SWC Report to HPAC

May 2023

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Background

The HPAC provided the SWC four tasks in August of 2022. This slide deck is the SWC's report to HPAC on each task.

The SWC convened with invited speakers and discussed these tasks in August 2022 and May 2023. This report is the result of those sessions and represents the consensus of the Council. The task discussions and the corresponding write-ups were organized by two Council members, shown in the table below:

Task	Task Leads
1	Janet Green and Michele Cash
2	Angelos Vourlidas and Piyush Mehta
3	Ron Turner and Alexa Halford
4	Paul O'Brien and Dan Baker

Task 1

HPAC Task 1

SWC is advised to research the activities of SWORM and SWAG, identify overlaps and gaps, and determine how SWC can complement and leverage ongoing efforts, with specific relevance to the interests of the NASA Heliophysics Division. This may include researching reports on the committee websites; attending their public meetings; organizing a meeting of committee chairs and staff; and defining how the role of the SWC can complement the work of these existing committees.

SWC Scope

The SWC response to this task includes the following:

- **Overview**: A brief explanation of the roles/responsibilities of 4 groups (SWORM, SWAG, Roundtable, and SWC)
- **Coordination**: A description and evaluation of how the groups coordinate activities
- **Highlights**: Summary of each group's activities that NASA HPD should consider and be aware of

Discussion

To address this task the SWC reviewed reports produced by the other committees and solicited presentations and input from the SWAG and Roundtable leads on their respective group's activities and their view of coordination efforts.

- The SWAG has been focused on developing the recently (April 2023) released report on the National Space Weather Strategy and Action Plan (https://www.weather.gov/media/nws/REPORT-Findings-and-Recommendations-04202023.pdf) and a user survey. They are continuing work on the user survey and welcoming suggestions for additional tasks to consider.
- The initial in-person meeting of the Roundtable (Oct 2022) introduced a number issues facing the space weather community including ground measurement support and the R2O process. Since the initial meeting, the group chose to focus on one or two topics per year and started with ground measurements. Virtual discussions are held monthly with two in-person meetings per year. The next in-person meeting in June 2023 will wrap up and summarize the ground measurement discussions and move on to issues with the R2O process.
- Committee leads agree that the groups are now working well together and coordinating effectively after some growing pains to understand their own roles and responsibilities and communication mechanisms.
- Group leads meet regularly, present activity updates at meetings for other committees and pass ideas back and forth.
- Most of the committees are identifying similar needs, gaps, and issues.
- SWC's role is to inform NASA's space weather program by addressing specific tasks provided by the HPAC. However, the council is actively examining the work of these other groups which give a more complete view of the overall needs of the national and international SW program. The SWC will provide tactical recommendations that consider how NASA can strategically contribute to this global effort.

Response: Overview of committees

SWORM: Interagency working group led by the White House, composed of government agency representatives including FAA, NASA, NOAA, DOE, DHS, NSF, USGS, and the DOD. (For a full list of participating departments and agencies see https://www.sworm.gov/about.htm)

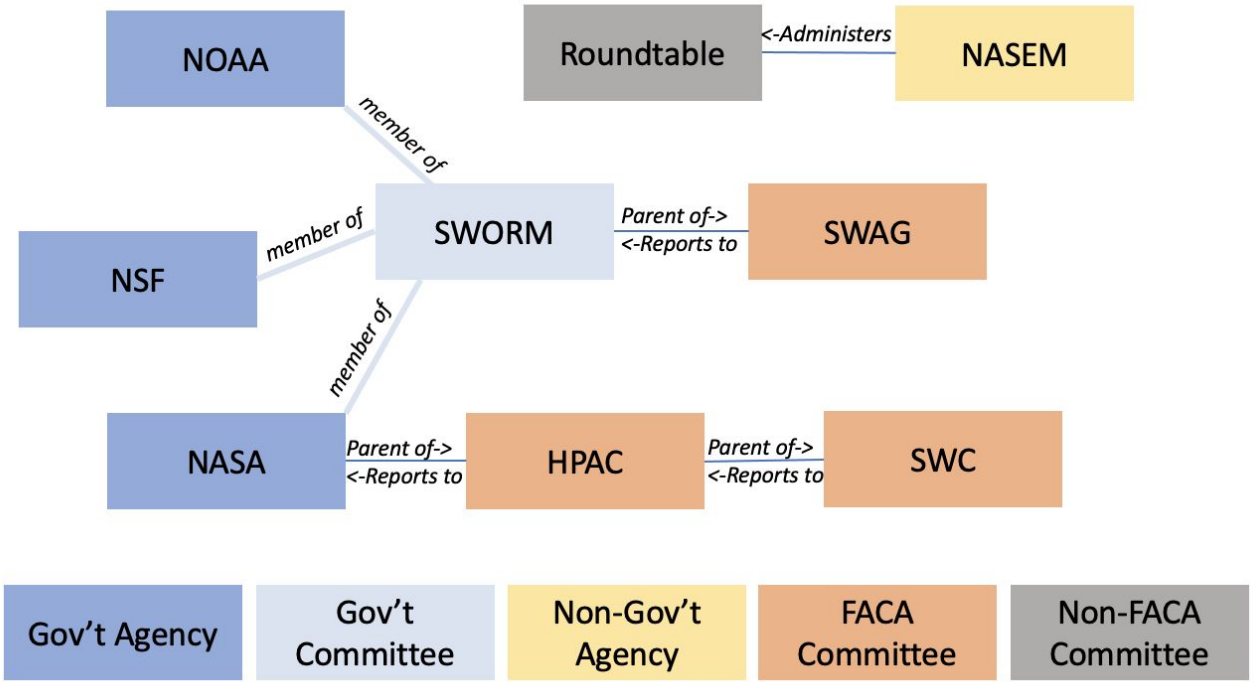
SWAG: Provides recommendations and findings to the SWORM who can then implement those recommendations into agencies plans. Consists of 5 academia, 5 commercial space weather, and 5 user group members.

Roundtable: Brainstorming group that generates ideas but no written suggestions or recommendations. Ideas generated by the Roundtable may be considered by other groups to inform policy decisions.

SWC: Gives tactical advice to NASA on its space weather program. Responds specifically to tasks given from the Heliophysics Advisory Committee.

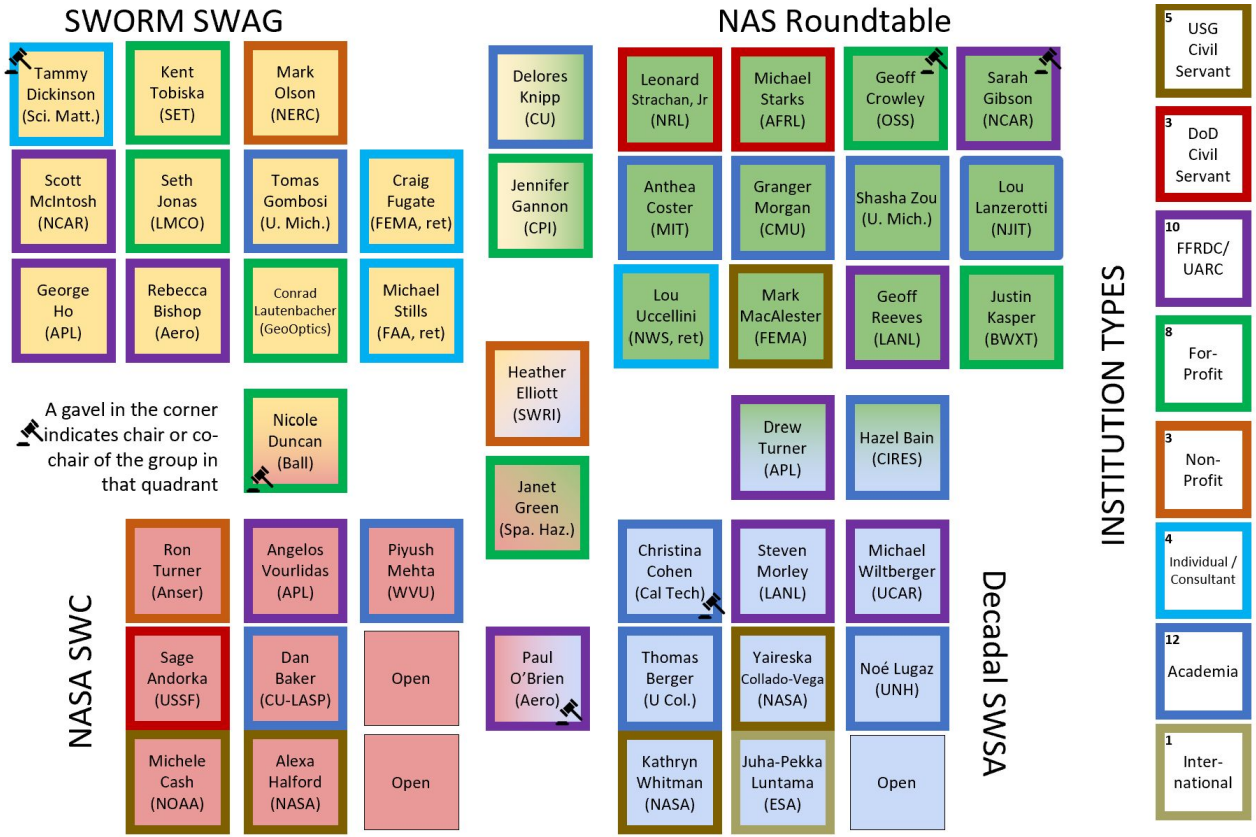
Response: Overview of committees

Flow chart depiction how the groups interact



Response: Overview of committees

Current committee make-up and overlapping members



Response: Coordination

The four groups have focused on related but independent topics and tasks. Each have different mechanisms for communicating findings to agencies for consideration and possible implementation.

Coordination between the groups has been successfully achieved with regular tag-ups between the leads, invitations to present and participate in each others meetings, and overlapping members within the groups sharing ideas.

The SWC will improve coordination further by:

- Sharing the specific tasks assigned by the HPAC with the other groups when they are received
- Asking other groups to notify the SWC when they address topics specifically related to NASA

SWC views successful coordination and communication between the groups as an opportunity to address the greater national/international space weather needs and ensure a strong and effective global Space Weather Enterprise.

Response: Highlights (from SWAG)

The SWAG report on implementation of the PROSWIFT act contains a number of items relevant to NASA that the HPAC should be aware of. The report includes 25 findings and associated recommendations with a few of note listed below: (https://www.weather.gov/media/nws/REPORT-Findings-and-Recommendations-04202023.pdf).

R.2.1-3 discuss the establishment of a research group in the NOAA Office of Atmospheric Research and expansion of the R2O2R function that could impact NASA's role in the space weather enterprise.

R.9.1-2 address needs for space weather service beyond Earth that is of particular interest to NASA

R.10.* all give specific suggestions for NASA science and space weather observations

R.11.1-2 recommend increasing sensor deployments with opportunistic missions and required sensors on all government vehicles

R.13.4-5 suggest advancing AI capabilities and increasing access to novel and underutilized data sets such as impact datasets (ex. satellite anomalies)

R.24.1-2 discuss the need to support coordinated applied research of the thermosphere to improve space traffic coordination

Response: Highlights (from SWORM)

The SWORM released the National Space Weather Strategy and Action Plan Implementation Status White Paper in January 2023 that discusses progress and remaining gaps toward achieving space weather objectives. (https://www.sworm.gov/publications/2023/2019_nswsap_ip_summary.pdf)

The section on “Objective II: Develop and Disseminate Accurate and Timely Space Weather Characterization and Forecasts” and the identified gaps highlighted below are particularly relevant to NASA HPD.

Section 2.2 Notes that policies need to be developed to facilitate the transition of research and academic data collection platforms to agencies responsible for long-term operational monitoring.

Section 2.3 Suggests that space-based monitoring projects and exploratory missions need to be coordinated with agencies responsible for ground-based monitoring.

Section 2.5 States that the space weather community has requested access to observational and operational data streams as the simulation output will contribute to the identification, preparation, maintenance and augmentation of high-quality datasets for assimilation, model validation, and to optimize utilization.

Section 2.7 The SWORM is now finalizing a report that will recommend R2O2R best practices. Identifying lessons learned and limitations of previous models transitioned from research to operations at SWPC will accelerate the R2O2R process.

Section 2.8 The broad scientific and engineering communities within the space-weather enterprise would benefit from the free and open exchange of data related to the impacts of space weather on technological systems operated by the commercial, academic, and governmental sectors. Such data would facilitate collaborations between providers and users of space-weather services.

Response: Highlights (from the Roundtable)

The Roundtable does not release written reports or recommendations. However, as part of their research the group created a comprehensive list of available ground based sensors and a summary of existing guidance and resources analyzing gaps and needs of ground-based sensor networks.

The next in person meeting of the Roundtable (June 1-2, 2023) may be of particular interest to the HPAC. The meeting will include a summary of the past discussions on ground measurements but the main focus of the meeting will be on identifying and improving issues with the R2O process.

Task 2

HPAC Task 2

Of specific interest to the HPD and HPAC is an analysis of the gaps in space weather fundamental science, modeling and impacts. Gap analysis studies have been performed by different agencies within the last decade, and a **summary review** of this material is of importance for HPD future plans. Specifically, the HPD supports development of a range of instruments at different technology readiness levels. Up-to-date understanding of knowledge gaps will assure that HPD can make an informed decision in prioritizing development of certain technologies, instruments, and models.

SWC Scope

The SWC response to this task comprises the following:

- Review recent gap analysis reports and summarize the current status
- Identify next steps based on Agency priorities/needs
- Provide feedback to HPAC: (1) high-level summary of the status of gap analyses; (2) Forward looking recommendations.

Discussion

The Council reviewed the latest Gap Analysis reports (NASA Gap Analysis & NAS Workshop Phase I/II) during its August 24, 2022 meeting. Members of the Council, who had contributed to those reports, presented summaries to inform the subsequent discussions on this task. The summary of these discussions follows:

- The Council finds that the two gap reports have comprehensively identified the measurement and infrastructure gaps. It is time to take **action** towards filling the identified gaps.

- A ‘gap-filler’ analysis seems to be the logical next step. This type of analysis would start with the selection of a gap (or a number of related gaps) that addresses an urgent Agency need and would then proceed to define a cost-efficient and timely path to filling that gap (or gaps) by considering all necessary elements (i.e, required measurements, infrastructure, and modeling) including a quantitative assessment of the anticipated improvement in SWx forecasting.

- Modeling and data-ingestion gaps have not been explored to the level of gaps in measurements and infrastructure. A gap analysis focused on SWx modeling needs (e.g., uncertainty quantification, data-ingestion, ensemble approaches, etc.) may be necessary to inform NASA research efforts and priorities in SWx.

Discussion (cont.)

The Council reconsidered the status of gap analyses after the freezing of the GDC mission development specified in the March 2023 PBR. The Council requested feedback from the NASA gap analysis committee which verified that the GDC and Dynamic measurements were assumed to become available in the near-future during the gap analysis work. A quick gap analysis with the new information resulted in following assessments:

- The lack of GDC measurements creates a knowledge gap on how the energy inputs from the magnetosphere affect the distributions of plasma density (a major factor associated with GNSS signal scintillations) as well as neutral mass density (a major factor associated with satellite drag). The multi-point measurements by the GDC mission would have also provided critical inputs and constraints to the ionosphere-thermosphere (IT) models for specification and/or nowcast/forecast of the IT system.

- The lack of DYNAMIC measurements will leave open the current gap on quantifying the forcing from the lower atmosphere onto the IT system.

Output #1: Top-level Summary of Gap Analyses

The two gap reports considered by the council provide summaries of their findings. Below we mention only their top-level actions for filling the measurement/infrastructure gaps. *Note: There are/maybe other gap reports that are not accessible to the public and the council.*

- Achieve 3D coverage of the Sun and inner heliosphere, with high temporal and energy resolution and dynamic range to fill the gaps stemming from the uncertain 3D structure of transient phenomena. This includes both off-ecliptic and off-'Sun-Earth line' architectures
- Multipoint distributed measurements within the inner heliosphere, at different scales, are critical for improving empirical and physics-based models across the various SWx domains.
- Reduced latency and improved data downlink rates to provide near-real-time information on the status of the Sun and the inner heliosphere. Repurposing existing infrastructure, as well as developing novel architectures, should be considered.
- Develop 'dual-use' instrumentation that can be used for research and SWx operations. Same concept should apply to future research spacecraft (i.e. by including 'SWx beacon capability' as standard service).
- The increase in data acquisition capabilities to fill critical gaps drives the need for efficient data management, including the development of on-board processing and automated decision making (autonomy).

Output #2: Recommendations

1. **Explore approaches to quantify the return-on-investment from filling a gap.** Such information will facilitate prioritization and programmatic planning for addressing SWx research and needs.

2. The SWC considered space weather needs for human exploration in Task 3. During that discussion it became clear that there is no focused gap analysis which considers the needs of space weather analysts in support of human exploration. From this conversation t**he SWC identified the urgent need for a comprehensive SEP gap-filler analysis.** Though some information exists in the current gap analyses, the timeline of the Artemis program should be considered in understanding and filling this gap.

3. **Consider undertaking a focused modeling gap analysis.** The analysis should use the existing gap findings as a starting point but focus on the gaps in R2O modeling capabilities (e.g. data-ingestion, uncertainty quantification, etc.) and the design of Observing System Simulation Experiments to provide a quantitative assessment of the impact from the closure of a given gap. The NAS Phase-II and the upcoming ISWAT Roadmap may contain enough information to render a further gap analysis unnecessary but the Council have not investigated this avenue. However, the Council identified two important gaps during its consultations:
   a. **Long-term, multi-event historical reanalysis** with numerical or data-assimilative models is a valuable tool for assessing extreme values and for model validation. Its use w/in HPD is limited which hinders anomaly resolution and benchmarking.
   b. **Extreme events cannot be modeled with the routine models**. Dedicated models (numerical or AI/ML) that address extreme events specifically (i.e., simplified to facilitate stable extrapolation) are needed.

Task 3

HPAC Task 3

The SWC is advised to address the NASA’s Artemis and space biology programs to determine the potential to extend our knowledge with lunar focused space weather measurements and studies.

SWC Scope

The SWC response to this task includes the following:

- Scope interpreted to include space weather considerations at the Moon and Mars to support Human Exploration
- Discussion of recent reports and gap analyses
- Recommendations for NASA based on committee discussion

Discussion:

A recent NASA Engineering and Safety Council study, Safe Human Expeditions Beyond Low Earth Orbit(LEO); NASA/TM−20220002905 / NESC-RP-20-01589 had addressed future space weather support to human missions in CIS lunar space and beyond:

“For the return to the Moon, existing and planned scientific and operational ground- and space-based assets will provide sufficient warning of sporadic eruptions from the Sun. The planned crew shelters will provide adequate protection for the event duration with minimal impact on the completion of mission objectives. For Mars missions, forecasting SPEs that will impact spacecraft and crew in interplanetary space becomes more challenging…”

Building on these and other space weather gaps, it is prudent and appropriate therefore, that NASA’s Heliophysics Division, together with appropriate divisions within NASA’s Operational Directorates, begin now to establish lines of communication and coordination to prioritize near term opportunities that could substantially improve forecasting radiation events, to include fundamental space weather research in areas that have direct impacts on Artemis (both observations and models, e.g. radiation effects, communication impacts, and impacts to technology used on the Lunar and Martian surface), improvements in transitioning promising space weather forecast models, and to prioritize deployment of early elements testing or contributing to an architecture that could simultaneously enhance forecasts for Artemis and begin to build up the architecture that would ultimately provide necessary support to missions beyond CIS-lunar space.

Discussion cont.

Some options have already been identified in Gap Analyses. For example, the NESC report acknowledged “Additional space weather monitoring assets (i.e., solar coronagraph and particle detector suites) at Sun-Earth Lagrange point L4 and Sun-Mars L1 and L4/L5 can enable sufficient early warnings for Mars missions during transit and stay. The Sun-Mars L4/L5 assets would also provide a communications relay solution for when the Earth line of sight to Mars is behind or close to the Sun.”

Additional items to consider to inform the prioritization of near-term implementation include

- Need for off Sun-Earth Line measurements
- Need for better quantification of all radiation impacts
    - Space Environment impacts on humans
    - Space Environment impacts on technology keeping humans alive
    - Technology radiation impacts on humans (e.g. if nuclear power used)
- Need for better and more coordination between the human exploration side of the house and the science side of the house.
- Need to be able to develop and test automated tools (e.g. forecasting tools) on the Moon that can be used for crewed Mars missions
- Need to have SWx environmental data included on Artemis assets e.g. LunaNet and Search and rescue nodes
- Need for development of Mars centric space weather infrastructure (e.g. GPS, space weather assets).
- Need for increased development of the deep space network.

Discussion cont.

Additionally the Artemis Architecture Definition Document finds…

- Improve understanding of space weather phenomena to enable enhanced observation and prediction of the dynamic environment from space to the surface at the Moon and Mars.
    - Emplace and operate science instrumentation in a variety of lunar orbits
    - Emplace and operate science instrumentation for solar monitoring off the Earth-Sun line
    - Emplace and operate science instrumentation on the lunar surface
    - Provide power, communications, and data to deployed science payloads to enable sustained operation for durations of several years
- Generating forecasting capabilities for space weather monitoring off the Earth-Sun line
- Characterize and monitor the contemporary environments of the lunar and Martian surfaces and orbits, including investigations of micrometeorite flux, atmospheric weather, space weather, space weathering, and dust, to plan, support, and monitor safety of crewed operations in these locations.
    - Emplace and operate science instrumentation in lunar and heliocentric orbits relevant to addressing the associated science objectives
    - Emplace and operate science instrumentation on the lunar surface at locations relevant to addressing associated science objectives, including polar and non-polar locations on the lunar near side and far side

Discussion cont.

- Coordinate on-going and future science measurements from orbital and surface platforms to optimize human-led science campaigns on the Moon and Mars
    - Emplace and operate science instrumentation in lunar and heliocentric orbits relevant to addressing the associated science objectives
    - Emplace and operate science instrumentation on the lunar surface at locations relevant to addressing associated science objectives, including polar and non-polar locations on the lunar near side and far side

We have pulled from the above to develop the current set of recommendations in the following slides

Recommendation: Continue R2O2R and other Artemis proposal calls.

Some examples of other potential proposal call mechanisms that take advantage of launch opportunities heading to unique locations include CLPS (through the Artemis program and managed through PSD), PRISM and Hfort.

Documentation which includes science priorities:

- The decadal surveys from the science directorates
- Artemis III science objectives
- Advancing science of the Moon
- Reports from the LEAG community.
- NESC report: NASA/TM−20205000837/Corrected Copy NESC-RP-17-01215: Space Weather

Recommendation: Continue and enhance collaborations across NASA directorates, NASA centers, agencies, and countries for Artemis

- Include collaborations in the Artemis Architecture Definition Document. https://ntrs.nasa.gov/api/citations/20230002706/downloads/M2MADD_ESDMD-001(TP-20230002706).pdf report and other guiding documents.
- Ensure space weather activities that are called out at a higher-level in the ADD, and other guiding documents, are included in future activities and lower-level documents/recommendations with the correct specifications and appropriate resources.
- SRAG is currently responsible for astronaut safety for the lunar missions. It is unclear, however, who takes responsibility once commercial crewed missions begin. This may be a discussion for SWAG.

Recommendation: Include, pursue, explore, and leverage SWx instrument opportunities on board Artemis infrastructure and opportunistic platforms as these arise.

For example:

- Consider a sensor development effort to prepare capabilities suitable for monitoring SWx off the Sun-Earth line on Artemis disposal equipment sent into heliocentric orbit.
- Instrumentation which is more space weather capability focused may have simpler accommodation requirements, and could possibly take advantage of non-science platforms.

Recommendation: Explore and pursue areas where NASA can cost share, reduce risks and perform enabling tasks (such as anomaly resolution) more effectively with the addition of space weather assets.

- Ensure SRAG and M2M space environment office have sufficient support and resources.
- Explore, leverage and pursue opportunities for broadening the Space Weather infrastructure for anomaly resolution.

Recommendation: Encourage existing missions and modeling efforts to provide their data and capabilities to the M2M Space Environment office (and others) to perform validation.

- Provide methods and resources to these missions and modeling efforts to support data and capabilities transfer
- This may include ability to gain real time data capabilities
- This may include ability to process real time data to higher level data products in a timely manner
- As suggested in topic 2 there is a strong need as identified by M2M analysts that the currently available imagery and in-situ data is inadequate for providing robust predictions of the cislunar radiation environment. A comprehensive gap analysis across the full workflow for SEP predictions is outside of the previous reports and should be undertaken asap.

Task 4

HPAC Task 4

The SWC is advised to work on the development of specific suggestions for interagency NASA-NOAA-NSF-DoD cooperation in order to maximize return on investment in research infrastructure supported by agencies. Specific examples include development of suggestions about better coordination between NASA and NOAA supported space-based instruments and NSF-supported ground-based infrastructure, data fusion from multiple instruments, data assimilation efforts, etc.

SWC Scope

- Report on what we see in relationships, roles and responsibilities
- Discuss cooperation throughout the levels within the organizations
- Broaden scope to International coordination
- Include specific recommendations for coordination

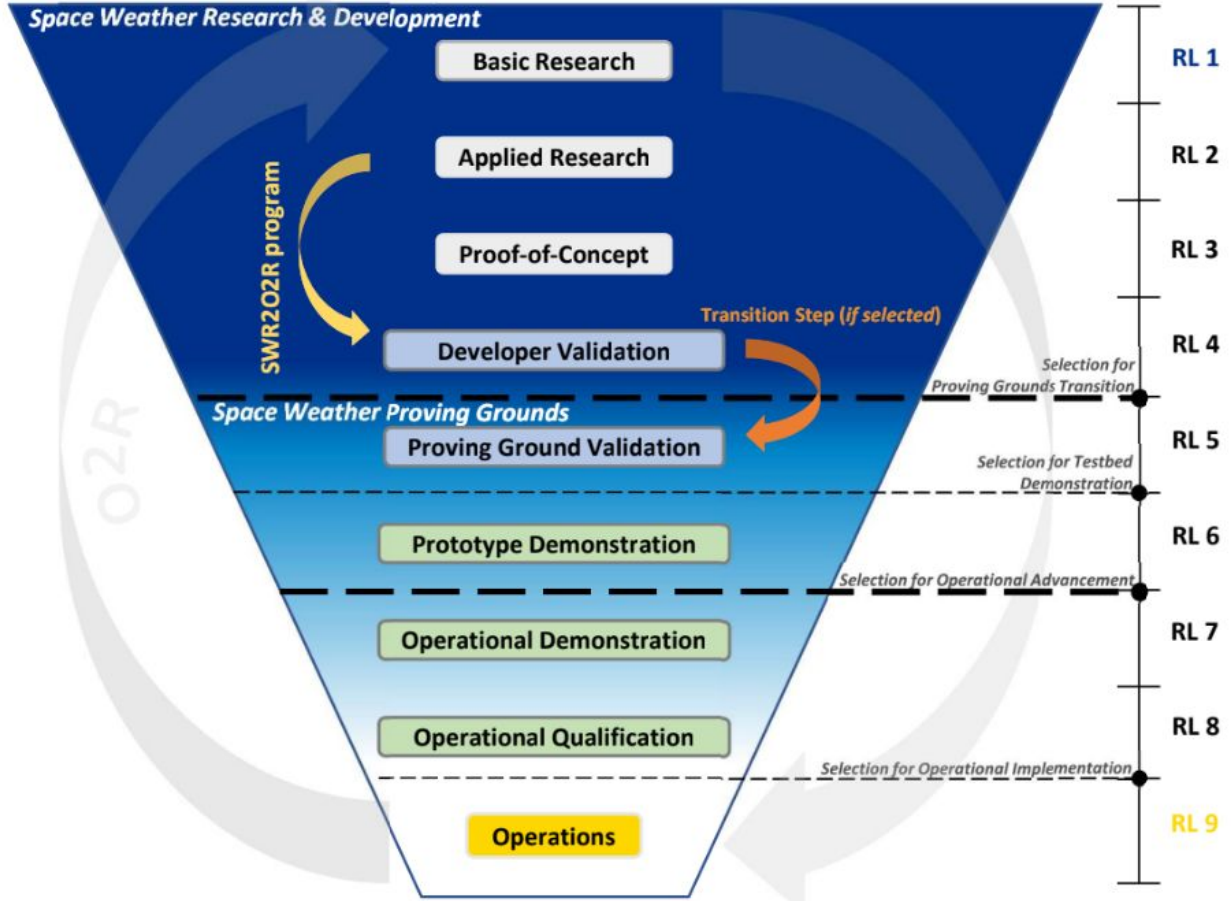
Discussion: Roles, responsibilities, relationships

- We still sense friction at high levels between NASA and NOAA over responsibility for Space Weather operations. We are concerned that resource allocation is not backing up claimed responsibilities.
- How does NOAA contribute to SWSA AOs and proposal evaluation/selection? Does NOAA weigh in on proposals after the review panels have identified what's selectable? Yes.
- (Note: R2O2R considers it a success to raies RL, not just to transition)

Discussion: cooperation throughout the levels within the organizations

- Build a contact list for DoD/IC
- Build a contact for other NASA centers with interest in SWx, NOAA (not just SWPC), NSF, DoC, DoE, DoT(FAA)
  - Have a monthly space-weather review that includes multiple agencies (hopefully all of them)
- Develop a clearinghouse for non-NASA SWx data
  - This was highlighted in the Gap analysis
  - Include high to low data transfer
  - Pull in data from UDL
  - NASA should examine their role in Space Weather data access and storage across agencies
- Formalize the process for connecting DoD SWx gaps to civil gap analyses and plans to fill gaps
  - AFRL/NRL/ARL are probably nominally in charge of this
  - Possible new weather POC at OSD to help. Nothing formal yet.

SWx Research to Operations to Research Process



Discussion: Broaden scope to International coordination

- Potential mission international collaboration opportunities could include ESA Vigil, CSA AOM, Gateway, KASI SNIPE. Exploitation of MetOp-SG NGRM
- Also need contact list for international (note that in Japan, there are two orgs: JAXA and NICT, sort of like NASA and SWPC. NASA is getting hands around these issues but it needs more work)
- Assist new ESA SW office to become an effective partner for NASA-ESA coordinated SWx efforts
- New UK R2O program
- Get MOUs in place in advance for general hosting/funding collaboration for foreign hosting of US sensors (Already uses a lot of bilateral agreements). Idea here is that advance MOUs may stimulate collaboration and will help it start faster when new opportunities arise
- Jim envisions an IASWCG - International Agency Space Weather Coordination Group. Research analog to CGMS and WMO. Establishing this forum is already in the NASA plan. Panel thought this was good.

Discussion: Include specific suggestions for coordination (1/2)

- Use the Unified Data Library to share SWx data with DoD/IC
- Encourage further and stronger collaboration between CCMC and DoD
- Pursue ride (launch) shares with other agencies (and commercial)
  - SMD (out of HPD) has a new ride share office
- Pursue payload hosting with other agencies (and commercial)
  - SWAPS RFI: https://nspires.nasaprs.com/external/solicitations/summary.do?solId={985C5CF7-AC4E-FEE7-0873-97CDC7BC01E0}&path=&method=init
- Does it make more sense for NASA SWxSA to take over the prototyping and product development / exploitation of commercial / commercially hosted SWx measurements? (i.e., if NOAA stood that up because NASA SWxSA didn't exist yet, maybe it should be relocated) Or is there just need for coordination? NASA thought things were OK as is on this point.

Discussion: Include specific suggestions for coordination (2/2)

- R2O2R
  - What is the process for selecting capabilities to enter the O2R process? Is that working well? (2022 Framework?)
  - It seems that only a very small number of NASA SW O2R2O projects are getting a foothold at SWPC. Why is that? Raising RL is also a positive outcome.
  - Should NASA SW be focusing on fewer projects, but taking them further (higher TRL)? NASA made convincing argument that this is not the situation now: aim at raising RLs on many capabilities instead of fewer longer/deeper projects.
- USSF's REACH is a newish opportunity for collaboration (it's already started with some work at GSFC using publicly-available REACH data)
- (NASA not formally involved in COSMIC. Some overlapping interest with SPORT cubesat)
- Study practical requirements for storing sensors long term to facilitate ride shares
- Coordinate funding use of SWx SBIRs across agencies
- Recommend NASA SWxSA review NASEM 2011 "Assessment of impediments to inter agency collaboration on space and Earth scienc emissions" https://nap.nationalacademies.org/catalog/13042/assessment-of-impediments-to-interagency-collaboration-on-space-and-earth-science-missions

Response: Roles & Responsibilities

We are delighted to see the successful collaboration occurring at the working level between the agencies and look forward to seeing that extend to the higher levels.

NASA HQ can improve understanding of diverse counterpart organizations by developing a comprehensive contact list including roles and responsibilities

- DoC/NOAA, NSF, DoD & IC, DoE, DoT/FAA
- SWC has begun one for DoD

Investigate developing a single location to collect current and historical interagency space weather data and information in support of modeling (Note: the Gap Analysis called this out as well, and it is therefore connected to Task 2). Explore the Unified Data Library as a pathway to obtain DoD data.

Response: R2O2R

Recognizing that the R2O2R framework is still in the early days of implementation, the SWC would like to see more consideration for the following points:

- Intentionality of overall lifecycle
- Transparency on the process for selecting capabilities for transition
- Improved definition of the transition process, especially as regards maturity at handoff to the receiving (operational) organization
- Enhanced Funding

Consider defining and expanding the role of non-government providers and users in the R2O2R framework.

Recommendation: International engagement

Building upon the recognition that foreign space weather activities are often spread across multiple agencies in each country, as they are in the US, NASA would benefit from developing a comprehensive contact list of international partners including roles and responsibilities.

NASA should continue developing MOUs with potential international partner agencies *in advance* of identifying specific opportunities, both for flights and collaborative R&D or R2O.

Recommendation: Future work

The SWC would like more time to explore NASA-NSF collaboration opportunities, including the new NSF Technology Innovation and Partnerships (TIP) program, the Decadal Survey’s output, and joint funding