NOAA Space Weather Observations from Lagrange 1

User Readiness for NOAA Space Weather Data

April 15, 2024

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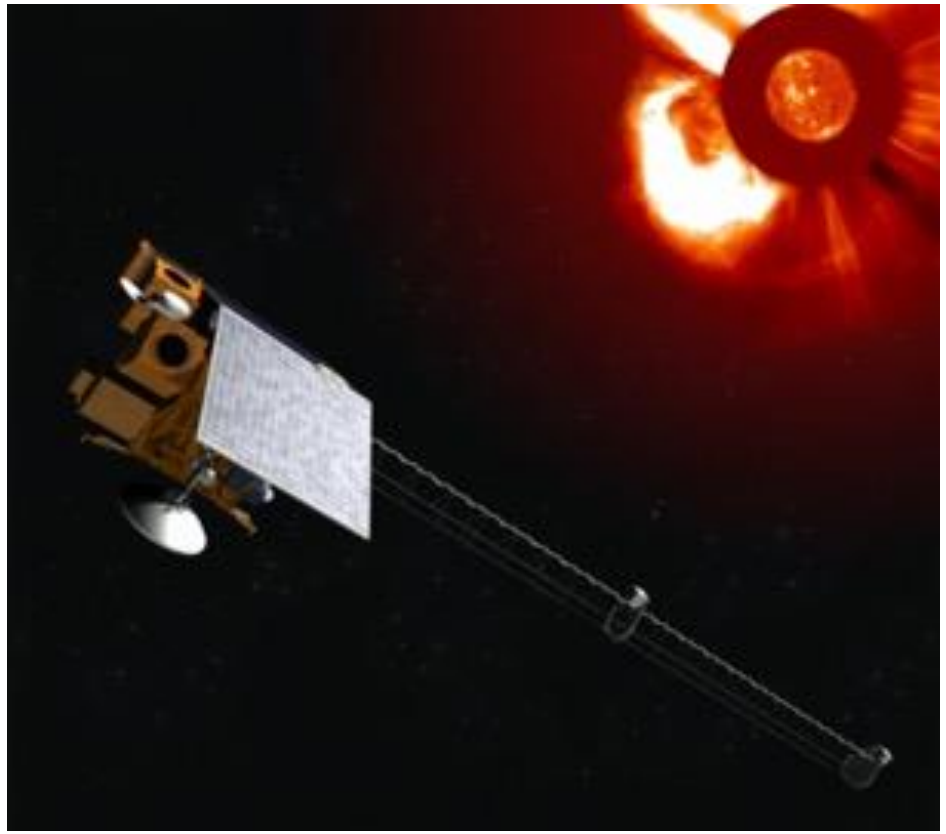
NOAA/NESDIS/Space Weather Observations

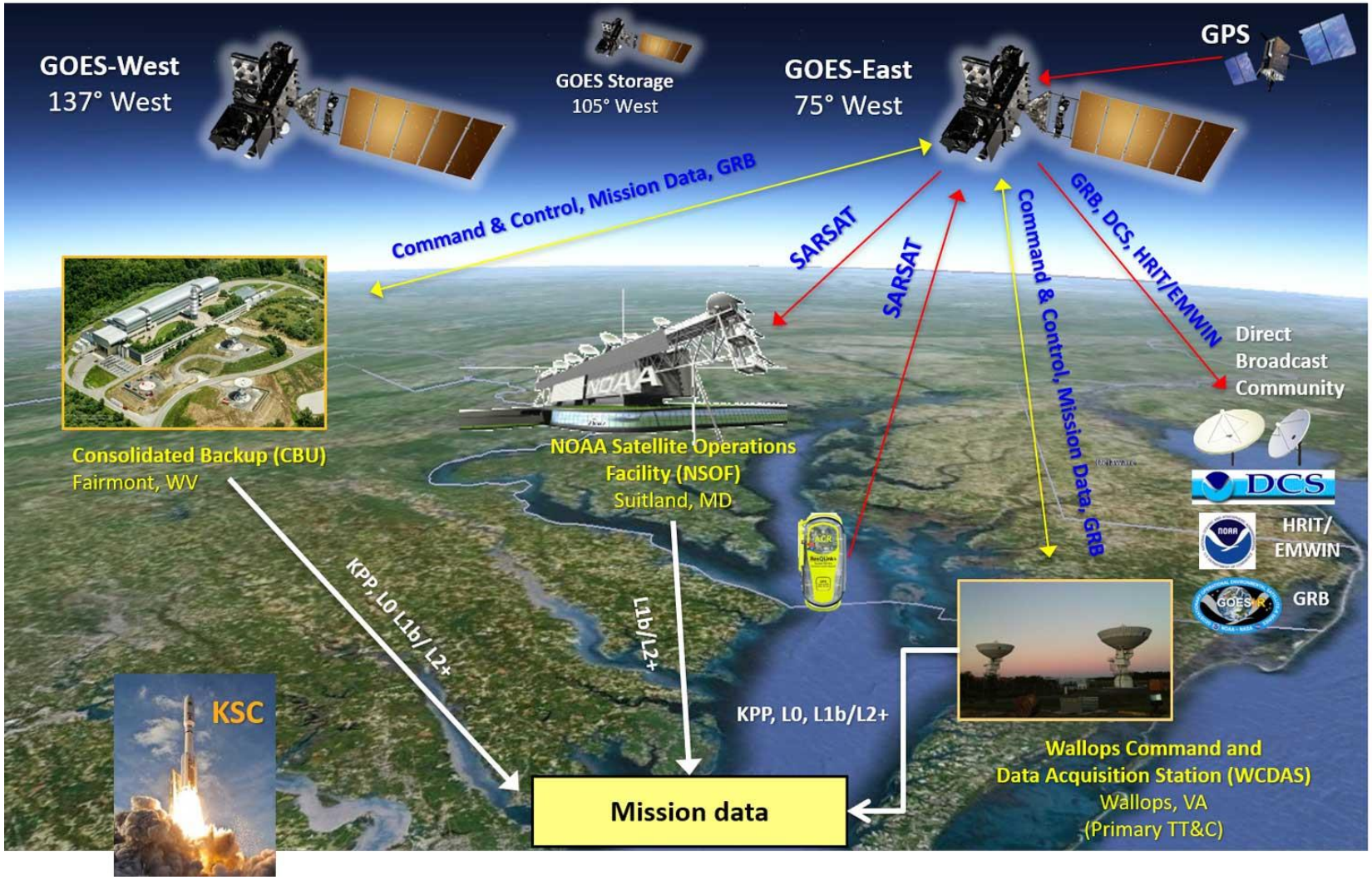
The Space Weather Follow On (SWFO) Program

- The Space Weather Follow On (SWFO) Program will provide high-quality coronal imaging and solar wind measurement capabilities to ensure continuity of critical data.
- SWFO's Flight Segment comprises the following components
  - The Compact Coronagraph (CCOR) on the GOES-U satellite (launch: 6/2024)
  - The SWFO-Lagrange 1 (SWFO-L1) Observatory (launch: 4/2025).
- SWFO will provide the following products:
  - Coronal imagery will be the basis of early situational awareness for long-term forecasting
  - Solar wind and interplanetary magnetic field measurements will be used as inputs to magnetospheric models.
  - Particle flux measurements will be used to improve estimates of the solar wind arrival time.



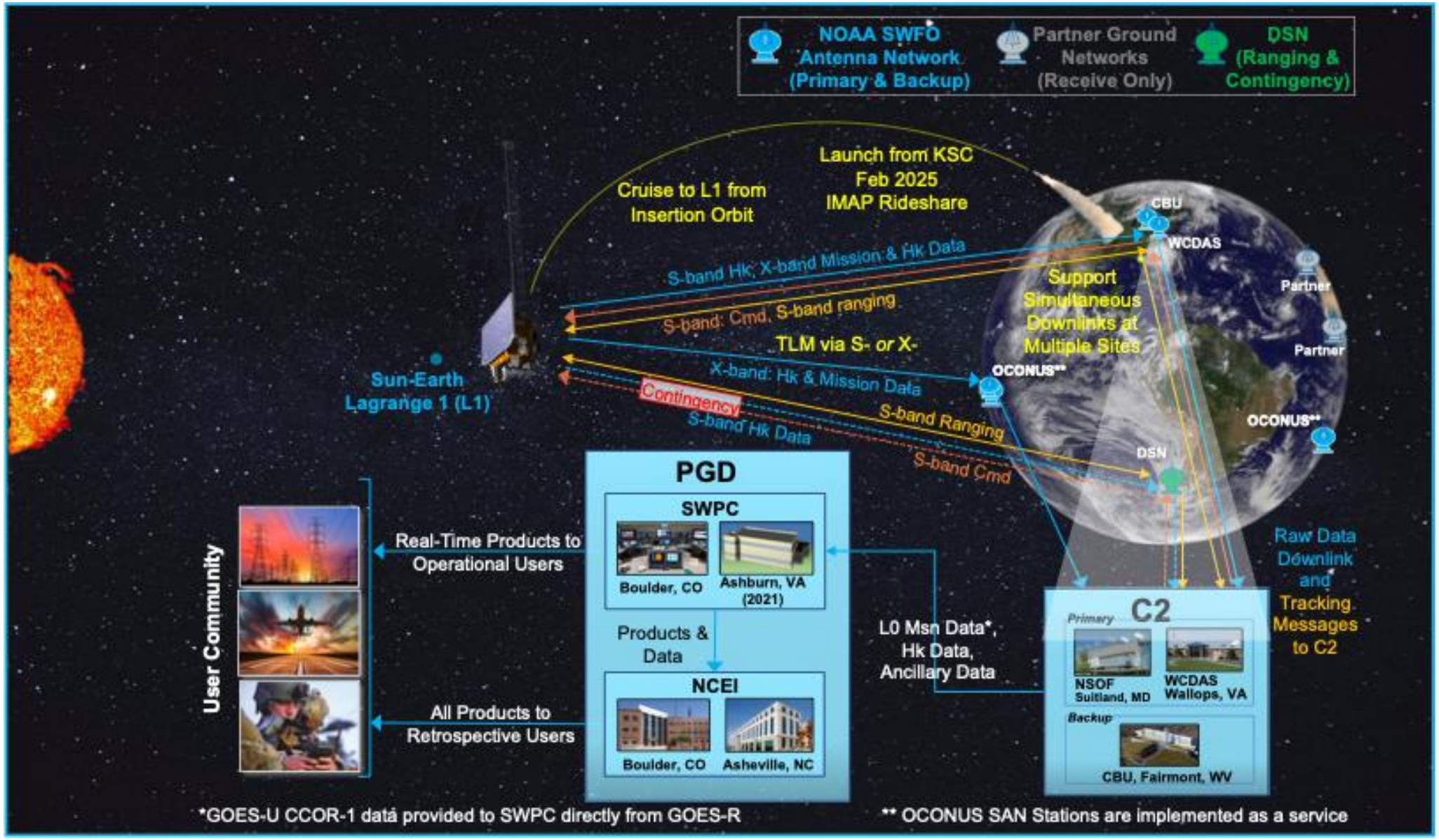
Concept of Operations for GOES-U

- GOES-U is planned to launch on June 25, 2024. It will be activated as an operational satellite after launch and will not go into storage. After commissioning, it will be designated as GOES-19.
- After post-launch testing (PLT), it will be handed over to NOAA.
- It will operate as GOES EAST replacing GOES-16.



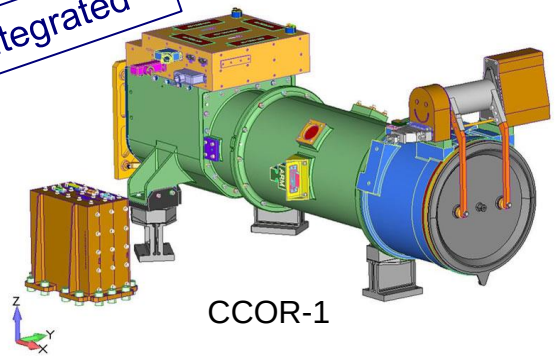
GOES-R system architecture

Concept of Operations for SWFO-L1



SWFO: Instrumentation for Space Weather and Heliophysics Research

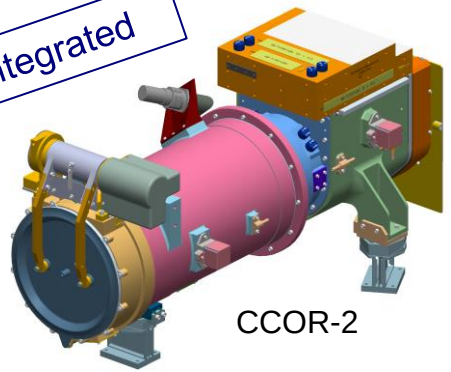
Integrated



CCOR-1

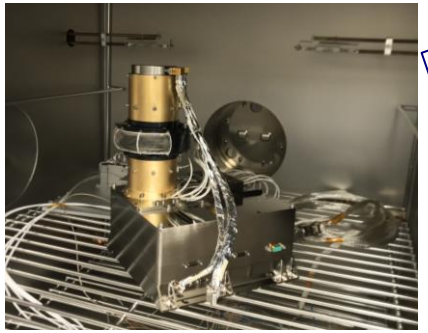
Compact Coronagraphs (CCORs): Developed by Naval Research Lab (NRL; PI: Arnaud Thernisien), the telescopes will be used to observe the solar corona and detect coronal mass ejections (CMEs) and other structures. CCOR-1 will fly on the GOES-U satellite and the nearly identical CCOR-2 on SWFO-L1. Heritage: SOHO/LASCO, STEREO/COR1,2, etc.

Integrated



CCOR-2

Solar Wind Plasma Sensor (SWiPS): Built by Southwest Research Institute (SwRI; PI: Rob Ebert), it will measure the solar wind density, velocity, and temperature. Heritage: Rosetta/IES.

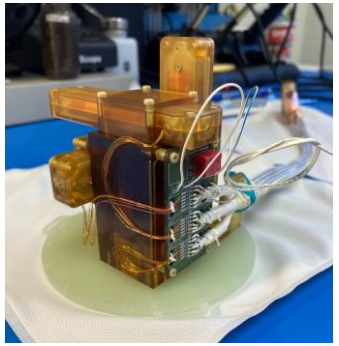


At PSR

Suprathermal Ion Sensor (STIS): Built by the University of California, Berkeley (UCB; PI: Davin Larson) it will measure suprathermal ion and electron flux. Heritage: MAVEN/SEP.

Integrated

Magnetometer (MAG): Built by the University of New Hampshire and SwRI (PI: Roy Torbert), it will measure the interplanetary magnetic field (IMF). Heritage: multiple NASA missions.



Integrated

SWFO Program Status: Highlights

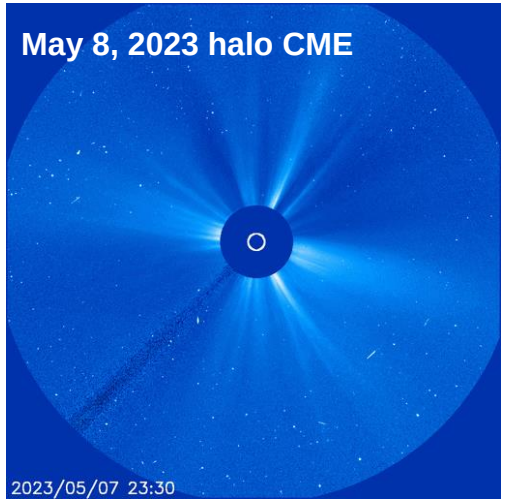
- As discussed in the previous talk, CCOR-1 has been integrated on GOES-U and thoroughly tested. The spacecraft is ready for launch, to take place in June 2024.
- For SWFO-L1, all instruments except SWiPS have been integrated on the spacecraft and tested. For SWiPS, the Pre-Ship Review (PSR) is scheduled for April 19, 2024 and it will be delivered to BAE in the following week. Launch is planned for April 2025.
- In addition to environmental and other tests, for all instruments there has been very good progress in modeling and understanding the instrument response including optical parameters, geometric factors and dead time for the particle sensors, contamination sources, temperature dependencies, and other parameters. Models for the CCORs and SWiPS are highly detailed. In addition, Cal/Val tools are being updated.
- The SWFO Systems Integration Review (January 23-24, 2024) included a report on performance margins for all instruments under both typical and extreme space weather conditions. The SWFO-L1 Pre-Environmental Review is scheduled for May 1-2, 2024.

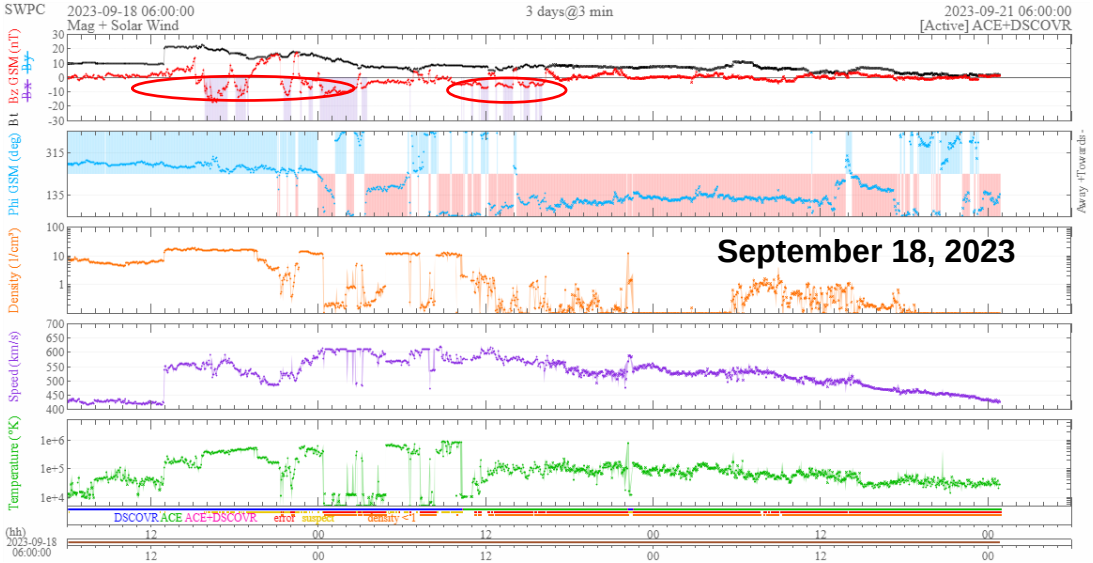
Product Generation and Distribution

SWFO PGD will enable the following data products and space weather services:

1. Processing of L0 datastreams into science products:

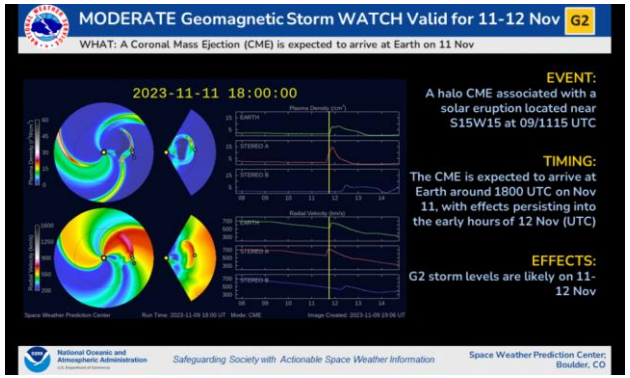
- Coronal images: From SOHO LASCO/C3 to GOES-U/CCOR-1 and SWFO-L1/CCOR-2
- Time series of solar wind plasma and magnetic field: From DSCOVR/FC, MAG and ACE/EPAM to SWFO-L1/SWiPS, MAG STIS



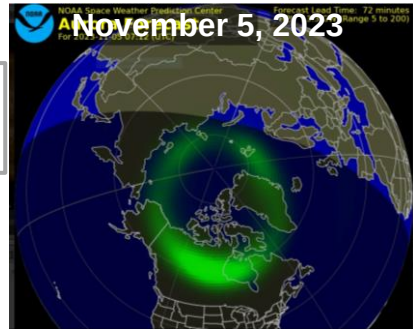


2. Immediate use of the products in providing situational awareness and in reliably driving real-time models. Thus, the data will result in SpWx nowcasts and forecasts.

Heliospheric forecast

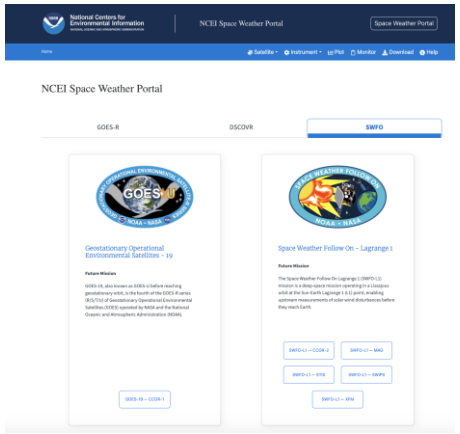


Auroral forecast



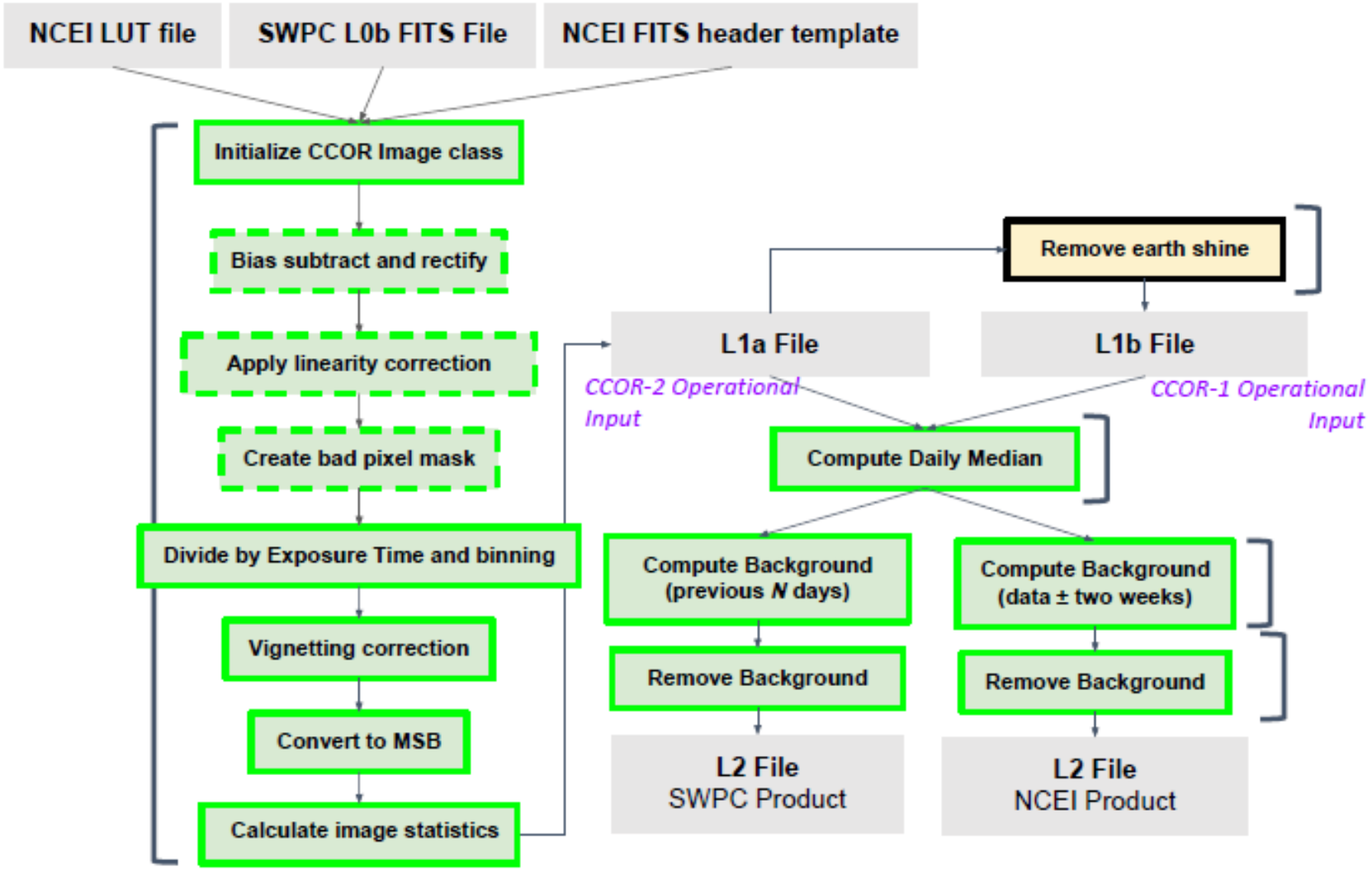
3. Archiving of data will enable access by the science community and other users.

The DSCOVR Data Portal will be replaced by the SWFO Science Center (right).



Algorithm Development: GPA Pipelines

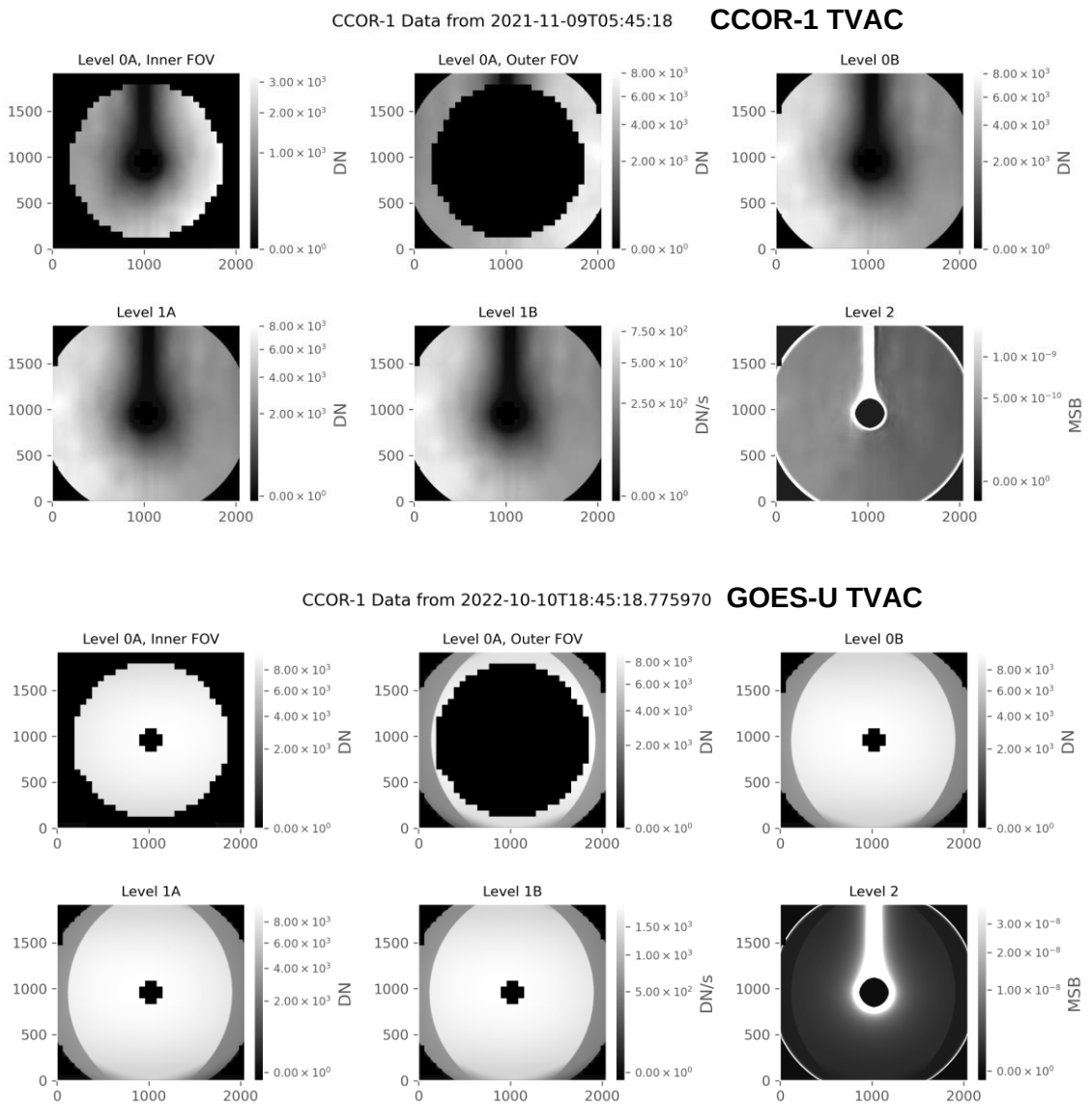
- Pipeline development has progressed significantly for all instruments. Most recently, emphasis is placed on CCOR-1 algorithms.
- Ground processing algorithms (GPAs) developed at SWPC and NCEI are based on vendor-provided versions and are tested under operational conditions.
- The CCOR-1 operational GPA was delivered in December 2023.
- The CCOR-1 retrospective GPA (shown on the right) has been refactored and ported in NCEI's SPADES environment.



Donald Schmit and Gabriel Dima, NCEI

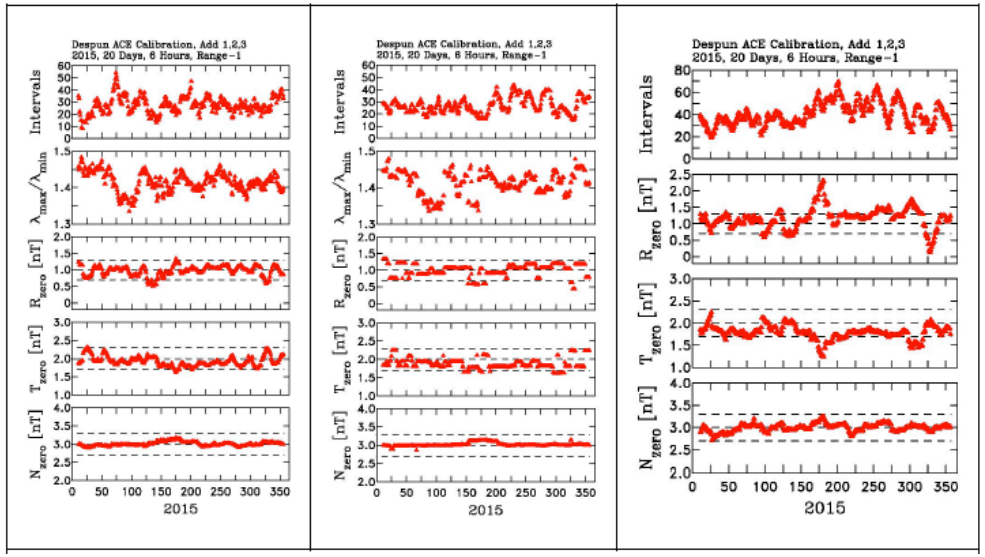
Algorithm Development: Product Testing

- SWPC and NCEI have advanced their tests of GPAs for products obtained from CCOR-1 and -2 data.
- Representative SWPC tests are shown on the right for data products of Levels 0a through 2.
- The first set of graphs is based on NRL's TVAC test data from November 2021.
- The second set is based on the GOES-U ETE 3A test data from October 2022 (spacecraft TVAC).
- Different illumination sources were used in each test.
- For all levels, the SWPC codes are compared with the original NRL algorithm and there is excellent agreement.
- In addition to offline tests, the pipelines have been tested in end-to-end and real-time conditions in GOES-R Data Operation Exercises (DOEs), and SWFO Data Validation Tests (DVTs) and Ground Validation Tests (GVTs).
- In summary, the pipelines are capable of successfully processing images from raw data from a wide range of illuminations and backgrounds.

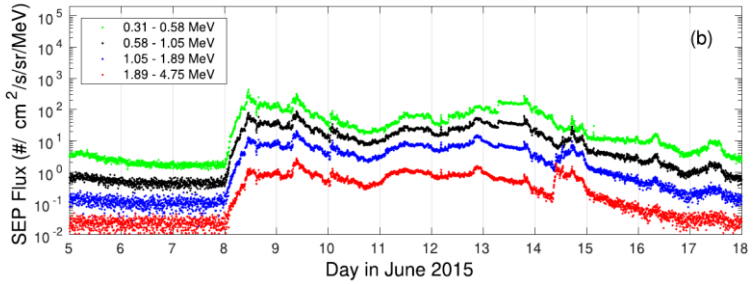


Calibration and Validation Procedures

- The Calibration Working Group (CWG), led by NCEI, defines the development of the SWFO Cal/Val processes including tests conducted during SWFO-L1's Post-Launch Commissioning (PLC) and related PLPTs (see also examples given in the previous presentation on GOES-U). For SWFO-L1, the PLPTs are part of Recommended Operational Procedures (ROPs) and include maneuvers such as rolls and off-points.
- The CWG makes recommendations on product maturity during the commissioning phase.
- Calibration procedures are described in the Calibration and Validation Plan which is available to users. It summarizes the Calibration Plans of individual instruments.

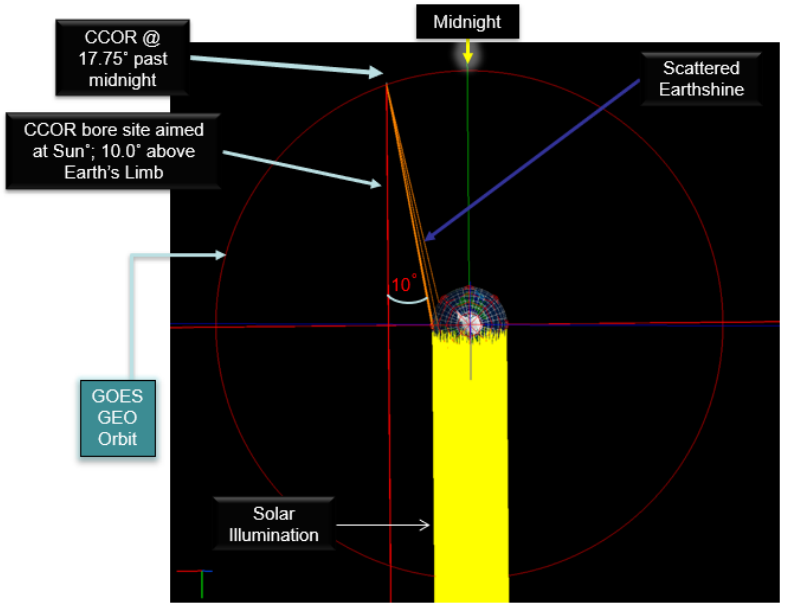


Above: Three methods of calibration and offset removal for MAG applied to ACE data.
Below: STIS' eight ion and four electron channels provide continuity to the measurements by ACE/EPAM. STIS will be intercalibrated with SWiPS in their energy range of overlap.



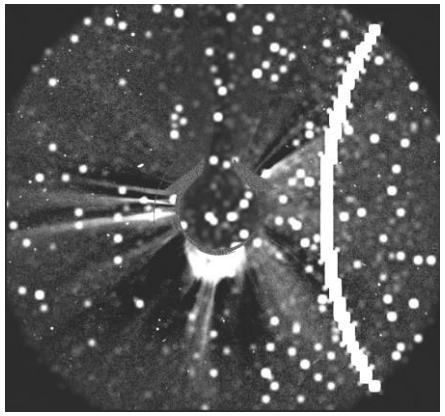
CCOR-1: Earthshine and Eclipse Impacts

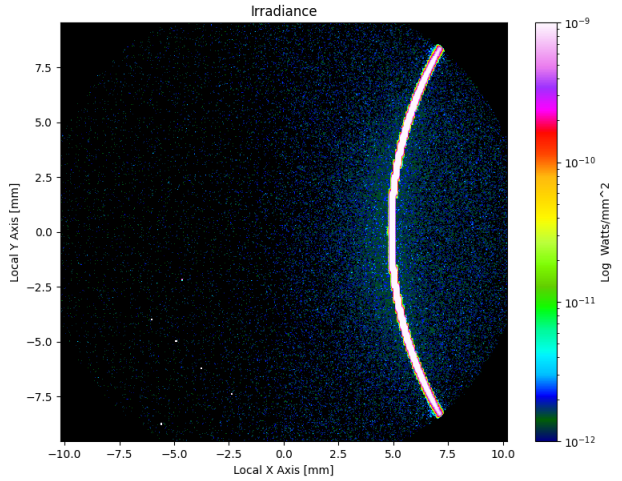
- In addition to noise sources common to deep-space coronagraphs (F-corona, zodiacal light, diffraction, stars/planets, vignetting, etc.), CCOR-1 is subject to impacts from earthshine and eclipses.
- For earthshine, ray-tracing simulations were conducted in 2022 and, with higher accuracy, in early 2024. The effect of earthshine must be removed before the products are considered for Provisional Maturity and use by operational users. The procedure is expected to take no less than 6 months and up to 1 year to evaluate.
- To mitigate the eclipse impact (maximum duration: 72 minutes), the CCOR-1 image cadence will increase from 15 to 5 minutes when approaching and receding from an eclipse event.



Left: Rendering of the ray-tracing simulation.

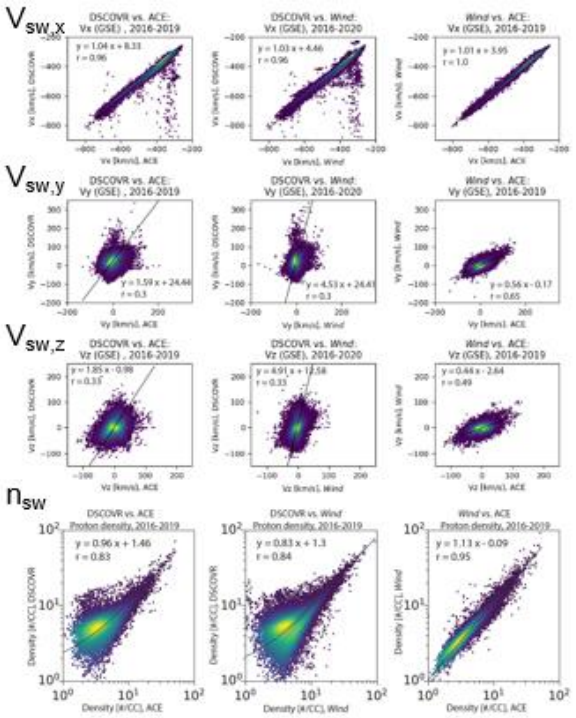
Below: derived images from simulations in 2022 (left) and Feb-Mar 2024 (right)





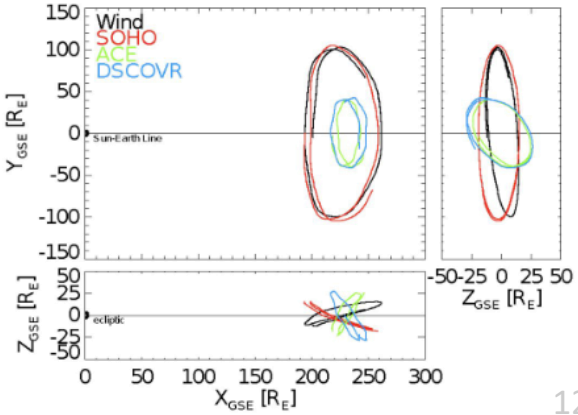
Intercalibration with Other L1 Missions

- SWFO is developing plans for intercalibration of observations from SWFO-L1 and other spacecraft at L1 (ACE, DSCOVR, IMAP, and WIND). Orbit information is made available by the GSFC Flight Dynamics Facility (FDF).
- CCOR-1 and -2 are planned to be intercalibrated with LASCO/C3. In addition, comparisons with STEREO will be undertaken.
- For MAG and SWiPS, the CWG and FDF are in the process of mapping out conjunctions with IMAP, ACE, and DSCOVR. Other missions will be included such as Aditya-L1 and WIND.
- STIS will be intercalibrated with ACE/EPAM and instruments on IMAP, SOHO, and WIND.



DSCOVR-ACE plasma instrument validation (Loto'aniu et al., 2022)

The presence of multiple sensors at L1 will improve the accuracy of solar wind coupling functions and the understanding of geoeffective structures.



Enabling Research

- Images and data from the SWFO-L1 observatory and the CCOR-1 on GOES-U will enable research in several areas continuing the SOHO, DSCOVR, and ACE capabilities:

1. Connections between the inner heliosphere and the 1-AU region. Monitoring the radial evolution of CMEs, HSSs, helmet streamers/pseudostreamers, fluxropes, and other structures as they propagate through the SW, and the associated particle acceleration.
2. Initial phase of CME acceleration in the low corona; fits to GCS and other models; relation to activity measures such as magnetic-field and SEP flux.
3. Driving of environmental models: global-MHD, radiation belt empirical and diffusion models, ionospheric, others. Geoeffectiveness of solar wind structures (CMEs, etc.).
4. Data analysis of plasma-moment, IMF, and/or particle flux for: a) Solar wind structure identification; b) Time evolution of particle energy spectra; c) Electric-field/other input to dayside magnetosphere reconnection models; d) Solar wind invariants, cascades, and dissipation mechanisms; e) power-law (fractal) and other distributions.
5. Solar system astronomy: sungrazer comet detection, zodiacal dust parameter estimation.
6. Statistical and long-term studies: solar cycle, space climate.
7. Other: Data assimilation, machine learning, etc.

- **Relevant SHINE Working Groups**: 1 (Solar, coronal), 2 (Interplanetary), 3 (SEPs). Next SHINE workshop: August 12-16, 2024.

Operational and Research Use Cases

The imagery and in situ measurements are expected to drive several operational and research applications:

- Situational awareness needed by a wide range of space weather information users.
- Real-time or retrospective driving of models:
  - Heliospheric MHD: inputs include CME parameters from CCOR image analysis
  - Ionospheric/magnetospheric models: time series from SWiPS and MAG. These include large-scale MHD/hybrid simulations; the magnetopause standoff calculation; radiation-belt models, and several empirical models.
- Coordination with CCMC and other user organizations is planned.
- Additional use cases include certain types of data assimilation, AI/ML, and citizen science.
- The SWFO Science Seminar started in January 2024 to raise awareness in the research community and help identify relevant applications.
- Metadata definitions will be informed by such use cases.

Summary and Next Steps

- In the last twelve months, almost all SWFO instruments have been delivered, integrated on the spacecraft, and tested. SWiPS is planned for delivery later this month. GOES-U is ready for launch in June 2024.
- The development of algorithms and calibration/validation tools has significantly progressed. The CCOR-1 launch-ready ops codes were delivered in December 2023 with updates pending this month. Other GPAs are being revised.
- The Calibration and Validation Plan has been updated and is available for distribution. The PLT and PLPTs have been defined; for GOES-U the PLT is being revised, and for SWFO-L1, the tests are used in defining ROPs.
- Use cases include operational applications (situational awareness, driving of ops models) and many solar, heliospheric, and geospace projects. Feedback from users is requested for refining these scenarios and adding new metadata.

Backup

NOAA: Responding to User Needs for Space Weather Information

- Awareness of the near-Earth space environment is crucial for a wide range of users. The lack of space weather specification and forecasts reduces efficiency and increases cost and risk in many different industry sectors that rely on satellite and other services.

- NOAA has the responsibility of providing such space weather information to its users. Since several monitoring satellites have a limited remaining lifespan (SOHO, ACE, DSCOVR) it is important to plan for follow-on missions for solar, heliospheric, and other observations.

Space Weather Observations from Lagrange 1 – April 15, 2024

Products, Latency, Availability

- The SWFO main products are shown on the right. The highest-priority products are the three Key Performance Parameters (KPPs).
- The Initial Operational Capability (IOC) of the program is based on the generation of KPPs at Levels 1 to 3 and on their delivery to users.
  - In addition, higher-level products are planned at SWPC.
- Data latency requirements: Products will be made available at 5 minutes for solar wind data and 30 minutes for coronal imagery.
- The data availability requirement at the program-level is 96%.

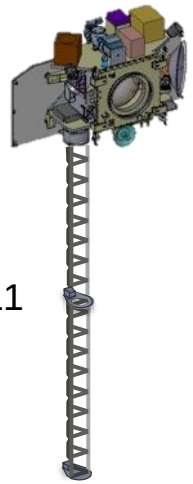
Space Weather Data Product	KPP
Coronal White Light Intensity	Y
Thermal Plasma Ion Velocity	Y
Thermal Plasma Ion Density	N
Thermal Plasma Ion Temperature	N
Vector Magnetic Field	Y
Suprathermal Ion Differential Flux	N
Dynamic Pressure	N

Performance Requirements: CCOR

Specifications	Requirements	
	CCOR-1	**CCOR-2**
Requirement Doc. (PORD*)	SSD-RQT-CC007 Rev. A	SSD-RQT-CL004 Rev. -
Spacecraft	GOES-U	SWFO-L1
Bandpass	WL: 450-750nm	WL: 450-750nm
FOV	3.7 to 17 Rsun	3.0 to 22 Rsun
Spatial resolution	50 arcsec	70 arcsec
Image size	2048x1920 pixels	2048x1920 pixels
Cadence	15 min	15 min
Latency	< 12 min	≤ 18 min
Photometric accuracy	< 10 %	< 10 %
Minimum corona intensity	≥1.0e-11 Bsun	≥1.0e-11 Bsun

*** PORD: Performance Operational Requirement Document**

The SWFO Ground Segment

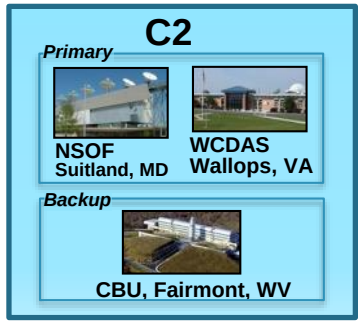


SWFO-L1

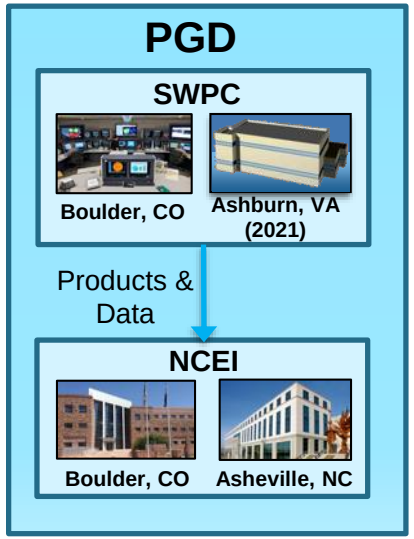
Via SAN element

The Ground Segment contains three elements.
Data are downlinked to the SWFO Antenna Network (SAN). The Command and Control (C2) element provides SWFO-L1 mission and housekeeping (HK) data to the Product Generation and Distribution (PGD) element. (*)
Within PGD:

- The Space Weather Prediction Center (SWPC) unit is responsible for processing and distributing products to operational users.
- The National Centers for Environmental Information (NCEI) unit is responsible for processing and making available all products to retrospective users.



L0 Mission Data,
Hk Data,
Ancillary Data



Real-Time Products
to
Operational Users

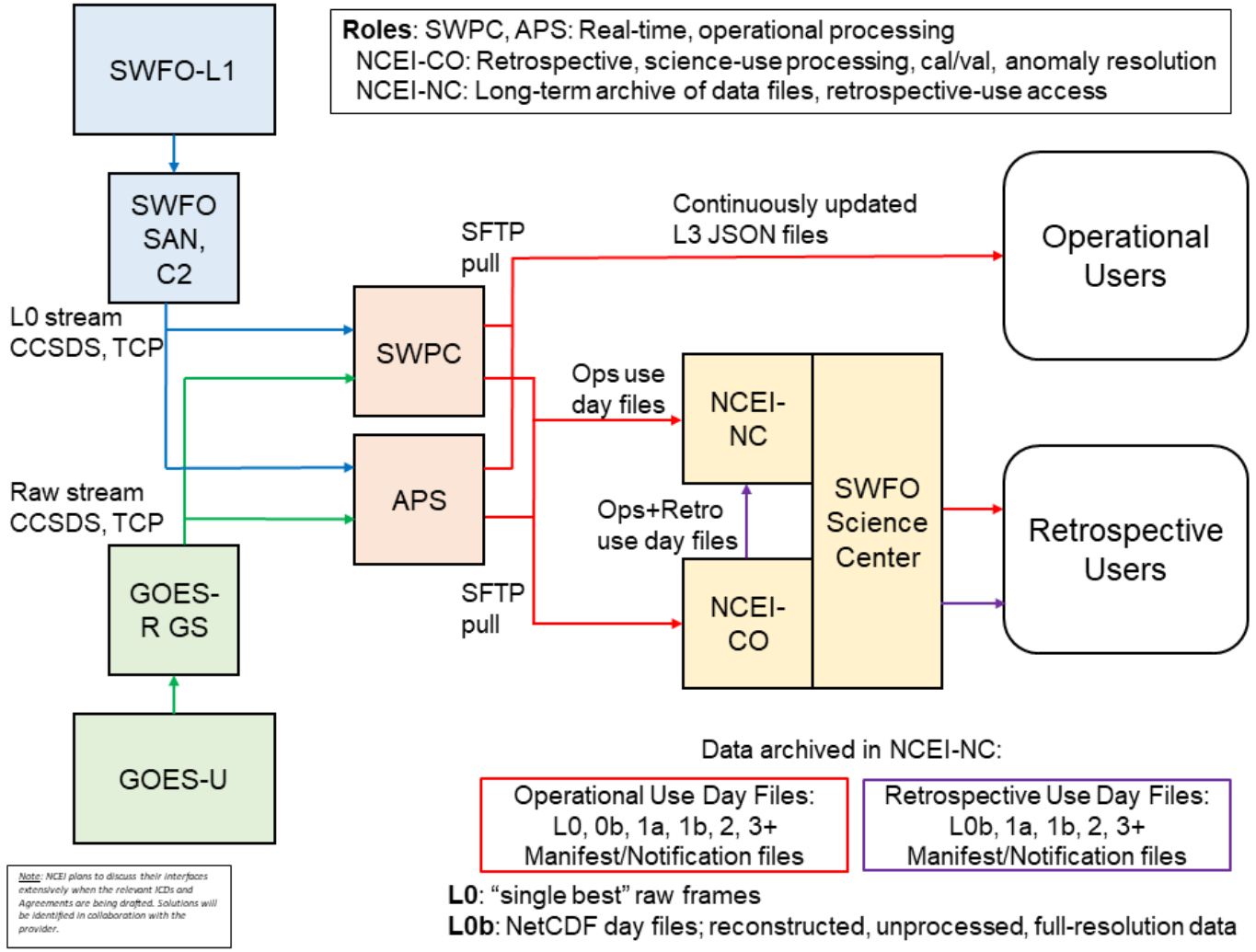
All Products to
Retrospective
Users

User Community

*In addition, SWPC receives GOES-U CCOR-1 data via the GOES-R Ground Segment (GS)

Product Generation and Distribution: The Roles of SWPC and NCEI

- **Product Generation**
  - Product generation for operational users takes place at NWS/SWPC (Boulder, CO) with a hot backup at the Alternate Processing Site (APS) on the East Coast.
  - Products for retrospective users are developed by NESDIS/NCEI.
- **Algorithm and Calibration Working Groups**
  - Include SWPC, NCEI, instrument developers, other Flight and Ground Segment teams.
- **Algorithm design and product development**
  - Takes place in a series of Git-based environment with information shared among the three types of developers (SWPC, NCEI, instrument teams)



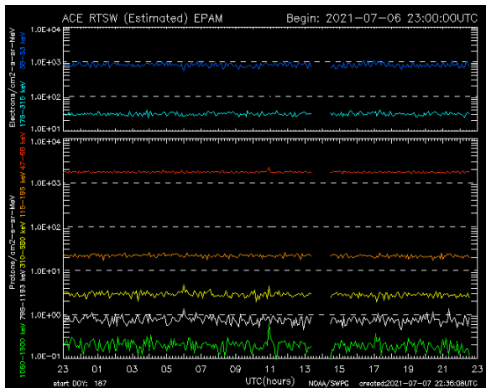
SWFO: Enabling Research

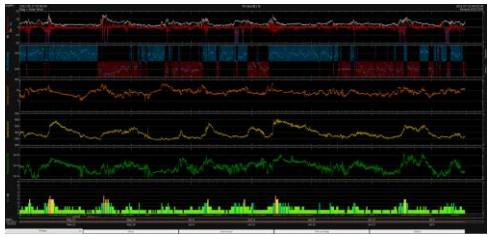
Questions from: "Nine Outstanding Questions of Solar Wind Physics" [Viall and Borovsky, JGR, June 2020]

Category	Question	SWFO Contributions
The formation of the solar wind	(1): From where on the Sun does the solar wind originate?	--
	(2): How is the solar wind released?	--
	(3): How is the solar wind accelerated?	--
Interpreting observations of solar wind parcels	(4): What determines the heavy-ion elemental abundances, the ionic charge states, and the alpha/proton density ratios in the solar wind? (And what do they tell us about the Sun?)	--
	(5): What is the origin and evolution of the mesoscale plasma and magnetic field structure of the solar wind?	✓
Physical mechanisms operating on solar wind formation and evolution	(6): What is the origin of the Alfvénic fluctuations in the solar wind?	✓
	(7): How is solar wind turbulence driven, what are its dynamics, and how is dissipated?	✓
	(8): How do the kinetic distribution functions of the solar wind evolve?	✓
	(9): What are the roles of solar wind structure and turbulence on the transport of energetic particles in the heliosphere?	✓

Products for SpWx Information Users

- **Data for operational users: SWPC**
  - SWPC will make available NRT data via NOAA's Web Operation Center (WOC)
  - All other files will be hosted for sftp access
  - SWPC will also provide QuickLook files to the instrument vendors. will send L3 data and images to the Forecast Center. It will provide day files to NCEI for further processing and archiving.
  - The data will support SWPC's Alerts, Warnings, Watches, and other notifications which are accessible via a subscription service.





- **Data for retrospective users: NCEI**
  - NCEI is developing the SWFO Science Center, similar to the DSCOVR data portal (pictured on the right) and the GOES-R Space Weather site.
  - The Science Center's Application Programming Interface (API) will be designed to allow meta-portals such as the VSO (https://virtualsolar.org/) and CDAWeb (https://cdaweb.gsfc.nasa.gov/) to access SWFO data.