic ionospheric space weather. The WAM in WAM-IPE is a whole atmosphere extension of the National Weather Service (NWS) Global Forecast System (GFS) operational weather model, extending the top boundary from 60 km in GFS to ~600 km. WAM can also be run with the NWS/NCEP Gridpoint Statistical Interpolation (GSI) data assimilation scheme in order to follow and forecast real changes in tropospheric weather. The WAM model is coupled to IPE, using the Earth System Modeling Framework (ESMF) and the National Unified Operational Prediction Capability (NUOPC) layer, under the NOAA Environmental Modeling System (NEMS). IPE is a time dependent, three-dimensional model of the ionosphere and plasmasphere developed through a collaboration between University of Colorado, George Mason University, NOAA Space Weather Prediction Center (SWPC), NOAA Global Systems Division (GSD), NCAR HAO, and NESII. WAM provides the thermospheric properties of wind, composition, and temperature to the IPE, and can respond to changes in terrestrial weather propagating upward and influencing the thermosphere. IPE in turn provides time dependent, global, three-dimensional plasma densities for nine ion species, electron and ion temperatures, and both parallel and perpendicular velocities of the ionosphere and plasmasphere. IPE reproduces not only the climatology of global TEC observations, but the model also responds to changes in solar wind conditions during geomagnetic storms, and to terrestrial lower atmosphere changes.

8:45 Whole Atmosphere Community Climate Model with Thermosphere and Ionosphere Extension (WACCM-X): Model Capabilities and Validation

Han-Li Liu, National Center for Atmospheric Research, High Altitude Observatory

The NCAR Whole Atmosphere Community Climate Model with Thermosphere and Ionosphere Extension (WACCM-X 2.0) has been developed to study the solar impact on the Earth system, to understand and quantify couplings between atmospheric layers through chemical, physical and dynamical processes, and to investigate the implications of the couplings to climate (downward coupling) and to space environment (upward coupling). The model extends from the Earth surface to the exobase, encompassing ~29 scale heights (13 order of magnitude change in pressure and density), and including both well-mixed and diffusively separated regions, and neutral and partially ionized constituents. In this talk, we will also discuss the new capabilities of WACCM-X 2.0, in particular the newly implemented modules of ionospheric electrodynamics, O+ transport and plasma temperatures, as well as modification of model dynamical core for the thermosphere, where mean molecular mass and specific heats are variables. With the interactive ionosphere modules and the improved dynamics core, we have made extensive simulations to validate the thermosphere and ionosphere results. The thermospheric compositional structures are in good agreement with climatology. Ionospheric plasma densities and ExB drifts, as well as their seasonal and short-term variability, are found to be in general agreement with observations. In particular, the pre-reversal enhancement (PRE) of the vertical ExB drift in the equatorial region from the simulations displays a clear longitudinal and seasonal pattern that is very similar to observations.

9:00 Global Modeling of Metal Ions in the Ionosphere with SAMI3
Joseph Huba, Naval Research Laboratory

Sporadic metallic ion layers (e.g. Mg+, Fe+) are known to form in the E region around 100 - 120 km but have been observed in the F region up to a few hundred kms. These metallic ion layers have a width of 1 to 3 km and result in ‘continuous’ radar echoes at VHF and HF frequencies.
Moreover they can adversely impact the performance of other the horizon radar (OTHR) systems by limiting the range or producing multiple propagation paths to the same target. In this talk we present preliminary results from the NRL SAMI3 ionosphere/plasmasphere model of the global dynamics of metal ions in the ionosphere. SAMI3 has recently been upgraded to include the metal ions Mg+ and Fe+. The new feature of the model is that it captures the transition in plasma transport from the E region to the F region. In the E region (< 150 km), plasma transport is dominated by ion-neutral coupling to the neutral wind and the metal ions are essentially unmagnetized because of ion-neutral collisions. In the F region (> 150 km) plasma transport is dominated by ion-neutral coupling along the geomagnetic field but by electrodynamics perpendicular to the field. We show that the metal ions can develop layered structures in the E region because of shears in the neutral wind, as well as strong latitudinal and longitudinal variations. Moreover, the metal ions can be transported to the F region via electrodynamic and thermospheric wind effects. In general, the results are consistent with observations.

9:15 Private Sector Contributions to Ionospheric Monitoring
Geoff Crowley, Atmospheric and Space Technology Research Associates

A number of models of the ionosphere and thermosphere have been transitioned to operations at ASTRA, including the TIEGCM, TIMEGCM, and AMIE. We describe ongoing work to improve these models and to provide model outputs at various latencies for different applications.

9:30 USU GAIM Data Assimilation Models for Space Weather Specifications and Forecasts
Robert Schunk, Utah State University

In an effort to specify and forecast space weather, we developed several physics-based data assimilation models of the ionosphere-upper atmosphere. Two of the models were developed in association with a program called Global Assimilation of Ionospheric Measurements (GAIM). One of the models became an Air Force operational model in 2006. This model is a Gauss-Markov Kalman Filter model (GAIM-GM) and it uses a physics-based model of the ionosphere and a Kalman filter as a basis for assimilating a diverse set of real-time (or near real-time) measurements. The physics-based model is the Ionosphere Forecast Model (IFM), which is global and covers the E-region, F-region, and topside from 90 to 1400 km. It takes account of five ion species (NO+, O2+, N2+, O+, H+), but the main output of the model is a 3-dimensional electron density distribution at user specified times.
The second data assimilation model uses a physics-based ionosphere-plasmasphere model that has been extended to be fully global and a Kalman filter as a basis for assimilating real-time (or near real-time) measurements. This full physics model (GAIM-FP) is currently being implemented as an upgraded operational model by the Air Force. GAIM-FP is global, takes account of six ion species (NO+, O2+, N2+, O+, H+, He+), covers the altitude range of from 40 to 30,000 km, provides a 24-hour forecast, includes a data-driven D-region extension, can incorporate low-latitude plasma bubbles, and includes generic satellite-to-satellite and satellite-to-ground slant TEC data. GAIM-FP is more sophisticated than the Gauss-Markov model, and therefore, it should provide more reliable specifications and forecasts in data poor regions and during severe weather disturbances.

Both of these GAIM models can assimilate bottom-side Ne profiles from hundreds of ionosondes, slant TEC from 1000 ground GPS/TEC stations, in situ Ne from 4 DMSP satellites, occultation data from multiple satellites, and line-of-sight UV emissions measured by satellites. Quality control algorithms for all of the data types are provided as an integral part of the GAIM models and these models take account of latent data (up to 3 hours).

9:45 **The Importance of 3-D Ground Conductivity in Determining Voltages at Electric Grid Substations Due to Space Weather and EMPs**
Adam Schultz, Oregon State University

The NSF-funded EarthScope Magnetotelluric Program, operated by Oregon State University, has obtained 3-D electromagnetic impedance tensors on a 70-km spaced grid of temporary MT stations that spans approximately 60% of the area of the CONUS. NSF-funded operations continue until the end of this year, at which point a continuous Pacific-to-Atlantic grid of impedance tensors will be available, covering the west coast from Washington, Oregon and northern California, eastward through the northern Great Plains and Mid-West, and finally covering the entire eastern seaboard from Maine to Florida. Various groups around the world have inverted these MT impedance tensors to obtain 3-D electrical conductivity models of the mid-crust through the upper mantle. Oregon State University has obtained additional MT stations using finer station spacing, and in some cases, wider frequency band instrumentation capable of obtaining higher-resolution conductivity information from the near-surface through the upper mantle. These additional data have been used by OSU, along with the publically-available large-scale EarthScope MT data that have also been used by OSU, USGS, NOAA, Colorado School of Mines, Computational Physics and other groups to estimate the ground electric fields induced by geomagnetic disturbances. In the present paper we discuss the critical contributions of the 3-D impedance information to determining the anomalous voltages at power grid substations as one integrates the vector ground electric fields along the paths of transmission lines and then applies those voltages to power flow models that represent power grid topology and configuration. We provide an overview of the stability vs. time and Kp number of the underlying magnetic field prediction algorithm. Shortcomings of previous 1-D regional conductivity models used to determine ground electric fields due to space weather events will be discussed.

10:00 **Special Presentation: A Few Words from NOAA Leadership**
Dr. Neil Jacobs, Assistant Secretary of Commerce for Environmental Observation and Prediction

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

10:30 – 12:00 Solar and Magnetosphere Modeling and Prediction
Chair: Michele Cash, NOAA/SWPC

10:30 **Toward a New Space Weather Model Suite**
Slava Merkin, Johns Hopkins University Applied Physics Laboratory

In this presentation, I will describe our recent efforts aimed at building a new suite of space weather models based on and derived from well-known high-heritage components. I will first discuss the project devoted to the redevelopment of the Lyon-Fedder-Mobarry (LFM) magnetohydrodynamic (MHD) code. LFM has been used extensively for space weather applications both in the magnetosphere and the inner heliosphere over the past three decades. Its underlying algorithms provide unique high quality numerical solutions but the software needed an upgrade to be able to take advantage of modern supercomputer architectures. We made the decision to rebuild the code from scratch with improvements in the accuracy of numerics but largely keeping them intact, while concentrating on the software infrastructure. The new code named Gamera takes advantange of hybrid parallelism (OpenMP and MPI), is very well optimized and ready for implementation on heterogeneous architectures (e.g., GPU's and Intel Phi's). In this presentation I will describe the primary features of Gamera, comparisons with LFM, space weather applications, including the magnetosphere and inner heliosphere, and plans for coupling with other space weather models. I will further discuss a partner effort of building a Hamiltonian test-particle code tightly integrated with the MHD-based Gamera code. The test-particle model named CHIMP is used for both radiation belt (electrons) and ring current (ions) simulations, and together with Gamera is intended for both scientific and operational use. I will describe recent results from this effort and plans for future developments.

10:45 **NASA GSFC Heliophysics Science Division and Space Weather**
Antti Pulkkinen, NASA Goddard Space Flight Center

The NASA Goddard Space Flight Center's Heliophysics Science Division (HSD) conducts research on the Sun, its extended solar-system environment (the heliosphere), and interactions of Earth, other planets, small bodies, and interstellar gas with the heliosphere. Division research also encompasses geospace -- Earth's uppermost atmosphere, the ionosphere, and the magnetosphere -- and the changing environmental conditions throughout the coupled heliosphere. Scientists in the HSD develop models, spacecraft missions and instruments, and systems to manage and disseminate heliophysical data. They interpret and evaluate data gathered from instruments, draw comparisons with computer simulations and theoretical models, and publish the results. The Division also conducts education and public outreach programs to communicate the excitement and social value of NASA heliophysics.

Space weather is a major part of HSD activities and the Division is the home for entities such as Community Coordinated Modeling Center and Space Physics Data Facility. HSD scientists work in close collaboration with federal partner organizations such as NOAA, USGS and Air Force to help transition the latest scientific information into space weather operations. HSD scientists are also supporting many of the National Space Weather Action Plan goals and play significant role in a variety of international space weather efforts. In this talk, we will provide a general introduction to HSD and its many activities that pertain to space weather.

11:00 **CIMI - Modeling the Inner Magnetosphere**

Mei-Ching Fok, NASA GSFC, Heliophysics Science Division

The Comprehensive Inner Magnetosphere-Ionosphere (CIMI) model has been developed at NASA Goddard to study the dynamics of the radiation belts and ring current as well as their coupling with the ionosphere [Fok et al., 2014]. The CIMI model has been used for scientific research, however it contains ample space weather applications. CIMI provides predictions of energetic electron (1 keV – 5 MeV) and ion (0.1 – 500 keV) fluxes in the magnetosphere from L ~ 2 to 10. The model is driven by solar wind parameters and geomagnetic indices, but it can run with just solar wind inputs. In addition to predicting the plasma environment of the inner magnetosphere, CIMI also calculates electron precipitation, ionospheric potential and currents. Recently, CIMI has employed a different numerical scheme to calculate particle diffusion in energy and pitch angle. With this advancement, the CIMI code is more stable and has better performance.

11:15 **Geoelectric Field Maps: Progress on NOAA's Operational Near Real-Time Geoelectric Field Estimation Capability**

Chris Balch, NOAA/SWPC

Estimation of ground-level geoelectric fields has been identified by the electrical power industry as a key capability in assessment and mitigation of the impacts of space weather. We describe an experimental system for near real-time estimation of spatially variable ground-level geoelectric fields. This system is in development at NOAA's Space Weather Prediction Center (SWPC) in collaboration with the USGS Geomagnetism Program and the NASA Community Coordinated Modeling Center (CCMC). Initial experimental capability is now available to the public at SWPC's website (http://www.swpc.noaa.gov/), and initial validation efforts are underway.

A critical component in geoelectric field estimation is the specification of Earth conductivity. We consider two different approaches: 1D Geoelectric Field Maps based on the Fernberg (2012) 1D conductivity model compilation, and 3D Geoelectric Field Maps which employ the best available three dimensional Earth conductivity models in the U.S. (Meqbel et al., 2014; Yang et al., 2015; Murphy and Egbert, 2017 and others) obtained through a USGS compilation of magnetotelluric community inversion results based on NSF's Earthscope USArray impedances (Schultz et al., 2006-2018). The work on the 3D conductivity models is ongoing as new USArray data are obtained, and new methods for improved magnetotelluric inversion are developed.

The maps use the best available observatory magnetic field data (operated by USGS and Natural Resources, Canada) interpolated in real time using the method of spherical elementary currents (SECs; e.g., Amm and Viljanen, 1999; Pulkkinen et al., 2003). The geoelectric field calculation is accomplished by convolving the geomagnetic field time series with the Earth conductivity response functions at each model grid point.

The deployment of these maps represents a significant advance in the specification of space weather hazards compared to what was previously available, i.e. global geomagnetic indices, providing the electric power industry with a tool to assess regional space weather hazards in near real-time. An emphasis will also be made to identify key priorities for future improvements of this product. We encourage the community to make use of these tools to assist us in cross-comparison and validation.

11:30 Forecasting the Arrival Time of Coronal Mass Ejections: Current Capabilities and Uncertainties

Peter Riley, Predictive Science Inc.

Accurate forecasting of the properties of coronal mass ejections as they approach Earth is now recognized as an important strategic objective for both NOAA and NASA. The time of arrival of such events is a key parameter, one that had been anticipated to be relatively straightforward to constrain. In this presentation, we analyze forecasts submitted to the Community Coordinated Modeling Center (CCMC) at NASA Goddard Space Flight Center over the last five years to answer the following questions: (1) How well do these models forecast the arrival time of CMEs? (2) What are the uncertainties associated with these forecasts? (3) Which model(s) perform best? (4) Have the models become more accurate during the past five years? We find that the models are generally able to predict CME arrival times -- in an average sense -- to within +/- 10 hours, but with standard deviations often exceeding 20 hours. The best model currently is NOAA/SWPC's "WSA-ENLIL+Cone model", which, over the five-year period, had a mean absolute error in arrival time of 11.6 hours. The mean error was found to be ~ 0.9 hours, suggesting a modest early arrival bias. There is no evidence that the models have become more accurate in the last five years. We discuss the intrinsic limitations of the various models analyzed and suggest possible paths to improve these forecasts in the future.

11:45 Will There Even Be Sunspot Cycle 25?

Scott McIntosh, National Center for Atmospheric Research, High Altitude Observatory

Every decade the solar physics community dabbles in a form of alchemy to try to predict the landmark times (solar min, solar max, etc) and strength of the sunspot cycle to come. There are many wrinkles, caveats, and nuances to those predictions that are, at best, educated guess work. However, maybe, just maybe - starting with 22 years of contemporary observations of the solar corona we readily see bands of activity. Those appear to be long-lived patterns that trace out the Sun's 22-year solar magnetic activity cycle. The "interaction" of those bands can explain the landmarks of the sunspot cycle – that only occurs over about half of the magnetic cycle span. So maybe there is observational predictability of the system! We can extend our analyses back 140 years to the dawn of H-alpha photography in the late 1870s and show that the 22-year magnetic cycle is extremely robust and is predictable through this continuous observational record. Using this record we explore the ”climatology” of the system and the root drivers of solar variability and activity. Given the apparent predictability in the system we look at sunspot cycle 25, how it has evolved since first appearing in 2012/2014, what it may yield in terms of activity..... and also what may follow…..

12:00 <u>Conference Closing Remarks</u>

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