Building Space Weather Literacy Through Sustained Engagement

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NEXT GENERATION SCIENCE STANDARDS

Endorsements

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Executive Summary

Space weather affects all space systems, both natural and artificial. There is a rapid growth of awareness in past decades of this reality and a critical need for space weather prediction due to technology advances. Above all, space weather science and its history are outstanding vehicles for teaching science, technology, engineering, and mathematics (STEM) topics. As a white paper group, we recommend that the Decadal Survey builds space weather literacy within K–14 classrooms and the general public, covering all areas of studies in heliophysics through sustained engagement beyond celestial and spacecraft events.

Introduction

The upcoming solar eclipses in 2023 and 2024 across the Americas are great opportunities to inspire, engage, and educate many. As the Sun goes through its 11-year cycle with an increasing number of solar flares, CMEs and auroras defining solar maximum, the public hears more about the Sun and its impact on Earth and our solar system. However, without these celestial events, what can the heliophysics community do to sustain public interest? How do we link the protection of our assets in space to space weather preparedness, especially with exploration initiatives back to the Moon and on to Mars? The answers to these questions are through *space weather literacy* in K-14 and a popularized *Space Weather Week.*

Rationale

Much as climate change affects people's lives, space weather events can wreak havoc on our technological society. Impacts ranging from personal inconvenience, to financial losses, homeland security vulnerabilities, space weather disturbances can be felt throughout society. Even the Federal Emergency Management Agency (FEMA) has readiness tips to assist the public before, during and after extreme space weather events. Severe space weather events are indeed natural disasters not only in need of preparedness but also predictive monitoring and analytics.

Earth science regularly engages the nation on Earth Day. Planetary sciences host annual events surrounding Observe the Moon Night. Astrophysicists recently started Black Hole Week. These annual events provide opportunities for multiple communities to share scientific knowledge, especially with youth and young adults. Heliophysics is preparing for the 2023 annual solar eclipse and the 2024 total solar eclipse; academia, federal agencies, industries, libraries, museums, science centers, and professional societies are actively sharing their coordinated plans and resources for the celebration of this one-time Sun-Earth celebration. However, these two events alone are not enough to increase and maintain student and public awareness of the importance of the Sun and space weather.

Compared to studies of hurricanes and earthquakes, space weather is still a relatively new research area. The National Space Weather program started its strategic plan in 1995, gained more momentum in the International Heliophysical Year in 2008, and continued via the International Space Weather Initiative (ISWI) started in 2009.

In the US, for more than a decade the Space Weather Enterprise Forum has involved stakeholders across federal agencies, private industries, media, and legislators. In 2015, The National Science and Technology Council issued a *National Space Weather Action Plan* that called for strong public-private partnerships[1]. In 2016, the Obama Administration took a significant step towards preparing critical infrastructure and technology for the risk of space weather through an executive order (Executive Order 13744 - *Coordinating Efforts to Prepare the Nation for Space Weather*[2]). In 2019, the Trump Administration released a *National Space Weather Strategy and Action Plan*[3]. In 2020, the Congress passed a bill called *Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act* or the *PROSWIFT Act*[4]. Also in 2020, NASA started the Space Weather Science Application Program that requested the *NASA Gap Analysis Report*[5]. In 2021, The National Oceanic and Atmospheric Administration (NOAA) set up a Space Weather Advisory Group[6] that included commercial providers, academia, and space weather data end users. Those are all great and necessary steps.

In 2017, unexpected space weather aligned with severe Earth weather as large solar storms interrupted rescue efforts following Hurricanes Irma and Maria[7]. Our nation needs more scientifically literate citizens who can apply scientific knowledge and processes to follow and analyze problems, assess risks, ask critical questions, and ultimately, explain both Earth and space weather events.

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[1] https://www.sworm.gov/publications/2015/swap_final__20151028.pdf
[2] https://obamawhitehouse.archives.gov/blog/2016/10/12/preparing-nation-space-weather-new-executive-order
[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
[5] https://science.nasa.gov/science-pink/s3fs-public/atoms/files/GapAnalysisReport_full_final.pdf
[6] https://www.weather.gov/news/091421-swag-members
[7] https://news.agu.org/press-release/solar-flares-disrupted-radio-communications-during-september-2017-atlantic-hurricane-relief-effort

Recommended Initiatives

Just as *Climate Literacy: The Essential Principles of Climate Science*[8] helps individuals and communities to know and understand Earth's climate, impacts of climate change, and approaches to adaptation or mitigation, we recommend developing *space weather literacy* and *a set of principles* using the 2013 Next Generation Science Standards[9] (NGSS) as a guide, to engage learners in scientific inquiry. This is an expansion of the 2012 "Mini-Atlas" of Heliophysics Literacy[10] that was created by the NASA-funded Heliophysics Science Education and Public Outreach Forum based on The AAAS Atlas of Science Literacy strand maps. By providing an educational framework of principles and concepts, we can promote heliophysics literacy so that educators may integrate space weather in existing science curricula.

The Heliophysics Big Year (October 2023–December 2024) will begin a global celebration of solar science and the Sun's influence on Earth and the entire solar system.[11] Two solar eclipses visible in the US, the Parker Solar Probe's closest approach to the Sun, final preparations to launch the Polarimeter to Unify the Corona and Heliosphere (PUNCH) mission in 2025, and the anticipated beginning of National Science Foundation's Daniel K. Inouye Solar Telescope steady-state operations are multiple opportunities to inspire many. Once the audiences have been attracted, it will be an enormous missed opportunity if the science community does not sustain the interest and build on the engagement. From an education perspective, more intentional cross-collaboration among federal agencies, academia, aerospace industries and professional societies would benefit everyone.

Therefore, we propose establishment of *Space Weather Week*, not just among the scientists and practitioners, but also with educators and learners of all ages. The public celebration of Space Weather Week may coincide with NOAA's annual space weather conference, Space Weather Enterprise Forum (SWEF), the European Space Weather Week, and/or around the spring and fall equinoxes. Earth Scientists celebrate Earth Science Week in addition to Earth Day. Similarly, planetary scientists promote observations of the Moon through the International Observe the Moon Night.

This is the decade to lay a solid foundation for space weather education, both in the K-14 classrooms and through out-of-school-time programming such as junior space weather forecasters training, space weather balloons, hack-a-thons, 4-H, Boys & Girls Clubs, Scouts, camps, etc. Existing and new heliophysics educational resources ought to be funded, curated, bundled, distributed, and shared.

[8] https://www.climate.gov/teaching/climate
[9] https://www.nextgenscience.org/
[10] https://smdepo.org/project/5831
[11] https://solarsystem.nasa.gov/solar-system/sun/helio-big-year/

Connecting to Next Generation Science Standards

To create space weather literacy and build proficiency in science and engineering practices**,** Space Weather Week activities will be rooted in the NGSS**,** expanding the reach to a wider audience. The NGSS are national K–12 science standards developed by the states, which set expectations for what students should know and be able to do. Space weather concepts such as sunspot cycles, solar wind, the ionosphere, the magnetosphere, and aurora can be explored at all levels via the NGSS. By using the NGSS as a foundation for Space Weather Week activities, we can support K-12 educators by providing them with a clear avenue for teaching the key concepts needed to build space weather literacy.

The NGSS performance expectations, listed below, clearly outline both content and the science and engineering practices required to build scientific competency. Some of these skills include developing and using models, analyzing, and interpreting data, carrying out investigations, and designing solutions.

For example, students can observe changes in solar patterns like sunspot cycles by making observations, developing models, and analyzing data**.**

- Elementary school students can explore the 11-year solar cycle by observing sunspots. [1-ESS1-1. Use observations of the Sun, Moon, and stars to describe patterns that can be predicted.]
- Middle school students can develop models showing the correlation of sunspot data to increased geomagnetic activity. [MS-ESS1-1. Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.]
- High school students can analyze evidence of changes in radiation due to increased solar activity on the surface of the Sun, including magnetic reconnection**.** [HS-ESS1-1. Develop a model based on evidence to illustrate the life span of the Sun and the role of nuclear fusion in the Sun's core to release energy that eventually reaches Earth in the form of radiation.]

Another example is engaging students in comparing space weather to weather on Earth, and exploring the roles of the ionosphere in both types of weather.

- Elementary school students can explore how scientists predict space weather and prepare for space weather-related hazards. [3-ESS3-1. Make a claim about the merit of a design solution that reduces the impacts of a weather-related hazard.]
- Middle school students can describe how the solar wind interacts with the ionosphere and the magnetosphere. [5-ESS2-1. Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.]
- High school students can develop models of ionization that occurs in the Earth's upper atmosphere associated with the phenomenon of aurora. [HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a

combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).]

For undergraduate students, we can expand on the NGSS foundation to deepen their understanding of space weather through integration in the core curriculum of Physics and Astronomy courses. Two examples are the American Association of Physics Teachers (AAPT) Digi Kits:

- Sunspot Science: A Digi Kit for Introductory Physics, https://www.compadre.org/books/Sunspot
- Exoplanet Atmospheres: A Digi Kit for Introductory Astronomy, https://www.compadre.org/books/?ID=67&FID=57433

Bridging formal and informal education, the heliophysics community may engage both high school and college students in citizen science projects such as:

- University of Alaska's Space Weather Underground initiative[12] that invites students to build and deploy a cost-effective and research-capable array of magnetometers across Alaska to analyze Earth's magnetic field disturbances during aurora activities.
- GLOBE Observer[13] project that allows anyone to collect data to track changes in the environment in support of Earth system science research, and interpret NASA and other satellite data, encouraging scientists and learners of all ages to do real scientific research through the GLOBE Program (see next section).

Connecting Researchers, Educators and Learners in a Global Program

Since the 2013-2022 Solar and Space Physics Decadal survey, the International Heliophysics Data Environment Alliance (IHDEA) has been meeting on a regular basis to encourage the use of common standards and services in order to enable sharing of data and to enhance science[14]. We recommend a similar global sharing of heliophysics education data that will in turn benefit science.

It would be desirable to have an equivalent of the Global Learning and Observation to Benefit the Environment (GLOBE**)** program**[15]** that is dedicated to supplying the STEM professionals of tomorrow with the scientific knowledge necessary to tackle the mysteries of the Sun and the Sun-Earth Connection. A national community of students, educators, scientists and citizens must work together to better understand the Sun, how it influences Earth, the planets and the solar system, and how it impacts humanity.

[12] https://sites.google.com/alaska.edu/swug/home
[13] https://observer.globe.gov/
[14] https://ihdea.net/
[15] https://www.globe.gov/

GLOBE is an international science education initiative that is co-sponsored by NASA, NOAA, NSF and Department of State, with a mission to "increase awareness of individuals throughout the world about the global environment, contribute to increased scientific understanding of the Earth, and support improved student achievement in science and mathematics."

By laying a foundation of space weather literacy, a GLOBE-equivalent program for heliophysics may be explored and actualized in the following decade.

Summary and Recommendations

Adding space weather to the model of Earth Systems science shows the interconnectedness of science, and how the critical interactions between systems create a unique, life-supporting environment on Earth. Understanding the delicate balance of those systems is critical to the sustainability of life on Earth.

With more scientifically literate citizens, our nation can observe, monitor, and accurately predict space weather. Space weather literacy will help multiple facets of our society in risk management and mitigations for both earthlings and spacefarers. Over time, space weather literacy will also benefit the study of space climate.

In summary, we highly recommend implementing space weather literacy in K-14 by connecting principles/concepts to the NGSS and expanding the celebration of Space Weather Week. We also recommend a GLOBE-equivalent program that would connect researchers with educators and learners.

Recommendations

- Create and popularize the celebration of an annual Space Weather Week**.**
- Promote interagency efforts with dedicated funding for space weather education.
- Align heliophysics educational resources to the Next Generation Science Standards (NGSS).
- Curate K-14 heliophysics education resources to incorporate space weather in K-14 curricula.
- Create programming aimed at youth for developing junior space weather forecasters.
- Foster space weather literacy among educators and learners of all ages.
- Begin an interagency collaboration to develop a GLOBE-equivalent program for space weather.

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