COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENVIRONMENT
SUBCOMMITTEE ON SPACE AND AERONAUTICS
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

Space Weather: Advancing Research, Monitoring, and Forecasting Capabilities

Wednesday, October 23, 2019
2:00 p.m.
2318 Rayburn House Office Building

PURPOSE

This hearing will provide an opportunity to discuss the current state of space weather research and federal efforts to monitor and predict space weather events with a specific focus on identifying what is needed to improve our space weather forecasting prediction capabilities. It will also examine how collaboration among federal, academic, and commercial sectors can best support advances in the field of space weather and space weather forecasting and prediction capabilities among other relevant issues.

WITNESSES

- **Mr. Bill Murtagh (MER-togg)**, Program Coordinator, National Oceanic and Atmospheric Administration's (NOAA) Space Weather Prediction Center (SWPC)
- **Dr. Nicola Fox**, Heliophysics Division Director, National Aeronautics and Space Administration (NASA)
- **Dr. Conrad C. Lautenbacher (LAW-ten-BAH-ker), Jr., VADM USN (ret.)**, CEO of GeoOptics, Inc, and former Under-Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator (2001-2008)

OVERARCHING QUESTIONS

- What are the top research, modeling, and operational questions that need to be addressed to improve our space weather prediction and forecasting capabilities?
- What is the current state of space weather research being conducted at federal agencies, and in the broader space weather community?
- What are the research-to-operations and operations-to-research processes in the field of space weather, and how can these processes be improved?
- What is the role of the commercial sector in the field of space weather?
- What is the status of our current observational infrastructure, and how do we sustain and enhance these observations?

BACKGROUND

What is Space Weather?

The term "space weather" describes an array of naturally occurring solar phenomena that can impact activities on Earth. Common space weather phenomena include solar flares, solar winds, coronal mass ejections (CMEs), and solar radiation storms. The movement of energized particles from the Sun into the Earth's magnetosphere can cause geomagnetic storms that can be disruptive to space-based and ground-based technologies.

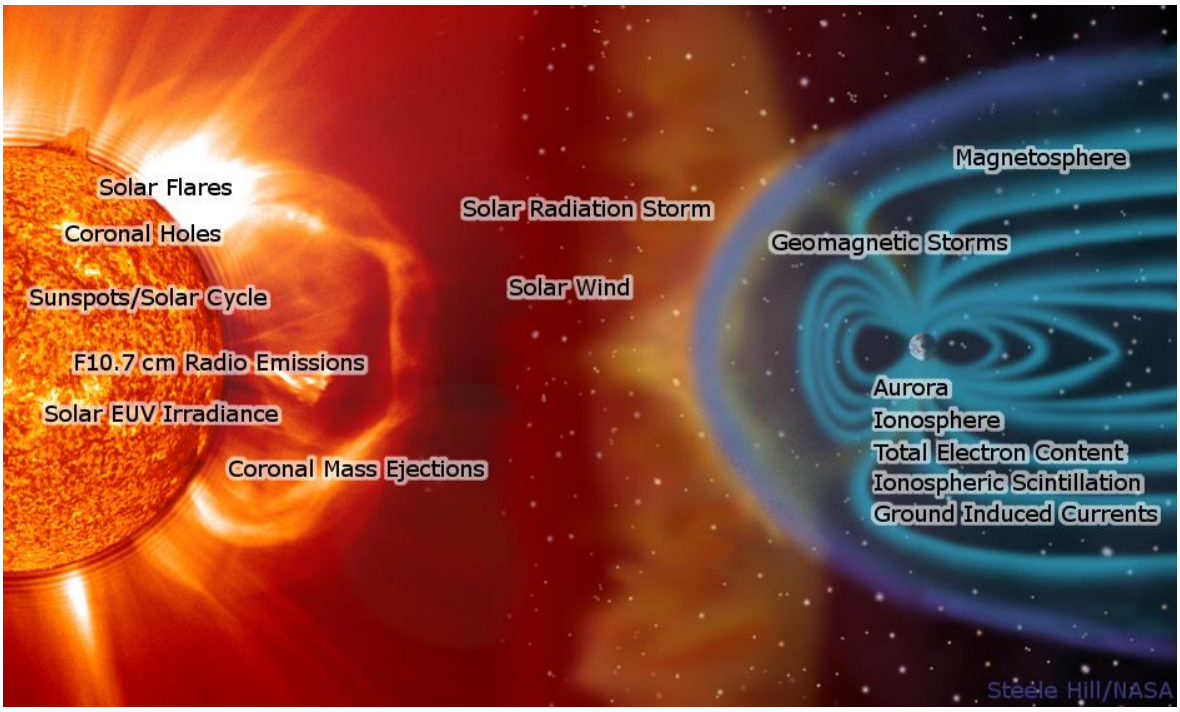

Figure 1. https://www.swpc.noaa.gov/phenomena

Societal and Economic Impacts of Space Weather Events

Though severe space weather events may occur once or twice every few decades more routine variabilities in the space environment can impact assets in space, in the near-earth environment, and on the ground on a more regular basis. A 2017 NOAA-sponsored report determined the societal and economic impacts to operations in four sectors. [1]

- Impacts to electric power grids: reactive power consumption, transformer heating, improper operations of protective relaying equipment, generator tripping, loss of precision timing.
- Impacts to satellites: loss of altitude, link disruption, anomalies, cumulative dosage.
- Impacts to global navigation satellite systems (GNSS): ranging errors, loss of lock.

[1] https://www.weather.gov/media/news/SpaceWeatherEconomicImpactsReportOct-2017.pdf

- Impacts to aviation: communication and navigation degradation, avionic upsets, effective dose.

The report also found that "scientific research on space weather contributes knowledge that is essential for designing and engineering robust and safeguarded systems," and found that proactive investments to prevent impacts are significantly low compared to the costs of recovering from an event. Additionally, the report noted that industry plays an important information-sharing role, further justifying the inter-disciplinary approach articulated in the Space Weather Action Plan.

In addition to the broader impacts of space weather on our space and ground-based infrastructure, space weather poses risks to human spaceflight operations due to the damaging particles emitted during geomagnetic storms. Astronauts on the International Space Station (ISS) exhibit evidence of radiation damage to cells and DNA from constant exposure to highly charged particles of solar and galactic origins.[2] Beyond low-earth orbit, however, the space radiation environment is far more severe, and poses more serious risks to astronauts.

Interagency Coordination on Space Weather Activities

The Office of Science and Technology Policy (OSTP) established the Space Weather Operations, Research, and Mitigation (SWORM) Task Force in November 2014. The SWORM Task Force is comprised of 13 federal agencies including NASA and NOAA, and has a goal of developing a path forward to improve space weather preparedness.[3] In 2015, the SWORM released its first National Space Weather Strategy and Space Weather Action Plan (SWAP) which established priorities and strategic goals to strengthen interagency partnerships and collaboration with the larger space weather community. In March 2019, the SWORM released an updated National Space Weather Strategy and SWAP that supersedes the 2015 versions.[4] The 2019 SWAP and Strategy identified three high-level actions to enhance preparedness for space weather events: 1) Enhance the protection of National Security, Homeland Security, and Commercial Assets and Operations against the Effects of Space Weather; 2) Develop and Disseminate Accurate and Timely Space Weather Characterizations and Forecasts; and 3) Establish Plans and Procedures for Responding to and Recovering from Space Weather Events.

The current decadal survey for solar and space physics (or Heliophysics) is the 2013 *Solar and Space Physics: A Science for a Technical Society.*[5] The report directs its recommendations primarily to NASA and NSF, but it also recommends actions by other agencies, particularly NOAA. The report makes recommendations specific to space weather as a set of Applications recommendations, separate from its Science recommendations, to enable effective space weather and climatology capabilities. Summaries of those recommendations are listed in the table below.

[2] National Research Council. 2008. *Managing Space Radiation Risk in the New Era of Space Exploration.* The National Academies Press, Washington, D.C.
[3] https://www.sworm.gov/index.html
[4] National Science and Technology Council. March 2019. *National Space Weather Strategy and Action Plan*. https://www.whitehouse.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf
[5] National Research Council. 2013. Solar and Space Physics: A Science for a Technological Society. Washington, DC: The National Academies Press. https://doi.org/10.17226/13060.

A mid-decade assessment of the progress implementing the decadal survey is currently underway and is expected to be released by the end of 2019.[6]

Heliophysics Decadal *Applications* Recommendations	
Program	*Notes from Decadal Recommendation*
1. Recharter the National Space Weather Program	As part of a plan to develop and coordinate a comprehensive program in space weather and climatology, the survey committee recommends that the National Space Weather Program be rechartered under the auspices of the National Science and Technology Council. With the active participation of the Office of Science and Technology Policy and the Office of Management and Budget, the program should build on current agency efforts, leverage the new capabilities and knowledge that will arise from implementation of the programs recommended in this report, and develop additional capabilities, on the ground and in space, that are specifically tailored to space weather monitoring and prediction.
2. Work in a Multiagency Partnership to Achieve Continuity of Solar and Solar Wind Observations	The survey committee recommends that NASA, NOAA, and the Department of Defense work in partnership to plan for continuity of solar and solar wind observations beyond the lifetimes of ACE, SOHO, STEREO, and SDO.

Space Weather Forecasting

NOAA's Space Weather Prediction Center (SWPC), part of the National Centers of Environmental Prediction under the National Weather Service (NWS), is the primary source of civilian warnings and forecasts for space weather. SWPC is jointly operated with the U.S. Air Force and conducts research on solar-terrestrial physics, develops techniques for forecasting solar and geophysical disturbances, and provides real-time monitoring and forecasting of solar and geophysical events.

NOAA contracted a report, finalized in 2019, to identify customer needs and requirements for space weather products and services.[7] The study assessed "the variety of uses and needs for SWPC space weather information across five sectors: (1) electric power, (2) satellites, (3) global navigation satellite systems (GNSS), (4) aviation, and (5)" emergency management. It showed that all five sectors utilized SWPC products, but that there were improvements that could be made to improve accessibility and usability of the products.

Current Observational Infrastructure

NOAA SWPC uses data from a suite of observing platforms to provide space weather forecasts. These include NOAA assets as well as observations from other federal partners. NOAA has multiple instruments for collecting space weather data on its Geostationary Operational Environmental Satellites (GOES) system. The Deep Space Climate Observatory (DSCOVR) satellite, launched in February 2015, is a partnership between NOAA, NASA, and the U.S. Air

[6] http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_174910
[7] Abt Associates. "Customer Needs and Requirements for Space Weather Products and Services. March 29, 2019. Accessed here: https://www.swpc.noaa.gov/news/customer-needs-requirements-space-weather

Force, and was developed to succeed the NASA Advanced Composition Explorer (ACE) satellite to provide real-time solar wind observations from the L1 orbit.[89] NOAA supports space based observational assets with ground-based tracking systems.

NASA's Heliophysics Division currently operates 26 spacecraft in diverse locations, several of which are making observations related to space weather:

- Advanced Composition Explorer (ACE), launched in 1997, measures the particles in the solar wind, which can originate not only from the Sun, but also from interplanetary or interstellar (galactic) space. ACE can provide an advance warning of about one hour for geomagnetic storms on Earth.
- Solar and Terrestrial Relations Observatory (STEREO), launched in 2006, provides stereoscopic measurements to study the Sun and coronal mass ejections (CMEs).
- Solar Dynamics Observatory (SDO), launched in 2010, is contributing to our understanding the fundamental nature of the Sun's magnetic field, as well as how it generates solar wind.
- Global-scale Observations of the Limb and Disk (GOLD), launched in 2018, measures the temperature and composition of neutral gases in the Earth's thermosphere, part of an effort to understand the cause of dense, unpredictable bubbles of charged gas that appear over the equator and tropics and can stymie terrestrial communications.
- Parker Solar Probe, launched in 2019, is making approaches closer to the Sun's surface than any previous spacecraft in order to study the flow of energy and the heating of the solar corona and to understand the acceleration of the solar wind.
- Ionospheric Connection Explorer (ICON), launched in 2019, will study the boundary region where the uppermost layers of the Earth's atmosphere interacts with the charged particles of the solar wind.

The Heliophysics Division also has a suborbital program that supports CubeSat, balloon, and sounding rocket investigations in space weather and other areas of Heliosphere research. In additional to space-based observations, ground-based assets also provide critical data for space weather forecasts. The data from the United States Geological Survey (USGS) Geomagnetism Program monitors the Earth's magnetic field to provide continuous records of magnetic field variations is used by NOAA to characterize geomagnetic storms.[10] NSF's Global Oscillations Network Group (GONG) also provides ground based solar observations.[11]

International Partnerships

NASA partners with other space agencies in a number of areas relevant to space weather. The most significant example in the current fleet of missions relevant to space weather is the Solar and Heliophysics Observatory (SOHO), a mission to study the internal structure of the Sun and the solar wind. SOHO, launched in December 1995 and still operating today, is a partnership between NASA and the European Space Agency (ESA). The coronagraph images captured by SOHO's Large Angle Spectrometer Coronagraph (LASCO) instrument are utilized by SWPC to

[8] Lagrangian point 1, or L1, is approximately 1 million miles away from Earth.
[9] On June 27, 2019 the DSCOVR satellite was placed in Safehold mode and is not returning any space weather data in this mode, with NOAA relying on data from the ACE satellite to inform their operational space weather activities. The ACE satellite is currently the only source of real-time solar wind observations from L1.
[10] https://www.usgs.gov/natural-hazards/geomagnetism
[11] https://gong.nso.edu/

characterize the solar corona and is a vital tool for forecasting the impact of CMEs and the effects of solar winds on the Earth.[12]

NASA is also a partner in the upcoming ESA-led Solar Orbiter mission, set to launch in February 2020. The Solar Orbiter mission will travel close to the Sun to take both *in situ* and remote sensing measurements to aid in scientists' understanding of how the inner heliosphere works and how it is affected by solar surface activity.

Future Observational Infrastructure

To ensure consistent observations of space weather phenomena, NOAA and NASA are developing assets to continue space weather data collection in the near-term. NOAA is working with the Naval Research Laboratory (NRL) to develop a compact coronagraph (CCOR) to be deployed on the GOES-U satellite that is currently set for a 2024 launch. The CCOR will image the solar corona and observe CMEs to help determine their size, mass, and speed. This information can help space weather forecasters provide forecasts, warnings, and watches for space weather events over a day in advance.[13] The CCOR will succeed the SOHO/LASCO satellite for CME imagery. There is currently no backup to SOHO/LASCO for CME imagery. NOAA is also in conversation with NASA to launch a space weather follow-on L1(SWFO-L1) as a hosted payload on NASA's upcoming Interstellar Mapping and Acceleration Probe (IMAP) mission. On October 3, 2019 NOAA released a Broad Agency Announcement (BAA)[14] for the submission of white papers to conduct studies of instrument and mission concepts to support needs for space weather data collection.

NASA recently announced the initiation of the Interstellar Mapping and Acceleration Probe (IMAP) mission, a decadal recommended mission. IMAP is slated to launch 2024 and will study the interaction of the heliosphere with the interstellar medium and the particles streaming to Earth from the edge of interstellar space. The decadal survey also recommended a large mission -- the Geospace Dynamics Constellation reference mission --to study the ionosphere-thermosphere-mesosphere system of the Earth's atmosphere in an integrated fashion, focusing on how Earth's atmosphere absorbs solar wind energy, and NASA has supported preliminary studies on the mission.

Current Space Weather Research and Findings

NASA's Heliophysics Division, in the Science Mission Directorate (SMD), studies the fundamental nature of the Sun and its interactions with Earth and other bodies of the Solar System. The solar wind—a constant outflow of particles from the Sun as well as interplanetary and interstellar space—and solar activity like coronal mass ejections (CMEs) and solar flares influence the space environment and can interact with the Earth's atmosphere and magnetic field.

NASA recently initiated the Space Weather Science Application (SWxSA) project, a dedicated effort to transition space weather tools, models, data, and knowledge from research to operational environments.[15] In addition, NASA and its Goddard Space Flight Center leads the

[12] https://www.swpc.noaa.gov/products/lasco-coronagraph
[13] https://www.nesdis.noaa.gov/OPPA/ccor.php
[14] https://www.fbo.gov/index?s=opportunity&mode=form&id=e73adc85a721fb3425c506a6dec0aef8&tab=core&_cview=1
[15] Congress appropriated $15 million to dedicated space weather research in FY 2018 and FY 2019.

Community Coordinated Modeling Center (CCMC), a multi-agency partnership that provides access to modern space science simulations to the international community and CCMC supports space weather forecasters through transitioning modern space research models to space weather operations, evaluating models as an unbiased agent, and providing forecasting tools.

Academic Role

Fundamental scientific questions relevant to space weather remain unanswered. Apart from the continued need for observations of solar phenomena, gaps exist in our understanding of the foundational physics that *drive* these solar phenomena. Greater support of federally funded research to study the physical processes behind space weather will help improve the utilization of our observational data. Enhanced scientific understanding coupled with robust observations are vital to improving space weather forecasting capabilities.

Commercial Interest and Role

The decadal survey highlights a "maturing commercial space weather enterprise."[16] Similarly, the 2019 National Space Weather Strategy and Action Plan calls for "the coordination and collaboration within and across the Federal Government, as well as engagement with the commercial sector, academia and like-minded nations."[17] The American Commercial Space Weather Association (ACSWA), founded in 2011, represents 19 member companies that offer "support ranging from algorithmic development services to numerical modeling and simulation including the magnetosphere, ionosphere and lower atmosphere."[18]

To date, the commercial entities have mainly advised the federal government on critical space weather issues, but a number of private sector actors are increasingly interested in building space weather observational infrastructure and data capabilities to enhance United States' and global preparedness. The SWPC also works with commercial service providers and the international community to acquire and share information needed to carry out its role in serving the nation with space weather products and services.[19]

Legislation

On March 26 2019, Senator Gary Peters introduced S. 881 – *Space Weather Research and Forecasting Act*. It passed out of the Senate Committee on Commerce, Science, and Transportation on April 3, 2019. The bill's stated purpose is to "*improve understanding and forecasting of space weather events, and for other purposes."* The bill delineates responsibilities for space weather observations and forecasting, research and technology, and data among the various federal agencies, and also directs the Office of Science and Technology Policy, along with the interagency National Science and Technology Council, to coordinate research and preparedness efforts across the federal space weather enterprise.

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[16] National Research Council. 2013. *Solar and Space Physics: A Science for a Technological Society*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13060.
[17] National Science and Technology Council. March 2019. *National Space Weather Strategy and Action Plan*. https://www.whitehouse.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf
[18] http://www.acswa.us/
[19] National Research Council. 2013. *Solar and Space Physics: A Science for a Technological Society*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13060.