The NOAA-NASA Space Weather Follow On (SWFO) Program to Sustain Operational Space-based Observations of Solar Wind and Coronal Mass Ejections

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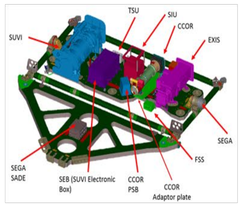
Introduction

The National Oceanic and Atmospheric Administration (NOAA) Space Weather Follow-On (SWFO) Program supports NOAA's goal of reducing the impact of severe space weather events, which directly responds to the 2020 Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act. The PROSWIFT Act directs NOAA and National Aeronautics and Space Administration (NASA) to enter into agreements to develop space weather spacecraft and instruments. SWFO will ensure the continuous availability of vital Solar Wind and Coronal Mass Ejection (CME) data beyond the lifespan of NOAA's Deep Space Climate Observatory (DSCOVR) and NASA-European Space Agency (ESA) research Solar and Heliospheric Observatory (SOHO), enabling us to better understand and prepare for space weather phenomena. The SWFO Program includes a SWFO Lagrange 1 (L1) observatory, which will host a Solar Wind Plasma Sensor (SWiPS), a Magnetometer (MAG), a SupraThermal Ion Sensor (STIS), and a Compact Coronagraph (CCOR). The program also supports the integration of a CCOR on the Geostationary Operational Environmental Satellite - Series U (GOES-U) spacecraft. Flying a second CCOR in a geostationary orbit adds operational resilience and reliability to the CME imagery necessary for space weather warnings and forecasts. NOAA is building and will operate a robust ground architecture for SWFO. The SWFO Program successfully completed the Mission Operations Review (MOR) in the Program life-cycle in June 2023. The next major Program Milestone, the Key Decision Point-D, is planned for Q2 FY24. SWFO remains on track for launch with NASA's Interstellar Mapping and Acceleration Probe (IMAP) mission, currently scheduled for FY 2025.

SWFO Program Elements

SWFO-L1 Mission

CCOR + SUVI + EXIS



GOES-U Solar Pointing Platform (SPP)

SWFO-L1 Mission Objectives

Establish operational capability and continuity of space weather observational requirements. Enable space weather watches, warnings, forecasting and predictions

- Coronal White Light Images for detection of Coronal Mass Ejections (CMEs)
  - Observe CME parameters, shape, density, velocity
  - Produce CME characteristics for input into operational heliospheric propagation code
- In situ solar wind measurements
  - Measure solar wind magnetic field, thermal plasma, and energetic particles

CCOR on GOES-U Mission Objectives

Establish operational capability and continuity of Sun CME imaging observational requirements with multiple platforms; primary operational objectives:

- Observe CME parameters, shape, density and velocity
- Produce CME characteristics for input into operational heliospheric propagation code
- Enable space weather watches, warnings, forecasting and predictions

SWFO-L1 Overview

- Launch: 2025; Orbit: Lagrange Point 1 (L1)
- Rideshare with NASA IMAP; ESPA Grande compatible spacecraft bus
- CCOR; Solar Wind Instruments: MAG, SWiPS, STIS
- Commanding and data through SWFO Ground Segment

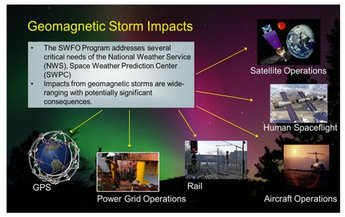
CCOR on GOES-U Overview

- Launch: 2024; Orbit: GEO
- CCOR integrated onto GOES-U Solar Pointing Platform
- Commanding and data through GOES-R Ground System

Solar Wind Instrument Suite (SWIS)

SWIS consists of three solar wind instruments:
Solar Wind Plasma Sensor. Data will be used to calculate density, velocity (vector), temperature, and dynamic pressure which are used in several SWPC models.
Magnetometer. The interplanetary magnetic field and its Bz component are key for predicting magnetospheric and ionospheric weather.
SupraThermal Ion Sensor. Flux data will be used to improve arrival time estimates for CME and other disturbances at Earth.

Uses of Space Weather Products



Space Weather impacts infrastructure and activities vital to **national security** and the **U.S. economy**

Space weather-induced electricity blackout: *Daily* domestic economic loss in the U.S. equal to **$41.5 billion**, plus an additional **$7 billion** loss through the international supply chain.

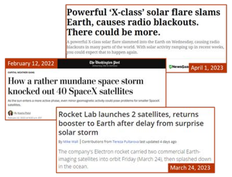
Space Weather Warnings Protect Critical Infrastructure

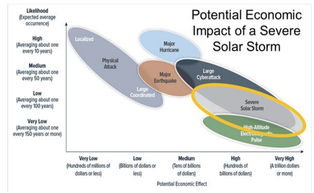
Space Operations
- Postpone launch of satellite
- Turn off/safe instruments and/or spacecraft in orbit

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

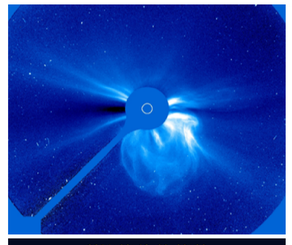


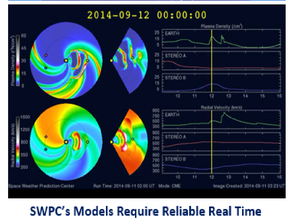


CME Imagery and In-situ Solar Wind Measurements are Key for Timely Space Weather Forecasts

NOAA's National Weather Service Space Weather Prediction Center (SWPC) is the nation's official source of Alerts, Watches, and Warnings

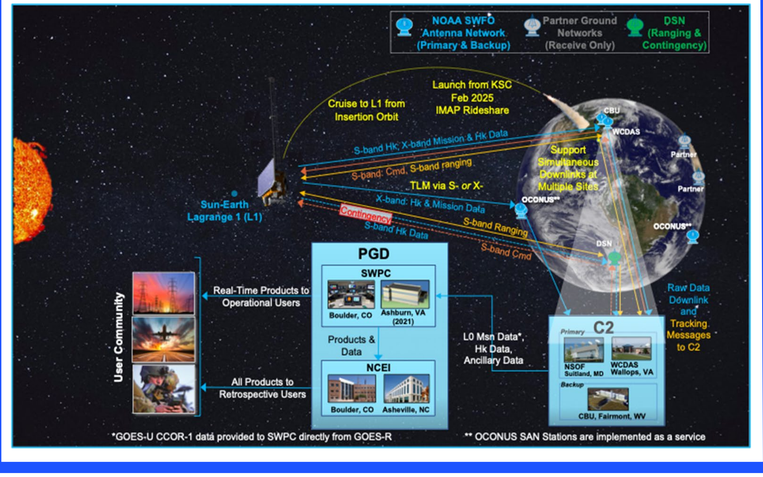
- Coronal Mass Ejection (CME) Imagery
  - CME imagery (visible-light imagery of the most destructive global events) are used for **1-4-day warnings** of geomagnetic storm conditions
  - Currently provided by ESA/NASA Solar and Heliophysics Observatory (SOHO) mission, which launched in 1995
- Upstream Solar Wind Data
  - Solar wind plasma and magnetic field measurements provide **15-60-minute notice** for geomagnetic storm conditions
  - Primary Source: NOAA's Deep Space Climate Observatory (DSCOVR), launched in 2015
  - Current backup: NASA Advanced Composition Explorer (ACE) launched in 1997
- NESDIS provides NWS/SWPC with essential observations to meet these requirements



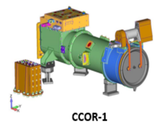


SWPC's Models Require Reliable Real Time Space Weather Data

SWFO-L1 Mission Architecture

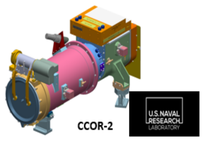


State-of-the-Art Heliophysics Instruments



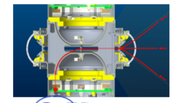
CCOR-1

Compact Coronagraphs (CCORs): Developed by Naval Research Lab (NRL), the telescope will be used to observe the solar corona and detect coronal mass ejections (CMEs) and other structures. CCOR-1 will fly on the GOES-U satellite and a nearly identical CCOR-2 on SWFO-L1.

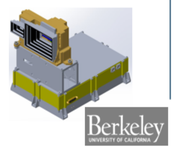


CCOR-2

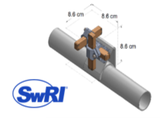
Solar Wind Plasma Sensor (SWiPS): Built by Southwest Research Institute (SwRI), it will measure properties of the solar wind plasma flowing past SWFO-L1, such as density, velocity, and temperature.



Suprathermal Ion Sensor (STIS): Developed by University of California, Berkeley, it will collect fast ions in the solar wind.

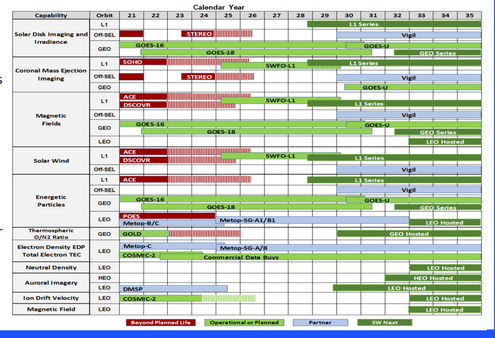


Magnetometer (MAG): Developed by the University of New Hampshire and SwRI, it will measure the magnetic field carried by the solar wind.

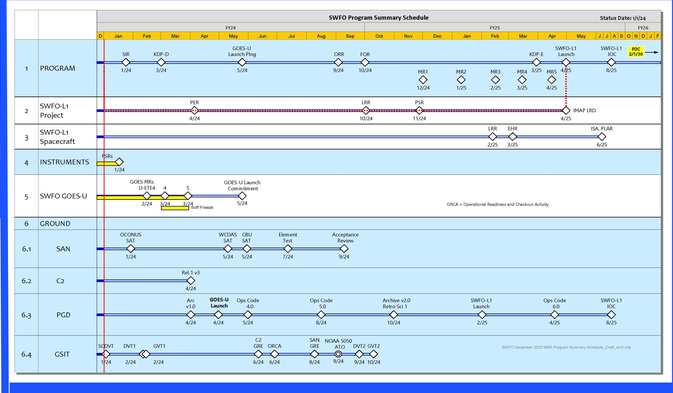


Continuity of Space Weather Data

- NOAA and partner missions collect and exchange space weather observations needed by SWPC.
- Many current platforms are beyond predicted end of life, and some new missions have lifespans short of 2030.
- NOAA Space Weather Observation (SWO) Programs and projects will provide necessary data continuity.



SWFO Program Schedule



Mission Success Criteria

Space Weather Data Product	KPP
Coronal White Light Intensity	Y
Thermal Plasma Ion Velocity	Y
Thermal Plasma Ion Density	N
Thermal Plasma Ion Temperature	N
Vector Magnetic Field	Y
Suprathermal Ion Differential Flux	N
Dynamic Pressure	N

Table 1: Space Weather Data Products

Full success of the SWFO Program is defined as the successful generation and availability to users of all products in Table 1.
Minimum success of the SWFO Program is defined as the successful generation and availability to users of all Key Performance Parameters (KPPs).