Space Weather Advisory Group (SWAG)
Public Meeting
Department of Commerce
Washington, D.C.
Meeting Minutes
Wednesday, January 18, 2023
9:00 AM – 5:00 PM

Meeting Attendees

Committee

Nongovernmental End User Representatives

Dr. Tamara Dickinson, Committee Chair, Science Matters Consulting
Mr. Mark Olson, North American Electric Reliability Corporation
Mr. Michael Stills, United Airlines (retired)
Mr. Craig Fugate, One Concern
Dr. Rebecca Bishop, Aerospace Corp.

Commercial Sector Representatives

Dr. Jennifer Gannon, Computational Physics, Inc.
Dr. Conrad Lautenbacher, GeoOptics, Inc.
Dr. Seth Jonas, Lockheed Martin
Dr. W. Kent Tobiska, Space Environment Technologies
Dr. Nicole Duncan, Ball Aerospace

Academic Community Representatives

Dr. Tamas Gombosi, University of Michigan, Ann Arbor
Dr. Delores Knipp, University of Colorado, Boulder
Dr. Scott McIntosh, National Center for Atmospheric Research
Dr. Heather Elliott, Southwest Research Institute
Dr. George Ho, Johns Hopkins University Applied Physics Laboratory

Designated Federal Officer

Dr. Jennifer Meehan, National Space Weather Program Manager, National Weather Service

Also Present

Ms. Kenyetta Blunt, FEMA
Mr. Richard Horne, British Antarctic Survey
Ms. Amy Macpherson, National Weather Service
Mr. William Murtagh, NWS Space Weather Prediction Center
Lt. Col. Omar Nava, U.S. Air Force
Dr. Mangala Sharma, NSF
Dr. James Spann, NASA
Ms. Jenn Sprague, National Weather Service
Dr. Elsayed Talaat, NOAA

<u>Meeting Minutes</u>

9:00-9:05: Welcome (Dr. Jennifer Meehan, SWAG DFO)

Dr. Meehan welcomed everyone to the fourth Space Weather Advisory Group (SWAG) meeting, in which SWAG continued discussion on how best to implement Section 60601 of the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act.

She provided a brief review of the PROSWIFT Act, which directed the National Oceanic and Atmospheric Administration (NOAA) to establish the SWAG to advise the White House Space Weather Operations Research and Mitigation (SWORM) Subcommittee. All 15 non-governmental representatives of the SWAG were appointed by the SWORM Interagency Working Group with three-year terms. The PROSWIFT Act directed SWAG members to receive advice from the academic community, the commercial space weather sector, and space weather end users that would inform the interests and work of the SWORM.

Members present stated their names and institutions.

9:05-9:15: Opening Remarks and Recap of Meeting 3 (Dr. Tamara Dickinson, Science Matters Consulting, and Chair, SWAG)

Dr. Dickinson gave an overview of what was discussed at the June meeting, which focused on the user survey. Each of the sectors gave a briefing on where they were with respect to the questions of the process they were going to use to conduct the survey, after which the group reached consensus on this item. It received remarks from NOAA's Social, Behavioral, and Economic Sciences Group; SWORM co-chairs; the Space Weather Roundtable; and the National Space Weather Council. It discussed how to incorporate community input into its activities, and how to gather information regarding its task to provide SWORM with an update to the strategy and action plan. The meeting included a public comment period.

Members had received copies of the March and June meeting minutes. They were asked to submit minor edits to Dr. Meehan. No members reported any major issues. Dr. Tobiska made a motion to approve the March meeting minutes with any changes that might come in. The motion was seconded and passed without opposition. Dr. Ho made a motion to approve the June meeting minutes with any changes that might come in. The motion was seconded and passed without opposition.

Dr. Dickinson reviewed the agenda for this meeting.

9:15-9:30: Progress since Meeting 3 (Tamara Dickinson, Science Matters Consulting, and Chair, SWAG)

Dr. Dickinson provided an update on the user survey. It had entered the Paperwork Reduction Act process. The first Federal Register notice was published August 16. After a 60-day open period, no comments were received. A second notice would be published soon and be open for 30 days. Any comments received would need to be adjudicated, after which the plan would go to OMB for approval. Work had begun on the implementation plan. Dr. Dickinson would be holding a call with sector leads to talk about some options. She hoped to be able to actually conduct some focus groups at Space Weather Workshop (SWW) 2023.

Dr. Bishop, Dr. Tobiska, Dr. Ho, Dr. McIntosh, and Dr. Dickinson held a town hall at AGU in December. Several SWAG members were in the audience and online, and there was good audience participation. In January, Dr. Bishop, Dr. Tobiska, Mr. Olson, Dr. McIntosh, Dr. Meehan, and Dr. Dickinson held a session at the American Meteorological Society (AMS) meeting in Denver which they ran as a town hall. Several SWAG members were in the audience, and there was good audience participation. An AMS town hall with a spotlight on space weather risks and resilience and preparing for Solar Cycle 25 was hosted by Dr. Dickinson, Jim Spann, Mary Erickson, Mona Harrington, Ezinne Uzo-Okoro, and Dr. Meehan.

9:30-9:45: NOAA Administrator Remarks (Rick Spinrad, Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator)

Dr. Spinrad welcomed attendees to the Herbert C. Hoover Building. He stressed the critical importance of the Group's work. The previous year, he had released NOAA's Weather, Water, and Climate Strategy for the upcoming five years. Space weather was one of six key areas of societal challenges the strategy identified.

The FY2023 Omnibus Bill funded several important pieces of the NESDIS Space Weather Follow-on program and Space Weather Next program. The bill also passed a request to rename the Office of Projects, Planning, & Analysis to the Office of Space Weather Observations and to build a Space Weather Test Bed.

Dr. Spinrad affirmed NOAA's commitment to working with other federal agencies as well as its counterparts overseas. At the AMS meeting, NOAA announced there had been 18 "billion-dollar disasters" in 2022 leaving a total impact of $165 billion. A geomagnetic storm had the potential to cause over a trillion dollars in damage. Public engagement was essential, and Dr. Spinrad commended the National Weather Service for incorporating the concept of impact-based decision support services the previous year.

Dr. Spinrad had discussed improving space weather monitoring and predicting capabilities with NOAA's private sector partners. The PROSWIFT Act emphasized a whole-of-community approach, including a lot of language about cross-sector partnership. Dr. Spinrad believed SWAG's user survey would be critical, particularly in helping NOAA and the community writ large define emerging mission areas.

For the first time in at least 27 years, NOAA had a full complement of confirmed Presidential appointments, which put the agency in a good position to accomplish its key objectives, such as transitioning research into operations. The Space Weather Prediction Center's operational budget was a modest $13 million, which meant NOAA had to be very careful about identifying priorities for research and how to transition.

Dr. Spinrad had engaged in a series of industry roundtables and welcomed SWAG input on what industries he should reach out to. He considered the SWAG's work enormously valuable and expressed a willingness to meet with the Group as often as possible.

9:45-10:15: SWORM Subcommittee Co-Chair Remarks

Ezinne Uzo-Ukoro, Assistant Director for Space Policy, Office of Science and Technology Policy (OSTP)

Dr. Uzo-Ukoro praised the SWAG for its extraordinary work and level of commitment. She particularly enjoyed the session dedicated to the SWAG at the recent AMS meeting. She noted that the Biden-Harris administration was committed to continuing the work on space weather begun at OSTP back in 2014. It recognized the U.S. must build the capabilities to improve the safety and security of its critical infrastructure to withstand space weather events.

The SWORM Subcommittee was reviewing its 2019 Strategy and Action Plan, which was due for update and reissue every four years or as needed. A summary on the progress and implementation of the SWORM was completed earlier this month and would be posted online.

There were shortcomings in ground and space-based observations, which made imperative the identification, implementation, and sustaining of a baseline of fundamental measurements. Effective and appropriate actions for space weather events required an understanding of their magnitude and frequency. NOAA's space weather scales needed to be updated and informed by the interests and needs of key domestic and international stakeholders.

Successful coordination between the public and private sectors could serve as the backbone to make the U.S. a space weather-ready nation. A better understanding of the fast-evolving infrastructure and systems would help the space weather community identify observations in research necessary to protect critical infrastructure. Data needed to be more usable and effective for space weather forecasting by using machine learning, artificial intelligence, and other techniques.

Mary Erickson, Deputy Assistant Administrator for Weather Services; Deputy Director, National Weather Service

Ms. Erickson compared SWAG to a startup for all the new ground it had to cover. She applauded the Group for the progress it had made in a few short meetings. She commented that the SWORM co-chairs town hall at AMS was pretty well-attended for an evening session. One questioner had mentioned the Forecast Office, which was a great avenue to raise awareness and build resilience. Numerous moderate to strong solar flares earlier that week underscored the importance for security of the nation's infrastructure.

The SWORM Subcommittee believed very strongly in the Space Weather R2O2R Framework Document. The National Weather Service was excited about working with NASA and NSF as well as the private sector and international partners. It had done some work with CRADAs and expected to do more. Deliberate, sustained collaboration across all sectors was necessary to make transition activities successful. The Subcommittee was excited about the possibilities of the Test Bed. It eagerly anticipated the results of the SWAG survey so it could better understand sensitivities to the different types of impacts and what types of products and services might be really helpful.

Mona Harrington, Assistant Director, National Risk Management Center, Cybersecurity and Infrastructure Security Agency (CISA), Department of Homeland Security

Ms. Harrington explained that CISA's mission was to lead the national effort to defend critical infrastructure against the threats of the present day working with partners in the private sector and across all levels of the government. The National Risk Management Center helped a wide variety of stakeholders address national-level risks in cybersecurity, physical security, emergency communications, and emerging hybrid threats. Most of the critical infrastructure CISA was charged with was owned by industry, not the government. As such, it was necessary to continually establish relationships with those stakeholders.

Space weather had the potential to cause disruptions to energy infrastructure. CISA recognized that preparation for space weather events was an all-of-nation endeavor requiring constant collaboration and communication with a broad coalition of federal and industry partners. With its partners in the SWORM, it supported the implementation of the National Space Weather Strategy and Action Plan. It leveraged the Space Systems Critical Infrastructure Working Group to understand the private sector's space weather requirements. The Working Group helped illustrate the effects space weather had on stakeholders, many of which were indirect.

10:15-10:30: Committee Discussion

Dr. Gombosi expressed concern about the Heliophysics Decadal Survey, which was instructed not to include any space weather mission in its priority list. He asked Dr. Spinrad if NOAA planned to do anything about it. Dr. Spinrad said he did not have information to respond other than to say NOAA should be at the table talking about its role as the operational entity associated with space weather prediction. Dr. Talaat commented that NOAA was a cosponsor of the Decadal Survey specifically because it wanted a good integration between the NASA and NSF science and NOAA capabilities. To that end, it sought a holistic view of what research missions would advance those capabilities. Dr. Spinrad insisted that in his discussions with NASA Administrator Bill Nelson, he had made clear that NOAA's operational responsibilities in space weather had to be part of the dialogue. Dr. Spann said he did not know the definition of a space weather mission in the context of the survey, but noted that NASA Heliophysics Division Director Nicky Fox had encouraged the survey leaders to be reasonable in their aspirational input for development, which he took to mean that space weather was not off the table. Dr. Meehan pointed out that there was a Space Weather Panel on the Decadal with NOAA representation. She promised to make sure that critical operational input was included in the Decadal.

Dr. Elliott asked if any of the agencies had considered "unknown unknowns," noting that the past couple solar cycles had been fairly mild and that plans would need to be in place to manage a more severe cycle. Ms. Harrington said the National Risk Management Center had a Critical Infrastructure Risk Register, which used risk statements and planning scenarios. Dr. Elliott suggested it was necessary to open up communications on research and risk management. Ms. Harrington assured her that the Center had good existing collaboration and communication with other stakeholders.

Dr. Tobiska asked how the agencies were ensuring the assets of space were used to improve conditions of life on Earth. Ms. Erickson said there had been a lot of work at NOAA and the other agencies on how to preserve data rights while maximizing societal benefits. Dr. Spinrad added that NOAA was part of the Department of Commerce, and as such was very focused on the buildout of industry.

Dr. Knipp noted the $165 billion estimate for damage caused by terrestrial weather events in 2022 and asked if there was a similar estimate for space weather events. Dr. Spinrad said he did not have that information readily available but suspected he could pull it up.

Dr. McIntosh applauded the enhanced levels of communication among the agencies as well as the creation of the Office of Space Weather Observations. He echoed Dr. Elliott's concern about "unknown unknowns," pointing out that forecasting space weather events would likely be very expensive. Dr. Spinrad acknowledged that it would require extensive inter- and intra-agency communication, which could prove challenging.

10:30-11:00: Break

11:00-11:30: Related Activities

National Academy of Sciences Space Weather Roundtable, Sarah Gibson (UCAR) and Geoff Crowley (Orion Space), Co-Chairs

The Space Weather Roundtable (SWR) sported a diverse membership because "business as usual" was not in the national interest. It served as a brainstorming group that sought to generate ideas for other committees. It held its first in-person meeting October 14. The topic that generated the most excitement concerned issues in R2O and O2R, including technology readiness levels (TRLs). Ground-based space weather observations also received a lot of attention.

The Roundtable held monthly calls. Its November 29 telecon focused on ground-based magnetometers because magnetometers provided a very low-cost insight into space weather. Speakers included Jenn Gannon, Jeff Love, and Mike Hartinger.

NASA Space Weather Council, Nicole Duncan (Ball Aerospace), Chair

The Space Weather Council (SWC) was established by NASA as a means to secure the counsel of a community of interdisciplinary space weather experts on topics relevant to the heliophysics (HPD) space weather program. It acted as a community-based forum to coordinate community input and provide advice via the Heliophysics Advisory Committee (HPAC). SWC was a FACA subcommittee to HPAC and was responsive to actions levied by its parent organization.

SWC held two meetings in 2022: an inaugural meet-and-greet by telecon on March 2 and an in-person hybrid on August 24. At a September 21 brief to HPAC, SWC presented progress on the HPAC requests but no formal conclusions or advice. On October 14, it briefed the SWR, introducing itself and providing a summary of key discussion topics and progress.

The Council's progress on the four key topics HPAC assigned it in 2022 was as follows:

- *Look into SWORM, SWAG, and SWR activities.* A coordination plan was established among SWAG, SWR, and SWC chairs, including coordination calls and reciprocal meeting invites to brief memberships. SWC DFO Jesse Woodroffe initiated a white paper describing the roles and responsibilities of each group.
- *Conduct (or commission) a gap analysis of space weather science, modeling, and applications.* The SWC discussed the existing 2021 NASA HPD Space Weather (SWx) Gap Analysis, the 2021 and 2022 NASEM SWx Operations and Research Infrastructure Workshops, and ongoing SWORM benchmark and prioritization activities. Its next meeting would address the scope of the task, prioritization criteria, and dovetailing with Decadal recommendations.
- *Look for synergies with NASA's Artemis and space biology efforts.* The Council conducted informational interviews with Moon2Mars and SRAG. It identified several topics for continued discussion.
- *Look for interagency and international cooperation opportunities.* Domestic cooperation was being addressed by SWAG and SWORM. SWC had not discussed international opportunities yet. Possibilities included ESA Vigil, CSA AOM, Gateway, and KASI SNIPE.

Discussion

Dr. Jonas asked if there were hard boundaries on NASA's purview. Dr. Duncan said one of the big discussion topics among the different chairs was how all the different pieces fit together and how topics transferred from one forum to another. So far, she had not encountered any strict boundaries. She thought of the relationships among the agencies as one of synchronized swimming rather than swim lanes. Dr. Spann added that NASA's motivation for establishing the NASA Space Weather Council was because it recognized that it played a growing role in the overall space weather enterprise, and that hard boundaries were counterproductive in such an environment. Dr. Jonas stressed the importance of reducing duplicative efforts. Dr. Duncan replied that SWC had been instructed by its parent agency to look at certain topics and that it could turn out that some subjects were better addressed by other groups. She pointed out that the Space Weather Council was only advising NASA, not other agencies. Dr. Dickinson said she expected the roles of various groups to evolve with time, and as such the boundaries would shift with each different project.

Dr. Knipp proposed a visual representation depicting who advised whom. Dr. Dickinson praised this idea.

Dr. Elliott asked if the Space Weather Council was addressing what NASA's role was in providing some of the infrastructure used for space weather. Dr. Spann said it dealt with anything concerning NASA's role in the space weather enterprise, including infrastructure.

Dr. Tobiska asked if the Roundtable was looking to help clarify the use of different data types. Dr. Crowley said the Roundtable did recognize that there were different types of data and different costs associated with them, but it had not focused on the issue in any detail. He acknowledged that it was definitely worth a conversation. Dr. Gibson agreed.

11:30-12:00: Current Status of Implementing the National Space Weather Strategy and Action Plan (Bill Murtagh, Program Coordinator, NWS Space Weather Prediction Center)

<u>Objective I: Enhance the protection of national security, homeland security, and commercial assets and operations against the effects of space weather</u>

- *Space weather benchmarks and scales*
  - The Science and Technology Policy Institute (STPI) project plan envisioned the SWAG as a key stakeholder for synthesizing and conveying the needs of the user community.
- *Model effects of space weather on national critical functions and associated priority critical infrastructure and national security interests*
  - Previous power grid vulnerability assessments may not have considered the full 3D effects of Earth conductivity structures.
  - Geographically denser magnetotelluric surveys were needed in high-risk areas.
  - The USGS ground-based magnetometer network needed to expand.
  - Magnetotelluric surveying was needed in areas of Canada where there were significant interdependencies between U.S. and Canadian electric infrastructure.
- *Assess the cost of space weather effects on the operations and implementation of critical missions*
  - The "extreme" estimates in the Abt report did not necessarily reflect a Carrington-like event or theoretical maximum event. Therefore, the SWORM recommended

refreshing this report to focus on a space weather event based on recent assessments of maximum geoelectric fields.

Objective II: Develop and disseminate accurate and timely space weather characterization and forecasts

- *Ensure baseline operational space weather observation platforms, capabilities, and networks*
    - Policies needed to be developed to facilitate the transition of research and academic data collection platforms to operational agencies.
    - There was a need for free and open exchange of data related to the impacts of space weather on technological systems operated by the commercial, academic, and environmental sectors.
    - A National Academies Space Weather Operations and Research Infrastructure Workshop for Phases I and II, requested by NOAA, NASA, and the NSF, considered options for continuity and future enhancements of the U.S. space weather operational and research infrastructure. The resulting report addressed strategic knowledge and observations gaps.
- *Engage international partners to ensure space weather products and services were globally coordinated and consistent, as appropriate, during extreme events*
    - Space weather event-specific protocol for the notification and situational awareness reports of space weather information during an extreme space weather event was needed at national and international levels.
- *Identify mechanisms for sustaining and transitioning models and observational capabilities from research to operations*
    - OSTP and SWORM had released the R2O2R Framework.
    - NASA, in partnership with NOAA and NSF, was continuing applied research grants.
    - The 2023 Omnibus funded Testbest at $1.75 million.

Objective III: Establish plans and procedures for responding to and recovering from space weather events

- *Exercise federal response, recovery, and operations plans and procedures for space weather events*
    - Such plans were needed at the state and local levels as well.

Mr. Olson asked if there had been any discussion about approaches to resolving the impact side of the need for geographically denser magnetotelluric surveys. Mr. Murtagh said NWS relied on those who oversaw the power grid for feedback on what was really needed.

Dr. Gombosi asked if there was dialogue between NSF and SWORM on funding needed projects. Mr. Murtagh said collaboration with NSF was a priority issue within SWORM.

Dr. Knipp noted that there seemed to be a lot of emphasis on the power grid and not as much on space traffic. She asked if SWORM or anyone else had conducted tabletop exercises to look at potential collisions. Mr. Murtagh said support for space traffic management was one of OSTP's priorities. An activity was planned for Space Weather Week.

Dr. Ho asked about the current model needs in terms of spatial resolutions in order to make advances in forecasting. Mr. Murtagh said he had been pressing for bringing in new magnetometers, but he had not been able to quantify their impact. Dr. Tobiska argued that both modeling and measurements were necessary. Mr. Murtagh pointed out that any airline could make in situ measurements, not necessarily one based in the U.S.

12:00-1:00: Lunch

1:00-2:00: 1.1 Observational Data and Access (Ground-Based) (Co-Chairs: Jenn Gannon (CPI) and George Ho (JHU APL)

Roger Varney (UCLA)

Incoherent scatter (IS) radars were powerful ground-based systems that could measure complete altitude profiles of important ionospheric parameters, such as electron density, electron and ion temperatures, and ion velocities. Facilities could be sorted into three groups: U.S. facilities originally built in the 1960s; advanced modular incoherent scatter radar (AMISR) facilities; and international facilities. Dr. Varney presented a series of future recommendations for IS radar facilities that were broadly sorted into three categories:

- Improved long-term planning, interagency coordination, and international cooperation
- Improved cyberinfrastructure for ground-based facilities
- Improved workforce development and education

Anthea Coster (MIT)

Ground-based networks were cost-effective for space weather monitoring, provided direct measure of the parameters relevant to effects on critical infrastructure, yielded global physics unattainable with single-point measurements, and were necessary for calibrating space-based missions. Typically, they were funded by a mixture of agencies, most of which were not designed for space weather operations. Several things were necessary for a successful ground-based network:

- Specification of the agency(ies) responsible for funding
- Long-term stable funding for operations
- Support for real-time operations, better communication infrastructure, and predictable data quality
- Support for continuous operations to catch space weather events; support for big data analysis
- A long-term plan for coordinated development and maintenance of ground-based infrastructure

Alan Liu (NSF)

NSF's statutory mission was to promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense. NSF supported fundamental and user-inspired space weather research and R2O2R, but did not directly support space weather operations. Funding for modeling, research infrastructure, and education was through competitive, merit-reviewed grant awards, typically for three to five years. NSF supported ground-based solar and geospace observations, such as:

- Magnetometers
- SuperDARN
- Neutron monitors
- DKIST
- Millstone Hill ISR
- HamSCI Personal Space Weather Station

- Expanded Owens Valley Solar Array
- Global Oscillation Network Group (GONG)

Asti Bhatt (SRI International)

Optical networks of All-Sky Imagers (ASIs) provided an accessible way to routinely observe nighttime dynamics of the thermosphere and the ionosphere on a continental scale. The U.S.-based ASI networks observed mid- and sub-auroral latitude thermosphere/ionosphere response to energetic events in the lower atmosphere and the sun. The data were currently available in near-real time. Networks of Fabry-Perot Interferometers (FPIs) provided nightly neutral measurements, a key but difficult-to-measure component of thermosphere dynamics, on a large scale. Currently, the U.S.-based optical instruments could be categorized as part of the MANGO network, Boston University imagers, or standalone instruments. The MANGO and BU networks operated autonomously, producing continuous data. Higher-level data products were available. Some PI involvement was needed. Dr. Bhatt provided a series of recommendations, the central point of which was that the infrastructure, data access, and workforce development needed to be more intentional rather than ad hoc.

Discussion

Dr. Bishop noted that the need for long-term support was a common theme of the presentations. She asked if any of the presenters knew of a facility or instrument chain that started out as a science facility and successfully transitioned over to operations, and if so, how long it maintained itself as an operational system. No one knew of any facility that had completely transitioned from science to operations. Dr. Bhatt pointed out that sites being maintained by professional agencies ensured longevity and proper data production. Dr. Liu added that if agencies knew from the outset that something would be useful for research and operations, they could work together to support it so that it worked for both purposes.

Dr. McIntosh observed that the Mauna Loa Observatory was not included on the slides, but that it was a critical piece of the ground-based infrastructure. Dr. Coster acknowledged that there were a number of networks that were not on the slides, but pointed out that presenters had been limited in the number of slides they were allowed to submit.

Dr. Elliott felt it was extremely important to note how magnetometers were used for the indices. She suggested establishing what was most critical and seeing if those things could be funded in a sustainable manner.

2:00-3:00: Economic Assessment (Co-Chairs: Seth Jonas (Lockheed) and Delores Knipp (UC Boulder))

Jonathan Eastwood (Imperial College)

Dr. Eastwood stressed the need to link physical drivers, technological and societal impact, and economic impact. The latter two were often not well understood. The space weather risk was constantly evolving. Challenges in determining space weather economic impact included:

- The lack of very severe impacts in the last 20 years
- The unique nature of each event
- Diverse technological systems fused into many aspects of everyday life
- High potential for interacting system failures
- "Unknown unknowns": the biggest risk might be something not anticipated

- How to acquire relevant data of sufficient quality to perform meaningful economic impact calculations
- Determining if the impact was in fact due to space weather

Tina Highfill (Bureau of Economic Analysis (BEA), DOC)

Space-related production included goods and services that:

- Were used in space, or directly supported those used in space
- Required direct input from space to function, or directly supported those that did
- Were associated with studying space

Space economy gross output in 2019 was estimated at $195 billion, or about 0.5 percent of the total U.S. economy. The largest component of the space economy was information, at $60 billion, followed by manufacturing at $51 billion, government at $38 billion, wholesale trade at $32 billion, professional and business services at $6 billion, and everything else at $8 billion.

Terry Griffin (Kansas State University)

Economists tended to see the world in terms of cost and benefit. Dr. Griffin evaluated how people in general had been using GPS and GNSS since they had become available for civilians, with a focus on the farming community. One of the more difficult questions was how people used the technology as it was adopted and integrated into their everyday lives. The question today was not what the benefit of adding these new technologies was, but what the penalty for removing them would be. Their use had become so integral to the farming community that their predecessors were no longer available. Data sensors often had secondary uses beyond their original intent. It was difficult to measure the impact of taking away data sensors on those secondary uses. The probability of a serious event occurring was something the space weather community needed to come to consensus on.

Discussion

Dr. Jonas noted that a common theme across the presentations was the flow needed to go from physical phenomena to economic impact. He asked the presenters if they knew any areas of "low-hanging fruit" or overriding challenges. Dr. Eastwood said it was extremely difficult to get meaningful data to connect actual events to economic impacts. He did not feel that much had been done in exploring the role of GPS and similar technologies in society, especially considering how quickly the technology was evolving. Dr. Highfill spoke of the difficulty BEA had had in measuring the space economy because of the lack of available data sources. She suggested reaching out directly to the insurance companies. Dr. Griffin said he had been looking at the use of technology to determine ideal planting times and that one potential area of "low-hanging fruit" would be measuring the impact of taking away those technologies. Dr. Eastwood urged SWAG to get the economist community more interested in this issue.

Dr. Knipp asked if the Space Environment Impact Group was self-born or mandated by national government. Dr. Eastwood said the group, formed about 12 years previously, provided expert advice to the U.K. government but was independent, drawing membership from academia, government, and industry.

Dr. Elliott observed that an event's economic impact would vary according to sector and duration. Dr. Eastwood replied that it was not just a question of how long an event lasted, but how long it took to recover.

Dr. Ho pointed out that part of SWAG's user survey involved collecting data on what sectors were being affected. Dr. Jonas agreed that was a good point.

Dr. Tobiska cited two possible examples of "low-hanging fruit": the recent loss of 40-some satellites and diversion of flights on polar routes. He was intrigued by the use of proxies to estimate impact and asked the presenters if they could comment further. Dr. Highfill said BEA would often look for indirect measures in the absence of direct data. Dr. Duncan asked to what degree the proxy data was trusted. Dr. Highfill said a lot depended on what specifically was being measured. It helped to be upfront about the assumptions being made. Dr. Griffin added that instrumental variables were important, and that it was often useful to note the second-best alternative. Dr. Jonas suggested there might be rich data in the effects from COVID, when whole sectors shut down due to lack of employment availability.

Mr. Olson asked Dr. Eastwood if he had considered economic assessments of everyday space weather events. Dr. Eastwood said he had, but it was a challenge determining how much certain effects were in fact due to space weather.

Dr. Sharma noted that the effects of space weather could be localized, even for global events. She asked the presenters what effect that granularity had on their considerations. Dr. Griffin said he often used Sentinel-2 imagery from the European Space Agency to diagnose what areas were particularly impacted by events and to what extent. Dr. Eastwood said it was important to know what was going on locally because local events could have global ramifications. Dr. Highfill said that if it was hard to find global or national data, it was even harder to find local data.

3:00-3:30: Break

3:30-4:55: Committee Discussion - Day 1 Recommendations

The Committee discussed what it had heard on the first day and brainstormed possible recommendations. The topics it identified were as follows:

Ground-Based Systems

The overall theme was there was a need for fundamental paradigm changes.

1. Recognize the importance of near-surface and ground-based sensors in operational space weather.
2. A prioritization of critical systems was needed, starting with data that NOAA was using already.
3. There needed to be a pathway between research and operational instruments, including transition to long-term operations.
4. Roadblocks were maintenance/transition funding levels.
5. Look at different funding models for data, such as grants and data buys.
6. Improve data access, standards, and usability.

Economic assessment

1. Evaluate the use of proxies and analogies (hazards or other events) to inform economic assessments of space weather.
2. Include/add economic assessments of space weather beyond the worst case - what were thresholds of operational concern that were important to consider.
3. Emphasize the importance of and challenge in completing economic assessments.

4. More economists looking at this issue were needed.
5. Cost of mitigation - operations, data, and contracts - "not getting it right"
6. Support the SWORM recommendation to modify Recommendation 1.5 of the 2019 Space Weather Strategy and Action Plan.
7. Societal benefit assessment for space weather forecasting, mitigation, etc.
8. Space environment assessments

4:55-5:00: Closing Remarks (Tamara Dickinson, Science Matters Consulting, and Chair, SWAG)

Dr. Dickinson thanked members, presenters, and attendees.

5:00: Adjourn Day 1

Dr. Meehan adjourned the meeting at 4:56 p.m.

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Dr. George Ho, Johns Hopkins University Applied Physics Laboratory

Designated Federal Officer

Dr. Jennifer Meehan, National Space Weather Program Manager, National Weather Service

Also Present

Mr. Bill Murtagh, NOAA
Lt. Col. Omar Nava, U.S. Air Force

Meeting Minutes

9:00-9:05: Welcome (Jennifer Meehan, SWAG DFO)

Dr. Meehan welcomed SWAG members to Day 2 of the meeting. She explained that Dr. Tamara Dickinson would not be in attendance because she wasn't feeling well, and had delegated her chair duties to Dr. Jonas and Dr. Bishop.

9:05-9:15: Opening Recap of Day 1 (Jennifer Meehan, SWAG DFO)

Dr. Meehan gave a quick recap of what occurred on Day 1. Dr. Bishop and Dr. Jonas reviewed the previous afternoon's discussion.

9:15-10:45: 2.1 Observational Data, Access, and Infrastructure in Space (Co-Chairs: Nicole Duncan (Ball Aerospace) and Heather Elliott (SWRI))

Sean Elvidge (University of Birmingham)

Dr. Elvidge cautioned that asking any five space weather scientists about their data needs was likely to yield at least 15 suggestions. Some of the most common were:

- (Near) real-time, high-resolution measurements of the solar wind density, temperature, magnetic and electric fields
- Measurements of the solar corona and inner heliosphere
- "L5" observations
- Thermosphere (species) density and winds

Operational access to data required long-term storage, good maintenance, redundancy, and documentation.

An observing system simulation experiment (OSSE) was a modeling experiment used to evaluate the value of new datasets. While used in space weather, they were ad hoc, often developed by the dataset proposers themselves, who were often not modeling experts. Building such a system could be complex to design and expensive to run. Data were likely not independent and tended to overestimate the benefits of a new dataset. Dr. Elvidge called for independent OSSE systems that were open to the community and developed by modeling experts allowing the fusion of potential new observations with a wide range of existing datasets. Common tools could help agencies when evaluating the cost-benefit analysis of new experiments.

Sarah Gibson (UCAR)

A systematic approach to heliophysics observations and modeling was needed because:

- Current operational requirements were based on knowledge gleaned primarily from single-discipline studies
- Going beyond "nowcasting" required a clear understanding of couplings between multiple regimes
- Ultimately, a comprehensive set of optimized observations and models was needed to fill space and time

Space-based observations provided the ability to observe short wavelengths, vantage points off the Sun-Earth line, and a continuous data stream. Ground-based observations offered access to measurements difficult or expensive from space, the ability to upgrade easily, data latency, and a high time cadence. Future needs included instrument miniaturization and standardization and new vantages from space-based observations, and global coverage and next-generation observations from ground-based ones. Also needed were tools for archiving, accessing, and utilizing observations across the system, and for globally interpreting them. Gaps could be filled with EUV imagers in space and ground-based coronagraphs.

Lisa Upton (SWRI)

STEREO-A and B, The Solar Orbiter, and Parker Solar Probe demonstrated the power that observations from new vantages provided for space weather research and operations. Recent missions included Firefly, Solaris+, COMPLETE, MOST, Seven Sisters, and MAKOS.

Dr. Upton recommended multi-spacecraft pathfinder and flagship missions with both remote sensing and in-situ observations. Several things were needed to provide actionable forecasts of space weather events and the solar cycle, including:

- Doppler and corona magnetographs, along with spectroscopic imaging
- View of sunspot active regions and filaments throughout their life cycles
- Accurate imaging of the magnetic field of the Sun's poles
- Observations of coronal dynamics from multiple new perspectives
- Measure of the solar wind at multiple points, including high latitudes
- An improved communications network

It was necessary to get away from the Sun-Earth line (SEL) to see the far side and to get out of the ecliptic to see the poles.

Slava Merkin (APL)

Dr. Merkin stressed the importance of data-model fusion and gray-box modeling. Challenges of data in global geospace included:

- Using spacecraft constellations and remote-sensing
- Leveraging better near-Earth coverage
- Leveraging historical data
- Using all available data to:
  - Rectify model incompleteness
  - Develop data ingestion and assimilation methods that nudge models by supplying missing physics

All of the above entailed using and developing data mining and machine learning (DM/ML) methods.

Dr. Merkin highlighted the need for mesoscale-resolving operations. Mesoscale processes were currently poorly sampled and understood, but they were ubiquitous in geospace and could have global-scale consequence.

Neal Nickles (Ball Aerospace)

Spacecraft needed alerts, worse-case scenarios, and historical and predictive climatology over forecasting. Unmet needs for designing for and attributing dose, single event, and space charging effects included instruments, modeling parameters, and orbital coverage. Planned observations had to be ready to continue a full suite of monitoring across belts and catch worst-case events.

Dr. Nickles recommended the use of instrumentation that struck a balance between space weather science and user needs. The government should fund low-cost, easily accommodated space weather instruments on more spacecraft. It needed one central website portal for all user data needs. Spacecraft users could benefit from easily accessible space weather data for quick anomaly resolution to re-start missions.

Discussion

Dr. Gannon asked Dr. Gibson to comment further about ground-based coronagraphs. Dr. Gibson said they were easier to change and moved at a faster cadence.

Dr. Gombosi asked if SWAG was expected to come up with a set of prioritized observations. Dr. Meehan said it was up to the Group to determine how best to advise the SWORM. Dr. Jonas suggested providing a recommendation to SWORM to establish a process that engaged experts to help determine priorities. Dr. Duncan pointed out that research was one of the sectors identified in the user needs survey. Dr. Gombosi noted that research and operational needs were so intertwined that it would be counterproductive to classify a specific recommendation as being for research or operations. Dr. Elliott feared that something critical would be missing if no ranking were done, because there would not be enough funding. Dr. Jonas predicted that as these missions became more complex, they would require more international collaboration. Dr. Upton suggested SWAG examine a recent NASA gap analysis study. Dr. Duncan felt the purpose of the SWAG was to provide higher-level recommendations about how the overall space weather program should be implemented, and that it was not within its scope to set priorities.

Dr. Knipp observed that a common theme across the presentations was how much was needed for workforce development, and that most education relating to space weather currently occurred in siloed departments. She asked if a different paradigm for workforce development was necessary. Dr. Gibson thought it was. Dr. Upton suggested focusing on the period when an individual was transitioning from a degree program to the workforce.

Dr. Tobiska asked Dr. Gibson if she saw high-heritage instruments in new places as a role for agencies, or if commercial and academic institutions could assist. He asked Dr. Upton if creating different observation points around the Sun was reasonable to do to fill gaps, or if it was already being done. Dr. Gibson said it could be confusing to try to solve everything altogether at once. Dr. Upton said having multiple vantage points allowed for the expansion of capabilities.

Dr. Bishop asked what challenges were involved in integrating multiple satellite mission data. Dr. Gibson said she and her colleagues had been working on what they called the "whole heliosphere," and integrating the data was central to that. Often just accessing the data was a challenge. Dr. Upton added that one of the difficulties in looking at magnetic fields was calibrating instruments from different generations. Examining overlapping observations was one way of addressing that problem. Dr. Elvidge said it was quite common that data repositories were not well funded or maintained.

Dr. McIntosh noted the importance of synoptic data sources. He asked if there were other pathways to data available besides the traditional astrophysical approach. Dr. Gibson said her colleagues came from all sorts of backgrounds, not just astrophysics. That made it essential to train the workforce in a way that emphasized the needs of space weather science. Dr. Upton added that NASA was funding a program with a cross-disciplinary focus. Dr. Merkin said the workforce development issue was well recognized across the space weather community. He reminded everyone that a professional panel was addressing the matter. He also said that synoptic measurements of the geosphere as well as the Sun were needed.

Dr. Knipp asked how Dr. Elvidge came to do the work he was doing. Dr. Elvidge said he did pure math for his undergraduate degree and later decided it would be fun to try something else. He stressed the importance of having a good spread of people across engineering and physics.

Dr. Duncan asked what could be done about architecture development and mission design. Dr. Gibson spoke of the need for standardization. It was already being done to a certain degree, but there was room for improvement. Dr. Upton stressed the importance of not thinking about missions individually, but rather how they fit together as a whole. Dr. Duncan asked Dr. Elvidge to comment further about the use of OSSE as a global architecture development. Dr. Elvidge said that more use was better but maybe not that much better, and that a concerted effort was needed. Dr. Duncan asked Dr. Nickles how important the anomaly database was to his workflow as a user. Dr. Nickles said anomaly databases could be used first and foremost to validate the correlation between space weather events and anomalies. To facilitate that, the U.S. government needed to take control of a centralized portal for this information. It was unrealistic to expect anomaly data from commercial entities.

Dr. Gombosi pointed out that FAA could mandate airlines to report incidents. He asked if there was any U.S. federal agency that could make a similar requirement of private satellite operators. Dr. Bishop suggested the Group table that question, because she was not sure it was appropriate for this panel.

10:45-11:00: Break

11:00-12:00: 2.2 Benchmarks, Metrics, and Scales (Co-Chairs: Kent Tobiska (SET), Craig Fugate (former FEMA), and Mike Stills (retired UA)

Steve Morley (Los Alamos National Laboratory)

Current geoelectric hazard benchmarks were limited. SWORM had presented geoelectric hazard maps for geoelectric field benchmarks. Hazard maps could be useful for informing probabilistic models of hazardous events, but a spatial map of a 1-in-100-year geoelectric field did not reflect spatial structuring of individual events. A map showing 1-in-100-year magnitudes did not reflect any possible realization of a 1-in-100-year event, and was prone to misinterpretation as a benchmark event. Power systems modeling required spatiotemporal time series, which hazard maps did not provide. The TPL-007 reliability standard included a benchmark time series. Scaled to a nominal 1-in-100-year peak geoelectric field magnitude, it did not account for uncertainty in the return period. A single realization of a benchmark event did not account for variability in spectral and temporal characteristics of geomagnetic disturbance (GMD) events. The 1D time series did not reflect spatial structuring of GMD events.

A probabilistic hazard analysis was required. Using a single reference event was not best practice for natural hazards. A database of event spectra was used for probabilistic seismic hazard analysis. Probabilistic models and Monte Carlo simulations were used for impacts of other natural hazards. Sparse data with limited history meant that uncertainties on event amplitudes and likelihoods could be large. Probabilistic statistical models or ensembles of simulated scenarios were required to reliably assess geoelectric hazard. Event time of day impacted the likely outcome due to different spectra, likelihood of localized enhancements, and local time of infrastructure. Temporal evolution of given events was important for outcomes such as transformer hotspot heating, so simple uncertainties on drivers were insufficient. The interaction of spatiotemporal evolution with transmission system load was important for outcomes such as voltage collapse, again suggesting a Monte Carlo approach.

David Boteler (Natural Resources Canada)

The focus in Canada had been on geomagnetic activity levels. The country was divided into three zones from north to south: the polar cap, the auroral zone, and the sub-auroral zone. Short-term hourly range activity levels were highest in the auroral zone and lowest in the sub-auroral. Dr. Boteler shared examples of impact statements for power systems, HF radio systems, and GNSS.

Domains for space weather scales included:

- Solar activity
- Disturbances at Earth
- Systems affected

Dr. Boteler stressed the importance of choosing the domain and being consistent in designing space weather scales. NOAA had scales for geomagnetic storms, solar radiation storms, and radio blackouts.

Richard Horne (British Antarctic Survey)

A reasonable worst-case scenario was developed in response to a government request by the Space Environment Impacts Expert Group (SEIEG). It aimed to focus on a natural environment that could disrupt key infrastructure. Officials could then discuss resilience with government departments and operators of that infrastructure. The results were published in a peer-reviewed paper by Hapgood et al. in Space Weather in 2021. SEIEG used examples of 1-in-100-year events such as 1859, as well as events such as 2003 which were not as big but still had a significant impact. As a result, SEIEG was able to identify new risks such as multiple storms and fast solar wind. It also used analysis such as dB/dt and electron flux when available for 1-in-100-year events. The work supported the 2020 National Risk Register, the 2021 National Space Strategy, and the 2021 Severe Space Weather Preparedness Strategy. It involved close collaboration with scientists, agencies, defense, companies, and government, which led to policy and mitigation.

Discussion

Dr. Bishop asked Dr. Boteler if consistency meant selecting the same domain for each application or specific ones that were more tailored to the systems. Dr. Boteler said it meant doing the same domain for all of them.

Dr. Gannon asked how to move end user communities away from a reliance on decay indices and heat without inserting more chaos. Dr. Boteler acknowledged that it was challenging, but with an index that made sense it was possible to slowly pry them away from decay heat. Dr. Jonas asked if any thought had been given to what they should move towards. He suggested digging a little deeper on the issue of legacy generic or planetary indices or proxies. Dr. Morley supported using measures of geospace effect for geospace response.

Dr. Knipp asked how valuable documentation of extreme events was to the work the panelists were doing. Dr. Horne said it was very important to learn from such events and try to mitigate them in order to make the case that space weather was very important. He pointed out that it was also important to document the day-to-day, not-so-extreme events as well.

Dr. Jonas asked to what extent the SEIEG's reasonable worst-case scenario had been adopted and used by the U.K. private sector. Dr. Horne said it had certainly been adopted by government agencies and the private electric power companies. Satellite operators also looked at these data.

Mr. Stills noted that, through positive interaction, he had recently persuaded an international airline operator to change its procedures. He believed education remained one of the most important aspects of solar activity from an aviation standpoint, because there were a lot of operators with misconceptions.

12:00-12:45: Lunch

12:45-1:45: Data Infrastructure and Methods (Co-Chairs: Jenn Gannon (CPI) and Tamas Gombosi (UMich))

Sage Andorka (Space Force)

The Unified Data Library (UDL) was the Space Force's data system. It operated according to eight tenets:

1. The data must be adequately secured.
2. The data owner must be able to control access to their data.
3. Persist and expose data in a manner that allowed for it to be optimally exploited.
4. Must not limit the technology set of the end user.
5. Users must be able to easily, intuitively, and autonomously discover and ingest new data sources.
6. Incentivize data owner participation and guarantee an identical interface across all environments.
7. Must be able to support the fundamental data distribution use cases.
8. Semper Supra (Always Above)

With the UDL, Space Force sought to take data and make it really meaningful. It realized that not everyone had structured data. Translation services were necessary, as was storage for raw data. The metadata repository would allow any user to query data, which would not need to be replicated where it was not needed. The tactical data thread consisted purely of data in motion. It was important for Space Force to have the information it needed on hand.

Enrico Camporeale (University of Colorado)

According to Dr. Camporeale, machine learning (ML) would become the standard way of space weather forecasting by the end of the decade. It was faster, more computationally affordable, more actionable, and more accurate than other methods.

Dr. Camporeale presented SWAG with his personal list of recommendations:

- Support ML competitions
  - Competitions were the quintessential citizen science projects.
  - A change of mindsets was needed. Competitions were a "way of doing science," and physicists had to accept that an outsider community could crack a problem they had been working on for decades.
- Support open data. Many SWPC outlet models were "public" but not really accessible.
- Support ML-specific grants. An ML version of the NASA R2O2R grant would advance space weather enormously.

Rebecca Ringuette (NASA GSFC)

Research software engineers were scientists that spoke the language of software and software engineers that spoke the language of science. Dr. Ringuette recommended including them because they could:

- Accelerate research to operations transition and the R2O2R feedback cycle
- Apply universal design concepts to forecasting and validation tools to increase accessibility
- Incorporate technology into science to enable reusability
- Easily harness research advances to improve forecasting through plug-and-play software design
- Apply modern computational methods to intelligently accelerate calculations
- Create and maintain virtual environments to simplify collaboration
- Apply a new generation of visualization technology for research, operations, and outreach
- Use software expertise to simplify interoperability

As an example, Dr. Ringuette cited the Community Coordinated Modeling Center (CCMC), which was serving as a bridge between scientific and technical experts to build Kamodo, a uniform access point to all model outputs in the field.

Jacob Bortnik (UCLA)

Data volumes were growing, which meant it was no longer tenable to "do science" the traditional way. Machine learning superseded physics-based models in many cases. Students needed to build ML models themselves. There were many different space weather domains, including solar flare/coronal mass ejection (CME) forecasts, geomagnetically induced currents (GICs), solar wind, space environment, and geomagnetic indices. Mostly existing data could be used for many applications, but new observations were needed for GICs.

Dr. Bortnik shared several considerations for a national strategy:

- Solar disk, solar wind, and geomagnetic index observations for real-time data feeds
- Using existing tools and data to develop ML models
- Funding to develop relevant ML tools
- Expanding observations in key regions depending on the space weather domain
- Investing in education by training students and postdocs, holding workshops and meetings, and distributing materials

Discussion

Dr. Gombosi asked Ms. Andorka to explain the connection between DOD and civilian space weather operations. Ms. Andorka said she would need to work with NOAA on this matter. Dr. Gombosi then asked how much funding Space Force had for basic research. Ms. Andorka said she did not know specifically for all the research entities within DOD, but for Space Force itself it was only on the order of a few million dollars because its primary focus was on operations. Dr. Gombosi asked where she took her models from. Ms. Andorka said she took them anywhere she could find them.

Dr. Gombosi asked Dr. Camporeale and Dr. Bortnik how they planned to train machine learning models for rare events. Dr. Camporeale said it would be necessary to generate data with a larger amount of such events, and more data would accumulate over time. He suggested "gray-box modeling," combining physics-based simulations with ML data.

Dr. Tobiska observed that UDL, from his experience, was primarily a mechanism or platform for providing data to provide a common operating picture across many different domains. He also asked Dr. Camporeale and Dr. Bortnik to comment on combining ML data with physics-based simulations. Ms. Andorka said the UDL was only a data-hosting platform, and for security reasons, Space Force did not validate data that it did not need to. Its aim was to get data quickly to where they needed to be. Dr. Bortnik said there were all kinds of ways that machine learning could work in conjunction with physics-based models to present a more accurate picture.

Dr. Jonas asked about the extent to which pattern identification and clustering had been developed. Dr. Bortnik said there was a whole host of models that had been validated and could be run fairly quickly.

1:45-3:00: 2.4 Evolving Infrastructure Services and Systems (Co-Chairs: Seth Jonas (Lockheed) and Mark Olson (NERC))

Emanuel Bernabeu (PJM)

PJM was part of the Eastern Interconnection, covering 65 million people in 13 states and Washington, D.C., with over 1,000 member companies, generating over 782,000 gigawatt-hours of energy in 2020. As of February 2021, 21 percent of the U.S. GDP was produced in the area served by PJM.

PJM's core function consisted of:

- System operations
- Transmission planning
- Market operations

The grid was evolving, with more renewable resources and inverters, more electrification, and more distributed energy resources. One major risk from geomagnetic disturbance (GMD) was voltage collapse, especially in weaker power grids. Another was potential equipment damage, although as science evolved, this had become less concerning. Dr. Bernabeu suggested that any space weather strategy include the use of magnetometers for model validation, a regional forecast in volts per kilometer (V/km), and continuous refinement of the 1-in-100-year event.

Steve Stone (Lockheed)

Lockheed had been contracted to develop a portion of the Space Development Agency (SDA) transport layer. The layer, located approximately 1,000 miles up in low Earth orbit (LEO), currently included 126 satellites. In order to get such a system deployed, Lockheed evaluated quality, quickness, and cost, and picked two of the three categories to optimize. In this case, it chose faster and cheaper. It relied on constellation performance to drive operation, availability, profitability, and success overall. The design phases were compressed to 18 months. Components were designed to operate very close to their limits with very little margin. The transport layer was designed to operate around single-loss nodes, but widespread events could ultimately be much more impactful. Having detailed information about approaching solar particles could help in the development of procedures to avoid outages or lost nodes.

Yari Collado-Vega (NASA GSFC)

As NASA planned for missions beyond LEO, new advancements in modeling, observations, and communications were needed to establish a suitable monitoring and protection environment for the missions and the crew. Efforts had been made to identify the gaps and to study the space weather architecture needed to support the new steps. Dr. Collado-Vega highlighted what was needed:

- Multipoint solar observations
- Solar polar missions
- Data availability and acquisition
- International collaboration
- Space weather on Mars

Currently, NASA relied on research missions to analyze the real-time environment. As missions transitioned beyond LEO into free space, many forecast and nowcast capabilities would become limited during both transit and on the lunar/planetary surface. As NASA looked to these future missions, measurements at varied locations, better data cadence and latency, and measurements away from the Sun-Earth line were necessary to provide earlier assessments and therefore have more time to respond to an enhancement in the space environment. NASA looked forward to the upcoming NOAA missions GOES-U and SWFO and the ESA Vigil mission, but a lot more was needed for Mars exploration.

Rich DalBello (NOAA, Office of Space Commerce)

The Office of Space Commerce (OSC) was formed to serve as an advocate for commercial space programs and as the regulatory agency for commercial remote sensing. During the last administration, the Space Council determined through Space Policy Directive 3 (SPD3) that space situational awareness (SSA) should move from the Defense Department to Commerce. The Open Architecture Data Repository (OADR) had been renamed the Traffic Coordination System for Space (TraCSS). Unfortunately, SPD3 did not come with money or instructions. It was not until this year that Congress increased OSC's budget to $70 million. After building a staff, OSC had launched a series of pilots. Going forward, it would need to develop an architecture and acquisition strategy. Dr. DalBello expected that the new system would include space weather, but the details still needed to be worked out.

Discussion

Dr. Tobiska asked Dr. DalBello how he envisioned building up the new architecture. Dr. DalBello said the simple answer was that OSC was not there yet. Basically, it had one eye on what it could have in place by the Congressional deadline of September 2024, and the other on where it ultimately saw the program going.

Dr. Bishop asked the presenters from the private sector whether they thought the evolving technology and their concepts of operations (CONOPs) would leave them more or less susceptible to space weather impacts. Mr. Stone thought the developments in technology made Lockheed more vulnerable to space weather, but he was confident that the CONOPs it developed would be sufficient to address the issue. Dr. Collado-Vega added that NASA had engaged in extensive conversations on finding ways to minimize the risk of space weather impact on astronauts and equipment. Dr. Bernabeu said JPM was definitely not less susceptible because of the technological advances, but he was not sure whether it was more susceptible or about the same.

Dr. McIntosh expressed concern that there was widespread complacency about solar activity, which was expected to rise after being in decline for 30 years. Mr. Stone said Lockheed's worst-day and worst-week events were based on the 1989 model, so it saw its designs as adequate for events going forward. Dr. Ho pointed out that in the last cycle, when solar activity was low, GCL was the highest.

Mr. Olson asked Dr. Bernabeu to comment on the power grid. Dr. Bernabeu allowed that while planning for a 1-in-100-year event, PJM did not have 100 years, so there was some extrapolation of statistics and estimation involved. Dr. Collado-Vega added that NASA was always working with the research community trying to understand the different solar cycles and making sure it got the best data possible.

Dr. Knipp asked Mr. Stone and Dr. Bernabeu if they concerned themselves with global navigation satellite system (GNSS) capabilities or the loss of them in his design work. Mr. Stone said he worked mostly down at the circuit and box level, so GNSS considerations were largely the purview of the system architects. Dr. Bernabeu said PJM did not rely on GPS on any of its critical systems. Losing GPS would be inconvenient, but other ways of rendering were available. Mr. Olson asked Dr. Bernabeu to expand on what a potential exposure might look like. Dr. Bernabeu said PJM had protective devices in the field which constantly monitored the network, isolating problems. Dr. Jonas asked if there was a change of GPS or GNSS being given critical data input. Dr. DalBello said there was a big push to get more sophisticated information, either from direct observation or onboard systems.

Dr. Duncan asked about the process by which gaps were being identified, catalogued, and passed along to representative agencies. Dr. DalBello said he associated gaps with a system that was up and running, and at this point, OSC aspired to have gaps with TraCSS. Dr. Collado-Vega added that the Moon to Mars Office acknowledged there were a lot of gaps it was trying to fill.

Dr. Tobiska asked Mr. Stone if he saw a need in the community for a dynamic capability, or if statistical capabilities were sufficient from an engineering design point of view. Mr. Stone said developing statistical models would help Lockheed generically bound its environment, enabling it to design appropriate shielding, grounding, bonding, and mitigation strategies. However, it was also necessary to correlate anomalies with some type of event.

Dr. McIntosh asked Dr. Collado-Vega if she was saying that she would rather observe something than have to guess about it. Dr. Collado-Vega assured him that was true.

3:00-3:30: Break

3:30-4:30: 2.5 Industry and Government Collaborations, Coordination, Outreach, and Communications on Space Weather (Co-Chairs: Rebecca Bishop (Aerospace Corp) and Scott McIntosh (UCAR))

Dipak Srinivasan (APL)

The government had published two different National Strategy & Action Plans: the March 2019 National Space Weather Strategy and Action Plan and the June 2018 Near-Earth Object Preparedness Strategy and Action Plan. Both plans contained language calling for the development of a set of exercises to stress out protocols to see if they were working.

In February 2022, NASA and FEMA co-sponsored Planetary Defense Interagency Tabletop Exercise 4 at Johns Hopkins Applied Physics Laboratory (APL) that simulated a planetary event scenario. The event included participants from various federal, state, and local agencies, and was widely successful. Mr. Srinivasan proposed a similar exercise focused on space weather. With Solar Max approaching, the planet was at an unprecedented level of susceptibility. There was a need for speed, to get the word out fast. Designing a scenario, engaging with stakeholders, and then executing the scenario took time. It was important to include the right people and organizations, and have the right discussions. If successful, the event would address gaps in policy, technology, and communications.

Yuri Shprits (UCLA)

Data assimilation (DA) allowed the blending of observations from various satellites with physics-based models. The vast amount of data from ongoing missions required new methods to combine data. Unlike machine learning (ML) models, DA could give accurate predictions during extreme events.

A number of space weather products had already been developed and operated in real time, including:

- ML predictions of the Kp index and comparison with observations
- Data-assimilative radiation belt forecast
- Data-assimilative ring current forecast

Bob Arritt (EPRI)

Extreme space weather had demonstrated its capability to disrupt normal power delivery, so the industry took this issue very seriously. Power utilities continued to apply the DOD vulnerability assessment set forth in the TPL-007 standard. EPRI worked to assist the industry in applying its scientific research to the assessment.

Continued engagement was critical in geomagnetic disturbance (GMD) preparedness. EPRI was involved in several forms of cross-sector engagement, including:

- North American Electric Reliability Corporation (NERC's) GMD meetings
- Collaborative research
- Industry meetings
- NASA engagement
- DOE engagement
- NSF workshops

Erin Miller (Information Sharing and Analysis Center (ISAC))

ISAC was building out a watch center and a vulnerability lab so it could actively share threats and vulnerabilities that affected critical infrastructure. Space weather was just one of the areas ISAC was involved in. The Space ISAC was composed of a variety of members from the public and private sectors that looked at different threat scenarios that could affect the industry. Ms. Miller presented the initial operating capability (IOC) data architecture concept. Microsoft Azure facilitated the ingestion and analysis of multi-source data feeds and surfaced results to end-user visualizations. The IOC architecture did not persist ingested data; only analytic results were persisted in Azure storage.

Discussion

Dr. Duncan asked Dr. Shprits how private companies and other entities would fulfill the validation piece, making sure that what was provided was of a level of accuracy comparable to an item provided by the Space Weather Prediction Center (SWPC). Dr. Shprits pointed out that it was important that validation be done not by scientists, but a third party, preferably government.

Dr. Jonas asked how often the topic of space weather had been distributed to ISAC members so far. Ms. Miller said there had just been a meeting of a task force on cyberthreat intelligence. She added that the general concept of issuing out weather alerts had been part of Space ISAC from the very beginning. Dr. Knipp asked Ms. Miller whether space weather from open source referred to data from SWPC or from private providers. Ms. Miller said SWPC was the first source ISAC pulled data from, but there were other sources as well. Dr. Jonas asked about ISAC membership. Ms. Miller said it was composed of 63 different members, mostly from the private sector, including universities, international members, and owner-operators.

Dr. Ho asked how useful the tabletop exercise had been. Mr. Murtagh said there had been a two-hour senior officials' exercise at the White House which was largely focused on the federal response. The exercise Mr. Srinivasan referred to lasted a day and a half and brought in state and local officials. A space weather exercise would be more like the latter. NOAA leadership felt such an exercise was useful.

Dr. Gannon asked if there had been any lessons learned in the research and prep for TPL-007. Mr. Arritt said the biggest takeaway was that the benchmarks had to be created in terms of what the power system engineers could use.

Dr. Bishop asked Mr. Srinivasan what things APL considered when inviting people to the planetary defense tabletop. Mr. Srinivasan said they first wanted to include all the government agencies that would be involved in such a scenario. Another important consideration was making sure it was truly an end-to-end exercise. Dr. Duncan asked Mr. Srinivasan if he had thought about what stakeholders would be most beneficial to include in a space weather tabletop. Mr. Srinivasan said APL was currently considering power the most important group to engage because of its significant local impact, but it was open to suggestions.

4:30-5:00: Public Comments

Paul Boerner, Lockheed Martin Advanced Technology Center

Terrestrial weather forecasting was impossible without measurements of the whole Earth. Similarly, improving the ability to understand and predict space weather demanded new observations:

- Global measurements of the solar magnetic field and the configuration of the lower corona at all solar longitudes to predict solar eruptions, including those triggered by events on the far side of the Sun
- Widely distributed measurements of the heliospheric field and solar wind configuration to predict the effects of solar activity on Earth
- Observations of space weather throughout the solar system, not just at Earth

Technology and the accelerating commercialization of space had enabled lower launch costs, more capable instruments, and onboard intelligence. To take advantage of the convergence of these trends and fill the gap in space weather observations, it was time for the United States to lead the development and deployment of space weather constellation mission architecture to dramatically improve the power, relevance, and resilience of the space weather data that the nation relied on. This constellation was global, intelligent, flexible, and integrated.

Dr. Tobiska suggested SWAG could take a look at future pathways to get to measurement strategies.

Chris Leeds, Lockheed Martin

Parsec was a SmallSat-based lunar communications and navigation service. The first node was projected for launch in mid-2025, to be followed by a second node 18 months later. Parsec would transmit an augmented forward signal from the spacecraft to the Moon. Messages within that signal would contain data-like space weather alerts. Lockheed also planned on supporting a network-level protocol that would enable communications from one lunar user to another without having to run the data back through Earth. It was excited to be involved in the next wave of lunar development and exploration, and was happy to entertain other ideas or opportunities of using its network to advance space weather science or distribution of data products.

Dr. Bishop asked if Lockheed had considered the susceptibility of its system to space weather, and what sort of forecast or CONOPs it was taking for that. Mr. Leeds said they had not gotten into forecasting, but they were working on a radiation-tolerant product in a commercial class of parts. It had also built in workarounds to avoid destructive effects.

Jeff Love, United States Geological Survey (USGS)

Intermagnet was a voluntary consortium consisting of over 120 stations, many of which were real-time. All magnetic indices relied on Intermagnet stations. The operational standards in place for the magnetic observatories' projects were determined by a wide variety of customers, not just space weather. Dr. Love said it would be helpful to know what standards the space weather community needed in its data. USGS planned to deploy three more observatories and 12 variometer stations across CONUS over the next two or three years. Dr. Love did not consider it out of the question that hundreds of magnetometers would be necessary to resolve the ionospheric signal. If the public wanted more from USGS, it should tell USGS what it wanted.

Dr. Duncan asked how many magnetometers were currently in CONUS. Dr. Love said it was fair to say the current level was insufficient. Dr. Elliott asked if USGS needed better latitude and/or longitude coverage. Dr. Love said it needed both. Dr. Gombosi asked what the difference was between this network and SuperMAG. Dr. Love explained that SuperMAG was a database, and it did not operate magnetometers. Dr. McIntosh suggested that data from constellations would also be useful. Dr. Love agreed, asserting that data from above and below the ionosphere each played an important role. Dr. Knipp asked if there had been any effort to determine where data was most needed. Dr. Love said a lot of factors went into determining where to put a magnetometer. The simplest solution was to put them where they currently were not.

Thomas Berger, University of Colorado Boulder

The Space Weather Technology, Research & Education Center (Swx TREC) recently developed the Space Weather Data Portal, a web-based interface that accessed over 175 disparate databases all over the world to present an easily accessible, timelined format of data related to a space weather event. New databases or events could be added into the event library very easily. This kind of technology was difficult to find funding for because NASA considered it software tool development rather than scientific research, but it was nevertheless very valuable. Dr. Berger challenged SWAG to find possible funding sources.

Dr. Duncan asked about any crossover between the Space Weather Data Portal and Space Force's Unified Data Library. Dr. Berger said the Portal was an interface tool, database-agnostic and data location-agnostic. It pointed users to databases but did not actually download anything. It could easily point to the UDL database and display anything it had available. Dr. Ringuette asked how the Portal differed from other access tools. Dr. Berger explained that while other tools were back-end tools, the Space Weather Data Portal combined a back-end access tool with a front-end web interface and was much more developed. Dr. Tobiska suggested SWAG include the notion of data visualization versus network science versus data-accessible operations in its discussion.

Dr. Knipp relayed a question from a member of the public on whether SWAG was considering making the public education sector, particularly as it related to ham radio, a survey sector.

Another member of the public wanted to know if there would be a survey of proposers, awardees, and end users in terms of how successful things had been. Dr. Meehan shared a series of written public comments with the Group.

5:00-5:10: Overnight Assignments

Dr. Meehan announced that because it had been a long day, the meeting would not run until 5:35 as originally scheduled. Instead, all discussion would be held until the following morning.

Dr. Jonas outlined members' homework assignment for the evening: each member would take about 15 minutes to identify possible recommendations from the session s/he co-chaired. Dr. Jonas and Dr. Bishop would organize those thoughts, and SWAG as a whole would have the opportunity to discuss and modify them the following day.

5:10: Closing Remarks and Adjourn Day 2

Dr. Meehan adjourned the meeting at 5:09 p.m.

Space Weather Advisory Group (SWAG)
Virtual Public Meeting
Department of Commerce
Washington, D.C.
Meeting Minutes
Friday, January 20, 2023
9:00 AM – 12:00 PM

Meeting Attendees

Committee

Nongovernmental End User Representatives

Mr. Mark Olson, North American Electric Reliability Corporation
Mr. Michael Stills, United Airlines (retired)
Mr. Craig Fugate, One Concern
Dr. Rebecca Bishop, Aerospace Corp.

Commercial Sector Representatives

Dr. Jennifer Gannon, Computational Physics, Inc.
Dr. Conrad Lautenbacher, GeoOptics, Inc.
Dr. Seth Jonas, Lockheed Martin
Dr. W. Kent Tobiska, Space Environment Technologies
Dr. Nicole Duncan, Ball Aerospace

Academic Community Representatives

Dr. Tamas Gombosi, University of Michigan, Ann Arbor
Dr. Delores Knipp, University of Colorado, Boulder
Dr. Scott McIntosh, National Center for Atmospheric Research
Dr. Heather Elliott, Southwest Research Institute
Dr. George Ho, Johns Hopkins University Applied Physics Laboratory

Designated Federal Officer

Dr. Jennifer Meehan, National Space Weather Program Manager, National Weather Service

Also Present

Mr. Bill Murtagh, NOAA
Lt. Col. Omar Nava, U.S. Air Force

Meeting Minutes

9:00-9:05: Welcome (Jennifer Meehan, SWAG DFO)

Dr. Meehan welcomed SWAG members to Day 3 of the meeting. She explained that Dr. Tamara Dickinson was still not feeling well, and Dr. Jonas and Dr. Bishop would continue to chair the meeting in her absence.

9:05-9:15: Opening Recap of Day 2 (Jennifer Meehan, SWAG DFO)

Dr. Meehan gave a quick recap of what occurred on Day 2. Dr. Bishop and Dr. Jonas reviewed the previous afternoon's discussion.

9:15-10:15: Committee Discussion - National Space Weather Strategy and Action Plan Update

Dr. Bishop explained that the goal for that day was to come up with final recommendations. The wording did not need to be perfect, but the Group needed to agree in principle on what they were. She had gone through the recommendations members had submitted, and mapped each one to the white paper gap (WPG) most closely associated.

SWAG discussed the following topic areas for recommendations:

1.1 Ground-Based Systems

The overall theme was there was a need for fundamental paradigm changes.

1. Recognize the importance of near-surface and ground-based sensors in operational space weather.
2. A prioritization of critical systems was needed, starting with data that NOAA was using already.
3. There needed to be a pathway between research and operational instruments, including transition to long-term operations.
4. Maintenance and transition funding was the roadblock.
5. Look at different funding models for data, such as grants and data buys.
6. Improve data access, standards, and usability.

1.2 Economic assessment

1. Evaluate the use of proxies and analogies (hazards or other events) to inform economic assessments of space weather.
2. Include/add economic assessments of space weather beyond the worst case - what were thresholds of operational concern that were important to consider.
3. Emphasize the importance of and challenge in completing economic assessments.
4. More economists looking at this issue were needed.
5. Cost of mitigation - operations, data, and contracts - "not getting it right"
6. Support the SWORM recommendation to modify Recommendation 1.5 of the 2019 Space Weather Strategy and Action Plan.
7. Societal benefit assessment for space weather forecasting, mitigation, etc.
8. Establish space environment assessments through an ongoing standing group or committee, such as SEIGE.
9. Evaluate and integrate benchmarks to inform the economics assessment or vice versa.

2.1 Observational Data, Access, and Infrastructure in Space

1. In-space infrastructure needed space weather data to be 1) organized into a central portal; 2) in standard formats and documentation; 3) expanded to orbits of national interest, such as LEO, MEO, GEO, Moon, and Mars; 4) compiled into relevant databases, like CMEs and anomalies; and 5) consistently available.
2. How space weather research, application, and operations gaps were determined, prioritized, and refreshed needed to be codified.
3. The conflict between rapidly changing space weather operation and application needs and longer decadal timescales complicated prioritization and needed to be resolved.
4. Adequately addressing space weather gaps to connect systems-of-systems, address multiple mesoscale and global processes, access key vantage points, and improve modeling and forecast required updated approaches to mission formulation, such as R2O traceability, O2R feedback, pathfinder missions, model-based decision making, incorporating observing system simulation experiments (OSSEs) early and often, increased domestic and international coordination, ground-space coordination, transition funding, data standardization, and operational data links.
5. Prioritize space weather and science user needs by flying additional and including low-cost and/or COTS as well as miniaturized high-heritage standardized instruments to provide consistent datasets and fill key coverage gaps.
6. Have standard common observing system simulation experiments (OSSEs) open and developed by experts.
7. Gaps in the solar and coronal coverage, such as longitudinal, latitudinal, and regions, like middle coronal, needed to be addressed because this impacted the accuracy and lead time of all the space weather forecasts.
8. Maintaining well-documented databases enabled the effective use of historical observations to help fill in gaps in current coverage empirically.
9. With the increasing amount of observations, automated techniques were needed, such as leveraged machine learning, cloud computing, artificial intelligence, and data mining. This would require interdisciplinary research with experts in this area and put new demands on the training of the workforce.
10. The recent cycle, 24, was a mild cycle with a limited number of extreme weather events in the datasets. This hindered many automated empirical forecasting techniques. Mitigation strategies and plans to rapidly update models and forecasting techniques needed to be in place for when a more active solar cycle occurred.
11. For critical measurements, redundancy of observations or backup estimates and proxies were necessary for operational usage. This drove the need for a pipeline of backup instrumentation providing critical observations to be ready for deployment. Additionally, there were staffing demands for such critical observations because only one or two experts may have had specific knowledge.

2.2 Benchmarks, Metrics, and Scales

Reconciliation between SWORM and the industry was needed for managing space weather risks using benchmarks, metrics, and scales.

1. Benchmarks, metrics, and scales should be expressed in terms and parameters that end users could apply to assessing vulnerability or taking operating actions.
2. Focus on near-Earth domain for scale and metrics; be consistent throughout all applications.

3. Move scales from being based on the driver to being based on specific response or impacts that would help decision-making by the user community.
4. Different de facto surrogates that were used in the community might be tied to scales.

2.3 Data Infrastructure and Methods

1. Space Force needed to coordinate with NOAA on space weather models, data sources, and operations.
2. There was a need for specially trained space weather data scientists and software engineers who could help to design, maintain, and efficiently use space weather cyberinfrastructure.
3. Artificial intelligence and machine learning (AI/ML) had an important role in future space weather models, but they could not replace physics-based models for extreme events. Interpretable ML models must be developed.

10:15-10:30: Break

10:30-11:30: Committee Discussion - National Space Weather Strategy and Action Plan Update Continued

2.4 Evolving Infrastructure Systems and Services

1. Continue to engage international and commercial partners in overcoming obstacles to effective space situational awareness (SSA), with focus on efficient dialogue and system compatibility.
2. Unified space weather or space environment database.
3. SWORM should engage end users to focus vulnerability assessments on emerging space weather risks to key critical infrastructures that were rapidly evolving, including the changing electric power grid, space traffic management, and space-based communications, such as satellite mesh networks.
4. Additionally, as interdependencies among many infrastructures were growing, capabilities for evaluating cascading risk scenarios should be pursued.
5. The Space Weather Strategy should be updated to reflect the multipoint solar observation, solar polar mission, data acquisition and availability, and modeling needs to support plans for human and robotic space exploration and space commerce.

2.5 Industry and Government Collaborations, Coordination, Outreach, and Communications on Space Weather

1. Promote the use of exercises, such as tabletop, for improving coordination, outreach, and communications.
2. Promote a concept such as the Space ISAC Watch Center or increase purview and stakeholders of Space ISAC.
3. Emphasize industry-government interaction outside of well-established industries. Utilize lessons and a collaboration-coordination structure developed by these industries, such as a power grid.

Miscellaneous recommendations

1. There was a need to fund the transition from research to operations, particularly the final stages, to become operational.

2. Encourage NOAA to increase engagement, prioritization, and investment on space weather to align it with their identification of space weather as one of six priority areas.
3. International engagement and coordination.
4. National security annex.
   (a) Risk assessment, workforce, etc.
5. Broaden and augment community stakeholder engagement with the public, local government, etc.

There was a sense among SWAG members that they needed more time to digest what they had heard over the past three days and how it integrated with the white paper before formally approving a set of recommendations. They also wanted the time to organize so they were not repeating themselves.

Dr. Bishop moved that SWAG follow a plan outlined by Dr. Jonas to refine the topic areas listed above into recommendations, taking into account the previous recommendations it had worked on. Dr. Jonas seconded the motion. The motion passed without opposition or abstention.

11:30-11:50: Committee Discussion - Writing Assignments

The thought was that members would take the lead on writing and consolidating the recommendations in their respective sections that they co-chaired. Anyone who wanted to help with a particular section should contact the chairs of that section directly.

SWAG planned to hold a closed meeting to work on the recommendations, followed by an open meeting when it would deliberate and vote on them. The open meeting would need to be held before the SWORM meeting on March 1, but would require 15 days' advance notice in the Federal Register. The Group agreed to hold the open meeting from 11:00 a.m. to 3:00 p.m. EST on Thursday, February 23, and the closed from 11:00 a.m. to 2:00 p.m. EST on Thursday, February 9.

Dr. Bishop asked that the co-chairs for each section submit their revised recommendations no later than Monday, February 6.

11:50-12:00: Closing Remarks (Dr. Jennifer Meehan, SWAG DFO)

Dr. Meehan reminded SWAG that the Space Weather Workshop was scheduled for April 17-21 at the Embassy Suites in Boulder, Colorado, the first time since 2019 that it would be in person. Events would include a SWAG session.

Dr. Meehan adjourned the meeting at 11:49 a.m.