GOES
40 Years of Satellite Space Environmental Monitoring

W.F. Denig

National Centers for Environmental Information (NCEI)

NOAA/NESDIS

Boulder, Colorado

26 April 2016

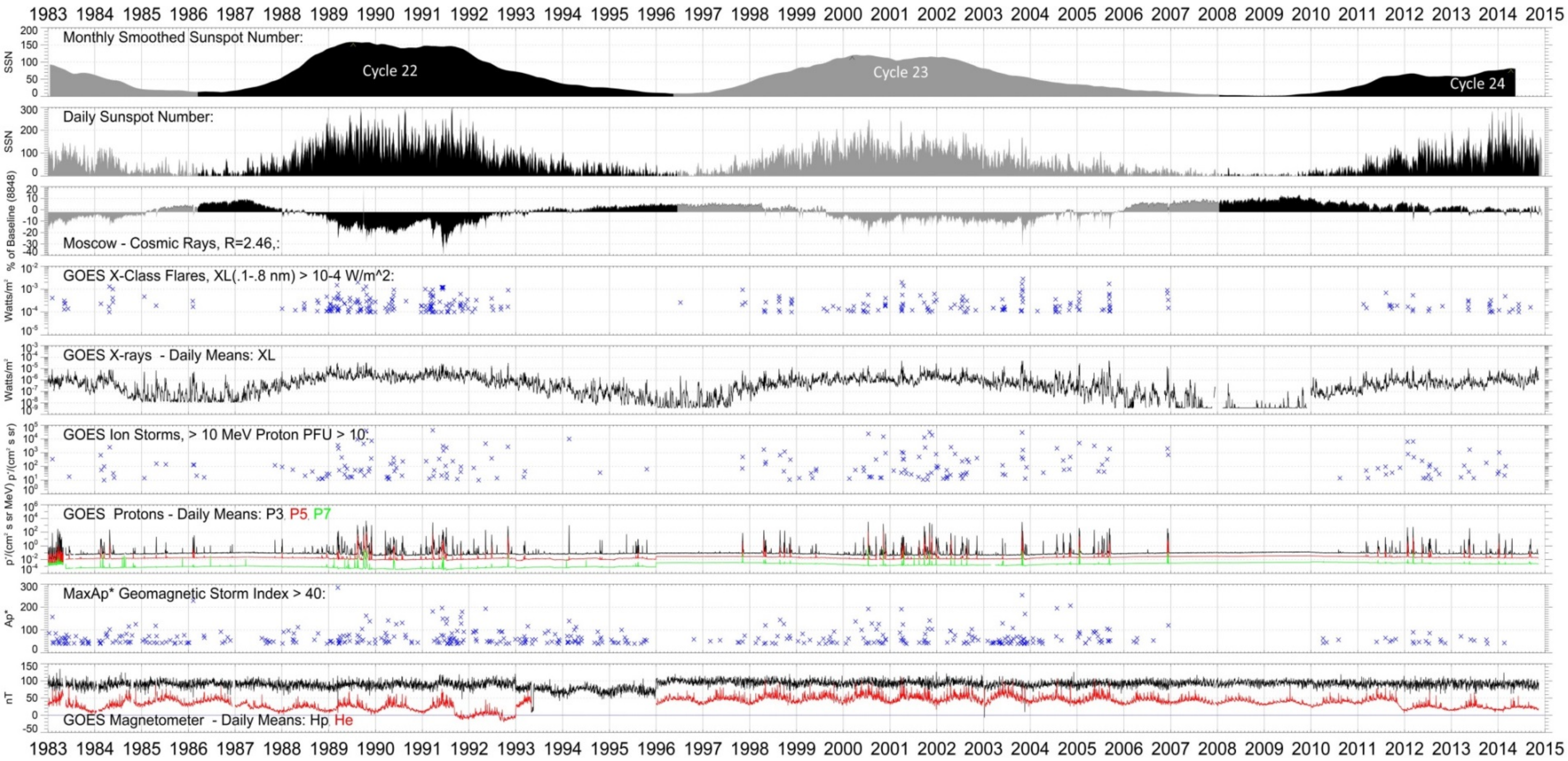
Upcoming GOES-R Launch

GOES-R is scheduled for a 13 Oct 2016 launch 21:43 GMT (17:43 EDT) from the Cape Canaveral Air Force Station. The GOES-R series of spacecraft will offer unprecedented operational capabilities for serving NOAA's space weather mission.

YouTube

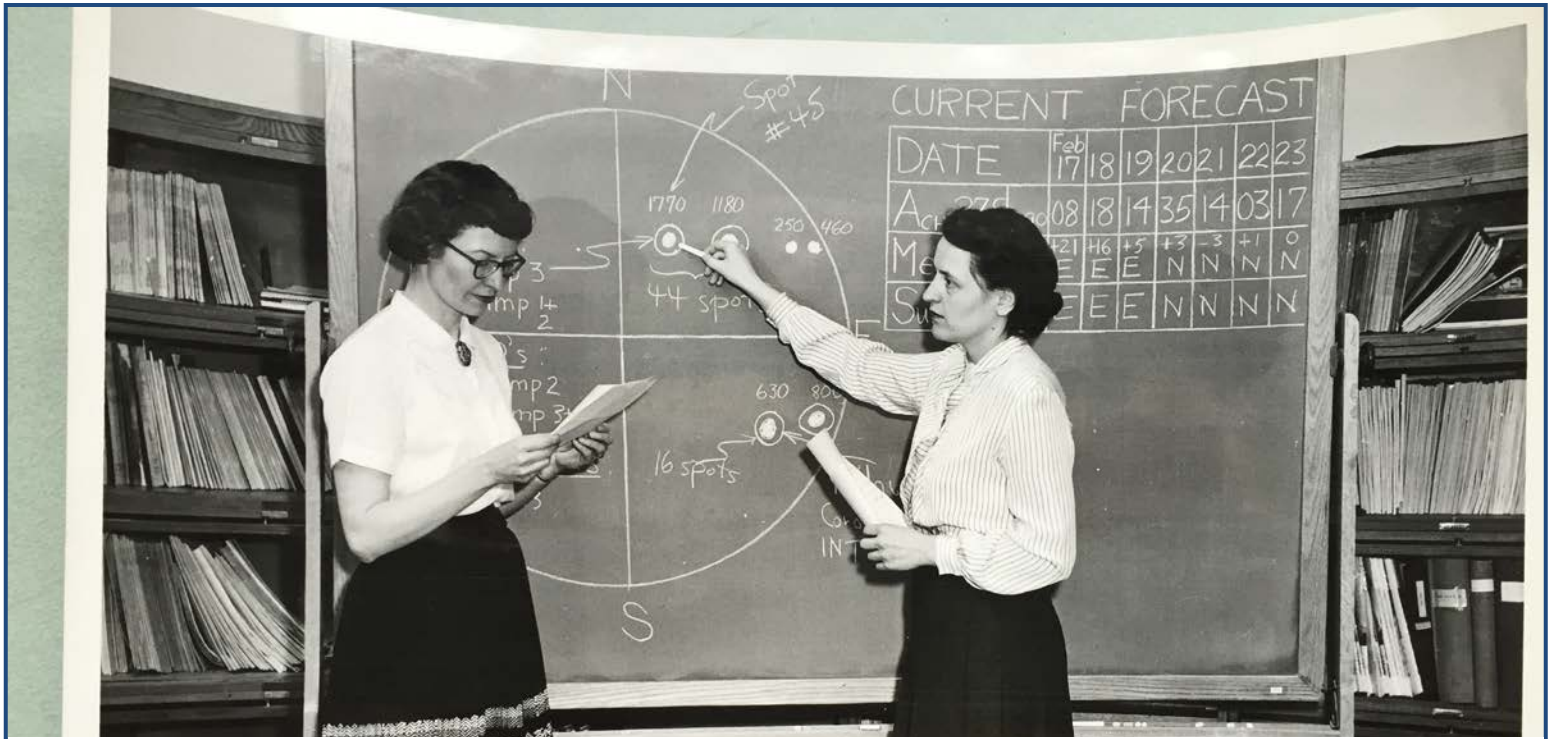
GOES-R – 40+ Years of SWx

Space Environment Overview: 1983-01-01 - 2014-12-31



	Start Date	Max Date	End Date	C-Class Flares	M-Class Flares	X-Class Flares	Ion Storms	Mag Storms Ap* > 40
Solar Cycle 22	1986-03	1989-07	1996-06	12,447	2,021	151	73	191
Solar Cycle 23	1996-06	2000-03	2008-01	13,102	1,437	126	92	158
Solar Cycle 24 *	2008-01	2014-04	TBD	5,288	488	35	32	25

Long Range Communications



Marion Wood (left) and Hope Leighton (right) preparing the **North Pacific Radio Propagation Forecast**

Public Law 619 (July 22, 1950) – “authorizes the DOC to investigate conditions which affect the transmission of radio waves from their source to a receiver, the compilation and distribution of information on such transmission of radio waves as a basis for choice of frequencies to be used in radio operation, the prosecution of such research in engineering, mathematics, and the physical sciences.” See also 15 USC Section 1532 and DOO 10-15. (Reference the DOC’s High Latitude Monitoring Station)

Astronaut Health and Safety

Space radiation exposure was recognized as a risk that needed to be considered for manned spaceflight. In 1960 NASA established the Solar Particle Alert Network (SPAN). During Apollo missions SPAN data were relayed to the Space Environment Console at the Mission Control Center in Houston, Tx. (also AF SOFNET/SEON)

Bursts Of Cosmic Rays Imperil Space Travelers

BERKELEY, Calif. (AP)—Another potentially deadly radiation hazard for space travelers was reported today by researchers who sampled the upper air of the arctic region with instrument-carrying balloons.

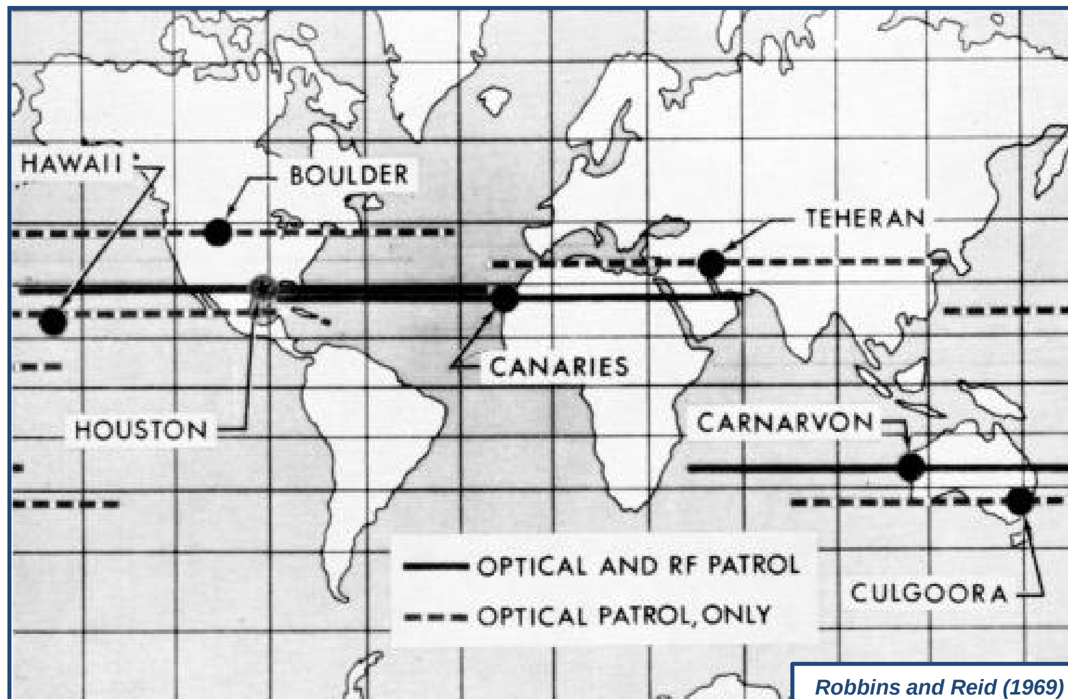
During periods of solar flares the investigators found that the top of the earth's atmosphere near the polar region was showered with stupendous bursts of cosmic rays.

This radiation was 10,000 to 100,000 times above normal, said Dr. Robert A. Brown, physicist, and Ray D'Arcy, graduate student, of the University of California.

Dr. Brown made his report after returning here from College, Alaska, where the balloon flights were made. Cosmic rays are more intense in the polar areas because they encounter less interference there from the earth's magnetic field.

The experimenters put up a balloon immediately after the University of Alaska detected a solar flare. A solar flare is a sudden brightening of the sun's surface in the vicinity of a sunspot.

Trenton Times (15 Oct 1959)



Robbins and Reid (1969)

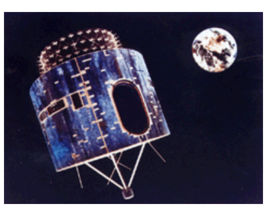
Before GOES – Early Satellites

NRL

SOLar RADiation (SOLRAD, 1960-1976) – Determined relationship between solar x-rays and radio-wave fadeouts. Non operational.

Vela Hotel (She Watches Over, 1963-1971) – 1963 Partial Test Ban Treaty compliance but detected solar events.

Advanced Technology Satellites (ATS, 1966-1977) – Demonstrated utility of geosynchronous orbit for meteorological monitoring.



Synchronous Meteorological Satellites (1974-1979) – Immediate predecessor to GOES; Identical to GOES 1-3

Memorandum to David Johnson from George Benton (04 Mar 1969)

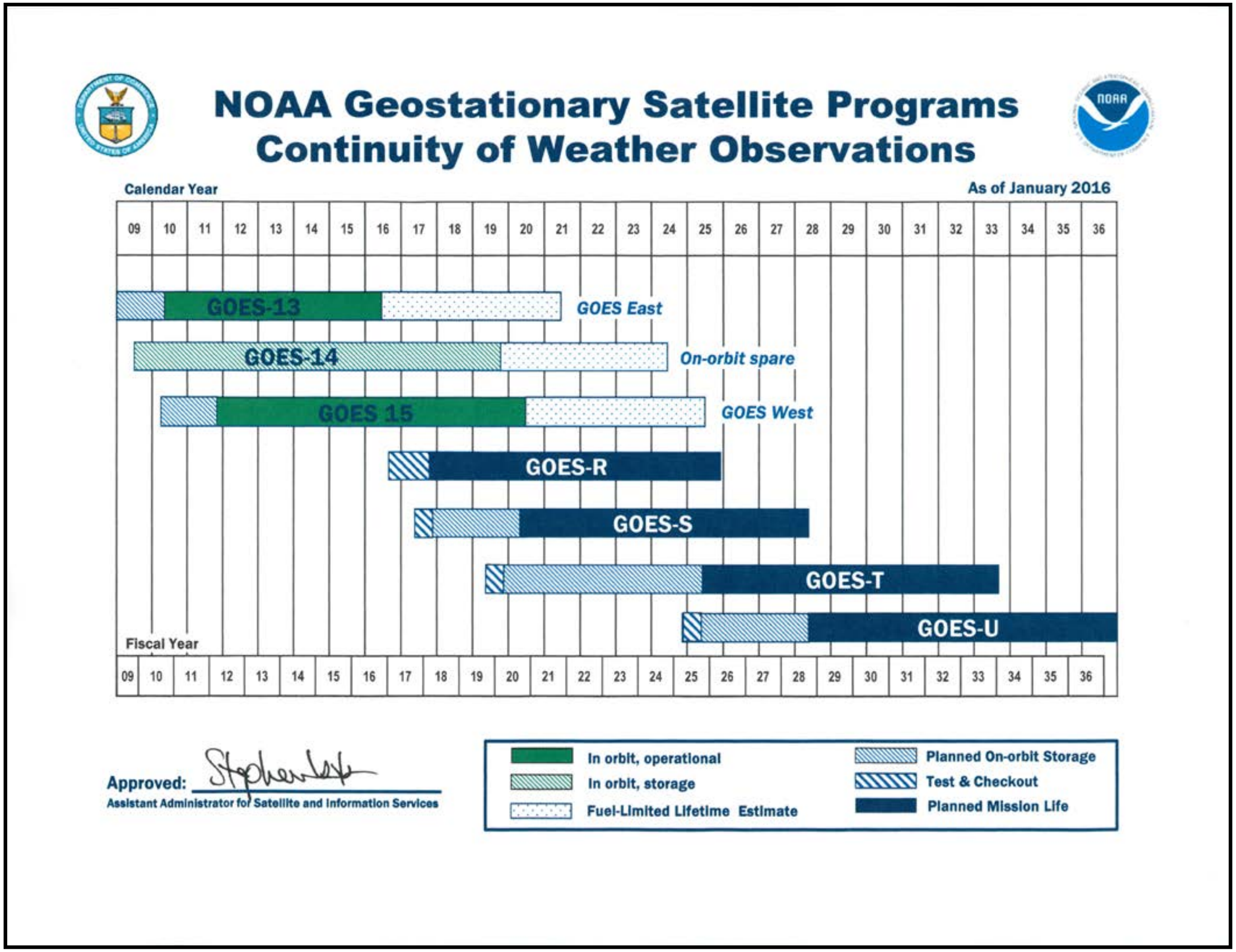
"I am pleased to submit to you in outline our firm requirements for operational space disturbance monitoring from the first GOES satellite. These are for operational monitoring of ***energetic protons, alpha particles and solar x-rays*** *in the 1 – 8 and 0.5 – 3 Angstrom bands."*

Dr. George Benton
ESSA Research Laboratories (ERL)

David Johnson
National Environmental Satellite Center (NESC)

(unsigned file copy, courtesy Dick Grubb)

GOES Flyout Chart



NOAA Space Weather Scales

GOES Particles

Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
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: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2} Based on this measure, but other physical measures are also considered.
** These events can last more than one day.
*** High energy particle (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.

GOES X-rays

Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
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 ($2x10^{-3}$)	Fewer 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 of the Earth, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side of the Earth, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

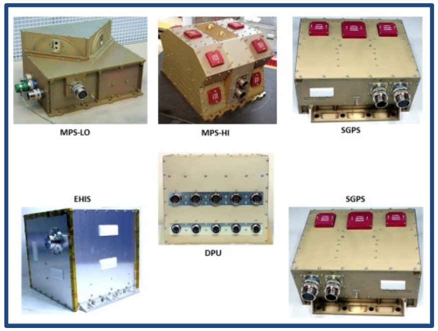
* Flux, measured in the 0.1-0.8 nm range, in W·m^{-2}. Based on this measure, but other physical measures are also considered.
** Other frequencies may also be affected by these conditions.

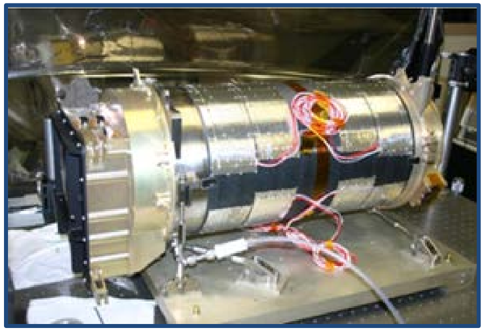
Space Weather Sensors

GOES-R

Space Environmental In-Situ Suite

(SEISS)





Solar Ultra-Violet Imager

(SUVI)

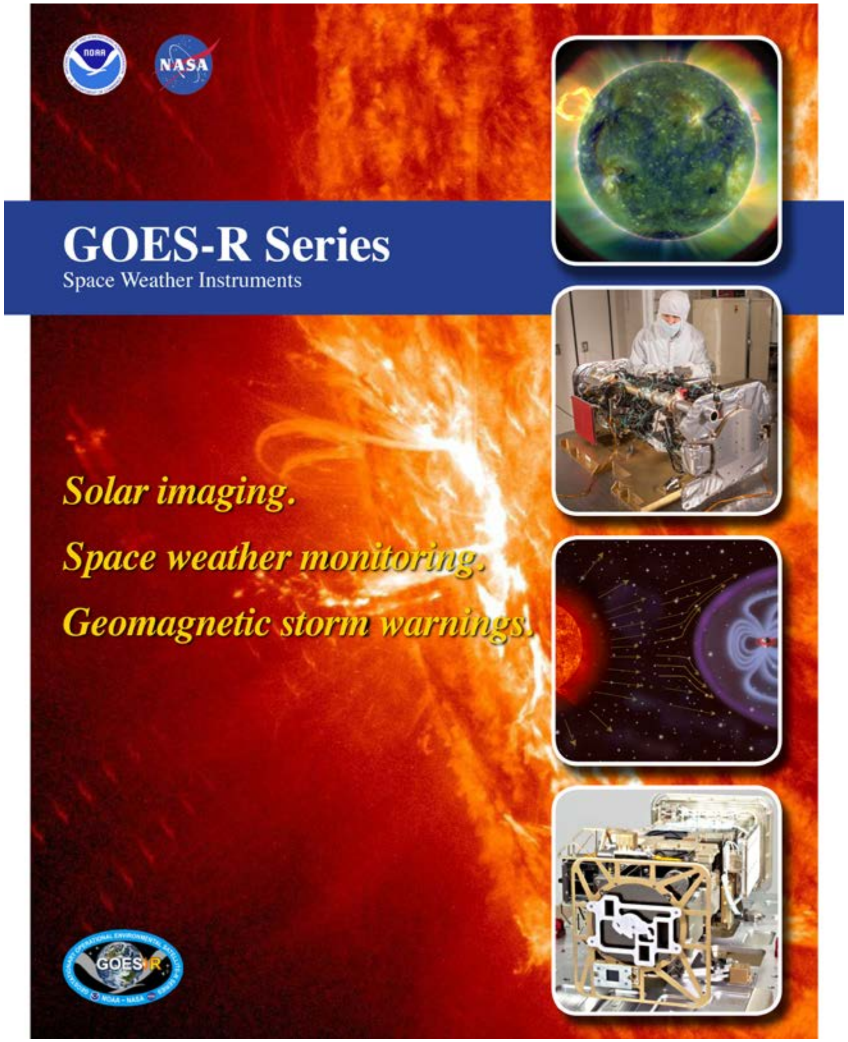
Magnetometer

MAG

EUV and X-ray Irradiance Sensors

(EXIS)

GOES-R SWx Handout



What is space weather?

The changing environmental conditions from the sun's atmosphere are known as space weather. Space weather is caused by electromagnetic radiation and charged particles being released from solar storms. Changes in the magnetic field and a continuous flow of solar particles during a powerful storm headed to Earth can cause disruption to communications, navigation, and power grids as well as result in spacecraft damage and exposure to dangerous radiation.

How will GOES-R monitor space weather?

The GOES-R series of satellites will host a suite of instruments that provide significantly improved detection of approaching space weather hazards. Two sun-pointing instruments will measure solar ultraviolet light and x-rays. The Solar Ultraviolet Imager (SUVI) will observe and characterize complex active regions of the sun, solar flares, and the eruptions of solar filaments which may give rise to coronal mass ejections. The Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) will detect solar flares and monitor solar irradiance that impacts the upper atmosphere.

The satellites will also carry two instruments that measure in-situ. The Space Environment In-Situ Suite (SEISS) will monitor proton, electron and heavy ion fluxes in the magnetosphere. The Magnetometer (MAG) will measure the magnetic field in the outer portion of the magnetosphere.

The SEISS instrument is composed of five sensors.

What benefits will the GOES-R space weather mission provide?

Solar eruptions can cause geomagnetic and solar radiation storms, which can disrupt power utilities, communication and navigation systems, damage satellite electrical systems, and may cause radiation exposure to orbiting satellites, high-latitude aircraft, and the International Space Station. The GOES-R series SUVI and EXIS instruments will provide improved imaging of the sun and detection of solar eruptions, while SEISS and MAG will provide more accurate monitoring, respectively, of energetic particles and the magnetic field variations that are associated with space weather. Together, observations from these instruments will enable NOAA's Space Weather Prediction Center to significantly improve space weather forecasts and provide early warning of possible impacts to Earth's space environment and potentially disruptive events on the ground.

Astronauts working outside the International Space Station are especially vulnerable to radiation from solar storms.

- √ Improved detection of coronal holes, solar flares and coronal mass ejection source regions
- √ More accurate monitoring of energetic particles responsible for radiation hazards
- √ Improved power blackout forecasts
- √ Increased warning of communications and navigation disruptions

Learn more:

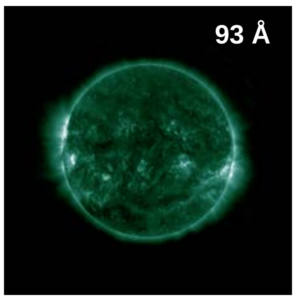
http://www.goes-r.gov/
http://www.goes-r.gov/spacesegment/exis.html
http://www.goes-r.gov/spacesegment/suvi.html
http://www.goes-r.gov/spacesegment/seiss.html
http://www.goes-r.gov/spacesegment/mag.html
http://www.swpc.noaa.gov/

WWW.NESDIS.NOAA.GOV | WWW.GOES-R.GOV | TWITTER: NOAASATELLITES | FACEBOOK: GOES-R

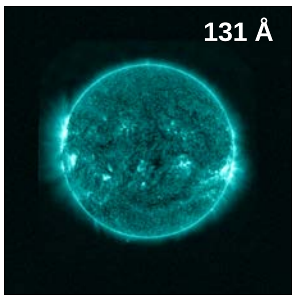
10/2015

SUVI Overview

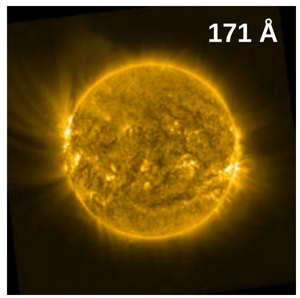
GOES-R shifts current x-ray imagery to the ultraviolet for improved solar feature characterization. Wavelength bands comparable to SDO/AIA.



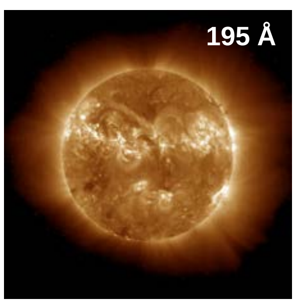
Flaring Regions (Fe XVIII)



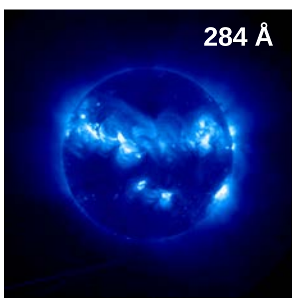
Flaring Regions (Fe VIII / XX / XXIII)



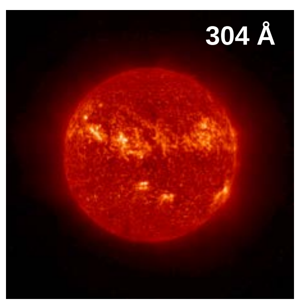
Transition Region (Fe IX)



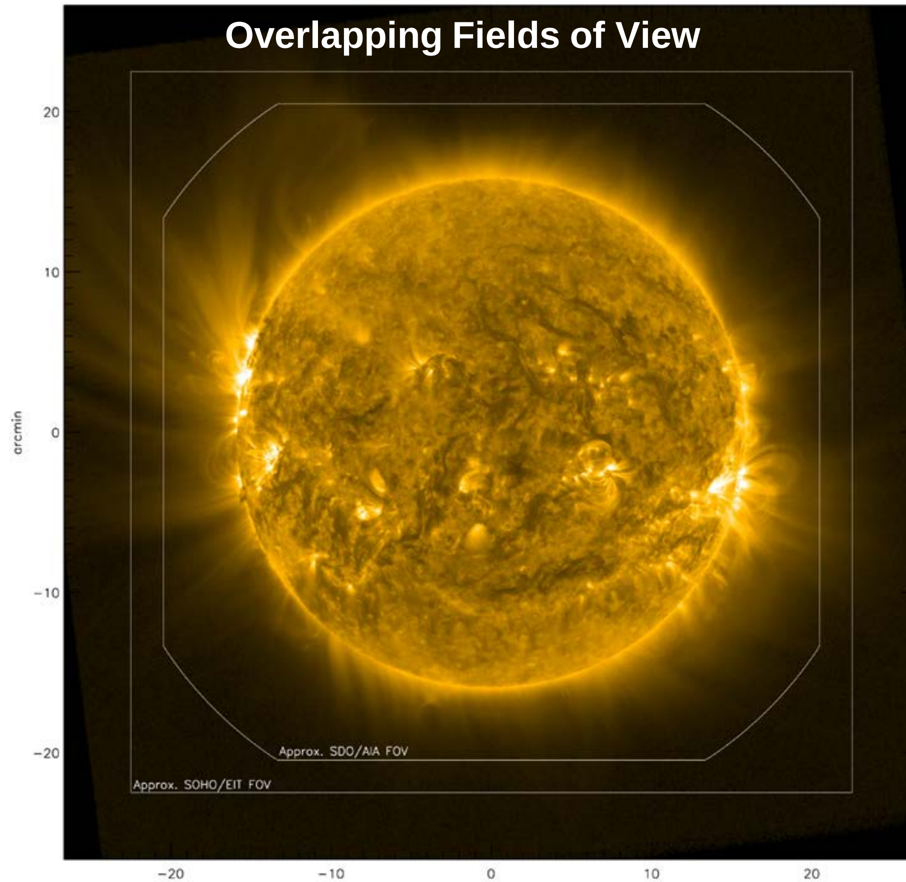
Corona (Fe XII / XXIV)



Flaring Regions (Fe XV)



Chromosphere (He II)



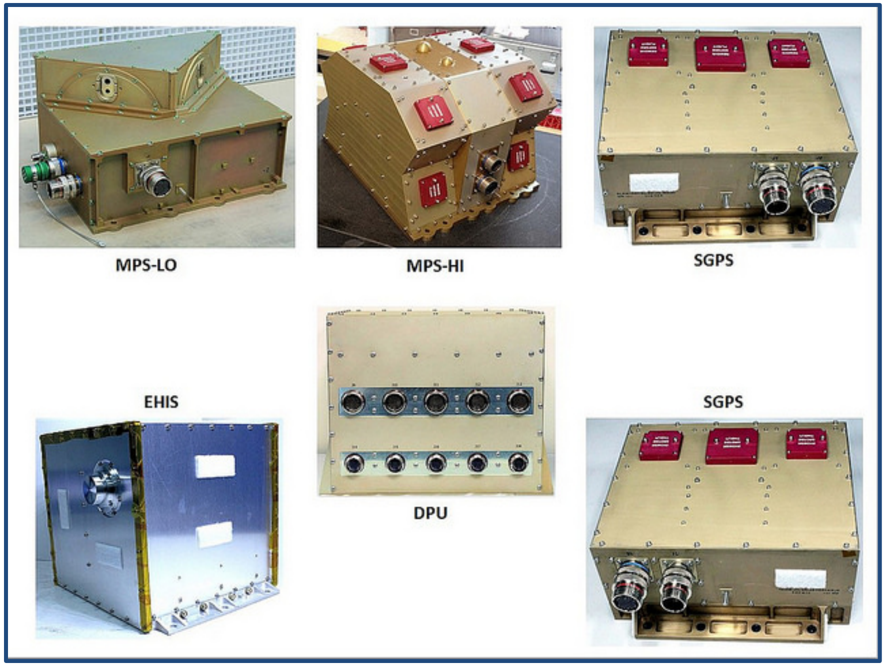
Simulated SUVI image at 171 Angstroms (Fe IX)
Transition Region (chromosphere-corona)

SEISS Overview

Instrument	Species	Energy Range
MPS-LO	Ions	0.03-30 keV
MPS-LO	Electrons	0.03-30 keV
MPS-HI	Protons (H+)	80-10,000 keV
MPS-HI	Electrons	50-4000 keV and >2000 keV
SGPS	Protons (H+)	1-500 MeV and >500 MeV
EHIS	Ions (H through Ni, separately resolved)	10-200 MeV/nucleon

Improvements over current SEM:

- Low-energy range for surface charging.
- Ion mass discrimination at high energies.
- Overall improved energy resolution.

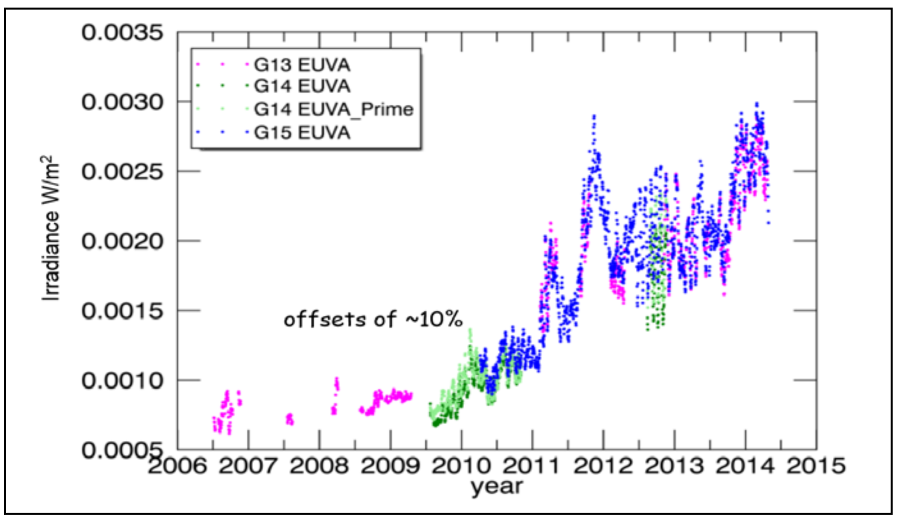


EXIS and MAG

Extreme Ultraviolet and X-ray Sensor

- EUVS will set the standard for continuous monitoring of solar EUV irradiance.
- Intensity and location of x-ray flares will be measured by the XRS.

EUVS (EUV sensor) // XRS (X-ray sensor)

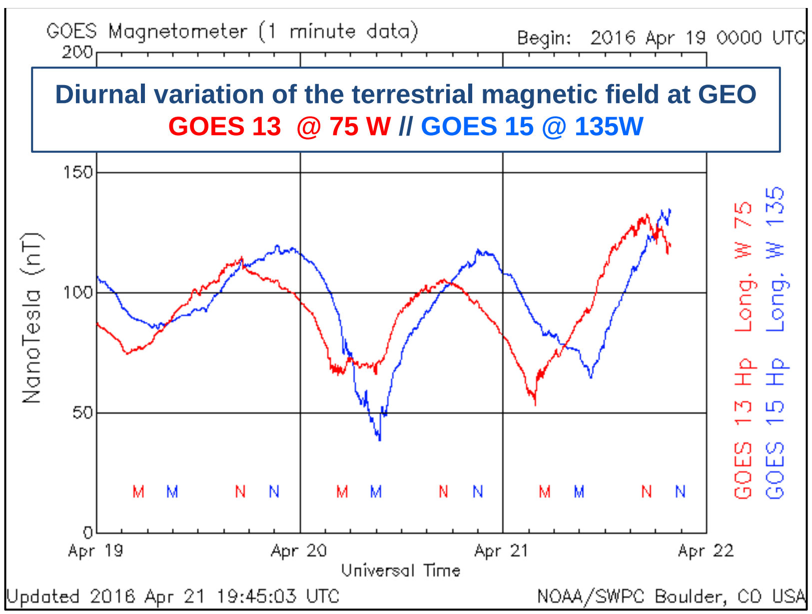


Inter-calibration and Degradation Workshop Belgium Solar-Terrestrial Center of Excellence (10-13 June 2014).

Magnetometer[1]

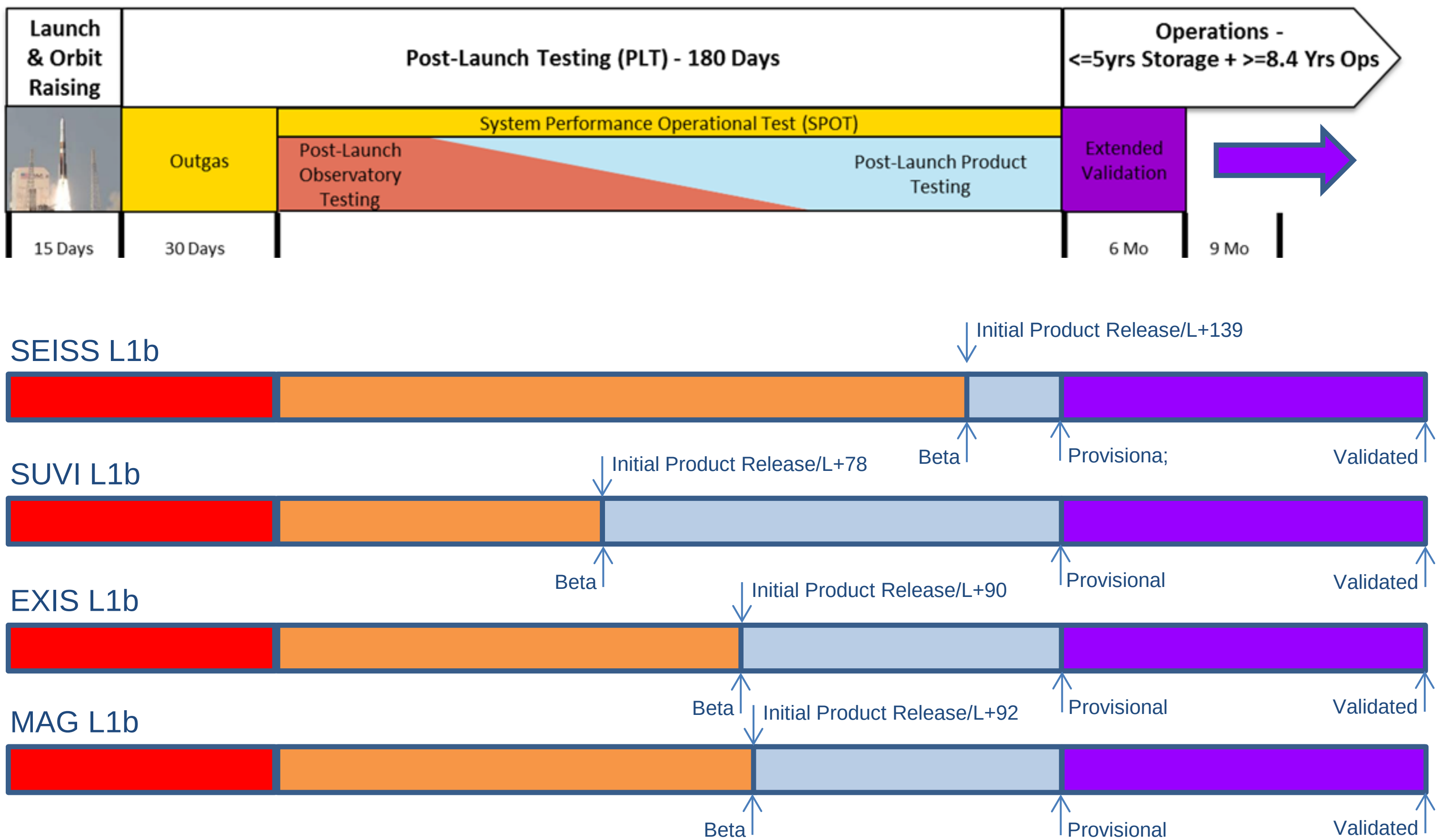
- <u>Dayside Measurements</u> – MAG will detect magnetopause crossing events for standoff distances within the GEO orbit.
- <u>Nightside Measurements</u> – Alert operators to the occurrence of geomagnetic substorms.

[1]Boom-mounted gradiometer approach.



Product Availability (L1b)

Nominal L1b Product Validation Schedule



Launch
2016/287
13 Oct 2016

Product Release
2017/60
01 Mar 2017

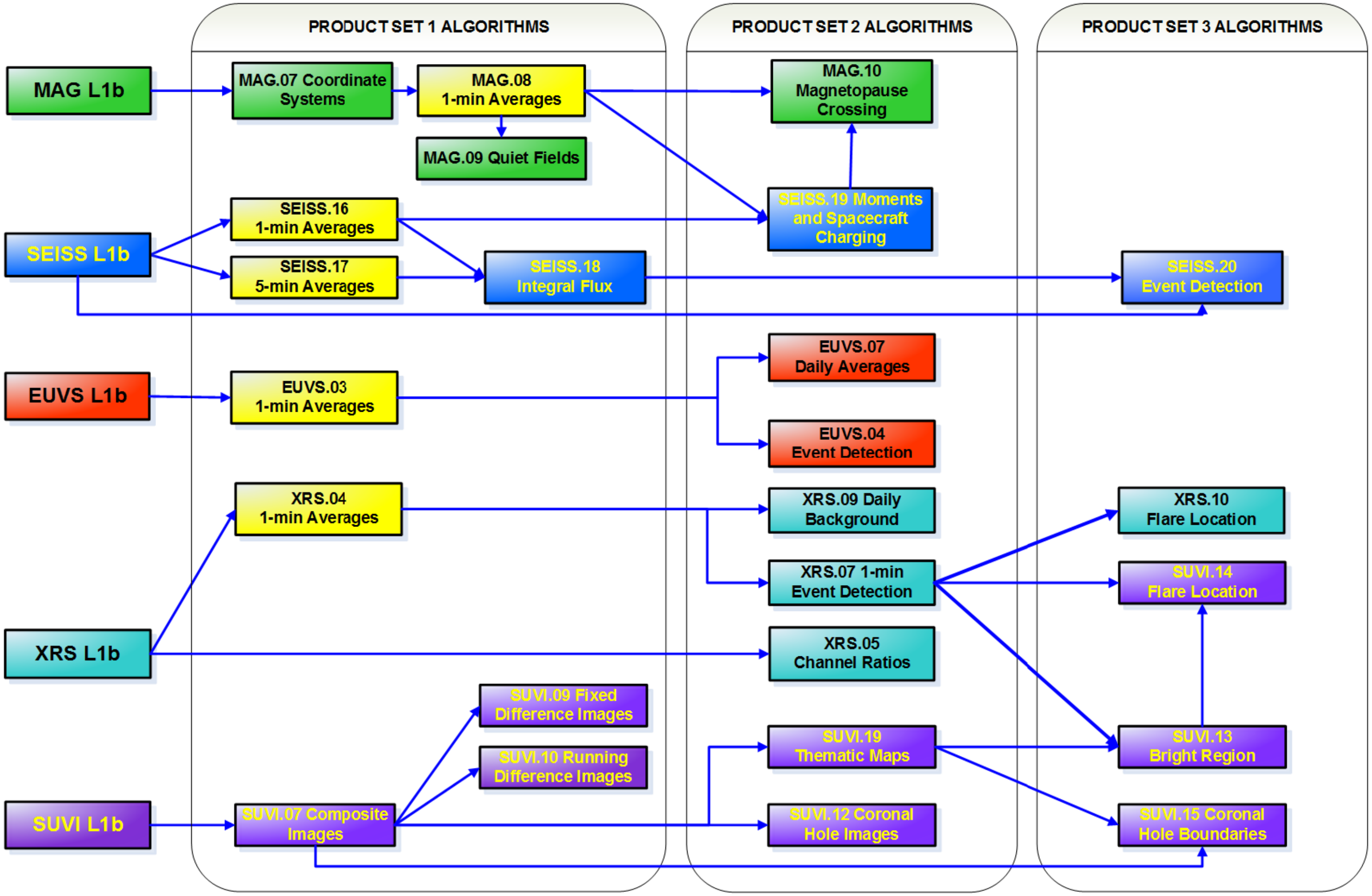
2016/365
30 Dec 2016

2017/11
11 Jan 2017

2017/13
13 Jan 2017

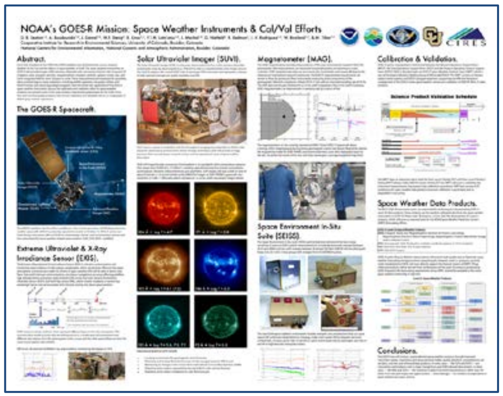
AGU – 12-16 Dec 2016
AMS – 22-26 Jan 2017

Derived Operational Products (L2+)

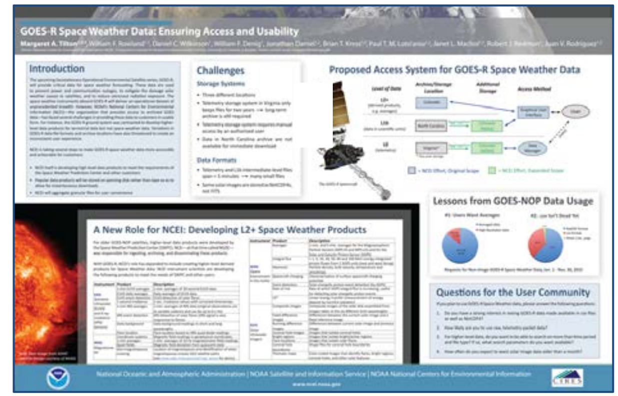


GOES-R Posters at SWW-2016

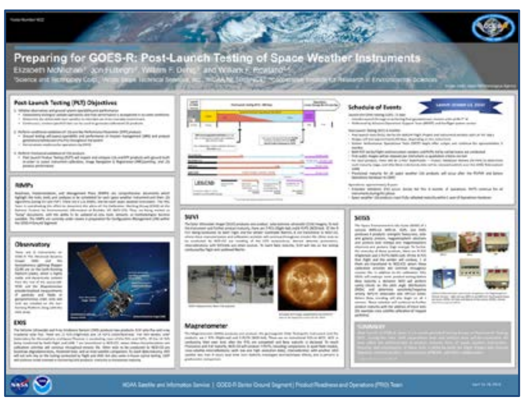
Dan Seaton – *NOAA's GOES-R Mission: Space Weather Instruments & Cal/Val Efforts.*



Meg Tilton – *GOES-R Space Weather Data: Promoting Assess and Usability.*



Liz McMichael – *Preparing for GOES-R: Post-Launch Testing.*



Thanasis Boudouridis – *Comparison of Matrix Inversion and Bow-tie Techniques (SEISS).*

GOES-R Space Weather Team