UNITED STATES DEPARTMENT OF COMMERCE
Chief Financial Officer
Assistant Secretary for Administration
Washington, D.C. 20230

APR 0 2 2019

The Honorable Jerry Moran
Chairman
Subcommittee on Commerce, Justice,
Science, and Related Agencies
Committee on Appropriations
United States Senate
Washington, DC 20510

Dear Mr. Chairman:

This report constitutes the National Oceanic and Atmospheric Administration's (NOAA) Report to Congress, "Space Weather Follow-On: Space Weather Observation Needs and Plans, Including and Beyond a Solar Coronagraph."

The report responds to congressional direction in the Joint Explanatory Statement accompanying the Consolidated Appropriations Act, 2018 (P.L. 115-141), and outlines NOAA's assessment of launch options for a coronagraph as well as a plan to address its non-coronagraph space weather requirements. The report reflects consensus opinion of subject matter experts from NOAA, the U.S. Air Force, U.S. Navy, and the National Aeronautics and Space Administration.

If you have any further questions, please contact me at (202) 482-4951. Thank you for your continued support of the Department of Commerce and its programs.

Sincerely,

Lisa Casias for

Thomas F. Gilman
Chief Financial Officer and
Assistant Secretary for Administration

Enclosure

REPORT TO CONGRESS

SPACE WEATHER FOLLOW ON:
Space Weather Observation Needs and Plans, Including and Beyond a Solar Coronagraph

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Developed pursuant to: The Consolidated Appropriations Act, 2018 (Public Law 115-141)

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THE JOINT EXPLANATORY STATEMENT THAT ACCOMPANIED THE CONSOLIDATED APPROPRIATIONS ACT, 2018, PUBLIC LAW 115-141

Report language included in House Report 115–231 (''the House report'') or Senate Report 115–139 (''the Senate report'') that is not changed by this explanatory statement or this Act is approved. The explanatory statement, while repeating some language for emphasis, is not intended to negate the language referred to above unless expressly provided herein. In cases where both the House report and the Senate report address a particular issue not specifically addressed in the explanatory statement, the House report and the Senate report should be read as consistent and are to be interpreted accordingly. In cases where the House report or the Senate report directs the submission of a report, such report is to be submitted to both the House and Senate Committees on Appropriations (''the Committees'').

Space Weather Follow-on.-- The agreement includes $8,545,000 for Space Weather Follow-On. Direction in the House and Senate reports is retained, and NOAA is further directed to provide a full assessment of launch options for a coronagraph, and a plan to address non-coronagraph space weather requirements, within 180 days of enactment of this Act. NOAA shall coordinate with NASA and the Department of Defense to ensure that NOAA is providing cost-effective operational space weather assets and NASA is providing technology development, in accordance with the National Space Weather Action Plan.

THIS REPORT RESPONDS TO THE COMMITTEE'S REQUEST.

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I. Executive Summary

The National Oceanic and Atmospheric Administration (NOAA), part of the Department of Commerce (DOC), is pursuing the near-term objective of sustaining the baseline operational space-based observation and measurement capabilities for coronagraph imaging and solar wind measurements. Requirements for these measurements derive from the NOAA Space Weather Mission Service Area Observational User Requirements baselined by the NOAA Observing Systems Council (NOSC) in November 2017. Funding provided within *the Consolidated Appropriations Act, 2018* and the President's fiscal year (FY) 2019 Budget request will continue development of two Compact Coronagraphs (CCOR) under an interagency agreement with the U.S. Naval Research Laboratory (NRL). To ensure near term continuity of space weather measurements required for operations, NOAA will deploy CCOR instruments at the soonest availability for operational robustness and to monitor the upstream solar wind.

This report (1) assesses and prioritizes the integration and launch options for the CCOR, specifically analyzing manifesting the instrument on a satellite at the Earth-Sun Lagrange 1 (L1) and the Geostationary Operational Environmental Satellite-U (GOES-U) platform in geostationary orbit and; and (2) provides information to inform the manifesting option for the most critical space weather data for forecasting Coronal Mass Ejections (CME) imagery. CME imagery is currently only available through the European Space Agency (ESA)/National Aeronautics and Space Administration (NASA) research Solar and Heliospheric Observatory (SOHO) satellite (launched in 1995), which is projected to lose power in 2025. Upstream solar wind measurements are currently provided by NOAA Deep Space Climate Observatory (DSCOVR) satellite (launched in 2015), which is presently expected to operate until the mid-2020s. To sustain these operational capabilities going forward, NOAA has analyzed the following:

- Develop a L1 satellite mission (SWFO L1) for launch in late 2024:
  - with a Solar Wind Instrument Suite (SWIS) to measure essential solar wind properties, and a second CCOR for continuous coronal imagery; and
  - work with NASA to launch the SWFO L1 mission as a rideshare with NASA's Interstellar Mapping and Acceleration Probe (IMAP) launch;
- Integrate a CCOR on the GOES-U spacecraft planned for launch in early 2024;
- Establish a robust ground architecture and system – together with interagency and international partners – to acquire and process data in support of the space weather mission;
- Seek a partnership with ESA to obtain CME imagery and solar wind measurements from Lagrange 5 (L5) and with the U.S. Air Force (USAF) in various Earth orbits for obtaining energetic charged particle measurements; and
- Archive space weather observations and measurements at NOAA's National Centers for Environmental Information (NCEI) to facilitate model development and benchmarking.

To begin planning of space weather forecast watch and warning capabilities beyond the Space Weather Follow On (SWFO) program, NOAA has included space weather observational requirements as baseline parameters in the NOAA Satellite Observing System Architecture (NSOSA) study. A mix of U.S. and international partnerships with support from the commercial sector form the basis of this proposed plan.

II. NOAA's Requirements for Space-based Space Weather Observations

NOAA's space-based space weather requirements are addressed by observations and measurements from Low-Earth Orbit (LEO), Geostationary Earth Orbit (GEO), and L1 (a position approximately one million miles from Earth, along the Earth-Sun line). These capabilities and partnerships are overviewed in Appendix C. In particular, the National Space Weather Action Plan, coordinated among DOC, NASA, and the Department of Defense (DoD), identified a clear priority for the Nation's space weather observing system:

> *"DOC, in coordination with NASA and DOD, will develop options to deploy an operational satellite mission to a position at least 1 million miles upstream on the Earth-Sun line (i.e., the L1 Lagrange point). The primary instrument on this mission will be a solar coronagraph to replace the SOHO/LASCO coronagraph capability. This mission will also provide solar wind measurements and other measurements essential to space-weather forecasting."*

This report focuses on the CME observations and L1-based solar wind measurements, which are at greatest risk of experiencing a gap in continuity and NOAA's proposed implementation addresses these critical mission performance objectives.

NOSC is the authority for NOAA's observing requirements. NOSC validation process creates a baseline of objectively-verifiable observation requirements based on documented mandates, scientific studies, ongoing research, and consensus among NOAA leadership and expert opinion of NOAA mission service area leads. Requirements are ranked by priority from 1 through 3 depending on the demonstrated need and identified by observation type and vantage point. In 2017, NOSC approved a revision to NOAA's Space Weather Mission Service Area Observational User Requirements Document (OURD). These revisions to the previous 2009 baseline document were driven largely by the advent of more sophisticated numerical space weather modeling in the intervening years since the 2009, and the need to specify a core set of user requirements to plan future satellite missions. The OURD identifies both requirements that are continuity with existing capability and new requirements necessary to meet future needs. Solar imagery of the corona and a suite of space weather *in situ* parameters from L1 and L5 are assessed by NOSC as, mission critical, priority 1 requirements drawn from documented sources, mandates, and mission need. This report discusses the approaches available near-term to NOAA to avoid a gap in continuity of the observations that satisfy operational requirements and provides options for resilience in these critical parameters.

The L1 *in situ* measurements called out in the OURD are in continuity with the existing NSOSA as they are returned by the NOAA's DSCOVR spacecraft. The coronal imagery observation is a continuity of the Large Angle and Spectrometric Coronagraph (LASCO) coronagraph imagery from NASA/ESA's SOHO research satellite. In accord with the OURD, the future NSOSA study notes that additional solar observations off the Earth-Sun line, for example at L5 (a point along Earth's orbit at 60 degrees behind Earth), could benefit space weather prediction capabilities. These space-based observations and measurements are obtained through NOAA-developed satellite missions, partner contributions, and commercial sources as they become available.

III. NOAA's Space Weather Follow On Program

A comprehensive and reliable operational Space Weather Follow On Program will include requirements to monitor and forecast the Sun's photon and plasma energy inputs to Earth. NOAA's National Environmental, Satellite, Data, and Information Service (NESDIS) plan for the SWFO program will be to secure the foundational capability for this essential requirement, thereby enabling NOAA's Space Weather Prediction Center (SWPC) and the DoD to issue superior watches, warnings and alerts for Earth-directed space weather events. A dedicated, operational capability could include:

1. Procuring through NASA, a SWFO L1 satellite mission to carry a SWIS and a CCOR, launched as a ride share with NASA's IMAP scheduled to launch in 2024.
2. Integrating a CCOR on NOAA's GOES-U spacecraft planned for launch in early 2024.

As well as:

3. Establish a robust ground architecture and system to ensure reliable receipt and processing of space weather observations and measurements.
4. Partnering with ESA for observations and measurements from L5 and with the USAF for energetic particle measurements.
5. Archive space weather observations and measurements at NOAA's NCEI to facilitate model development and benchmarking.

This report will discuss the various advantages of the complementary CCOR accommodation approaches. A schematic outlining the timeline NOAA's proposed capability development is provided in Appendix B. The SWFO Program Requirements Outyear Funding Estimates is provided in Appendix D.

A. CCOR Development

Figure 1. CCOR instrument optical test bed initial illumination test

NRL is the world leader in space-based coronagraph development and this capability is also integral to the DoD's space weather requirements. NOAA performed extensive market research from 2014 to 2016 to determine possible alternatives for acquisition of CME imagery; the CCOR proved to be the only instrument that could be deployed in the timeframe required to maintain continuity of CME imagery given the expected power failure of the ESA/NASA spacecraft.

The NRL-developed CCOR will be NOAA's first operational coronagraph (Figure 1). It is in Phase B of development and successfully concluded a Preliminary Design Review in September 2018. CCOR has completed an end-to-end optical bench test with exceptional performance results.

Deployment options for CCOR were assessed by way of a number of independent studies, internal analyses, and a public Request for Information (RFI) from industry. These include:

- 2014 RFI – NOAA's Request for Information on Commercial Sources for Solar Wind Data and Hosted Payloads.
- 2014 concept studies provided to NOAA:
    - NASA's Goddard Space Flight Center (GSFC)
    - NASA's Ames Research Center
    - Johns Hopkins University's Applied Physics Laboratory
    - RFI response from Sentinel Satellite Incorporated and its partners
- Independent Analysis of Space Weather Follow-On Compact Coronagraph & CME Gap-Filler Strategies, December 2016.
- NASA GSFC Mission Design Lab study of Space Weather Follow-On Options, March 2018.

B. SWFO L1 Satellite Mission

The SWFO L1 mission is necessary to deploy in order to provide solar wind measurements at L1 and also provide CME observations on the Earth-Sun line. The SWFO L1 mission will be a small-sat, three-axis-stabilized Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) Grande-compatible spacecraft launched as a ride share on NASA's IMAP mission scheduled for launch in 2024. This rideshare approach significantly lowers overall mission cost. SWIS will comprise a solar wind bulk plasma detector, a set of magnetometers, and a low energy ion spectrometer. The SWFO L1 satellite mission will also manifest a CCOR, and provide for accommodation of a possible space weather research to operation instrument of opportunity provided by NASA, another partner, or a commercial provider. With SWIS and CCOR, the SWFO L1 mission will ensure the continuity of upstream solar wind measurements and CME imagery along the Earth-Sun line. As a rideshare with the NASA IMAP launch, it will deploy in time to avoid a gap in capability that could result from the anticipated end of SOHO and DSCOVR missions. As such, the development of this mission is prioritized by NOAA and NOAA is working with NASA's Science Mission Directorate to formalize the partnership and develop a joint project management structure to oversee the SWFO L1 mission acquisition.

C. CCOR Deployment on NOAA GOES-U

Hosting the CCOR on the GOES-U satellite's Sun Pointing Platform (SPP) is technically a low-risk approach as NOAA, with analysis provided by NASA, has determined that CCOR accommodation is feasible on the GOES-U satellite as the third instrument on the SPP together with the Solar Ultraviolet Imager (SUVI), and the Extreme Ultraviolet and X-Ray Irradiance Sensors (EXIS). The CCOR observational data stream is a very small addition to the existing data flow from the GOES-U mission, requiring minimal adjustments to the mission and data operations for GOES-U. In addition, as NOAA controls the launch of the GOES-U satellite, this approach would be low-risk in terms of schedule. NRL's scheduled CCOR delivery in February 2021 meets the GOES-U integration schedule. NOAA has determined that a satellite at the Earth-Sun L1 is the first critical step in ensuring continuity of space weather observations and has prioritized its resources towards that effort. Accommodation of a CCOR on GOES-U would provide operational resiliency behind the L1 mission for the critical CME imagery. Funding is required in the out-years to continue modification of GOES-U SPP to accommodate the CCOR instrument on the SPP.

D. Control, Reception, and Processing System

NOAA has begun formulation of the ground architecture to support the SWFO L1 satellite mission. In 2017, NOAA released an RFI to industry seeking input. Initial results indicate that a minimum of three ground data acquisition stations equally spaced around the globe would provide 24/7 coverage. These stations could be established as a combination of NOAA-operated sites, commercial sites, or interagency partnerships. Use or augmentation of the existing international Real Time Solar Wind Network partnership is also envisioned to provide partial capability. Full requirements and acquisition planning for the SWFO L1 control, reception, and processing system would need to start in FY 2020 in order to meet the 2024 launch date.

E. Partnerships

For a relatively brief time several years ago, the NASA research mission Solar Terrestrial Relations Observatory (STEREO) had a satellite positioned around the L5 location. Use of the STEREO coronagraph measurements at L5 in addition to SOHO observations at L1 highlighted the advantage to space weather forecasts that could be provided by complementary observations at these two locations. NOAA is coordinating to obtain CME imagery and solar wind measurements from a proposed dedicated ESA L5 mission that would fulfill NOAA's priority 1 requirement.

DoD has validated the need for energetic charged particle measurements and identified that it requires a material solution to address the gap. NOAA has a broad umbrella agreement with the USAF on interagency cooperation on the collection of space-based environmental monitoring data. NOAA will coordinate with the USAF under this agreement for access to energetic charged particle measurements. NOAA is also working with the National Science Foundation and the U.S. Geological Survey on their contributions, including data from various networks and telescopes.

F. Space Weather Observations Beyond SWFO

The NSOSA study has identified space weather as an observational objective and NOAA plans to provide operational continuity beyond the SWFO program. NOAA will continue to evaluate and identify partner and commercial options to meet its observational requirements.

IV. Conclusion

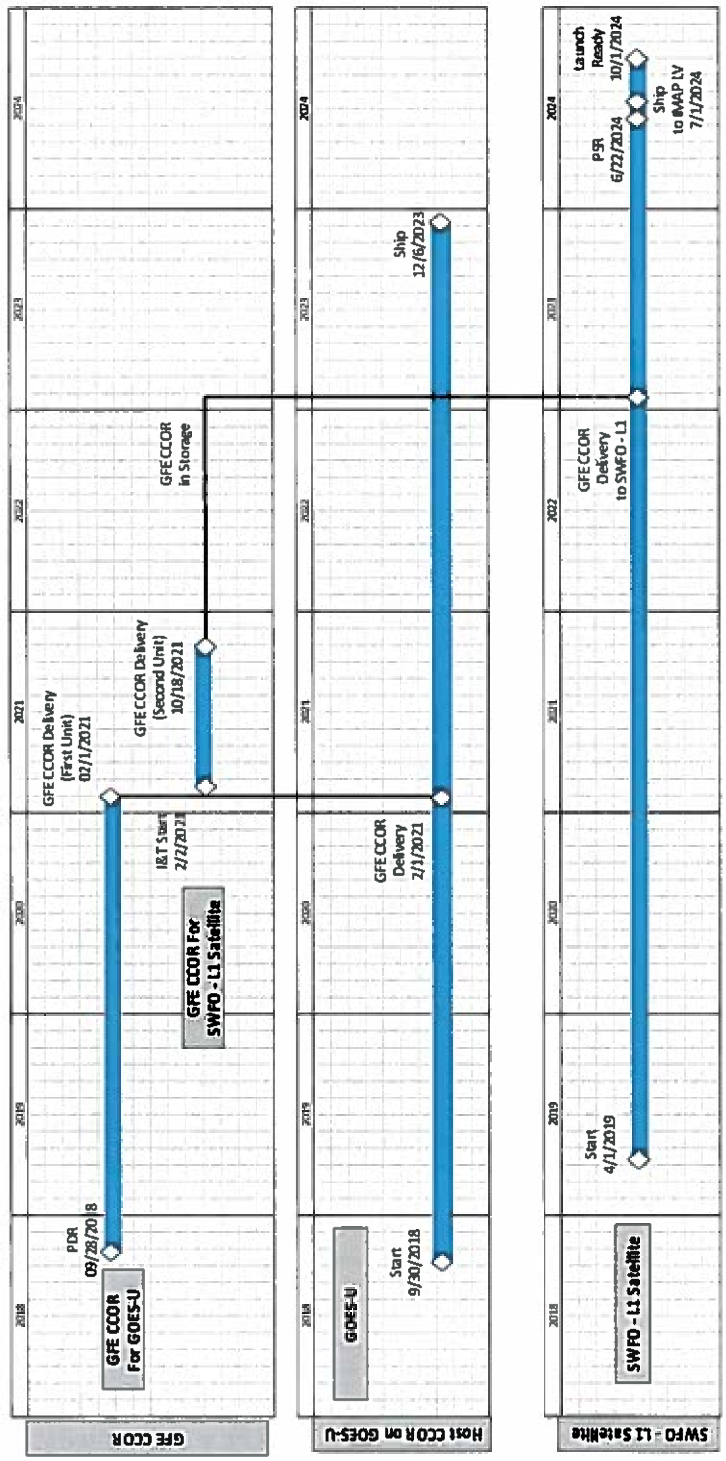
To ensure near term continuity of space weather measurements required for operations, NOAA will deploy the CCOR instruments at the soonest availability for operational robustness and to monitor the upstream solar wind. For the necessary observations to be collected at L1, NOAA proposes to use a NASA ride share to reduce overall program costs, ensure continuity of space weather data, and provide the upstream solar wind observations and the CME imagery on the sun-earth line. NOAA prioritizes a satellite at the Earth-Sun L1 and is dedicating resources towards that effort. Flying a second CCOR in geostationary orbit on GOES-U would add operational resilience and reliability to the CME imagery necessary for space weather forecasting, as well as programmatic resiliency to ensure deployment of this critical observation.

Appendix A: List of Acronyms

ACE	Advanced Composition Explorer
CCOR	Compact Coronagraph
CME	Coronal Mass Ejection
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
CTC	Cost to Complete
DOC	Department of Commerce
DoD	Department of Defense
DSCOVR	Deep Space Climate Observatory
EELV	Evolved Expendable Launch Vehicle
ESA	European Space Agency
ESPA	EELV Secondary Payload Adapter
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EXIS	Extreme Ultraviolet and X-ray Irradiance Sensors
GEO	Geostationary Earth Orbit
GSFC	Goddard Space Flight Center
GOES-U	Geostationary Operational Environmental Satellite – U
GNSS	Global Navigation Satellite Systems
GPS	U.S. Global Positioning System
IMAP	NASA Interstellar Mapping and Acceleration Probe
LASCO	Large Angle and Spectrometric Cosronagraph
L1	Earth-Sun Lagrange Point 1
L5	Earth-Sun Lagrange Point 5
LEO	Low Earth Orbit
LCC	Lifecycle Cost
Metop	Meteorological Operational satellite programme
NASA	National Aeronautics and Space Administration
NCEI	National Centers for Environmental Information
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NOSC	NOAA Observing Systems Council
NRL	Naval Research Laboratory
NSOSA	NOAA Satellite Observing System Architecture
OURD	Observational User Requirements Document
POES	Polar-orbiting Operational Environmental Satellite
PB	President's Budget
RO	radio occultation
R2O	Research to Operations
RFI	Request for Information
SMEX	Small Explorer program
SEP	Solar Energetic Particles
SEISS	Space Environment *In Situ* Suite
SEM	Space Environmental Monitor
SOHO	Solar and Heliospheric Observatory

SPP	Solar Pointing Platform
STEREO	Solar Terrestrial Relations Observatory
SUVI	Solar Ultraviolet Imager
SWIS	Solar Wind Instrument Suite
SWFO	Space Weather Follow On
SWPC	Space Weather Prediction Center
USAF	U.S. Air Force

Appendix B: Preliminary SWFO Development Schedule



Schematic timeline of NOAA's proposed options to ensuring continuity of critical space weather measurements.

Appendix C: Review of Space Weather Observing Systems

A current array of space observing assets provide information in support of current national and user needs, but it is an *ad hoc* collection of U.S. and international research and operational assets. Importantly, in some critical observation and measurement areas the system provides no resiliency, relies on assets decades beyond the mission design life, and lacks follow-on capability. Figure 2 provides an overview of current assets supporting the space weather mission; assets include spacecraft in LEO, GEO, and at L1 (the closest stable orbit point upstream toward the Sun along the Earth-Sun line). NOAA has agreements with many but not all of these missions for real time access to the data for operational use. NOAA is evaluating additional agreements for those systems which are not yet integrated into the global observing system network.

Figure 2. Existing global space-based assets making space weather observations. Solar and space environment measurements are obtained by numerous domestic and international partners on platforms in different orbit planes.

1. LEO

LEO *in situ* monitoring provides an extensive range of space weather observations. These include the intensity of the Earth's radiation belts and the flux of charged particles at the satellite altitude. It provides knowledge of solar-terrestrial phenomena and also provides evidence of space weather occurrences that may impair long-range communications, high-altitude operations, damage to satellite circuits and solar panels, or cause changes in atmospheric drag and magnetic torque on satellites. The NOAA Polar-orbiting Operational Environmental Satellite (POES) and the European Organization for the Exploitation of Metrological Satellite (EUMETSAT) Meteorological Operational satellite programme (Metop) satellites both fly the NOAA-provided Space Environmental Monitor (SEM) instrument that measures intensities of charged particle radiation that can degrade radio communications, disrupt the proper operation of satellite systems, and increase the radiation dose to astronauts in space and aircraft at high altitudes. SEM observations will end when the final POES and Metop satellite ceases to provide useful data. NOAA plans to explore continuing LEO space weather measurements with its domestic and international partners.

An *ad hoc* collection of Global Navigation Satellite Systems (GNSS) radio occultation (RO) measurements obtained from LEO yield ionospheric scintillation and altitude profiles of vertical electron density, and total electron content. Variations in ionosphere can detrimentally impact high frequency communication and GNSS (which includes the U.S. Global Positioning System (GPS)) accuracy. Ultraviolet (UV) measurements on the Defense Meteorological Satellite Program provide horizontal and vertical distribution of electron density in the ionosphere. The space-based RO and UV measurements are combined with ground-based measurements to provide a global three-dimensional picture of the ionosphere and forecasts when assimilated into ionospheric models.

NOAA currently obtains GNSS/GPS RO profiles of the ionosphere comes from the U.S.-Taiwan Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) launched in 2006, the EUMETSAT Metop series, and the Korea Aerospace Research Institute's Korean Multi-purpose Satellite-5. When launched in the coming year, COSMIC-2 will increase the number of RO profiles observed in the tropical and mid latitudes. Additional UV sensors are being placed into orbit by NASA and DoD that will be assessed for future utility for operations. Ionosphere models require timely, geographically distributed profile data to make useful operational specifications and forecasts. Through the Commercial Weather Data Pilot, NOAA is in the process of working with the commercial sector to assess the availability of suitable commercial data (including RO data) for numerical weather forecast modeling. These data could be used for space weather forecasting.

2. GEO

GEO provides an exceptional vantage point for viewing the Sun in the UV spectrum, both to measure the flux of solar X-ray and Extreme Ultraviolet photons in solar flares and monitor solar irradiance fluctuations that impact the upper atmosphere and ionosphere and to observe and characterize complex active regions structures on the Sun and eruptions of solar filaments that may give rise to coronal mass ejections that can cause near-Earth radiation storms. As energetic particles reach Earth, forecasters use *in situ* monitoring of particle data to determine intensity and to issue warnings with 20-30 minutes of lead time.

NOAA operates two Sun imaging instruments on the GOES-R Series satellites: SUVI and EXIS detect solar flares and support forecasting of radio blackouts, solar radiation storms, and geomagnetic storms. The GOES-R Series satellites also carry two instruments that measure the *in situ* space environment. The Space Environment In Situ Suite (SEISS) monitors proton, electron and heavy ion fluxes in the magnetosphere. The Magnetometer measures the magnetic field in the outer portion of the magnetosphere. GOES-R Series space weather data will be available through the 2030s when the mission comes to an end. The NSOSA process is assessing the best ways to continue geostationary space weather observations beyond the GOES-R Series.

3. L1

L1, upstream toward the Sun along the Earth-Sun line, is the current vantage point for CME imaging and for early assessment of the intensity of a solar wind likely to affect Earth. Analysis of solar imagery provides 1- to 4-day advance warnings of geomagnetic storm conditions pending the transit of CMEs toward the Earth. The shape, direction and velocity of the CME as it leaves the Sun, deduced from images of the solar corona and heliosphere (the intervening space between the Sun and the Earth through which the solar wind travels) help forecasters predict the timing of the storms' arrival at Earth. However, the strength and orientation of the magnetic field contained within the CME can only be measured *in situ* at L1. *In situ* conditions at L1 provide inputs to NOAA's SWPC operational codes that provide 15- to 60-minute warnings of geomagnetic storms and geographically localized storm activity predictions to its customers – particularly useful for power grid operators. Additionally, without L1 observations, physics-based or data-driven near-Earth space weather models can neither be developed, function effectively, nor fully validated.

The only source of solar imagery at L1, to assess a CME eruption from the Sun, is the ESA/NASA SOHO research mission that was launched in 1995 and is operating well beyond its two-year mission lifetime design. The LASCO onboard SOHO detects the visible radiation from the Sun's surface that electrons in the corona scatter into its field of view. These images show the region of the Sun's corona relatively close to the sun itself, and reveal CMEs, which are material ejected from the inner corona into interplanetary space. Because the Sun's visible surface is orders of magnitude brighter than the radiation scattered from the corona and the ejected material, the Sun's disc must itself be blocked out by an artificial "eclipse," a function performed by coronagraphs.

Preventing the impending gap in CME image observation when SOHO ceases operation is NOAA's most critical satellite space weather monitoring priority. The SOHO mission's solar panels are degrading and its life is limited by available power production that is predicted to fall below sustainable levels by 2025. At that time there will be no sources of CME imagery in the Earth-Sun line unless a new coronagraph is launched; there is currently no back up capability. L1 provides a continually unobstructed view of the Sun and so is an ideal place for a coronagraph, and the most important attribute of the vantage point is that it is in the direct Earth-Sun line.

Also, at L1, NOAA DSCOVR launched in 2015 is currently NOAA's primary source for *in situ* magnetic field and bulk solar wind plasma measurements. DSCOVR was designed as a low-cost NASA Small Explorer program (SMEX) spacecraft; the SMEX are single-string spacecraft that are subject to failure if any single mission-critical function fails. DSCOVR is also sensitive to periodic radiation upsets, which causes the plasma and magnetic field instrument suite to go offline. DSCOVR's mission life is presently expected to extend beyond its 5-year design objective and operate until the mid-2020s. The backup for solar wind *in situ* monitoring is the NASA research Advanced Composition Explorer (ACE) mission, launched in 1997 and is operating well beyond its design life of 5 years. The ACE capabilities that NOAA relies on are also healthy, but its mission life is limited by available propulsion needed to maintain orbit around L1, projected to last only until the mid-2020s.

4. L5

There are other stable and favorable orbit points in the Sun-Earth system that spacecraft observations, when combined with those at L1, can yield more accurate warning of impending CME interactions with Earth. L5 is such a point being equidistant from Earth and the Sun, trailing the Earth in orbit at a sixty-degree angle. Since the Sun's rotation on its axis (27 days) is much faster than the time for Earth to orbit the Sun, active regions on the Sun become visible at L5 before they do at the Earth. For this reason, an observatory at L5 may provide earlier warning of a developing space event and indication of its strength. A coronagraph at L5, in combination with imager from L1, could provide improved estimates of CME speed and the forecast of its arrival time at Earth. Currently there are no space weather monitoring assets at L5. NOAA is discussing with ESA about the potential of obtaining observations from L5 once ESA finalizes its plans to build and launch an L5 mission around 2024. Pairing a U.S. L1 mission with an ESA L5 mission would provide the best constellation for solar imagery and solar wind monitoring.

Appendix D: Space Weather Follow On Program Requirements Outyear Funding Estimates

($M)	FY 2018 & Prior	FY 2019 Enacted	FY 2020 *	FY 2021 *	FY 2022 *	FY 2023 *	CTC *	Total LCC *
SWFO L1	0.51	7.00	11.22	50.97	64.96	49.45	32.09	**216.20**
Ground System Development, Operations, & Sustainment	-	-	0.04	14.66	28.79	42.04	173.94	**259.47**
GOES-U Integration	-	10.00	13.02	10.13	4.48	3.93	8.73	**50.29**
CCOR	12.99	10.00	14.32	3.24	3.17	0.99	5.84	**50.55**
Total	**13.50**	**27.00**	**38.60**	**79.00**	**101.40**	**96.40**	**220.60**	**576.50**

* Outyears are estimates. Future requests will be determined through the annual budget process.

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