Summary of Space Environment Magnetometer and Particle Replacement Experiment (SEMPRE) Study

GOES-R Flight Project
Code: 417

Monica Todirita, Cindy Merrow, Jeffrey Kronenwetter, Evan Goldstein,
Monica Coakley, Ashley Carlton, Fredrick Rich, Paul Loto'aniu

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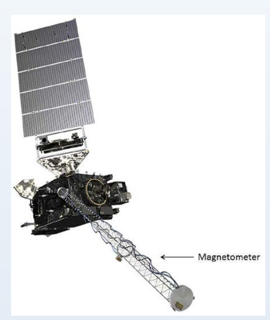
I. Abstract

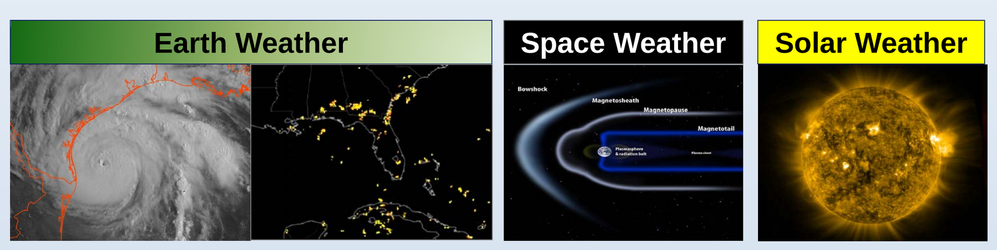
As part of the GOES-R series follow on architecture study following the NOAA Satellite Observing System Architecture (NSOSA) study, a study team evaluated the feasibility of accommodating the GOES in-situ instruments (Magnetometer and Particle Detectors) on a dedicated spacecraft with no impact to the overall baseline mission cost assuming two large observatories. The accommodations cost on a primary operational type observatory are non-negligible requiring: a large non-magnetic boom to reduce the impact of the spacecraft interference on the magnetometer; and strict contamination control and magnetic cleanliness to prevent magnetic contamination near the magnetometers. These, along with the additional interface complexities greatly increase the cost of larger spacecraft by extending integration time with a large marching army. By contrast, a dedicated mission provides flexibility in location and refresh rate not afforded when these sensors are launched as secondary payloads. This study performed an informal industry survey of small form-factor instruments currently flying or in process of being developed. The study identified three potential particle detector suites and multiple magnetometers that will satisfy the requirements while having low enough volume and mass to allow accommodation on a rideshare class spacecraft. Using the largest of the identified particle detector suites, the Goddard Space Flight Center Mission Design Lab developed a design for a rideshare spacecraft that will accommodate the particle detector suite and magnetometer. The cost of the spacecraft, based on multiple cost models, is comparable to the cost of accommodating the magnetometer and particle detector suite on two (East and West) larger main observatories.

II. GOES-R Series Overview

Mission: Provide continuous imagery and atmospheric measurements of Earth's Western Hemisphere and space weather monitoring.

- GOES-R is the newest generation of United States geostationary weather satellites
  - Provides the first update in sensor technology since the GOES-I launch in 1994
- Four satellites in the series: GOES-R, S, T and U
- Joint mission between NASA and NOAA
  - Continuing the successful partnership on weather satellite programs since the 1970s

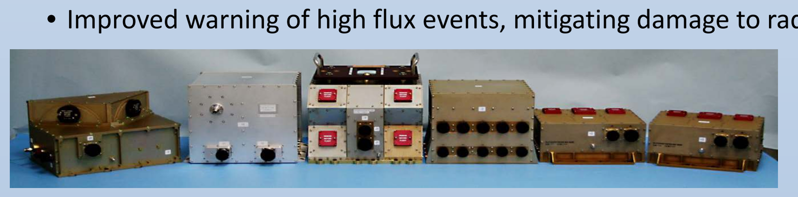




Advanced Baseline Imager | *Geostationary Lightning Mapper* | *Space Environment In-Situ Suite & Magnetometer* | *Solar Ultraviolet Imager & Extreme UV & X-ray Irradiance Sensors*

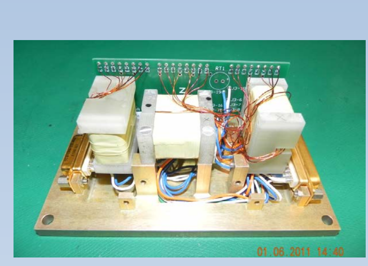
Space Environment in-Situ Sensor Suite (SEISS)

- SEISS consists of energetic particle sensors to monitor proton, electron and alpha particle fluxes
- SEISS provides:
  - More accurate monitoring of energetic particles responsible for radiation hazards to humans and spacecraft
  - Better monitoring of ionizing responsible for spacecraft charging
  - Improved warning of high flux events, mitigating damage to radio communication



Magnetometer

- Consists of two sensors located on an 8 meter deployable boom structure that distances them from the magnetic signature of the spacecraft
  - Each sensor uses 3 flux gate magnetometers to measure the orthogonal vector components of the Earth's mag field
- Magnetic field measurements provide information on the general level of geomagnetic activity, and enable detection of sudden storm commencements, substorms, & magnetopause crossings



III. Purpose

- Evaluate feasibility of accommodating the GOES in-situ instruments on dedicated spacecraft with no cost impact (for more info see https://www.goes-r.gov/).
- Accommodations cost on primary S/C are non-negligible
  - Large Magnetometer Boom
  - Magnetic cleanliness of spacecraft and other instruments
  - Additional testing of spacecraft and other instruments
- Dedicated spacecraft provides flexibility in location and refresh

IV. Approach

- Based on NOAA Satellite Observing System Architecture (NSOSA) requirements identify small form-factor instruments currently available or being developed
- Evaluate possible mission orbits
  - Super/Sub Geostationary
  - Geostationary Transfer Orbit
  - Geostationary orbit (single location)
- Using representative payload meeting performance requirements perform feasibility study of EELV Secondary Payload Adapter (ESPA) class spacecraft bus
  - Goddard Space Flight Center Mission Design Lab developed potential spacecraft design that meets requirements
  - Cost evaluated using multiple cost models

V. Candidate Payload

Space Weather GEO Baseline Observation Requirements

	Requirement	ST	EXP	ME
Magnetic Field	Measurement Range:	±400 nT	±512 nT	±550 nT
	Measurement Accuracy:	2 nT/axis	1 nT/axis	0.2nT/axis
	Sampling Interval:	2 Hz	10 Hz	20 Hz
	Data Latency:	60 sec	10 sec	5 sec
Electrons and Protons	Coverage:	N/A	5 ang. in range 10-90°	N/A
	Measurement Range:			
	Electrons	800,000 eV - 4 MeV	30 eV- 4 MeV ≥ 15 log energy bins	20 eV - 10-MeV
	Ions (inc. Protons)	1.0 X 10^6 eV - 500 MeV	30 eV- 10 MeV; ≥ 10 log bins	10 eV - 1000 MeV
	Measurement Accuracy:	40%	25%	10%
	Sampling Interval:	60 sec	30 sec	10 sec
	Data Latency:	60 sec	30 sec	10 sec

ST = Study Threshold, EXP = Expected in mid-2030s, ME = Max Effective

Not required to fly with magnetometer but goal to fly on same S/C:

Energetic Heavy Ions	Measurement Range:	$0.055(E/n)^{-1}-5x10^4(E/n)^{-2.3}$

Potential Payloads

Magnetometer:

Instrument	Existing	Capability	Size	Mass
A	Yes, Not flown	Accuracy: <1.5 nT Noise: <25 pT/√Hz	0.5 U	0.5 Kg
B	Yes	Accuracy: <1.5 nT Noise: 8 pT;	1 U	~1 Kg
C	Yes, Not Flown	Accuracy: 0.5 nT Noise: 600 pT/√Hz	0.3 U	0.2 Kg

Particle Detector (Low Range):

Instrument	Existing	Capability	Size	Mass
D	No	elec: 30 eV to 30 keV prot: 30 ev to 30 keV	1.5 U	2.2 Kg
E	No	elec: 10 eV to 40 keV prot: 10 eV to 40 keV	1.3 U	2.1 Kg

Particle Detector (Mid Range):

Instrument	Existing	Capability	Size	Mass
F	No	elec: 100 eV – 100 keV prot: 100 eV - 100 keV	1.5 U	2.4 Kg
G	No	prot: 3 keV to 70 keV		

VI. Candidate Payload *(continued)*

Particle Detector (High Range):

Instrument	Existing	Capability	Size	Mass
H	No	elec: 35 keV to 1.0MeV prot: 35 keV to 1.0MeV	~1 U	0.9 Kg
I	No	elec: 50 keV to 4 Me prot: 80 keV to 12 MeV	3.4 U	2.4Kg
J	No	elec: 5 keV to 10 MeV; prot: 200 keV to 200 MeV	1.5 U	

Heavy Ions:

Instrument	Existing	Capability	Size	Mass
K	Yes	prot: 1 MeV to 500 MeV Alphas: 4MeV to 500 MeV	9 U	8 Kg
L	Yes	H+He: 10 MeV to 200 MeV	19 U	10 Kg

Selected Payload for Feasibility Study

Set of instruments with largest SWAP and potentially meet performance requirements

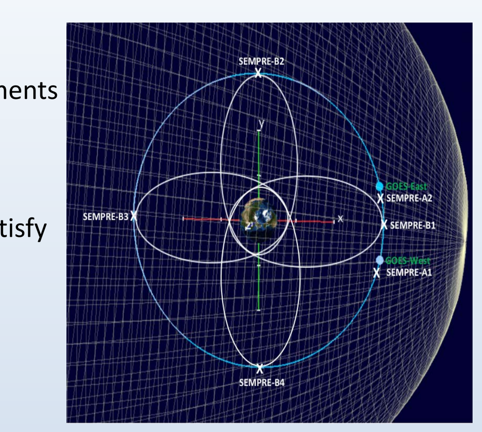
Instrument	Size	Mass	Power	Data Rate
Magnetometer	0.5 U	0.5 Kg	0.4 W	2 Kbps
Particle Det – Low Range	1.5 U	2.2 Kg	2.5 W	1.6 Kbps
Particle Det – Mid Range	1.5 U	2.4 Kg	2.0 W	3.2 Kbps
Particle Det – High Range	3.4U	2.4 Kg	6.0 W	3.2 Kbps
Heavy Ions	9 U	8 Kg	5.0 W	2.2 Kbps
	19 U	10 Kg	6.0 W	1.6 Kbps
Totals		**25.5 Kg**	**21.9 W**	**13.8 Kbps**

Note: All particle detector payloads in trade have limited field of view necessitating spacecraft to rotate instruments about earth pointing axis to provide required coverage

VII. Candidate Orbits

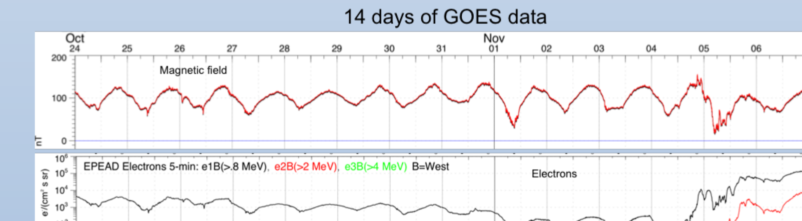
Possible Orbits Considered for constellation:

- Super/Sub GEO
  - Advantages:
    - At super GEO lack of disposal requirements would eliminate need for redundancy
    - Station Keeping not required
  - Disadvantages:
    - Require total of 4 to 6 spacecraft to satisfy continuous coverage over Americas

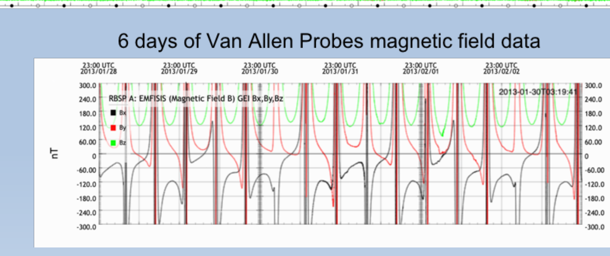


- GEO Transfer Orbit
  - Advantages:
    - More launch opportunities
  - Disadvantages:
    - Require total of multiple (>4) spacecraft to satisfy continuous coverage over Americas
    - Disposal requirements will dictate some redundancy and propulsion
- GEO Orbit
  - Advantages:
    - Continuous coverage consistent with historical observations
    - Single spacecraft vs constellation
  - Disadvantages:
    - Disposal requirements will dictate some level of redundancy and propulsion

14 days of GOES data

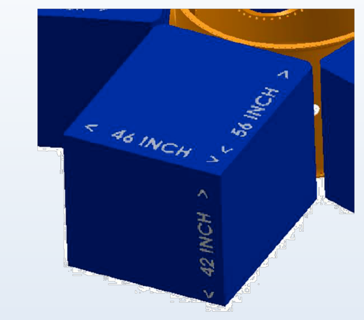


6 days of Van Allen Probes magnetic field data



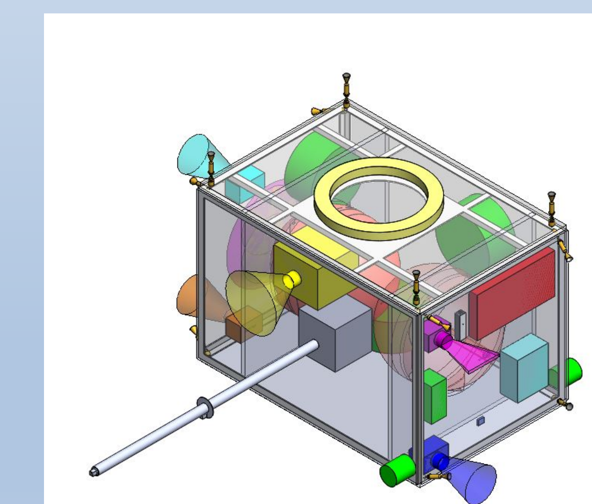
GEO Orbit at single location chosen as baseline due to payload costs of constellation

VIII. Goddard Space Flight Center Mission Design Lab Results



Driving Requirements:
- ESPA-class spacecraft (Envelope Constraints)
- Geosynchronous Orbit
  - Inclination less than 14 deg
  - Located over CONUS (75W to 137W)
- 2 revolutions per orbit about NADIR vector **with** 1 revolution per orbit to maintain NADIR pointing
- Mission Lifetime of 8 years; 10 year goal for consumables

Major Trades:
- Instrument platform spinning vs. entire spacecraft spinning
  - Bus spinning
    - ✓ Spinning platform deemed unnecessary complexity
- Launch to GEO Transfer Orbit with transfer to GEO vs direct inject to GEO
  - Direct inject chosen
    - ✓ Launch to GTO exceeds allowed mass due to additional delta V required.
- Body Mounted Solar Arrays vs 2-axis Solar Arrays
  - Body mounted Solar Arrays chosen
    - ✓ Launch to GTO exceeds allowed mass due to additional delta V required.
- Green propulsion vs. Mono-prop vs. Bi-prop
  - mono-prop (hydrazine) chosen
    - ✓ Sufficient delta V with minimal complexity



Results
Total cost of developing, integrating and operating single ESPA class spacecraft is consistent with cost of integrating set of instruments on two large typical GOES spacecraft.

IX. Class D Option - Inexpensive, Short Mission Life

- ESPA Class Spacecraft
  - Minimal hardware to provide increased resiliency for safe disposal
  - 3-5 years expected mission life
- Reduced Mission Life will result in needing 3 to 4 S/C to provide equivalent mission life of 10 years
  - Instrument costs become driver.
  - Exclude Heavy Ion detector due to size and cost

Instrument	Capability
Low Range	10 eV to 40 keV
High Range	35 keV – 10 MeV (with mods)
Magnetometer	~1 nT accuracy

Results
Total cost of developing, integrating and operating 4 Class D ESPA class spacecraft is consistent with cost of integrating set of instruments on two large typical GOES spacecraft.

X. Acknowledgments

Contact Information: Monica Todirita
(301) 286-3284
Monica.Todirita@nasa.gov