SPACE WEATHER TABLETOP EXERCISE

AFTER-ACTION REPORT

8-9 May 2024

NASA NOAA NSF FEMA JOHNS HOPKINS APPLIED PHYSICS LABORATORY

24-04830

SWx TTX
8–9 May 2024

Space Weather Tabletop Exercise

After-Action Report

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Executive Summary

Background

The Space Weather Operations, Research, and Mitigation (SWORM) task force, an interagency group organized under the National Science and Technology Council (NSTC), was chartered in November 2014 to develop a national strategy and action plan to enhance national preparedness for space weather events.

In October 2015, the SWORM—which is co-chaired by the National Ocean and Atmospheric Administration (NOAA), the Department of Homeland Security (DHS), and the Office of Science and Technology Policy (OSTP)—issued both the *National Space Weather Strategy*[1] and *National Space Weather Action Plan*.[2] Together, these documents were developed to enhance the integration of existing national efforts and to add important capabilities to help meet growing demands for space weather information. The *National Space Weather Strategy and Action Plan*, which was updated in March 2019,[3] built on efforts to reduce risks associated with a space weather event and improve the resilience of critical infrastructure and systems. One of the specific objectives outlined in these documents was to "Exercise Federal response, recovery, and operations plans and procedures for space weather events."

In October 2020, Congress passed the *Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act*[4] (PROSWIFT Act), which served to (1) define the roles and responsibilities of the federal departments and agencies regarding space weather, (2) codify the SWORM subcommittee, and (3) direct NOAA and SWORM to establish a Space Weather Advisory Group (SWAG). In April 2021, NOAA chartered the SWAG to advise SWORM on a variety of space weather issues, including the development and implementation of an integrated strategy for space weather.

On 8–9 May 2024, the United States government held the first-ever end-to-end Space Weather (SWx) Tabletop Exercise (TTX). The SWx TTX provided opportunities for participants to better understand the preparedness and response challenges associated with the threat of an impending space weather event. The TTX was sponsored jointly by NOAA National Satellite, Data, and Information (NESDIS) Office of Space Weather Observations (SWO), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Federal Emergency Management Agency (FEMA). The exercise incorporated federal, state, local, and tribal considerations to improve our nation's whole-of-government preparedness for space weather events.

The SWx TTX scenario, which was organized into four modules, involved a series of solar events that drove a range of adverse space weather effects on Earth and in geospace, including the following:

[1] https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/final_nationalspaceweatherstrategy_20151028.pdf
[2] https://www.sworm.gov/publications/2015/swap_final__20151028.pdf
[3] https://trumpwhitehouse.archives.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf
[4] https://www.congress.gov/bill/116th-congress/senate-bill/881

- Intense radiation exposure to satellites, astronauts, and commercial aviation
- Radio communications outages and disruptions
- Loss of functionality or degraded performance of GPS for precision navigation and timing
- Degraded ability to communicate with and track on-orbit satellites
- Local- to regional-scale power outages

It is important to note that, by chance, a significant real-world space weather event—the largest geomagnetic disturbance in more than 20 years (i.e., the "Gannon Storm")—began at the same time as the SWx TTX. These extraordinary events required key participants to divide their time between the simulated actions of the TTX and the real-world needs of the Nation.

Following the DHS Homeland Security Exercise and Evaluation Program (HSEEP) guiding principles for exercise events, the SWx TTX was organized and developed around four high-level objectives:

1. Education and Awareness: Raise awareness of the nature of space weather and the challenges related to preparing an effective response;
2. Space Weather Preparedness: Enhance whole-of-government readiness for a multiregional disaster with impact on our nation's critical infrastructure;
3. Information Sharing and Public Messaging: Assess the effectiveness of information and communication protocols and pathways; and
4. Cislunar Space Readiness: Assess the nation's resiliency in the face of increasingly degraded space assets due to a space weather event.

The TTX was designed to provide a low-stress, no-fault environment for generating dialogue about the challenges of preparing for and responding to an impending SWx event. Participants from over thirty government departments and agencies, including senior leaders, interacted at two locations: the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland, and FEMA Region 8 (R8) in Denver, Colorado.

Summary of Results

Overall, the exercise demonstrated the need for better coordination to produce meaningful SWx notifications that describe the potential impacts to critical infrastructure, as well as emphasized the importance of the whole-of-government planning approach for significant SWx events. Feedback forms completed by participants at the end of each module highlighted that 93% of participants agreed or strongly agreed that the exercise enhanced cross-agency communications and coordination, and 100% agreed or strongly agreed that the TTX generated important dialogue.

A key theme emerging from the TTX was the need for space weather information that is readily available and easily understood by a broad audience with clear and actionable particulars. It was also recognized that there is a critical need to develop more robust forecasting capabilities of space weather drivers and effects.

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Chapter 1. Introduction and Background

1.1. Exercise Overview

Exercise Name	Space Weather (SWx) Tabletop Exercise (TTX)
Exercise Dates	8–9 May 2024
Location	Hybrid event hosted at the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland, and at the Federal Emergency Management Agency (FEMA) Region 8 (R8) in Denver, Colorado
Scope	Two-day tabletop exercise (TTX) to improve preparedness and planning for an impending Space Weather event
Objectives	1. Education and Awareness: Raise awareness of the nature of space weather and the challenges related to preparing an effective response 2. Space Weather Preparedness: Enhance whole-of-government readiness for a multiregional disaster with impact on our nation's critical infrastructure 3. Information Sharing and Public Messaging: Assess the effectiveness of information and communication protocols and pathways 4. Cislunar Space Readiness: Assess the nation's resiliency in the face of increasingly degraded space assets due to a space weather event
Threat/Hazard	Impending Space Weather Event
Scenario	The SWx TTX scenario was made up of a series of solar events driving a range of space weather effects on Earth and in near-Earth space. The TTX scenario incorporated solar and geomagnetic activity that was posited to result in multiple hazards.
Sponsors	The National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF) in close partnership with FEMA
Points of Contact	James Spann, Senior Scientist for Space Weather, NOAA NESDIS SWO Jamie Favors, Space Weather Program Director, NASA Heliophysics Division William Murtagh, NOAA Space Weather Prediction Center (SWPC) Program Coordinator

1.2. Background

"Space weather" is the term generally applied to the effects on critical functions, assets, and operations in space and on Earth that arise from naturally occurring solar phenomena. These space weather effects can have potentially global-scale impacts across multiple sectors and aspects of critical infrastructure including electric power, communications, and transportation. Space weather events are driven by solar eruptions, which can be associated with any of three separate phenomena: solar flares, solar energetic particles (SEPs), and coronal mass ejections (CMEs). Solar flares are eruptions of significant x-rays and extreme ultraviolet radiation from the Sun. The effects of these flares, which can temporarily degrade communications signals through Earth's atmosphere, are felt immediately along with initial observation of the flare. Some flares produce elevated levels of SEPs that can arrive at Earth tens of minutes to hours after an eruption and pose a risk to humans and satellites in space as well as passengers and crew in aircraft. CMEs launch billions of tons of solar plasma and energetic particles outward from the Sun. If/when they impact Earth's magnetic field tens of hours to days later, they can create days-long geomagnetic disturbances and enhanced radiation that can affect communications; satellite operations, tracking, and collision avoidance; and the power grid.

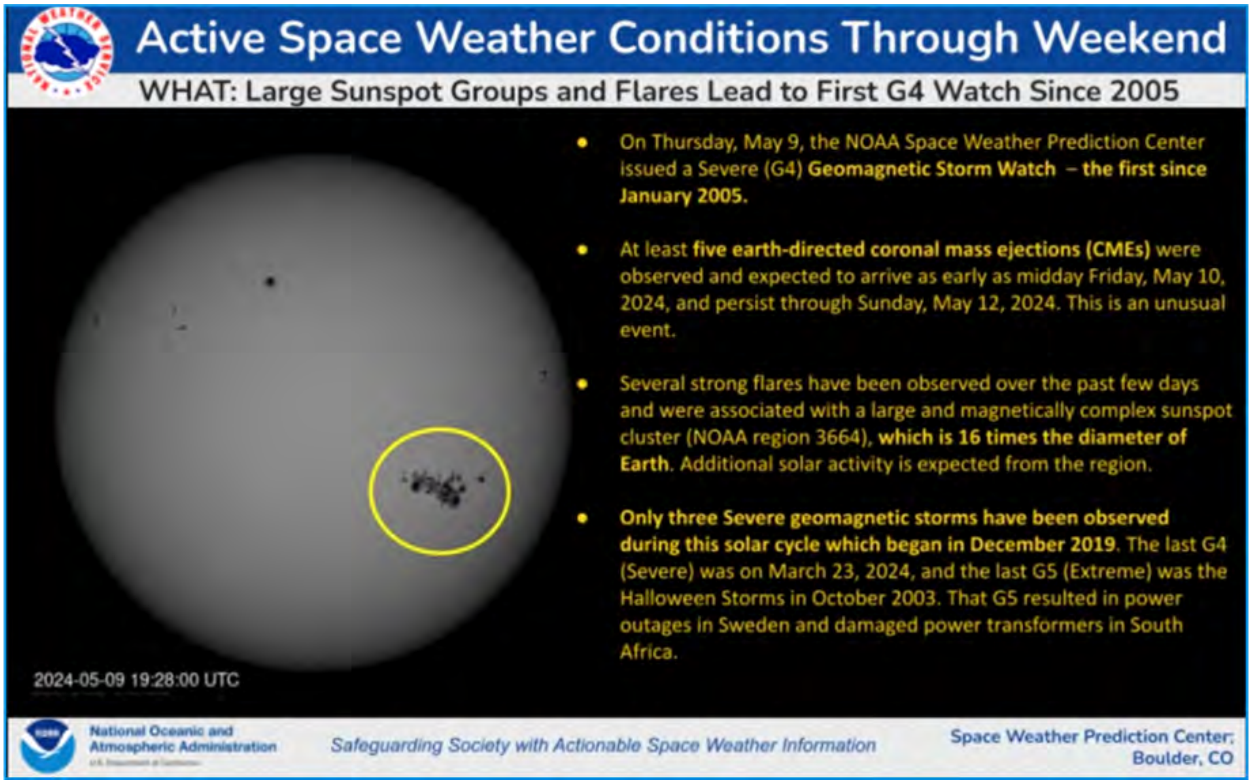


Figure 1-1. On Thursday, 8 May 2024—during the second day of the SWx TTX, NOAA SWPC issued its first Severe Geomagnetic Storm Watch in almost two decades (image from https://www.swpc.noaa.gov/news/swpc-issues-its-first-g4-watch-2005).

In fall 2023, the National Ocean and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Federal Emergency Management Agency (FEMA) to sponsor the first end-to-end Space Weather (SWx) Tabletop Exercise (TTX). This SWx TTX was held on 8–9 May 2024 at the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland, and FEMA Region 8 (R8) in Denver, Colorado, with some additional participants attending remotely. The exercise incorporated federal, state, local and tribal representatives; a conscious decision was made not to include industry and/or international partners for this initial exercise.

It is important to note that, by chance, a significant real-world space weather event—the largest geomagnetic disturbance in more than 20 years (i.e., the “Gannon Storm”)—began at the same time as the SWx TTX. Figure ES-1 provides an overview of the numerous real-word solar eruptions and SWPC watch that took place during the SWx TTX. These extraordinary events required key participants to divide their time between the simulated actions of the TTX and real-world needs.

Chapter 2. Exercise Objectives and Planning

The exercise was planned using a modified version of the Department of Homeland Security's (DHS) Homeland Security Exercise and Evaluation Program (HSEEP). The HSEEP approach allows for tracking and comparison of current capabilities and an assessment of overall preparedness. It also supports the following improvement-related processes:

- Alignment with a common planning structure and nomenclature;
- Collection and analysis of both quantitative and qualitative data; and
- Documentation of baseline data to track ongoing and future improvement planning efforts.

Planning for this event took approximately six months and included hybrid, virtual, and in-person meetings, science-based module "deep dives"; as well as initial, midterm, and final planning conferences. Final preparatory efforts included a slide flip through with presenters and module facilitators; a dry-run; and a technical rehearsal with R8 to ensure communications and video feeds would be able to be shared between the two locations. Scenario and inject development were influenced by analysis of information from previous relevant events and exercises as well as relevant national documents. In addition, reviews of key documents took place, including:

- *National Space Weather Action Plan*[5], NSTC, October 2015
- *National Space Weather Strategy*[6], NSTC, October 2015
- *National Space Weather Strategy and Action Plan*[7], NSTC, March 2019
- *Federal Operating Concept for Impending Space Weather Events*[8], DHS, May 2019
- *Space Weather Strategy and Implementation Plan*[9], NASA Heliophysics, December 2020
- *Space Weather Science and Observation Gap Analysis*[10], NASA Heliophysics, April 2021
- *Space Weather: An Overview of Policy and Select U.S. Government Roles and Responsibilities*[11], Congressional Research Service, March 2022
- *Space Weather Research-to-Operations and Operations-to-Research Framework*[12], NSTC, March 2022
- *White Paper on the Implementation Status of the National Space Weather Strategy and Action Plan*[13], SWORM Subcommittee, January 2023

5 https://www.sworm.gov/publications/2015/swap_final__20151028.pdf
6 https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/final_nationalspaceweatherstrategy_20151028.pdf
7 https://trumpwhitehouse.archives.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf
8 https://www.fema.gov/sites/default/files/2020-07/fema_incident-annex_space-weather.pdf
9 https://science.nasa.gov/wp-content/uploads/2023/05/SpaceWeatherStrategyandImplementationPlan.pdf?emrc=6332a4
10 https://science.nasa.gov/wp-content/uploads/2024/09/gapanalysisreport-full-final-tagged.pdf
11 https://crsreports.congress.gov/product/pdf/R/R46049/6
12 https://bidenwhitehouse.archives.gov/wp-content/uploads/2022/03/03-2022-Space-Weather-R2O2R-Framework.pdf
13 https://www.sworm.gov/publications/2023/2019_nswsap_ip_summary.pdf

1.1 TTX Objectives, Structure and Planning Team

The aim of the SWx TTX was to improve long-term preparedness and planning for impending space weather events. The SWx TTX objectives are provided in Table 2-1 below:

Table 2-1. SWx TTX objectives.

Objective	Objective Statements
1. Assess effectiveness of communication protocols and pathways	1.1. Assess participants' knowledge of their specific roles and responsibilities related to information sharing, public messaging and public alerting
	1.2. Review and enhance agency-specific public information and community messaging plans and procedures for accurate, timely, consistent, and trusted notifications and information
	1.3. Increase participants' understanding of necessary protocols required for interagency planning and operational coordination
	1.4. Review NOAA Space Weather Prediction Center (SWPC) nowcast, forecast, alerts and communications systems for a major space weather event
	1.5. Determine gaps/obstacles to ensuring effective information sharing to enhance the operation and restoration of critical infrastructure at greatest risk of space weather effects
2. Enhance whole-of-government preparedness and response to a multi- regional disaster with widespread impact on the nation's critical infrastructure	2.1. Assess each agency's high-level understanding of preparedness and response plans and protocols to include identifying gaps and gaining clarity on authorities, and roles and responsibilities of key decision-makers
	2.2. Understand national plans and response protocols for potential power outages impacting national security to include readiness, command and control of assets, and augmenting local public safety needs to protect the nation's critical infrastructure
	2.3. Assess each agency's understanding of their roles and responsibilities as outlined in the National Response Framework (NRF), National Incident Management System (NIMS) and FEMA's Federal Operating Concept for Impending Space Weather Events
3. Assess resiliency to increasingly degraded space assets due to a space weather event	3.1. Identify existing capabilities that support the understanding and forecasting of space weather events, and introduce innovative observational platforms and technologies
	3.2. Understand impact of satellite health during all phases of a Space Weather event
	3.3. Understand the impacts of a severe Space Weather event on positioning, navigation, and timing (PNT)
	3.4. Assess current space weather models, modeling techniques and outputs to identify opportunities for improvement
4. Assess response to space weather effects in cislunar space	4.1. Assess and understand the impacts of a Space Weather event on assets in cislunar space
	4.2. Assess NASA's procedures and preparedness for hazards on crewed vehicles in cislunar space and activity on the lunar surface

2.1.1. Exercise Structure

The exercise was a dynamic, facilitated event that was structured in four distinct modules (see Table 2-1). Each module consisted of four components: (1) injects—i.e., new information provided by the facilitators or another subject-matter expert (SME); (2) facilitated questions to prompt discussion with and among participants, (3) decision points and/or actions that would need to be considered; and (4) a module "hotwash" to collect participants' observations verbally along with participant feedback forms.

Table 2-2. Overview of the structure of the SWx TTX.

Module	Title	Topic(s)
0	Introductory Sessions	Education and awareness briefings
1	Solar Drivers	Detection of solar eruptions and immediate geospace impacts
2	Geomagnetic Storm	Impact of first coronal mass ejection (CME) and onset of severe geomagnetic storm
3	Intensifying Storm	Impact of second coronal mass ejection (CME) and escalation to extreme geomagnetic storm
4	Response and Recovery	Aftereffects of geomagnetic storm and transition from response to recovery

Module 0 included briefs from members of the TTX planning team, as well as relevant sponsors and participating government agencies. These presentations were aimed at providing participants with a deeper understanding of how the relevant department and agency preparedness and response plans support a whole-of-government approach to an impending threat. APL SMEs and SWPC staff provided space weather 101 briefs to ensure all participants had a baseline level of knowledge regarding space weather and its potential impacts on Earth.

During Modules 1 through 4 facilitators provided situation updates to the participants to help guide the discussions, and ensure all issues and objectives were explored as thoroughly as possible within time constraints. When appropriate, facilitators also introduced additional subject-matter experts to brief and/or educate the players on key topics.

At the conclusion of each module, a facilitator asked participants to share lessons learned and best practices identified during the discussion. In the participant feedback forms, participants answered a series of Likert scale and free-response questions via Qualtrics. On average, 43 attendees[14] completed each of the various participant feedback forms. A final hotwash (accompanied by a closing feedback form) took place as the exercise wrapped up on Day 2. The final hotwash offered selected participants an additional opportunity to speak freely, offer potential improvements, and share key insights.

Noting a difference in time zones, and acknowledging the need for different levels of information needed at each of the exercise locations, Module 1 was not implemented at the Denver location as the scenario and injects were only applicable to federal participants. However, a modified version of the introductory session content (i.e., educational briefs) was implemented at the Denver location to ensure those participants had sufficient knowledge of space weather events to participant effectively in the TTX. See Appendix D for the agenda at each location.

2.2. Exercise Planning Team

The planning team comprised individuals from several organizations working under the guidance of NOAA, NASA, NSF and FEMA sponsors, along with advisors from the U.S. White House Office of Science and Technology Policy (OSTP) and the United States Air Force (USAF) 557th Weather Wing.

[14] See Appendix C, Participating Organizations.

APL led the planning, execution, and assessment of the TTX and also provided space weather, critical infrastructure, and emergency response subject-matter expertise. Table 2-3 summarizes the roles and contributions of the various organizations on the planning team. See Appendix B for a complete list of individuals who participated on the planning team.

Table 2-3. SWx TTX Planning Team.

Organization	Role
NOAA Office of Space Weather Observations (SWO)	Sponsor. Space weather and space weather prediction subject-matter expertise, TTX direction
NASA Heliophysics Division	Sponsor. Space-related operations subject-matter expertise, TTX direction
NSF Geospace Cluster	Sponsor. Space-related research subject-matter expertise, TTX direction
FEMA Exercise Branch	Sponsor. Preparedness and response operational subject-matter expertise, TTX direction, management and support for coordination with FEMA Region 8 partners
Johns Hopkins Applied Physics Lab (APL)	Organizer, Developer, Evaluation and Host. TTX planning, execution, data collection, evaluation and reporting
NOAA Space Weather Prediction Center (SWPC)	Space weather and space weather prediction subject-matter expertise, TTX direction, management and lead for coordination with federal government partners
White House OSTP	Policy advisory, subject-matter expertise, support for coordination with federal government partners
United States Air Force 557th Weather Wing	Space weather subject-matter expertise, military operational expertise, support for coordination and communication with federal government partners
Cybersecurity and Infrastructure Security Agency (CISA)	Critical infrastructure preparedness and response subject-matter expertise
NASA Moon to Mars Space Weather Analysis Office (M2M)	Space weather subject-matter expertise, NASA spaceflight expertise, support for generation and interpretation of scenario data and Artemis-related injects

2.3. Data Collection and Evaluation

Effective and accurate data collection during the exercise was essential in order to identify meaningful outcomes, including documenting core capability gaps and providing recommendations. Data collectors were responsible for recording information to document discussions and understanding participants' familiarity with the *National Response Framework (NRF)*[15] and the *May 2019 Federal Operating Concept for Impending Space Weather Events*[17]; the latter was considered a key operation concept as it provides guidance to departments and agencies (D/A's) to be used in the development of their operational plans to prepare for, protect against, and mitigate the effects of impending space weather events. Additional data from the exercise were collected via participant feedback forms and through a digital platform.

The primary objective of data collection was to document participant discussions, including how they weighed priorities, options and recommendations. At least four data collectors with varied subject-

[15] https://www.fema.gov/sites/default/files/2020-04/NRF_FINALApproved_2011028.pdf
[17] https://www.fema.gove/sites/default/files/2020-07/fema_incident-annex_space-weather.pdf

matter expertise were assigned per location, per module. They were positioned throughout each location to take detailed discussion notes without interfering with exercise activities. Before the TTX, the data collectors were instructed on how to use the data collection forms. These forms served as a structured format to guide data collection while aligning to the modules, injects, discussion questions, and exercise objectives. The data collectors' documentation was vital to capture the technical, logistical, and operational challenges associated with space weather impacts. The evaluation was based on the review and analysis of TTX discussions. The full Data Collection and Evaluation Plan is available upon request.

2.4 Exercise Locations and Participants

This TTX was unique in that not only was it the first end-to-end space weather TTX, it was also implemented in two different locations in two different time zones (Eastern Time [ET] and Mountain Time [MT]). Federal participants were encouraged to attend in person in Laurel, Maryland, to help simulate the federal discussions and decisions that would take place during an impending space weather event. State. local and tribal participants, along with select representatives from FEMA Region 8 (see Figure 2-1), were encouraged to participate in person in Denver, Colorado, to better replicate regional, state, local and tribal discussions and decisions. FEMA Region 8 (which encompasses Colorado, Utah, Wyoming, Montana, North Dakota, and South Dakota) was specifically selected as a critical partner in this TTX because it was previously designated to work with NOAA SWPC as a center of excellence for space weather prediction. Throughout the exercise R8 served as a local proxy to represent the communication chain and decision-making authorities at the state, local, tribal, and territorial (SLTT) levels.

Figure 2-1. FEMA Region 8 (which encompasses Colorado, Utah, Wyoming, Montana, North Dakota, and South Dakota) has been directed by FEMA to work with NOAA SWPC as a center of excellence for space weather prediction. As such, FEMA Region 8 was selected as a critical partner for this TTX to emulate the communications and decision-making authorities across multiple levels of government necessary for a potential future space weather event.

A wide range of senior-level federal participants from key government D/A's helped to drive critical discussions at the APL site in Laurel, Maryland, over the course of the exercise (Figure 2-2). The executive branch was represented by members of the White House OSTP and the National Security Council (NSC). NOAA was represented by the Assistant Administrator for Satellite and Information Services (NESDIS), Director of the National Weather Service (NWS), Director of the Office of SWx

Observations (SWO), and the SWPC Coordinator. FEMA was represented by the Deputy Administrator and R8 Regional Administrator, as well as key personnel from FEMA's Operations Branch and their Public Information Office. NASA was represented by the Deputy Associate Administrator for Science, the Director of the Heliophysics Division, and the Director of the Space Weather Program. NSF was represented by the Atmospheric and Geospace Sciences Division Director and Coordinator of the Geospace Cluster CISA was represented by leadership from their National Risk Management Office (NRMC).

To provide realistic inputs on the likely response from regional, state, and local leaders, Region 8 TTX participation was led by FEMA R8 staff under the purview of the FEMA Region 8 Deputy Regional Administrator. Additional representatives from the Denver, Colorado, Department of Transportation and Infrastructure (DOTI); the Denver Office of Emergency Management (OEM); the Southern Ute Tribal Emergency Manager; and Denver International Airport also provided key organizational insights. Critical infrastructure and relevant national security concerns and recommendations were reflected by representatives from the Western Area Power Administration (WAPA), the Department of Energy (DOE), the Colorado National Guard, U.S. Northern Command (USNORTHCOM). Their questions and observations guided FEMA Region 8's discussion on the courses of action needed to help support and prioritize energy restoration. The space weather injects and associated scientific explanations were provided by a SWPC representative.

In total, over 35 departments and agencies took part in the exercise, providing realistic inputs on the breadth of the national response. Please see Appendix C for full list of attendees and organizations.

Figure 2-2. The first end-to-end SWx TTX was co-sponsored by NOAA, NASA, NSF, and FEMA and hosted at the Johns Hopkins Applied Physics Laboratory (APL) on 8–9 May 2024. Nearly 80 players and observers represented the federal response on-site at APL in Laurel, Maryland.

Chapter 3. Overview of Modules

Each module included scenario details and associated “injects” specifically designed to address the key TTX objectives outlined in Table 2-1. Upon completion of each module, the players were provided with a participant feedback form to fill out. A final hotwash immediately followed the conclusion of the exercise on Day 2, providing the players with the additional opportunity to speak freely, offer potential improvements, and share key insights. This chapter focuses on the content presented to participants in each of the modules; more details on how the injects, facilitated discussion, hotwashes, and feedback forms aligned with the exercise’s objectives can be found in Appendix A.

3.1. Module 0: Introductory Sessions

Module 0, “Introductory Sessions” focused on educational briefs to help prepare participants to take part in meaningful cross-cutting discussions during the subsequent modules. Module 0 content helped to meet the first two TTX objectives: (1) “Assess effectiveness of communication protocols and pathways,” and (2) “Enhance whole-of-government preparedness and response to a multiregional disaster with widespread impact on the nation’s critical infrastructure.”

The briefs provided to participants during this session included the basics of space weather, a primer on NOAA SWPC mission and operations, an overview of NASA actions to protect Artemis astronauts, a review of key FEMA guidance documents dictating roles and responsibilities during disasters, and a summary of specific federal guidance and doctrine used to help prepare for the impacts of a space weather event. This session focused on ensuring that all participants had a baseline of both science and operational knowledge in order to contribute to the facilitated discussions for Modules 1 through 4.

As previously mentioned, two locations were utilized for the exercise in order explore challenges to response coordination across different locations and time zones. As such, the Module 0 content was presented to participants at APL (federal) and at FEMA R8 (regional, state, local, tribal) asynchronously, as can be seen on the agendas for the respective locations presented in Appendix D.

When parallel activities were taking place in at the federal level at APL, participants at R8 convened for introductory exercise information. Following these opening activities, select educational briefs that mirrored those given at the federal level were given in Denver, Colorado, including the basics of space weather, NOAA SWPC capabilities and processes, and FEMA’s Federal Operating Concept for US response and recovery following a space weather event. Note that the overview of NASA actions to protect Artemis astronauts and review of key FEMA guidance documents dictating roles and responsibilities during disasters were not provided for the R8 participants.

3.2. Module 1: Solar Drivers

Module One, “Solar Drivers,” addressed subobjectives across all four of the TTX objectives. This included all aspects of Objective 1 (“Assess effectiveness of communication protocols and pathways”), Objective 2 (“Enhance whole-of-government preparedness and response to a multiregional disaster with widespread impact on the nation's critical infrastructure"), and Objective 4 ("Assess response to space weather effects in cislunar space"), as well as subobjective 3.4 ("Assess current space weather models, modeling techniques and outputs to identify opportunities for improvement").

The injects and discussions during Module 1, which were only presented to the federal participants at APL, were focused on: comprehension of SWPC monitoring, tracking, and notifications; critical information during the onset of solar activity with potential impacts; notification pathways and processes; and federal coordination and preparation.

3.2.1. Module 1: Scenario Details

Module 1 began on scenario date 26 January 2028 at 3:00 p.m. Eastern Time (ET) with the facilitator introducing the TTX scenario by noting that SWPC had been tracking an evolving active solar region for the previous seven days. By the start of the scenario, the active region had rotated into a location where, if it erupted, it would most likely result in space weather impacts on Earth. Also, NASA's Artemis-IV mission was in progress with two astronauts in the Orion command module in orbit around the Moon and two astronauts having just landed in the lunar module on the Moon's surface. The module spanned 46 hours in scenario time and included four injects during which a variety of information was provided to TTX participants, including simulated SWPC notifications, to prompt discussions.

Inject 1.1 was introduced as simulated NOAA SWPC notifications that the solar active region had erupted in an M7-class solar flare. This resulted in an R2+ Alert and S1+ Warning from NOAA SWPC; USAF separately reported a minor solar radio burst. There were no notable immediate impacts from this eruption.

For Inject 1.2, additional simulated NOAA SWPC notifications were provided depicting a time jump of 11 hours later with increased SEP levels (S2 Alert) and a halo CME was confirmed (G3 Watch).

During Inject 1.3 the second, the facilitator stated that a much more intense solar flare erupted with immediate impacts, plus potential harmful SEPs and confirmation of a second "halo" (i.e., Earthward-directed) CME (see Figure 3-1 for exemplar Situation Report—or "SitRep"—developed by APL for participants' reference).

Inject 1.3a simulation revealed a larger second eruption with an X15.3-class flare from the same active region 1 day and 19 hours after the initial eruption in Inject 1.1. This flare, with subsequent SEP observations and confirmation of a second CME, triggered multiple new notifications from NOAA SWPC: R4 Alert, S3 Alert, G4+ Watch. Figure 3-2 is an example of "Situation Report" slide presented to TTX participants to provide snapshots of the NOAA SWPC notification status and analyses, underlying data, timelines, and potential impacts for each scenario inject.

In Inject 1.3b, the initial space weather effects on geospace were described from the second larger flare began; these included reports of impacts on high-frequency (HF) communications; satellite communications and very-high-frequency (VHF) radio operations; and GNSS/GPS positioning, navigation, and timing services.

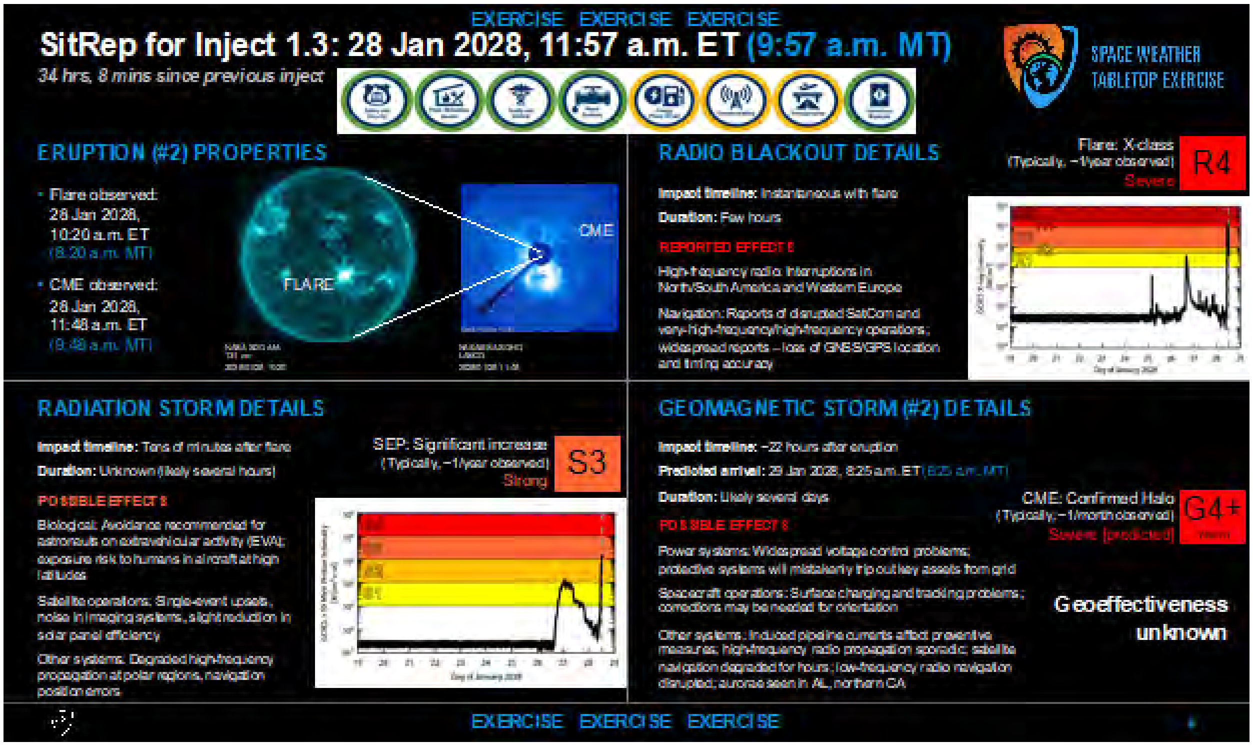
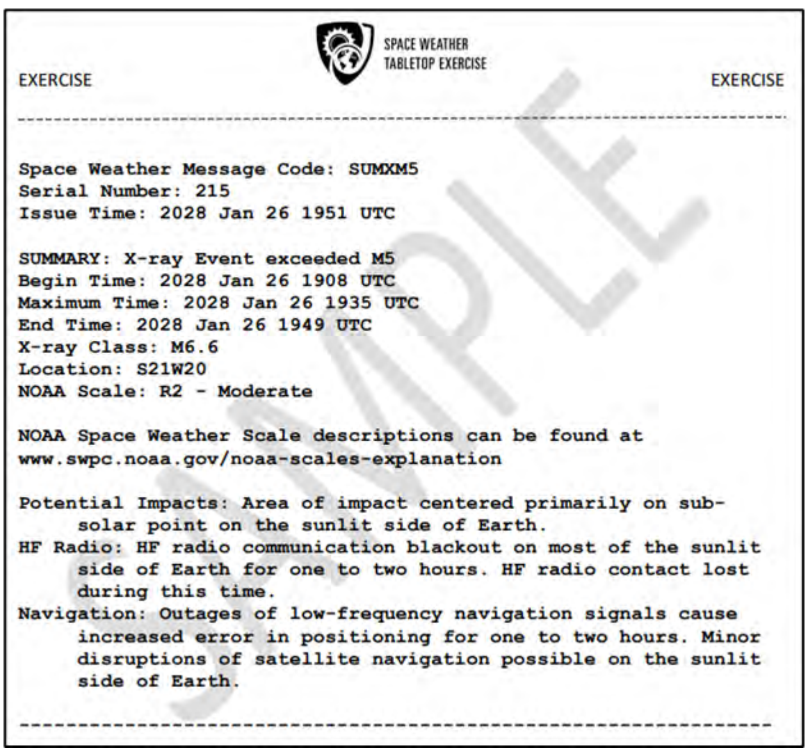


Figure 3-1. Situation Report (SitRep) example provided to participants through the TTX for reference purposes. Additional SitRep slides can be found in Appendix G.



EXERCISE SPACE WEATHER TABLETOP EXERCISE EXERCISE

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Space Weather Message Code: SUMXM5
Serial Number: 215
Issue Time: 2028 Jan 26 1951 UTC

SUMMARY: X-ray Event exceeded M5
Begin Time: 2028 Jan 26 1908 UTC
Maximum Time: 2028 Jan 26 1935 UTC
End Time: 2028 Jan 26 1949 UTC
X-ray Class: M6.6
Location: S21W20
NOAA Scale: R2 - Moderate

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact centered primarily on sub-
     solar point on the sunlit side of Earth.
HF Radio: HF radio communication blackout on most of the sunlit
     side of Earth for one to two hours. HF radio contact lost
     during this time.
Navigation: Outages of low-frequency navigation signals cause
     increased error in positioning for one to two hours. Minor
     disruptions of satellite navigation possible on the sunlit
     side of Earth.
```


Figure 3-2. EXERCISE ONLY. Example synthetic SWPC notification used for the SWx TTX.

Inject 1.4 focused on a simulated miscommunication within the U.S. Government during which NOAA SWPC and USAF agreed that there has been a severe solar flare and radio burst, but another federal department/agency reported contradictory information, suggesting that the radio and communications disruptions were possibly the result of a cyberattack.

3.2.2. Module 1: Summary of Key Discussions

Module 1 provided participants with additional space weather science-based information on the simulated initial detection of a solar storm, as well as critical introductory information with only federal level players participating. This simulated how the information would be initially received, understood and shared at the federal level given the level of alerts. Opportunity was also taken during this module to help participants acquire additional knowledge regarding space weather phenomena in preparation for the follow-on modules.

Upon distribution of the first SWPC alert, participants offered multiple suggestions for improvement to the SWPC notifications with a focus on providing actionable information to help notification recipients better understand the potential impact to communities and infrastructure. The simulated notifications that were provided to participants were modeled after SWPC's current notifications, which were highly scientific in nature. See Figure 3-2 for a simulated notification used during the TTX.

To help participants better understand some of the space weather information and potential impacts, members from APL planning team developed a Situation Report (SitRep) to accompany each of the injects. The SitReps (see Figure 3-1) were introduced at this time, and then throughout the remainder of the TTX. They included helpful science-based and more understandable information for participants and aligned with the scenario information being presented.

Module 1 discussions also highlighted key needs in predictive capabilities, situational awareness, impacts attribution and overall communications. First, the lack of a truly comprehensive space weather observatory system (both space- and ground-based) was noted. Second, the absence of clearer, more effective communications within the government, particularly concerning how many space weather impacts might be attributable to other causes (e.g., cyberattacks, etc.). Additionally, participants noted that identification of a trusted public relations officer would be necessary to ensure effective communications to the public.

Extensive discussion took place regarding opportunities to improve the current SWPC notifications. Representatives from FEMA defined what "actionable information" the emergency management community would be looking for. They also described the need for information that would assist them with consequence management efforts such as potential for power outages and degradation to communications and GPS, as well as the location of where the impact may occur. SWPC discussed the uncertainty of the information, but FEMA's operational participants overwhelming agreed that they would "rather have more information with less certainty, then less information with more certainty."

In summary, the discussions concerning Module 1 focused predominantly around effective communications, both within the government at all levels and also to the public, and increased assessment, prediction, and awareness of actual impacts of space weather.

3.3. Module 2: Geomagnetic Storm

Module 2, "Geomagnetic Storm," represented the start of the synchronized activity between the federal participants at APL and the regional, state, and local participants at FEMA R8 in Denver. Module 2 addressed all of the subobjectives for three of the four TTX objectives: Objective 1 ("Assess effectiveness of communication protocols and pathways"), Objective 2 ("Enhance whole-of-government preparedness and response to a multiregional disaster with widespread impact on the nation's critical infrastructure"), and Objective 3 ("Assess resiliency to increasingly degraded space assets due to a space weather event").

The injects and discussions during Module 2 were focused on understanding the impact of the rapidly evolving information, as well as its consistency and timeliness; notification pathways and processes, and federal coordination with FEMA Region 8.

3.3.1. Module 2: Scenario Details

Module 2 began on scenario date 29 January 2028 at 2:38 p.m. ET with the facilitator providing participants with a simulated space weather outlook report from FEMA's National Watch Center. The module spanned only six hours in scenario time but included six injects to prompt discussion surrounding radiation effects, degraded communications, and GPS interruptions.

The first inject for this module was a simulated information inject to advise participants of a new G3 Alert notification from NOAA SWPC as the first CME (from the first eruption) impacted geospace. Discussion surrounded familiarity with the FEMA daily operations brief and if the relevant departments/agencies had conducted vulnerability assessments as directed in the Federal Operating Concept for Impending Space Weather Events.

Inject 2.2 noted the geospace effects intensifying with new S4 Alert and G4 Alert notifications from NOAA SWPC. Radiation effects included an anomaly to an undisclosed surveillance asset at the federal level, while FEMA R8 received reports that residents' internet services were impacted by damage to a commercial satellite. Additional consideration was given to radiation effects associated with the aviation sector, including whether operations at the Denver National Airport would be impacted by concerns about high-altitude radiation.

Inject 2.3 addressed impacts to communications in geospace, including widespread outages of major telecommunication systems as well as reports of intensifying satellite and HF communication disruptions and outages. Meanwhile, R8 officials were informed that local officials in Montana and North Dakota had lost HF communications.

Inject 2.4 focused on coordinating public messaging and addressing miscommunication as various government officials presented contradictory information to the public via social media.

Inject 2.5 presented initial impacts to the power grid as power was redirected from Region 8 to support FEMA Region 10 following reports of power disruptions in the Pacific Northwest. Participants talked through the procedures for regional redistribution of electricity during a geomagnetic storm and whether there is a requirement to obtain approval from regional authorities prior to decisions being made regarding redistribution.

In Inject 2.6, observations of the second incoming CME from the Sun-Earth Lagrange Point 1 (L1) provided only ~30 minutes of lead time and reveal that it has a very large (80–90 nT) total magnetic field with a strong southward orientation ($B_Z = -50$ nT) suggesting the potential for very high "geoeffectiveness"—i.e., to trigger severe space weather impacts. Significant discussion was dedicated to the topic of whether the thirty minutes of notice for the imminent arrival of a CME was sufficient and the potential benefit/need of any advance, even if imprecise, warning. Discussion included what actionable steps Region 8 should advise the public to take in the following hours and days before anticipated degradation of communication systems and infrastructure.

3.3.2. Module 2: Summary of Key Discussions

The discussions during Module 2 were centered around the initial effects and the resulting impact of the first CME and the subsequent "severe" (G4) geomagnetic storm. Initial discussions in the module included issues arising from this initial geomagnetic storm, such as the radiation concerns to orbital assets, as well as the aviation sector and communications disruptions. These discussions included NASA participants recognizing that they were unsure who their public information counterparts and points of contact were at other federal agencies, such as NOAA and FEMA for a space weather event. NOAA and NASA continued discussion regarding responsible parties for monitoring impacts to spacecraft with an important question surfacing regarding "who is communicating publicly about the potential risk to astronauts during a significant space weather event at the Moon?"

The Module 2 facilitator encouraged discussion regarding the guidance found in the *Federal Operating Concept for Impending Space Weather Events*[16], which directs that "each [department/agency] will evaluate vulnerabilities to infrastructure and operations—including operational continuity and across the 16 critical infrastructure sectors—and assess their potential consequences to" achieving their mission. Several participants suggested that more guidance may be needed on "how" to conduct this vulnerability assessment given their unfamiliarity with space weather phenomena and the resulting impact to critical infrastructure systems.

There was discussion at both the federal level and at the FEMA R8 location regarding the issue of miscommunication by official government channels to the public with a specific emphasis on a "trusted one voice." Participants also voiced their concern over the fact that there is vast public unfamiliarity with SWPC and what they do, which may contribute to public distrust if a SWPC SME was to serve as the SME for public information. In response, representatives from SWPC outlined three outcomes from a March 2022 senior officials exercise on space weather: (1) the need for clear lines of communication in government, (2) communications to key critical infrastructure (e.g., energy, transportation) is critical and (3) the need for coordination with PIOs and NOAA's NWS to establish processes to communicate with the media, e.g., in press releases and at conferences. A component of this discussion also concerned terms used by SWPC in their notifications, such as "watch" and "warning." To avoid confusion, it was recommended that to the extent possible, terms such as these should be consistent with those used by

[16] https://www.fema.gov/sites/default/files/2020-07/fema_incident-annex_space-weather.pdf

the NWS for other natural disasters/hazards. Agency PIOs also recommended using plain language whenever possible—for example, similar to how the NWS issues notifications by adding the impact type to the name of the notification (e.g., flash flood warning, radio disruption).

At the Laurel, Maryland, location, conversations during this module also briefly touched on national security concerns regarding the potential threat to some key on-orbit assets. It was recognized that even though there are established communication channels between the intelligence community, FEMA, and NOAA for events other than space weather, more discussion is needed regarding this in a classified setting.

3.4. Module 3: Intensifying Storm

Module 3, "Intensifying Storm," addressed objectives across all four of the TTX objectives, however particular focus was placed on Objective 1 ("Assess effectiveness of communication protocols and pathways"), and Objective 2 ("Enhance whole-of-government preparedness and response to a multiregional disaster with widespread impact on the nation's critical infrastructure").

Much of the focus of Module 3 was on coordination and communication to support the first responders and public safety communities in the immediate aftermath from the impact of the 2nd CME. It was agreed by participants that the near-term priorities would be assessing and mitigating power grid failures, restoring essential services and ensuring public safety. Discussions included information sharing and decision-making needs to support the ongoing and evolving impact to key critical infrastructure stakeholders such as communications, energy, and transportation sectors.

3.4.1. Module 3: Scenario Details

Module 3 began on scenario date 29 January 2028 at 9:14 p.m. ET as the second CME was about to impact geospace. The module spanned approximately eleven hours in scenario time and included five injects to prompt discussion surrounding the intensifying space weather effects across multiple sectors.

Inject 3.1 opened with an update that the second CME had hit Earth's magnetosphere and triggered an extreme geomagnetic storm (G5 Alert from SWPC) with SEP intensities peaking during the first ~12 hours (S4 Alert from SWPC). There were conversations regarding the overwhelming amount of information that would be expected to follow as numerous impacts on critical infrastructure were anticipated—explicitly in R8. Targeted questions focused on the timelines for emergency declarations and/or Defense Support of Civil Authorities initial actions. Participants considered the processes for communications among the federal agencies and state and local authorities and what information each group felt was necessary and should be prioritized.

Injects 3.2 and 3.3 focused on the increasing negative impacts on communication capabilities and satellite infrastructure, largely mirroring the content in Module 2 but with more severe effects to include discussion about the status of backup generators for cellular providers. Participants from FEMA explained the role of IPAWS (Integrated Public Alert & Warning System) as several participating agencies were not familiar with their role and responsibilities. At this point, it was noted that GPS accuracy (both spatial and temporal) and HF, VHF, and cellular communications would be significantly degraded, while increased thermospheric drag would lead to loss of accuracy and knowledge in the North American Aerospace Defense Command (NORAD) satellite catalog.

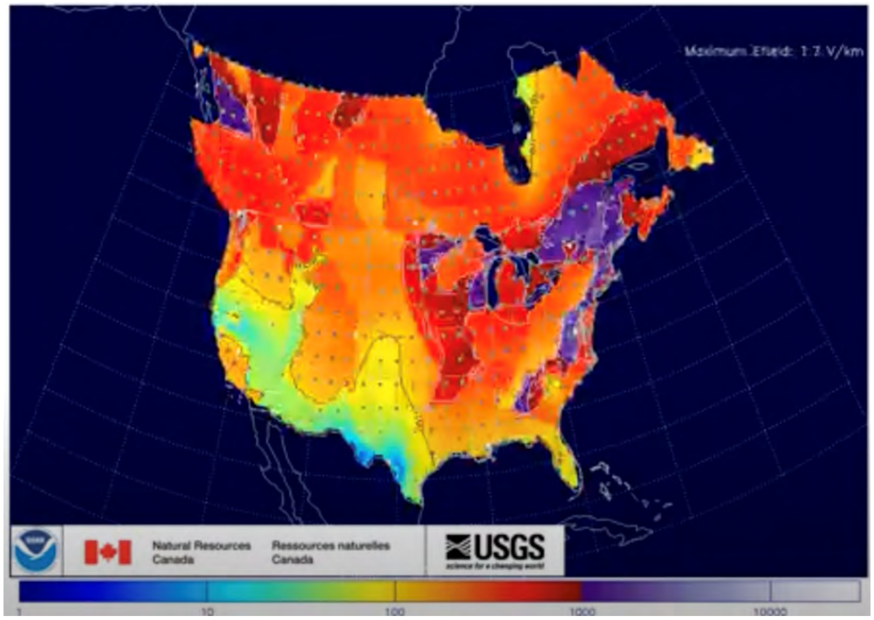

Figure 3-3. EXERCISE ONLY. Simulated NOAA SWPC "US Canada 1D Geoelectric Field Model" product used in Inject 3.4 to show the potential areas where an extreme geomagnetic storm could give rise to geomagnetically induced currents (GICs), which are a concern for power grid operators.

Inject 3.4 mirrored the power grid effects addressed in Module 2 but with more severe impacts. Here the G5 storm triggered geomagnetically induced currents (GICs) that caused a power outage across the greater Denver Metropolitan Area. A prolonged outage was expected and with that a dependence on backup systems, generators, fuel, as well as major disruptions to supply chains. Participants anticipated that 911 call centers, and medical and health care facilities would quickly be overwhelmed and discussion addressed risk factors related to safety and security. Representatives at both locations described their initial steps would be to assess the damage to transformers and substations, and then determine what actions might be needed to prevent total grid failure. Energy partners also emphasized the important of working with the Federal Energy Regulatory Commission (FERC) and Nuclear Energy Regulatory Commission (NERC) to ensure stable systems.

Other topics included in the exchange ranged from the potential impacts to other systems, federal management of the crisis response, resource allocation prioritization, and preparation for the high potential of growing public concern. Figure 3-3 presents a simulated NOAA SWPC "US Canada 1D Geoelectric Field Model" product showing the predicted geoelectric field across North America.

Finally, Inject 3.5 provided participants with a simulated intentional social media miscommunication, which prompted a discussion again around the need for "trusted voices" and accurate information.

3.4.2. Module 3: Summary of Key Discussions

The TTX attempted to coordinate the two groups at APL in Laurel, Maryland, and at R8 in Denver, Colorado, in real time as part of the exercise, but found that there were challenges in communications between the two exercise locations. In an attempt to improve coordination and communication, participants at APL provided out briefs from the federal level to R8. It was noted by participants that these briefings were extremely useful and showed how information flow was a critical element of coordinating the federal and local responses.

Discussion in Module 3 also considered the potential impact to critical infrastructure and the management of resources across all levels of government, which consequently spurred deliberations on the need for an emergency declaration and the policy threshold and limitations surrounding declarations. NOAA acknowledged that for a scenario such as this, where “multiple CMEs are coming and it is known there will be an impact, we can’t do much...the hope is that maybe in the next decade or so, we will have an L5 capability to see threats like this [differently] and be able to track them and have better information about the CMEs.” This was in reference to a NASA and NOAA partnership with the European Space Agency (ESA) to outfit a future mission, called Vigil, which is planned to launch in 2031 and will use remote sensing instruments to monitor the evolution of CMEs from a vantage point off the Sun-Earth line. This platform will provide complementary observations to those from Earth and the Sun-Earth L1 point, which can provide better information and inform predictions on when CMEs are expected to arrive at Earth. It was generally agreed by participants that having more information earlier would greatly impact our preparedness and resource planning capabilities.

Attention was brought to the fact there can be confusion regarding the expectant power outage as different segments of the grid will respond differently to induced currents and dependencies on the orientation of the magnetic field and direction of lines. In R8, the Denver DOTI described the potential technical challenges involved in safely reducing, then resuming the Denver Light Rail system, and how to prevent passengers being stranded on stalled trains. Concerns about overwhelmed emergency services and hospital centers were also explored.

Following the inject regarding an increase in GPS degradation, the R8 discussion shifted to contingencies to ensure continuity in communications with the public, adjusting or amending declarations as needed, and determining what critical decisions may be needed and what to expect regarding the impact of GPS degradation. Anticipated prolonged power outages in the Denver metro area prompted debate on how to proactively address public safety concerns. When R8 participants were notified that misinformation about the cause of outages was emerging, discussions focused again on the need for coordination of national and local messaging, specifically regarding the importance of leveraging pre-scripted messages and ongoing joint information coordination.

A critical finding that arose from Module 3 was that processing a significant amount of science-based information during times of high stress, may slow responses at all levels. The start of Module 3—i.e., notifying participants of the arrival of the 2nd CME at Earth (Inject 3.1) —marked a significant increase in the information flow. Federal participants in Laurel, Maryland, and at the local level in R8 had many questions and requested clarification, specifically requesting input from the space weather experts that were participating at both locations. Data collectors and facilitators observed that the amount of information available began to overwhelm TTX participants, and it was acknowledged that this would likely also occur during an actual space weather event of this magnitude.

The final major discussion point in this module circled back to the importance of consistent and frequent communications with the public, as it will be key to minimizing the influence of misinformation and miscommunication. Participants acknowledged that public messaging scripts and templates are needed, similar to what is used for other hazard events. R8 stated that they would be looking to FEMA for pre-scripted messages, however it was acknowledged that given this is a new hazard type, pre-scripted messages do not yet exist and need to be draft in coordination with lead agency PIOs and space weather SMEs.

3.5. Module 4: Response and Recovery

Module 4, "Response and Recovery," addressed subobjectives across three of the four TTX objectives. This included all aspects of Objective 2 ("Enhance whole-of-government preparedness and response to a multiregional disaster with widespread impact on the nation's critical infrastructure") and Objective 4 ("Assess response to space weather effects in cislunar space," as well as the following subobjectives:

The injects and discussions during Module 4 focused on considerations and key decisions needed in the days to weeks following the impact of the second CME as efforts transitioned from response to recovery. Specific areas addressed included damage assessments, short- and long-term recovery actions, and impacts on planning for the next potential space weather event.

3.5.1 Module 4: Scenario Details

Module 4, Response and Recovery, began on scenario date 30 January 2028 at 8:00 a.m. ET and spanned approximately four days in scenario time. This included four injects to prompt discussion surrounding the transition from response to recovery.

Inject 4.1 presented a simulated Senior Leadership Brief by FEMA (see Figure 3-4 below) to demonstrate what information FEMA Operations would be tracking, and depicted key information about how the Lifelines would be used for resource planning.

Inject 4.2 focused on issues with air traffic and ongoing power outages. It was reported that people were stranded in various transportation facilities, and Denver International Airport was non-operational. There were rumors that a major transformer was down, and the local news was showing videos of a damaged transformer. Discussion focused on what processes are used to guide decisions regarding priorities and resources; the status of the National Response Coordination Center (NRCC), the Regional Response Coordination Center (RRCC), and state and local Emergency Operations Centers (EOCs); and major modes of communication.

At the federal level, Inject 4.3 focused on issues surrounding the return of the Artemis-IV astronauts through a very enhanced outer radiation belt despite null solar radiation levels. In R8, Inject 4.3 focused on the discovery of physical damage to a large transformer supporting Denver International Airport and discussion of the need for resilient communications and the redirection of power to R10 that occurred earlier in the TTX.

Inject 4.4—the final inject of the exercise—focused on an unavoidable collision of two satellites in low Earth orbit (LEO). During this inject, it was relayed to the federal participants that NORAD regained satellite catalog accuracy and discovered an impending collision with a commercial satellite that was rendered inoperable earlier in the storm. In R8, Inject 4.4 focused on returning to normalcy with discussions considering which problems would most likely linger, what transitioning to recovery might look like, which EOCs and/or response centers were still activated, and long-term critical infrastructure damage.

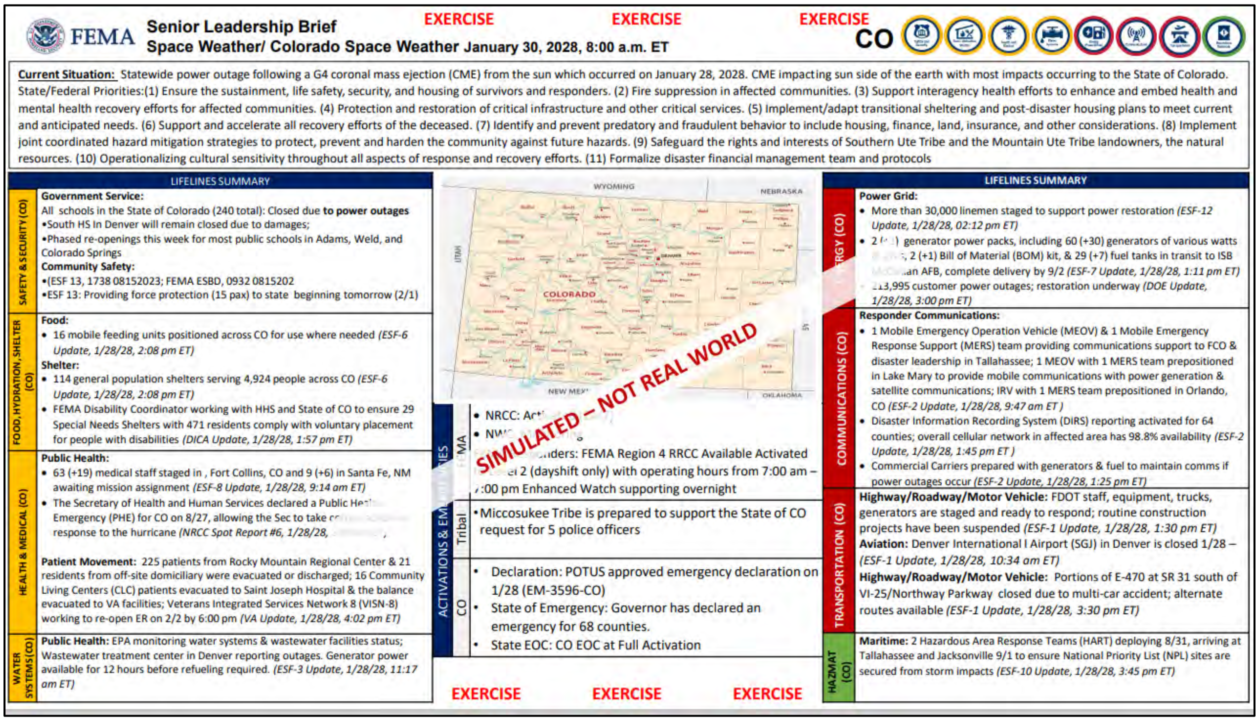

Figure 3-4. Simulated FEMA Senior Leader Brief. A full-size version can be found in Appendix G.

3.5.1. Module 4: Summary of Key Discussions

Module 4 focused on issues and key decisions needed 3+ days post-event and included considerations during the transition from response to recovery. As previously described, FEMA provided a simulated senior leaders' brief to demonstrate what information FEMA Operations would be tracking, and depicted key information about how the Lifelines would be used for resource planning. Since not all federal participants were familiar with this senior leader brief and its purpose, a representative from the FEMA Operations Branch took the opportunity to educate the federal players, which prompted very valuable discussion as to how the information was used to ensure situational awareness and informed decision-making at a high level. Of note was the acknowledgment that much of this critical information comes from the local level to the state emergency management agencies, and is then provided to FEMA via the RRCC and thereby underpinning the critical information sharing that must take place at all levels of government.

Federal participants in Laurel, Maryland, then discussed the recovery of satellite tracking capability in the aftermath of the geomagnetic storm, which touched on the topic of whether industry can/must report damage to on-orbit commercial assets. The discussion expanded to touch on the potential national security concerns regarding orbital debris in the result of collisions and the subsequent impact on broad swaths of on-orbit assets. Their concerns ranged from the sharing of information with the

U.S. Space Command (SPACECOM), the Space Commerce Operations Center, as well as with international partners.

Initial R8 discussion in Module 4 focused on determining what the local priorities would be and how the state could support response efforts given the ongoing power concerns and communication challenges in the Denver metro area. Cancellation of all flights coming out of Denver International Airport shifted discussion to how decisions regarding resource prioritization would be made. Prior exchanges about R8 supporting power to other regions via redirection of the western interconnect (from Module 2) were revisited, but now in the context of the need for R8 to restore their own power given that the transformer supporting the airport had been damaged.

Ongoing discussion in R8 focused on local issues including power restoration and discussed the needed information exchange between local and federal partners. Attendees were advised by WAPA that a physical inspection of key power transformers was probably needed to assess potential damage. Finally, R8 wrapped up the exercise with a conversation about what operations would look like in an effort to return to normal. This included considerations for transitioning into recovery mode, balancing needs across infrastructure and the standing down of federal state and local EOCs.

Chapter 4. Results

This chapter summarizes, at a high level, the results, recommendations, and lessons learned produced by the exercise. These items were identified through analysis of the data collected, including observations made by data collectors, the written comments made by participants, and the information reported in participant feedback forms. These data were distilled and traced back to the exercise objectives for analysis purposes.

The data collected during the facilitated discussions throughout Modules 1 through 4, were assessed and resulted in key takeaways that summarized the event and identified gaps and associated recommendations. Overall, the exercise demonstrated the **need for better coordination to produce meaningful SWx notifications** that describe the potential **impacts to critical infrastructure**, as well as emphasized **the importance of the whole-of-government planning** approach for significant SWx events. Feedback forms were also completed at the end of each module and highlighted that 93% of participants agreed or strongly agreed that the exercise enhanced cross-agency communications and coordination, and 100% agreed or strongly agreed that the TTX generated important dialogue (see Appendix G for complete results from the participant feedback forms).

4.1. Findings

Outcomes that emerged from the data collected over the two-day TTX from both locations are provided below along with potential recommendations to remedy these gaps. It should be noted that many of these successes and areas for improvement were underscored as lessons learned in review of the real-life events that occurred as a result of the Gannon Storm in May 2024.

1. **There is a need for better coordination to produce meaningful SWx notifications that are useful for decision making and clearly describe the potential impacts to critical infrastructure.**

A key theme from the TTX was the need for space weather information that is readily available and easily understood and clearly showing the potential impact to communities and infrastructure. TTX participants without space weather expertise struggled to translate the scientific information and determine what the specific impacts would be on Earth. Participants suggested that visual depictions of the potential sequence of events could be helpful, as well as recognized the value of including subject-matter experts during senior leader briefs, as well as in the development of public messaging. They also acknowledged the need for more clarity when transitioning from a watch to a warning. Specifically, when information was needed to determine at what level of severity does a SWx notification indicate the need to begin coordinating public information.

Important caveats for space weather messaging include:

- Without clear notification thresholds, there is the risk of “notification fatigue” for both government agencies and the general public;
- Success often means there is a perception that “nothing happened” because notifications were made in a timely manner and appropriate actions were taken;

- Federal, state and local public communication plans should be aligned as much as possible for consistent and customized public engagement of what steps to take and when; and
- Public communications should acknowledge the uncertainty in prediction and lead time given the complexities of space weather science and limitations of early warning systems.

This was highlighted as a key area for almost immediate improvement as NOAA SWPC and FEMA coordinated in the days during and immediately following the TTX to update the National Watch Center (NWC) Daily Operations Brief to focus on impacts instead of causes/drivers in preparation for the Gannon Storm.

2. A whole-of-government planning approach will be critical to preparing for and responding to significant SWx events.

TTX participants came to understand that the federal government, in coordination with SLTT partners, must better coordinate during a space weather event including designating NOAA as the lead agency for disseminating information. They discussed information requirements regarding who generates what notifications, and who receives the notifications and through what communication modes and recommended developing templates for pre-scripted public messaging content based on thresholds, and determining “trusted voices” for public messaging.

Currently not all relevant government institutions address the impacts in their Continuity of Operations (COOP) planning documents and even those organizations that include space weather in their documents fail to provide clarity regarding how and at what point a COOP would be activated for this type of event.

TTX discussions made clear that the US lacks a detailed interagency SWx response plan that identifies the final decision-maker(s) for resource acquisition, prioritization, and allocation. Participants agreed that policies must be strengthened to ensure all government partners with roles and responsibilities involving SWx preparedness have appropriate resources. The May 2019 document, *Federal Operating Concept for Impending Space Weather Events*[17] is an excellent resource. Unfortunately, very few government organizations have followed the recommendation in the document which called on them to evaluate their infrastructure and operational vulnerabilities to space weather events. The document should be updated to clearly specify roles and responsibilities, as well as to provide guidance to D/A’s on how to implement the recommendations and directives found withing this document.

Participants also acknowledged a need to improve communication channels with a clear decision tree for when information is shared with senior leaders, including establishing interagency calls when an impact likelihood threshold is reached

Additionally, more federal guidance, resources, complimented by space weather expertise are needed to help state and local public safety entities develop SWx emergency operations plans. All FEMA Regions and SLTT partners should be encouraged to add a Space Weather annex to their emergency management plans. Beyond better space weather forecasting, there is also a lack of current research

[17] https://www.fema.gov/sites/default/files/2020-07/fema_incident-annex_space-weather.pdf

which would better facilitate the understanding of the risks to and potential impacts on satellite operations and key vulnerable systems, specifically in the critical infrastructure sectors. The government should provide technical guidance for departments and agencies on how to identify vulnerabilities, conduct vulnerability assessments and develop mitigation plans.

Interagency organization supported successful response to the Gannon Storm as FEMA and SWPC established coordination calls during the incident to garner real-time updates from SWx SMEs. The government-wide and international extent of such coordination was paramount as NOAA products were redistributed by the Department of State to over 260 consulates and embassies around the world during the real-life event.

3. The nation must better understand its current technology limitations and determine a path to improve space weather forecasting capabilities.

Interactions and discussion during the TTX highlighted a critical need to develop more robust capabilities in space weather forecasting of potential eruptions, as well as the arrival time of CMEs and their associated phenomena (shocks and particles). Despite the current operational assets from NOAA, applied research and scientific observations from NASA, and research and observational infrastructure from NSF, participants agreed that deploying more satellites to monitor space weather would significantly improve our ability to predict events, enhance real-time data collection to improve forecasting models, and provide earlier warnings. Emergency response organizations also indicated that they require more specific information on when solar eruptions will occur, as well as the arrival time and geoeffectiveness of CMEs to effectively prepare and respond to the associated impacts.

Importantly, participants identified a capability gap for predicting N-S direction of interplanetary magnetic field and highlighted the need for modeling advances; new imaging technology; solar sail development; solar polar mission concepts; comprehensive ionosphere, thermosphere, and radiation environment monitors; etc. The US, along with trusted international partners, must address the significant observational gaps via new ground- and space-based sources.

This was another area flagged specifically during the real-life preparations and response to the Gannon Storm. NOAA SPWC identified that even though advance warning and good communication was able to successfully mitigate many impacts of that storm, missing science and operational capabilities inhibit their ability to accurately forecast the timing and intensity of a geomagnetic storm.

4. It is time to develop and implement a national SWx education and awareness campaign.

Space weather is a complex subject and its potential impacts are not well understood outside of NOAA and NASA. There is a strong need to educate not only government and agency staff but the general public as well. The May 2024 SWx TTX was a good first step toward educating emergency management and public safety agencies across the nation regarding the concept of SWx and its range of potential impacts. This type of educational outreach must continue as well as efforts to improve awareness of SWx impacts for critical infrastructure stakeholders and owners.

Because space weather is not a common topic for the general public, it is critical that the "trusted voices of the community" (e.g., fire department, sheriffs, local government, religious leaders, etc.) be provided training to better communicate SWx effects to their communities. A good start would include the promotion of the FEMA Emergency Management Institute's "Preparing the Nation for Space Weather Events" (IS-66)[18] course. Additionally, government departments and agencies' Emergency Support Function (ESF) 15 (External Affairs and Incident Communication Entities) should work with the NOAA SWPC and FEMA to develop messaging and coordinate to develop and enhance educational awareness campaigns.

5. **Whole-of-government exercises are an effective tool for preparing the nation for scientifically complex threats.**

The May 2024 TTX served as an exemplar event demonstrating the benefits of bringing together a wide range of government departments and agencies when confronting the impacts of less understood, complex threats like space weather. Representation by an extensive range of government partners at all levels helps to ensure information sharing and enhanced situational awareness. Because space weather is a global phenomenon, its impacts will be felt across the world and therefore lead agencies should pursue opportunities for further international engagement to include collaboratively planning and implementing international exercises.

6. **There is a time-critical need for a classified SWx TTX to identify gaps specific to national security requirements.**

Participants acknowledged that SWx events can result in vulnerabilities that adversaries can exploit because space weather impacts often mimic typical cyberattack effects. The lack of legally required commercial satellite outage and/or loss-of-control reporting is problematic as it is not currently routinely done. These vulnerabilities as well as the challenges listed above spotlight the urgent need for more exercises and training related to SWx forecasting and communications, to include adding a focus on defense support for civil authorities and potential impacts to national security.

[18] https://training.fema.gov/is/courseoverview.aspx?code=IS-66&lang=en

A set of identified high-level gaps and actionable recommendations are summarized in the Table below. Addressing these gaps will help to advance both our technological capabilities and the nation's preparedness for space weather events.

Gaps by Preparedness Categories	Recommendations for Consideration
Planning and Policy	Enhance policies to ensure all government partners with roles and responsibilities for space weather preparedness have appropriate resources available.
	Address space weather event impacts in Continuity of Operations Plans.
	Create a detailed interagency SWx response plan that identifies the final decision-maker(s) for resource acquisition, prioritization, and allocation.
	Add specificity and clarity to the Federal Operational Concept for Impending SWx for government departments and agencies roles and responsibilities.
Research and Observations	Research the potential impacts to vulnerable systems, specifically in the critical infrastructure sectors.
	Develop more robust capabilities in forecasting when eruptions will occur, as well as the arrival time and geoeffectiveness of CMEs.
	Address significant current observational gaps via new ground- and space-based sources.
	Determine opportunities for further international engagement.
Communications and Coordination	Establish a process to determine when and how to alert senior leaders regarding a SWx event. (Note that this is currently a component of the SWORM Implementation Plan actions and is in progress.)
	Establish a broader communication plan to include a focus on public messaging.
	Improve overall understanding of SWx thresholds and when coordination should occur among FEMA, NOAA, NASA, and other agencies for public messaging.
	Enhance coordination with critical infrastructure sectors to ensure notification information is meaningful and actionable.
Training and Education	Continue to educate emergency management and public safety agencies across the nation regarding the concept of space weather and its impacts.
	Provide more training for the trusted voices of the community (e.g., fire department, sheriff, local government) to better communicate SWx effects.
	Promote FEMA Emergency Management Institute's "Preparing the Nation for Space Weather Events" (IS-66) course19.

[19] https://training.fema.gov/is/courseoverview.aspx?code=IS-66&lang=en

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Chapter 5. Conclusion

The SWx TTX brought together participants from a wide range of U.S. departments and agencies for the first time to better understand the challenges posed by an impending space weather event. As historical events (e.g., 1859 Carrington Event, 1989 Quebec blackout) have shown, a series of strong CMEs could induce geomagnetic storms with significant effects to ground-based infrastructure; more recent events (e.g., 2005 Halloween Storm, 2024 Gannon Storm) have shown that effects can also extend to space-based assets. As multiple sectors increase their dependency on potentially vulnerable systems, sectors and capabilities ranging from communications and GPS to critical military operations, air travel, banking, and agricultural systems could be affected. Improved government preparation will reduce economic fallout, protect communities and speed up recovery.

The participants recognized that in order to effectively prepare for a space weather event a multi-layered approach must be taken. That approach should include, at a minimum, the following:

- **Increase capabilities to better understand and predict space weather events** by:
  - Enhancing and improving models to enable forecasting and early warning systems;
  - Investing in next-generation operational space weather satellites; and
  - Developing and deploying more sensors (space and ground) to monitor space weather drivers and effects.
- **Identify and reduce/mitigate critical infrastructure vulnerabilities** by:
  - Developing and deploying resilient and redundant systems; and
  - Investigating backup systems and power grid hardening.
- **Educate and prepare the public** by:
  - Working with space weather SMEs to develop and deploy public awareness campaigns and personal preparedness initiatives (just as we do with other potential emergencies)
- **Encourage collaboration with international partners and the private sector**
- **Continue to implement joint preparedness and response planning, training and exercises**

Ongoing preparedness efforts for a space weather event are crucial because an extreme event has the potential to severely impact our nation’s critical infrastructure and threaten our national security. Just as we prepare for earthquakes, hurricanes and cyberattacks, our nation must take action before a major space weather event occurs.

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Appendix A. Exercise Objectives

Objective	Objective Statements
1. Assess effectiveness of communication protocols and pathways	1.1. Assess participants' knowledge of their specific roles and responsibilities related to information sharing, public messaging and public alerting
	1.2. Review and enhance agency-specific public information and community messaging plans and procedures for accurate, timely, consistent, and trusted notifications and information
	1.3. Increase participants' understanding of necessary protocols required for interagency planning and operational coordination
	1.4. Review NOAA Space Weather Prediction Center (SWPC) nowcast, forecast, alerts and communications systems for a major space weather event
	1.5. Determine gaps/obstacles to ensuring effective information sharing to enhance the operation and restoration of critical infrastructure at greatest risk of space weather effects
2. Enhance whole-of-government preparedness and response to a multi- regional disaster with widespread impact on the nation's critical infrastructure	2.1. Assess each agency's high-level understanding of preparedness and response plans and protocols to include identifying gaps and gaining clarity on authorities, and roles and responsibilities of key decision-makers
	2.2. Understand national plans and response protocols for potential power outages impacting national security to include readiness, command and control of assets, and augmenting local public safety needs to protect the nation's critical infrastructure
	2.3. Assess each agency's understanding of their roles and responsibilities as outlined in the National Response Framework (NRF), National Incident Management System (NIMS) and FEMA's Federal Operating Concept for Impending Space Weather Events
3. Assess resiliency to increasingly degraded space assets due to a space weather event	3.1. Identify existing capabilities that support the understanding and forecasting of space weather events, and introduce innovative observational platforms and technologies
	3.2. Understand impact of satellite health during all phases of a Space Weather event
	3.3. Understand the impacts of a severe Space Weather event on positioning, navigation and timing (PNT)
	3.4. Assess current space weather models, modeling techniques and outputs to identify opportunities for improvement
4. Assess response to space weather effects in cislunar space	4.1. Assess and understand the impacts of a Space Weather event on assets in cislunar space
	4.2. Assess NASA's procedures and preparedness for hazards on crewed vehicles in cislunar space and activity on the lunar surface

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Appendix B. Planning Team and Contributing Subject-Matter Experts

The SWx TTX planning team was led by APL with direction from the exercise sponsor agencies (Genene Fisher (NASA), James Spann (NOAA SWO), Mangala Sharma (NSF), Glenn Proska (FEMA), and additional advising from and close coordination with both Bill Murtagh (NOAA) and Jinni Meehan (OSTP). The planning team, included:

Johns Hopkins Applied Physics Laboratory

- Dipak Srinivasan, *Exercise Manager*
- Ruth Vogel, *Exercise Lead & Facilitator*
- Lisa Turner, *Logistics Lead*
- Anne Roberts-Smith, *Evaluation Lead*
- Drew Turner, *Scenario Lead & Facilitator*
- Ian Cohen, *Science Lead & Facilitator*
- Daniel Meidenbauer, *Facilitator*
- Julee Rendon, *FEMA Region 8 Liaison*
- Megan Toms, *FEMA Region 8 Team*
- Ben Sheppard, *FEMA Region 8 Facilitator*
- John Hicks, *DoD Liaison*
- Larry Paxton, *Science Team*
- Angelos Vourlidas, *Science Team*
- Cheryl Williams, *Communications Lead*
- Aaron Chrietzberg, *IT Infrastructure Lead*
- Joseph Comberiate, R. Terik Daly, Mary Lasky, Emma Rainey, Angela Stickle, *Data Collectors*

Cybersecurity and Infrastructure Security Agency

- Chris Cannizzaro, *Operations SME*

FEMA

- Glenn Proska, *Exercise SME*
- Kenyetta Blunt, *Operations SME*

FEMA Region 8

- David Ouimet, *Region 8 Coordination*

- Matthew Burns, Amelia Iraheta, Kirsten Maltese, Jennifer Pendley, Haley Ward, Brianna Young, *Data Collectors*

NASA Heliophysics Division

- Jamie Favors, *Sponsor*
- Genene Fisher, *Space Weather SME*
- Matthew McClure, *Space Weather Operations SME*

NASA Moon to Mars Space Weather Analysis Office (M2M)

- Michelangelo Romano, *Space Weather Modeling SME*

NOAA Office of Space Weather Observations

- Yaireska Collado-Vega, *Space Weather SME*
- James Spann, *Sponsor and Space Weather SME*

NOAA Space Weather Prediction Center

- Amy Macpherson, *Space Weather Operations SME*
- William Murtagh, *Space Weather SME*
- Clinton Wallace, *Space Weather Operations SME*

NSF Geospace Cluster

- Mangala Sharma, *Sponsor and Space Weather SME*

United States Air Force 557th Weather Wing

- Jennifer Benson, *Space Weather SME*
- Austin Gibbons, *Space Weather Operation SME*

White House Office of Science and Technology Policy

- Jinni Meehan, *Space Weather Policy SME*

Appendix C. Participating Organizations

C.1. Players

Players were personnel (e.g., senior leader decision makers) in emergency management and public safety personnel within the federal, SLTT government communities that may have roles and responsibilities for space weather preparedness and response activities. Players initiated actions in response to the events.

Table A-1. Key Participants at APL in Laurel, Maryland

Organization	Name/Title
Cybersecurity and Infrastructure Security Agency (CISA)	Mona Harrington, Assistant Director, National Risk Management Center (NRMC)
Cybersecurity and Infrastructure Security Agency (CISA)	Chris Cannizzaro, Senior Advisor, National Risk Management Center (NRMC)
Cybersecurity and Infrastructure Security Agency (CISA)	Sunny Wescott, Chief Meteorologist, Infrastructure Security Division
Department of Defense (DoD)	Lt. Col. Omar Nava, Chief, Space Weather and Environmental EM Effects, United States Air Force/A3WX
Department of Defense (DoD)	Aparna Srinivasan, Chief, Authority Portfolio
Department of Defense (DoD)	Bobby Mitchell, Senior Advisor
Department of Defense (DoD)	Lt Col Omar Nava, PhD, Chief Space Weather and Environment Emergency Management, Office of the Secretary of Defense (OSD)
Department of Defense (DoD)	John Meadows, Information Security
Department of Energy (DOE)	Joseph Blankenburg, Physicist
Department of Homeland Security (DHS) Integration Public Alert and Warning System (IPAWS)	Jared Reese, Analyst
Department of State	Joshua Wolny, Foreign Affairs Officer
Environmental Protection Agency (EPA)	Miranda Magdangal, National Exercise Coordinator
Federal Emergency Management Agency (FEMA)	Erik Hooks, FEMA Deputy Administrator
Federal Emergency Management Agency (FEMA)	Joseph “Andy” Couch, Office of the Administrator, Director, DHS Continuity Division
Federal Emergency Management Agency (FEMA)	Nancy Dragani, Regional Administrator, FEMA Region 8
Federal Emergency Management Agency (FEMA)	Kenyetta Blunt, Branch Chief, Recovery Planning
Federal Emergency Management Agency (FEMA)	Glenn “Rocky” Proska, Deputy Branch Chief, Planning and Exercise Division

Organization	Name/Title
Federal Emergency Management Agency (FEMA)	Jessica Wieder, Director of Incident Communications Planning, External Affairs
Federal Emergency Management Agency (FEMA)	Leviticus “L.A.” Lewis, FEMA Detailee, NASA Planetary Defense Program Officer
Federal Emergency Management Agency (FEMA)	Michael Manchester, Senior Watch Officer
Federal Emergency Management Agency (FEMA)	Vince Dumas, Emergency Preparedness Specialist
Federal Emergency Management Agency (FEMA)	Dennis Red, Field Operations Coordination (FOC), Director
Federal Emergency Management Agency (FEMA)	Kevin Remsberg, FOC, Deputy Director
Federal Energy Regulatory Commission (FERC)	Amelia Lewis, Engineer, Office of Energy Infrastructure Security
National Aeronautics and Space Administration (NASA)	Sandra Connelly, PhD, Deputy Associate Administrator for NASA's Science Mission Directorate
National Aeronautics and Space Administration (NASA)	Dr Joseph Westlake, Director of NASA's Science Mission Directorate's Heliophysics Division
National Aeronautics and Space Administration (NASA)	Jamie Favors, Director, NASA Space Weather Program
National Aeronautics and Space Administration (NASA)	Ursula Rick, PhD, Program Executive, Heliophysics Division
National Aeronautics and Space Administration (NASA)	Eddie Semones, Johnson Space Center (JSC) Space Radiation Analysis Group (SRAG)
National Aeronautics and Space Administration (NASA)	Dr. Genene Fischer, Program Scientist, Space Weather Program
National Aeronautics and Space Administration (NASA)	Joshua Barnes, Program Manager, Disaster Response Coordination System
National Oceanic and Atmospheric Administration (NOAA)	Ken Graham, Director, National Weather Service, and Assistant Administrator for Weather Services at NOAA
National Oceanic and Atmospheric Administration (NOAA)	Clinton Wallace, Director at NOAA National Weather Service, Space Weather Prediction Center
National Oceanic and Atmospheric Administration (NOAA)	Dr. Elsayed Talaat, Director of the Office of Space Weather Observations at NOAA’s National Environmental Satellite and Data Information Service (NESDIS)
National Oceanic and Atmospheric Administration (NOAA)	William Murtagh, Program Coordinator, Space Weather Prediction Center
National Oceanic and Atmospheric Administration (NOAA)	Michael Morgan, Assistant Secretary of Commerce for Environmental Observation and Prediction
National Oceanic and Atmospheric Administration (NOAA)	Dr. James Spann, Senior Scientist for Space Weather for NESDIS Office of Space Weather Observations (SWO)
National Science Foundation (NSF)	Dr. Anne Johansen, Division Director, Atmospheric & Geospace Sciences
National Science Foundation (NSF)	Dr. Mangala Sharma, Program Director for Space Weather

Organization	Name/Title
Office of the Director of National Intelligence (ODNI)	David Colbert, IC Space Advisor
White House Office of Science and Technology Policy (OSTP)	Jinni Meehan, Assistant Director for Space Policy
White House Office of Science and Technology Policy (OSTP)	Ann Schwartz, PhD, Assistant Director for Research, Infrastructure
White House National Security Council	Brooke Bingaman, NOAA Liaison to the National Security Council
U.S. Air Force	Major Austin Gibbons, Liaison Officer to the Space Weather Prediction Center (SWPC)
U.S. Air Force	Dr, Jennifer Benson, Chief Space Scientist, 557th Weather Wing
U.S. Space Command	Mr. Joseph Johnson, USSPACECOM/J85 Global Warfare Requirements Division
U.S. Space Command	Bryan Cochran, J852 Space Domain Awareness Program Analyst

Table A-2. Key Participants at Region 8 Facility in Denver, Colorado

Organization	Name/Title
Colorado Department of Transportation and Infrastructure (DOTI)	Erin Palmer, Emergency Management Specialist
Colorado Division of Homeland Security and Emergency Management (DHSEM)	Elizabeth Ownsby, State EOC Systems Administrator and IT Director
Colorado National Guard (NG)	Harry Smith, Senior Enlisted Leader, 157th Space Warning Squadron, National Guard
Colorado National Guard (NG)	Amy Towe, NEED INFO
Colorado Regional Transportation Division (RTD)	Diana Rawles, Emergency Management Specialist
Cybersecurity and Infrastructure Security Agency (CISA)	Mark MacAlester, CISA Liaison at NORAD and USNORTHCOM
Denver Colorado, Department of Transportation and Infrastructure (DOTI)	Erin Palmer, Emergency Management Specialist
Denver International Airport (DIA)	Leonard Spomer, Communications Manager
Department of Commerce	Douglas Kahn, Senior Emergency Management Advisor
Denver Office of Emergency Management (OEM)	Matthew Mueller, Executive Director Emergency Management, City and County of Denver
Department of Energy (DOE)	Victor Pearson, Program Manager
Division of Homeland Security and Emergency Management (DHSEM)	Elizabeth Ownsby, State Emergency Operations Center (SEOC), Operations Officer
Federal Emergency Management Agency (FEMA), Region 8	Morgan Dzakowic, Public Affairs Specialist

Organization	Name/Title
Federal Emergency Management Agency (FEMA), Region 8	Nathan Knapp, Liaison Officer US NORTHCOM
Federal Emergency Management Agency (FEMA), Region 8	Zachary Lamb, FEMA Region 8 Response Director
Federal Emergency Management Agency (FEMA), Region 8	Jennifer Dick, FEMA Regional Counsel
Federal Emergency Management Agency (FEMA), Region 8	Katherine Fox, Deputy Regional Administrator, Region 8
Federal Emergency Management Agency (FEMA), Region 8	Kirsten Maltese, Community Preparedness Officer
Federal Emergency Management Agency (FEMA), Region 8	Ryan Pietramali, Branch Chief, Risk Analysis
National Oceanic and Atmospheric Administration (NOAA)	Shawn Dahl, NOAA SWPC Forecaster
Southern Ute Indian Tribal Emergency Management	Don Brockus, Emergency Manager
U.S. Air Force North American Aerospace Defense Command (NORAD)	Patricia Vollmer, Deputy Senior METOC Officer, NORAD
U.S. Air Force	Maj. Jeremy Hromscho, Operations Officer, 45th Weather Squadron
U.S. Army North	COL Sean Williams, Defense Coordinating Officer (DCO) for FEMA Region 8
Western Area Power Administration (WAPA)	Tarra Keithley, Director of Communications
Western Area Power Administration (WAPA)	Steven Yexley, Manager, WAPA Training Center

Appendix D. Exercise Readaheads – EXERCISE

D.1. Readaheads

EXERCISE EXERCISE EXERCISE

SPACE WEATHER TABLETOP EXERCISE

PARTICIPANT READAHEAD

INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Federal Emergency Management Agency (FEMA) are sponsoring a two-day Space Weather (SWx) tabletop exercise (TTX) with senior officials from key federal, state and local partners to assess preparedness and response procedures for a hypothetical space weather event. The TTX, which is being designed and coordinated by the Johns Hopkins Applied Physics Lab (APL), will be held on May 8th & 9th, 2024 with participants at two different venues – APL in Laurel, MD and the Denver Federal Center in Denver, CO. Options for virtual participation will be provided for those who cannot attend in-person. Senior leaders from federal agencies are encouraged to attend in person at APL in Laurel, MD.

This event will begin with space weather relevant tutorials to provide baseline information and to foster meaningful participation. The SWx scenario includes simulated, though realistic, notifications from NOAA's Space Weather Prediction Center (SWPC) and will evolve to include critical events prompting key decision makers at all levels of government to discuss relevant plans, policies and responses. In addition to the sponsors, participants will include senior leaders from the Colorado Division of Homeland Security and Emergency Management (DHSEM), Denver Office of Emergency Management (OEM), Department of Defense (DoD), Department of Homeland Security (DHS) Cybersecurity and Infrastructure Agency (CISA), Department of Energy (DOE), Department of Transportation (DOT), Environmental Protection Agency (EPA), Office of Science and Technology Policy (OSTP), and various other public safety and national security leaders.

TTX OBJECTIVES

The TTX objectives were derived in partnership with the sponsors, as well as space weather and emergency management subject matter experts and are aimed at helping to enhance our nation's space weather preparedness. As FEMA's designated Center of Excellence for Space Weather Prediction, FEMA Region 8 (R8) is a critical partner. During the TTX, FEMA R8 will serve as a "use case" opportunity for the rest of the nation in developing and sharing best practices, as well as lessons learned. The SWx TTX objectives include:

1) Assess effectiveness of communication protocols and pathways,
2) Enhance whole-of-government preparedness and response to a regional disaster and the widespread impact on the Nation's critical infrastructure,
3) Assess resiliency to increasingly degraded space assets due to a space weather event, and
4) Assess response to space weather effects in cislunar space.

SCENARIO SUMMARY

The hypothetical scenario involves a series of solar events that drive a range of adverse SWx effects on Earth and in near-Earth space. Solar activity, solar flares and coronal mass ejections (CME), have direct consequences and impacts on critical infrastructure, particularly when those events drive additional activity in Earth's atmosphere, ionosphere (i.e., the ionized gas or plasma in the upper atmosphere), and magnetosphere (i.e., the plasma on the protective magnetic field above the atmosphere and around Earth).

The scenario incorporates solar and geomagnetic activity resulting in hazards ranging from intense radiation exposure to satellites, astronauts, and commercial aviation, communication disruptions, loss of functionality or degraded GPS, satellite failures and on-orbit collisions, and power outages with impacts which could last for hours to days or longer.

EXERCISE EXERCISE EXERCISE

PREPARATION

This TTX will provide a collaborative, low-stress, no-fault environment for participants to uncover various challenges associated with preparing for and responding to a space weather scenario that impacts the U.S. infrastructure. To help prepare, participants should become familiar with their organization's policies and procedures relevant to space weather events and are encouraged to share information during the exercise. Such information may include, but need not be limited to, preparedness and response procedures, space weather policies, organizational structures, contingency plans, public information sharing and communications protocols.

During the TTX, participants will engage in interactive dialogue regarding information needs and will also be given opportunities to enhance cross-agency communications and coordination. Preparation prior to the TTX will enable richer discussion. Provided below are a few examples of questions that will be posed. (Please note: The views expressed during the TTX will not be official government or organizational positions).

- How might your organization respond to an impending space weather event?
- With which partners and/or stakeholders would you be communicating and coordinating?
- What roles might your department/agency play?
- How would you develop and share crisis information regarding an impending space weather event?

SPACE WEATHER PRIMERS

NOAA – What is Space Weather
https://www.swpc.noaa.gov/sites/default/files/images/u33/swx_booklet.pdf

Space Weather 101 Short Video:
https://www.youtube.com/shorts/YU6wmS9hctc
https://www.youtube.com/shorts/3FHbn5wMfFs
https://www.youtube.com/shorts/zRrhDEK8yzo

NOAA SWPC Resources:
https://www.swpc.noaa.gov

Federal Operation Concept for Impending Space Weather Events:
https://www.fema.gov/sites/default/files/2020-07/fema_incident-annex_space-weather.pdf

Space Weather for Hazard Mitigation & Emergency Management (webinar 10/11/23):
https://piepc.org/october-2023-webinar/

Implementation-Plan-for-National-Space-Weather-Strategy:
https://www.whitehouse.gov/wp-content/uploads/2023/12/Implementation-Plan-for-National-Space-Weather-Strategy-12212023.pdf

SWx Effects on Technology:
https://www.nesdis.noaa.gov/events/space-weather-effects-technology

Preparing the Nation for Space Weather:
https://training.fema.gov/is/courseoverview.aspx?code=IS-66&lang=en

For more information, please contact the TTX coordinator: *spaceweatherttx@jhuapl.edu*

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Second Read-Ahead Document for the Space Weather Tabletop Exercise (SWx TTX)

Space Weather (SWx) TTX Scenario Overview

The hypothetical TTX scenario involves a series of solar events that drive a range of adverse space weather effects on Earth and in near-Earth space. The TTX scenario incorporates solar and geomagnetic activity that is posited to result in multiple hazards, including:

- intense radiation exposure to satellites, astronauts, and commercial aviation
- radio communications outages and disruptions
- loss of functionality or degraded performance of GPS for precision navigation and timing
- satellite failures and on-orbit collisions
- local- to regional-scale power outages

These effects can last for hours to days or even longer. Power outages may even last weeks or months depending on event severity and mitigation measures.

The TTX scenario takes place over approximately 8 days of scenario time from late January to early February 2028. In the hypothetical scenario, the National Oceanic and Atmospheric Administration's (NOAA) Space Weather Prediction Center (SWPC) has been tracking an evolving active region on the solar surface. Over approximately 7 days, the active region has rotated into the location where, if it erupts, it is most likely to result in space weather at Earth (i.e., it will be "geoeffective"). During the scenario, NASA's Artemis IV mission is in progress, with two astronauts in the Orion command module in orbit around the Moon and two astronauts having just landed in the lunar module on the surface of the Moon. Those two astronauts on the Moon are preparing for a 7-day-long mission of lunar exploration, including rover activity. At the start of the exercise on January 26 in the scenario timeline, it is around 3 p.m. Eastern Time (i.e., afternoon on the U.S. East Coast and around noon on the West Coast).

TTX Environment

This TTX will provide a low-stress, no-fault environment to generate dialogue about various challenges associated with preparing for and responding to an impending space weather event. Participants should become familiar with their organization's policies or procedures relevant to this scenario and are encouraged to share information during the exercise. Such information may include, but need not be limited to, disaster preparedness and response procedures, space weather policies, organizational structures, contingency plans, and information-sharing and communications protocols, including public engagement.

During the TTX, participants will engage in an interactive dialogue regarding information requirements for senior leaders to make actionable decisions. They will also be given opportunities to learn from each other and enhance cross-agency communications and coordination. (Please note: The views expressed during the TTX will *not* be official government or organizational positions.)

Questions will be posed to the participants during the TTX, such as:

- Are you familiar with the potential impact a severe space weather event might have on your department or agency's day-to-day mission operations?
- What resources does your department or agency depend on that could be at risk given a major space weather event?
- Does your agency or organization have policies or protocols for information-sharing and decision-making given this type of threat?
- How would you develop and share crisis information with the public?

Typical Questions

What is space weather?

Space weather encompasses variability of the solar and space environments that results in adverse effects on human systems (both biological and technological) in deep space, lunar, near-Earth space, and Earth (i.e., ionosphere, atmosphere, and ground) environments. Some of the most common and impactful space weather effects include:

- Enhanced radiation (total ionizing dose) exposure to personnel and technology on aircraft (military, private, and commercial) and astronauts in space and on the Moon, as a result of solar and magnetospheric radiation variability
- Satellite damage and anomalies due to natural galactic, solar, and magnetospheric radiation variability and auroral activity

- Satellite drag (orbital degradation including station-keeping and ground-repeat times) and position uncertainty (e.g., for collision avoidance) due to thermospheric variability for near-Earth-orbit regimes
- Radio and satellite communications disruptions and outages due to solar radio noise, ionospheric disturbances, and auroral activity
- Degradation of global navigation satellite system (e.g., GPS) position, navigation, and timing services due to ionospheric disturbances and auroral activity
- Induced currents affecting pipelines, long transmission cables, and railways, due to geoelectric fields induced by geomagnetic storms
- Power grid infrastructure impacts, including the possibility of regional power outages and critical infrastructure damage, as a result of large currents induced in long-distance power lines by geomagnetic storms

The most visible and well-known phenomena associated with space weather are the aurora (i.e., the northern and southern lights). During extremely active periods, the aurora can be observed at latitudes reaching the southern United States and beyond.

Figure 1. The aurora borealis. Image credit: Bigstock.

NOAA's SWPC is part of the U.S. National Weather Service and responsible for civil space weather monitoring and maintaining operational products relevant to space weather end-user needs. Other U.S. government departments and agencies with stake and interest in space weather include: NASA, the National Science Foundation, the Department of Defense, the Intelligence Community, the U.S. Geological Survey, the Federal Aviation Administration, and the Federal Emergency Management Agency. As our society becomes more and more dependent on advanced technology, including space-based and satellite technology, space weather is becoming of higher and higher consequential relevance and will have a measurable impact on everyday people.

How often does space weather occur?

Severe space weather can occur at any time. However, there are certain times when the likelihood and intensity of space weather are higher. Solar activity and corresponding space weather effects follow an 11-year periodicity known as “the solar cycle.” Figures 2 and 3 show this solar cycle in two different formats, as recorded in sunspot number and with solar imagery. Throughout the solar cycle, and particularly during the peak in the cycle known as solar maximum, solar drivers of space weather include large, eruptive events such as solar radio bursts (SRBs), solar flares, and coronal mass ejections (CMEs). Toward the cycle minima, large eruptions become less frequent, but occurrences of a different type of solar driver, fast solar wind streams, increase in frequency, causing less intense but still serious space weather effects.

Space weather events known as geomagnetic storms occur approximately once per week on average, regardless of solar-cycle phase. During geomagnetic storms, solar drivers result in intense activity within Earth’s magnetic field. Space weather can also occur even outside of geomagnetic storm periods. For example, spacecraft charging anomalies, enhanced radiation hazards, and communications and navigation disruptions can occur during periods of enhanced auroral activity, known as substorms.

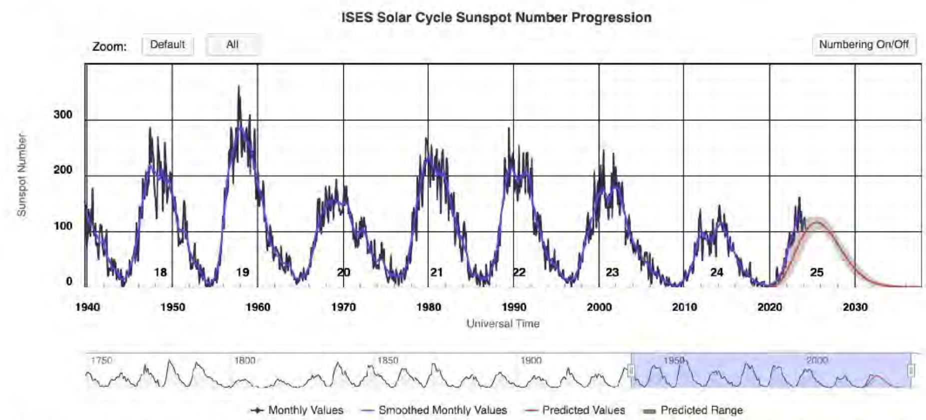

Figure 2. Solar cycle as quantified by the sunspot number, a count of solar active regions on the solar disk. The upper plot shows the cycle of sunspot number versus time from the year 1940 to present, including the predicted range of the current cycle (number 25). The bottom plot shows the same data back to 1750. Image credit: NOAA SWPC.

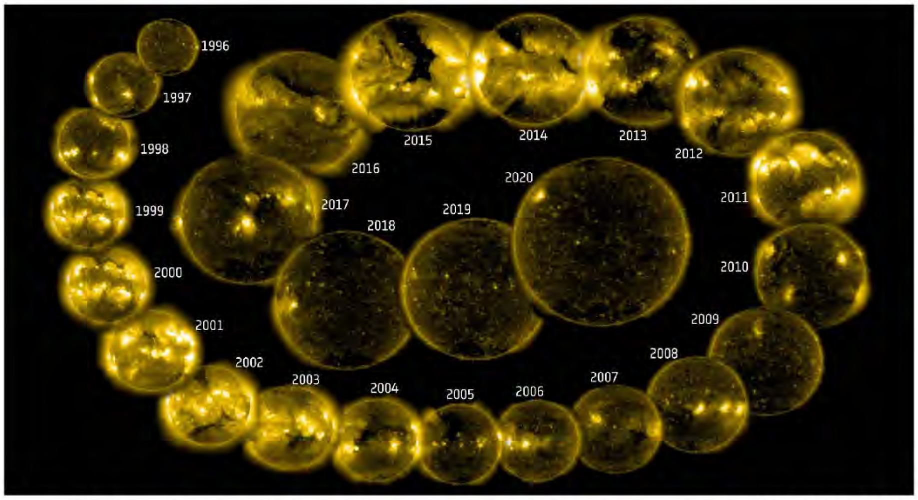

Figure 3. Solar cycle as quantified with solar imagery. Around solar minima years (e.g., 1996, 2009, 2020), the Sun showcases little activity (appearing darker in this particular wavelength), while around solar maxima years (e.g., 2001, 2012), the Sun's activity levels, including the drivers of extreme space weather, peak (active regions appear brighter in this wavelength). During these active periods, severe-to-extreme space weather events are more likely to occur. Image credit: European Space Agency (ESA)/Solar and Heliospheric Observatory (SOHO).

Drivers of Space Weather

Space weather is the result of extremely complex, natural systems extending from the Sun itself to Earth's interior. The Sun is a variable, enormous sphere of superheated plasma (the fourth state of matter) that sporadically erupts, producing direct drivers of space weather at Earth and throughout the solar system. Active regions consisting of concentrations of intense magnetic fields on the solar surface, known as "sunspots" (see Figure 4, black spots in the image), are the sources of solar eruptive events such as SRBs, flares, and CMEs, each of which is discussed below.

SRBs and solar flares (see Figure 5) involve the explosive release of intense electromagnetic emissions in the radio wavelengths (SRBs) and X-ray to gamma-ray wavelengths (flares) from active regions on the solar disk. SRBs can result in communications disruptions on the sunlit side of Earth. X-ray flares pose a radiation concern and significantly enhance Earth's ionosphere, which causes the subsequent loss of use of high-frequency (HF, 3–30 MHz) radio bands and disruptions to satellite communications and navigation signals. Flares and SRBs are of a space weather concern only when they occur on the solar disk visible from Earth.

SPACE WEATHER
TABLETOP EXERCISE

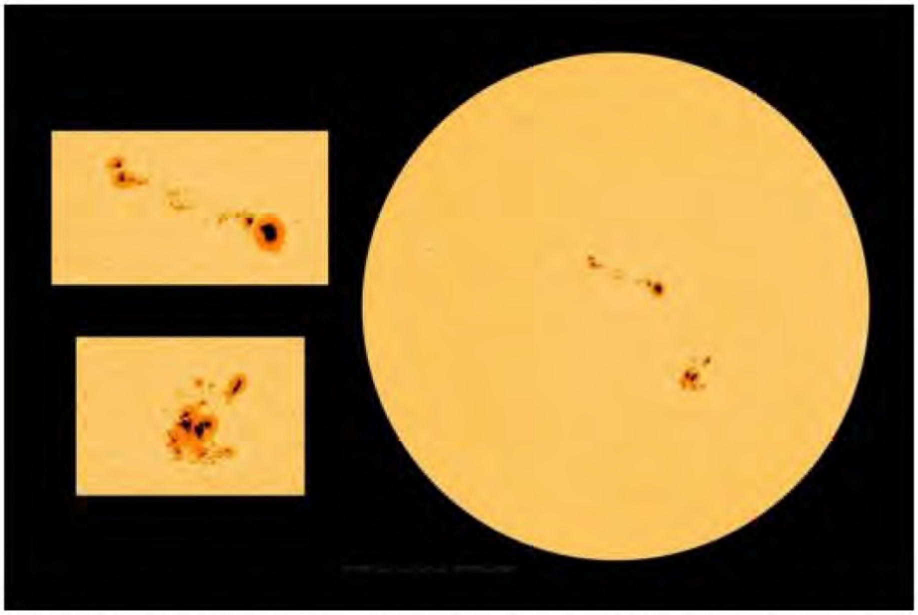

Figure 4. Examples of solar active regions ("sunspots") on the solar disk. Sunspots correspond to regions of intense solar magnetic fields, which can explosively erupt in solar flares, radio bursts, and coronal mass ejections. Note that each of the largest sunspots shown here is many times the size of the entire planet Earth. Image credit: NOAA SWPC.

CMEs (see Figure 6) involve the explosive release of up to billions of tons of magnetized material from the outermost layers of the solar atmosphere (the corona) that travel at approximately 1 million miles per hour into interplanetary space. CMEs form shock waves on their forward edges, and when those blast waves and material hit Earth's system, the combination can result in some of the most extreme geomagnetic storms.

Also often associated with solar eruptive events are intense periods of enhanced particle (e.g., protons, alpha particles, electrons) radiation known as solar energetic particle (SEP) events. SEPs pose the most significant natural radiation hazard to astronauts, satellites, and high-altitude aircraft and crews and can also result in ionospheric disturbances that affect communications and navigation signals.

Even in the absence of solar eruptions, the Sun emits the solar wind. Even typical, everyday changes in the solar wind can drive severe space weather at Earth, including auroral substorms and enhancements to the Van Allen radiation belts that surround Earth.

Why Is Space Weather So Challenging to Predict and Deal With?

The natural systems and drivers of space weather are complex, and the volume of space contributing to space weather spans the entirety of the inner solar system and is drastically under-observed. The state of space weather observatories today is analogous to the state of terrestrial weather observatory networks during the 1940s (full Earth satellite imagery of weather patterns and atmospheric data were entirely unavailable prior to the Space Age). Space weather observatories are few and far between, and there are no true global pictures of the full system. Because of these system complexities and known observational blind spots, the current state-of-the-art predictive and forecasting models for space weather offer only short-notice warnings (if any) and very high uncertainties. Furthermore, we are still establishing exactly how and why space weather detrimentally impacts human systems and technology, yet as human society becomes more and more dependent on advanced technology (e.g., electrical power; GPS position, navigation, and timing data; and satellite communications, internet, and other services) and our critical infrastructure systems become more global in scale, we are also becoming much more vulnerable to the threat of space weather.

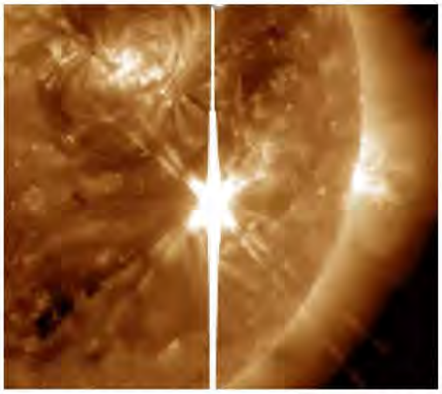

Figure 5. Example of a solar flare, in an intense burst of electromagnetic emissions up through X-ray and sometimes even gamma-ray wavelengths. Image credit: NASA.

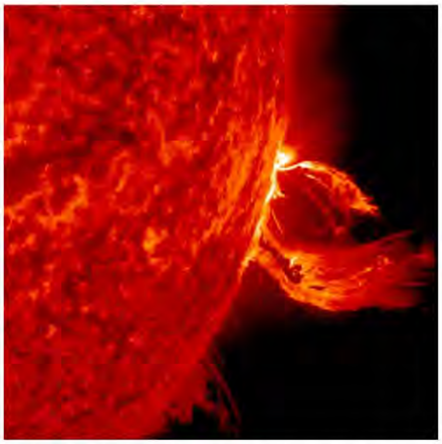

Figure 6. Example of a coronal mass ejection erupting from the Sun. This image is a composite of three instruments that continually observe the Sun from near Earth. Image credit: Solar Dynamics Observatory, NASA.

Appendices

Appendix A: Resources for Background Information

Primers on impending space weather events are available via the following:

- Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act (PROSWIFT Congressional Act S.881): https://www.congress.gov/bill/116th-congress/senate-bill/881/text
- NOAA Space Weather Prediction Center (SWPC) resources: https://www.swpc.noaa.gov
- National Space Weather Strategy and Action Plan: https://trumpwhitehouse.archives.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf
- Implementation Plan of the National Space Weather Strategy and Action Plan: https://www.whitehouse.gov/wp-content/uploads/2023/12/Implementation-Plan-for-National-Space-Weather-Strategy-12212023.pdf
- Federal Operating Concept for Impending Space Weather Events: https://www.fema.gov/sites/default/files/2020-07/fema_incident-annex_space-weather.pdf
- Space weather YouTube shorts:

  https://www.youtube.com/shorts/YU6wmS9hctc
  https://www.youtube.com/shorts/3FHbn5wMfFs
  https://www.youtube.com/shorts/zRrhDEK8yzo
- Space Weather Effects on Technology: https://www.nesdis.noaa.gov/events/space-weather-effects-technology
- Space Weather for Hazard Mitigation and Emergency Management (webinar, recorded October 11, 2023): https://piepc.org/october-2023-webinar/
- IS-66: Preparing the Nation for Space Weather Events: https://training.fema.gov/is/courseoverview.aspx?code=IS-66&lang=en
- Findings and Recommendations to Successfully Implement PROSWIFT and Transform the National Space Weather Enterprise: https://www.weather.gov/media/nws/REPORT-Findings-and-Recommendations-04202023.pdf
- Space Weather Science and Observation Gap Analysis for the National Aeronautics and Space Administration (NASA): https://science3.nasa.gov/science-pink/s3fs-public/atoms/files/GapAnalysisReport_full_final.pdf

Appendix B: Selected Examples of Significant Documented Space Weather Events

The SWx TTX is based on observations, scientific calculations and analysis, and documented impacts. Below are multiple documented instances of actual historical space weather impacts on human systems.

1859 Carrington Event: This event comprised an extreme solar flare, geomagnetic storm, and geomagnetically induced currents that occurred in September 1859. During this period of extreme space weather, the solar flare was visible to the naked eye, and the aurora was observed as far south as Panama. The geomagnetically induced currents in telegraph lines were so intense that they resulted in fires at multiple telegraph stations. The Dst index (a geomagnetic index compiled from low-latitude, ground-based magnetometers used to qualify geomagnetic storm events and classify their intensity) for this storm was estimated at ≤1600 nT, over three times more intense than anything that has been observed in the last 50 years. See Tsurutani et al. (2003), Li et al. (2006), and Green and Boardsen (2006) for further detail.

1967 Solar Flare: On May 23, 1967, a large solar flare enhanced the polar ionosphere, which resulted in jammed radars and communications loss with U.S. military assets. The Department of Defense first attributed the loss to a Soviet attack, and the U.S. Air Force started preparing to launch a nuclear counterstrike. The counterstrike was aborted once space weather experts attributed the effects to the solar flare. See this American Geophysical Union (AGU) press release for further details.

1972 Solar Eruptions and Solar Energetic Particles (SEPs): In August 1972, the Sun erupted with a large flare, coronal mass ejection (CME), and intense SEPs. The events were associated with (and potentially the cause of) a near-simultaneous and entirely unintended detonation of dozens of sea mines deployed off the coast of North Vietnam by the U.S. Navy to interdict shipping during the Vietnam War. The event occurred between the Apollo 16 (April 1972) and Apollo 17 (December 1972) missions, and had the astronauts been in space at the time, the SEPs would have been sufficient to result in potentially fatal levels of radiation exposure. See Knipp et al. (2018) and this NOAA National Environmental Satellite, Data, and Information Service (NESDIS) webpage for further detail.

1989 Geomagnetic Storm and Hydro-Québec Outage: In March 1989, an extreme (Dst ≤ 500 nT) geomagnetic storm resulted in the sudden collapse of the power grid and a power outage in Québec, Canada. The outage was attributed to the compounding effects of multiple CMEs hitting Earth within a short period while the electrical grid was under stress. See Boteler (2019) and references therein for further detail.

2002 Battle of Takur Ghar Incident: This incident—an ultra-high-frequency (UHF)-SatCom communications failure during the U.S. War in Afghanistan—resulted in the deaths of three U.S. active service members. The incident occurred around solar maximum, and ionospheric disturbances capable of disrupting the UHF signals were observed between the ground forces and the communications satellite, suggesting a possible root cause of the communications link failure. See Kelly et al. (2014) for further detail.

2003 Halloween Storms: This series of extreme (G5 [see Appendix C for an explanation of the space weather G-scale]) CME-driven geomagnetic storms in late October and early November 2003 (around solar maximum) resulted in widespread space weather effects, including multiple satellite anomalies and losses, power grid disruptions and outages, recorded impacts on GPS, loss of the satellite tracking catalog, emergency diversions of polar flights to lower latitudes, and aurora observed across the southern United States (Arizona, New Mexico, Texas, Oklahoma). See Pulkkinen et al. (2005) for further details.

2010 Galaxy 15 Satellite Event: This event is one of hundreds of documented cases of satellite anomalies associated with and attributed to space weather. The Galaxy 15 anomaly resulted in a loss of capability to receive ground commands and the satellite drifting uncontrollably out of its orbit, affecting services for Intelsat customers. The fault was attributed to an electrostatic discharge affecting an electrical device onboard the space vehicle. See Loto'aniu et al. (2015) for further details.

2022 Starlink Event: Shortly after their launch in February 2022, SpaceX lost control of the majority of 49 Starlink satellites as a result of thermospheric expansion and enhanced density during a moderate geomagnetic storm. Ultimately, 38 of those 49 satellites were lost as a result of unanticipated atmospheric reentry—a loss of $10–20 million to SpaceX within only a matter of hours. See Berger et al. (2023) and Fang et al. (2022) for further details.

December 2023 Solar Radio Burst and Aviation Blackout: A solar radio burst—the most intense ever recorded—effectively jammed high-frequency line-of-sight communications over much of the sunlit portion of Earth. All communications were lost between air traffic control and every plane flying over the U.S. West Coast for approximately 8 minutes. See this CBS News report for more details.

Appendix C: NOAA SWPC and the Space Weather Scales

NOAA SWPC can provide approximately 18–72 hours of advance warning before a space weather event impact. However, many of the important characteristics of the space weather event will not be known until approximately 30 minutes before it impacts Earth. The SWPC warning provides limited information concerning a geomagnetic storm's impacts and what locations will be impacted; the true effects will only be determined once the storm arrives and impacts to critical infrastructure become evident. If a G4–G5 geomagnetic storm event is predicted with S4–S5 solar radiation (see the explanation of the space weather R-, S-, and G-scales on the next page), the Federal Emergency Management Agency (FEMA) Operations Center will notify FEMA leadership and the National and Regional Watch Centers, and an email will be distributed. In the case of an S5 or G5 event, notification will be sent over the National Warning System NAWAS/Washington Metropolitan Area Warning System (WAWAS).

For further details on these scales, see NOAA SWPC's website. Throughout the exercise, participants can expect to receive updates on the current scale levels during the scenario timeline. These scales do not offer definitive or comprehensive insight into all aspects of space weather effects. There is an ongoing discussion within the space weather research and operations community to consider upgrades to the scales system.

Currently, NOAA SWPC uses three scale systems—the R-, S-, and G-scales—to evaluate the severity of space weather at Earth. The R-scale corresponds to solar radio blackouts:

Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
R 5	Extreme	**HF Radio:** Complete HF (high frequency) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. **Navigation:** Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 (2×10^{-3})	Less than 1 per cycle
R 4	Severe	**HF Radio:** HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. **Navigation:** Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	**HF Radio:** Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	**HF Radio:** Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navigation signals for tens of minutes.	M5 (5×10^{-5})	350 per cycle (300 days per cycle)
R 1	Minor	**HF Radio:** Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

The S-scale corresponds to solar radiation “storms”:

Scale	Description	Effect	**Physical measure** (Flux level of >= 10 MeV particles)	**Average Frequency** (1 cycle = 11 years)
S 5	**Extreme**	**Biological:** Unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. **Other systems:** Complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	**Severe**	**Biological:** Unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** May experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. **Other systems:** Blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	**Strong**	**Biological:** Radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. **Other systems:** Degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	**Moderate**	**Biological:** Passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk. **Satellite operations:** Infrequent single-event upsets possible. **Other systems:** Small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	**Minor**	**Biological:** None. **Satellite operations:** None. **Other systems:** Minor impacts on HF radio in the polar regions.	10	50 per cycle

SPACE WEATHER
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The G-scale corresponds to geomagnetic activity and storms:

Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
G 5	Extreme	**Power systems:** Widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. **Spacecraft operations:** May experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. **Other systems:** Pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).	Kp = 9	4 per cycle (4 days per cycle)
G 4	Severe	**Power systems:** Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. **Spacecraft operations:** May experience surface charging and tracking problems, corrections may be needed for orientation problems. **Other systems:** Induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).	Kp = 8, including a 9-	100 per cycle (60 days per cycle)
G 3	Strong	**Power systems:** Voltage corrections may be required, false alarms triggered on some protection devices. **Spacecraft operations:** Surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. **Other systems:** Intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).	Kp = 7	200 per cycle (130 days per cycle)
G 2	Moderate	**Power systems:** High-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. **Spacecraft operations:** Corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. **Other systems:** HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).	Kp = 6	600 per cycle (360 days per cycle)
G 1	Minor	**Power systems:** Weak power grid fluctuations can occur. **Spacecraft operations:** Minor impact on satellite operations possible. **Other systems:** Migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).	Kp = 5	1700 per cycle (900 days per cycle)

Appendix D: Glossary of Key Terms

See the SWx TTX1 glossary (https://spaceweather-ttx.jhuapl.edu/files/SWx_TTX_Glossary.pdf) for a listing of key terms, including links for more information.

D.2. Agenda – EXERCISE

Space Weather Tabletop Exercise (SWx TTX) Agenda

DAY 1 AGENDA (MAY 8, 2024) Asynchronous times until 2:30 ET/12:30 MT			
ET	LAUREL, MD	MT	DENVER, CO
7:00	Arrivals and Registration		
8:00	Welcome and Introductions		
8:30	Logistics and Intro to Software		
9:00	Space Weather 101		
9:30	Intro to Space Weather Prediction		
10:00	Break		
10:15	NASA: Artemis Contingency Plans		
10:30	Overview: NRF and NIMS		
11:00	Overview: FOC for Impending SWx Events	9:00	Arrivals and Registration
11:30	Lunch	9:30	Welcome and Introductions
		9:45	Background, Instructions, Logistics
		10:00	Space Weather 101
12:30	MODULE 1: Solar Drivers	10:30	Intro to Space Weather Prediction
		11:00	Overview: FOC for Impending SWx Events
		11:15	Intro to Hybrid TTX and R8
		11:30	Lunch Break for R8
2:00	MODULE 1: Hotwash		
2:15	Break		
R8 joins via Zoom: Injects will be the same at each location, but questions and discussions will vary. We encourage information sharing and inquiries between locations.			
2:30	MODULE 2: Geomagnetic Storm	12:30	MODULE 2: Geomagnetic Storm
4:30	MODULE 2: Hotwash	2:30	MODULE 2: Hotwash
4:45	Day 1 Wrap-up	2:45	Day 1 Wrap-up
5:00	Adjourn	3:00	Adjourn

EXERCISE EXERCISE EXERCISE

FEMA JOHNS HOPKINS APPLIED PHYSICS LABORATORY

EXERCISE EXERCISE EXERCISE

SPACE WEATHER
TABLETOP EXERCISE

Space Weather Tabletop Exercise (SWx TTX) Agenda

DAY 2 AGENDA (MAY 9, 2024)			
ET	LAUREL MD	MT	DENVER CO
8:30	Arrivals and Registration	6:30	Arrivals and Registration
9:30	Welcome and Recap from Day 1	7:30	Welcome and Recap from Day 1
10:00	Background and Logistics	8:00	Background and Logistics
10:15	Break	8:15	Break
10:30	MODULE 3: Intensifying Storm	8:30	MODULE 3: Intensifying Storm
12:00	Lunch	10:00	Brunch
1:00	MODULE 3: Continued	11:00	MODULE 3: Continued
2:15	MODULE 3: Hotwash	12:15	MODULE 3: Hotwash
2:30	Break	12:30	Break
2:45	MODULE 4: Response and Recovery	12:45	MODULE 4: Response and Recovery
4:00	MODULE 4: Hotwash	2:00	MODULE 4: Hotwash
4:15	Joint Hotwash	2:15	Joint Hotwash
4:45	Closing Comments: A Word from Our Sponsors	2:45	Closing Comments: A Word from Our Sponsors
5:00	Adjourn	3:00	Adjourn

EXERCISE EXERCISE EXERCISE

FEMA JOHNS HOPKINS APPLIED PHYSICS LABORATORY

D.3. Injects

D.3.1. Inject 1.1 – EXERCISE

SPACE WEATHER
TABLETOP EXERCISE

EXERCISE EXERCISE

Space Weather Message Code: ALTXMF
Serial Number: 284
Issue Time: 2028 Jan 26 1910 UTC

ALERT: X-Ray Flux exceeded M5
Threshold Reached: 2028 Jan 26 1908 UTC
NOAA Scale: R2 - Moderate

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact centered on sub-solar point on the sunlit side of
Earth. Extent of blackout of HF (high frequency) radio communication dependent
upon current X-ray Flux intensity. For real-time information on affected area and
expected duration please see
http://www.swpc.noaa.gov/products/d-region-absorption-predictions-d-rap.

EXERCISE PAGE 1 OF 2 EXERCISE

Space Weather Message Code: WARPX1
Serial Number: 488
Issue Time: 2028 Jan 26 1930 UTC

WARNING: Proton 10MeV Integral Flux above 10pfu expected
Valid From: 2028 Jan 26 1928 UTC
Valid To: 2028 Jan 27 0200 UTC
Warning Condition: Onset
Predicted NOAA Scale: S1 - Minor

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Radio - Minor impacts on polar HF (high frequency) radio propagation
resulting in fades at lower frequencies.

D.3.2. Inject 1.2 – EXERCISE

EXERCISE SPACE WEATHER TABLETOP EXERCISE EXERCISE

```
Space Weather Message Code: SUMXM5
Serial Number: 215
Issue Time: 2028 Jan 26 1951 UTC

SUMMARY: X-ray Event exceeded M5
Begin Time: 2028 Jan 26 1908 UTC
Maximum Time: 2028 Jan 26 1935 UTC
End Time: 2028 Jan 26 1949 UTC
X-ray Class: M6.6
Location: S21W20
NOAA Scale: R2 - Moderate

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact centered primarily on sub-
     solar point on the sunlit side of Earth.
HF Radio: HF radio communication blackout on most of the sunlit
     side of Earth for one to two hours. HF radio contact lost
     during this time.
Navigation: Outages of low-frequency navigation signals cause
     increased error in positioning for one to two hours. Minor
     disruptions of satellite navigation possible on the sunlit
     side of Earth.
```

EXERCISE PAGE 1 OF 3 EXERCISE

Space Weather Message Code: WATA50
Serial Number: 70
Issue Time: 2028 Jan 27 0114 UTC

WATCH: Geomagnetic Storm Category G3 Predicted

Highest Storm Level Predicted by Day:
Jan 28: G3 (Strong) Feb 29: G2 (Moderate) Mar 30: None (Below G1)

THIS SUPERSEDES ANY/ALL PRIOR WATCHES IN EFFECT

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact primarily poleward of 50 degrees Geomagnetic Latitude.
Induced Currents - Power system voltage irregularities possible, false alarms may be triggered on some protection devices.
Spacecraft - Systems may experience surface charging; increased drag on low Earth-orbit satellites and orientation problems may occur.
Navigation - Intermittent satellite navigation (GPS) problems, including loss-of-lock and increased range error may occur.
Radio - HF (high frequency) radio may be intermittent.
Aurora - Aurora may be seen as low as Pennsylvania to Iowa to Oregon.

Space Weather Message Code: ALTPX1
Serial Number: 324
Issue Time: 2028 Jan 27 0121 UTC

ALERT: Proton Event 10MeV Integral Flux exceeded 10pfu
Begin Time: 2028 Jan 27 0107 UTC
NOAA Scale: S1 - Minor

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Radio – Minor impacts on polar HF (high frequency) radio propagation
Resulting in fades at lower frequencies.

Space Weather Message Code: ALTPX2
Serial Number: 365
Issue Time: 2028 Jan 27 0549 UTC

ALERT: Proton Event 10MeV Integral Flux exceeded 100pfu
Begin Time: 2028 Jan 27 0535 UTC
NOAA Scale: S2 - Moderate

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts:
Biological: Passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.
Satellite operations: Infrequent single-event upsets possible.
Other systems: Small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.

D.3.3. Inject 1.3 – EXERCISE

SPACE WEATHER
TABLETOP EXERCISE

EXERCISE EXERCISE

Space Weather Message Code: ALTXMF
Serial Number: 225
Issue Time: 2028 Jan 28 1422 UTC

ALERT: X-Ray Flux exceeded M5
Threshold Reached: 2028 Jan 28 1420 UTC
NOAA Scale: R2 - Moderate

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact centered primarily on sub-solar point on the sunlit side of Earth.
HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time.
Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.
For real-time information on affected area and expected duration please see
http://www.swpc.noaa.gov/products/d-region-absorption-predictions-d-rap.

EXERCISE PAGE 1 OF 3 EXERCISE

Space Weather Message Code: ALTPX3
Serial Number: 347
Issue Time: 2028 Jan 28 1522 UTC

ALERT: Proton Event 10MeV Integral Flux exceeded 1000pfu
Begin Time: 2028 Jan 28 1519 UTC
NOAA Scale: S3 - Strong

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts:
HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth.
Navigation: Low-frequency navigation signals degraded for about an hour.

ABOVE ALERT PRECEDED BY S1 AND S2 ALERTS

Space Weather Message Code: WATA50
Serial Number: 75
Issue Time: 2028 Jan 28 1556 UTC

WATCH: Geomagnetic Storm Category G4 or Greater Predicted

Highest Storm Level Predicted by Day:
Jan 29: G4 (Severe) Jan 30: G4 (Severe) Jan 31: G3 (Strong)

THIS SUPERSEDES ANY/ALL PRIOR WATCHES IN EFFECT

Comment: Combined impacts from the anticipated arrival of the 26 Jan CME, and the addition of the 28 Jan CME warrant an increased Geomagnetic Watch readiness to the G4 level.

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact primarily poleward of 45 degrees Geomagnetic Latitude.
Induced Currents - Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid, induced pipeline currents affect preventive measures.
Spacecraft - May experience surface charging and tracking problems, corrections may be needed for orientation problems.
Navigation - Satellite navigation (GPS) degraded for hours, low-frequency radio navigation disrupted
Radio - HF (high frequency) radio propagation sporadic
Aurora - Aurora may be seen as low as Alabama and northern California.

D.3.4. Inject 2.1 – EXERCISE

Space Weather Message Code: SUMX10
Serial Number: 206
Issue Time: 2028 Jan 28, 1557 UTC

SUMMARY: X-ray Event exceeded X10
Begin Time: 2028 Jan 28 1420 UTC
Maximum Time: 2028 Jan 28 1514 UTC
End Time: 2028 Jan 28 1531 UTC
X-ray Class: X10.6
Location: S12W44
NOAA Scale: R4 - Severe

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact centered primarily on sub-solar point on the sunlit side of Earth.
HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time.
Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.

Space Weather Message Code: ALTK07
Serial Number: 123
Issue Time: 2028 Jan 28 1638 UTC

ALERT: Geomagnetic K-index of 7
Threshold Reached: 2028 Jan 28 1632 UTC
Synoptic Period: 1500-1800 UTC

Active Warning: Yes
NOAA Scale: G3 - Strong

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact primarily poleward of 45 degrees Geomagnetic Latitude.
Induced Currents - Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid.
Spacecraft - May experience surface charging and tracking problems, corrections may be needed for orientation problems.
Navigation - Satellite navigation degraded for hours, low-frequency radio navigation disrupted
Radio - HF (high frequency) radio propagation sporadic.
Aurora - Aurora has been seen as low as Alabama and northern California

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D.3.5. Inject 2.2 – EXERCISE

SPACE WEATHER
TABLETOP EXERCISE

EXERCISE EXERCISE

Space Weather Message Code: SUMX01
Serial Number: 203
Issue Time: 2028 Jan 28 1603 UTC

SUMMARY: X-ray Event exceeded X1
Begin Time: 2028 Jan 28 1420 UTC
Maximum Time: 2028 Jan 28 1514 UTC
End Time: 2028 Jan 28 1557 UTC
X-ray Class: X10.6
Location: S12W44
NOAA Scale: R3 - Strong

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact centered primarily on sub-solar point on the sunlit side of Earth.
HF Radio: Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes.
Navigation: Degradation of low-frequency navigation signals for tens of minutes.

ABOVE SUMMARY FOLLOWED BY M5 (R2) SUMMARY REPORT

EXERCISE PAGE 1 OF 3 EXERCISE

Space Weather Message Code: ALTK08
Serial Number: 130
Issue Time: 2028 Jan 28 1148 UTC

ALERT: Geomagnetic K-index of 8
Threshold Reached: 2028 Jan 28 1143 UTC
Synoptic Period: 0900-1200 UTC

Active Warning: Yes
NOAA Scale: G4 - Severe

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact primarily poleward of 45 degrees Geomagnetic Latitude.
Induced Currents - Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid.
Spacecraft - May experience surface charging and tracking problems, corrections may be needed for orientation problems.
Navigation - Satellite navigation degraded for hours, low-frequency radio navigation disrupted
Radio - HF (high frequency) radio propagation sporadic.
Aurora - Aurora has been seen as low as Alabama and northern California

---

Space Weather Message Code: ALTPX4
Serial Number: 381
Issue Time: 2028 Jan 29 0300 UTC

ALERT: Proton Event 10MeV Integral Flux exceeded 10000pfu
Begin Time: 2028 Jan 29 0257 UTC
NOAA Scale: S4 - Severe

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts:
Biological: Unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.
Satellite operations: May experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded.
Other systems: Blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.

D.3.6. Inject 2.6 – EXERCISE

EXERCISE SPACE WEATHER TABLETOP EXERCISE EXERCISE

```
Space Weather Message Code: WARSUD
Serial Number: 219
Issue Time: 2028 Jan 30 0051 UTC

WARNING: Geomagnetic Sudden Impulse expected
Valid From: 2028 Jan 30 0109 UTC
Valid To: 2028 Jan 30 0209 UTC
IP Shock Passage Observed: 2028 Jan 30 0038 UTC

NOAA Space Weather Scale descriptions can be found at
www.swpc.gov/noaa-scales-explanation
```

EXERCISE PAGE 1 OF 1 EXERCISE

D.3.7. Inject 3.1 – EXERCISE

SPACE WEATHER
TABLETOP EXERCISE

EXERCISE EXERCISE

Space Weather Message Code: ALTPX4
Serial Number: 311
Issue Time: 2028 Jan 30 0111 UTC

ALERT: Proton Event 10MeV Integral Flux exceeded 10000pfu
Begin Time: 2028 Jan 30 0109 UTC
NOAA Scale: S4 - Severe

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts:
Biological: Unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.
Satellite operations: May experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded.
Other systems: Blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.

EXERCISE PAGE 1 OF 2 EXERCISE

Space Weather Message Code: ALTK09
Serial Number: 166
Issue Time: 2028 Jan 30 0114 UTC

ALERT: Geomagnetic K-index of 9
Threshold Reached: 2028 Jan 30 0111 UTC
Synoptic Period: 0000-0300 UTC

Active Warning: Yes
NOAA Scale: G5 - Extreme

NOAA Space Weather Scale descriptions can be found at
www.swpc.noaa.gov/noaa-scales-explanation

Potential Impacts: Area of impact primarily poleward of 40 degrees Geomagnetic Latitude.
Induced Currents - Possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Transformers may experience damage. Pipeline currents can reach hundreds of amps.
Spacecraft - May experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites.
Navigation - Satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours.
Radio - HF (high frequency) radio propagation may be impossible in many areas for one to two days.
Aurora - Aurora has been seen as low as Florida and southern Texas

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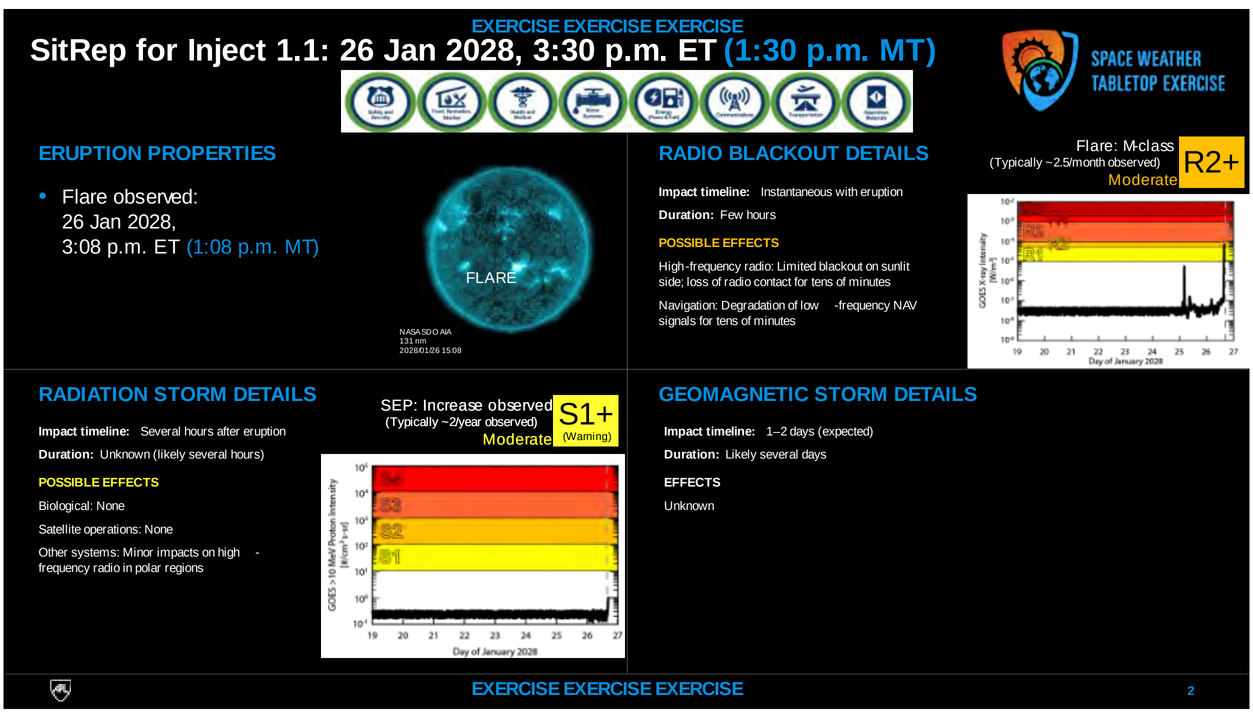
D.4. Situation Report Slides – EXERCISE



EXERCISE EXERCISE EXERCISE

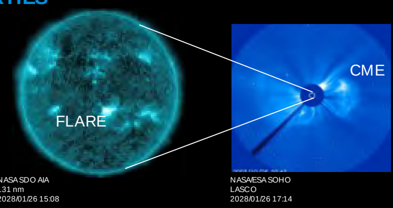
SitRep for Inject 1.2: 27 Jan 2028, 1:49 a.m. ET (11:49 p.m. MT)

10 hrs 19 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTION PROPERTIES

- Flare observed: 26 Jan 2028, 3:08 p.m. ET (1:08 p.m. MT)
- CME observed: 26 Jan 2028, 5:14 p.m. ET (3:14 p.m. MT)



RADIO BLACKOUT DETAILS

Flare: Ended
None
N/A

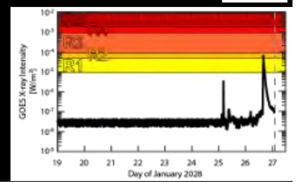
Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

High-frequency radio: Limited blackout on sunlit side; loss of radio contact for tens of minutes

Navigation: Degradation of low-frequency NAV signals for tens of minutes



RADIATION STORM DETAILS

SEP: Few observed
(Typically ~4.5/year observed)
Minor
S2

Impact timeline: Several hours after eruption

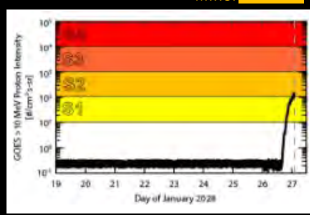
Duration: Unknown (likely several hours)

POSSIBLE EFFECTS

Biological: Exposure risk to humans in high-flying aircraft at high latitudes

Satellite operations: Infrequent single-event upsets

Other systems: Small effects on high-frequency propagation through the polar regions; navigation issues at polar cap locations



GEOMAGNETIC STORM DETAILS

Impact timeline: 30 hours after eruption

Predicted arrival: 27 Jan 2028, 9:08 p.m. ET (7:09 p.m. MT)

Duration: Likely several days

CME: Confirmed Halo
(Typically ~1.5/month observed)
Strong [predicted]
G3
(Watch)

POSSIBLE EFFECTS

Power systems: Voltage corrections; false alarms on protection devices

Spacecraft operations: Surface charging on satellite components; increased drag on low-Earth-orbit satellites; corrections for orientation problems

Other systems: Intermittent satellite navigation and low-frequency radio-frequency navigation issues, intermittent high-frequency comms; aurorae as low as Chicago, Pittsburgh

Geoeffectiveness unknown

EXERCISE EXERCISE EXERCISE

3

EXERCISE EXERCISE EXERCISE

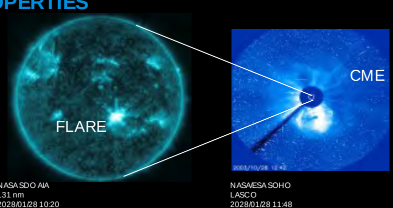
SitRep for Inject 1.3: 28 Jan 2028, 11:57 a.m. ET (9:57 a.m. MT)

34 hrs, 8 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTION (#2) PROPERTIES

- Flare observed: 28 Jan 2028, 10:20 a.m. ET (8:20 a.m. MT)
- CME observed: 28 Jan 2028, 11:48 a.m. ET (9:48 a.m. MT)



RADIO BLACKOUT DETAILS

Flare: X-class
(Typically ~1/year observed)
Severe
R4

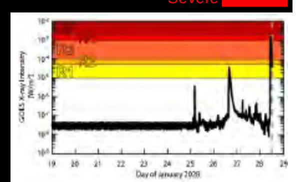
Impact timeline: Instantaneous with flare

Duration: Few hours

REPORTED EFFECTS

High-frequency radio: Interruptions in North/South America and Western Europe

Navigation: Reports of disrupted SatCom and very-high-frequency/high-frequency operations; widespread reports – loss of GNSS/GPS location and timing accuracy



RADIATION STORM DETAILS

SEP: Significant increase
(Typically ~1/year observed)
Strong
S3

Impact timeline: Tens of minutes after flare

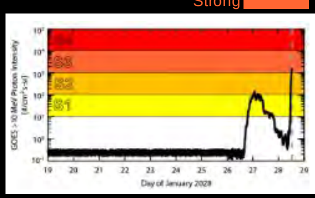
Duration: Unknown (likely several hours)

POSSIBLE EFFECTS

Biological: Avoidance recommended for astronauts on extravehicular activity (EVA); exposure risk to humans in aircraft at high latitudes

Satellite operations: Single-event upsets, noise in imaging systems, slight reduction in solar panel efficiency

Other systems: Degraded high-frequency propagation at polar regions, navigation position errors



GEOMAGNETIC STORM (#2) DETAILS

Impact timeline: ~22 hours after eruption

Predicted arrival: 29 Jan 2028, 8:25 a.m. ET (6:25 a.m. MT)

Duration: Likely several days

CME: Confirmed Halo
(Typically ~1/month observed)
Severe [predicted]
G4+
(Watch)

POSSIBLE EFFECTS

Power systems: Widespread voltage control problems; protective systems will mistakenly trip out key assets from grid

Spacecraft operations: Surface charging and tracking problems; corrections may be needed for orientation

Other systems: Induced pipeline currents affect preventive measures; high-frequency radio propagation sporadic; satellite navigation degraded for hours; low-frequency radio navigation disrupted; aurorae seen in AL, northern CA

Geoeffectiveness unknown

EXERCISE EXERCISE EXERCISE

4

SitRep for Inject 1.4: 28 Jan 2028, 1:00 p.m. ET (11:00 a.m. MT)

1 hr, 3 mins since previous inject

SPACE WEATHER
TABLETOP EXERCISE

NO UPDATE

EXERCISE EXERCISE EXERCISE

SitRep for Inject 2.1: 28 Jan 2028, 2:38 p.m. ET (12:38 p.m. MT)

1 hr, 38 mins since previous inject

SPACE WEATHER
TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, 8:25 a.m. ET (6:25 a.m. MT)

NASA/ESA SOHO
LASCO
2028/01/26 17:14

NASA/ESA SOHO
LASCO
2028/01/28 11:48

RADIO BLACKOUT DETAILS

Flare: X-class
(Typically ~1/month observed)
Strong
R3

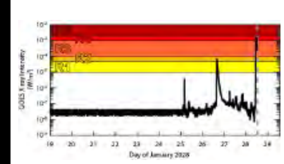
Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

High-frequency radio: Wide area blackout of high-frequency radio communication; loss of radio contact for about an hour on sunlit side of Earth

Navigation: Low-frequency navigation signals degraded ~1 hour



RADIATION STORM DETAILS

Impact timeline: Tens of minutes after flare

Duration: Unknown (likely several hours)

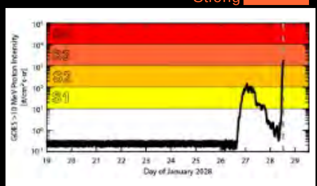
POSSIBLE EFFECTS

Biological: Avoidance recommended for astronauts on EVA; exposure risk to humans in aircraft at high latitudes

Satellite operations: Single-event upsets, noise in imaging systems, slight reduction in solar panel efficiency

Other systems: Degraded high-frequency propagation at polar regions, navigation position errors

SEP: Increase observed
(Typically ~1/year observed)
Strong
S3



GEOMAGNETIC STORM (#1) DETAILS

Impact timeline: 47.5 hours after eruption (arrived 17.5 hours later than predicted)

Duration: Likely several days

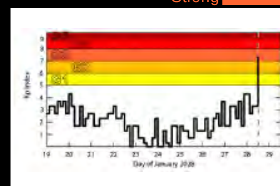
POSSIBLE EFFECTS

Power systems: Voltage corrections; false alarms on protection devices

Spacecraft operations: Surface charging on satellite components; increased drag on low-Earth-orbit satellites; corrections for orientation problems

Other systems: Intermittent satellite navigation and low-frequency radio-frequency navigation issues; intermittent high-frequency radio; aurorae as low as Chicago, Pittsburgh

Storm: Kp = 7
(Typically ~2/month observed)
Strong
G3



EXERCISE EXERCISE EXERCISE

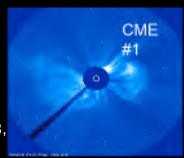
SitRep for Inject 2.2: 28 Jan 2028, 11:16 p.m. ET (9:16 p.m. MT)

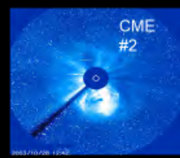
8 hrs, 38 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, 8:25 a.m. ET (6:25 a.m. MT)





RADIO BLACKOUT DETAILS

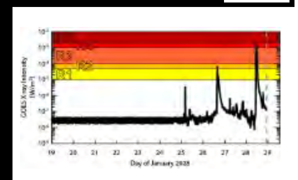
Flare: Ended N/A
None

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

Impact timeline: Several hours after eruption

Duration: Unknown (likely several hours)

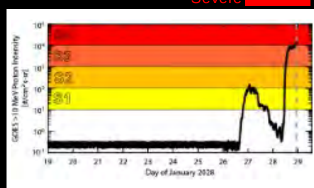
SEP: Increase observed S4
(Typically ~3/decade observed)
Severe

POSSIBLE EFFECTS

Biological: Unavoidable hazard to EVA astronauts; exposure risk to humans in aircraft at high latitudes

Satellite operations: Memory device problems and imaging system noise; star tracker orientation problems; degraded solar panel efficiency

Other systems: High -frequency comms blackout through polar regions; increased navigation errors over several days



GEOMAGNETIC STORM (#1) DETAILS

Impact timeline: 47.5 hours after eruption (arrived 17.5 hours later than predicted)

Duration: Likely several days

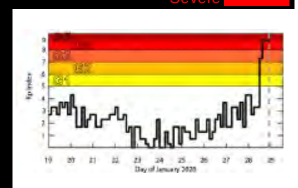
Storm: Kp = 8 G4
(Typically ~1/month observed)
Severe

POSSIBLE EFFECTS

Power systems: Voltage corrections required; false alarms on protection devices

Spacecraft operations: Surface charging on satellite components; increased drag on low -Earth -orbit satellites; corrections for orientation problems

Other systems: Intermittent satellite navigation and low-frequency radio -frequency navigation issues; intermittent high -frequency radio; aurorae as low as Chicago , Pittsburgh



EXERCISE EXERCISE EXERCISE 7

EXERCISE EXERCISE EXERCISE

SitRep for Inject 2.3: 29 Jan 2028, 12:15 a.m. ET (10:15 p.m. MT)

59 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, 8:25 a.m. ET (6:25 a.m. MT)

RADIO BLACKOUT DETAILS

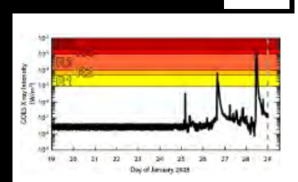
Flare: Ended N/A
None

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

Impact timeline: Several hours after eruption

Duration: Unknown (likely several hours)

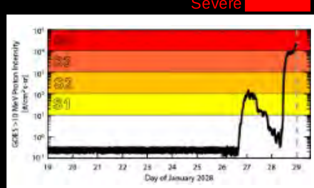
SEP: Increase observed S4
(Typically ~3/decade observed)
Severe

POSSIBLE EFFECTS

Biological: Unavoidable hazard to EVA astronauts; exposure risk to humans in aircraft at high latitudes

Satellite operations: Memory device problems and imaging system noise; star tracker orientation problems; degraded solar panel efficiency

Other systems: High -frequency comms blackout through polar regions; increased navigation errors over several days



GEOMAGNETIC STORM (#1) DETAILS

Impact timeline: 47.5 hours after eruption (arrived 17.5 hours later than predicted)

Duration: Likely several days

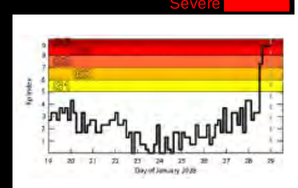
Storm: Kp = 8 G4
(Typically ~1/month observed)
Severe

POSSIBLE EFFECTS

Power systems: Voltage corrections required; false alarms on protection devices

Spacecraft operations: Surface charging on satellite components; increased drag on low -Earth - orbit satellites; corrections for orientation problems

Other systems: Intermittent satellite navigation and low-frequency radio -frequency navigation issues; intermittent high -frequency radio; aurorae as low as Chicago , Pittsburgh



EXERCISE EXERCISE EXERCISE 8

EXERCISE EXERCISE EXERCISE

SitRep for Inject 2.4: 29 Jan 2028, 7:00 a.m. ET (5:00 a.m. MT)

6 hrs, 45 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

NO UPDATE

EXERCISE EXERCISE EXERCISE 9

EXERCISE EXERCISE EXERCISE

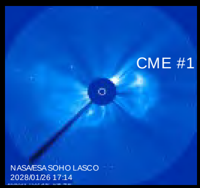
SitRep for Inject 2.5: 29 Jan 2028, 2:27 p.m. ET (12:27 p.m. MT)

7 hrs, 27 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, 8:25 a.m. ET (6:25 a.m. MT)



RADIO BLACKOUT DETAILS

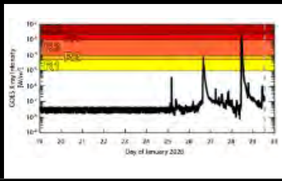
Flare: Ended
None
N/A

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

Impact timeline: Several hours after eruption

Duration: Unknown (likely several hours)

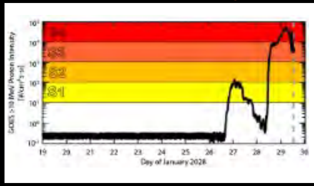
SEP: Increase observed
(Typically ~1/year observed)
Strong
S3

POSSIBLE EFFECTS

Biological: Avoidance recommended for astronauts on EVA; exposure risk to humans in aircraft at high latitudes

Satellite operations: Single-event upsets, noise in imaging systems, slight reduction in solar panel efficiency

Other systems: Degraded high-frequency propagation at polar regions, navigation position errors



GEOMAGNETIC STORM (#1) DETAILS

Impact timeline: 47.5 hours after eruption (arrived 17.5 hours later than predicted)

Duration: Likely several days

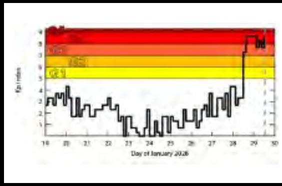
Storm: Kp = 8
(Typically ~1/month observed)
Severe
G4

POSSIBLE EFFECTS

Power systems: Voltage corrections required; false alarms on protection devices

Spacecraft operations: Surface charging on satellite components; increased drag on low-Earth-orbit satellites; corrections for orientation problems

Other systems: Intermittent satellite navigation and low-frequency radio-frequency navigation issues; intermittent high-frequency radio; aurorae as low as Chicago, Pittsburgh



EXERCISE EXERCISE EXERCISE 10

EXERCISE EXERCISE EXERCISE

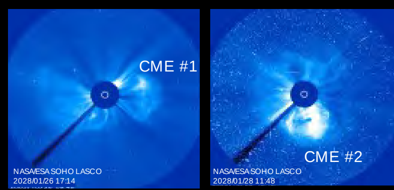
SitRep for Inject 2.6: 29 Jan 2028, 8:53 p.m. ET (6:53 p.m. MT)

6 hrs, 26 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, 8:25 a.m. ET (6:25 a.m. MT)



RADIO BLACKOUT DETAILS

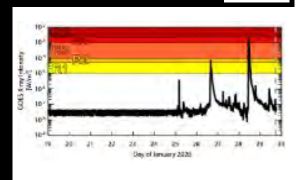
Flare: Ended
None
N/A

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

Impact timeline: Several hours after eruption

Duration: Unknown (likely several hours)

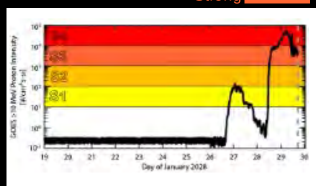
SEP: Increase observed
(Typically ~1/year observed)
Strong
S3

POSSIBLE EFFECTS

Biological: Avoidance recommended for astronauts on EVA; exposure risk to humans in aircraft at high latitudes

Satellite operations: Single-event upsets, noise in imaging systems, slight reduction in solar panel efficiency

Other systems: Degraded high-frequency propagation at polar regions, navigation position errors



GEOMAGNETIC STORM (#2) DETAILS

Impact timeline: Imminent (~30 min) (arrived 12.5 hours later than predicted)

Duration: Likely several days

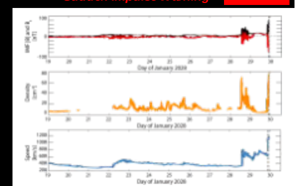
CME: Observed at L1
Potentially highly geoeffective
Sudden Impulse Warning
G4

POSSIBLE EFFECTS

Power systems: Voltage corrections required; false alarms on protection devices

Spacecraft operations: Surface charging on satellite components; increased drag on low-Earth orbit satellites; corrections for orientation problems

Other systems: Intermittent satellite navigation; low-frequency radio-frequency navigation issues; sporadic high-frequency radio; aurorae as low as Chicago, Pittsburgh



EXERCISE EXERCISE EXERCISE

11

EXERCISE EXERCISE EXERCISE

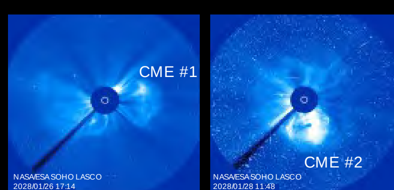
SitRep for Inject 3.1: 29 Jan 2028, 9:14 p.m. ET (7:14 p.m. MT)

21 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, ~9:15 a.m. ET (~7:15 a.m. MT)



RADIO BLACKOUT DETAILS

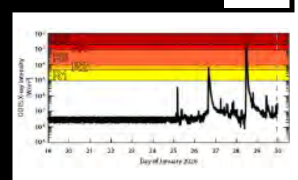
Flare: Ended
None
N/A

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

Impact timeline: Several hours after eruption

Duration: Unknown (likely several hours)

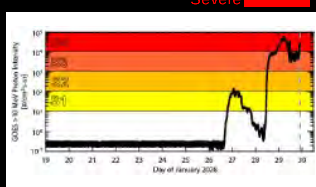
SEP: Increase observed
(Typically ~3/decade observed)
Severe
S4

POSSIBLE EFFECTS

Biological: Unavoidable hazard to EVA astronauts; exposure risk to humans in aircraft at high latitudes

Satellite operations: Memory device problems and imaging system noise; star tracker orientation problems; degraded solar panel efficiency

Other systems: High-frequency comms blackout through polar regions; increased navigation errors over several days



GEOMAGNETIC STORM (#2) DETAILS

Impact timeline: 22 hours after eruption (arrived 12.5 hours later than predicted)

Duration: Likely several days

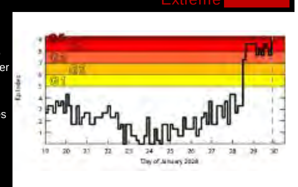
Storm: Kp = 9
(Typically ~4/decade observed)
Extreme
G5

POSSIBLE EFFECTS

Power systems: Widespread voltage control and protective system issues; some grid collapse or blackouts; transformer damage

Spacecraft operations: Extensive surface charging orientation problems, uplink/downlink and tracking satellites

Other systems: Pipeline currents can reach 100 A; high frequency comms impossible in many areas for 1-2 days; satellite navigation degraded for days; low-frequency radio navigation out for hours; aurorae as low as FL and southern TX



EXERCISE EXERCISE EXERCISE

12

EXERCISE EXERCISE EXERCISE

SitRep for Inject 3.2: 29 Jan 2028, 9:52 p.m. ET (7:52 p.m. MT)

38 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, ~9:15 a.m. ET (~7:15 a.m. MT)

RADIO BLACKOUT DETAILS

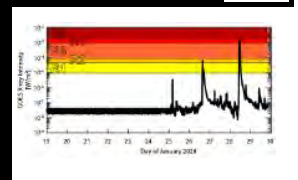
Flare: Ended
None
N/A

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

Impact timeline: Several hours after eruption

Duration: Unknown (likely several hours)

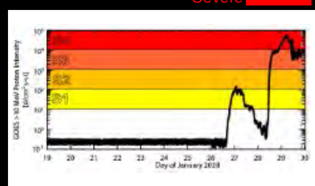
SEP: Flux still elevated
(Typically ~3/decade observed)
Severe
S4

POSSIBLE EFFECTS

Biological: Unavoidable hazard to EVA astronauts; human exposure risk in high -flying aircraft at high latitudes

Satellite operations: Memory device problems and imaging system noise; star tracker orientation problems; degraded solar panel efficiency

Other systems: High -frequency comms blackout through polar regions; increased navigation errors over several days



GEOMAGNETIC STORM (#2) DETAILS

Impact timeline: ~40 min since arrival

Duration: Likely several days

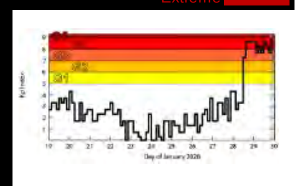
Storm: Kp = 9
(Typically ~4/decade observed)
Extreme
G5

POSSIBLE EFFECTS

Power systems: Widespread voltage control problems and protective system issues; some grid collapse or blackouts; transformer damage

Spacecraft operations: Extensive surface charging orientation problems, uplink/downlink and tracking satellites

Other systems: Pipeline currents can reach 100 A; high-frequency comms impossible in many areas for 1–2 days; satellite navigation degraded for days; low-frequency radio navigation out for hours; aurorae as low as FL and southern TX



EXERCISE EXERCISE EXERCISE

13

EXERCISE EXERCISE EXERCISE

SitRep for Inject 3.3: 29 Jan 2028, 10:43 p.m. ET (8:43 p.m. MT)

51 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, ~9:15 a.m. ET (~7:15 a.m. MT)

RADIO BLACKOUT DETAILS

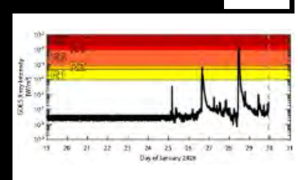
Flare: Ended
None
N/A

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

Impact timeline: Several hours after eruption

Duration: Unknown (likely several hours)

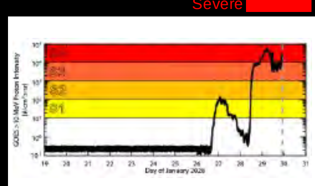
SEP: Flux still elevated
(Typically ~3/decade observed)
Severe
S4

POSSIBLE EFFECTS

Biological: Unavoidable hazard to EVA astronauts; human exposure risk in high -flying aircraft at high latitudes

Satellite operations: Memory device problems and imaging system noise; star tracker orientation problems; degraded solar panel efficiency

Other systems: High -frequency comms blackout through polar regions; increased navigation errors over several days



GEOMAGNETIC STORM (#2) DETAILS

Impact timeline: ~1.5 hours since arrival

Duration: Likely several days

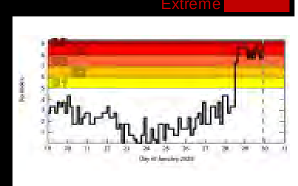
Storm: Kp = 9
(Typically ~4/decade observed)
Extreme
G5

POSSIBLE EFFECTS

Power systems: Widespread voltage control problems and protective system issues; some grid collapse or blackouts; transformer damage

Spacecraft operations: Extensive surface charging orientation problems, uplink/downlink and tracking satellites

Other systems: Pipeline currents can reach 100 A; high-frequency comms impossible in many areas for 1–2 days; satellite navigation degraded for days; low-frequency radio navigation out for hours; aurorae as low as FL and southern TX



EXERCISE EXERCISE EXERCISE

14

EXERCISE EXERCISE EXERCISE

SitRep for Inject 3.4: 29 Jan 2028, 11:39 p.m. ET (9:39 p.m. MT)

56 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, ~9:15 a.m. ET (~7:15 a.m. MT)

RADIO BLACKOUT DETAILS

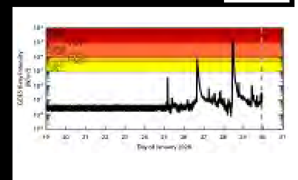
Flare: Ended None **N/A**

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

Impact timeline: Several hours after eruption

Duration: Unknown (likely several hours)

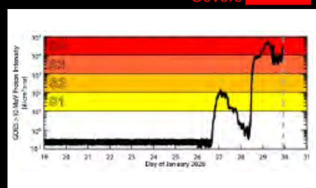
SEP: Flux still elevated (Typically ~3/decade observed) Severe **S4**

POSSIBLE EFFECTS

Biological: Unavoidable hazard to EVA astronauts; human exposure risk in aircraft at high latitudes

Satellite operations: Memory device problems and imaging system noise; star tracker orientation problems; degraded solar panel efficiency

Other systems: High -frequency comms blackout through polar regions; increased navigation errors over several days



GEOMAGNETIC STORM (#2) DETAILS

Impact timeline: ~2.5 hours since arrival

Duration: Likely several days

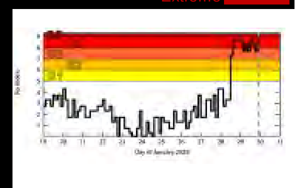
Storm: Kp = 9 (Typically ~4/decade observed) Extreme **G5**

POSSIBLE EFFECTS

Power systems: Widespread voltage control problems and protective system issues; some grid collapse or blackouts

Spacecraft operations: Extensive surface charging orientation problems, uplink/downlink and tracking satellites

Other systems: Pipeline currents can reach 100 A; high-frequency comms impossible in many areas for 1–2 days; satellite navigation degraded for days; low-frequency radio navigation out for hours; aurorae as low as FL, TX



EXERCISE EXERCISE EXERCISE

15

EXERCISE EXERCISE EXERCISE

SitRep for Inject 4.1: 30 Jan 2028, 8:00 a.m. ET (6:00 a.m. MT)

8 hrs, 21 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, ~9:15 a.m. ET (~7:15 a.m. MT)

RADIO BLACKOUT DETAILS

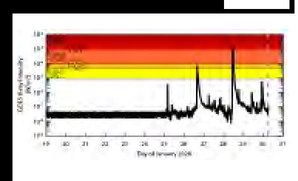
Flare: Ended None **N/A**

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

Impact timeline: Several hours after eruption

Duration: Unknown (likely several hours)

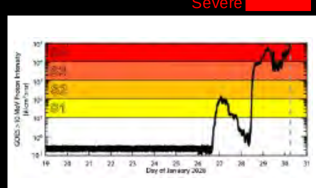
SEP: Flux still elevated (Typically ~3/decade observed) Severe **S4**

POSSIBLE EFFECTS

Biological: Unavoidable hazard to EVA astronauts; human exposure risk in aircraft at high latitudes

Satellite operations: Memory device problems and imaging system noise; star tracker orientation problems; degraded solar panel efficiency

Other systems: High -frequency comms blackout through polar regions; increased navigation errors over several days



GEOMAGNETIC STORM (#2) DETAILS

Impact timeline: ~11 hours since arrival

Duration: Likely several days

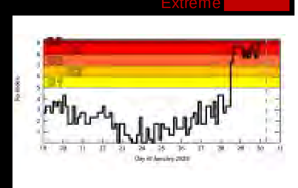
Storm: Kp = 9 (Typically ~4/decade observed) Extreme **G5**

POSSIBLE EFFECTS

Power systems: Widespread voltage control problems and protective system issues; some grid collapse or blackouts

Spacecraft operations: Extensive surface charging orientation problems, uplink/downlink and tracking satellites

Other systems: Pipeline currents can reach 100 A; high-frequency comms impossible in many areas for 1–2 days; satellite navigation degraded for days; low-frequency radio navigation out for hours; aurorae as low as FL, TX



EXERCISE EXERCISE EXERCISE

16

EXERCISE EXERCISE EXERCISE

SitRep for Inject 4.2: 30 Jan 2028, 12:00 p.m. ET (10:00 a.m. MT)

4 hrs since previous inject

SPACE WEATHER TABLETOP EXERCISE

NO UPDATE

EXERCISE EXERCISE EXERCISE 17

EXERCISE EXERCISE EXERCISE

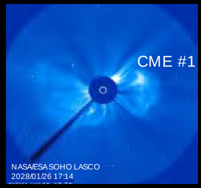
SitRep for Inject 4.3: 02 Feb 2028, 2:08 p.m. ET (12:08 p.m. MT)

2 days, 22 hrs since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, ~9:15 a.m. ET (~7:15 a.m. MT)



RADIO BLACKOUT DETAILS

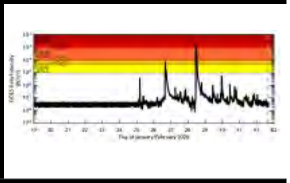
Flare: Ended
None
N/A

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

SEP: Few observed
(Typically ~4.5/year observed)
Minor
S1

Impact timeline: Several hours after eruption

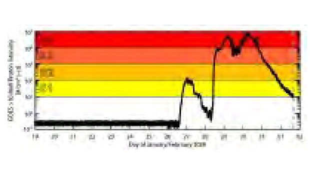
Duration: Unknown (likely several hours)

POSSIBLE EFFECTS

Biological: None

Satellite operations: None

Other systems: Minor impacts on high-frequency radio in polar regions



GEOMAGNETIC STORM (#2) DETAILS

Storm: Kp = 5
(Typically ~1/month observed)
Minor
G1

Impact timeline: ~70 hours since arrival

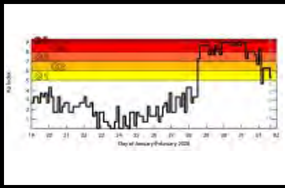
Duration: Likely several days

POSSIBLE EFFECTS

Power systems: Weak power grid fluctuations

Spacecraft operations: Minor impacts

Other systems: Migratory animals affected; aurorae commonly visible at high latitudes (MI, ME)



EXERCISE EXERCISE EXERCISE 18

EXERCISE EXERCISE EXERCISE

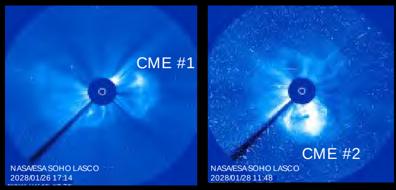
SitRep for Inject 4.4: 03 Feb 2028, 9:20 a.m. ET (7:20 a.m. MT)

19 hrs, 12 mins since previous inject

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, ~9:15 a.m. ET (~7:15 a.m. MT)



RADIO BLACKOUT DETAILS

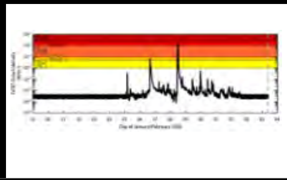
Flare: Ended
None
N/A

Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

None



RADIATION STORM DETAILS

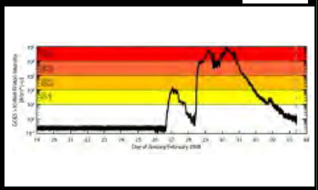
SEP details: Flux low
None
N/A

Impact timeline:

Duration:

POSSIBLE EFFECTS

None



GEOMAGNETIC STORM (#2) DETAILS

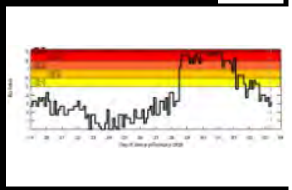
Storm: Kp < 4
None
N/A

Impact timeline: 4.5 days since arrival

Duration: Transitioning

POSSIBLE EFFECTS

None



EXERCISE EXERCISE EXERCISE

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Appendix E. Glossary and Acronym List

E.1. Glossary

A-class (solar flare):

The weakest classification level for solar flares; A-class flares have peak soft X-ray intensities ranging from 10^{-8} to 10^{-7} W/m^2.

Advanced Composition Explorer (ACE):

The satellite observatory at the first Sun-Earth Lagrange point (L1). It is responsible for collecting observational space weather data from the Sun and assessing a solar wind incident's impact on Earth's magnetosphere.

Alert (as defined by NOAA's Space Weather Prediction Center [SWPC]):

Alerts indicate that the observed conditions, highlighted by the warnings, have crossed a preset threshold or that a space weather event has already started.

Astronomical unit (AU):

The average distance between the center of the Earth and the center of the Sun, equal to 149.6 million kilometers or 92.96 million miles. Earth is in a nearly circular orbit around the Sun.

B-class (solar flare):

A weak-intermediate classification level for solar flares; B-class flares have peak soft X-ray intensities ranging from 10^{-7} to 10^{-6} W/m^2.

Black start:

The ability of electricity generation plants to restart parts of the power system to recover from a blackout. This entails isolated power stations being started individually and gradually reconnected to one another to form an interconnected system again.

C-class (solar flare):

An intermediate classification level for solar flares; C-class flares have peak soft X-ray intensities ranging from 10^{-6} to 10^{-5} W/m^2.

Combatant Commands (COCOMs):

The Department of Defense has 11 combatant commands, each with a geographic or functional mission that provides command and control of military forces during peacetime and wartime.

Common operating picture (COP):

A continuously updated overview of an incident compiled throughout an incident's life cycle from data shared between integrated systems for communication, information management, and intelligence and information sharing.

Community Coordinated Modeling Center (CCMC):

NASA Goddard Space Flight Center space weather science and modeling center.

Community lifelines:

The seven community lifelines represent only the most basic services a community relies on—services that, when stable, enable all other activity within a community.

Contiguous United States (CONUS):

The 48 adjoining U.S. states and the District of Columbia; Alaska and Hawaii are not part of the contiguous United States.

Coronal mass ejection (CME):

A large, sudden, and coherent eruption of plasma and magnetic flux from the outer, hottest part of the Sun's atmosphere, the solar corona.

Cosmic rays:

A specific type of energetic particle radiation originating from the outer heliosphere, galaxy, and extragalactic sources.

Critical infrastructure:

There are 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof.

Cybersecurity and Infrastructure Security Agency (CISA):

CISA is the operational lead for federal cybersecurity and the national coordinator for critical infrastructure security and resilience. It is one component of the Department of Homeland Security.

Declarations:

There are two types of disaster declarations:

- A **major disaster declaration** provides more federal programs for response and recovery than an emergency declaration. This type of declaration may only be issued after an incident.

- An **emergency declaration** is more limited in scope than a major disaster declaration, involves fewer federal programs, and is not normally associated with recovery programs.

Defense Support of Civil Authorities (DSCA):

Support provided by U.S. federal military forces, Department of Defense (DoD) civilians, DoD contract personnel, DoD component assets, and, in coordination with governors, federally funded National Guard forces in response to requests for assistance from civil authorities.

Department of the Interior (DOI):

The agency that protects and manages the nation's natural resources and cultural heritage.

Disturbance storm-time (Dst) index:

Geomagnetic index compiled from low-latitude, ground-based magnetometers used to qualify geomagnetic storm events and classify their intensity.

Division of Homeland Security and Emergency Management (DHSEM):

Specifically the Colorado Division of Homeland Security and Emergency Management.

Electronvolt (eV):

A unit of energy. 1 megaelectronvolt (MeV) = 1,000,000 eV.

Emergency Alert System (EAS):

A national public warning system that requires radio and TV broadcasters, cable TV, wireless cable systems, and satellite and wireline operators to provide the president with the capability to address the American people within 10 minutes during a national emergency.

State, local, tribal, and territorial (SLTT) emergency managers also have access in order to distribute local alerts where authorized by the Federal Emergency Management Agency (FEMA) to become an Integrated Public Alert & Warning System (IPAWS) alerting authority.

Emergency Communications Center (ECC):

Also referred to as 911 centers or public safety answering points (PSAPs), ECCs receive calls for service from the community and dispatch police, fire, and rescue resources in response.

Emergency declaration:

More limited in scope than a major disaster declaration, an emergency declaration involves fewer federal programs and is not normally associated with recovery programs. However, the president may issue an emergency declaration before an actual incident to lessen the threat of or avert a catastrophe.

Emergency Operations Center (EOC):

The physical location at which the coordination of information and resources to support domestic incident management activities normally takes place.

Emergency Support Function (ESF):

The 15 ESFs provide the structure for coordinating interagency support for a federal response to an incident.

F10.7:

A routine space weather index based on solar radio emissions.

Federal Aviation Administration (FAA):

In addition to managing airspace and commercial spaceflight, the FAA supports research on identifying radiation hazards in the aviation environment and studies methods for protection from these hazards.

Federal Coordination Officer (FCO):

The FCO is responsible for coordinating the timely delivery of federal disaster assistance resources and programs to affected states, local and tribal governments, individual victims, and the private sector.

Federal Emergency Management Agency (FEMA):

The Department of Homeland Security agency responsible for helping people before and after disasters.

Federal Interagency Operational Plans (FIOPs):

FIOPs describe how the federal government aligns resources and delivers core capabilities to implement the five National Planning Frameworks.

Federal Operating Concept for Impending Space Weather Events:

This federal operating concept (FOC) provides guidance to departments and agencies, to be used in the development of their operational plans to prepare for, protect against, and mitigate the effects of impending space weather events.

Geomagnetically induced current (GIC):

A large-scale, direct current system resulting from changes in Earth's geomagnetic field associated with space weather events, such as geomagnetic substorms and storms (see next two entries).

Geomagnetic storm:

A period of enhanced geomagnetic activity within Earth's magnetosphere creating global effects.

Geomagnetic substorm:

A phenomenon in Earth's magnetosphere associated with enhanced ionospheric disturbances, auroral activity, and bursts of intense radiation, currents, and energy flows in near-Earth space.

Geostationary (or Geosynchronous) Earth orbit (GEO):

An orbital regime where satellites have an orbit period of approximately one sidereal Earth day (23.934472 hours). In Earth's equatorial plane, GEO is located at approximately 6.6 Earth radii (42,100 km) geocentric distance.

Geostationary Operational Environmental Satellites (GOES):

The National Oceanic and Atmospheric Administration (NOAA) operational satellites located in GEO on either side of North American local time. Each satellite carries a suite of weather and space weather payloads.

Global Navigation Satellite System (GNSS):

Satellite systems used for precision timing and position services. Several countries operate a number of GNSS constellations in near-Earth space.

Global Positioning System (GPS):

The U.S. Global Navigation Satellite System constellation, consisting of 26 satellites in near-Earth space providing precision timing and position services.

Ground-level event/ground-level enhancement (GLE):

A special subset of a solar energetic particle (SEP) event in which radiation levels are enhanced as measured by terrestrial, ground-based neutron monitors.

G-scale:

The official National Oceanic and Atmospheric Administration (NOAA) space weather scale index used to categorize the intensity and severity of geomagnetic storms and quantified based on the (K-planetary) Kp index. G-scale classification levels are as follows: G1, minor; G2, moderate; G3, strong; G4, severe; G5, extreme.

High-frequency (HF) radio:

Range of the electromagnetic spectrum spanning radio frequencies from 3 to 30 MHz. HF radio is used for a variety of communication applications, including military and government communication systems, aviation air-to-ground communications, and amateur radio.

Homeland Security Exercise Evaluation Program (HSEEP):

A set of guiding principles for exercise and evaluation programs as well as a common approach to emergency response exercise program management, design and development, conduct, evaluation, and improvement planning.

Integrated Public Alert & Warning System (IPAWS):

FEMA's national system for local alerting that provides authenticated emergency and life-saving information to the public through mobile phones using Wireless Emergency Alerts (WEAs), via radio and television using the Emergency Alert System (EAS), and via the National Oceanic and Atmospheric Administration's Weather Radio.

Ionizing radiation:

See "radiation" below. Ionizing radiation results in a total ionizing dose that adversely degrades materials in the human body and technological systems. Total ionizing dose is measured in "grays" (Gy) or "rads," while for human tissue impacts, effective dose is measured in units of "sieverts" (Sv) and "rems."

Ionosphere:

The region of Earth's upper atmosphere that is charged by solar and magnetospheric energy inputs, resulting in distinct layers of plasma that interact with Earth's magnetic field and neutral atmosphere.

Joint Field Office (JFO):

Joint Field Office is a temporary federal multiagency coordination center established locally to facilitate field-level domestic incident management activities.

Joint Information Center (JIC):

A physical location where public affairs professionals from organizations involved in incident management activities work together to provide critical emergency information, crisis communications, and public affairs support. It is established as a component of the Joint Field Office (JFO).

K-planetary (Kp) index:

A geomagnetic index compiled from ground-based magnetometers and used to quantify the level of general geomagnetic activity in Earth's magnetosphere. The Kp index is on a logarithmic scale and reported every 3 hours.

L1, 1st Sun-Earth Lagrange point:

L1 is located approximately 1 million miles sunward from Earth along the Sun-Earth line. Satellites are used at L1 for solar and solar wind monitoring.

L4, 4th Sun-Earth Lagrange point:

L4 is located approximately 60 degrees off of the Sun-Earth line, ahead of Earth in its orbit around the Sun.

L5, 5th Sun-Earth Lagrange point:

L5 is located approximately 60 degrees off of the Sun-Earth line, behind Earth in its orbit around the Sun.

Land mobile radio (LMR):

A land mobile radio system (LMRS) is a person-to-person voice communication system consisting of two-way radio transceivers (an audio transmitter and receiver in one unit) that can be stationary (base station units), mobile (installed in vehicles), or portable (handheld transceivers [e.g., “walkie-talkies”]).

Low Earth orbit (LEO):

An orbital region in near-Earth space ranging from ~200 km to ~2000 km altitude and used increasingly for satellite operations.

M2M (Moon to Mars):

A NASA programmatic architecture detailing human spaceflight and the plan to return astronauts to the Moon and extend human exploration onward to Mars in the future.

Magnetosphere:

The region of near-Earth space dominated by Earth's magnetic field.

Major disaster declaration:

A type of declaration that provides more federal programs for response and recovery than an emergency declaration.

Master Scenario Events List (MSEL):

A master document scripting and detailing the events to be covered in the scenario that forms the basis of a tabletop exercise.

M-class (solar flare):

A strong-intermediate classification level for solar flares.

National Aeronautics and Space Administration (NASA):

The National Aeronautics and Space Administration is an independent agency of the U.S. federal government responsible for the civil space program, aeronautics research, and space research.

National Centers for Environmental Information (NCEI):

The federal agency responsible for preserving, monitoring, assessing, and providing public access to the nation's geophysical data and information.

National Disaster Recovery Framework (NDRF):

The framework that enables the provision of effective recovery support to disaster-impacted states and tribal, territorial, and local jurisdictions. It provides a flexible structure that enables disaster recovery managers to operate in a unified and collaborative manner.

National Incident Management System (NIMS):

Guides all levels of government, nongovernmental organizations, and the private sector to work together to prevent, protect against, mitigate, respond to, and recover from incidents. More information is provided on FEMA's NIMS webpage. Tools are provided on FEMA's NIMS Components - Guidance and Tools webpage.

National Oceanic and Atmospheric Administration (NOAA):

NOAA space weather is at the Space Weather Prediction Center (SWOC; see below).

National Response Coordination Center (NRCC):

A multiagency coordination center located at FEMA headquarters. NRCC's staff coordinates the overall federal support for major disasters and emergencies, including catastrophic incidents, and emergency management program implementation.

National Response Framework (NRF):

A guide to how the nation responds to all types of disasters and emergencies.

National Science and Technology Council (NSTC):

A cabinet-level council of advisers to the president on science and technology.

National Science Foundation (NSF):

An independent federal agency that supports science and engineering in all 50 states and U.S. territories.

National Security Emergency Preparedness (NSEP):

A program that encompasses policies, plans, procedures, and readiness measures that enhance the ability of the U.S. government to mobilize for, respond to, and recover from a national security emergency.

National Watch Center (NWC):

Part of FEMA's Response Directorate. The NWC issues the Daily Operations Briefing.

National Weather Service (NWS):

The National Weather Service provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, and adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. Under the National Oceanic and Atmospheric Administration (NOAA), NWS provides active alerts, forecast maps, and data and analysis products.

Nongovernmental organization (NGO):

An organization (typically a nonprofit organization) formed independent of the government and active in several different sectors.

North American Aerospace Defense Command (NORAD):

The North American Aerospace Defense Command is a United States and Canada binational organization charged with the missions of aerospace warning, aerospace control, and maritime warning for North America.

Office of Emergency Management (OEM):

Alternatively called an emergency management office (EMO), or an emergency management agency (EMA) in some areas, this is an agency at the local, tribal, state, federal, or international level that holds responsibility for comprehensively planning for, responding to, and helping with recovery from all manner of disasters, whether human-caused or natural.

Polar cap absorption (PCA):

PCA causes enhanced ionization of the lower layer (D-region) of the *ionosphere* (see entry above) over Earth's polar caps (i.e., high geomagnetic/geographic latitudes).

Positioning, navigation, and timing (PNT):

A broad term used to refer to services and end-user data products provided by global navigation satellite systems (GNSS), such as *GPS* (see entry above). GNSS provides end users with precise position and timing solutions for geolocation, navigation, and time-synchronization and precision scheduling tasks.

Presidential Policy Directive (PPD):

PPDs are a specific form of executive order that state the executive branch's national security policy. They describe the requirements for the executive branch and carry the force and effect of law.

Principal Federal Official (PFO):

The PFO is designated by the secretary of Homeland Security to act as their representative locally to oversee, coordinate, and execute the secretary's incident management responsibilities under HSPD-5 for incidents requiring a coordinated federal response.

Public Information Officer (PIO):

PIO functions include advising leadership on public information matters; gathering, verifying, coordinating, and disseminating accurate, accessible, and timely information; handling inquiries from the media, the public, and elected officials; providing emergency public information and warnings; and conducting rumor monitoring and responding to rumors that arise.

Public Safety Answering Point (PSAP):

Sometimes called a public safety access point, a PSAP is a type of call center where the public's telephone calls to first responders (such as the police, fire department, or emergency medical services/ambulance) are received and handled.

Radiation:

Energy in the form of photons (electromagnetic energy, zero mass) and massive particles (e.g., electrons, protons, alphas, neutrons) with relatively high levels of kinetic energy, particularly those capable of ionizing materials through which they pass. The term radiation is used generally for both forms of electromagnetic and particle energy.

Radiation belts:

Earth's radiation belts usually exist in two distinct regions of enhanced radiation levels—the inner and outer radiation belts, which collectively extend from very near Earth (~1200-km altitude near the equator but a few 100 km of altitude near the poles) to beyond geostationary (or geosynchronous) Earth orbit. These belts are often referred to as the "Van Allen radiation belts."

Radio blackout:

The complete disruption of and inability to use high-frequency radio communications because of ionospheric absorption. Radio blackouts can be localized (associated with solar energetic particles or geomagnetic activity, limited to the polar cap; see "PCA" above) or global (over up to the entire sunlit side of Earth during intense solar flares).

Recovery Support Function (RSF):

Six RSFs act as the coordinating structure for key areas of recovery assistance to support local governments by facilitating problem-solving, improving access to resources, and fostering coordination among state, tribal, territorial, and federal agencies, nongovernmental partners, and stakeholders.

Response:

Actions to save lives, protect property and the environment, stabilize the incident, meet basic human needs, restore community lifeline services and other basic community functionality, and establish a safe and secure environment to facilitate the integration of recovery activities *after* an incident.

R-scale:

An index used to categorize the intensity and severity of solar radio blackouts, such as those associated with *solar eruptive events* (see entry below).

Satellite communications (SatCom):

Communications systems involving satellites as points of contact or relays. SatCom can involve ground-to-space, space-to-ground, and/or space-to-space communications.

Solar cycle:

A solar cycle is usually described as an 11-year full cycle in which the Sun becomes more active. Activity peaks during a 1- to 2-year period referred to as "solar maximum" and wanes during a 1- to 2-year period referred to as "solar minimum."

Solar energetic particles (SEPs):

High-energy, charged particles originating in the solar corona and solar wind. Formerly known as solar cosmic rays, SEPs are hazardous to humans and human technology.

Solar eruptive event/solar eruption:

A general term used to describe sudden, explosive solar phenomena such as *solar flares* (see entry below) and *coronal mass ejections* (CMEs; see above).

Solar flare:

A solar eruptive event generally (but not always) associated with coronal mass ejections (CMEs; see above). Solar flares can last from minutes to hours, and the increased radiative output affects the entire sunlit side of Earth.

Solar particle event (SPE):

A classification of a solar energetic particle event in which the intensity of >10-MeV protons exceeds 10 particles/cm^2-s-sr, as measured by the NOAA GOES (Geostationary Operational Environmental Satellites) observatories.

Solar radio burst (SRB):

An intense burst of radio noise from the Sun that can disrupt radio communications.

Solar wind:

The constant stream of solar particles (mostly protons and electrons) and magnetic field that floods interplanetary space and is the driver of most space weather.

Space weather (SWx):

The physical state of space environments and the solar and nonsolar phenomena that disturb them.

Space Weather Operations, Research, and Mitigation (SWORM):

The U.S. federal coordinating body under the National Science and Technology Council (NSTC) charged with coordinating federal government department and agency activities to meet the goals and objectives specified in the National Space Weather Strategy and Action Plan. Additional details are provided on the SWORM website.

Space Weather Prediction Center (SWPC):

NOAA's national space weather center, responsible for the official reporting of space weather events for the federal government.

S-scale:

An index used to categorize the intensity and severity of solar radiation storms, such as those associated with solar energetic particles (SEPs; see above), including solar particle events (SPEs; see above). S-scale classification levels are as follows: S1, minor; S2, moderate; S3, strong; S4, severe; S5, extreme.

Stafford Act:

The act that authorizes the president to provide financial and other assistance to SLTT (state, local, tribal, and territorial) governments to support response, recovery, and mitigation. Additional information is available on FEMA's Stafford Act webpage.

State, local, tribal, and territorial (SLTT):

SLTT governments play a critical role in energy security planning and emergency response and are vital to protecting critical infrastructure and ensuring the resilience of the communities they serve.

Subject-matter expert (SME):

A person who has accumulated great knowledge in a particular field or on a particular topic.

Sun-synchronous orbit (SSO; SunSynch):

An orbit that goes from equator to poles and is designed so that it passes over Earth at a particular solar time.

Symmetric H-index (Sym-H):

Sym-H is a geomagnetic index compiled from low-latitude, ground-based magnetometers and used to qualify geomagnetic storm events and classify their intensity.

Thermosphere:

The thermosphere extends from 85 km up to approximately 1000-km altitude, fully encompassing low Earth orbit (LEO; see above) and coexisting with much of Earth's *ionosphere* (see entry above).

Universal Time (UT/UTC):

Greenwich Mean Time.

U.S. Northern Command (USNORTHCOM):

U.S. Northern Command is responsible for Department of Defense homeland defense efforts and coordinating defense support of civil authorities. USNORTHCOM is integrated and aligned with North American Aerospace Defense Command (NORAD), with a common goal of defending North America.

U.S. Space Command (USSC, or SPACECOM):

Working with allies and partners, USSC plans, executes, and integrates military space power into multi-domain global operations in order to deter aggression, defend national interests, and, when necessary, defeat threats. More information is available at https://www.spacecom.mil/.

U.S. Space Force (USSF):

USSF is the sixth independent U.S. military service branch and is tasked with missions and operations in the rapidly evolving space domain. The Space Force falls under the U.S. Air Force in the same way that the Marines fall under the Navy.

Warning (as defined by NOAA's Space Weather Prediction Center [SWPC]):

A Warning is issued when a significant space weather event is occurring, imminent, or likely. A Warning is a short-term, high confidence prediction of imminent activity. The purpose of a Warning is notification of impending space weather activity with a lead time of minutes to a few hours. A Warning can be upgraded to a higher Warning if space weather conditions are expected to change sufficiently enough to warrant the upgrade.

Watch (as defined by NOAA's Space Weather Prediction Center [SWPC]):

Watch is issued when the risk of a potentially hazardous space weather event has increased significantly but its occurrence or timing is still uncertain. It is intended to provide enough advance notice so those who need to set their plans in motion can do so. The purpose of a Watch is to give preliminary notification of possible space weather activity with a lead time of hours to days. A Watch can be upgraded to a higher-level Watch.

Western Area Power Administration (WAPA):

WAPA is one of four Department of Energy power marketing administrations and encompasses a 15-state region of the central and western United States.

White House Executive Office of the President (WHEOP):

Referred to as the Executive Office of the President, the WHEOP includes the management of official communications from the White House/president. More information is available here and here.

Wireless Emergency Alerts (WEA):

WEA, managed by FEMA IPAWS (the Federal Emergency Management Agency Integrated Public Alert & Warning System), is a public safety system that allows customers who own compatible mobile devices to receive geographically targeted, text-like messages alerting them of imminent threats to safety in their area. WEAs can be issued by IPAWS-approved SLTT (state, local, tribal, and territorial) alerting authorities and NOAA. National alerts can be issued by the president of the United States or the administrator of FEMA.

X-class (solar flare):

The strongest classification level for solar flares; X-class flares have peak soft X-ray intensities at 10^{-4} W/m^2 and higher.

E.2. Acronym List

ACE	Advanced Composition Explorer
AU	Astronomical Unit (1 AU is the distance from the center of the Earth to the center of the Sun)
CCMC	Community Coordinated Modeling Center
CISA	Cybersecurity and Infrastructure Security Agency
CME	Coronal Mass Ejection
COCOMs	Combatant Commands
CONUS	Contiguous United States
COP	Common Operating Picture

DCO	Defense Coordinating Officer
DHSEM	Division of Homeland Security and Emergency Management
DoD	Department of Defense
DOI	Department of the Interior
DSCA	Defense Support of Civil Authorities
Dst	Disturbance Storm-Time Index to Classify Geomagnetic Storms
EAS	Emergency Alert System
ECC	Emergency Communications Center
EMA	Emergency Management Agency
EMO	Emergency Management Office
EOC	Emergency Operations Center
ESF	Emergency Support Function
ET	Eastern Time
eV	Electronvolt
FAA	Federal Aviation Administration
FCO	Federal Coordination Officer
FEMA	Federal Emergency Management Agency
FIOPs	Federal Interagency Operational Plans
FOC	Federal Operating Concept
GEO	Geosynchronous (or Geostationary) Earth Orbit
GIC	Geomagnetically Induced Current
GLE	Ground-Level Event (solar radiation)
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellites (NOAA weather satellites in GEO)
GPS	Global Positioning System
HF	High Frequency

HSEEP	Homeland Security Exercise Evaluation Program
IPAWS	Integrated Public Alert & Warning System
JFO	Joint Field Office
JIC	Joint Information Center
Kp	Planetary K-index, quantifying general magnetospheric activity level
L1	1st Sun-Earth Lagrange Point in the Sun-Earth System
L4	4th Sun-Earth Lagrange Point in the Sun-Earth System
L5	5th Sun-Earth Lagrange Point in the Sun-Earth System
LEO	Low Earth Orbit
LMR	Land Mobile Radio
M2M	Moon to Mars
MERS	Mobile Emergency Response Support
MSEL	Master Scenario Events List
MT	Mountain Time
NASA	National Aeronautics and Space Administration
NCEI	National Centers for Environmental Information
NDRF	National Disaster Recovery Framework
NGO	Nongovernmental Organization
NIMS	National Incident Management System
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NRCC	National Response Coordination Center
NRF	National Response Framework
NSEP	National Security/Emergency Preparedness
NSF	National Science Foundation
NSTC	National Science and Technology Council

NWC	National Watch Center
NWS	National Weather Service
OEM	Office of Emergency Management
PCA	Polar Cap Absorption
PFO	Principal Federal Official
PIO	Public Information Officer
PNT	Positioning, Navigation, and Timing
PPD	Presidential Policy Directive
PSAP	Public Safety Answering Point
RSF	Recovery Support Function
SatCom	Satellite Communications
SatNav	Satellite-Based Navigation
SEP	Solar Energetic Particle
SLTT	State, Local, Tribal, and Territorial
SME	Subject-Matter Expert
SPE	Solar Particle Event
SRB	Solar Radio Burst
SSO/SunSynch	Sun-Synchronous Orbit
SWORM	Space Weather Operations, Research, and Mitigation
SWPC	Space Weather Prediction Center
SWx	Space Weather
Sym-H	Symmetric H-Index, similar to Dst
TTX	Tabletop Exercise
USAF	United States Air Force
USNORTHCOM	U.S. Northern Command
USSC	U.S. Space Command

USSF	U.S. Space Force
UT/UTC	Universal Time (i.e., Greenwich Mean Time)
VHF	Very High Frequency
WAPA	Western Area Power Administration
WEA	Wireless Emergency Alert
WHEOP	White House Executive Office of the President

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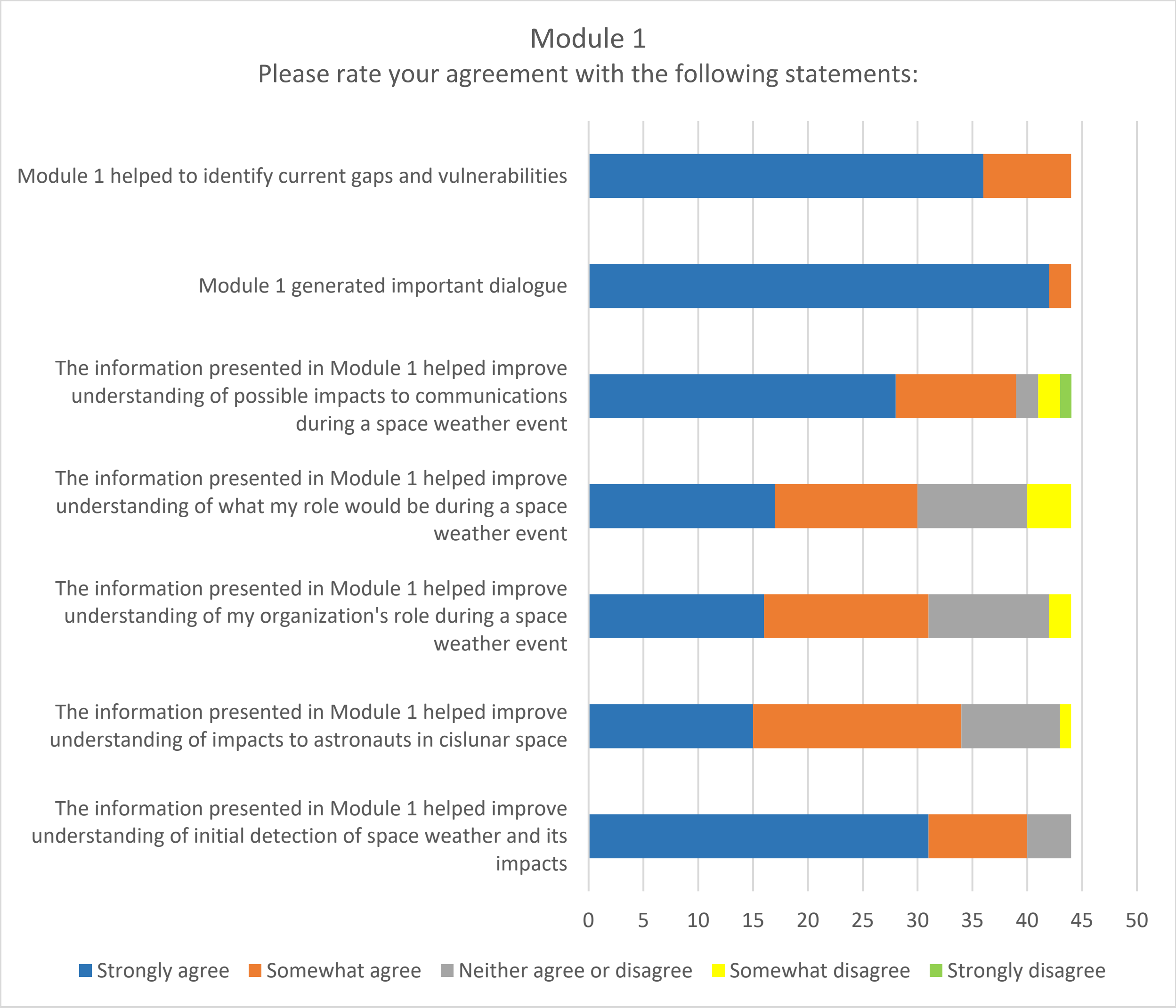
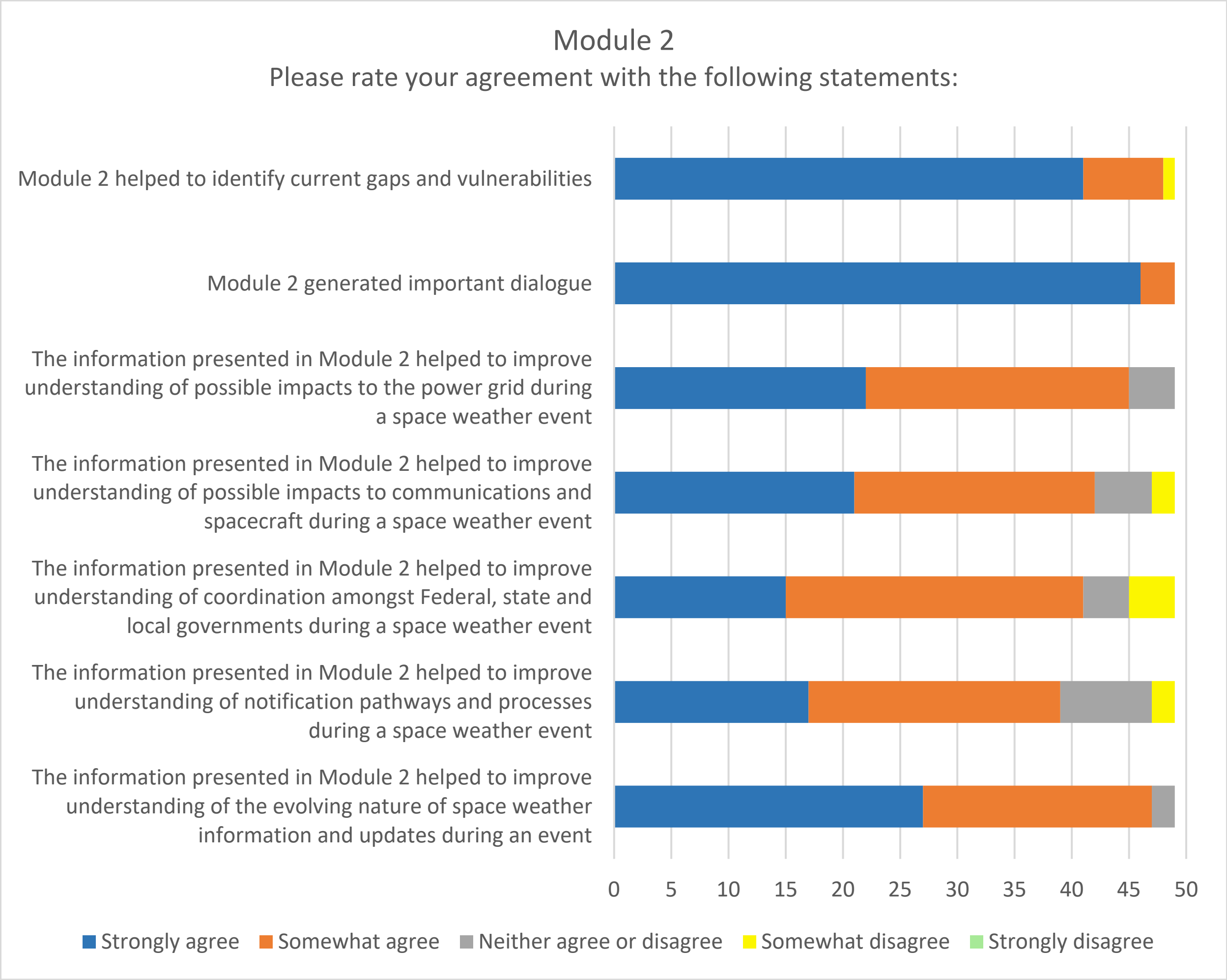
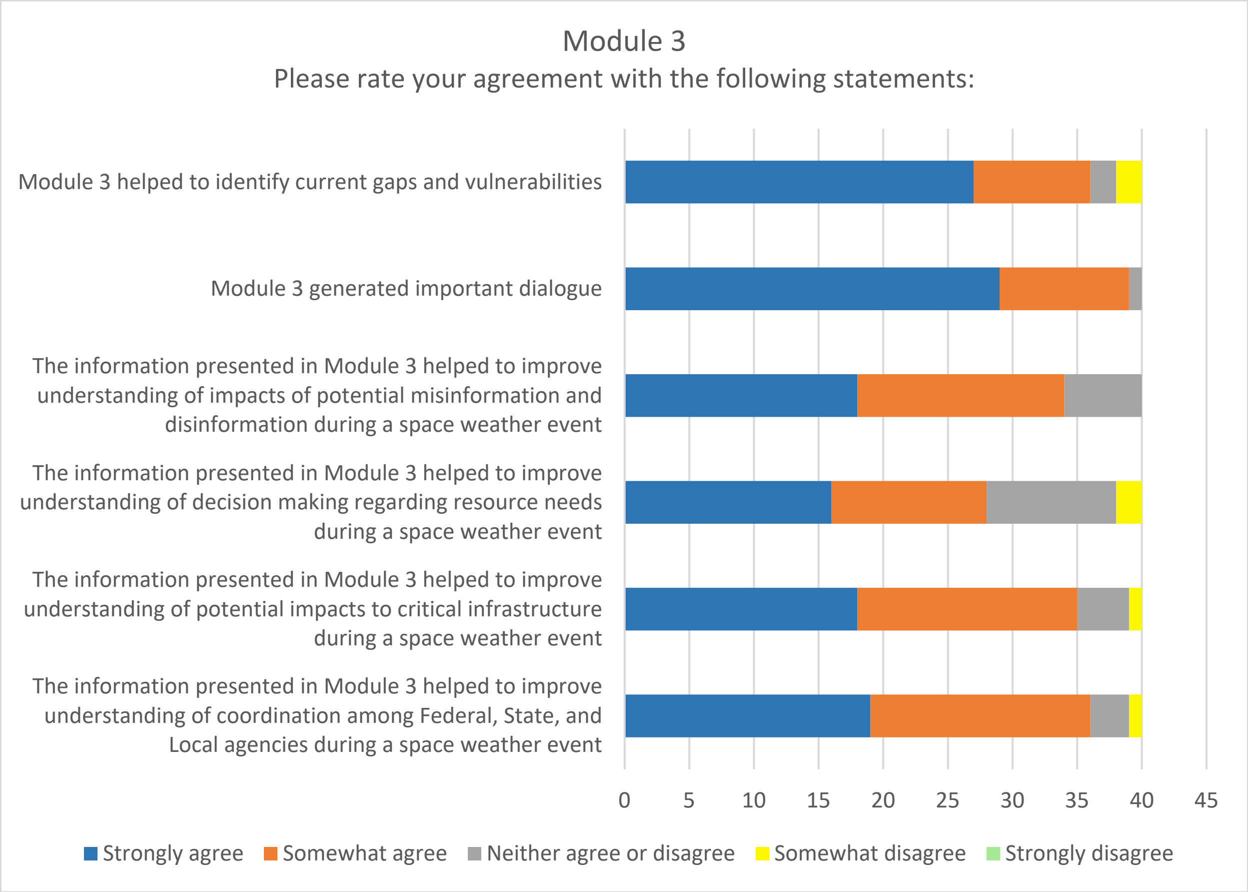
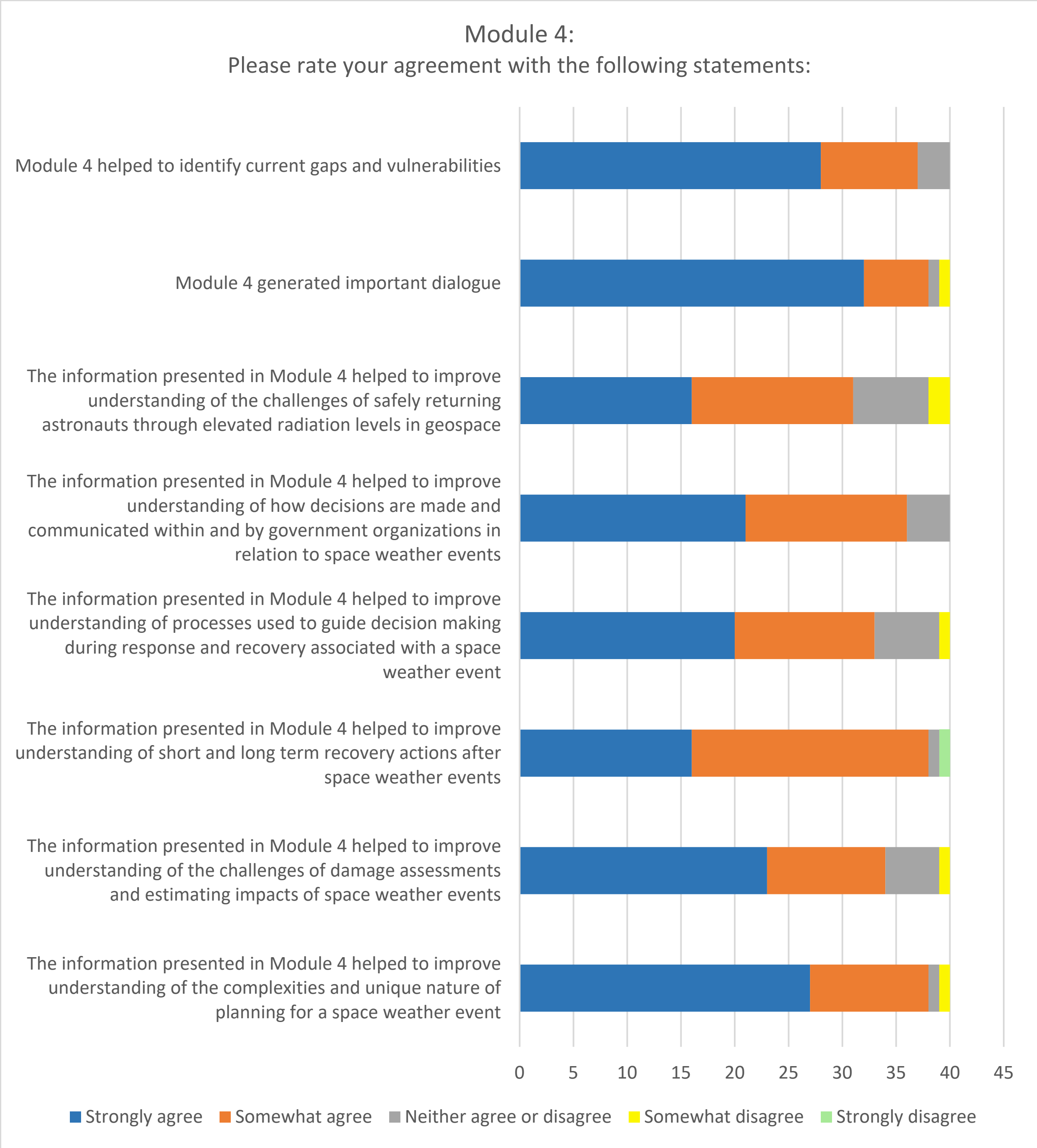
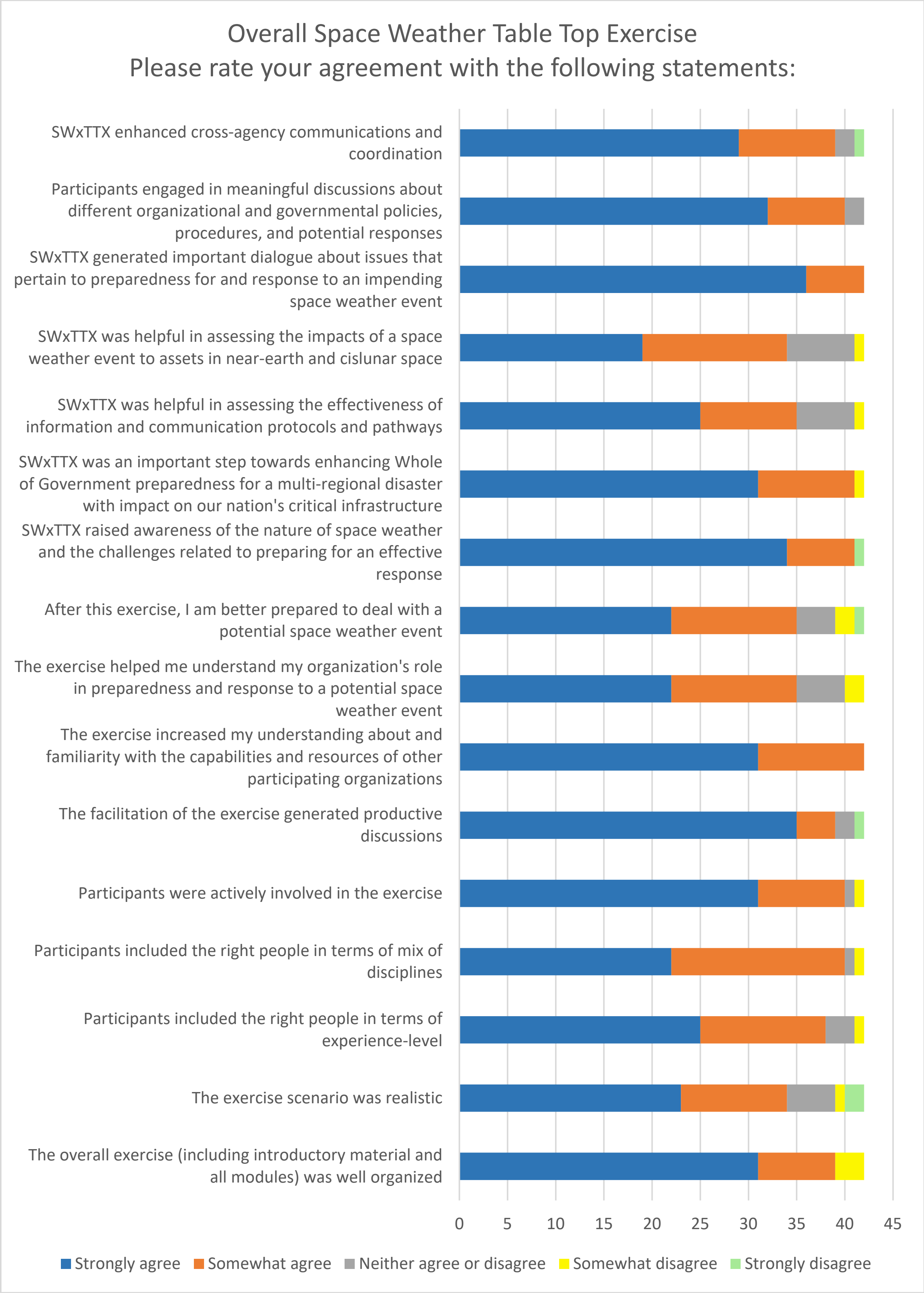
Appendix F. Participant Feedback




Module 2
Please rate your agreement with the following statements:
Module 2 helped to identify current gaps and vulnerabilities
Module 2 generated important dialogue
The information presented in Module 2 helped to improve understanding of possible impacts to the power grid during a space weather event
The information presented in Module 2 helped to improve understanding of possible impacts to communications and spacecraft during a space weather event
The information presented in Module 2 helped to improve understanding of coordination amongst Federal, state and local governments during a space weather event
The information presented in Module 2 helped to improve understanding of notification pathways and processes during a space weather event
The information presented in Module 2 helped to improve understanding of the evolving nature of space weather information and updates during an event
0 5 10 15 20 25 30 35 40 45 50
Strongly agree
Somewhat agree
Neither agree or disagree
Somewhat disagree
Strongly disagree


Module 3
Please rate your agreement with the following statements:
Module 3 helped to identify current gaps and vulnerabilities
Module 3 generated important dialogue
The information presented in Module 3 helped to improve understanding of impacts of potential misinformation and disinformation during a space weather event
The information presented in Module 3 helped to improve understanding of decision making regarding resource needs during a space weather event
The information presented in Module 3 helped to improve understanding of potential impacts to critical infrastructure during a space weather event
The information presented in Module 3 helped to improve understanding of coordination among Federal, State, and Local agencies during a space weather event
0 5 10 15 20 25 30 35 40 45
Strongly agree
Somewhat agree
Neither agree or disagree
Somewhat disagree
Strongly disagree


Module 4:
Please rate your agreement with the following statements:
Module 4 helped to identify current gaps and vulnerabilities
Module 4 generated important dialogue
The information presented in Module 4 helped to improve understanding of the challenges of safely returning astronauts through elevated radiation levels in geospace
The information presented in Module 4 helped to improve understanding of how decisions are made and communicated within and by government organizations in relation to space weather events
The information presented in Module 4 helped to improve understanding of processes used to guide decision making during response and recovery associated with a space weather event
The information presented in Module 4 helped to improve understanding of short and long term recovery actions after space weather events
The information presented in Module 4 helped to improve understanding of the challenges of damage assessments and estimating impacts of space weather events
The information presented in Module 4 helped to improve understanding of the complexities and unique nature of planning for a space weather event
0
5
10
15
20
25
30
35
40
45
Strongly agree
Somewhat agree
Neither agree or disagree
Somewhat disagree
Strongly disagree


Overall Space Weather Table Top Exercise
Please rate your agreement with the following statements:
SWxTTX enhanced cross-agency communications and coordination
Participants engaged in meaningful discussions about different organizational and governmental policies, procedures, and potential responses
SWxTTX generated important dialogue about issues that pertain to preparedness for and response to an impending space weather event
SWxTTX was helpful in assessing the impacts of a space weather event to assets in near-earth and cislunar space
SWxTTX was helpful in assessing the effectiveness of information and communication protocols and pathways
SWxTTX was an important step towards enhancing Whole of Government preparedness for a multi-regional disaster with impact on our nation's critical infrastructure
SWxTTX raised awareness of the nature of space weather and the challenges related to preparing for an effective response
After this exercise, I am better prepared to deal with a potential space weather event
The exercise helped me understand my organization's role in preparedness and response to a potential space weather event
The exercise increased my understanding about and familiarity with the capabilities and resources of other participating organizations
The facilitation of the exercise generated productive discussions
Participants were actively involved in the exercise
Participants included the right people in terms of mix of disciplines
Participants included the right people in terms of experience-level
The exercise scenario was realistic
The overall exercise (including introductory material and all modules) was well organized
0 5 10 15 20 25 30 35 40 45
Strongly agree
Somewhat agree
Neither agree or disagree
Somewhat disagree
Strongly disagree

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Appendix G. SWx TTX Slides

This appendix contains static versions of the as-presented slides from the SWx TTX. The actual slides in some cases contained animations to better inform or describe the scenario.

G.1. TTX Day 1

G.1.1. Morning Slides

EXERCISE EXERCISE EXERCISE

Welcome

SPACE WEATHER
TABLETOP EXERCISE

- Welcome from APL
- Welcome and a word from each of our sponsors

NASA NOAA NSF FEMA

EXERCISE EXERCISE EXERCISE | 2

SWx TTX: Government Participants

SPACE WEATHER
TABLETOP EXERCISE

NASA NOAA NSF FEMA U.S. AIR FORCE

DENVER OFFICE OF EMERGENCY MANAGEMENT

UNITED STATES SPACE FORCE

USDA

wapa.gov

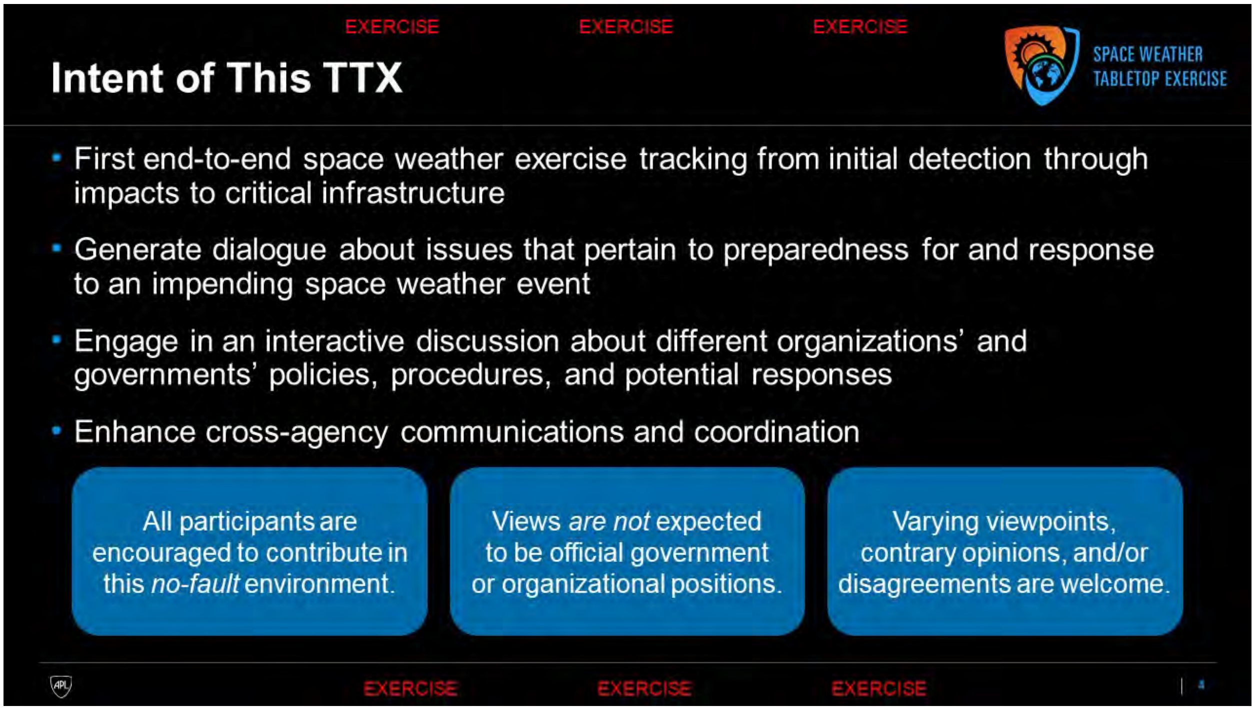
557th WEATHER WING

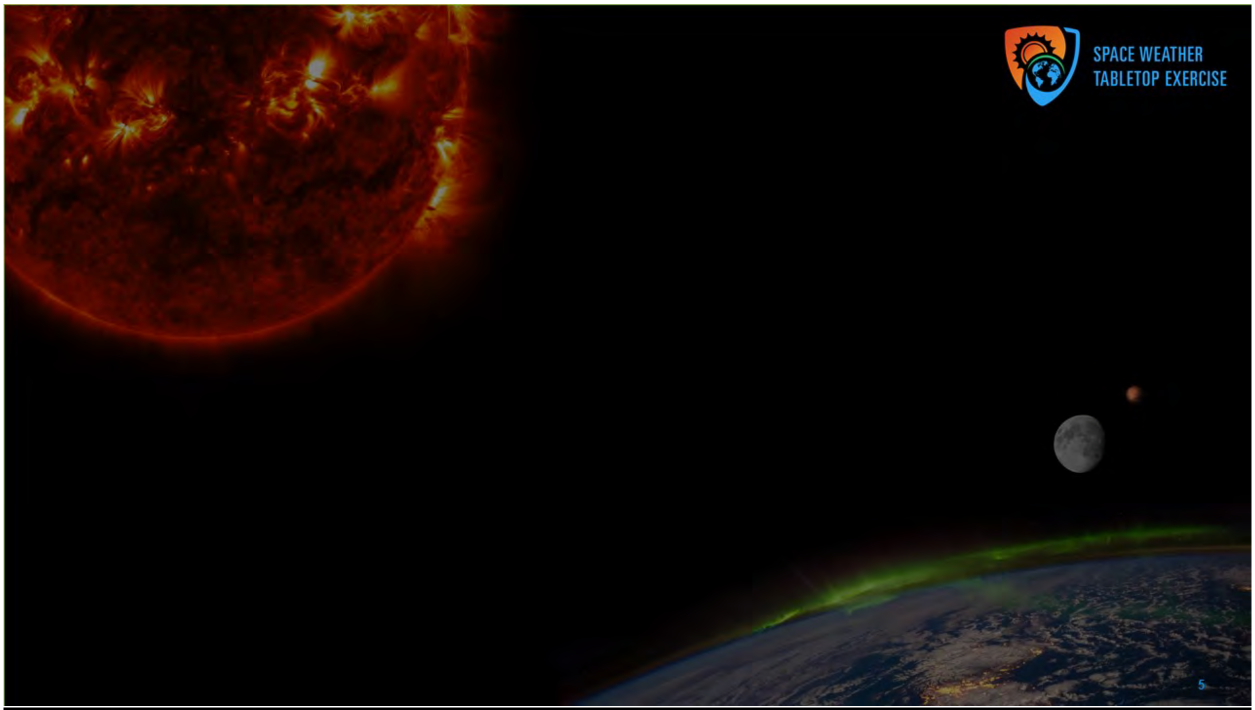
COLORADO Department of Transportation

USGS science for a changing world

DEN

| 3


EXERCISE EXERCISE EXERCISE
Intent of This TTX
SPACE WEATHER
TABLETOP EXERCISE
First end-to-end space weather exercise tracking from initial detection through impacts to critical infrastructure
Generate dialogue about issues that pertain to preparedness for and response to an impending space weather event
Engage in an interactive discussion about different organizations' and governments' policies, procedures, and potential responses
Enhance cross-agency communications and coordination
All participants are encouraged to contribute in this no-fault environment.
Views are not expected to be official government or organizational positions.
Varying viewpoints, contrary opinions, and/or disagreements are welcome.
EXERCISE EXERCISE EXERCISE
4



This TTX Is Organized around Four Objectives

SPACE WEATHER
TABLETOP EXERCISE

Education & Awareness	Space Weather Preparedness	Information Sharing & Public Messaging	Cislunar Space Readiness
Raise awareness of the nature of space weather and the challenges related to preparing an effective response	Enhance whole-of-government preparedness for a multiregional disaster with impact on our nation's critical infrastructure	Assess the effectiveness of information and communication protocols and pathways	Assess our resiliency in the face of increasingly degraded space assets due to a space weather event

APL | 6

TTX Participants

SPACE WEATHER
TABLETOP EXERCISE

Various types of *participants* will be involved in this TTX:

- **Players:** Designated senior leader representatives who would be decision makers for their organization and have an active role in discussing, initiating, or performing their regular roles and responsibilities in response to the simulated event
- **Facilitators:** Plan and manage exercise play, direct the pace of the exercise, provide key data to players, and issue prompts or initiate certain player actions to ensure exercise continuity
- **Data Collectors:** Observe and document key discussion points, gaps, recommendations, and certain topics, as well as the general dialogue surrounding each inject
- **Observers:** View the exercise from a designated observation area and remain within the observation area during the exercise; observers do not play in the exercise but will be provided designated opportunities for feedback and recommendations based on their observations
- **Exercise Staff:** Individuals who perform administrative and logistical support tasks during the exercise, to include managing the multimedia applications

APL | 7

Momentum Towards this Exercise

SPACE WEATHER
TABLETOP EXERCISE

The PROSWIFT Act of 2020 (Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow) prompted NOAA to establish the Space Weather Advisory Group (SWAG)

The SWAG conducted a **comprehensive survey of user needs of space weather products**; select survey gaps and recommendations from the April 2024 annual Space Weather Workshop:

6.1. **There is not consistent or sufficiently broad awareness of space weather** and its effects across the EM community.

6.1.3. FEMA and SPWC should develop tabletop exercise packages for state, local & tribal governments. Exercises should address impacts of space weather events.

6.1.4. FEMA in collaboration with the National Security Council Staff, should incorporate space weather into the FEMA National Exercise Program Schedule.

6.2. EMs **need more information on the impacts of space weather**, including cascading impacts, across the broad set of national critical functions and/or infrastructure services.

6.2.1. NOAA should develop forecasts that include the impacts of space weather events on critical infrastructure similar to what the are doing for terrestrial weather events.

Full Report to be released summer 2024

APL | 8

EXERCISE EXERCISE EXERCISE

FEMA Region 8 (R8) Role

SPACE WEATHER
TABLETOP EXERCISE

R8 AT-A-GLANCE

Serving: Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming, and 28 Tribal Nations

Regional Office: Lakewood, Colo.
Coverage Area: 573,259 square miles
Estimated Population: 11,435,332

Key Facts:
- Lead nation in coal production
- Significant products: natural gas, crude oil, and barley

Primary Industries:
- Food & Agriculture
- Energy
- Mining
- Recreation and Tourism

CISA Priority Areas:
- Elections security
- K-12 Education
- Water and Wastewater
- Health Care and Hospitals

Contact us:
- *Email:* CISARegion8@hq.dhs.gov

Local Focal Point
for the purposes of this TTX

- FEMA's designated Center of Excellence for Space Weather Prediction
- R8 is a critical partner in this TTX
- Serves as a local proxy to represent communication chain and decision-making authorities at the SLTT levels

EXERCISE EXERCISE EXERCISE

9/18/2024 | 9

Dual exercise locations

SPACE WEATHER
TABLETOP EXERCISE

- We will be exploring many challenges associated with preparing for, protecting against, and mitigating the effects of impending space weather events at the Federal, State, and Local levels

- Senior leaders participating and interacting via two locations in Laurel, MD (ET) & Denver, CO (MT)
  - *Participants in Laurel MD from federal departments and agencies*
  - *Participants in Denver from state, local & Region 8 departments & agencies*

Photos from PD TTX4:

Two locations interacting virtually, simulating real-world coordination

18 April 2024 | 10

EXERCISE EXERCISE EXERCISE

TTX Scenario and Modules

SPACE WEATHER TABLETOP EXERCISE

MODULE 0 Introductory Sessions	MODULE 1 Solar Drivers	MODULE 2 Geomagnetic Storm	MODULE 3 Extreme Storm	MODULE 4 Response & Recovery

- Space Weather 101
- Space Weather Prediction
- Artemis Contingency Planning
- National Response Framework
- National Incident Management Systems
- Federal Operating Concept

Scenario Spans 26 January 2028 – 03 February 2028

EXERCISE EXERCISE EXERCISE | 11

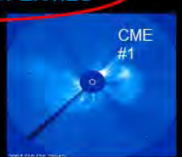
EXERCISE EXERCISE EXERCISE

Situation Report (SitRep) Example

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, 8:25 a.m. ET (6:25 a.m. MT)



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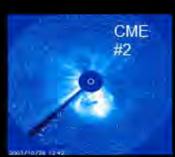


NASA/ESA SOHO LASCO 2028/01/28 11:48

RADIO BLACKOUT DETAILS

Flare: X-class (Typically ~1/month observed) Strong **R3**

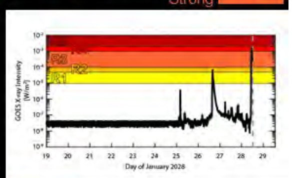
Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

High-frequency radio: Wide area blackout of high-frequency radio communication; loss of radio contact for about an hour on sunlit side of Earth

Navigation: Low-frequency navigation signals degraded ~1 hour



RADIATION STORM DETAILS

Impact timeline: Tens of minutes after flare

Duration: Unknown (likely several hours)

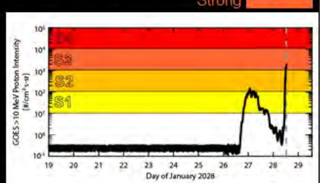
SEP: Increase observed (Typically ~1/year observed) Strong **S3**

POSSIBLE EFFECTS

Biological: Avoidance recommended for astronauts on EVA; exposure risk to humans in aircraft at high latitudes

Satellite operations: Single-event upsets, noise in imaging systems, slight reduction in solar panel efficiency

Other systems: Degraded high-frequency propagation at polar regions, navigation position errors



GEOMAGNETIC STORM (#1) DETAILS

Impact timeline: 47.5 hours after eruption (arrived 17.5 hours later than predicted)

Duration: Likely several days

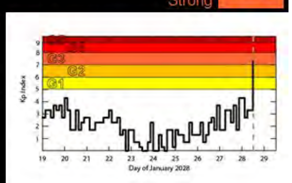
Storm: Kp = 7 (Typically ~2/month observed) Strong **G3**

POSSIBLE EFFECTS

Power systems: Voltage corrections; false alarms on protection devices

Spacecraft operations: Surface charging on satellite components; increased drag on low-Earth-orbit satellites; corrections for orientation problems

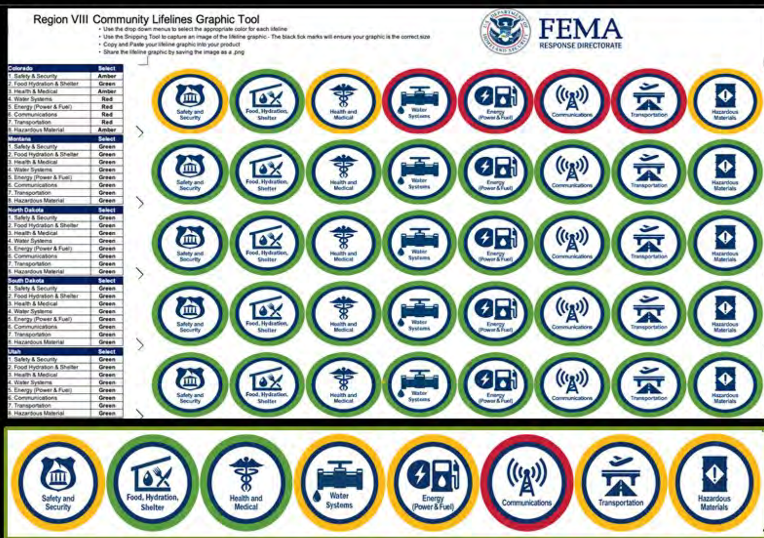
Other systems: Intermittent satellite navigation and low-frequency radio-frequency navigation issues; intermittent high-frequency radio; aurorae as low as Chicago, Pittsburgh



EXERCISE EXERCISE EXERCISE | 12

FEMA's Community Lifelines

SPACE WEATHER
TABLETOP EXERCISE



- Enables continuous operation of critical government and business functions
- Helps prioritize rapid stabilization after a disaster and is used day to day to support the recurring needs of the community
- Community Lifelines will be provided throughout the remainder of the modules

- Provided at the *whole of region level* as a single line for the purposes of this TTX
- Red: Severely degraded
- Yellow: Partially degraded or at risk
- Green: Full functionality

What to Expect: Data Collection

SPACE WEATHER
TABLETOP EXERCISE

- Data collectors in the room will take notes on discussions
- Players will share thoughts via participant feedback forms
- Facilitators will lead hot washes to get lessons learned and best practices from players
- There will be no media in the TTX room; comments in the final report will be anonymized

TTX4 AAR helped define future investments

Your comments, discussions, and written responses are the data that will help this TTX culminate in an impactful after-action report.

EXERCISE EXERCISE EXERCISE

What to Expect: Hot Washes

SPACE WEATHER
TABLETOP EXERCISE

- At the end of each module we will ask for *a designated representative* from each participating organization to briefly summarize their observations
- Please limit comments to ~1 min so we have the opportunity to hear from every participating organization:
  - *One lesson learned*
  - *One best practice*
- Participants may post comments in the chat during this time as well

All comments from the hot wash sessions will be captured and combined with comments from the chat, the data collectors' notes, and the participant feedback forms to support the development of the After Action Report and Improvement Plan

EXERCISE EXERCISE EXERCISE | 15

EXERCISE EXERCISE EXERCISE

Day 1 Agenda

Asynchronous Timing Until 2:30 PM EDT/12:30 PM MDT

SPACE WEATHER
TABLETOP EXERCISE

EDT	LAUREL, MD
7:00	Arrivals and Registration
8:00	Welcome and Introductions
8:30	Logistics and Intro to Software
9:00	Space Weather 101
9:30	Intro to Space Weather Prediction
10:00	*Break*
10:15	NASA: Artemis Contingency Plans
10:30	Overview: NRF and NIMS
11:00	Overview: FOC for Impending Space Weather Events
11:30	*Lunch*
12:30	MODULE 1: Solar Drivers
—	
—	
	Federal Agency Focused Injects and Discussion
—	
2:00	MODULE 1: Hotwash
2:15	*Break*
2:30	MODULE 2: Geomagnetic Storm
4:30	MODULE 2: Hotwash
4:45	Wrap Up and Adjourn

MDT	DENVER, CO
9:00	Arrivals and Registration
9:30	Welcome and Introductions
9:45	Background, Instructions, Logistics
10:00	Space Weather 101
10:30	Intro to Space Weather Prediction
11:00	Overview: FOC for Impending Space Weather Events
11:15	Intro to Hybrid Component With SitRep or Ops Brief
11:30	*Lunch*
12:30	MODULE 2: Geomagnetic Storm
2:30	MODULE 2: Hotwash
2:45	Wrap Up and Adjourn

EXERCISE EXERCISE EXERCISE 18 September 2024 | 16

EXERCISE EXERCISE EXERCISE

Day 2 Agenda

SPACE WEATHER TABLETOP EXERCISE

EDT	LAUREL, MD
8:30	Arrivals and Registration
9:30	Welcome and Thoughts From Day 1
10:00	Background, Instructions, Logistics
10:15	*Break*
10:30	MODULE 3: Intensifying Storm
12:00	*Lunch*
1:00	MODULE 3: Cont'd
2:15	MODULE 3: Hotwash
2:30	*Break*
2:45	MODULE 4: Response and Recovery
4:00	MODULE 4: Hotwash
4:15	Joint Hotwash
4:45	Closing Comments: A Word From Our Sponsors
5:00	Adjourn

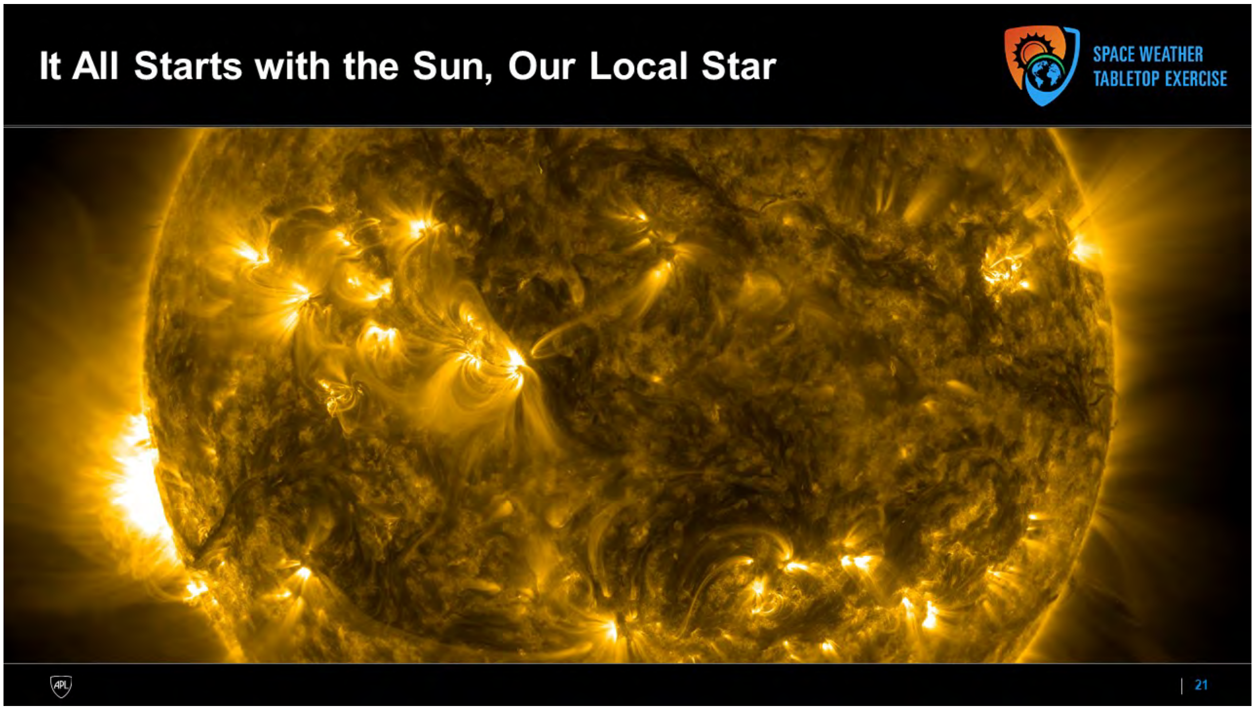
MDT	DENVER, CO
6:30	Arrivals and Registration
7:30	Welcome and Thoughts From Day 1
8:00	Background, Instructions, Logistics
8:15	*Break*
8:30	MODULE 3: Intensifying Storm
10:00	*Lunch*
11:00	MODULE 3: Cont'd
12:15	MODULE 3: Hotwash
12:30	*Break*
12:45	MODULE 4: Response and Recovery
2:00	MODULE 4: Hotwash
2:15	Joint Hotwash
2:45	Closing Comments: A Word From Our Sponsors
3:00	Adjourn

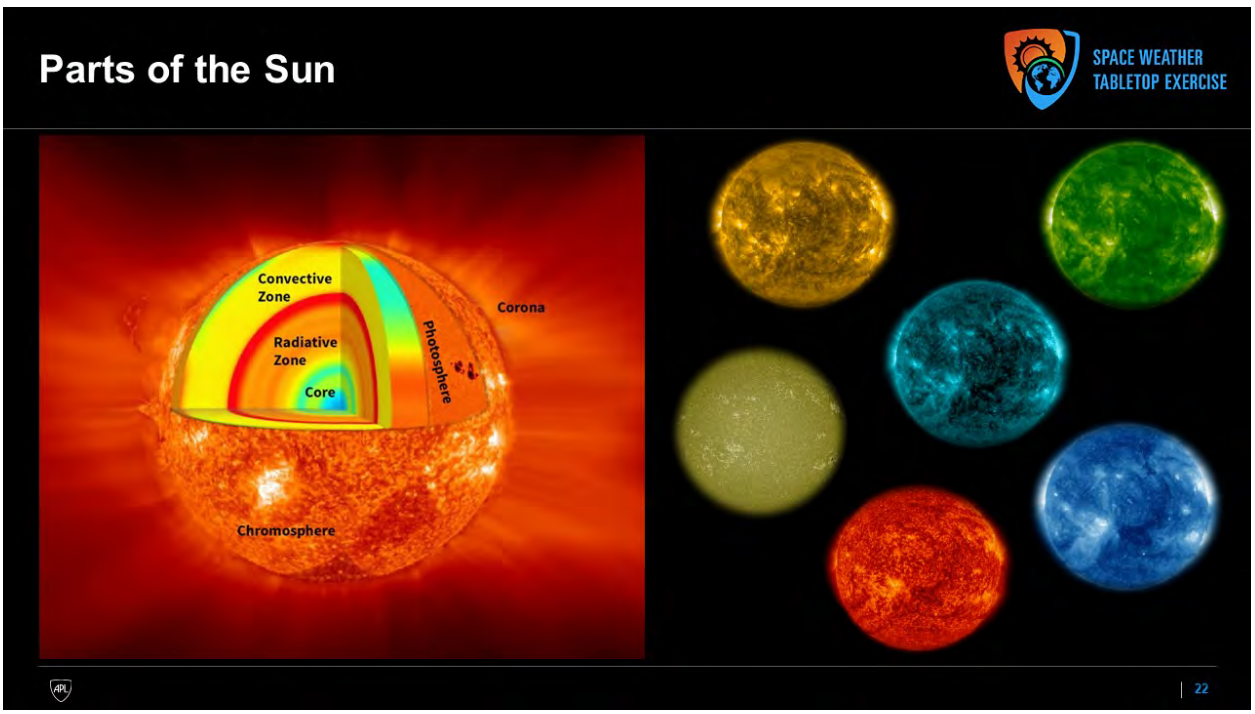
EXERCISE EXERCISE EXERCISE | 17

Zoom Login and Online protocols

SPACE WEATHER
TABLETOP EXERCISE

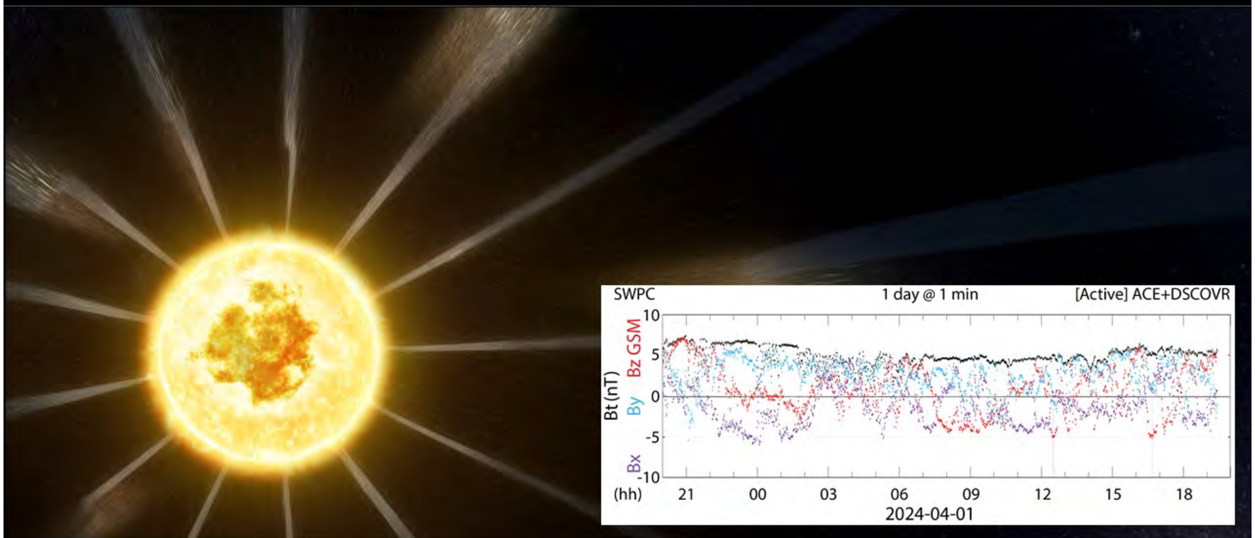
- Zoom links will be provided for all remote participants and observers.
- Groups of participants/players may be muted at designated times to limit unintentional noise during the discussions, but players will have the ability to unmute their microphones to speak during the event.
- We ask that participants/players chat and offer comments through the XLeap application.
  - Please avoid using Zoom chat. While Zoom chat will remain open during the event, it will only be monitored to address logistical and administrative questions.
- Each slide within the XLeap application will correspond to its own chat thread. However, if you are engaged in a smaller conversation on a specific topic and the team has moved on to the next slide, you may continue the conversation in two ways:
  1. Accessing the XLeap "main" chat room to carry on the discussion; and/or
  2. Scrolling back to the prior slide(s)


It All Starts with the Sun, Our Local Star
SPACE WEATHER
TABLETOP EXERCISE
APL
21


Parts of the Sun
SPACE WEATHER
TABLETOP EXERCISE
Convective Zone
Radiative Zone
Core
Photosphere
Corona
Chromosphere
APL
22

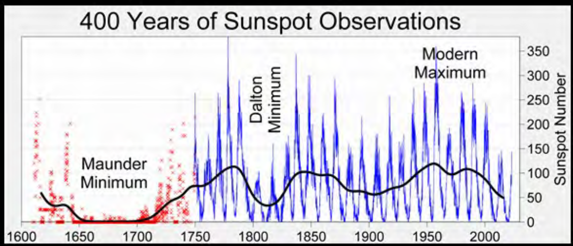
The Sun's Magnetic Field – i.e., the interplanetary magnetic field (IMF)

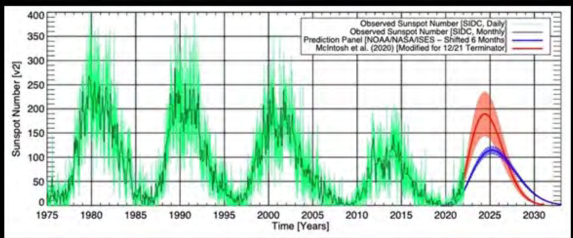
SPACE WEATHER
TABLETOP EXERCISE

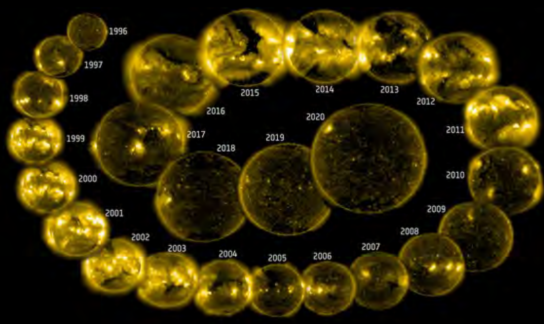


The Solar Cycle

SPACE WEATHER
TABLETOP EXERCISE



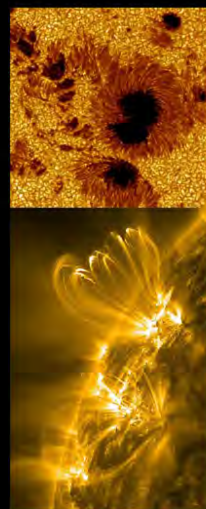


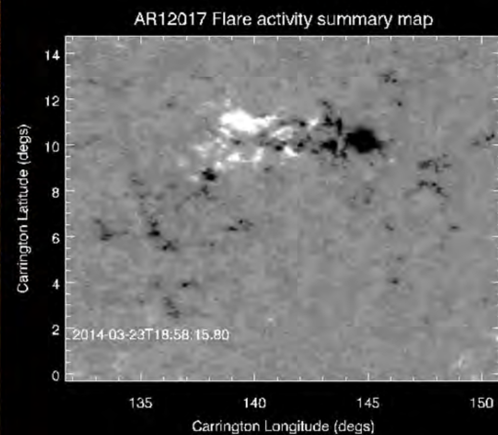


Solar Active Regions

SPACE WEATHER
TABLETOP EXERCISE

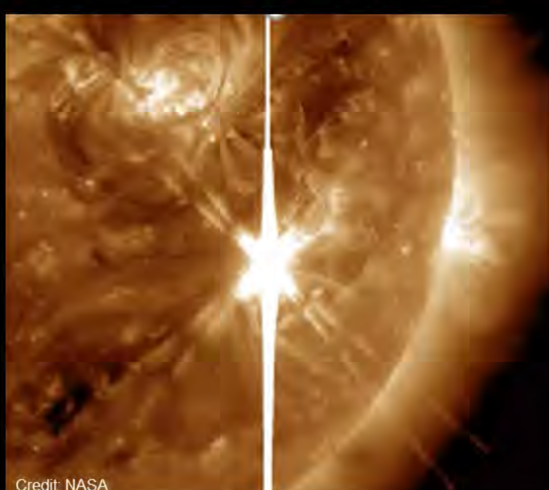
- Solar active regions are places where the Sun's magnetic field is disturbed.
- They frequently spawn solar eruptions, such as solar flares and coronal mass ejections (CMEs).
- These regions are typically indicated visually by sunspots.
- Solar active regions are individually identified, labeled, and tracked throughout their lifetimes.





Solar Flares

SPACE WEATHER
TABLETOP EXERCISE

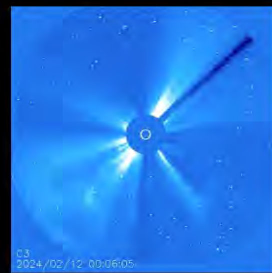

Credit: NASA

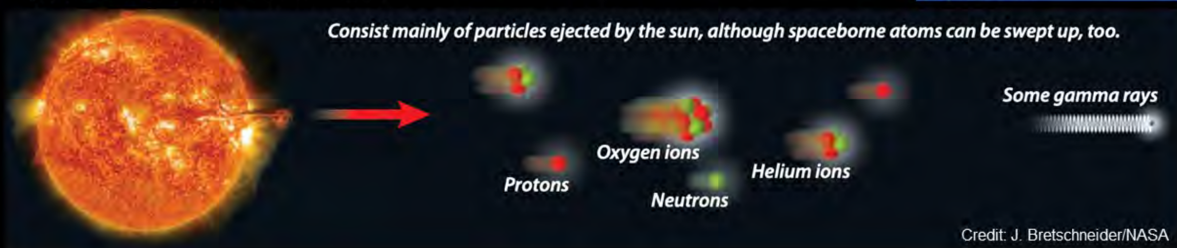
- Solar flares are eruptions of solar "active regions"—usually associated with sunspot pairs.
- The flare produces both radio noise (i.e., a solar radio burst) as well as X-rays that can interact with and modify Earth's ionosphere – *if we can SEE the flare, it will affect us* .
- Flares are monitored by solar imagers—e.g., NASA SDO and NOAA GOES—and GOES X-rays.
- Currently, we *cannot* predict when solar flares will occur, how intense they will be, or how long they will last once they begin.

Solar Energetic Particles (SEPs)

SPACE WEATHER
TABLETOP EXERCISE

- SEPs are very-high-energy particles released and accelerated by the eruption/flare.
  - *They travel very fast, but not quite at the speed of light, and they take tens of minutes to hours to reach Earth.*
- SEPs are monitored by coronagraphs (e.g., ESA/NASA SOHO), Lagrange Point 1 (L1) observatories, GOES particle measurements, and ground-based neutron monitors.





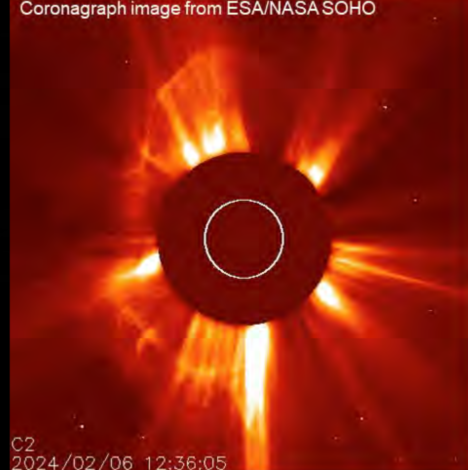
Credit: J. Bretschneider/NASA

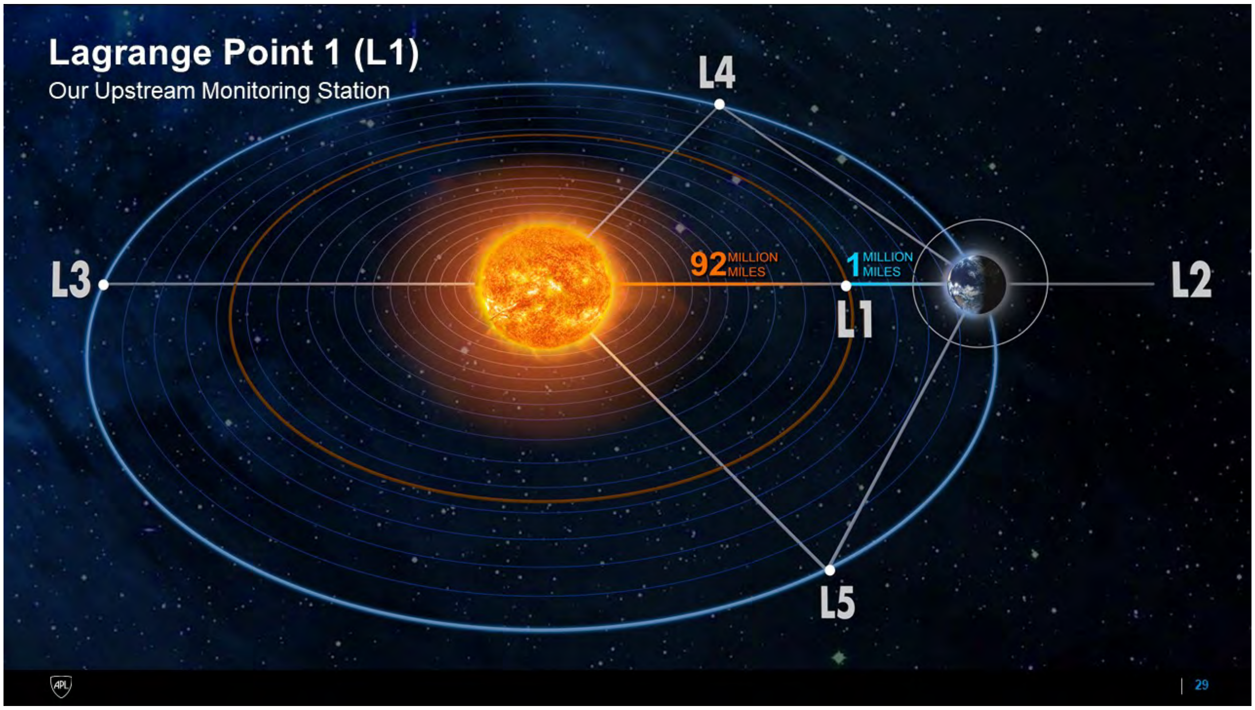
Coronal Mass Ejections (CMEs)

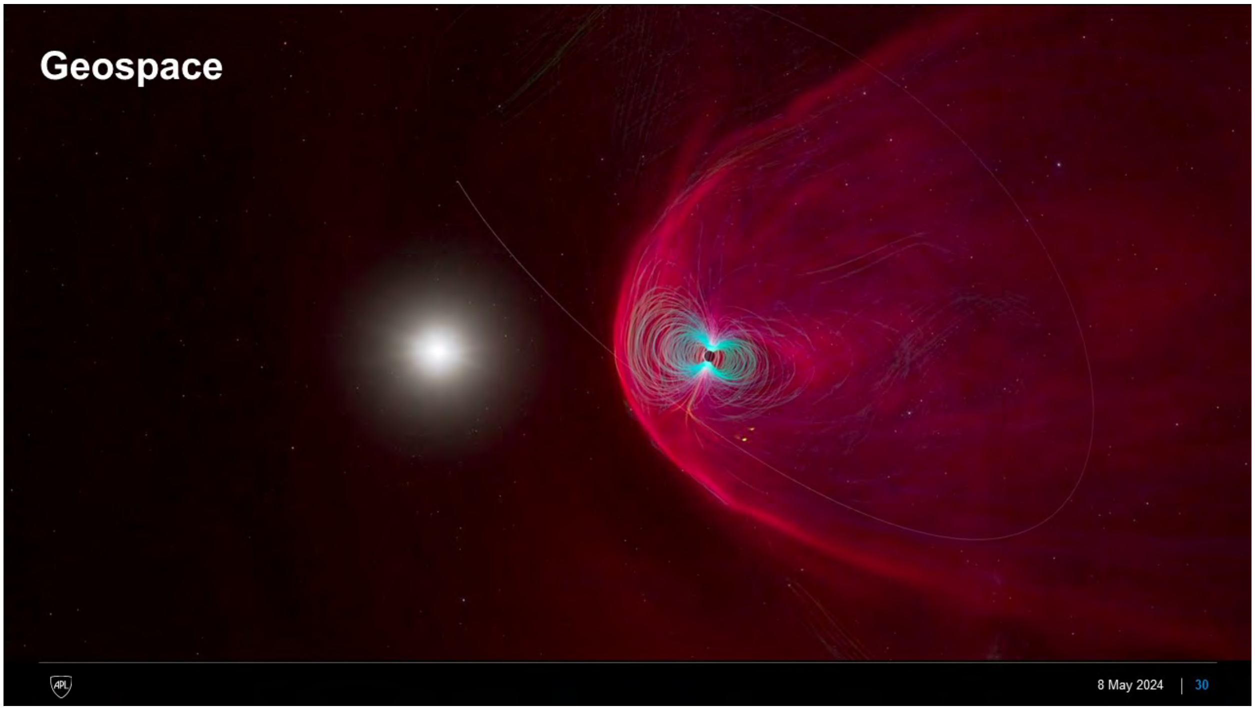
SPACE WEATHER
TABLETOP EXERCISE

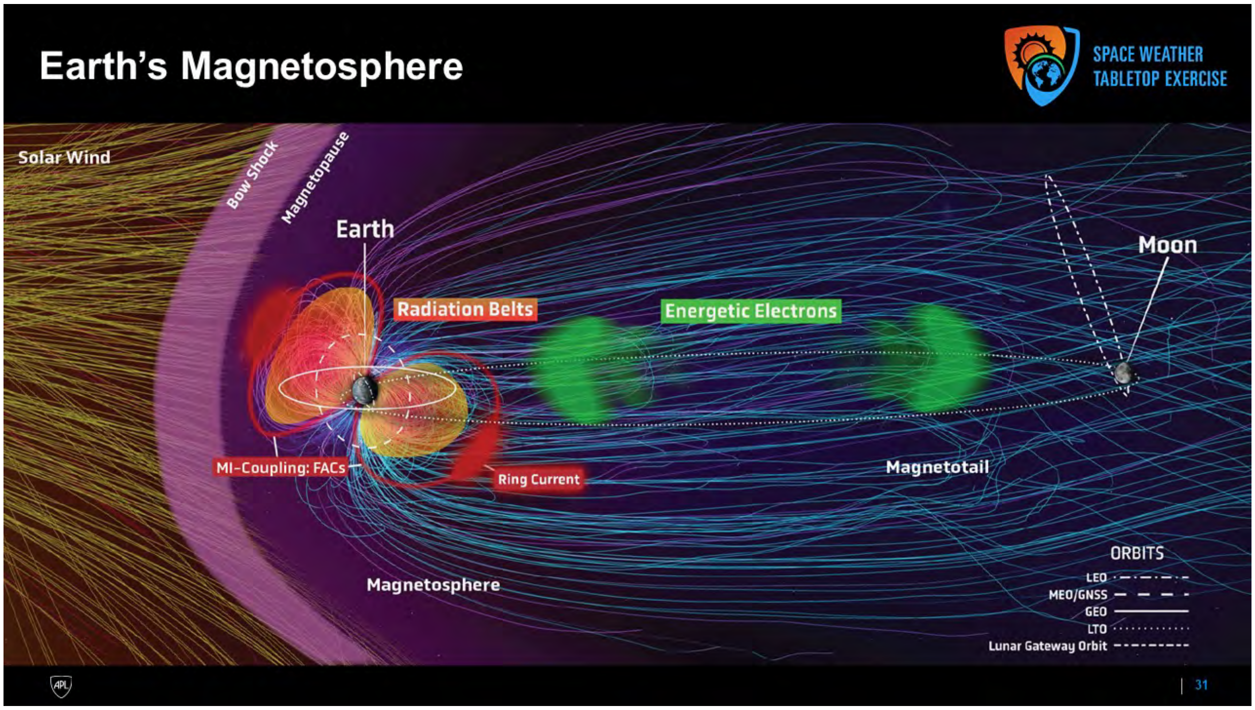
- A CME is a tremendous explosion of solar material from or through the solar corona, carrying embedded magnetic fields—*usually associated with/following a solar flare*.
- CMEs can be released in any direction but are only of concern if they are Earth-directed (these are known as "halo CMEs").
- CMEs are monitored by solar coronagraphs (e.g., ESA/NASA SOHO) and upstream solar wind assets at L1.

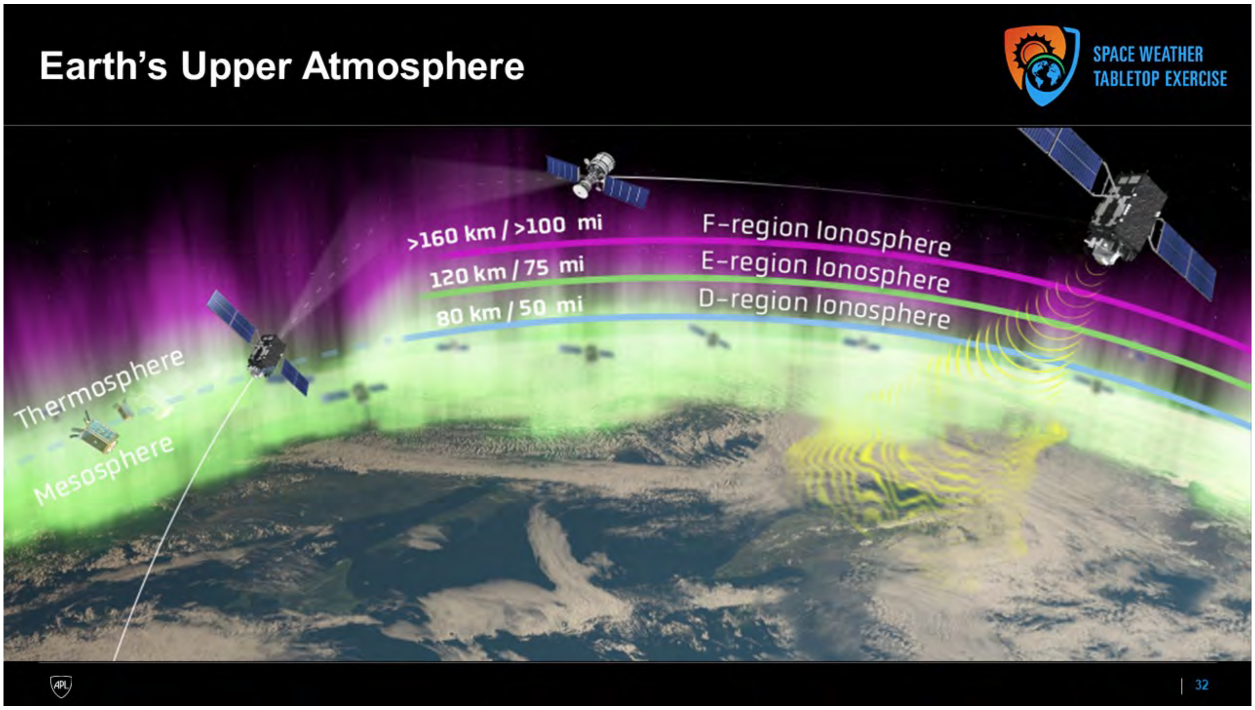
Coronagraph image from ESA/NASA SOHO




Lagrange Point 1 (L1)
Our Upstream Monitoring Station
L4
L3
92 MILLION MILES
1 MILLION MILES
L1
L2
L5
29


Geospace
8 May 2024
30

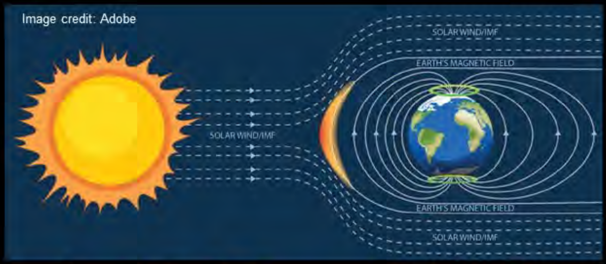

Earth's Magnetosphere
SPACE WEATHER
TABLETOP EXERCISE
Solar Wind
Bow Shock
Magnetopause
Earth
Moon
Radiation Belts
Energetic Electrons
MI-Coupling: FACs
Ring Current
Magnetotail
Magnetosphere
ORBITS
LEO
MEO/GNSS
GEO
LTO
Lunar Gateway Orbit
31


Earth's Upper Atmosphere
SPACE WEATHER
TABLETOP EXERCISE
>160 km / >100 mi
120 km / 75 mi
80 km / 50 mi
F-region Ionosphere
E-region Ionosphere
D-region Ionosphere
Thermosphere
Mesosphere
32

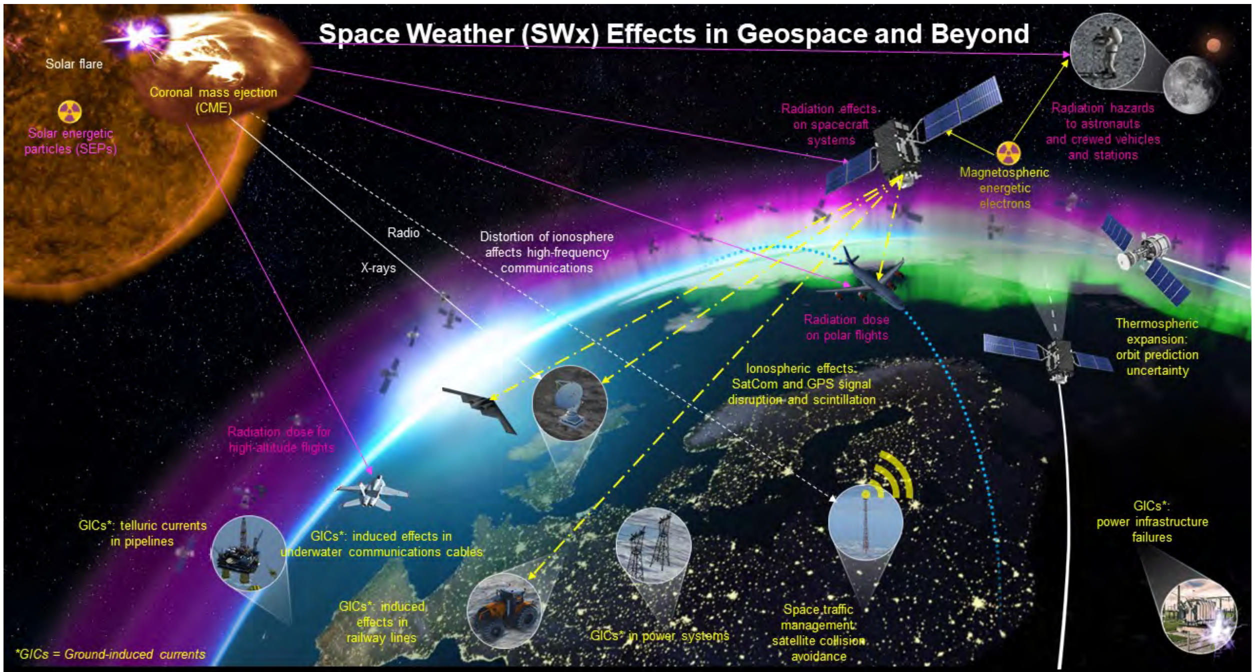
Geomagnetic Storms

SPACE WEATHER
TABLETOP EXERCISE

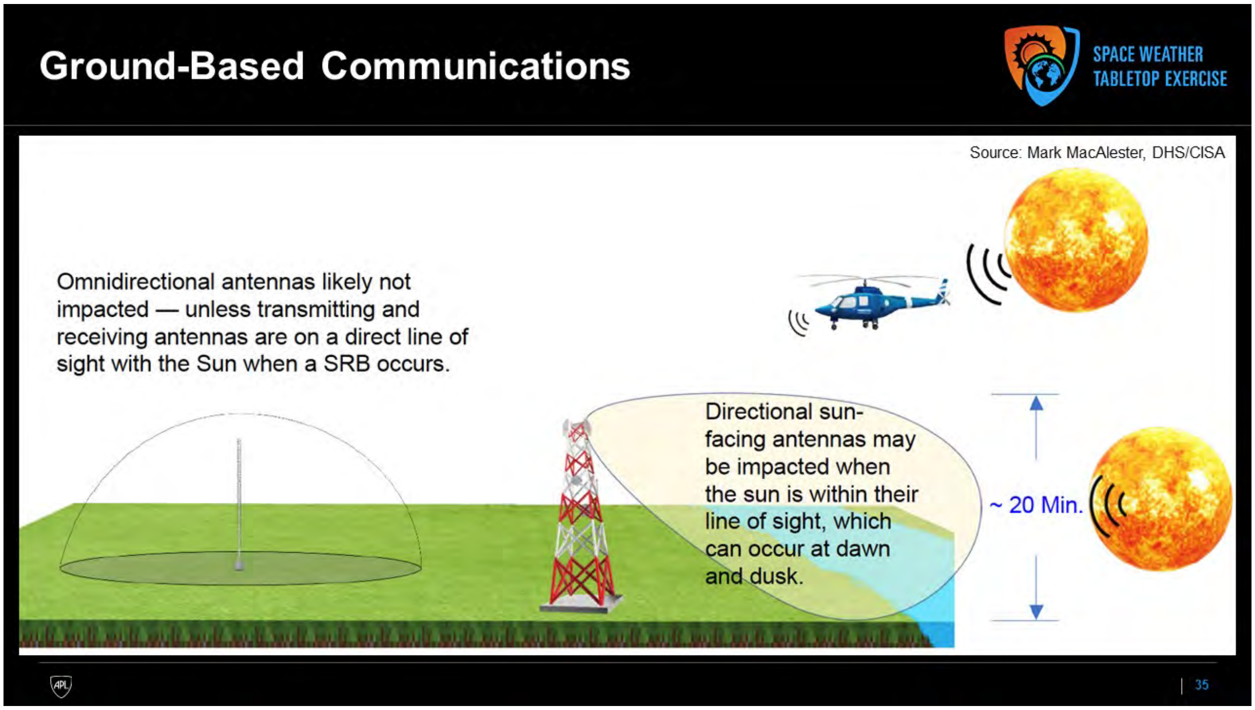
- A geomagnetic storm is the term for the overall geospace response to solar driving.
  - Encompasses a wide array of impacts and physical responses from radiation to upper atmosphere to ground effects
- Storms can begin almost immediately upon impact or several hours later. Response, intensity, and timing largely depend on the state and preconditioning of the system.
- Not all CMEs that hit Earth are created equally; *it depends on the CME magnetic field configuration and strength*.
- Geomagnetic storms are currently monitored by a global network of ground-based magnetometers.

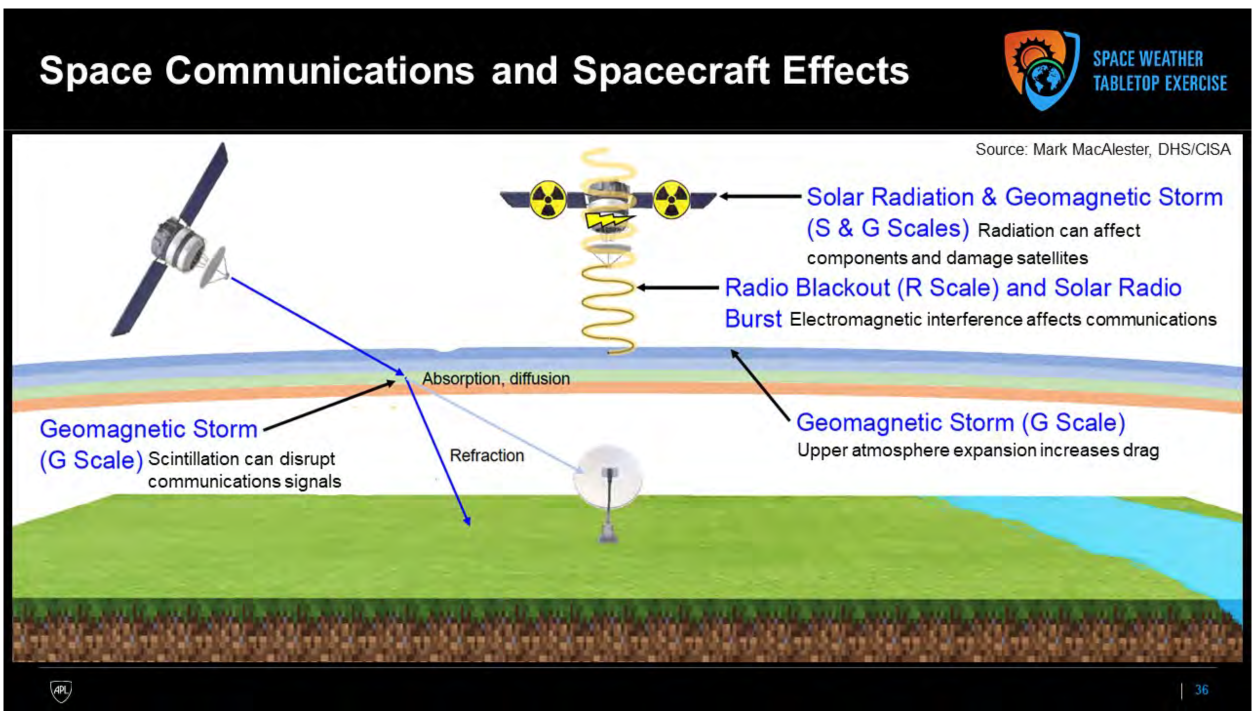


APL | 33



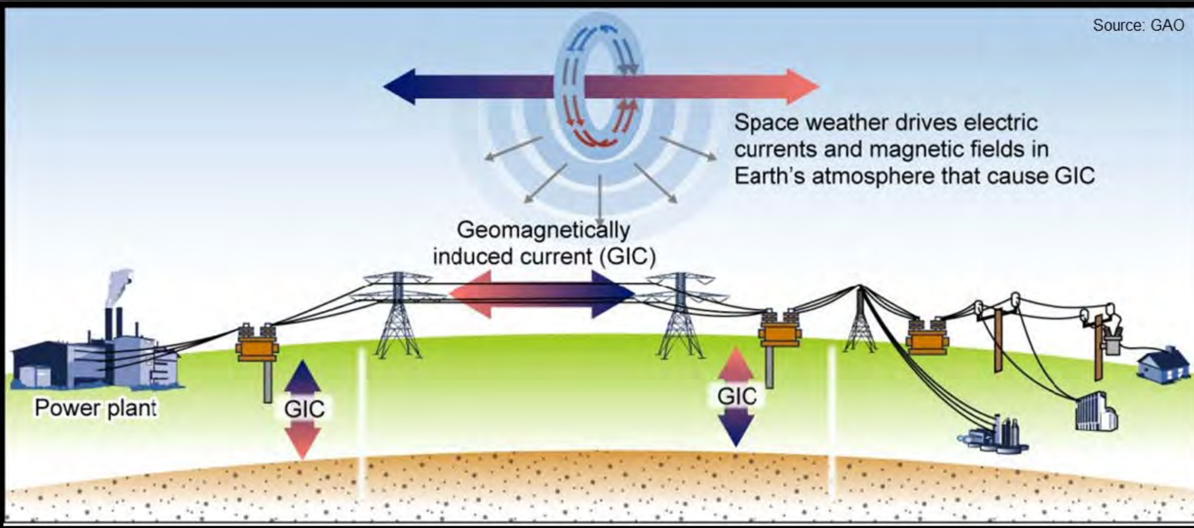
APL | 34


Ground-Based Communications
SPACE WEATHER
TABLETOP EXERCISE
Source: Mark MacAlester, DHS/CISA
Omnidirectional antennas likely not impacted — unless transmitting and receiving antennas are on a direct line of sight with the Sun when a SRB occurs.
Directional sun-facing antennas may be impacted when the sun is within their line of sight, which can occur at dawn and dusk.
~ 20 Min.
35


Space Communications and Spacecraft Effects
SPACE WEATHER
TABLETOP EXERCISE
Source: Mark MacAlester, DHS/CISA
Solar Radiation & Geomagnetic Storm (S & G Scales) Radiation can affect components and damage satellites
Radio Blackout (R Scale) and Solar Radio Burst Electromagnetic interference affects communications
Absorption, diffusion
Geomagnetic Storm (G Scale) Scintillation can disrupt communications signals
Refraction
Geomagnetic Storm (G Scale)
Upper atmosphere expansion increases drag
36

Geomagnetically Induced Currents (GICs)

SPACE WEATHER
TABLETOP EXERCISE



Historical Space Weather Events

SPACE WEATHER
TABLETOP EXERCISE

- **1859** ("Carrington Event"): Most significant space weather event on record. Worldwide telegraph system impacted. Aurora visible in Central America.
- **1921** ("New York Railway Storm"): CME-triggered geomagnetic storm caused issues with railway systems in New York City and upstate New York
- **1989** ("Hydro-Québec Storm"): CME-triggered storm caused power blackout across entire province of Québec. Severely damaged New Jersey transformers and caused numerous U.S. grid anomalies

Historical Space Weather Events, *continued*

SPACE WEATHER
TABLETOP EXERCISE

- **1972**: Extreme solar flare was a near miss for Apollo 16/17 astronauts, and a CME triggered naval mines in Vietnam
- **2002**: Space weather disrupted satellite communications, leading to the deaths of three U.S. soldiers during the Battle of Takur Ghar in Afghanistan
- **2003** ("Halloween Storm"): Power grid effects in Sweden and South Africa; Japanese satellites lost; first realization of impacts on GPS and polar flights

The last significant outbreak of SWx and the turning point of our "modern" understanding.

Credit: U.S. Air Force

8 May 2024 | 39

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

SPACE WEATHER
TABLETOP EXERCISE

Introduction to the NOAA Space Weather Prediction Center (SWPC)

Bill Murtagh
Program Coordinator
NOAA Space Weather Prediction Center

NASA NOAA NSF FEMA

Space Weather Prediction Center (SWPC)

SPACE WEATHER
TABLETOP EXERCISE

- The nation's official source of space weather decision support services, forecasts, watches, warnings, and alerts
- Provides 24/7 analysis and forecasting of space weather storms

"Safeguarding Society with Actionable Space Weather Information"

NOAA SWPC SPACE WEATHER PREDICTION CENTER

www.spaceweather.gov

The 557th Weather Wing provides space weather services for the Department of Defense.

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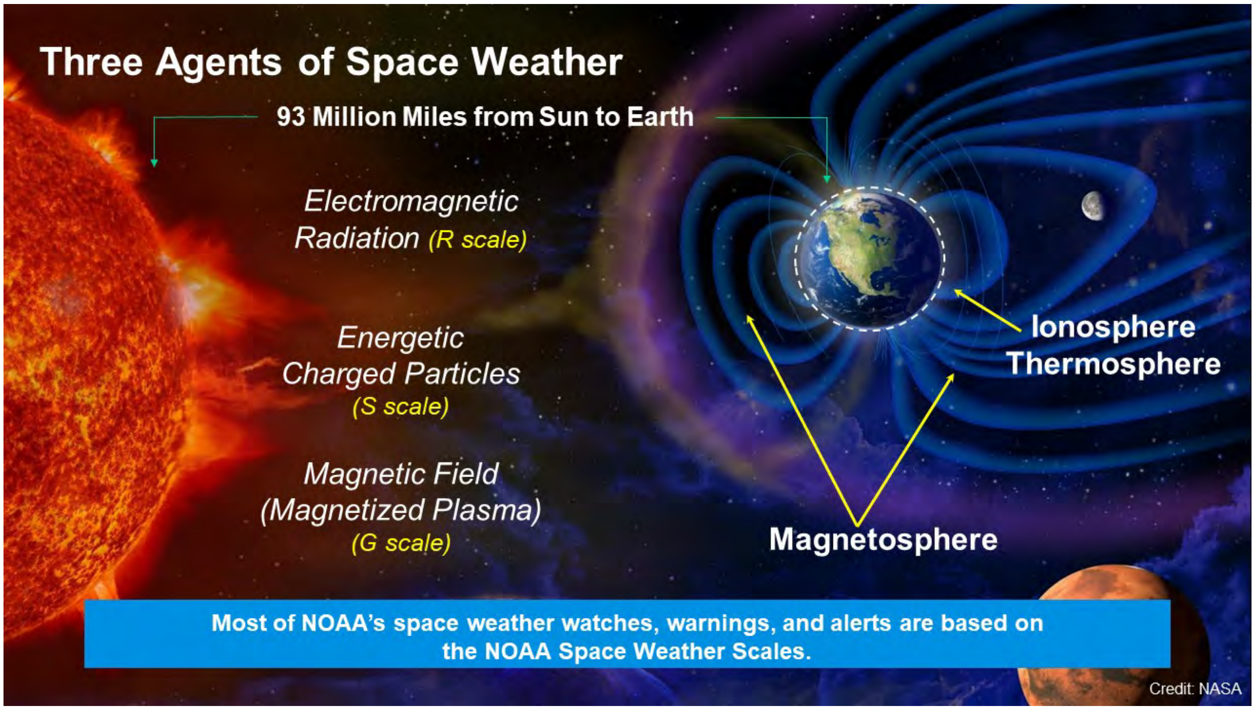

Three Agents of Space Weather
93 Million Miles from Sun to Earth
Electromagnetic
Radiation (R scale)
Energetic
Charged Particles
(S scale)
Magnetic Field
(Magnetized Plasma)
(G scale)
Ionosphere
Thermosphere
Magnetosphere
Most of NOAA's space weather watches, warnings, and alerts are based on
the NOAA Space Weather Scales.
Credit: NASA


Space Weather Impacts Infrastructure and Activities Vital to
National Security and the U.S. Economy
SPACE WEATHER
TABLETOP EXERCISE
FEMA
Growing interdependencies across critical infrastructure systems have increased
the potential vulnerabilities to space weather.
44

Space Weather Warnings Protect Critical Infrastructure

SPACE WEATHER
TABLETOP EXERCISE

Space Operations
- Postpone launch of satellite
- Turn off/safe instruments and/or spacecraft in orbit

Electric Power Grid
- Adjust/reduce system load
- Disconnect components
- Postpone maintenance

Airlines
- Divert polar flights
- Change altitude

GPS/Navigation
- Postpone activities
- Redo survey
- Use backup systems

Communications
- Use backup capabilities
- Alternative frequencies

Powerful 'X-class' solar flare slams Earth, causes radio blackouts. There could be more.

A powerful X-class solar flare slammed into the Earth on Wednesday, causing radio blackouts in many parts of the world. With solar activity ramping up in recent weeks, you could expect that to happen again.

April 1, 2023

February 12, 2022

The Washington Post

CAPITAL WEATHER GANG

How a rather mundane space storm knocked out 40 SpaceX satellites

As the sun enters a more active phase, even minor geomagnetic activity could pose problems for smaller SpaceX satellites.

By Kasha Patel

February 12, 2022 at 9:00 a.m. EST

Rocket Lab launches 2 satellites, returns booster to Earth after delay from surprise

Pultarova last updated 4 days ago

ket carried two commercial Earth-

Friday (March 24), then splashed down

March 24, 2023

SPACE.com

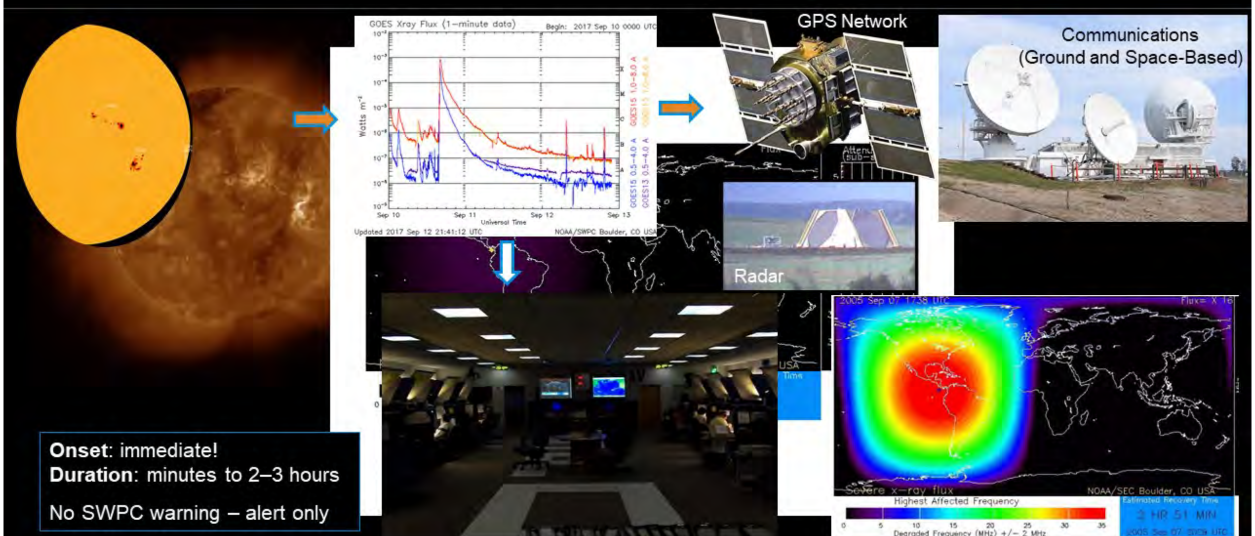
Powerful solar storm delays SpaceX rocket launch, stalls oil rigs in Canada amid aurora-palooza

By Tereza Pultarova published February 28, 2023

Feb 28, 2023

Solar Flares Radio Blackouts (R Scale)

SPACE WEATHER
TABLETOP EXERCISE



Onset: immediate!
Duration: minutes to 2–3 hours
No SWPC warning – alert only

September 2017

SPACE WEATHER TABLETOP EXERCISE

“Yesterday, during all the chaos of hurricane Irma hitting South Florida and Hurricane Jose impacting the Eastern area of the Miami Airspace, a Major Solar Flare occurred which disrupted the communications with airplanes over the Atlantic Ocean. A lot of misinformation was being stated to the FAA from different people about what was causing this problem.”

—***Miami Center Weather Service Unit (CWSU)***

“The solar flare [illegible] I'm not sure how long this blackout will last, but, these flares could not happen at a worse time. We are looking at 3 hurricanes threatening land and we cannot make contact with anyone on the 20 meter or 40 meter amateur bands.

Mother Nature is not playing well.”

—***Hurricane Watch Net, Net Manager***

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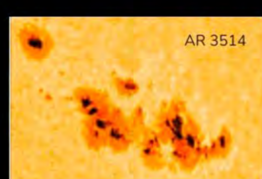
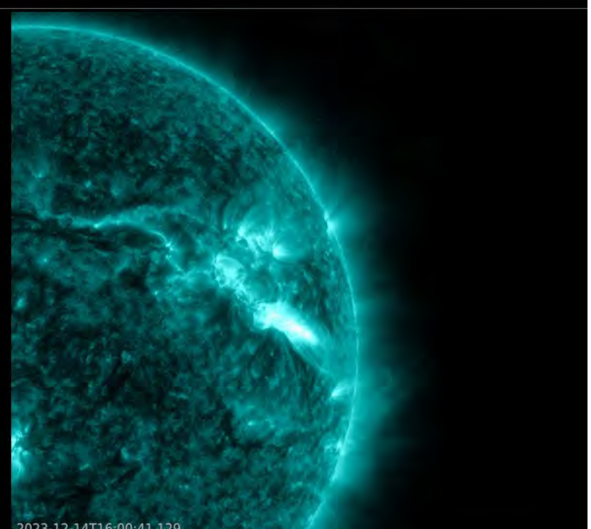
Powerful Radio Burst: 14 December 2023

SPACE WEATHER TABLETOP EXERCISE

For *8 minutes* at the FAA Air Traffic Control Center in Seattle:

- Complete loss of high-frequency to very-high-frequency communication with aircraft
- Loss of ground-based transceivers
- Loss of backup text-based communications with aircraft





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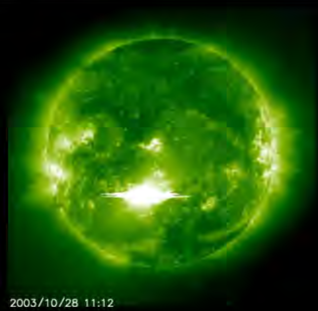
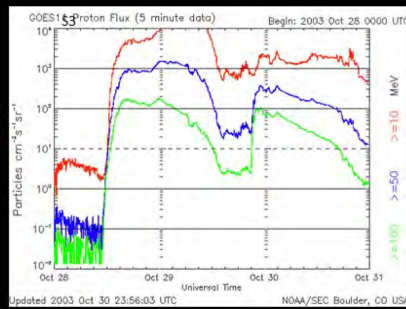
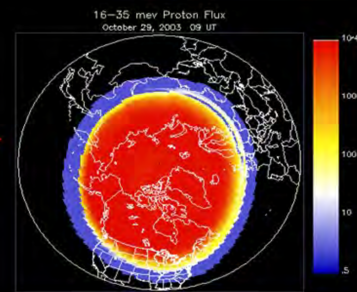
Solar Radiation Storms (S Scale)

SPACE WEATHER
TABLETOP EXERCISE







Impacts

- Satellite operations (range from loss of data to loss of satellite)
- Satellite launch operations
- Radiation exposure to astronauts
- Aviation (communications and exposure concern)
- High-latitude high-frequency communication outage

Onset: tens of minutes to several hours after flare

Duration: hours to days

SWPC warnings and alerts

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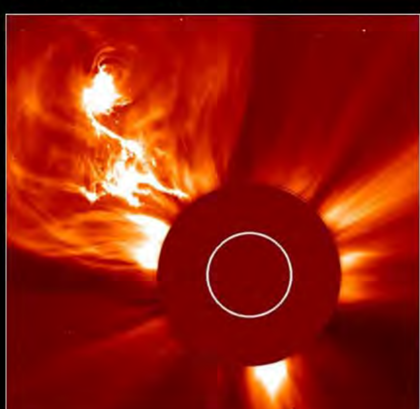
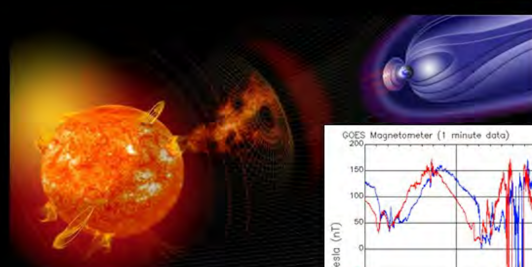
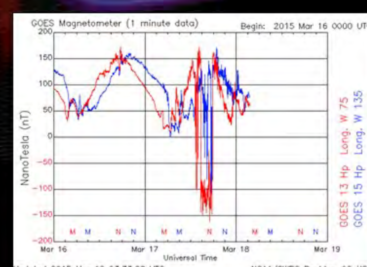
Geomagnetic Storms (G Scale)

SPACE WEATHER
TABLETOP EXERCISE

Coronal mass ejections (CMEs) create geomagnetic storms.





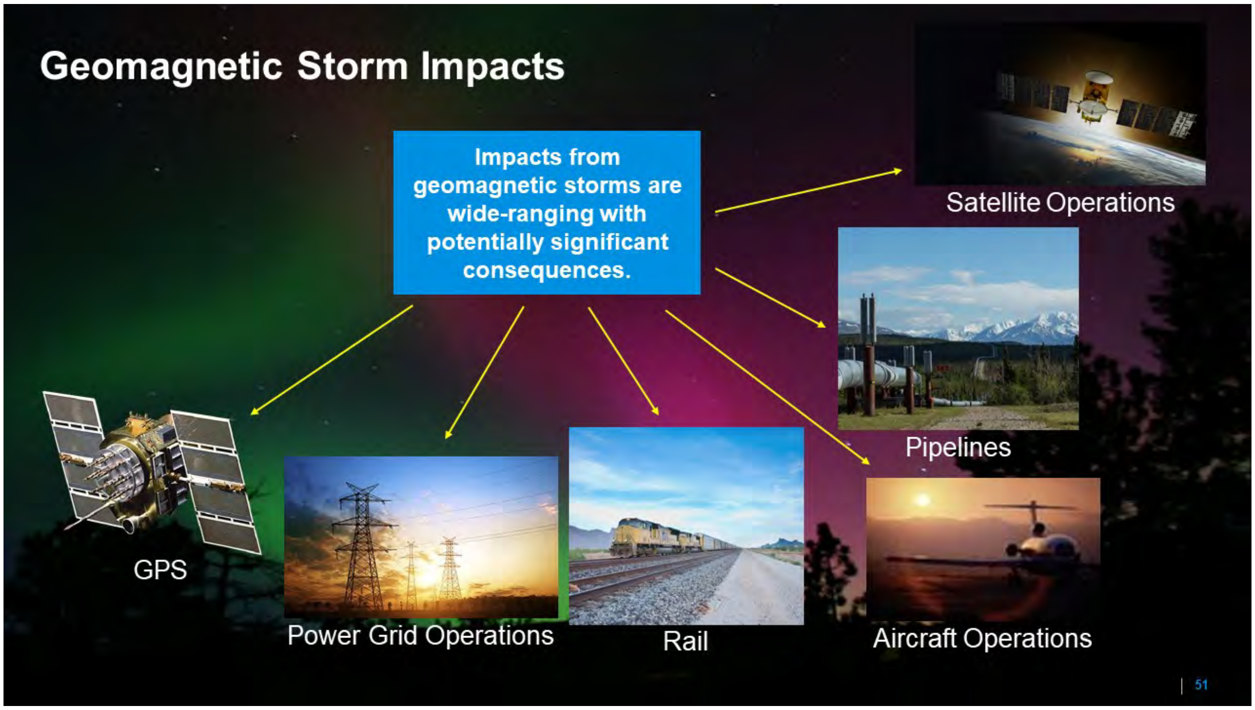


Onset: CME Sun-Earth transit ~15–100 hours

Duration: hours to a day or two

SWPC watches, warnings, and alerts

| 50



Impacts on Electric Power Grid

SPACE WEATHER
TABLETOP EXERCISE

- A CME impacts Earth's magnetic field.
- Fluctuations generate electric fields on Earth. These geomagnetically induced currents (GICs) can flow into power lines and transformers.
- Transformer saturation and overheating, voltage drops, transformer damage, and grid collapse can result.

Vulnerability of U.S. Grid

- Northern latitude (location of aurora during geomagnetic storms)
- Areas of relatively high resistive igneous rock
- Very-high-voltage interconnected transmission network
- Proximity to oceans (conductivity of ocean salt water)

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Significant Grid Problems Have Occurred…

SPACE WEATHER
TABLETOP EXERCISE

HYDRO-QUEBEC PRESS RELEASE

Direction Relations Publiques
HYDRO-QUEBEC
MONTREAL, CANADA

MARCH 13 BLACKOUT CAUSED BY AN EXCEPTIONALLY STRONG MAGNETIC STORM

Information Notice No. 90-42:
FAILURE OF ELECTRICAL POWER EQUIPMENT DUE TO SOLAR MAGNETIC DISTURBANCES

Specific events occurred at the Three Mile Island Unit 1, Hope Creek Unit 1, and Salem Unit 1 nuclear power plants. …generator step-up transformer… severe overheating, melted low-voltage service connections
Sep 1990

**Department of Homeland Security
Information Analysis and Infrastructure Protection
Daily Open Source Infrastructure Report
for 03 November 2003**

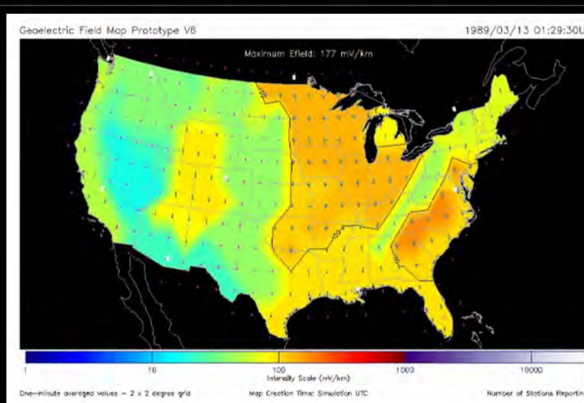
Current Nationwide Threat Level is ELEVATED
For info click here

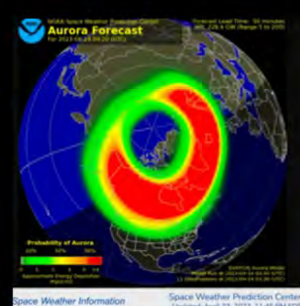
October 31 - ***Sun storm causes problems for Swedish power system. The solar storm has caused technical glitches in Sweden's power system in the past few days and may be to blame for a blackout that affected 50,000 people on Thursday, October 30.***

| 53

April 2023 G4 Geomagnetic Storm

SPACE WEATHER
TABLETOP EXERCISE





"This event was one of the most visible on our measurements in many, many years – very challenging voltage issues in the control room.

*SWPC support very important to make informed decisions to protect our critical assets" —**Hydro-Québec, Montréal***

| 54

Loss of 38 SpaceX Starlink Satellites

- Launch of **49 satellites** on Thursday, 3 February 2022
- Economic losses between **$12 million and $24 million**
- Joint NOAA-SpaceX Study (November 2022)

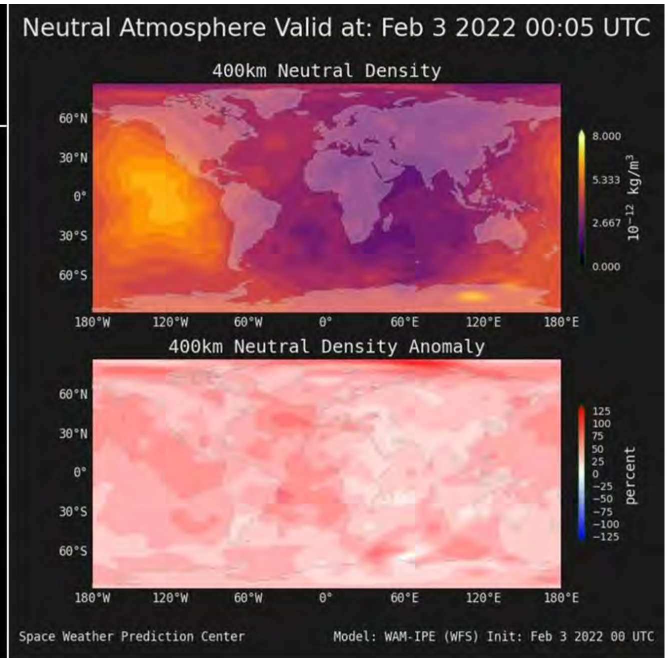
Space Weather®

Research Article | Open Access

Space Weather Environment During the SpaceX Starlink Satellite Loss in February 2022

Tzu-Wei Fang, Adam Kubaryk, David Goldstein, Zhuxiao Li, Tim Fuller-Rowell, George Millward, Howard J. Singer, Robert Steenburgh, Solomon Westerman, Erik Babcock

First published: 02 November 2022 | https://doi.org/10.1029/2022SW003193 | Citations: 20



SWPC Event-Driven Products

SPACE WEATHER
TABLETOP EXERCISE

WATCH	WARNING	ALERT
event potential; 1–3 days in advance (G1–G4+)	event imminent; minutes to hours notice (G1–G3+) and S1 events	event detected; in progress G1–G5, S1–S5, and >R2

Sample of SWPC Event-Driven Products

SPACE WEATHER
TABLETOP EXERCISE

Solar Flare Radio Blackout

Serial Number: 350
Issue Time: 2024 Mar 23 1354 UTC

ALERT: X-Ray Flux exceeded M5
Threshold Reached: 2024 Mar 23 1352 UTC
NOAA Scale: R2 - Moderate

NOAA Space Weather Scale descriptions can be found at www.swpc.noaa.gov/noaa-scales-explanation.

Potential Impacts: area of impact centered on sub-solar point on the sunlit side of Earth. Extent of blackout of HF (high frequency) radio communication dependent upon current X-ray flux intensity.

Geomagnetic Storm Watch

Space Weather Message Code: WATA50
Serial Number: 74
Issue Time: 2024 Mar 23 1840 UTC

WATCH: Geomagnetic Storm Category G3 Predicted

Highest Storm Level Predicted by Day:
Mar 24: G2 (Moderate) Mar 25: G3 (Strong) Mar 26: G1 (Minor)

THIS SUPERSEDES ANY/ALL PRIOR WATCHES IN EFFECT

NOAA Space Weather Scale descriptions can be found at www.swpc.noaa.gov/noaa-scales-explanation.

Potential Impacts: Area of impact primarily poleward of 50 degrees Geomagnetic Latitude.
Induced Currents - Power system voltage irregularities possible, false alarms may be triggered on some protection devices.
Spacecraft - Systems may experience surface charging; increased drag on low-Earth-orbit satellites and orientation problems may occur.
Navigation - Intermittent satellite navigation (GPS) problems, including loss-of-lock and increased range error may occur.
Radio - HF (high frequency) radio may be intermittent.
Aurora - Aurora may be seen as low as Pennsylvania to Iowa to Oregon.

Radiation Storm Warning

Space Weather Message Code: SUMPX2
Serial Number: 49
Issue Time: 2024 Mar 25 0701 UTC

SUMMARY: Proton Event 10MeV Integral Flux exceeded 100pfu
Begin Time: 2024 Mar 23 1405 UTC
Maximum Time: 2024 Mar 23 1820 UTC
End Time: 2024 Mar 24 1945 UTC
Maximum 10MeV Flux: 956 pfu
NOAA Scale: S2 - Moderate

NOAA Space Weather Scale descriptions can be found at www.swpc.noaa.gov/noaa-scales-explanation.

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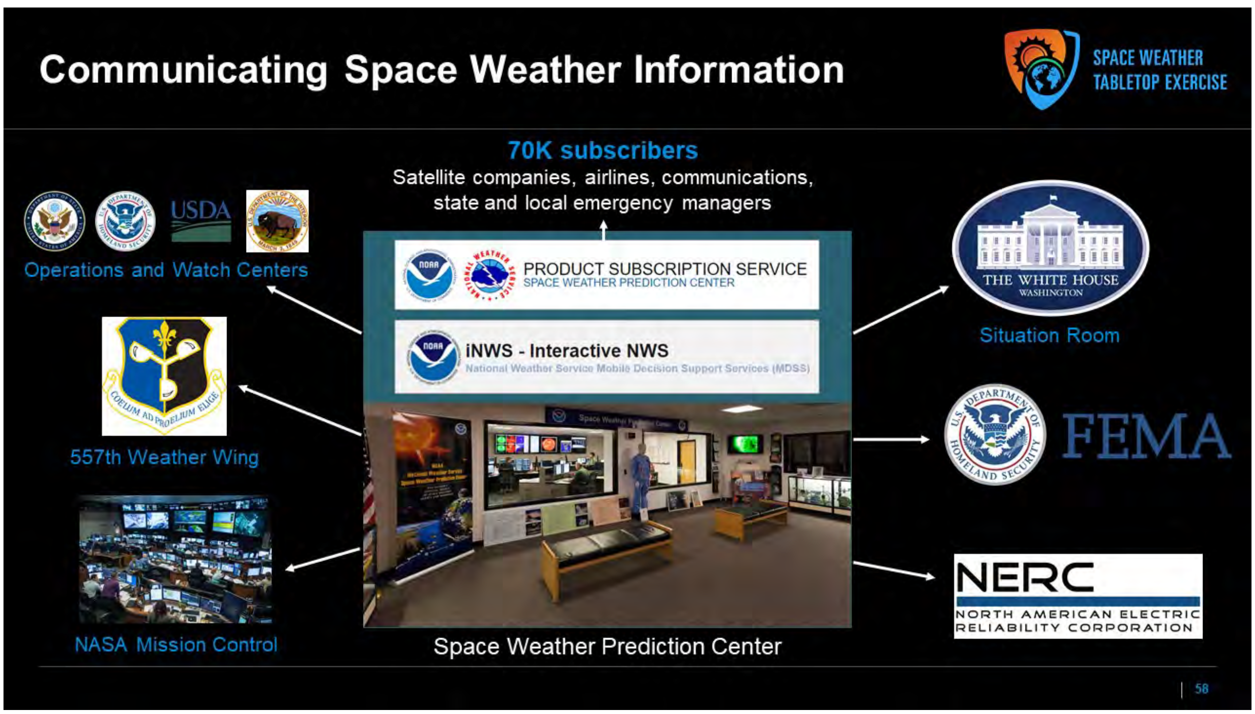

Event Alert and Notification – Emergency Response

SPACE WEATHER
TABLETOP EXERCISE

Directly or indirectly cause or exacerbate a major disaster or emergency
Interfere with or seriously degrade FEMA's response and recovery capability

S4–S5 Radiation Storms

G4–G5 Geomagnetic Storms

FEMA Operations Center (FOC) — **Notify Leadership**

FOC Alternate West (FAOC) — **ENS to MOCs and Watches; Send Plain-Language Email**

National Watch Center — **Notify NOC; Broad Distro Plain-Language Email**

FAOC-East — **NAWAS/WAWAS *(S5, G5 only)***

- Emergency notification system (ENS)
- FEMA MERS Operations Center (MOC)
- National Operations Center (NOC)
- National Warning System (NAWAS)
- Washington Metropolitan Area Warning System (WAWAS)

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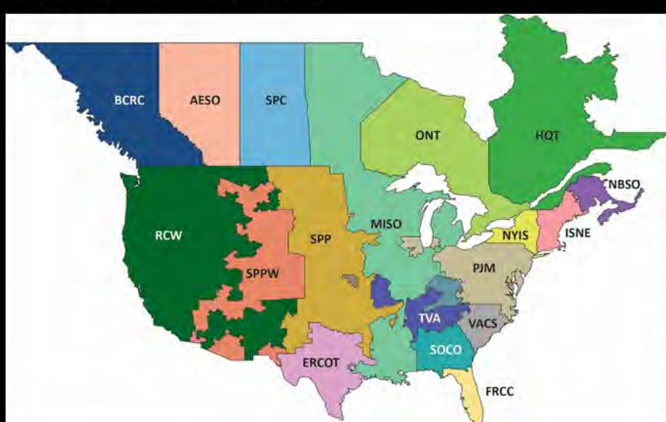
SWx Event Alert and Notification – Power Grid

SPACE WEATHER
TABLETOP EXERCISE

SWPC provides warnings to Reliability Coordinators through the North American Electric Reliability Corporation (NERC) Hotline



NERC Reliability Coordinators

Alberta Electric System Operator	SPP West
British Columbia Hydro	PJM Interconnection
Electric Reliability Council of Texas	Reliability Coordinator West
Florida Reliability Coordinating Council	Saskatchewan Power Corporation
Hydro-Quebec TransEnergie	Southern Company Services, Inc.
ISO New England, Inc.	Southwest Power Pool
Midcontinent ISO	BAs receive RC Services from SPP or TVA
New Brunswick Power Corporation	Tennessee Valley Authority
New York Independent System Operator	BAs recieve RC services from TVA or MISO
Ontario Independent Electricity System Operator	VACAR South

NERC is the electric reliability organization for North America, subject to oversight by the Federal Energy Regulatory Commission and governmental authorities in Canada.

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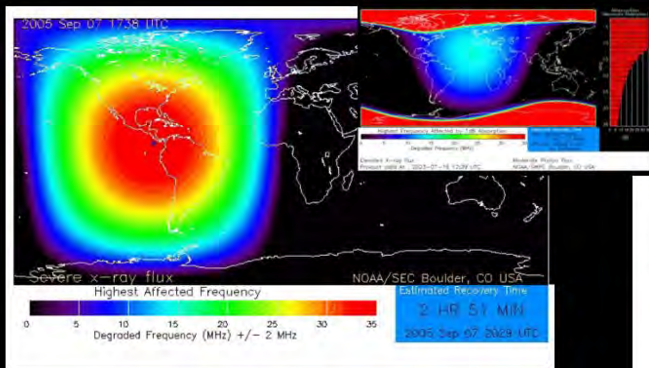
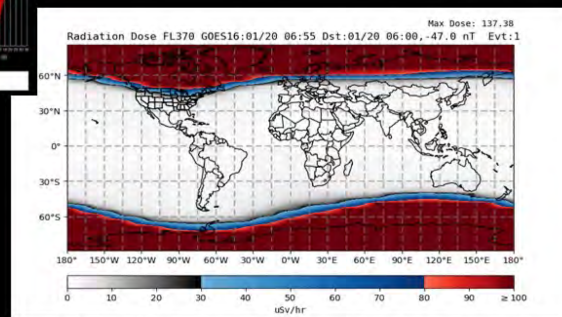
Graphics Products Necessary for Required Details

SPACE WEATHER
TABLETOP EXERCISE



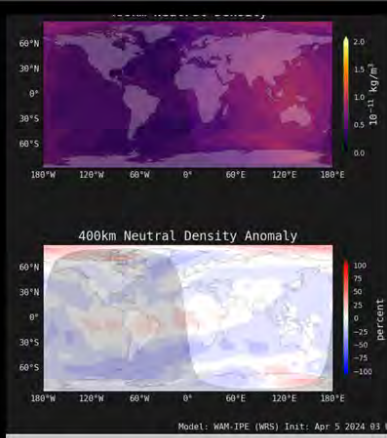
SWPC D-Region Absorption Product: impact of the solar X-ray flux and solar radiation storms on high-frequency radio communications



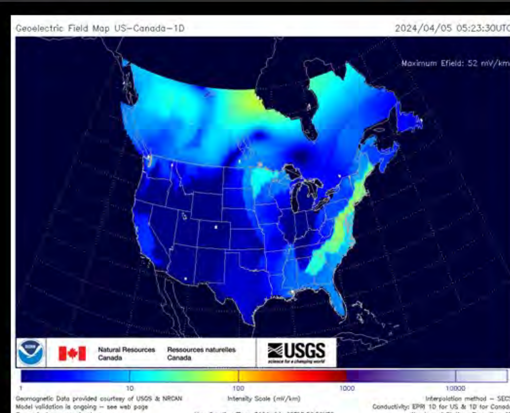
FAA CARI-7 Model: depicting location of moderate-to-severe radiation exposure at aircraft altitude

Graphics Products Necessary for Required Details

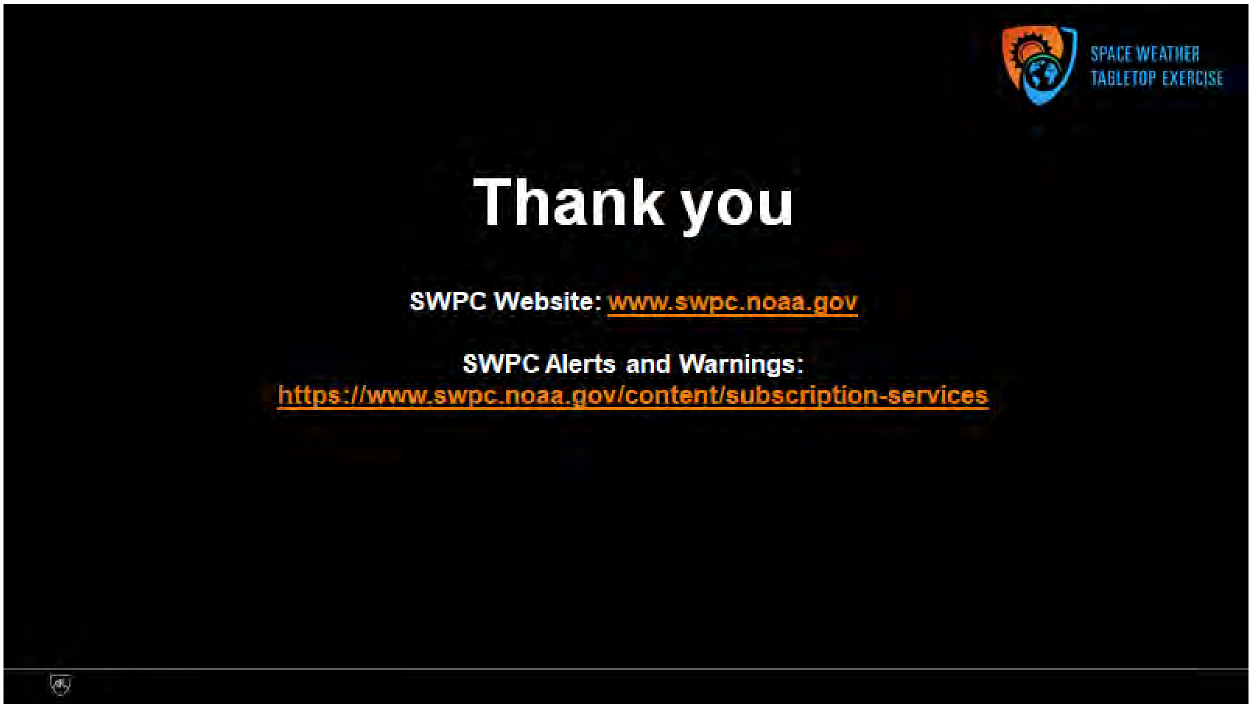
SPACE WEATHER
TABLETOP EXERCISE

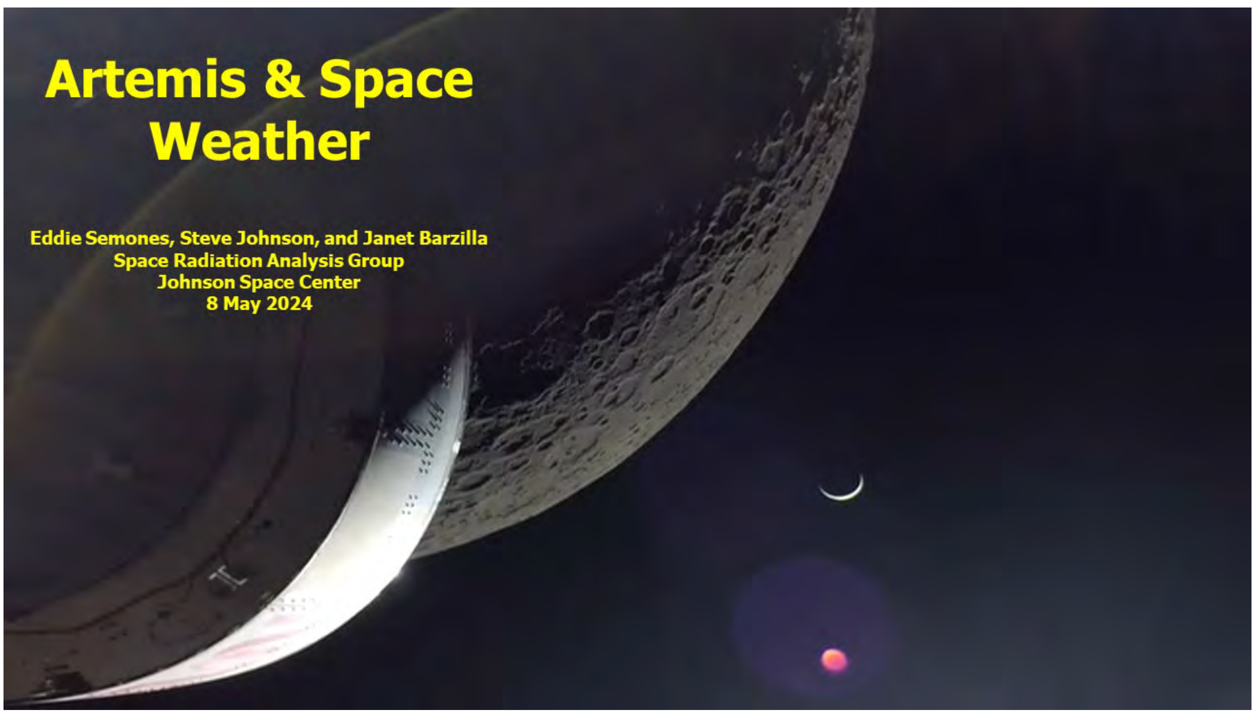


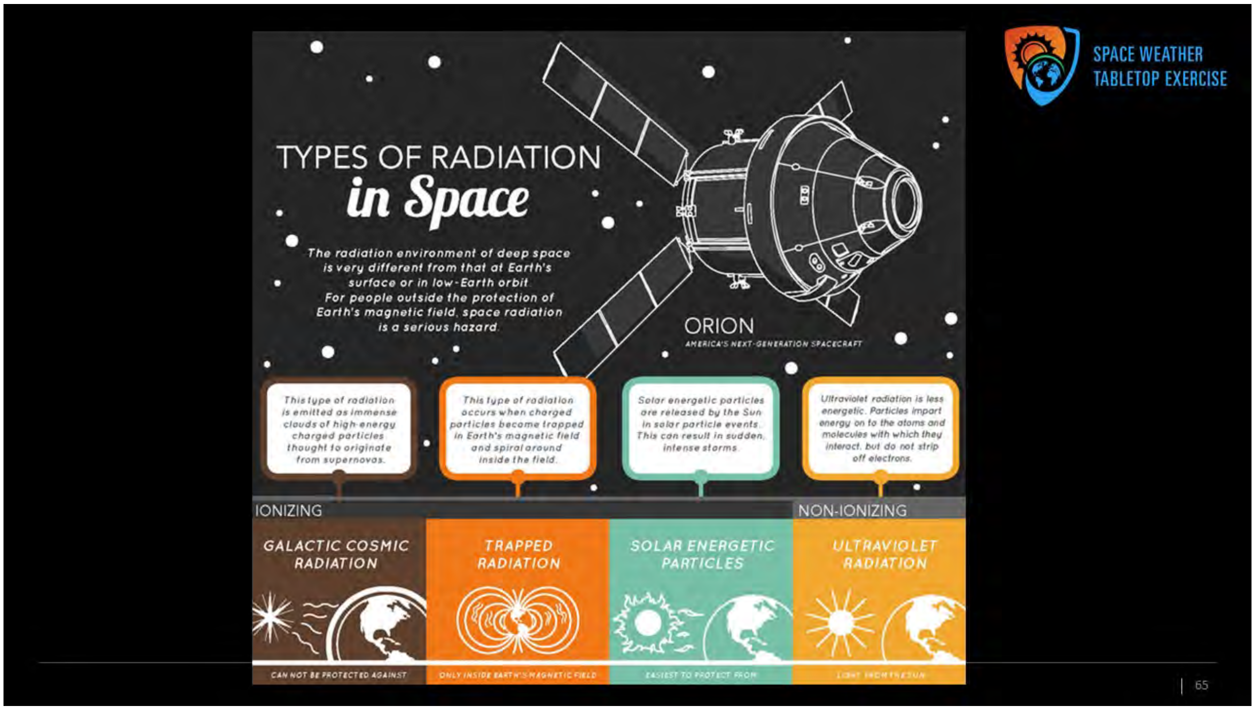
WAM-IPE shows real-time neutral density fields for orbit prediction and space traffic management.



Geoelectric field is a measure of the induction hazard to electrical power lines resulting from geomagnetic activity.


SPACE WEATHER TABLETOP EXERCISE
Thank you
SWPC Website: www.swpc.noaa.gov
SWPC Alerts and Warnings:
https://www.swpc.noaa.gov/content/subscription-services


Artemis & Space Weather
Eddie Semones, Steve Johnson, and Janet Barzilla
Space Radiation Analysis Group
Johnson Space Center
8 May 2024



Space Radiation Environment Summary

Trapped Radiation (Van Allen Belts)

- Protons/electrons
- High dose rate
- Transient concern
- Risk is understood

Aurora from CME that was geoeffective on 02 Aug 2021.
Credit: ISS Exp 65 crew.

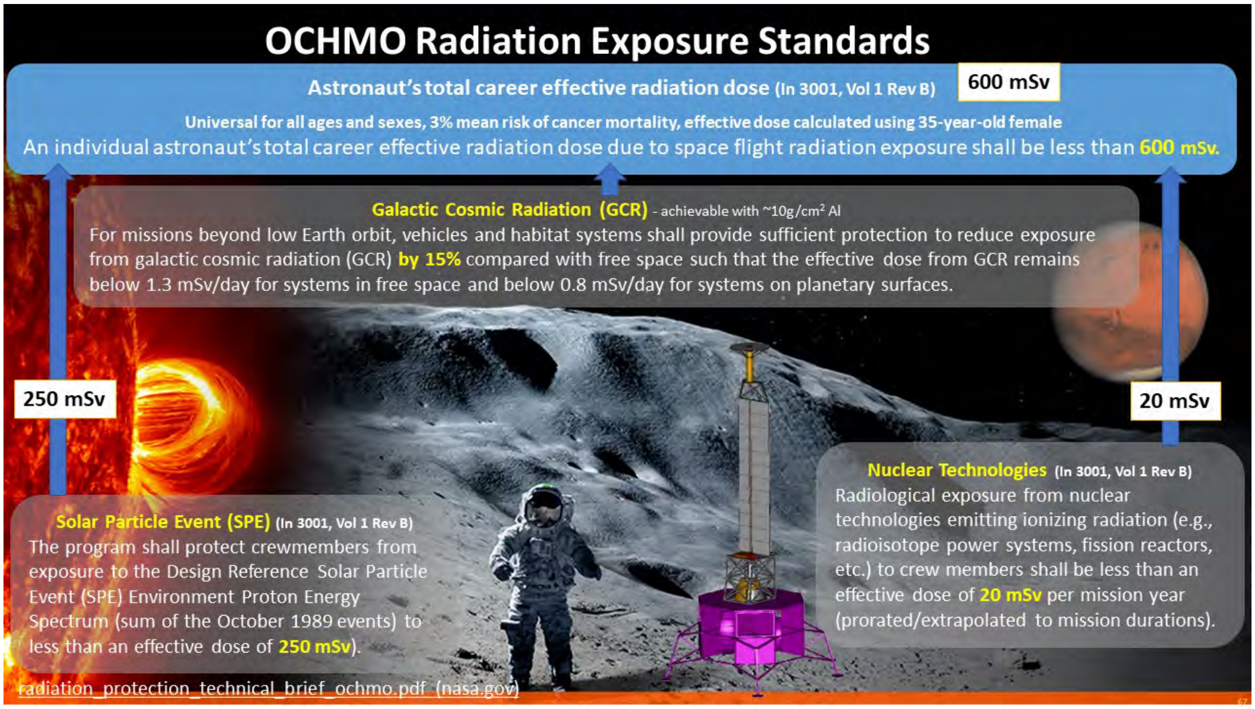
Galactic Cosmic Radiation (GCR)

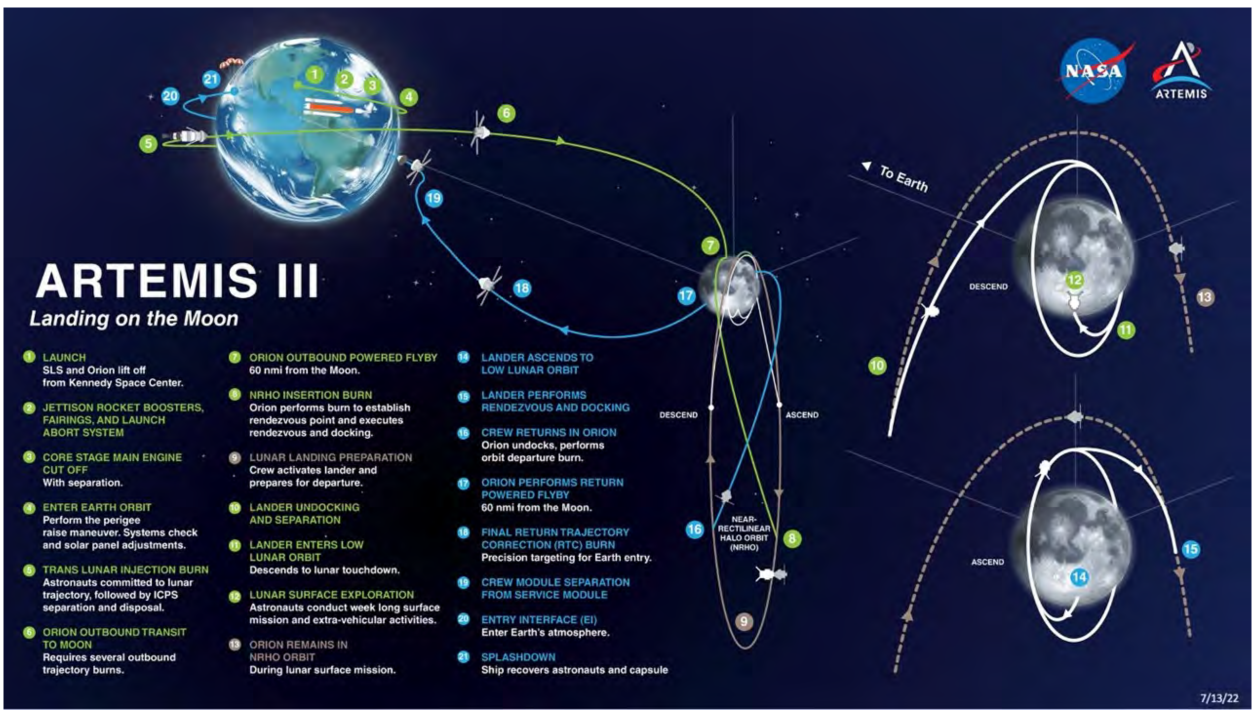
- Many particle types (hydrogen through iron)
- Low dose rate, high energy
- Difficult to shield
- Monitor for long-term health effects
- Peak: Solar Minimum

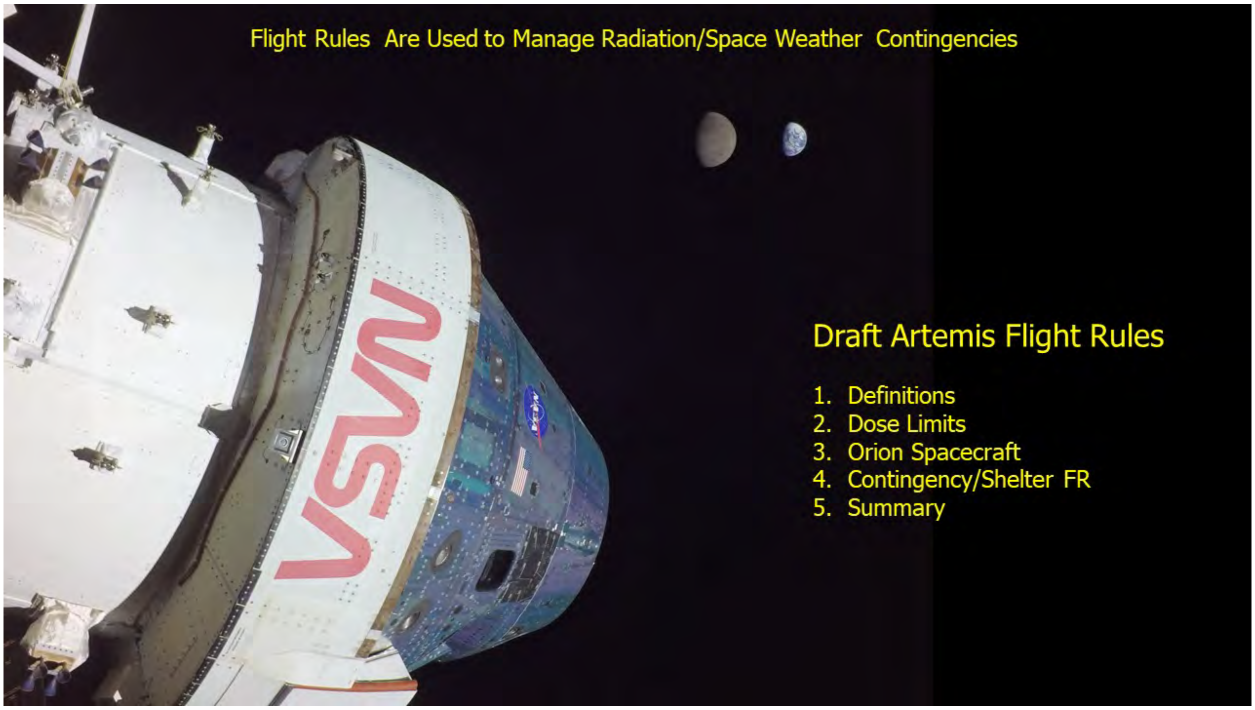
Solar Particle Events (SPEs)

- Mostly protons
- Potential for higher dose rate
- Easier to shield than GCR
- Risk of acute effects and exceeding short term/career limits
- Peak: Solar Maximum

SRAG considers all 3 sources in our radiation mitigation strategy – SPE impacts are main space weather concern


OCHMO Radiation Exposure Standards
Astronaut's total career effective radiation dose (In 3001, Vol 1 Rev B)
600 mSv
Universal for all ages and sexes, 3% mean risk of cancer mortality, effective dose calculated using 35-year-old female
An individual astronaut's total career effective radiation dose due to space flight radiation exposure shall be less than 600 mSv.
Galactic Cosmic Radiation (GCR) - achievable with ~10g/cm² Al
For missions beyond low Earth orbit, vehicles and habitat systems shall provide sufficient protection to reduce exposure from galactic cosmic radiation (GCR) by 15% compared with free space such that the effective dose from GCR remains below 1.3 mSv/day for systems in free space and below 0.8 mSv/day for systems on planetary surfaces.
250 mSv
20 mSv
Solar Particle Event (SPE) (In 3001, Vol 1 Rev B)
The program shall protect crewmembers from exposure to the Design Reference Solar Particle Event (SPE) Environment Proton Energy Spectrum (sum of the October 1989 events) to less than an effective dose of 250 mSv).
Nuclear Technologies (In 3001, Vol 1 Rev B)
Radiological exposure from nuclear technologies emitting ionizing radiation (e.g., radioisotope power systems, fission reactors, etc.) to crew members shall be less than an effective dose of 20 mSv per mission year (prorated/extrapolated to mission durations).
radiation_protection_technical_brief_ochmo.pdf (nasa.gov)


NASA
ARTEMIS
ARTEMIS III
Landing on the Moon
To Earth
DESCEND
ASCEND
NEAR-RECTILINEAR HALO ORBIT (NRHO)
1 LAUNCH
SLS and Orion lift off from Kennedy Space Center.
2 JETTISON ROCKET BOOSTERS, FAIRINGS, AND LAUNCH ABORT SYSTEM
3 CORE STAGE MAIN ENGINE CUT OFF
With separation.
4 ENTER EARTH ORBIT
Perform the perigee raise maneuver. Systems check and solar panel adjustments.
5 TRANS LUNAR INJECTION BURN
Astronauts committed to lunar trajectory, followed by ICPS separation and disposal.
6 ORION OUTBOUND TRANSIT TO MOON
Requires several outbound trajectory burns.
7 ORION OUTBOUND POWERED FLYBY
60 nmi from the Moon.
8 NRHO INSERTION BURN
Orion performs burn to establish rendezvous point and executes rendezvous and docking.
9 LUNAR LANDING PREPARATION
Crew activates lander and prepares for departure.
10 LANDER UNDOCKING AND SEPARATION
11 LANDER ENTERS LOW LUNAR ORBIT
Descends to lunar touchdown.
12 LUNAR SURFACE EXPLORATION
Astronauts conduct week long surface mission and extra-vehicular activities.
13 ORION REMAINS IN NRHO ORBIT
During lunar surface mission.
14 LANDER ASCENDS TO LOW LUNAR ORBIT
15 LANDER PERFORMS RENDEZVOUS AND DOCKING
16 CREW RETURNS IN ORION
Orion undocks, performs orbit departure burn.
17 ORION PERFORMS RETURN POWERED FLYBY
60 nmi from the Moon.
18 FINAL RETURN TRAJECTORY CORRECTION (RTC) BURN
Precision targeting for Earth entry.
19 CREW MODULE SEPARATION FROM SERVICE MODULE
20 ENTRY INTERFACE (EI)
Enter Earth's atmosphere.
21 SPLASHDOWN
Ship recovers astronauts and capsule
7/13/22



DRAFT ARTEMIS FLIGHT RULES

Dose Limits

Space Weather Tabletop Exercise 2024
Note: All rules are in draft stage

ORGAN	**LIMIT****
BLOOD FORMING ORGAN (BFO)	250 MILLI-GRAY-EQUIVALENTS
EYE	1000 MILLI-GRAY-EQUIVALENTS
SKIN	1500 MILLI-GRAY-EQUIVALENTS

- Primary endpoint is BFO (i.e. first threshold reached)
- Up to 30 Day mission
- For comparison
  - White blood cell count depression 500 mGy-eq
  - Nausea (50% population) 1000 mGy-eq
  - LD50 (3 to 6 wks, no medical) 4500 mGy-eq

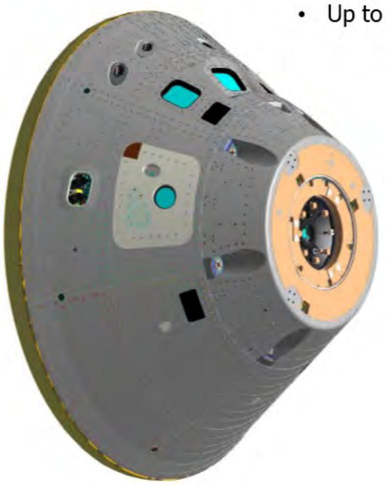
**NASA-STD-3001 Rev C – 4.8.2 Career Space Permissible Exposure Limit for Spaceflight Radiation.

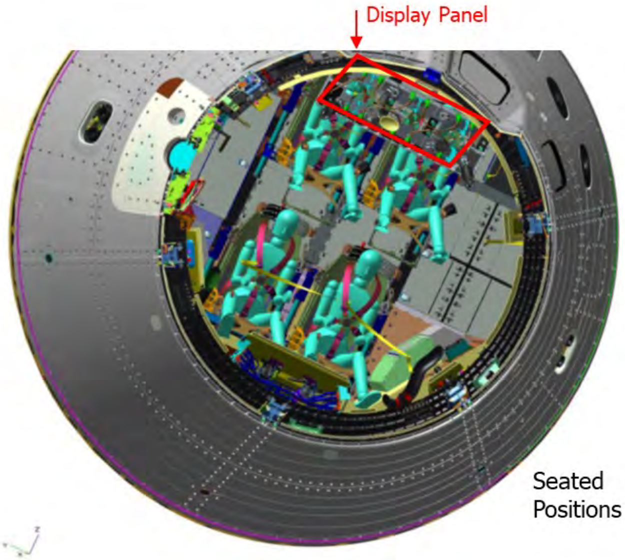
DRAFT ARTEMIS FLIGHT RULES

Orion Spacecraft

Space Weather Tabletop Exercise 2024
Note: All rules are in draft stage

- 4 crewmembers
- Up to 30 Day mission





DRAFT ARTEMIS FLIGHT RULES

Artemis Launch Flight Rule

Space Weather Tabletop Exercise 2024
Note: All rules are in draft stage

- There is a hardware rule that prohibits launching into an energetic solar proton event.
  - Slightly different definition than for crew
- If that rule is waived, then

  Do not launch if the current or projected >100 MeV flux $\geq$ 30 pfu at the time of launch.

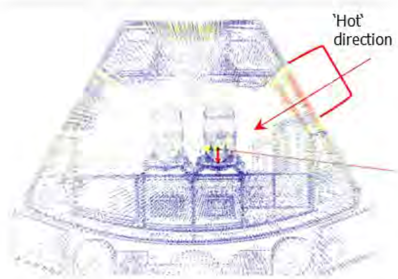
  - Since 1987, 75 % of the ESPE are smaller than this threshold
    - Lower event doses
    - Shorter duration

DRAFT ARTEMIS FLIGHT RULES

Contingency/Shelter Flight Rules

Space Weather Tabletop Exercise 2024
Note: All rules are in draft stage

- Avoid low shielded areas (Port wall)
- If Highest HERA dose rate > 75 uGy/min establish shelter configuration
  - >100 MeV fluxes ~ 100-130 pfu depending on event hardness
  - Hard event – Higher
  - Soft event – Lower
  - All HERA failed – Shelter at GOES >100 MeV > 50 pfu
- Stowage from central bays moved to port wall hot spot
- When Highest HERA dose rate is <20 uGy/min, shelter configuration can be terminated.
  - >100 MeV fluxes ~ 15-30 pfu
  - All HERA failed – Shelter at GOES >100 MeV < 20 pfu
- Shield effectiveness
  - Based on average of all positions
  - Average 10%
  - Hard event 7% (Jan05)
  - Soft event 14 % (Nov 00)



Orion Spacecraft is relatively highly shielded
Worst case event Oct 89

- No action: 80% of limit
  - Positional Range: 67% - 103%
- Shelter: 65% of limit
  - Positional Range: 48% - 82 %

DRAFT ARTEMIS FLIGHT RULES

Summary

Space Weather Tabletop Exercise 2024
Note: All rules are in draft stage

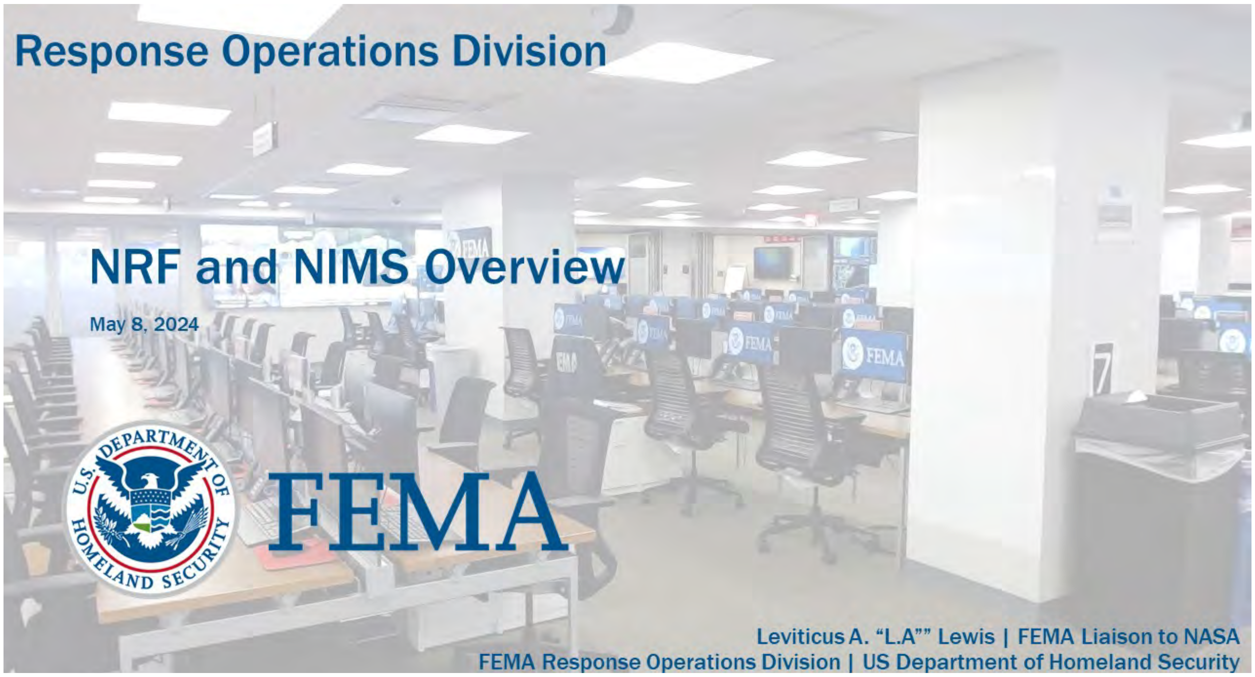
GOES proton fluxes are used in conjunction with internal measurements and operational tools to manage crew exposures

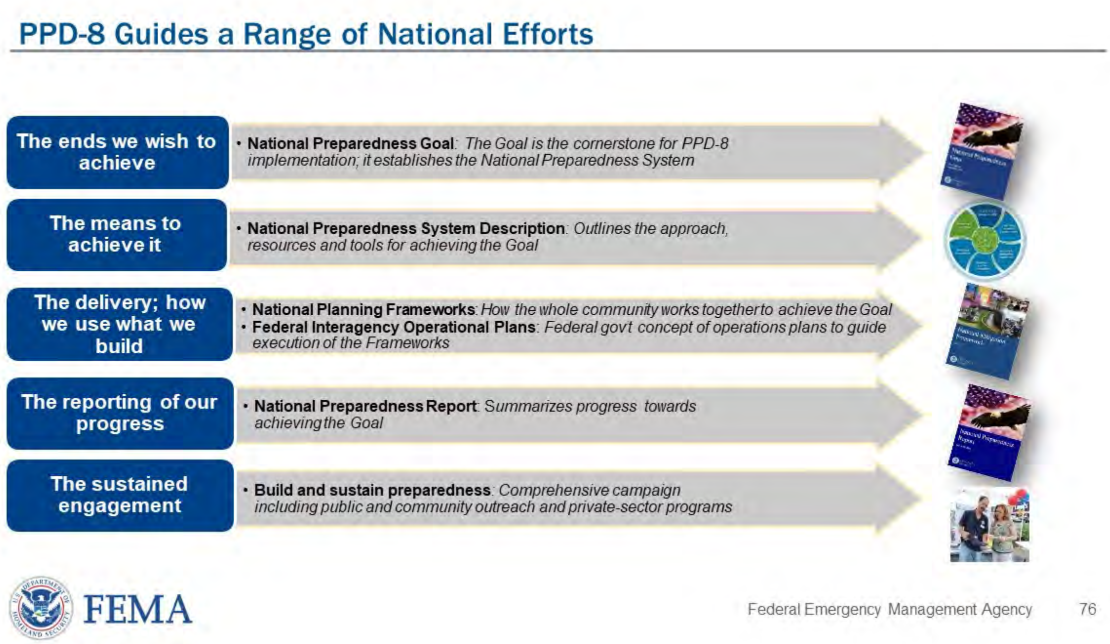
Orion Spacecraft is relatively highly shielded
Even with Worst case event Oct 89 events – No limit violation expected.

Robust Monitoring
- HERA – 6 Si detectors at different shield depths
  - Two independent strings of 3
  - Caution and Warning alarms
  - Different depths – facilitates spectral modeling
- Crew Active Dosimeters

EVA Rules are in development
- No showstoppers for Artemis 3 at this time

Artemis 3 is first lunar landing


Response Operations Division
NRF and NIMS Overview
May 8, 2024
FEMA
Leviticus A. "L.A"" Lewis | FEMA Liaison to NASA
FEMA Response Operations Division | US Department of Homeland Security


PPD-8 Guides a Range of National Efforts
The ends we wish to achieve
• National Preparedness Goal: The Goal is the cornerstone for PPD-8 implementation; it establishes the National Preparedness System
The means to achieve it
• National Preparedness System Description: Outlines the approach, resources and tools for achieving the Goal
The delivery; how we use what we build
• National Planning Frameworks: How the whole community works together to achieve the Goal
• Federal Interagency Operational Plans: Federal gov't concept of operations plans to guide execution of the Frameworks
The reporting of our progress
• National Preparedness Report: Summarizes progress towards achieving the Goal
The sustained engagement
• Build and sustain preparedness: Comprehensive campaign including public and community outreach and private-sector programs
FEMA
Federal Emergency Management Agency
76

All-Hazards Planning Framework

FEMA

Federal Emergency Management Agency 77

Coordinating the Federal Response

The FEMA Administrator assists the President to carry out the Stafford Act functions and serves as the principal advisor to the President and the Secretary of Homeland Security for all matters relating to emergency management in the United States.

Robert T. Stafford Disaster Relief and Emergency Assistance Act

Authorizes the President to issue a Major Disaster Declaration or Emergency Declaration to authorize federal aid to states/tribes overwhelmed by catastrophes.

FEMA

Federal Emergency Management Agency 78

The Stafford Act

- Presidential disaster declarations are governed by the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Stafford Act)
- FEMA's regulations detail the declarations process, including factors that the Administrator considers when making recommendations to the President

Emergency Declaration	**Definition:** Any occasion or instance for which, in the determination of the President, Federal assistance is needed to supplement State and local efforts and capabilities to save lives and to protect property and public health and safety, or to lessen or avert the threat of a catastrophe in any part of the United States (42 U.S.C. § 5122(1)). **FEMA Assistance:** Assistance usually < $5 million; limited to immediate and short-term assistance essential to save lives and protect public health, safety, and property.
Major Disaster Declaration	**Definition:** Any natural catastrophe (including any hurricane, tornado, storm, high water, winddriven water, tidal wave, tsunami earthquake, volcanic eruption landslide, mudslide snowstorm, or drought), or, regardless of cause, any fire, flood, or explosion, in any part of the United States, which in the determination of the President causes damage of sufficient severity and magnitude to warrant major disaster assistance under this Act to supplement the efforts and available resources of States, local governments, and disaster relief organizations in alleviating the damage, loss, hardship, or suffering caused thereby (42 U.S.C. § 5122(2)). **FEMA Assistance:** Triggers involvement of some/all of FEMA's disaster assistance and grant programs: Individual Assistance (IA), Public Assistance (PA), and Hazard Mitigation Assistance.
Fire Management Assistance Grant Program	**Definition:** Available to States, local and tribal governments, for the mitigation, management, and control of fires on publicly or privately owned forests or grasslands, which threaten such destruction as would constitute a major disaster. **FEMA Assistance:** Eligible firefighting costs may include expenses for field camps; equipment use, repair and replacement; tools, materials and supplies; and mobilization and demobilization activities.

Community Lifelines Defined

A CONSTRUCT FOR COMMUNITY IMPACT ASSESSMENT AND ANALYSIS

6

A lifeline enables the continuous operation of **critical government and business functions** and is **essential to human health and safety or economic security**.

- Lifelines are the most fundamental services in the community that enable all other aspects of society to function.
- Lifelines are the integrated network of assets, services and capabilities that are used day-to-day to support the recurring needs of the community.
- When disrupted, decisive intervention (e.g. rapid service re-establishment or employment of contingency response solutions) is required.

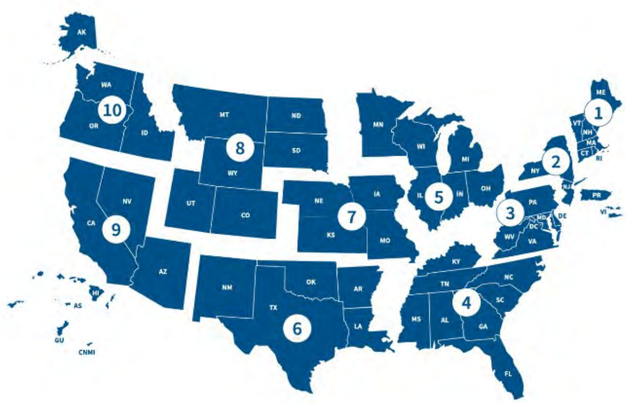
Emergency Support Functions (ESF)

- The ESFs provide the structure for coordinating Federal interagency support for a Federal response to an incident
- The National Response Framework outlines responsibilities of Departments/Agencies
- They group functions most frequently used to provide Federal support to States and Federal-to-Federal support, both for declared disasters and emergencies under the Stafford Act and for non-Stafford Act incidents

Emergency Support Functions (ESFs)	
ESF-1	Transportation
ESF-2	Communications
ESF-3	Public Works & Engineering
ESF-4	Firefighting
ESF-5	Information & Planning
ESF-6	Mass Care, Emergency Assistance, Temporary Housing & Human Services
ESF-7	Logistics
ESF-8	Public Health & Medical
ESF-9	Search & Rescue
ESF-10	Oil & HAZMAT Response
ESF-11	Agriculture & Natural Resources
ESF-12	Energy
ESF-13	Public Safety & Security
ESF-14	Cross-Sector Business & Infrastructure
ESF-15	External Affairs

FEMA

FEMA Regional Boundaries



Region	States/ Territory
Region 1	Connecticut | Maine | Massachusetts | New Hampshire | Rhode Island | Vermont
Region 2	New Jersey | New York | Puerto Rico | Virgin Islands
Region 3	Delaware | Maryland | Pennsylvania | Virginia | District of Columbia | West Virginia
Region 4	Alabama | Florida | Georgia | Kentucky | Mississippi | North Carolina | South Carolina | Tennessee
Region 5	Illinois | Indiana | Michigan | Minnesota | Ohio | Wisconsin
Region 6	Arkansas | Louisiana | New Mexico | Oklahoma | Texas
Region 7	Iowa | Kansas | Missouri | Nebraska
Region 8	Colorado | Montana | North Dakota | South Dakota | Utah | Wyoming
Region 9	Arizona | California | Hawaii | Nevada | Guam | American Samoa | Commonwealth of Northern Mariana Islands | Republic of Marshall Islands | Federated States of Micronesia
Region 10	Alaska | Idaho | Oregon | Washington

FEMA

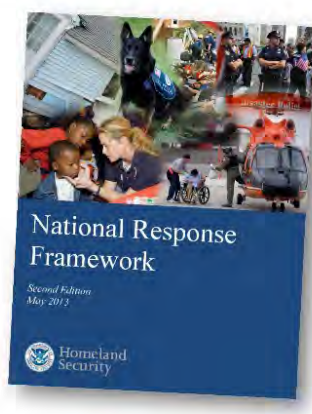
National Response Coordination Center (NRCC)

- National-level emergency coordination center
- Coordinates the overall federal support for major disasters and emergencies
- National Response Coordination Staff (NRCS) consists of FEMA staff, Departments and Agencies staff, and non-governmental partners serving as Emergency Support Functions (ESFs)
- The structure of the NRCC expands and contracts to meet the needs of the incident regardless of type, duration, and complexity

NRCC (EST) in 2005

National Response Framework

- The Response Framework covers:
  - The capabilities necessary to save lives, protect property and the environment, and meet basic human needs after an incident has occurred.
- Guiding principles:
  - Engaged partnership
  - Tiered response
  - Scalable, flexible and adaptable operations
  - Unity of effort through unified command
  - Readiness to act



Why the Framework is Always in Effect

- NRF elements can be implemented at any time for any hazard, including the employment of Emergency Support Function (ESF) mechanisms.
- The structures, roles, and responsibilities described herein can be partially or fully implemented in the context of a threat or hazard, in anticipation of a significant event, or in response to an incident.
- Implementation of NRF structures and procedures allows for a scaled response, delivery of the specific resources and capabilities, and a level of coordination appropriate to each incident.

FEMA

Federal Emergency Management Agency 85

Tiered Response

- A basic premise of the National Response Framework is that incidents are generally handled at the lowest jurisdictional level possible. Incidents begin and end locally, and most are managed at that level as well.
- Many incidents require unified response from local agencies, the private sector, and nongovernmental organizations. Other incidents may require additional support from neighboring jurisdictions or the state.
- A small number require Federal support. National response protocols recognize this and are structured to provide additional, tiered levels of support.
- When all levels of government become engaged, a response is federally supported, state managed, and locally executed, with tribes, territories, and insular area governments often managing the response, as well.

FEMA

Federal Emergency Management Agency 86

Scalable, Flexible, and Adaptable Operational Capabilities

- As incidents change in size, scope, and complexity, response efforts must adapt to meet evolving requirements. The number, type, and sources of resources must be able to expand rapidly to meet the changing needs associated with a given incident and its cascading effects. The National Incident Management System (NIMS) concepts and principles add this flexibility when dealing with an incident.
- As needs grow and change, response processes must remain nimble and adaptable. The structures and processes described in the NRF must be able to surge resources from the whole community.
- As incidents stabilize, response efforts must be flexible in order to move toward recovery outcomes.

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Response Federal Interagency Operational Plans

- The FIOPs are the Federal government's concept of operations plans to execute the Frameworks.
- The FIOPs contain:
  - An approach to integrating and synchronizing federal capabilities
  - Description of critical tasks and responsibilities
  - Specific provisions for the rapid integration of resources & personnel
  - Supersede existing incident annexes to the National Response Framework

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Relationship to NIMS

- The response protocols and structures described in the National Response Framework align with the National Incident Management System (NIMS). All of the components of the NIMS support response —including resource management, command and coordination*, communications and information management.
- Standardizing national response doctrine with NIMS provides a consistent, nationwide template to enable the whole community to work together to prevent, protect against, mitigate, respond to, and recover from the effects of incidents regardless of their cause, size, location, or complexity.

*The NRF incorrectly uses the term "management and coordination".

View the National Incident Management (https://www.fema.gov/national-incident-management-system) document to learn more.

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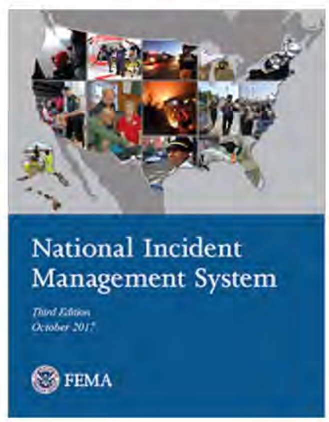
NIMS Overview

WHAT? The National Incident Management System (NIMS) defines the comprehensive approach guiding...

WHO? ...the whole community - solutions that serve the entire community are implemented while simultaneously making sure that the resources the different members of the community bring to the table are leveraged across all levels of government, nongovernmental organizations (NGO), and private sector organizations to work together seamlessly

WHY? ...to prevent, protect against, mitigate, respond to, and recover from the effects of incidents.

WHEN? NIMS applies to all incidents, regardless of cause, size, location, or complexity, from planned events to traffic accidents and to major disasters.



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NIMS Guiding Principles

- Incident management is the application of resources by organizations to plan for, respond to, and recover from an incident.
- Priorities for incident management in planning, response, and recovery efforts include saving lives, stabilizing the incident, and protecting property and the environment.
- To achieve these priorities, incident management personnel use NIMS components in accordance with three NIMS guiding principles:
  - Flexibility
  - Standardization
  - Unity of Effort

FEMA Federal Emergency Management Agency 91

Flexibility

- The NIMS guiding principle of flexibility allows NIMS to be scalable from routine, local incidents through those requiring interstate mutual aid up to those requiring Federal assistance.
- Flexibility enables NIMS to be applicable to incidents that vary widely in terms of hazard, geography, demographics, climate, cultural, and organizational authorities.
- NIMS components are adaptable to any type of event or incident.

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Standardization

- The NIMS guiding principle of standardization supports interoperability among multiple organizations in incident response.
- NIMS defines standard organizational structures that improve integration and connectivity among organizations.
- NIMS defines standard practices that allow incident personnel and organizations to work together effectively.
- NIMS includes common terminology, which enables effective communication.

Unity of Effort

- NIMS guiding principle
- Coordinating activities among various organizational representatives to achieve common objectives.
- Enables organizations with jurisdictional authority or functional responsibilities to support each other while allowing each participating agency to maintain its own authority and accountability.

NIMS Framework | Major Components

- Jurisdictions and organizations involved in the management of incidents vary in their authorities, management structures, communication capabilities and protocols, and many other factors.
- The major Components of NIMS provide a common framework to integrate these diverse capabilities and achieve common goals.
  - Resource Management
  - Command and Coordination
  - Communications and Information Management
- The application of all three components is vital to successful NIMS implementation.

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95

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Background

- Traditionally the Emergency Management community did not focus on preparing for and responding to impacts from space weather events.
- Executive Order 13744 established the policy of the United States to prepare for space weather events to minimize the extent of economic loss and human hardship.
- The Executive Order required the creation of the *Federal Operating Concept for Impending Space Weather Events* is designed to coordinate federal assets and activities to respond to notification of, and protect against, impending space weather events.

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Federal Operating Concept for Space Weather

- The Federal Operating Concept outlines the necessary actions departments and agencies should take to prepare for, and respond to, a notification of an *impending* space weather event.
- It provides guidance to departments and agencies to be used in the development of their operational plans to prepare for, protect against, and mitigate the effects of impending space weather events.
- Focuses on the operational and crisis planning functions, reporting structure, and reporting requirements of department and agencies in response to notification of a forecasted event.

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Planning Frameworks

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Federal Emergency Management Agency

Federal Operating Concept

Key Activities and Considerations

- **Risk Analysis:** Requires each department/agencies to evaluate vulnerabilities to infrastructure and operations and assess potential consequences to commend, control, communications, delivery of essential services, and cascading impacts to human life.
- **Alerts and Notifications:** Identifies official agencies who will disseminate notifications of elevated space weather threat or space weather incident.

- **Protective Actions:** Prescribes each department/agencies to develop and disseminate messaging, advise, protection and notification to its programs, personnel, customers, sector representatives, and stakeholders.

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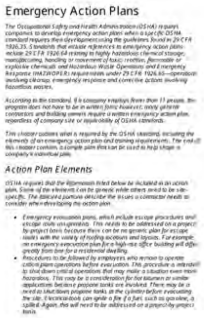
Federal Operating Concept – continued

- **Key Considerations Continued:**



Emergency Action Plans

Action Plan Elements

- **Operational Adaptations:** Encourages departments/agencies to consider employment of backup systems and crisis action planning to ascertain and execute infrastructure restoration.
- **Operational Coordination for Response:** Identifies FEMA to initiate incident management coordination among federal, state, territory, and non-governmental

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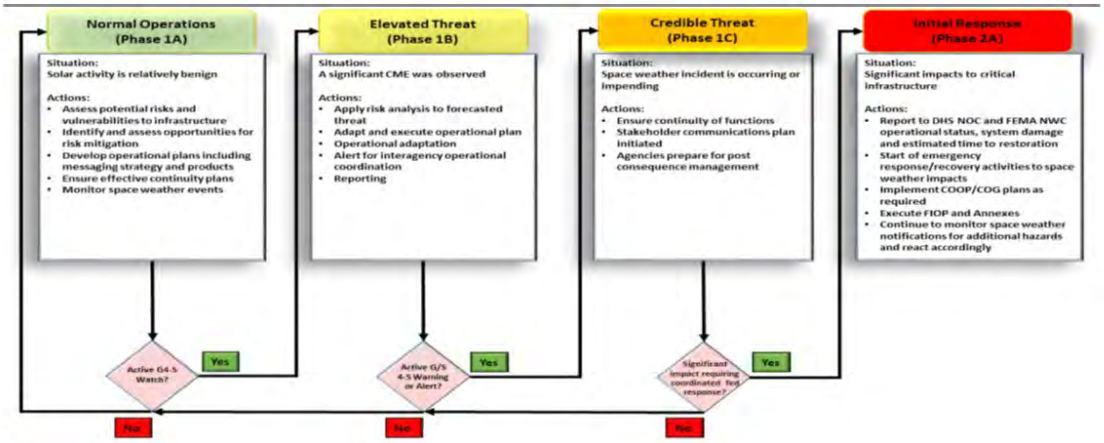
Emergency Management Operational Phases



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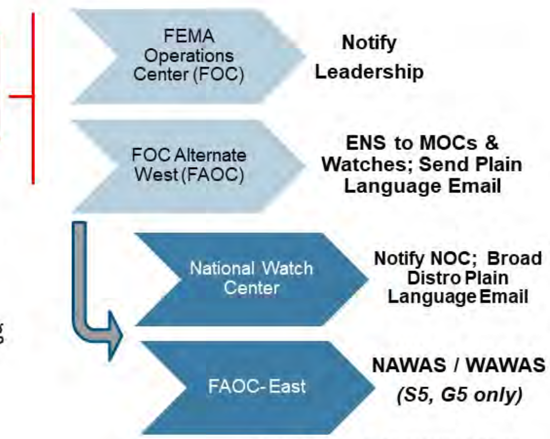
Space Weather Event Alert & Notification – Emergency Response

- Directly or indirectly cause or exacerbate a major disaster or emergency.
- Interfere with or seriously degrade FEMA's response & recovery capability.

S4-S5 Radiation Storms

G4-G5 Geomagnetic Storms



Emergency notification system (ENS)
FEMA MERS Operations Center (MOC)
National Operations Center (NOC)
National Warning System (NAWAS)
Washington Metropolitan Area Warning System (WAWAS)

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National Response Coordination Center (NRCC)

- National-level emergency coordination center
- Coordinates the overall federal support for major disasters and emergencies
- National Response Coordination Staff (NRCS) consist of FEMA staff, Departments and Agencies staff, and non-government partners serving as Emergency Support Functions (ESFs)
- The ESFs provide structure for coordinating Federal Interagency support for a Federal response to an incident

Emergency Support Functions (ESFs)	
ESF – 1	Transportation
ESF – 2	Communications
ESF – 3	Public Works & Engineering
ESF – 4	Firefighting
ESF – 5	Information & Planning
ESF – 6	Mass Care, Emergency Assistance, Housing & Human Services
ESF – 7	Logistics
ESF – 8	Public Health & Medical
ESF – 9	Search & Rescue
ESF – 10	Oil & HAZMAT Response
ESF – 11	Agriculture & Natural Resources
ESF – 12	Energy
ESF – 13	Public Safety & Security
ESF – 14	Cross-Sector Business & Infrastructure
ESF – 15	External Affairs

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ESF 15 Coordination Elements

- Joint Information Center
  - Local, State & National JIC
  - Media Relations
  - Intergovernmental Affairs
  - Congressional Affairs
  - Planning and Products & Strategic Comms
    - Liaisons
- National Incident Communications Conference Line (NICCL) calls
- Daily Battle Rhythm & Reporting

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Incident Communications

- Messaging prior to an event
- Disaster response and recovery phases
- Different types of messages
  - Equity-focused & Survivor-centric
  - Operational
- Local, state, and federal messaging
- Mechanisms for coordination

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National Joint Information Center

- Led by Associate Administrator and Deputy Associate Administrator of External Affairs
- Central location for unified incident communication planning & information sharing.
  - White House/political leadership
  - SLTT, interagency, nonprofit and congressional partners
- Link to initial ESF 15 field operations and ground support (IMATs).
- Generally connected to NRCC activation, has autonomy to standup without NRCC.

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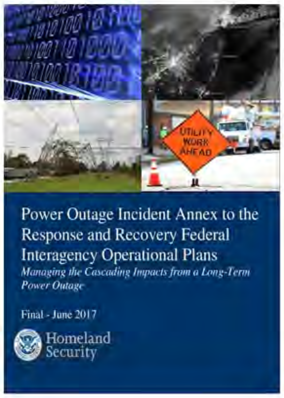
Impacts from Space Weather Events

- FEMA developed and released the *Power Outage Incident Annex (POIA) to the Response and Recovery Federal Interagency Operational Plans: Managing the Cascading Impacts from a Long-Term Power Outage*
  - The POIA provides guidance for federal level responders to provide response and recovery support to local, state, tribal, territorial, and insular area efforts while ensuring the protection of privacy, civil rights, and civil liberties.
  - The POIA is not an electricity restoration plan rather it outline the types of federal support available to Critical Infrastructure stakeholders in restoration activities and the responsibilities of industry stakeholders.
  - Also identifies potential critical information requirements and unique considerations that could hinder their ability to provide mission-essential services.



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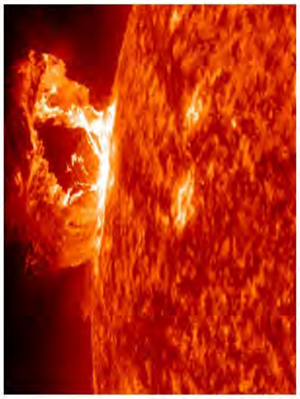
Ongoing Work: National Space Weather Strategy and Action Plan

- Establish Plans and Procedures for Responding to and Recovering from Space Weather Events
  - Federal departments and agencies are developed, review, and update response plans, programs, and procedures to address the effects of space weather.
  - Develop a comprehensive communications systems operations guidance to include planning factors.



FEMA

Training

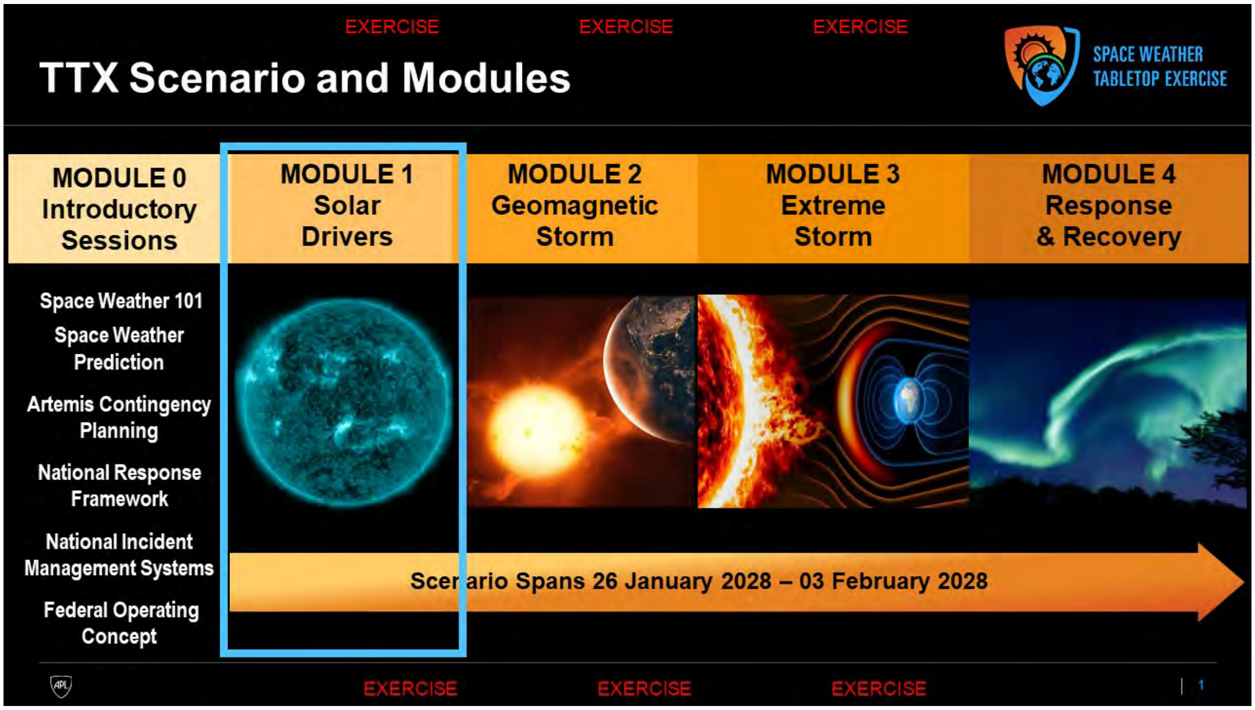
- **Establish Plans and Procedures for Responding to and Recovering from Space Weather Events**

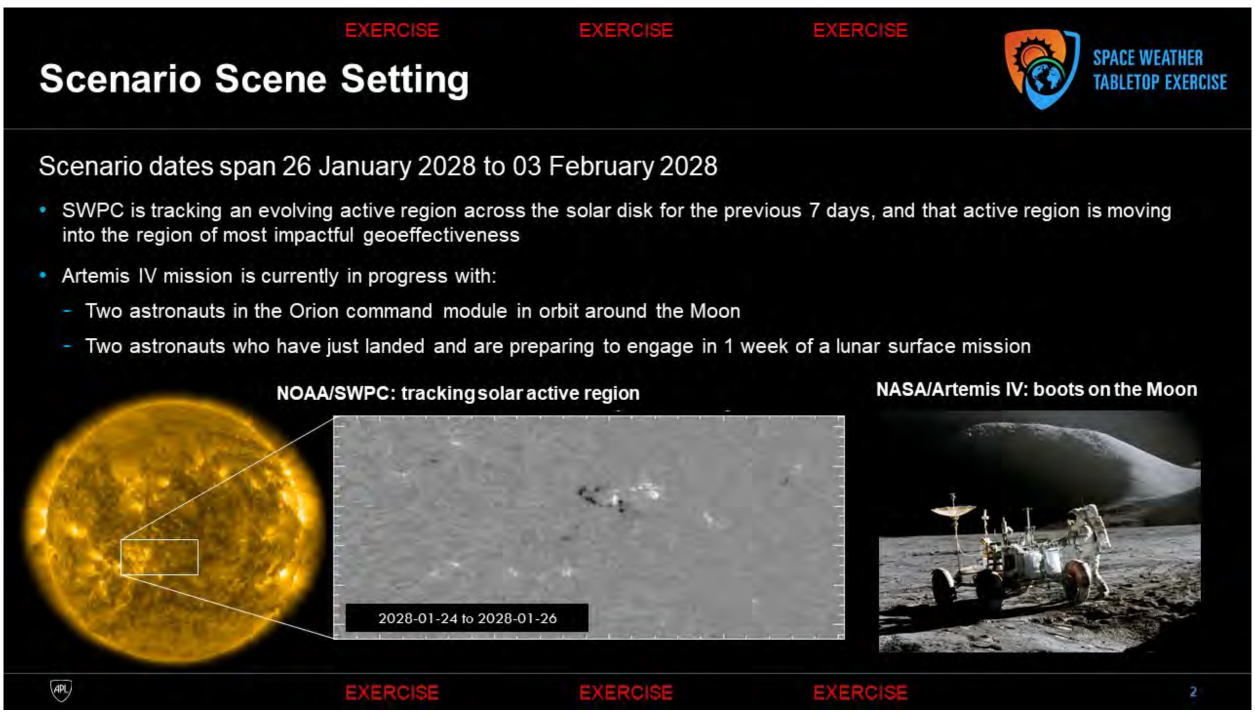
- Emergency Management Institute (EMI) recently releases an Independent Study Course Preparing the Nation for Space Weather Events IS-66.
- This course is designed to provide a greater understanding of space weather and its impacts, strengthen understanding of space weather events; the potential impacts from those events; and the roles of the Federal Government as well as the local and jurisdictional Emergency Manager in preparing for and mitigating such impacts.

Thank you

Kenyetta Blunt
Deputy Division Director
Planning and Exercise Division

G.1.2. Afternoon Slides





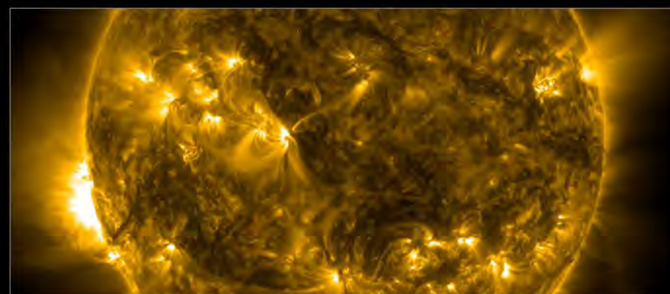
EXERCISE EXERCISE EXERCISE

Module 1: Solar Drivers – Scene Setting

SPACE WEATHER TABLETOP EXERCISE

Scenario timeline: 26 Jan 2028, 3:00 p.m. ET (1:00 p.m. MT),
to 28 Jan 2028, 1:00 p.m. ET (11:00 a.m. MT)

Scenario duration: 46 hours



Discussion will focus on:

- Comprehension of SWPC monitoring, tracking, and notifications
- Notification pathways and processes
- Federal coordination
- Existing policies to guide decisions

EXERCISE EXERCISE EXERCISE 3

EXERCISE EXERCISE EXERCISE

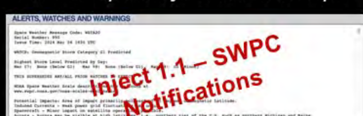
Inject 1.1: Solar Eruption – Notifications

SPACE WEATHER TABLETOP EXERCISE

R2+ S1+ (Warning) G#

Scenario time: 26 Jan 2028, 3:10 p.m. ET (1:10 p.m. MT)
Time since eruption: 0 days, 0 hours

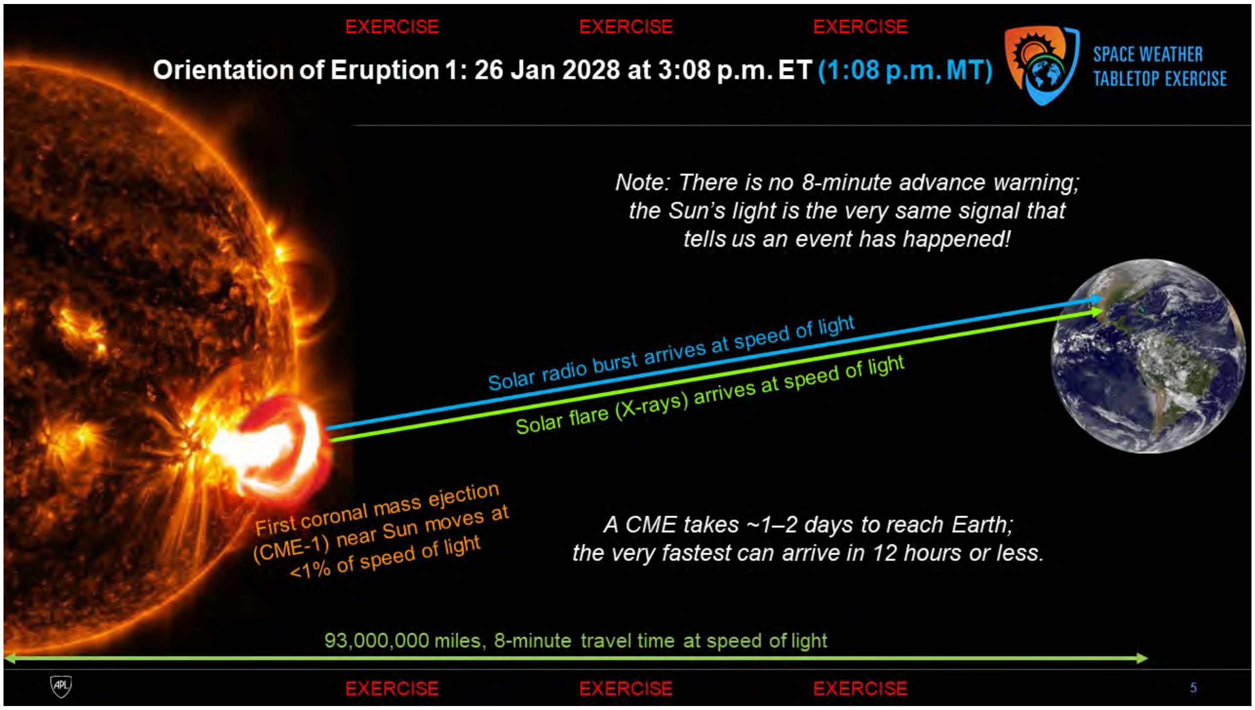
Please open inject 1.1 envelope

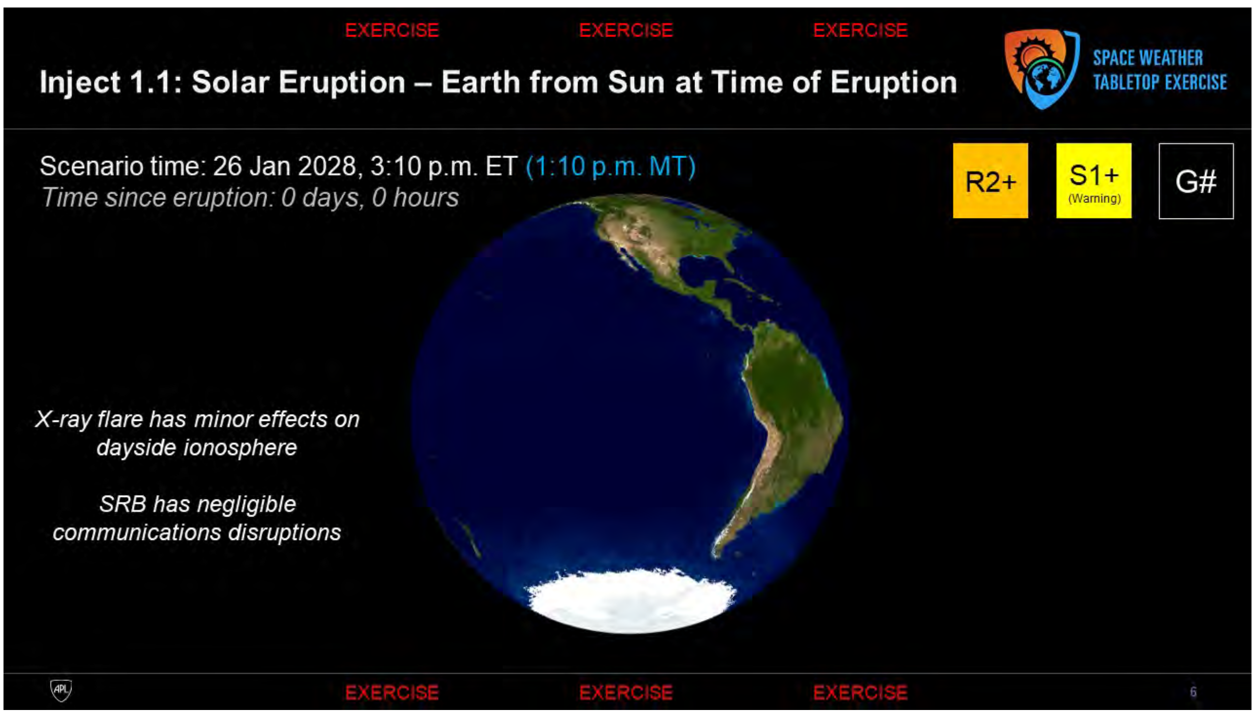


- The solar active region has erupted
- ***R-scale:*** M7-class solar flare
- ***S-scale:*** No immediate intensification of solar particle radiation (SEPs)
- ***G-scale:*** Corresponding coronal mass ejection (CME) is not yet confirmed
- A minor solar radio burst occurs with this (reported separately by USAF)

1. Is the SWPC notification helpful/understandable?

EXERCISE EXERCISE EXERCISE 4


EXERCISE EXERCISE EXERCISE
Orientation of Eruption 1: 26 Jan 2028 at 3:08 p.m. ET (1:08 p.m. MT)
SPACE WEATHER TABLETOP EXERCISE
Note: There is no 8-minute advance warning; the Sun's light is the very same signal that tells us an event has happened!
Solar radio burst arrives at speed of light
Solar flare (X-rays) arrives at speed of light
First coronal mass ejection (CME-1) near Sun moves at <1% of speed of light
A CME takes ~1–2 days to reach Earth; the very fastest can arrive in 12 hours or less.
93,000,000 miles, 8-minute travel time at speed of light
EXERCISE EXERCISE EXERCISE
5


EXERCISE EXERCISE EXERCISE
Inject 1.1: Solar Eruption – Earth from Sun at Time of Eruption
SPACE WEATHER TABLETOP EXERCISE
Scenario time: 26 Jan 2028, 3:10 p.m. ET (1:10 p.m. MT)
Time since eruption: 0 days, 0 hours
R2+
S1+ (Warning)
G#
X-ray flare has minor effects on dayside ionosphere
SRB has negligible communications disruptions
EXERCISE EXERCISE EXERCISE
6

EXERCISE EXERCISE EXERCISE

Inject 1.1: Solar Eruption – Notifications

SPACE WEATHER TABLETOP EXERCISE

R2+ | S1+ (Warning) | G#

Scenario time: 26 Jan 2028, 3:10 p.m. ET (1:10 p.m. MT)
Time since eruption: 0 days, 0 hours

1. Who, if anyone, has seen or been briefed on a SWPC notification before?
2. What additional information or clarification from SWPC might be helpful at this point?

EXERCISE EXERCISE EXERCISE 7

EXERCISE EXERCISE EXERCISE

Inject 1.2: Solar Radiation Storm and Inbound Halo CME

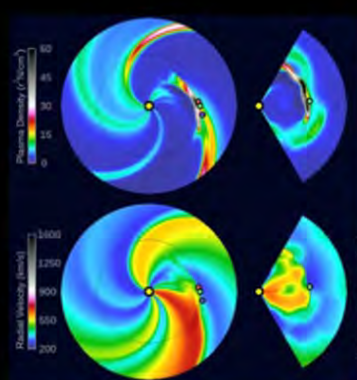
SPACE WEATHER TABLETOP EXERCISE

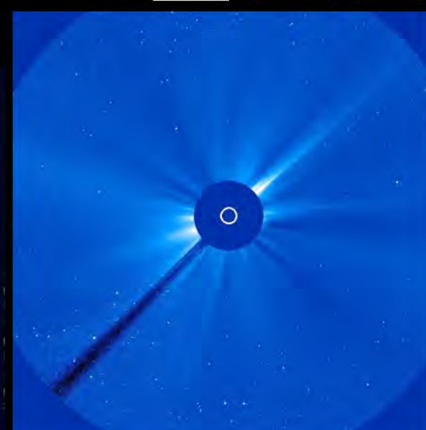
R# | S2 | G3 (Watch)

Scenario time: 27 Jan 2028, 1:49 a.m. ET (26 Jan, 11:49 p.m. (MT)
Time since eruption: 0 days, 11 hours

Please open inject 1.2 envelope: Two simultaneous notifications

1. Is this information shared "up the chain"? By who, to whom?
2. How does your D/A expect this information to be reported and managed? What is the response?
3. NASA-SRAG: How does this alter the Artemis IV mission profile?
4. If there are varying analyses and/or processes, is that shared between entities? If so, how? If variations in the analysis and reporting occur, how is that handled?





EXERCISE EXERCISE EXERCISE 8

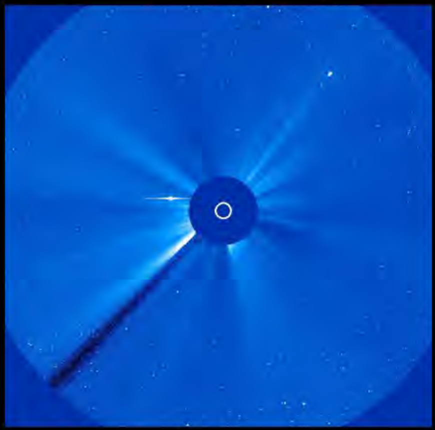
Inject 1.3a: Second Solar Eruption and SWPC Update

R4 | S3 | G4+ (Watch)

Scenario time: 28 Jan 2028, 10:20 a.m. ET (8:20 a.m. MT)

Time since first eruption: 1 day, 19 hours

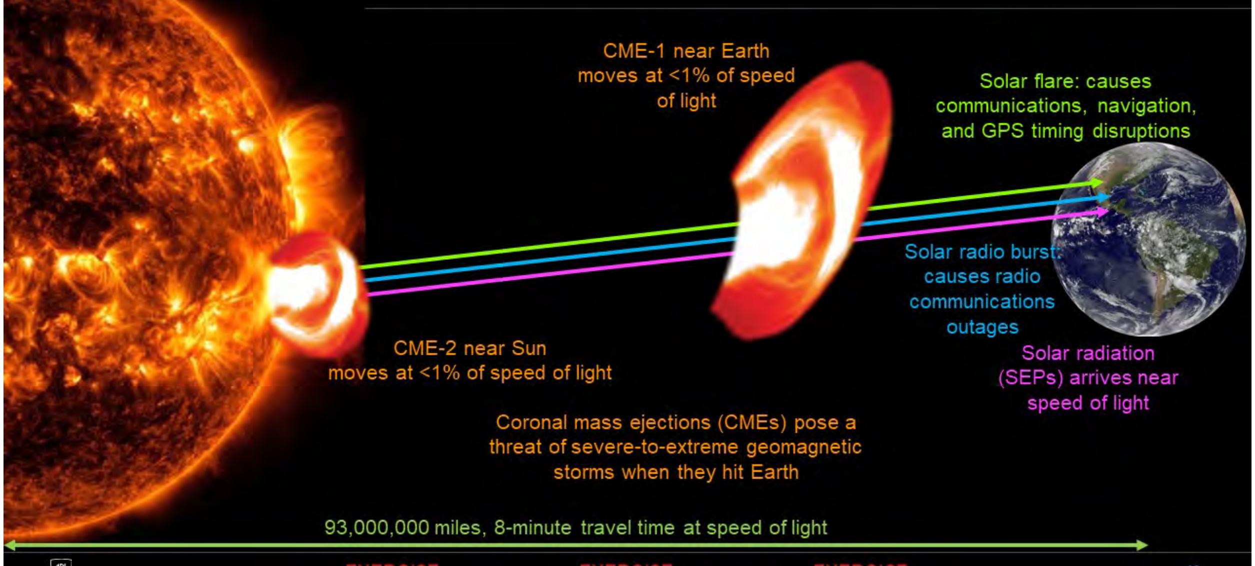
Next envelope (1.3), please



- The active region erupts again, much more intensely
- ***R-scale:*** X15.3-class solar flare
- ***S-scale:*** Near-immediate arrival of intense solar radiation (SEPs)
- ***G-scale:*** Within ~4 hours, another halo CME is confirmed
- Intense solar radio burst and corresponding radio blackout (from USAF)

1. Is it readily understandable that this is now a more severe threat? What difference would that make in terms of your actions, if any?
2. How does the “G4” impact activities at the National Watch Center (NWC)?
3. What decisions would be made regarding the crewed mission that is currently in space?
4. What type of additional information would be helpful?

Orientation of Eruption 2: 28 Jan 2028 at 10:20 a.m. ET (8:20 a.m. MT)



Inject 1.3a: Solar Eruption – Earth from Sun at Time of Eruption 2

SPACE WEATHER
TABLETOP EXERCISE

Scenario time: 28 Jan 2028, 10:20 a.m. ET (8:20 a.m. MT)

Time since first eruption: 1 day, 19 hours

R4 | S3 | G4+ (Watch)

X-ray flare has immediate, significant effects on dayside ionosphere, affecting communications, navigation, and GPS timing

SRB results in immediate, major communications disruptions over most of sunlit globe:
All of North America
All of South America
Western Europe
West Africa

When CMEs hit Earth, their effects may occur over the entire globe and throughout near-Earth space

Inject 1.3b: Communications and Radiation Effects

SPACE WEATHER
TABLETOP EXERCISE

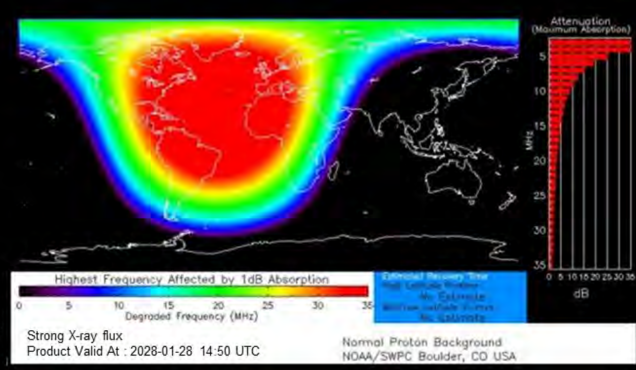
Scenario time: 28 Jan 2028, 11:57 a.m. ET (9:57 a.m. MT)

Time since first eruption: 1 day, 21 hours

R4 | S3 | G4+ (Watch)

- Widespread official, media, and social media reports of interruptions of high-frequency (HF) communications from North and South America and Western Europe
- Intermittent (in time) and widespread, dispersed (in locale) reports of disrupted SatCom and VHF radio operations from across government and public sector
- Official and social media reports of widespread loss and degradation of GNSS/GPS positioning, navigation, and timing services

1. Given that the reports are "intermittent" and globally dispersed, would you expect this to be something other than a space weather "event"?
2. How would a radio blackout affect your D/A's operations?



Inject 1.4: Miscommunications

SPACE WEATHER
TABLETOP EXERCISE

Scenario time: 28 Jan 2028, 1:00 p.m. ET (11:00 a.m. MT)
Time since first eruption: 1 day, 22 hours

- This inject pertains only to communications *internal to the US Government*
- NOAA-SWPC and USAF coordinate and agree: There has been a severe solar flare (NOAA X-ray data) and solar radio burst (USAF data)
- Another federal department/agency reports contradictory information, suggesting that the radio and communications disruptions they are experiencing are possibly the result of a cyberattack

1. Which, if any, federal agencies might be releasing information? Through what sources and modes? How are data and information compared and corroborated?
2. What insight can be gained from recent real-world events?
3. Are there existing public information protocols in place that could be leveraged?

EXERCISE EXERCISE EXERCISE

Module 1 Hot Wash

SPACE WEATHER
TABLETOP EXERCISE

Goal is to gather quick comments and impressions

- One representative from each organization to provide
- Please limit comments to ~1 min so we have an opportunity to hear from every participating organization):
  - One lesson learned
  - One best practice
- Remember, you can also post and respond to comments in the chat
- **PLEASE COMPLETE YOUR PARTICIPANTS FEEDBACK FORM FOR MODULE 1**

Your comments and discussions are the data that will help this TTX culminate in an impactful after-action report.

EXERCISE EXERCISE EXERCISE

TTX Scenario and Modules

MODULE 0 Introductory Sessions	MODULE 1 Solar Drivers	MODULE 2 Geomagnetic Storm	MODULE 3 Extreme Storm	MODULE 4 Response & Recovery

- Space Weather 101
- Space Weather Prediction
- Artemis Contingency Planning
- National Response Framework
- National Incident Management Systems
- Federal Operating Concept

Scenario Spans 26 January 2028 – 03 February 2028

EXERCISE EXERCISE EXERCISE 15

EXERCISE EXERCISE EXERCISE

Module 2: Geomagnetic Storm

Introduce Participants in Laurel and Region 8 (R8)

Scenario timeline: 29 Jan 2028, 2:38 p.m. ET (12:38 p.m. MT) to 29 Jan 2028, 8:53 p.m. ET (6:53 p.m. MT)

Scenario duration: 6 hours

Discussion will focus on:

- Understanding impact of evolving information
- Notification pathways and processes
- Federal coordination with R8
- Consistency and timeliness of information

Credit: Getty

EXERCISE EXERCISE EXERCISE 16

EXERCISE EXERCISE EXERCISE

Inject 2.1: First CME Arrives at Earth

SPACE WEATHER TABLETOP EXERCISE

Scenario time: 28 Jan 2028, 2:38 p.m. ET (12:38 p.m. MT)
Time since first eruption: 1 day, 23 hours

R3 S3 G3

Please open your inject 2.1 envelope

1. Familiarity with and utility of FEMA daily ops brief?
2. D/A vulnerability assessment?

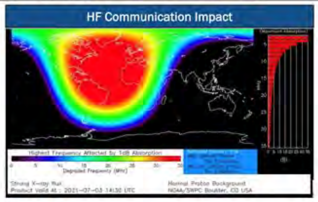
EXERCISE EXERCISE EXERCISE

Space Weather Outlook

	Space Weather Activity	Geomagnetic Storms	Solar Radiation	Radio Blackouts
Past 24 Hours	Severe	G4	S4	R4
Next 24 Hours	Extreme	G4/5	S4	R4

For further information on NOAA Space Weather Scales refer to: http://www.swpc.noaa.gov/noaa-scales-explanation
For further information on Sunspot Activity refer to: https://www.swpc.noaa.gov/phenomena/sunspotssolar-cycle

HF Communication Impact



Sunspot Activity

FEMA EXERCISE EXERCISE EXERCISE National Watch Center

EXERCISE EXERCISE EXERCISE 17

EXERCISE EXERCISE EXERCISE

Inject 2.2: Geospace Radiation Effects

SPACE WEATHER TABLETOP EXERCISE

Scenario time: 28 Jan 2028, 11:16 p.m. ET (9:16 p.m. MT)
Time since first eruption: 2 days, 8 hours

R# S4 G4

Please open your inject 2.2 envelope

Space Radiation

Federal: A classified report states that an “on-orbit surveillance asset” is reporting a “serious anomaly.”

1. National security concerns (UNCLASSIFIED)?
2. SWx expertise?

R8: Commercial internet satellite is damaged, with impact to some residents (lapses in internet services) in R8 according to reports from users.

1. R8 operations?
2. Information-sharing within the R8?

High-Altitude Radiation

1. FAA concerns and potential actions?
2. Denver International Airport (DIA) impacts/needs?

Credit: Deposit Photos

EXERCISE EXERCISE EXERCISE 18

EXERCISE EXERCISE EXERCISE

Inject 2.3: Comms Issues in Geospace

SPACE WEATHER
TABLETOP EXERCISE

Scenario time: 29 Jan 2028, 12:15 a.m. ET (28 Jan, 10:15 p.m. MT)
Time since first eruption: 2 days, 9 hours

R# S4 G4

- Widespread outages of major telecommunication systems
- Spreading reports of intensifying SatCom and high-frequency (HF) comm disruptions and outages, and loss of HF comms from Montana and North Dakota local officials in R8

1. Severity understood?
2. G4 notifications?
3. D/A actions?
4. Consistency in actions and messaging?
5. GNSS/GPS services?

Credit: Adobe

EXERCISE EXERCISE EXERCISE 19

EXERCISE EXERCISE EXERCISE

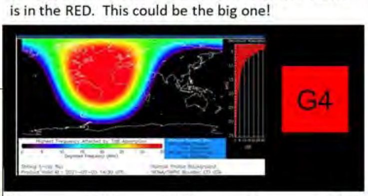
Inject 2.4: Miscommunication

SPACE WEATHER
TABLETOP EXERCISE

Scenario time: 29 Jan 2028, 7:00 a.m. ET (5:00 a.m. MT)
Time since first eruption: 2 days, 16 hours

1. Space weather "spokesperson"?
2. PIO coordination
3. ESF 15 (External Affairs) activation?
4. Coordination of other ESFs?

Apprehensive Andy Follow
3,865 posts
AA
29 Jan 2028, 7:00 AM ET (5:00 AM MT)
The government just released a WARNING for an extreme weather event. NOAA indicates that a warning means that something severe is **EXPECTED** to happen in a certain area. All of the United States is in the RED. This could be the big one!



32 626 878

Ad hoc Government Alerts Follow
U.S. AGOV
29 Jan 2028, 7:00 AM ET (5:00 AM MT)
Severe SPACE Weather ALERTS. There have several alerts and warnings issued. Expect power grid disruptions and communications outages. Travel advisories are also in effect. Americans are warned not to travel during this heightened time as we continue to receive multiple alerts and notifications.

EXERCISE EXERCISE EXERCISE 20

EXERCISE EXERCISE EXERCISE

Inject 2.5: R10 Power Issues

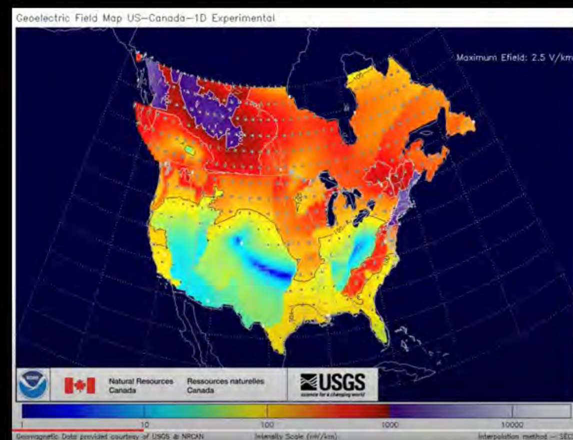
SPACE WEATHER TABLETOP EXERCISE

R# S3 G4

Scenario time: 29 Jan 2028, 2:27 p.m. ET (12:27 p.m. MT)
Time since first eruption: 2 days, 23 hours

There are reports of power grid upsets and disruptions in FEMA Region 10 (Pacific Northwest); Power is redirected from the grid in Region 8 to support energy needs via the western interconnect.

1. Energy organization awareness?
2. Decision process and awareness?



EXERCISE EXERCISE EXERCISE 21

EXERCISE EXERCISE EXERCISE

Inject 2.6: Impending Second CME

SPACE WEATHER TABLETOP EXERCISE

R# S3 G4

Scenario time: 29 Jan 2028, 8:53 p.m. ET (6:53 p.m. MT)
Time since first eruption: 3 days, 5 hours

Please open your inject 2.6 envelope

Second CME is observed by ACE satellite at L1 showing 80-90 nT total field with B_Z = -50 nT

1. SWPC actions?
2. Utility of 30-min warning?

Credit: Phys.org

Closing Question

(Please be prepared to discuss on Day 2.)

What differences of opinion might there be based on perspectives and community expectations?

EXERCISE EXERCISE EXERCISE 22

EXERCISE EXERCISE EXERCISE

Module 2 Hot Wash

SPACE WEATHER
TABLETOP EXERCISE

Goal is to gather quick comments and impressions

- One representative from each organization to provide
- Please limit comments to ~1 min so we have an opportunity to hear from every participating organization):
  - One lesson learned
  - One best practice
- Remember, you can also post and respond to comments in the chat
- **PLEASE COMPLETE YOUR PARTICIPANTS FEEDBACK FORM FOR MODULE 2**

Your comments and discussions are the data that will help this TTX culminate in an impactful after-action report.

EXERCISE EXERCISE EXERCISE 23

EXERCISE EXERCISE EXERCISE

Day 1 "Parking Lot" topics

SPACE WEATHER
TABLETOP EXERCISE

- Briefly revisit any topics that may have been cut short

Module	Description
0	Introductory Sessions
1	Solar Drivers
2	Geomagnetic Storm

EXERCISE EXERCISE EXERCISE 24

EXERCISE EXERCISE EXERCISE

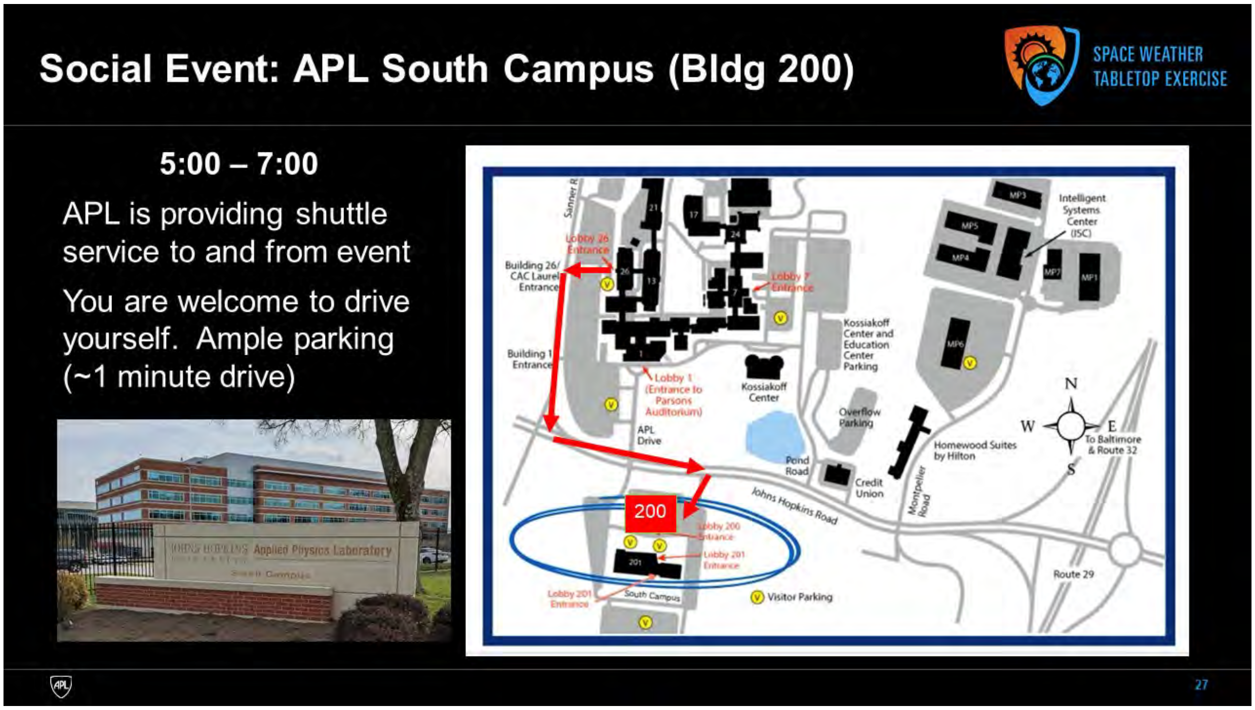
Looking ahead to Day 2

SPACE WEATHER TABLETOP EXERCISE

EDT	LAUREL, MD
8:30	Arrivals and Registration
9:30	Welcome and Thoughts From Day 1
10:00	Background, Instructions, Logistics
10:15	*Break*
10:30	MODULE 3: Intensifying Storm
12:00	*Lunch*
1:00	MODULE 3: Cont'd
2:15	MODULE 3: Hotwash
2:30	*Break*
2:45	MODULE 4: Response and Recovery
4:00	MODULE 4: Hotwash
4:15	Joint Hotwash
4:45	Closing Comments: A Word From Our Sponsors
5:00	Adjourn

MDT	DENVER, CO
6:30	Arrivals and Registration
7:30	Welcome and Thoughts From Day 1
8:00	Background, Instructions, Logistics
8:15	*Break*
8:30	MODULE 3: Intensifying Storm
10:00	*Lunch*
11:00	MODULE 3: Cont'd
12:15	MODULE 3: Hotwash
12:30	*Break*
12:45	MODULE 4: Response and Recovery
2:00	MODULE 4: Hotwash
2:15	Joint Hotwash
2:45	Closing Comments: A Word From Our Sponsors
3:00	Adjourn

EXERCISE EXERCISE EXERCISE 25


Social Event: APL South Campus (Bldg 200)
SPACE WEATHER
TABLETOP EXERCISE
5:00 – 7:00
APL is providing shuttle service to and from event
You are welcome to drive yourself. Ample parking (~1 minute drive)
Johns Hopkins Applied Physics Laboratory
Building 26/ CAC Laurel Entrance
Lobby 26 Entrance
Building 1 Entrance
Lobby 1 (Entrance to Parsons Auditorium)
Lobby 7 Entrance
APL Drive
Kossiakoff Center
Kossiakoff Center and Education Center Parking
Overflow Parking
Pond Road
Credit Union
Montpelier Road
Homewood Suites by Hilton
Intelligent Systems Center (ISC)
MP3
MP5
MP4
MP7
MP1
MP6
N
W
E
S
To Baltimore & Route 32
Johns Hopkins Road
200
Lobby 200 Entrance
Lobby 201 Entrance
201
Lobby 201 Entrance
South Campus
Visitor Parking
Route 29
27

G.2. TTX Day 2


JOHNS HOPKINS
APPLIED PHYSICS LABORATORY
SPACE WEATHER
TABLETOP EXERCISE
Welcome to the Space Weather Tabletop Exercise
May 8 and May 9, 2024
NASA
NOAA
NSF
FEMA

EXERCISE EXERCISE EXERCISE

SPACE WEATHER
TABLETOP EXERCISE

Welcome

- Welcome from APL
- Welcome and a word from each of our sponsors

NASA NOAA NSF FEMA

EXERCISE EXERCISE EXERCISE

| 2

SPACE WEATHER
TABLETOP EXERCISE

SWx TTX: Government Participants

NASA NOAA NSF FEMA CISA U.S. AIR FORCE

DENVER OFFICE OF EMERGENCY MANAGEMENT

UNITED STATES SPACE FORCE

USDA

wapa.gov

557th WEATHER WING

COLORADO Department of Transportation

CDOT

USGS science for a changing world

DEN

| 3

EXERCISE EXERCISE EXERCISE

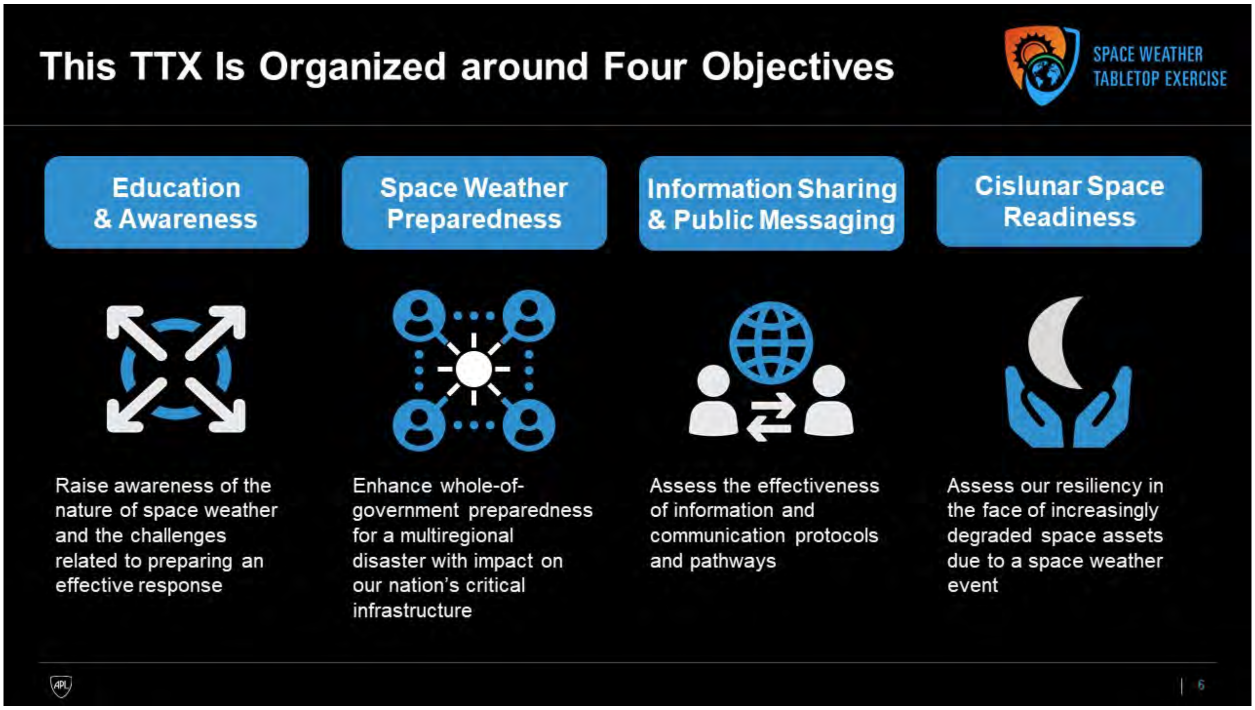
Intent of This TTX

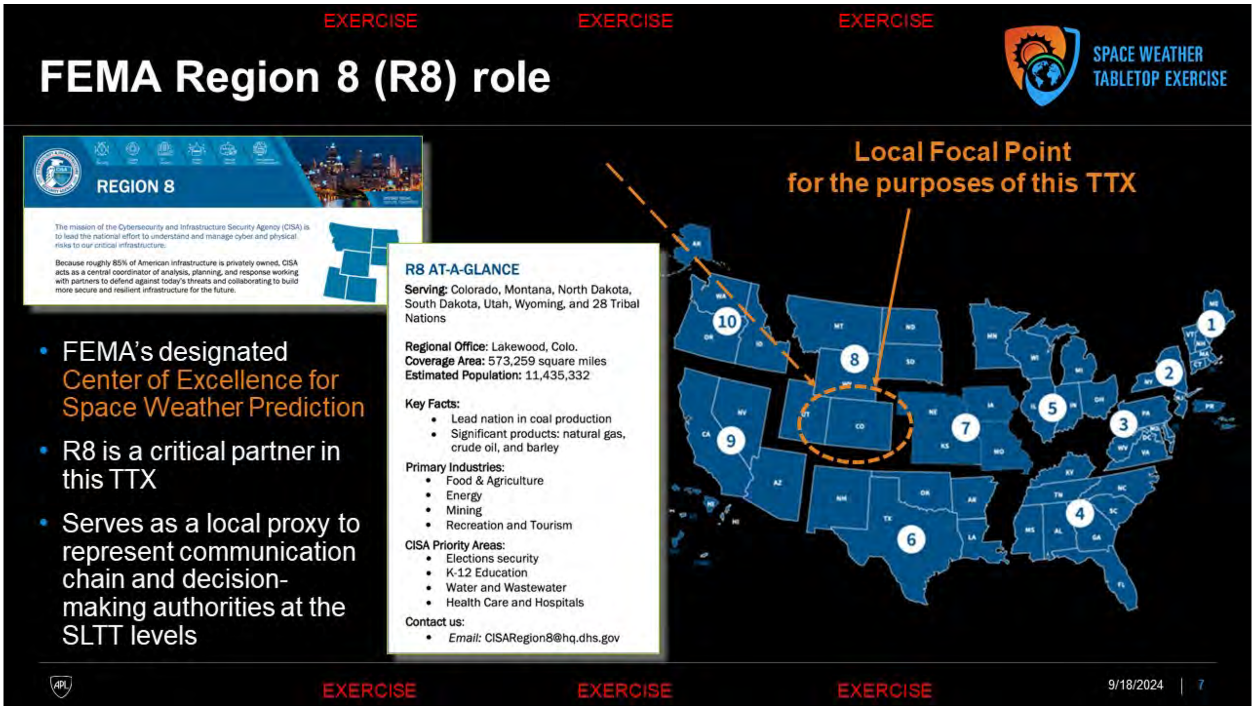
SPACE WEATHER
TABLETOP EXERCISE

- First end-to-end space weather exercise tracking from initial detection through impacts to critical infrastructure
- Generate dialogue about issues that pertain to preparedness for and response to an impending space weather event
- Engage in an interactive discussion about different organizations' and governments' policies, procedures, and potential responses
- Enhance cross-agency communications and coordination

All participants are encouraged to contribute in this *no-fault* environment.	Views *are not* expected to be official government or organizational positions.	Varying viewpoints, contrary opinions, and/or disagreements are welcome.

EXERCISE EXERCISE EXERCISE | 4


This TTX Is Organized around Four Objectives
SPACE WEATHER TABLETOP EXERCISE
Education & Awareness
Space Weather Preparedness
Information Sharing & Public Messaging
Cislunar Space Readiness
Raise awareness of the nature of space weather and the challenges related to preparing an effective response
Enhance whole-of-government preparedness for a multiregional disaster with impact on our nation's critical infrastructure
Assess the effectiveness of information and communication protocols and pathways
Assess our resiliency in the face of increasingly degraded space assets due to a space weather event
APL
6


EXERCISE EXERCISE EXERCISE
FEMA Region 8 (R8) role
SPACE WEATHER TABLETOP EXERCISE
REGION 8
The mission of the Cybersecurity and Infrastructure Security Agency (CISA) is to lead the national effort to understand and manage cyber and physical risks to our critical infrastructure.
Because roughly 85% of American infrastructure is privately owned, CISA acts as a central coordinator of analysis, planning, and response working with partners to defend against today's threats and collaborating to build more secure and resilient infrastructure for the future.
R8 AT-A-GLANCE
Serving: Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming, and 28 Tribal Nations
Regional Office: Lakewood, Colo.
Coverage Area: 573,259 square miles
Estimated Population: 11,435,332
Key Facts:
• Lead nation in coal production
• Significant products: natural gas, crude oil, and barley
Primary Industries:
• Food & Agriculture
• Energy
• Mining
• Recreation and Tourism
CISA Priority Areas:
• Elections security
• K-12 Education
• Water and Wastewater
• Health Care and Hospitals
Contact us:
• Email: CISARegion8@hq.dhs.gov
• FEMA's designated Center of Excellence for Space Weather Prediction
• R8 is a critical partner in this TTX
• Serves as a local proxy to represent communication chain and decision-making authorities at the SLTT levels
Local Focal Point for the purposes of this TTX
1
2
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10
CO
APL
EXERCISE EXERCISE EXERCISE
9/18/2024 | 7

EXERCISE EXERCISE EXERCISE

TTX Scenario and Modules

SPACE WEATHER TABLETOP EXERCISE

MODULE 0 Introductory Sessions	MODULE 1 Solar Drivers	MODULE 2 Geomagnetic Storm	MODULE 3 Extreme Storm	MODULE 4 Response & Recovery

Space Weather 101

Space Weather Prediction

Artemis Contingency Planning

National Response Framework

National Incident Management Systems

Federal Operating Concept

Scenario Spans 26 January 2028 – 03 February 2028

EXERCISE EXERCISE EXERCISE | 8

EXERCISE EXERCISE EXERCISE

Situation Report (SitRep) Example

SPACE WEATHER TABLETOP EXERCISE

ERUPTIONS' PROPERTIES

- CME #1 arrived: 28 Jan 2028, ~2:30 p.m. ET (~12:30 p.m. MT)
- CME #2 predicted arrival: 29 Jan 2028, 8:25 a.m. ET (6:25 a.m. MT)

RADIO BLACKOUT DETAILS

Flare: X-class (Typically ~1/month observed) Strong **R3**

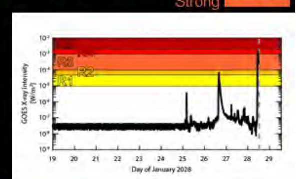
Impact timeline: Instantaneous with eruption

Duration: Few hours

POSSIBLE EFFECTS

High-frequency radio: Wide area blackout of high-frequency radio communication; loss of radio contact for about an hour on sunlit side of Earth

Navigation: Low-frequency navigation signals degraded ~1 hour



RADIATION STORM DETAILS

Impact timeline: Tens of minutes after flare

Duration: Unknown (likely several hours)

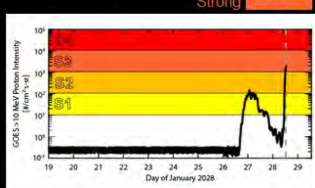
SEP: Increase observed (Typically ~1/year observed) Strong **S3**

POSSIBLE EFFECTS

Biological: Avoidance recommended for astronauts on EVA; exposure risk to humans in aircraft at high latitudes

Satellite operations: Single-event upsets, noise in imaging systems, slight reduction in solar panel efficiency

Other systems: Degraded high-frequency propagation at polar regions, navigation position errors



GEOMAGNETIC STORM (#1) DETAILS

Storm: Kp = 7 (Typically ~2/month observed) Strong **G3**

Impact timeline: 47.5 hours after eruption (arrived 17.5 hours later than predicted)

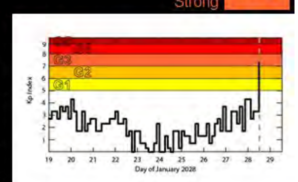
Duration: Likely several days

POSSIBLE EFFECTS

Power systems: Voltage corrections; false alarms on protection devices

Spacecraft operations: Surface charging on satellite components; increased drag on low-Earth-orbit satellites; corrections for orientation problems

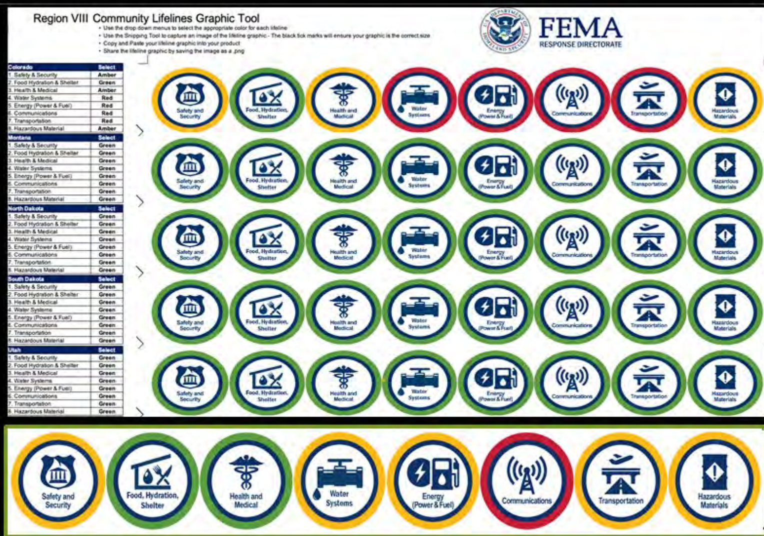
Other systems: Intermittent satellite navigation and low-frequency radio-frequency navigation issues; intermittent high-frequency radio; aurorae as low as Chicago, Pittsburgh



EXERCISE EXERCISE EXERCISE | 9

FEMA's Community Lifelines

SPACE WEATHER
TABLETOP EXERCISE



- Enables continuous operation of critical government and business functions
- Helps prioritize rapid stabilization after a disaster and is used day to day to support the recurring needs of the community
- Community Lifelines will be provided throughout the remainder of the modules

- Provided at the *whole of region level* as a single line for the purposes of this TTX
- Red: Severely degraded
- Yellow: Partially degraded or at risk
- Green: Full functionality

APL | 10

EXERCISE EXERCISE EXERCISE

What to Expect: Data Collection

SPACE WEATHER
TABLETOP EXERCISE

- Data collectors in the room will take notes on discussions
- Players will share thoughts via participant feedback forms
- Facilitators will lead hot washes to get lessons learned and best practices from players
- There will be no media in the TTX room; comments in the final report will be anonymized

TTX4 AAR helped define future investments

Your comments, discussions, and written responses are the data that will help this TTX culminate in an impactful after-action report.

APL EXERCISE EXERCISE EXERCISE | 11

EXERCISE EXERCISE EXERCISE

What to Expect: Hot Washes

SPACE WEATHER TABLETOP EXERCISE

- At the end of each module we will ask for *a designated representative* from each participating organization to briefly summarize their observations
- Please limit comments to ~1 min so we have the opportunity to hear from every participating organization:
  - *One lesson learned*
  - *One best practice*
- Participants may post comments in the chat during this time as well

All comments from the hot wash sessions will be captured and combined with comments from the chat, the data collectors' notes, and the participant feedback forms to support the development of the After Action Report and Improvement Plan

EXERCISE EXERCISE EXERCISE | 12

EXERCISE EXERCISE EXERCISE

Day 2 Agenda

SPACE WEATHER TABLETOP EXERCISE

EDT	LAUREL, MD
8:30	Arrivals and Registration
9:30	Welcome and Thoughts From Day 1
10:00	Background, Instructions, Logistics
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3:00	Adjourn

EXERCISE EXERCISE EXERCISE 18 September 2024 | 13

EXERCISE EXERCISE EXERCISE

Where we left off yesterday: Impending 2nd CME

SPACE WEATHER TABLETOP EXERCISE

Additional Thoughts or Comments since yesterday?

R# S3 G4

Closing Question

What differences of opinion might there be based on perspectives and community expectations?

Credit: Phys.org

EXERCISE EXERCISE EXERCISE 14

EXERCISE EXERCISE EXERCISE

TTX Scenario and Modules

SPACE WEATHER TABLETOP EXERCISE

MODULE 0 Introductory Sessions	MODULE 1 Solar Drivers	MODULE 2 Geomagnetic Storm	MODULE 3 Extreme Storm	MODULE 4 Response & Recovery

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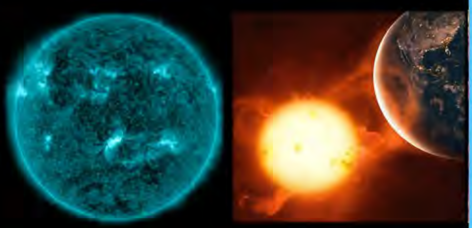
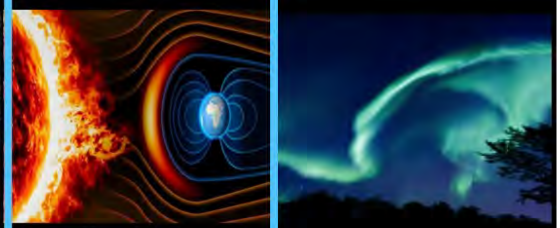
Federal Operating Concept





Scenario Spans 26 January 2028 – 03 February 2028

EXERCISE EXERCISE EXERCISE 15

EXERCISE EXERCISE EXERCISE

Module 3: Intensifying Storm

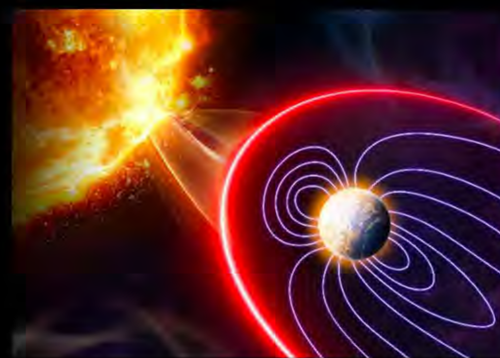
SPACE WEATHER
TABLETOP EXERCISE

Scenario timeline: 29 Jan 2028, 9:14 p.m. ET (7:14 p.m. MT), to 30 Jan 2028, 08:00 a.m. ET (6:00 a.m. MT)
Scenario duration: ~11 hours

- A second CME hits Earth's magnetosphere and triggers an extreme geomagnetic storm (G5).
- Solar energetic particle (SEP) intensities peak during the first ~12 hours of this storm.
- On Earth, there are numerous impacts on critical infrastructure, communications, and population—explicitly in Region 8 (R8).

Discussion will focus on:

- Ongoing coordination with federal, state, and local agencies
- Understanding impacts to critical infrastructure
- Decision-making regarding resource needs
- Consistency and timeliness of information



Credit: Phys.org

EXERCISE EXERCISE EXERCISE 16

EXERCISE EXERCISE EXERCISE

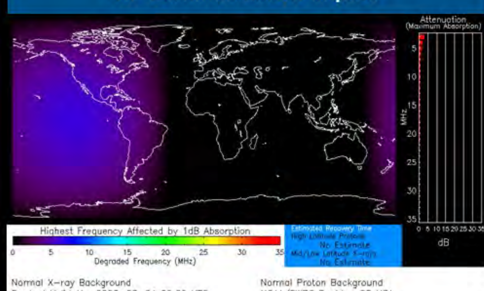
Space Weather Outlook

SPACE WEATHER
TABLETOP EXERCISE

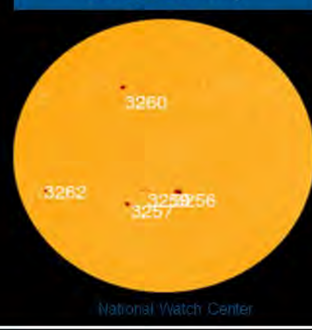
	Space Weather Activity	Geomagnetic Storms	Solar Radiation	Radio Blackouts
Past 24 Hours	Severe	G4	S4	R4
Next 24 Hours	Extreme	G4/5	S4	R4

For further information on NOAA space weather scales, refer to http://www.swpc.noaa.gov/noaa-scales-explanation.
For further information on sunspot activity, refer to https://www.swpc.noaa.gov/phenomena/sunspotssolar-cycle.

HF Communication Impact



Sunspot Activity



National Watch Center

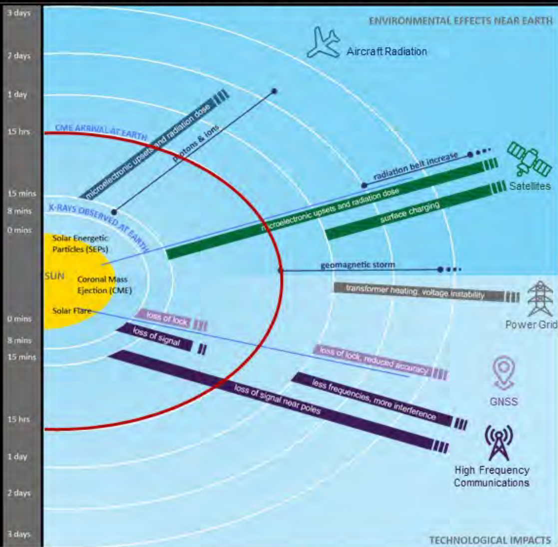
FEMA

EXERCISE EXERCISE EXERCISE 17

EXERCISE EXERCISE EXERCISE

Inject 3.1: Second CME Arrives at Earth – Overwhelming Information Arriving Quickly

SPACE WEATHER
TABLETOP EXERCISE



R# S4 G5

Scenario Time: 29 Jan 2028, 9:14 p.m. ET (7:14 p.m. MT)
Time since first eruption: 3 days, 8 hours

OPEN ENVELOPE 3.1

1. Emergency declarations?
2. National security concerns?
3. Processes for communications between the federal agencies and state and local authorities?
4. When would Defense Support of Civil Authorities initial actions occur?

APL EXERCISE EXERCISE EXERCISE 18

EXERCISE EXERCISE EXERCISE

Inject 3.2: Comms, Ops, PNT Issues

SPACE WEATHER
TABLETOP EXERCISE

R# S4 G5

Scenario time: 29 Jan 2028, 9:52 p.m. ET (7:52 p.m. MT)
Time since first eruption: 3 days, 8.5 hours

GPS degradation is increasing, causing major errors (greater than 1 km), and GPS timing has lost effective accuracy. High-frequency comms are substantially degraded locally, very-high-frequency and cellular comms are all effected.


Credit: Deposit Photos

1. What type of an event might this appear as to responders?
2. What contingencies are in place to ensure communications and coordination?
3. What sort of amendments/adjustment might be needed?
4. What are major roles and responsibilities at this point?

APL EXERCISE EXERCISE EXERCISE 19

EXERCISE EXERCISE EXERCISE

Inject 3.3: Loss of Satellite Catalog

SPACE WEATHER TABLETOP EXERCISE

Scenario time: 29 Jan 2028, 10:43 p.m. ET (8:43 p.m. MT)
Time since first eruption: 3 days, 9 hours

R# | S4 | G5

Loss of accuracy/knowledge in the NORAD satellite catalog (i.e., satellite and debris orbital tracking database).

Orbits are affected by increased thermospheric drag, leading to potential satellite reentry and increased threat of collision.

A percentage of satellites will experience single-event upset and other damage.

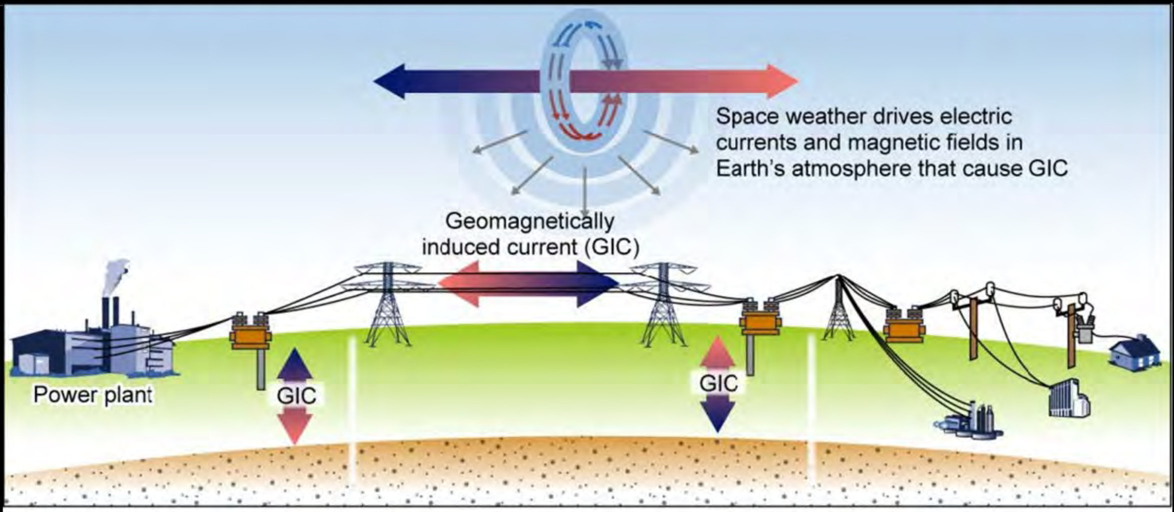
1. What are your concerns?
2. How do we verify communications are working with key platforms?
3. How do you verify functionality? What missions are you prioritizing?

EXERCISE EXERCISE EXERCISE

20

Geomagnetic Induced Current

SPACE WEATHER TABLETOP EXERCISE



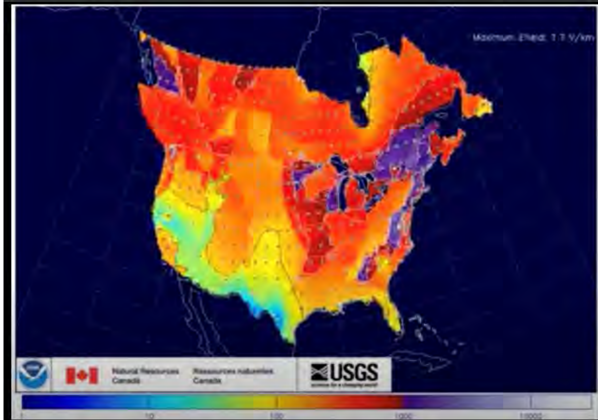
Sources: GAO (presentation); Art Explosion (images). | GAO-19-98

21

EXERCISE EXERCISE EXERCISE

Inject 3.4: Denver Metro Area Power Outage

SPACE WEATHER
TABLETOP EXERCISE



Scenario time: 29 Jan 2028, 11:39 p.m. ET (9:39 p.m. MT)
Time since first eruption: 3 days, 10 hours

R# S4 G5

1. What sorts of risk factors related to safety and security come to mind?
2. What steps are you taking at the federal level to manage the crisis response?
3. How are resource allocations being prioritized?
4. What other systems might be impacted by geomagnetically induced currents (GICs)?
5. What are thoughts and key points regarding preparing for the high potential of growing public concern?

- Expecting prolonged power outages
- Dependencies on backup systems, generators, fuel, supply chain
- Medical and health care facilities and 911 centers overwhelmed

EXERCISE EXERCISE EXERCISE 22

EXERCISE EXERCISE EXERCISE

Inject 3.5: Information Dissemination

SPACE WEATHER
TABLETOP EXERCISE

Scenario time: 30 Jan 2028, 12:00 a.m. ET to 08:00 a.m. ET
(29 Jan 2028, 10:00 p.m. MT – 30 Jan 2028, 6:00 a.m. MT)
Time since first eruption: 3 days, 10.5 hours

R# S4 G5

Red Auroras are widely visible across continental United States.

Miscommunication:

a. ...between responders, government, and industry on response (limited to plain ordinary telephone service and line-of-sight very-high-frequency, intermittent internet access)

b. ...with the public (intermittent cellular and internet access) to include “experts” interviewed by the media

1. If communications are still impacted, how would you reach the public?
2. Do you expect this would exacerbate the public’s heightened anxiety?
3. Who is responsible for informing the public about the phenomena?

EXERCISE EXERCISE EXERCISE 23

Module 3 Hot Wash

SPACE WEATHER
TABLETOP EXERCISE

Goal is to gather quick comments and impressions

- One representative from each organization to provide
- Please limit comments to ~1 min so we have an opportunity to hear from every participating organization):
  - One lesson learned
  - One best practice
- Remember, you can also post and respond to comments in the chat
- **PLEASE COMPLETE YOUR PARTICIPANTS FEEDBACK FORM FOR MODULE 3**

Your comments and discussions are the data that will help this TTX culminate in an impactful after-action report.

TTX Scenario and Modules

SPACE WEATHER
TABLETOP EXERCISE

MODULE 0 Introductory Sessions	MODULE 1 Solar Drivers	MODULE 2 Geomagnetic Storm	MODULE 3 Extreme Storm	MODULE 4 Response & Recovery

Space Weather 101

Space Weather Prediction

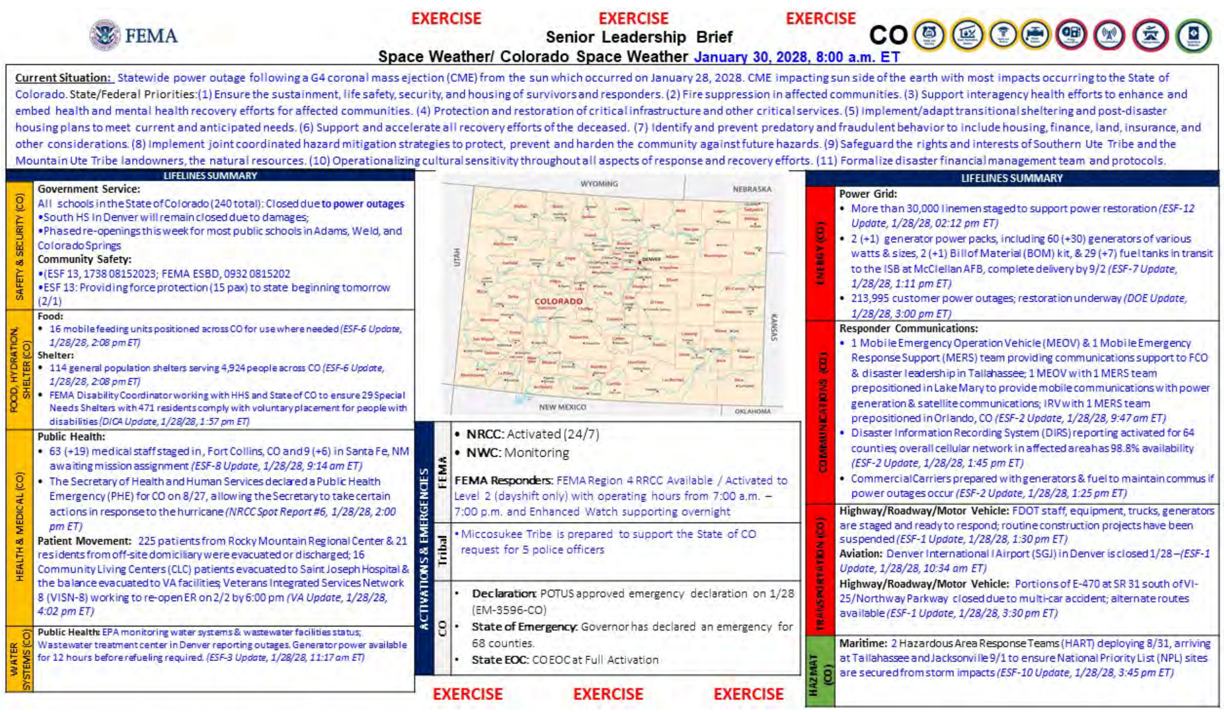
Artemis Contingency Planning

National Response Framework

National Incident Management Systems

Federal Operating Concept

Scenario Spans 26 January 2028 – 03 February 2028



FEMA

EXERCISE EXERCISE EXERCISE

Senior Leadership Brief

Space Weather/ Colorado Space Weather January 30, 2028, 8:00 a.m. ET

CO

Current Situation: Statewide power outage following a G4 coronal mass ejection (CME) from the sun which occurred on January 28, 2028. CME impacting sun side of the earth with most impacts occurring to the State of Colorado. State/Federal Priorities:(1) Ensure the sustainment, life safety, security, and housing of survivors and responders. (2) Fire suppression in affected communities. (3) Support interagency health efforts to enhance and embed health and mental health recovery efforts for affected communities. (4) Protection and restoration of critical infrastructure and other critical services. (5) Implement/adapt transitional sheltering and post-disaster housing plans to meet current and anticipated needs. (6) Support and accelerate all recovery efforts of the deceased. (7) Identify and prevent predatory and fraudulent behavior to include housing, finance, land, insurance, and other considerations. (8) Implement joint coordinated hazard mitigation strategies to protect, prevent and harden the community against future hazards. (9) Safeguard the rights and interests of Southern Ute Tribe and the Mountain Ute Tribe landowners, the natural resources. (10) Operationalizing cultural sensitivity throughout all aspects of response and recovery efforts. (11) Formalize disaster financial management team and protocols.

LIFELINES SUMMARY

SAFETY & SECURITY (CO)

Government Service:
All schools in the State of Colorado (240 total): Closed due **to power outages**
•South HS In Denver will remain closed due to damages;
•Phased re-openings this week for most public schools in Adams, Weld, and Colorado Springs

Community Safety:
•(ESF 13, 1738 08152023; FEMA ESBD, 0932 0815202
•ESF 13: Providing force protection (15 pax) to state beginning tomorrow (2/1)

FOOD, HYDRATION, SHELTER (CO)

Food:
- 16 mobile feeding units positioned across CO for use where needed *(ESF-6 Update, 1/28/28, 2:08 pm ET)*

Shelter:
- 114 general population shelters serving 4,924 people across CO *(ESF-6 Update, 1/28/28, 2:08 pm ET)*
- FEMA Disability Coordinator working with HHS and State of CO to ensure 29 Special Needs Shelters with 471 residents comply with voluntary placement for people with disabilities *(DICA Update, 1/28/28, 1:57 pm ET)*

HEALTH & MEDICAL (CO)

Public Health:
- 63 (+19) medical staff staged in , Fort Collins, CO and 9 (+6) in Santa Fe, NM awaiting mission assignment *(ESF-8 Update, 1/28/28, 9:14 am ET)*
- The Secretary of Health and Human Services declared a Public Health Emergency (PHE) for CO on 8/27, allowing the Secretary to take certain actions in response to the hurricane *(NRCC Spot Report #6, 1/28/28, 2:00 pm ET)*

Patient Movement: 225 patients from Rocky Mountain Regional Center & 21 residents from off-site domiciliary were evacuated or discharged; 16 Community Living Centers (CLC) patients evacuated to Saint Joseph Hospital & the balance evacuated to VA facilities; Veterans Integrated Services Network 8 (VISN-8) working to re-open ER on 2/2 by 6:00 pm *(VA Update, 1/28/28, 4:02 pm ET)*

WATER SYSTEMS (CO)

Public Health: EPA monitoring water systems & wastewater facilities status; Wastewater treatment center in Denver reporting outages. Generator power available for 12 hours before refueling required. *(ESF-3 Update, 1/28/28, 11:17 am ET)*

WYOMING NEBRASKA UTAH COLORADO KANSAS NEW MEXICO OKLAHOMA

ACTIVATIONS & EMERGENCIES

FEMA
- **NRCC:** Activated (24/7)
- **NWC:** Monitoring

FEMA Responders: FEMA Region 4 RRCC Available / Activated to Level 2 (dayshift only) with operating hours from 7:00 a.m. – 7:00 p.m. and Enhanced Watch supporting overnight

Tribal
- Miccosukee Tribe is prepared to support the State of CO request for 5 police officers

CO
- **Declaration:** POTUS approved emergency declaration on 1/28 (EM-3596-CO)
- **State of Emergency:** Governor has declared an emergency for 68 counties.
- **State EOC:** CO EOC at Full Activation

LIFELINES SUMMARY

ENERGY (CO)

Power Grid:
- More than 30,000 linemen staged to support power restoration *(ESF-12 Update, 1/28/28, 02:12 pm ET)*
- 2 (+1) generator power packs, including 60 (+30) generators of various watts & sizes, 2 (+1) Bill of Material (BOM) kit, & 29 (+7) fuel tanks in transit to the ISB at McClellan AFB, complete delivery by 9/2 *(ESF-7 Update, 1/28/28, 1:11 pm ET)*
- 213,995 customer power outages; restoration underway *(DOE Update, 1/28/28, 3:00 pm ET)*

COMMUNICATIONS (CO)

Responder Communications:
- 1 Mobile Emergency Operation Vehicle (MEOV) & 1 Mobile Emergency Response Support (MERS) team providing communications support to FCO & disaster leadership in Tallahassee; 1 MEOV with 1 MERS team prepositioned in Lake Mary to provide mobile communications with power generation & satellite communications; IRV with 1 MERS team prepositioned in Orlando, CO *(ESF-2 Update, 1/28/28, 9:47 am ET)*
- Disaster Information Recording System (DIRS) reporting activated for 64 counties; overall cellular network in affected area has 98.8% availability *(ESF-2 Update, 1/28/28, 1:45 pm ET)*
- Commercial Carriers prepared with generators & fuel to maintain commus if power outages occur *(ESF-2 Update, 1/28/28, 1:25 pm ET)*

TRANSPORTATION (CO)

Highway/Roadway/Motor Vehicle: FDOT staff, equipment, trucks, generators are staged and ready to respond; routine construction projects have been suspended *(ESF-1 Update, 1/28/28, 1:30 pm ET)*

Aviation: Denver International I Airport (SGJ) in Denver is closed 1/28 –*(ESF-1 Update, 1/28/28, 10:34 am ET)*

Highway/Roadway/Motor Vehicle: Portions of E-470 at SR 31 south of VI-25/Northway Parkway closed due to multi-car accident; alternate routes available *(ESF-1 Update, 1/28/28, 3:30 pm ET)*

HAZMAT (CO)

Maritime: 2 Hazardous Area Response Teams (HART) deploying 8/31, arriving at Tallahassee and Jacksonville 9/1 to ensure National Priority List (NPL) sites are secured from storm impacts *(ESF-10 Update, 1/28/28, 3:45 pm ET)*

EXERCISE EXERCISE EXERCISE

EXERCISE EXERCISE EXERCISE

Inject 4.1: Simulated Senior Leader Brief

SPACE WEATHER TABLETOP EXERCISE

Scenario time: 30 Jan 2028, 8:00 a.m. ET (6:00 a.m. MT)
Time since first eruption: 3 days, 17 hours

R# | S4 | G5

Current Situation: Statewide power outage following a G4 coronal mass ejection (CME) from the sun which occurred on January 28, 2028. CME impacting sun side of the earth with most impacts occurring to the State of Colorado. State/Federal Priorities:(1) Ensure the sustainment, life safety, security, and housing of survivors and responders. (2) Fire suppression in affected communities. (3) Support interagency health efforts to enhance and embed health and mental health recovery efforts for affected communities. (4) Protection and restoration of critical infrastructure and other critical services. (5) Implement/adapt transitional sheltering and post-disaster housing plans to meet current and anticipated needs. (6) Support and accelerate all recovery efforts of the deceased. (7) Identify and prevent predatory and fraudulent behavior to include housing, finance, land, insurance, and other considerations. (8) Implement joint coordinated hazard mitigation strategies to protect, prevent and harden the community against future hazards. (9) Safeguard the rights and interests of Southern Ute Tribe and the Mountain Ute Tribe landowners, the natural resources. (10) Operationalizing cultural sensitivity throughout all aspects of response and recovery efforts. (11) Formalize disaster financial management team and protocols.

1. What are you organization's priorities?
2. Do you expect to need ongoing subject-matter expertise?
3. Would the routine "damage assessment" approach be sufficient?
4. How might an event like this impact your current approach to conducting vulnerability assessments?

EXERCISE EXERCISE EXERCISE 28

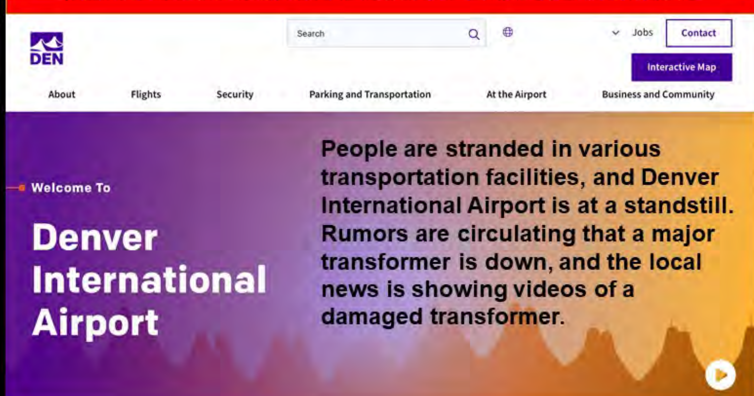
EXERCISE EXERCISE EXERCISE

Inject 4.2: Air Traffic and Ongoing Power Concerns

SPACE WEATHER TABLETOP EXERCISE

Scenario time: 30 Jan 2028, 12:00 p.m. ET (10:00 a.m. MT)
Time since first eruption: 3 days, 21 hours

ALL FLIGHTS CANCELED UNTIL FURTHER NOTICE



People are stranded in various transportation facilities, and Denver International Airport is at a standstill. Rumors are circulating that a major transformer is down, and the local news is showing videos of a damaged transformer.

1. What processes used to guide decisions regarding priorities and resources?
2. Status of the NRCC, the RRCC, and state and local EOCs?
3. Major communications modes?
4. Transportation impacts in general?

EXERCISE EXERCISE EXERCISE 29

EXERCISE EXERCISE EXERCISE

Inject 4.3 for Laurel MD: Artemis Mission Return

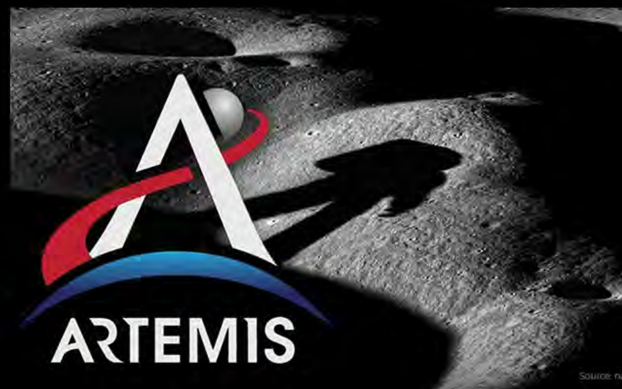
SPACE WEATHER
TABLETOP EXERCISE

Scenario time: 02 Feb 2028, 02:08 a.m. ET (00:08 a.m. MT)

Time since first eruption: 6 days, 11 hours

R#	S1	G1

Federal Participants: Artemis returns to Earth through very enhanced outer radiation belt (GOES >2 MeV electrons). Note: Solar radiation levels are back to null, but the radiation belt is extremely enhanced, contributing additional, significant dose to astronauts.



1. Key decision needs?
2. Communication and coordination needs?
3. Other concerns?

EXERCISE EXERCISE EXERCISE 30

EXERCISE EXERCISE EXERCISE

Inject 4.4 for Laurel MD: Unavoidable LEO Collision

SPACE WEATHER
TABLETOP EXERCISE

Scenario time: 02 Feb 2028, 02:08 a.m. ET, to 03 Feb 2028, 09:20 a.m. ET
02 Feb 2028, 12:08 a.m. MT, to 03 Feb 2028, 07:20 a.m. MT

Time since first eruption: 7 days, 18 hours

R#	S#	G#

NORAD regains satellite catalog accuracy and issues a warning to a commercial satellite operator that a collision between one of their space vehicles and a large (>10 cm) piece of debris is highly probable within the next 24 hours. The commercial operator responds that the satellite was rendered inoperable earlier in the storm and cannot be diverted; a collision occurs.


Credit: Space.com

1. Commercial operator requirements (e.g., reporting loss of control capability)?
2. Other concerns or considerations?

EXERCISE EXERCISE EXERCISE 31

EXERCISE EXERCISE EXERCISE

Inject 4.4 for Region 8: Returning to Normal

SPACE WEATHER
TABLETOP EXERCISE

Scenario time: 02 Feb 2028, 02:08 a.m. ET, to 03 Feb 2028, 09:20 a.m. ET
(02 Feb 2028, 12:08 a.m. MT, to 03 Feb 2028, 07:20 a.m. MT)
Time since first eruption: 7 days, 18 hours

R# S# G#

1. What ground problems have been resolved, and which linger?
2. Considerations for transitioning to recovery?
3. Which emergency operations centers and/or response centers are still activated?
4. Balancing the needs between the varying infrastructure?

EXERCISE EXERCISE EXERCISE 32

EXERCISE EXERCISE EXERCISE

Module 4 Hot Wash

SPACE WEATHER
TABLETOP EXERCISE

Goal is to gather quick comments and impressions

- One representative from each organization to provide
- Please limit comments to ~1 min so we have an opportunity to hear from every participating organization):
  - One lesson learned
  - One best practice
- Remember, you can also post and respond to comments in the chat
- **PLEASE COMPLETE YOUR PARTICIPANTS FEEDBACK FORM FOR MODULE 4**

Your comments and discussions are the data that will help this TTX culminate in an impactful after-action report.

EXERCISE EXERCISE EXERCISE 33

EXERCISE EXERCISE EXERCISE

Day 2 “Parking Lot” topics

SPACE WEATHER TABLETOP EXERCISE

- Briefly revisit any topics that may have been cut short

Module	Description
0	Introductory Sessions
1	Solar Drivers
2	Geomagnetic Storm
3	Intensifying Storm
4	Response and Recovery

EXERCISE EXERCISE EXERCISE | 34

EXERCISE EXERCISE EXERCISE

Final Hot Wash

SPACE WEATHER TABLETOP EXERCISE

- Comments are welcome that pertain to *any module or brief*.
- Limited time, but we welcome comments and discussion from everyone, so *please be brief to allow opportunity for others to speak*. Consider comments related to:
  - Best practice or lesson learned
  - Recommendation for improvement
- Participants may post comments in the chat during this time as well.
- Completion of the final feedback forms.

PD TTX4 After Action Report helped define future investments

All comments from the hot wash sessions will be captured and combined with comments from the chat, the data collectors’ notes, and the participant feedback forms to support the development of the After Action Report and Improvement Plan

EXERCISE EXERCISE EXERCISE | 35

EXERCISE EXERCISE EXERCISE

Final Participant Feedback Form

SPACE WEATHER
TABLETOP EXERCISE

- See the Xleap Link
- Please take a few minutes to fill this out!

APL EXERCISE EXERCISE EXERCISE | 36

EXERCISE EXERCISE EXERCISE

Closing Remarks

SPACE WEATHER
TABLETOP EXERCISE

APL EXERCISE EXERCISE EXERCISE | 37


Thank you for joining us!
SPACE WEATHER
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