NATIONAL SPACE WEATHER PARTNERSHIP

2019

SPACE WEATHER ENTERPRISE FORUM

SUMMARY REPORT

Note: Speaker and audience remarks are paraphrased and not to be used as quotations.

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SUMMARY REPORT

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SERVICES AND SUPPORTING RESEARCH
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Washington, D.C.

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2019 SPACE WEATHER ENTERPRISE FORUM SUMMARY REPORT

This document provides a synopsis of the 2019 Space Weather Enterprise Forum (SWEF)—an event sponsored by the National Space Weather Partnership (NSWP) and hosted by Dr. William "Bill" Leith, Associate Coordinator, Geomagnetism Program, U.S. Department of Interior. This year's theme was "Preparing the Nation for Space Weather."

Meeting Location: Montpelier Room, Yates Auditorium, Department of Interior, Main Building, 1849 C Street NW, Washington, DC.

Motivation

Space weather is always present and constantly changing. It affects a variety of important components of modern infrastructure, including communication, navigation, and energy supply. As we approach returning to the moon, we recognize that space weather can threaten the well-being of space travelers. The recent publication of the National Space Weather Strategy and Action Plan (NSWSAP) attests to the seriousness with which the government takes space weather impacts. The content of that plan also makes it clear that those impacts must be addressed through a partnership that includes not just various government departments and agencies, but also the academic and commercial sectors. The SWEF, organized by the NSWP, brings those sectors together on a recurring basis. It provides an opportunity to review progress and discuss plans across the entire range of space weather phenomena and to discuss the human and technological impacts of those phenomena.

The Forum

The SWEF has been bringing the space weather community together for over a decade to share information and ideas among policymakers, senior government leaders, researchers, responders, service-provider agencies, private-sector service providers, space weather information users, media, and legislators and staff from Capitol Hill. The outreach continued this year with the focus on what we've learned about the impact of space weather on critical infrastructure, what we've been doing to protect that infrastructure, plans to respond and recover from those impacts, and what still needs to be done. It addition, with manned space flight outside low earth orbit once again being planned, the forum considered the risks to space travelers posed by space weather, and the potential for protecting astronauts from those risks.

Forum Objectives

- Discuss vulnerabilities of our technological infrastructure to space weather impacts.
- Support actions being taken to prepare for and respond to space weather impacts.
- Highlight partnership opportunities among the government, commercial, and academic stakeholders.
- Emphasize the importance of new policy guidance pending space weather related legislation.

Format

The 2019 SWEF marked a return to the full-day format after the introduction of the half-

day format in 2018. The 2020 Forum will revert to the half-day format following the NSWP plan to alternate formats each year. Planned for November, next year's Forum will coincide with the John's Hopkins University Applied Physics Lab Conference on Space Environment Applications, Systems, and Operations for National Security (SEASONS).

The 2019 SWEF was planned to coincide with the Electronic Infrastructure Security (EIS) Summit, sponsored by the EIS Council in Washington, D.C., June 24-26, 2019. This arrangement provided synergistic benefits for both the EIS Summit and SWEF events.

A panel format was used, which included presentations by the expert panelists followed by time for questions from a diverse group of attendees. The agenda was developed by the interagency SWEF Organizing Committee. Forum presentations can be found at: http://www.ofcm.gov/meetings/SWEF/swefmeeting.htm.

Forum Sponsors

This Forum is co-sponsored by the United States Geological Survey (USGS) and the NSWP, which organized it through the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM).

Session 1: Opening and Welcoming

Mr. Michael Bonadonna, the Federal Coordinator for Meteorological Services and Supporting Research and Executive Secretary for the NSWP and the Space Weather Operations, Research, and Mitigation (SWORM) Interagency Working Group of the National Science and Technology Council (NSTC), opened the Forum. After brief welcoming remarks, Mr. Bonadonna introduced the Forum host, Dr. Bill Leith, Senior Science Advisor for Earthquake and Geologic Hazards, USGS.

Dr. Leith began his introduction to the Forum with a brief definition of space weather and a description of the NWSP, highlighting and thanking the government agencies, commercial entities, academic institutions, and non-profit organizations that comprise the Partnership. He then presented the objectives of the Forum and reviewed the agenda before completing his opening remarks by introducing the Honorable Cory Gardner, United States Senator.

Senator Gardner represented Colorado's 4th District from 2011 to 2015, after which he became Colorado's junior senator. He serves on the Energy and Natural Resource Committee and chairs the Energy Subcommittee. In addition, Senator Gardner serves on the Foreign Relations Committee, and the Commerce, Science, and Transportation Committee. He has been recognized for his bipartisan approach to legislation and has been a leader in supporting a broad approach to providing energy for the nation through traditional and renewable sources and improving energy efficiency.

In his recorded remarks, Senator Gardner thanked the participants for the opportunity to address the forum. He pointed out that, with his colleague Senator Gary Peters, he had reintroduced the Space Weather Research and Forecasting Act last March. The Act, which passed the Senate unanimously last congress, would, among other things, codify the roles and responsibilities of the Federal agencies. The Senator emphasized the importance of our nation preparing for a potential space weather event, which could have a major impact on our economy and our security. He went on to highlight the role of his home state of Colorado in the space weather enterprise, hosting government operations and research organizations, supporting academic endeavors, and hosting commercial businesses. All

these institutions, working together, further our understanding of and ability to prepare for, respond to, and recover from space weather events. Senator Gardner pledged that he is committed to making sure the Space Weather Research and Forecasting Act again passes the senate and is ultimately signed into law. He thanked the forum participants for their efforts on behalf of the country, and, again, for the opportunity to speak with them.

Following Senator Gardner's comments, Dr. Leith introduced Dr. James (Jim) Reilly, II, Director of the USGS. Dr. Reilly began his remarks by recounting an experience as an astronaut when he noticed the aurora during a spacewalk from the Space Shuttle, and later wondered about his potential exposure to radiation during that event. He noted that most of what we know about radiation exposure comes from the use of the atomic bomb during World War II and the Chernobyl disaster. Space, however, is a continuing source of radiation, as well as a variety of other processes that impact our technological infrastructure. The USGS role in monitoring space weather involves observations taken on the surface of the earth that characterize the earth's reaction to space weather. It does this through the USGS Geomagnetic Program, a part of their natural hazards mission. The program employs 14 observatories and is associated with INTERMAGNET, a global network of geomagnetic observatories. Recognizing that the risk to the electric grid during solar storms varies with location based on the make-up of the Earth, USGS is combining data from magnetotelluric surveys with geomagnetic monitoring data to evaluate hazardous geoelectric currents induced in the earth during geomagnetic storms. He presented a map of the northeastern U.S. showing the results of the surveys in terms of 100-year geoelectric hazard. Dr. Reilly also presented a map showing the large region of the U.S. that has not yet been surveyed and noted that the President's budget for 2020 includes funding to complete the survey, which was part of the USGS funding bill that passed the House of Representatives yesterday. Dr. Reilly invited questions, and one of those questions related to the President's March 26, 2019, Executive Order (EO) on Coordinating National Resilience to Electromagnetic Pulses. That EO includes addressing geomagnetic disturbances (GMDs) as a type of "natural" electromagnetic pulse (EMP), and it mandates completion of the magnetotelluric survey of the contiguous United States within four years. Dr. Reilly's response focused largely on EMT, but he acknowledged the connection with GMDs from a space weather perspective, and commented further on the non-partisan nature of the work USGS does and the strong support that work receives from Congress.

Dr. Louis Uccellini, Director, National Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA) Assistant Administrator for Weather Services, took the podium next to discuss the 2019 NSWSAP. Dr. Uccellini, who co-chairs the Space SWORM, began by reviewing the 2015 National Space Weather Action Plan (NSWAP), its six primary objectives, and the interagency work that has been accomplished thus far to address those objectives. Of the 99 actions detailed in the plan supporting those six objectives, 50 have been completed. Major accomplishments include 1) public release of Global Positioning System particle data; 2) release of Phase 1 space weather benchmarks in October, 2018; 3) advances in international cooperation; 4) the Federal Operating Concept for Impending Space Weather Events (Department of Homeland Security (DHS), May 2019); and 5) and new Federal agency partnerships to improve research to operations, including a related Memorandum of Understanding between NOAA, the National Aviation and Space Administration (NASA), and the National Science Foundation (NSF). He then quickly reviewed the status of NWS space weather models and efforts that are underway to

improve research-to-operations and operations-to-research processes related to those models. Dr. Uccellini completed his remarks by highlighting the NSWSAP, which was issued in March and supersedes and builds on the NSWAP. That plan focuses on three primary objectives that will be addressed through coordination and collaboration within and across the Federal government, as well as engagement with the commercial sector, academia, and allied countries.

Session 2: Preparing for Space Weather Impacts

Moderator: Dr. Antti Pulkennen, Deputy Director, Heliophysics Science Division, NASA Goddard Space Flight Center

Dr. Pulkennen opened the session by pointing out that those who work in heliophysics measure the length of their careers in solar cycles, and his career spans two solar cycles. When he got started there were just a handful of people working the problem of solar impacts on infrastructure. Since that time, there has been an explosion of interest in the topic, and it's particularly encouraging to see that the government and industry recognize the seriousness of the problem. Dr. Pulkennen noted that a great deal of research has been and is being done to address it, and that research covers not just the geophysical aspects, but also the engineering necessary to build and operate resilient systems.

Panelists:

- Dr. Jeff Love, Research Geophysicist, Advisor for Geomagnetic Research, USGS Deputy Assistant Secretary for Infrastructure Security and Energy Restoration

  After acknowledging his collaborators, Dr. Love explained his work conceptually, illustrating three levels of complexity. The theoretical level showed the time series of an input signal that is passed through a filter to produce the time series of an output signal. Applied to the specific problem, geomagnetic variation is the input signal, the earth is the filter, and the geoelectric field in the output signal. In practice, then, the geomagnetic variation is recorded at observatories, the impedance of the earth is characterized with magnetotelluric surveys, and then geoelectric hazards at specific locations are calculated based on historical observations and the make-up of the earth. A final step involves mapping those hazards onto the existing power grid. To illustrate the data-collection points, Dr. Love showed a map with the seventeen observatories in North America overlaid on the locations of the magnetotelluric surveys. He then showed a map of the eastern U.S. illustrating the voltage and polarization of the field at each survey location based on data from 1983 to 2016 and explained some general characteristics of those results. Finally Dr. Love showed a map showing the 100-year voltages on the U.S. power grid for the areas where surveys had been completed. The map showed that high hazards are particularly notable in the Northern Midwest and in the East, near many major metropolitan centers.

- Mr. John Moura, Director - Reliability Assessment at the North American Electric Reliability Corporation (NERC)

  Mr. Moura opened his remarks by explaining the mission of NERC, which is to develop and enforce standards, and to assess current and future reliability of the North American electric grid. He illustrated the source of the challenge, which starts with a coronal mass ejection (CME) that interacts with the magnetosphere causing variations in the

geomagnetic field. Those variations, when combined with the conductive characteristics of the earth and the configuration of the power grid, cause geomagnetically induced currents (GICs) in the grid. The result can be overheating, reactive power consumption, and voltage distortion in transformers, as well as system anomalies such as transformer saturation, overloaded capacitors, and incorrect system operations. Transformers have been the focus of concern in the past because they have overheated and melted, causing extensive power outages. The amount of heating a transformer experiences depends on a number of factors, including its design, the geology in the area, and number and character of GICs previously experienced. NERC's 2012 GMD Task Force report, however, did not rank transformer damage as the greatest threat from GMDs. The task force concluded that the most likely risk from a GMD in North America would be the elevated risk of voltage instability or collapse. The report also stated that some transformers may be damaged or experience reduced life depending on design and current health. Mr. Moura pointed out that newer transformers are designed to me resistant to damage due to overheating, so the problem of damaged transformers is limited to older models, which will be replaced over time. Other problems will persist, however, and he spent the remainder of his presentation detailing the NERC's extensive work addressing those problems. This work includes guidance documents developed by the Task Force, GMD reliability standards, and GMD research. The research encompasses geoelectric field evaluation and earth conductivity models, harmonic analysis enhancements and harmonic impacts, and transformer thermal impacts.

- Dr. Emanuel Bernabeu, Director, Applied Innovation & Analytics, PJM Interconnection

  Dr. Bernabeu explained that PJM is a part of Eastern Interconnection Planning Collaborative. The collaborative is a coalition of 20 Planning Authorities (power providers and distributors) listed in the NERC compliance registry. They engage in coordinated interregional analysis guided by the consensus input of an open and transparent member process. PJM Interconnection, with 20% of the Eastern Interconnection assets carrying 28% of the load, serves 65 million people in 13 states and the District of Columbia. Dr. Bernabeu stated that GIC impacts on the grid are hot-spots, MVARs (megavolt-ampere-reactive), and harmonics. These impacts are addressed through equipment hardening, situational awareness, and operating procedures. He showed data illustrating that transformers can be hardened by using non-magnetic (vice magnetic) yoke plates, which provide an order of magnitude slower temperature change under the influence of GICs. In terms of situational awareness, the key is to anticipate G5 geomagnetic storms. An average of four of these storms occurs per solar cycle; and while many G5 storms, like G1 through G4 storms, have negligible impact, the G5 category is "unbounded," so it can include very dangerous events. When the potential exists for these dangerous storms, operating procedures become the final defense to protect the grid. Dr. Bernabeu explained that this involves "conservative operations," the application of data and tools that allow operators to see GICs and other inputs, system balancing, procuring reserves, delaying maintenance, running contingencies, etc. In conclusion, he pointed out that the interdependent models associated with GMDs and their potential impacts are highly complex, and those potential impacts pose an extraordinarily high risk to our society. There are no silver bullets—we can't harden everything against GICs. Situational awareness is very key—USGS data and NWS forecasts and important and used.

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Q & A:

- *Are we prepared to deal with a GMD and a cyberattack at the same time?* Mr. Moura stated that NERC has procedures to deal with both rare events. But they are separate, at least in terms of how we prepare for and deal with them. In particular, current protections from cyber-attacks are world-class. While nothing is certain, we are well prepared to deal with both. Dr. Bernabeu agreed, but suggested that they would not necessarily be separate events. A cyber-attack intentionally timed to occur during a heighten threat of GMD would disrupt operations and distract operators from addressing the GMD threat.
- *Do we have an adequate understanding of the less-powerful coronal hole events, which are not full CME events?* Dr. Pulkennen responded that ultimately it comes down to geomagnetic activity and the induced current regardless of the source, but we need additional research into this area. Mr. Moura stated that NERC is trying to capture more data from GIC monitoring, which can be used to relate those events to their source of solar activity. This will help to better understand the reaction to coronal holes.
- *What is the hold-up on completing the magnetotelluric survey?* Dr Love responded that it's a funding problem. USGS needs $5 million and a few years to complete the project. Congress must act to appropriate the funds, and the President must sign the appropriations bill before they can proceed.

Session 3: Advancing Space Weather Science and Services

Moderator: Dr. Devrie Intriligator, Director, Space Plasma Laboratory, Carmel Research Center, Inc., and member, American Commercial Space Weather Association (ACSWA) Executive Committee.

Dr. Intriligator introduced the topic by highlighting a few historical events related to space weather, including the 2½ hour blackout of communications with Air Force 1 during Presidents Nixon's historic trip to China and several events during the Reagan administration that resulted in a proposal to double the funding for space weather research and an effort to promote cooperation between Federal agencies involved in space weather research. The variety of academic, private industry, and government operations and research representatives on this session's panel is indicative of the progress that has been made since those historic events.

- Mr. Clinton Wallace, Director, NOAA Space Weather Prediction Center (SWPC)

  Mr. Wallace opened his remarks by highlighting the uptick in the interest in space weather as evidenced by the number of customer subscriptions at the SWPC, which has continued in spite of the ongoing solar minimum. He detailed the kind of decisions that were being made based on space weather forecasts in such areas as space operations, power transmission, airline operations, and navigation. He also listed a number of new application areas where needs are evolving, such as autonomous vehicles, space tourism and exploration, and supersonic and hypersonic air transport. In particular, he highlighted the challenges of supporting manned space flight outside the magnetosphere. Mr. Wallace reported on the International Civil Aviation Organization (ICAO) initiative to provide space weather services for global aviation activities.

Starting in November, routine operational space weather services will be provided by the SWPC and two international consortia. He reviewed the status of the space weather models the SWPC uses (or will start using within the next year) to provide those and other services to national and international users. He provided additional detail on the WSA-Enlil (corona and heliospheric magneto-hydrodynamic), WAP+IPE (whole atmosphere and ionosphere plasmosphere electrodynamics) models, and the geoelectric field model. He wrapped up his presentation by reviewing the critical observations required for effective space weather forecasting, the platforms/sensors that provide those observations, and some of the efforts underway to ensure continuity of those observations.

- Dr. James Spann, Chief Scientist, Heliophysics Division, Headquarters NASA.

  Dr. Spann began by touting the position of the Heliophysics Division as it works to usher in a new era in heliophysics by augmenting its fleet with new missions that will result in amazing discoveries and help fulfill their role in enabling advances in space weather, engaging the public, and developing the next generation of heliophysicists. He briefly reviewed the current and planned missions, then introduced NASA's new Space Weather Science and Applications (SWxSA) program, which will compete ideas and products, leverage existing capabilities, collaborate with other agencies, and partner with user communities. SWxSA will be different from other heliospheric research elements in that it will be focused on space weather and will transition its products into operations. He detailed the steps they are taking to implement the program, which include, inter alia, working in concert with the SWORM and in accordance with the 2019 NSWSAP. The remainder of Dr. Spann's presentation comprised a review of NASA missions. The small explorer (SMEX) program selected two missions this year for launch in 2022—Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) and Polarimeter to Unify the Corona and Heliosphere (PUNCH). E-TBEx (Enhanced and Tandem Beacon Experiment) was launched on June 24th. The two E-TBEx cubesats will work with other assets to investigate ionospheric disruption of radio signals. Sharing the same launch was the Space Environment Testbed (SET-1) mission, designed to address environment-induced spacecraft anomalies and failures. Dr. Spann provided an update on existing missions, including the Parker Solar Probe, the Van Allen Probes, and the Magnetospheric Multiscale (MMS) mission, then discussed a variety of suborbital campaigns. He finished his briefing with a review of six upcoming cubesat missions.

- Dr. Conrad Lautenbacher, CEO, GeoOptics Incorporated and member, ACSWA Executive Committee.

  Dr. Lautenbacher once again served as the voice for the commercial sector at the SWEF. He started by presenting a schematic of the space weather enterprise, illustrating the role of the commercial sector with academia and the government focusing on maximizing value in products and services. He then presented the value chain process, showing how the fundaments of instrumentation, data, and research support data processing, algorithms, and models to generate products and services. He asserted that the commercial sector covers the entire value chain, from research to services. Dr. Lautenbacher provided a brief overview of the organization and participants of the commercial sector in space weather activities and went on to describe that sector,

particularly as it is represented by ACSWA. The Association, which was formed in 2010 with 5 members, has expanded to 19 members representing all aspects of the enterprise. He pointed out that the National Space Weather Strategy mandates the involvement of industry, and pointed out that the Space Weather Act should explicitly include the commercial sector mandates for organizational structure and basic activities such as surveys, planning, and research. He suggested that, properly structured within the mandate of the Space Weather Act, the sectors would occupy "swim lanes" that would define their functions and avoid a "free-for-all" within the enterprise. Dr. Lautenbacher completed his presentation with a series of illustrations of contributions being made by ACSWA members.

- Dr. Daniel Baker, Director, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder.

  After presenting a comprehensive poster-style slide describing Sun-Earth interactions and the subsequent space weather events, Dr. Baker highlighted three problems facing the space weather enterprise—the need for more timely, accurate forecasts; the challenges in transitioning new technology to operations; and the disconnect between the research community and the operators that it supports (the O2R problem).
  He presented a model of the research to operations—operations to research (R2O-O2R) regimen as it currently operates, depicting a circular process of eight sequential steps. He contended that this approach does not accommodate the necessary interaction between the various components for effective R2O-O2R. As an alternative, he proposed the establishment of "R2O-O2R Centers" in the middle of the circle of interactions. All components of the process would interact with the centers, where more comprehensive coordination and collaboration would be managed.
  Dr. Baker then introduced the University of Colorado Space Weather Technology, Research and Education Center (SWx-TREC) as a potential R2O-O2R center. The remainder of his presentation described SWx-TREC and how it might incorporate that function into its mission. He presented a schematic, based on his earlier R2O-O2R solution model, showing how the Center could interact with the research community, forecast users, data and models, and providers (SWPC, USAF/557th Weather Wing, industry) to facilitate more effective R2O-O2R. Dr. Baker went on to describe some of the research SWx-TREC is involved in, including models, observing systems, and tools such as neural networks to forecast solar eruptions. Finally, he introduced the Mission, Applications and Data Technology (MADTech) office, which provides the supporting infrastructure (testbed, portal, etc.) for SWx-TREC.

Q & A:

- *Dr. Baker asked Dr. Spann whether it might be possible for NASA to be more involved in operational observations in the future.* Dr. Spann responded that NASA will always be foremost and principally a research agency. However, NASA has opened a discussion of sharing their research platforms with NOAA. Dr. Baker suggested that another approach might be for NASA to "turn the keys over" to another operational agency after their objectives have been satisfied for a particular mission. Dr. Spann responded that such an arrangement could be considered.
- *Dr. Uccellini commented that we have made strides in improving R2O—it's no longer the "valley of death." But it could still be improved with better O2R. On another topic,*

he observed that other nations are envious of our government-commercial sector relationship. Some nations have commercialized their government weather services without engaging private industry, and that has become problematic. Our model of growing the private sector while maintaining the government function is viewed as an effective model.

- *Jamie Hawkins discussed various issues related to deploying coronagraphs in research versus observation modes. There is an effort underway to get the compact coronagraph on GOES U, but how do we get to the point where that type of capability becomes routine the way geostationary observation of terrestrial weather has become since 1975.* Mr. Wallace acknowledged the issue and responded that NWS is working on that challenge, not just for GOES platforms, but for platforms at L1 and perhaps L5.

Session 4: Space Weather for a Spacefaring Nation

Moderator: Mr. Steve Clarke, Deputy Associate Administrator for Exploration, Science Mission Directorate, NASA HQ

Mr. Clark set the stage for the session by updating the forum on NASA's spacefaring plans. NASA's direction is to return to the moon by 2024 leading to a sustained presence on the moon by 2028. He reviewed the rationale for the initiative, which is called "Artemis" after the twin sister of Apollo and Greek goddess of the moon. Artemis astronauts are expected to land on the moon's South Pole, and the project is envisioned as eventually leading to travel to Mars. Mr. Clarke presented the timeline for the first three Artemis missions, which will be 1) unmanned, 2) crewed return to the moon, and 3) crewed landing on the moon's surface with access via the Gateway orbiting lunar outpost. He discussed the science projects to be completed before the first crewed landing in 2024. Those projects will involve lunar orbiters and polar and non-polar landers and rovers, which will address a variety of objectives. After discussing the science projects and objectives after 2024, Mr. Clark provided further information on the Gateway outpost, which, because it will accommodate astronauts for longer periods than in the Apollo missions, is highly relevant to the session's topic. With that background, he introduced the panelists.

- Dr. Eddie Semones, NASA Space Radiation Analysis Group (SRAG), Johnson Space Center (JHC).

  Dr. Semones began by citing Dr. Reilly's "human satellite" comments earlier in the day about seeing aurora while on an extra vehicular activity (EVA). While that was an entertaining comment, crews have made it clear that they want solar particle event warning and sheltering. He went back to Apollo, and showed that those missions fortuitously avoided serious particle events by virtue of their schedule, but there was a framework of flight rules in place that could almost be put into present-day documents. There was one event during Apollo 16. While it wasn't serious enough to be a problem, Dr. Semones used it to illustrate the risk. With this background, he went through the list of solar phenomena and discussed each in the context of human exposure during spaceflight. Solar particle events (SPE) are a problem only during EVAs, but energetic solar particle events (ESPE), require crews to shelter in better shielded areas. Flares and geomagnetic storms are not normally a problem unless they are associated with an SPE or ESPE. In support of the International Space Station (ISS), the SRAG at JSC has a direct interface with the SWPC to monitor SPE. In some situations, ISS crew are asked

to shelter in a higher shielded location even though there is usually little potential impact. Because of the nature of the ISS orbit, the full potential of an event may not be experienced because it occurs during a time when the station is in a less vulnerable position (i.e., "shielded" by Earth's geomagnetic field). That type of fortuitous situation will not occur on the moon or on the way to the moon. Dr. Semones presented an analysis of the 10 largest SPEs (by dose), showing the variations in the way the events played out. These data indicate that SPEs will impact Artemis, and controllers will need more detailed, reliable forecasts of peak flux and temporal evolution. To develop this capability the SRAG is collaborating with NASA's Community Coordinated Modeling Center to assemble a suite of models that includes both US and European Space Agency/European Union components. The suite is called the Integrated Solar Energetic Proton (ISEP) Event Alert/Warning System. The effort employs two approaches—statistical-based empirical models and more complex but less mature physics-based models. He showed "scoreboards" that illustrate the likelihood and potential intensity of SPEs over time based on input from ISEP. Dr. Semones completed his presentation with a list of recommendations, including 1) communicating needs to both SWPC and the research community, 2) creating national and international forecasting collaborations, 3) developing forecast tools for testing during ISS operations and short Artemis missions before the longer Artemis missions, and 4) build the foundation for human Mars missions by collaborating on space weather architectures that include data from manned vehicles to support forecast models for locations away from Sun-Earth.

- Mr. Ralph Stoffler, Director of Weather, Deputy Chief of Staff for Operations, Headquarters, U.S. Air Force.

  Mr. Stoffler briefly touched on the Air Force's mandate and mission to conduct space weather operations. He then reviewed important types of solar phenomena (flares, energetic particles, scintillations, and geomagnetic storms) and the impacts associated with those phenomena. He went on to list six specific instances of space weather events that impacted defense systems and/or operations. With that background, Mr. Stoffler discussed the work underway to insure that the quality of space weather support to Department of Defense (DoD) operations continues to improve. Current observing systems are being upgraded and will be augmented with data from commercial sources. An effort will be made to develop smaller, deployable observing systems and to exploit non-traditional data sources; and plans are underway to collect charged particle data from more Air Force space platforms. Efforts are also underway to upgrade models. Under consideration is an initiative to develop a separate education track for space weather personnel, who in the past have been drawn from the pool of meteorologists. That initiative could lead to a new General Schedule (GS) series related to space physics. Mr. Stoffler closed his presentation by detailing the many interagency initiatives the Air Force is supporting, including the 2015 SWAP, O2R collaboration memoranda of understanding, response to EO 13744, 2019 NSWSAP, and many others.

- Ms. Karen Shelton Mur, Office of Commercial Space Transportation, Federal Aviation Administration (FAA).

  Ms. Shelton Mur updated the forum on FAA's Office of Commercial Space Transportation, which, similar to other FAA aviation responsibilities, has two roles. The first is to regulate the U.S. commercial space transportation industry, to ensure

compliance with international obligations of the United States, and to protect the public health and safety, safety of property, and national security and foreign policy interests. The second is to encourage, facilitate, and promote commercial space launches and reentries by the private sector. She pointed out that commercial activity in space is becoming more diverse and complex. For example, the map of spaceports continues to expand. In addition to the seven Federal spaceports that have been around for some time, there are 12 licensed launch and reentry ports. To provide a focal point for developing policies to promote and strengthen infrastructure on commercial launch sites, the Office of Spaceports was established in 2018 as part of the FAA's Reauthorization Act. With that background, Ms. Shelton Mur provided specifics on three of the more active commercial space endeavors: Virgin Galactic, SpaceX, and Blue Origin. She went on to note that the National Space Council, which was established 30 years ago but had been disbanded, has been reestablished and has released several Space Policy Directives. The first related to the overall goals for the lunar mission. SPDs 2 and 3 addressed the rulemaking process and National Space Traffic Management Policy oversight, both of which are the responsibility of the Department of Commerce. Ms. Shelton Mur completed her comments by pointing out that FAA has authority for just launch and reentry, not orbital (or beyond) spaceflight. The agency's Human Spaceflight regulations require launch operators to disclose all risks associated with launch and reentry, and encourages the launch operator to discuss the potential risks associated with the radiation environment that may be experienced during the flight. However, regulations regarding suborbital spaceflight do not have specific requirements regarding total radiation dose for crew or passengers because this is not an acute hazard. She closed by acknowledging the importance of SWEF and the ongoing SWORM activities and pledged continuing FAA support.

- Mr. Richard Ullman, Deputy Director, Office of Projects, Planning, and Analysis, National Environmental Satellite Data and Information Service (NESDIS).

  Mr. Ullman briefed the forum on NOAA's current and future space weather observational architecture needed to fulfill the mandate to provide operational space weather watches and warnings. He provided a quick update on the status of current and planned space weather observing systems, including those on GOES platforms, the Global Oscillation Network Group (GONG) program, Deep Space Climate Observatory (DSCOVR), Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC)-2, and the commercial weather data buy program. He then presented a timeline showing operational and planned systems projected through 2030 organized by type of observations taken and position in space (e.g., low earth orbit, L1, etc.). Mr. Ullman covered the Space Weather Follow-On (SWFO) program in some detail. The two space-born components of SWFO are the L1 mission and the Geostationary Operational Environmental Satellite (GOES)-U mission, both scheduled for launch in 2024. The L1 mission is a rideshare with NASA's IMAP (Interstellar Mapping and Acceleration Probe), and will include a Solar Wind Instrument Suite, a Compact Coronagraph (CCOR), and a possible instrument of opportunity. The GOES-U mission will include a CCOR as well as the Solar Ultraviolet Imager (SUVI) and X-ray Irradiance Sensors (EXIS) which are deployed on the GOES-16 and -17 spacecraft. After describing the CCOR in more detail, he completed his discussion of SWFO with a description of the ground services component of the program, which will include the

archive of space weather data products by the National Centers for Environmental Information. Mr. Ullman discussed the 6 COSMIC-2 spacecraft, successfully launched on June 25th (early yesterday morning), which carry, as secondary sensors, an Ion Velocity Meter (IVM) and an radio frequency beacon (for measuring total electron content). Mr. Ullman presented slides showing NOAA's current and future space sensing architecture before closing his briefing with a discussion of the status of NOAA's Commercial Weather Data Pilot project.

Q & A:

- *Mr. Clarke opened this Q&A by asking the panelists in what ways they see commercial and international contributions improving space weather forecasting—not just for terrestrial applications, but also for deep space.* Mr. Stoffler responded that companies are offering space on satellites for sensors. The DoD is looking to develop miniature sensors that the companies can buy, fly on their satellites, and then sell the data to the DoD. They are willing to exchange resolution for refresh rate, which is something commercial satellites can provide. Mr. Semones added that NASA uses the Small Business Innovative Research program to engage the commercial sector in improving modeling capabilities. Mr. Ullman suggested that as the commercial sector continues to recognize opportunities, focus on understanding and adapting to requirements, and develop their capabilities, NOAA will be using more commercial data. He emphasized the "swim lanes" approach mentioned earlier by Dr. Lautenbacher, pointing out that some data will remain a government responsibility, but that there are will be expanding opportunities for the commercial sector. Ms. Sheldon Mur suggested that sensors could ride along on commercial launch vehicles to add to data availability.
- *We should be concerned about near term observing capabilities with Polar Orbiting Environmental Satellites (POES), Defense Meteorological Satellite Program(DMSP) satellites, Solar Terrestrial Relations Observatory (STEREO), Van Allen Probes all aging. There are plans for far term, but are there ideas about how to fill the gap? And how do we assure that this situation won't happen in the future?* Mr. Ullman acknowledged the problem, especially in the very near term. He stated that he couldn't address operational work-arounds, but that SWPC has been working on how provide the best possible service with whatever data is available. Going forward, we must get away from the one-off approach. NOAA is working on L-1, and we should be working now (even before the L-1 launch) on the follow-on. The enterprise should remind those in authority of the need for on-going observations. Mr. Clarke added that cubesats are becoming remarkably capable. We no longer need large platforms for all observations. Cubesats or a constellation of smaller platforms should be considered in the future.
- *Mr. Clarke asked Mr. Semones about the mitigations that are being planned for astronauts in traveling to the moon or in the Gateway.* Mr. Semones responded that the storage area in the Orion capsule can be reconfigured to make a well-performing shelter. The other aspects of a moon mission (Gateway, descent and ascent, and activities on the surface) are more problematic. However, there is still time to address these issues through design and operations, and early missions are streamlined, providing less vulnerability to exposure.
- *Mr. Clark then queried the panelists how the enterprise is doing with the maturation of models.* Mr. Stoffler responded that model development is not progressing at what he felt was an acceptable rate. But part of the problem is the lack of data. A near-term

approach would be to see if bringing in more commercial data would improve the performance of current models. If not, that would provide the impetus to address model improvements more aggressively. In any case, improving models is a challenging task that takes time. Mr. Ullman referred to Mr. Wallace's presentation earlier in the day, suggesting that NOAA has made progress on operational models in recent years and is continuing to make advancements.

- *A final question related to DoD's approach to space weather observations as indicated by a recent request for proposal from the Space and Missile Systems Center.* Mr. Stoffler replied that DoD is reconsidering the "Starship Enterprise" approach to satellites, where one platform hosts numerous sensors that collect data for many years. They are looking instead at using more numerous smaller satellites and fielding sensors as secondary missions on other satellites, including commercial platforms. This approach would provide more data from more locations and greater flexibility in replacing sensors that fail. Mr. Ullman agreed with that concept, but suggested that there should be a suite of core observations at key locations that anchor the data for models, and the enterprise should have to own the platforms for those observations if there is no other platform available in those locations. That is, the location of space weather observations shouldn't be completely random based on the availability of rides on other types of missions.

Session 5: Response and Recovery Following Space Weather Events

Moderator: Ms. Jackie Keshian, Policy Advisor, Executive Office of the President (EOP), Office of Science and Technology Policy (OSTP)

Ms. Keshian opened the session by introducing the panelists.

- Ms. Kenyetta Blunt, Chief, Recovery Planning Branch, Federal Emergency Management Agency (FEMA)

  Ms. Blunt started by pointing out that emergency management has not focused on preparing for and responding to space weather events in the past. However EO 13744 (October, 2016) changed that tradition, mandating preparation for space weather events to minimize economic loss and human hardship. The EO required the creation of the Federal Operating Concept for Impending Space Weather Events to coordinate Federal response. The Operating Concept outlines department and agency (D/A) actions to prepare for and respond to a notification of an impending space weather event. It focuses on operational and crisis planning, as well as on reporting structure and requirements. The Concept directs D/As to evaluate vulnerabilities to infrastructure and operations, and it designates those agencies responsible for notifying other D/As of elevated space weather threats and events. D/As, in turn must develop procedures to notify their various stakeholders. In addition, it encourages D/As to develop backup systems to restore damaged infrastructure. Finally, it specifies that FEMA will initiate incident management coordination among federal, state, territory, and non-governmental organizations. Ms. Blunt went on to brief the SWEF on the Power Outage Incident Annex (POIA) to the Response and Recovery Federal Interagency Operational Plans. This annex guides federal responders in providing response and recovery support. It identifies critical information requirements and unique considerations that could hinder responders' ability to provide services. The POIA is not an electricity

restoration plan, but it outlines the responsibilities of industry stakeholders and specifies the federal resources available to infrastructure stakeholders to support their restoration activities. Ms. Blunt closed her briefing by highlighting the third objective to the NSWSAP related to response to and recovery from space weather events. FEMA has played an important role in identifying the actions necessary to address response and recovery challenges, a task which is nearly complete, and will be in the forefront of efforts to deal with those actions.

- Mr. John Ostrich, Infrastructure Systems Analyst, U.S. Department of Energy (DOE)

  Mr. Ostrich began his briefing by explaining DOE's organization and programs related to infrastructure security and energy restoration. His work is under the Office of Cybersecurity, Energy Security, and Emergency Response, which leads the DOE's emergency preparedness and coordinated response to disruptions to the energy sector. This mission is accomplished through ten programs grouped under preparedness and exercises, situational awareness, and emergency response and recovery. Their responsibilities under the EO on Coordinating National Resilience to Electromagnetic Pulses is to conduct R&D with the private sector and other agencies to characterize sources of EMPs and their couplings to the electric power grid, to understand failure modes, and to coordinate preparedness and mitigation measures. DOE is addressing GMD together with EMP in a coordinated effort through CE-SMART, the Center for EMP/GMD Simulation, Modeling, Analysis, Research, and Testing. After explaining how GMDs induce GICs affecting long conductors, Mr. Ostrich detailed the effects that GICs have on transformers and other components of the bulk electric system. These effects include the biggest voltage collapse (the most serious concern), as well as damage to transformers, wear or damage to other generation/transmission equipment, and power quality issues and damage to customer equipment. The effects can be mitigated with current systems by adjusting protective equipment, maintaining ample reactive power (VAR) compensation, reducing the load on vulnerable transformers, cooling transformers, and reconfiguring the grid to reduce transmission over long distances. Future mitigation efforts could involve deploying new transformers with lower susceptibility to GICs, relying more on distributed energy resources, and considering factors that affect strength of GICs when siting new substations, such as latitude, geology, orientation of transmission lines, and proximity to large bodies of water. Mr. Ostrich emphasized the importance of situational awareness, including monitoring and reporting prior to, during, and after an extreme GMDs. Going forward, DOE is supporting the NSWSAP, developing and implementing the new CE-SMART initiative, and implementing a pilot program to deploy mitigation and protection devices on grid.

- Mr. Frank Koza, Electric Subsector Coordinator, Electricity Infrastructure Security (EIS) Council

  Mr. Koza opened his presentation with a quick review of the EIS mission and some of the EIS resources available to address space weather issues. He described coronal mass ejections, how they induce GICs, and the variables that determine the strength of those currents. He then presented an interesting schematic illustrating the impacts of GICs on electrical equipment. It all starts with transformer half-cycle saturation, which directly causes transformer heating and also results in harmonic currents that can affect

protection systems. In addition, transformer half-cycle saturation causes, through a more complex chain of events, voltage instabilities and collapse leading to blackouts. Mr. Koza stated that preparing for an event involves tracking the space weather status through the SWPC and Space Weather Canada, and performing sensitivity reviews to investigate and adjust operations for resiliency. During an event, operators monitor GIC detectors, adjust voltage, and otherwise adopt conservative operations techniques. If, in spite of these efforts, a blackout occurs, the length of the recovery will depend on the extent of damage. If there is no damage, restoring service should take from 8 to 24 hours. During that time, other components of the infrastructure (transportation, water and fuel supply, communications, etc.) would also be impacted. Should electrical generation and supply systems be damaged, recovery could take days or weeks depending on the type of damage. Due to the loss of power and associated infrastructure impacts, evacuations could be necessary. Mr. Koza addressed the issue of trying to engineer space weather impacts out of the system. NERC requires GMD vulnerability and transformer thermal impact assessments, as well as appropriate mitigation steps. Research continues on earth conductivity models, harmonics analysis tools, and transformer thermal impacts. A GIC reduction device has been installed. All these initiatives mark progress, but his "sobering points" slide suggesting that we could be due for a major event that could happen during any phase of the solar cycle clearly indicated that more work needs to be done before we can assume that the system is sufficiently hardened against GMD impacts. Mr. Koza's final slide presented some of the continuing initiatives underway at the EIS Council.

Q & A:

Bill Harris started by complementing the EIS Council on the quality of their handbooks He commented on the relative strength of GMDs and EMPs, and asked for comments on joint (rather than separate) planning for these two types of events. Mr. Koza responded that the Council is developing a handbook on EMP best practices, which will be published by this fall. Mr. Ostrich commented that DOE is investigating waveforms of GMDs and EMPs, expecting the EMP waveforms to be more intense. The intent is to publish declassified versions of that information for the various impacted industries to use in planning.

In an exercise in Florida, during which there was a blackout, the biggest problem was the loss of communications, especially cell phone service, which severely impacted recovery operations. How can we address that? Mr. Koza responded that the council is working on a stand-alone, self-supporting communications system called BSX, a pilot of which will be built this year. It's difficult, because it needs to interoperate with existing systems as they start to come back up. Ms. Blunt highlighted some of the cascading impacts beyond communications that were discovered during the Florida experiment and pointed out that FEMA is incorporating those into their planning.

It is feasible for enemies to execute an EMP. There is a need for various components to be available for restoration. What is in protective storage to do that? Mr. Koza responded that testing of electric devices is underway to determine what we need. For example, digital relays have been tested. Most will survive, but there are problems with the conductive energy coming into the control wires that go into relay. They are starting to get test results that point to where we need to do more. But there are millions of

relays, and we can't protect everything. So it becomes an issue of prioritization. Mr. Ostrich added the agencies are looking into what components might break and comparing costs of protecting versus replacing them. It may be too expensive to protect some components, so sparing programs should be put into place.

We recently experienced the weakest solar max in 100 years, and some have suggested that the next will be similar. But sooner or later the sun will become more active. How to we stay focused until then and not become complacent? Mr. Ostrich pointed out that even though we're presently in solar min, the enterprise is very focused. We're preparing for rare events, recognizing that will happen someday. Mr. Koza stated that the Council is modifying standards that were issued just a few years ago. The science continues to advance regardless of the state of the sun, and industry is working on dealing with whatever that science tells us as it becomes more settled. Ms. Blunt concurred, emphasizing that, from a planning perspective, monitoring the state of the science as it advances (rather than the current state of the sun) is key to ensuring that we've planned for potential impacts.

Some government data has been moved out of government centers into 3rd party "cloud" data centers which are not necessarily considered critical infrastructure. Are we recognizing that issue and planning accordingly? Ms. Blunt responded that one of the requirements in the Federal Operating Concept is for D/As, as they plan, to consider data integrity. This is tied to continuity of operations. Recognizing that technology changes over time, the requirements are written at a high enough level to require D/As to insure data access regardless of what storage technology is currently employed.

Session 6: Summary and Wrap-up

Mr. Bonadonna (OFCM) began his summary of the forum by highlighting the role of OFCM. He pointed out that space weather is included in the office's function of coordinating with the 15 Federal agencies that work with some aspect of meteorology. The goal is to facilitate interagency cooperation and to report that cooperation to Office of Management and Budget and Congress. OFCM established the National Space Weather Program over 20 years ago, which has seen a number of achievements over the years. OFCM continues to work in the enterprise through its support of the National Space Weather Partnership, which reaches beyond the Federal government to the academic and commercial sectors. Mr. Bonadonna announced that next year's SWEF will be a half day event on Capitol Hill, which will likely convene in November in conjunction with the Johns Hopkins University Applied Physics Laboratory SEASONS event. With that introduction, Mr. Bonadonna quickly reviewed some of the key points from the forum.

- Senator Gardner's support for the Space Weather Research and Forecasting Act continues to show strong bipartisan support in Congress. Director Reilly's presence and remarks were important to set the stage for much of what was discussed the rest of the day.
- Session 2 highlighted the progress that is being made to address space weather challenges and the level of cooperation across the enterprise that has contributed to that progress. However, it was also clear that, at least when it comes to dealing with GMDs, there are no silver bullets. Work is still needed on modeling, situational awareness, and development of procedures.

- Session 3 presented advances in space weather sciences, including model advances at the SWPC, NASA's enthusiastic support for the enterprise, and the R2O-O2R facilitation approach being advanced at University of Colorado's SWx-TREC. Dr. Lautenbacher's "swim lane" concept for work within the enterprise clearly resonated, as it was cited more than once later in the forum.
- Session 4 focused on human space travel. We saw how NASA is preparing to return to the moon (and eventually Mars), and how they're addressing space weather issues as part of that endeavor. Mr. Stoffler again reminded us of the importance of space weather in national defense, and we got an enlightening look at some practical aspects of how FAA is managing commercial space travel. Finally we reviewed current and future NOAA/NESDIS contributions to observing space weather.
- In Session 5 we looked at where we stand on learning how to recover from space weather events. We were encouraged by all the progress that has been and is being made in both dealing with events and recovering from their impacts. However, it remains clear from statements by Mr. Ostrich and Mr. Koza that we have more work to do to protect and, as necessary, restore our electric supply infrastructure. Ms. Blunt's broader comments on planning for recovery from space weather events highlighted both how much we're doing and how much more we still have to do across the enterprise.

Mr. Bonadonna wrapped up his remarks by reminding the forum that OFCM will be completing a summary of the event in the next several weeks, and it will be posted along with the presentations on SWEF web site. With that, he invited forum host Dr. Bill Leith to the podium for his final thoughts.

Dr. Leith began by thanking Mike and the OFCM team for putting together the forum, and all those who spoke and attended for their time and effort. He then remembered back to SWEFs years ago, and recalled that they were largely made up of questions being asked and concerns expressed about the effects of space weather. We have more answers now, and strategies are being implemented to mitigate the effects of space weather. It's rewarding to see the progress being made by a large, engaged community. Dr. Leith added that he has also noticed an increased willingness for people to come to the microphone, ask questions, and build a dialogue that contributes to addressing space weather issues. He closed the forum by encouraging everyone to participate in next year's SWEF.

2019 Space Weather Enterprise Forum

Agenda

"Preparing the Nation for Space Weather"

June 26, 2019

Yates Auditorium

Department of Interior, Main Bldg

1849 C St NW, Washington, DC 20240

7:30 am **Registration**

8:30 am **Session 1: Welcome and Opening Addresses**

- **Dr. William Leith**, Senior Science Advisor for Earthquake and Geologic Hazards U.S. Geological Survey (USGS)
- **The Honorable Cory Gardner**, United States Senate
- **Dr. James Reilly II,** Director, United States Geological Survey (USGS)
- **Dr. Louis Uccellini,** National Oceanic and Atmospheric Administration (NOAA) Assistant Administrator for Weather Services and Director, National Weather Service

9:30 am **Session 2: Preparing for Space Weather Impacts**

Moderator: Dr. Antti Pulkennen, Deputy Director, Heliophysics Science Division, National Aeronautics and Space Administration (NASA), Goddard Space Flight Center

- **Dr. Jeffrey Love**, Research Geophysicist, Advisor for Geomagnetic Research, US Geological Survey (USGS)
- **Mr. John Moura,** Director - Reliability Assessment at the North American Electric Reliability Corporation (NERC)
- **Dr. Emamuel Bernabeu,** Director, Applied Innovation & Analytics, PJM Interconnection

10:35 am **Break**

10:50 am **Session 3: Advancing Space Weather Science and Services**

Moderator: Dr. Devrie Intriligator, Director, Space Plasma Laboratory, Carmel Research Center, Inc. and American Commercial Space Weather Association Executive Committee

- **Mr. Clinton Wallace,** Director, NOAA Space Weather Prediction Center
- **Dr. James Spann**, Chief Scientist, Heliophysics Division Chief Scientist, Headquarters National Aeronautics and Space Administration (NASA).
- **Dr. Conrad Lautenbacher**, Chief Executive Officer, GeoOptics Incorporated and American Commercial Space Weather Association.
- **Dr. Daniel Baker,** Director Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder.

Note: Speaker and audience remarks are paraphrased and not to be used as quotations.

12:10 pm **Lunch**

1:30 pm **Session 4: Space Weather for a Space Faring Nation**

Moderator: Mr. Steve Clarke, Deputy Associate Administrator for Exploration, Science Mission Directorate, NASA HQ

- **Dr. Eddie Semones,** NASA Space Radiation Analysis Group, Johnson Space Flight Center
- **Mr. Ralph Stoffler**, Director of Weather, Deputy Chief of Staff for Operations, Headquarters, U.S. Air Force.
- **Ms. Karen Shelton Mur**, Office of Commercial Space Transportation, Federal Aviation Administration
- **Mr. Richard Ullman,** Deputy Director, Office of Projects, Planning, and Analysis (OPPA) National Environmental Satellite Data and Information Service (NESDIS)

3:15 pm **Break**

3:30 pm **Session 5: Response and Recovery following Space Weather Events**

Moderator: Jackie Keshian, Policy Advisor, Executive Office of President (EOP), Office of Science and Technology Policy (OSTP)

- **Ms. Kenyetta Blunt**, Chief, Recovery Planning Branch, Federal Emergency Management Agency (FEMA)
- **Mr. John Ostrich,** Infrastructure Systems Analyst at U.S. Department of Energy
- **Mr. Frank Koza,** Electric Subsector Coordinator, Electricity Infrastructure Security (EIS) Council

4:35 pm **Session 6: Summary and Wrap up**

- **Mr. Michael Bonadonna,** Executive Secretary, Space Weather Operations Research and Mitigation (SWORM) Interagency Working Group and Director, Office of the Federal Coordinator for Meteorology (OFCM)
- **Dr. William Leith**, Senior Science Advisor for Earthquake and Geologic Hazards U.S. Geological Survey (USGS)

4:45 pm **End**