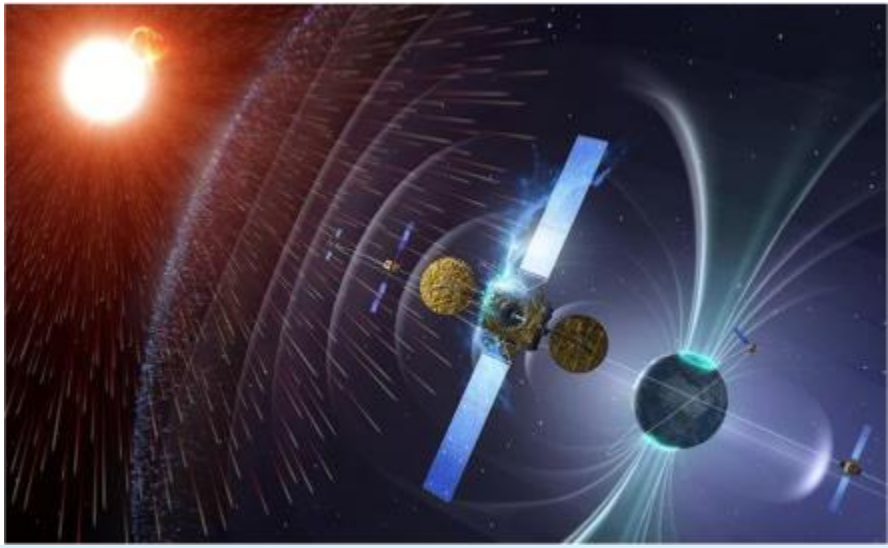
NOAA Space Weather (SWX) Program: Magnetospheric Requirements

Rob Redmon[1], D. Vassiliadis[2], T. G. Onsager[3], L. Zanetti[2], S. Anand[2]
[1]NOAA/NESDIS/NCEI, [2]NOAA/NESDIS/OPPA, [3]NOAA/NWS/SWPC

Community Meeting on NOAA Satellites

Informing the Future of NOAA Satellite Observations

September 30, 2020



Outline

- Magnetospheric Monitoring Rationale
  - Magnetospheric Weather Effects
- Requirements Capture
  - Efforts to capture and evaluate needs to maintain and enable future capabilities
- Summary

Magnetospheric Weather Effects

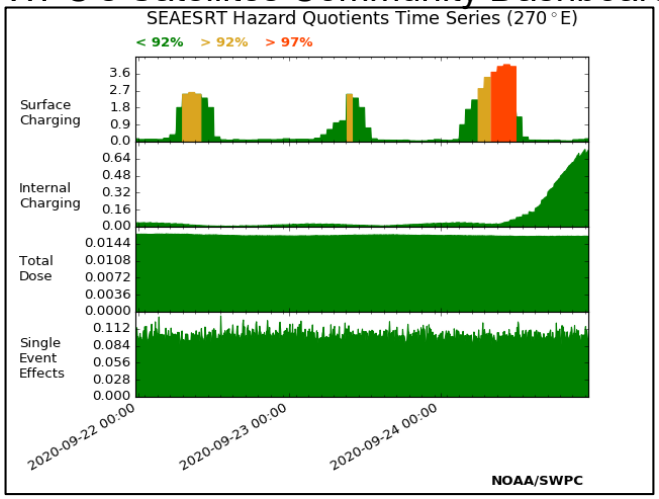
The magnetosphere and its radiation belts → wide range of space weather conditions. In situ effects depend on spacecraft or human experienced radiation environment history. Energetic particles penetrating the Earth's magnetospheric shield can impact space, aviation and ground systems. E.g.:

- Spacecraft charging → Electrostatic Discharge (ESD) damage
  - i.e. >2 MeV electron Alert
- Single-event effects (SEEs) → System reboots / upsets
  - i.e. Solar Radiation Storm S-Scale
- Event and lifetime total dose → Performance degradation
- Solar and Galactic ions → Comms. effects and potential Human risk
  - i.e. >500 MeV proton Aviation Alert

Satellite Regional Warning (notional, O'Brien, 2017)

	Surface Charging	Internal Charging	Single Event Effects	Event Total Dose
GEO				
High Inc LEO				
Low Inc LEO				
ISS				
GNSS				
MEO				
HEO				
Tundra				

SWPC's Satellites Community Dashboard



https://www.swpc.noaa.gov/communities/satellites

Magnetospheric Obs and Ops Models

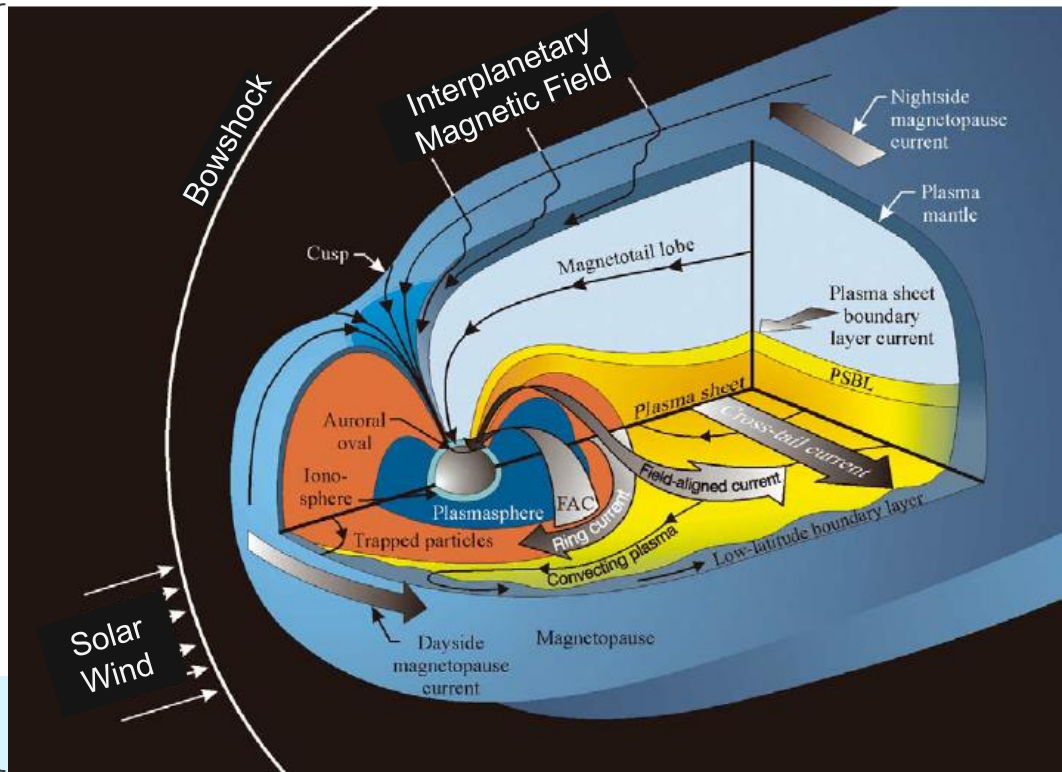
Subset of Operational Models and Magnetospheric Observations

Model (Existing and In Development)	**Required (Magnetosphere) Data**
Aviation Radiation (Supporting ICAO needs Link to Aviation Community Dashboard)	GEO high energy protons GEO high energy alphas
D Region Absorption Predictions (D-RAP)	GEO high energy protons
Geospace	Magnetic field for validation
GOES Magnetopause (GOES-R SPADES L3 coming soon)	GEO magnetic field
Relativistic Electron Forecast Model (REFM)	GEO electrons
Spacecraft Environmental Anomalies Expert System – Real Time (SEAESRT) (Link to Satellite Community Dashboard)	GEO protons GEO >2MeV electrons

Magnetosphere Requirements Capture

- Objective: Develop and explore the **trade space** for a NOAA satellite constellation focusing on **magnetospheric weather** prediction
- Within the trade space, **estimate benefits** from the mission, e.g. improvements in data-product and model accuracy and availability.
- Examine the **impacts on accuracy and latency** due to different orbit combinations.
- Scope: Results from trade space studies will be combined with those of others (solar, heliospheric, ionospheric). The final **constellation** will have satellites whose instruments will likely fulfill **not only magnetospheric but also other objectives**.
  - These studies contribute to the formulation of the SWX Program.
- These activities are synergistic with the efforts to meet the objectives of the 2019 National Space Weather Strategy and Action Plan (SWORM 2.1).

Magnetospheric regions and current systems



Trade Space: Objectives

Evaluations focus on two magnetospheric objectives [POR 2025 in SPRWG 2018]:

1. Magnetospheric Magnetic field
   a. LEO
   b. GEO: SPRWG B13 (table on right).
   c. Other locations
2. Ion/electron flux (includes SPRWG B14).
   a. High-energy particles: SPRWG B14
   b. Low- and medium-energy particles

Attribute	POR	SPRWG EXP
Range (nT/axis)	512	512
Accuracy (nT/axis)	1.0	1.0
Refresh rate (Hz)	10	10
Data Latency (s)	>5	10

[SPRWG Final Report, 2018]

SEISS	Species	Energy Range (eV)	Energy Channels
MPS-LO	Ions	0.03-30 k	15
MPS-LO	Electrons	0.03-30 k	15
MPS-HI	Protons	80 - 10M	11
MPS-HI	Electrons	50 - 40M, >2M	11
SGPS	Protons	1 - 500M, >500 M	11

[SPRWG Final Report, 2018]

POR = Program of Record

SPRWG = Space Platform Requirements Working Group

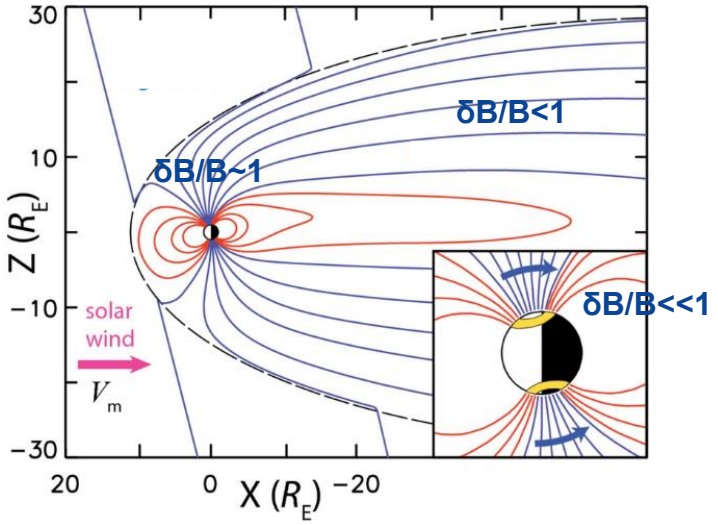
Trade Space: Key Performance Parameters and Measures of Effectiveness

- Key performance parameters (KPPs) selected:
  1. Magnetic field at GEO
  2. Electron flux at 1 keV at GEO (surface charging)
  3. Electron flux at 2 MeV at GEO (internal charging)
  4. Proton flux at >10 MeV at GEO (single-event upsets)
  5. Proton flux at >500 MeV at GEO (aviation radiation)
  - Not included at this stage: B-field at other locations, ion/electron fluxes at other energies
- The measure of effectiveness (MOE) is a function of the accuracy of DA models:
  1. Field model accuracy
  2. Electron flux model accuracy
  - The above accuracies depend on sensor accuracy, availability, and event timescales (e.g. charging time or energization duration).
  - To be added to MOE: Data latency, particularly important for LEO.

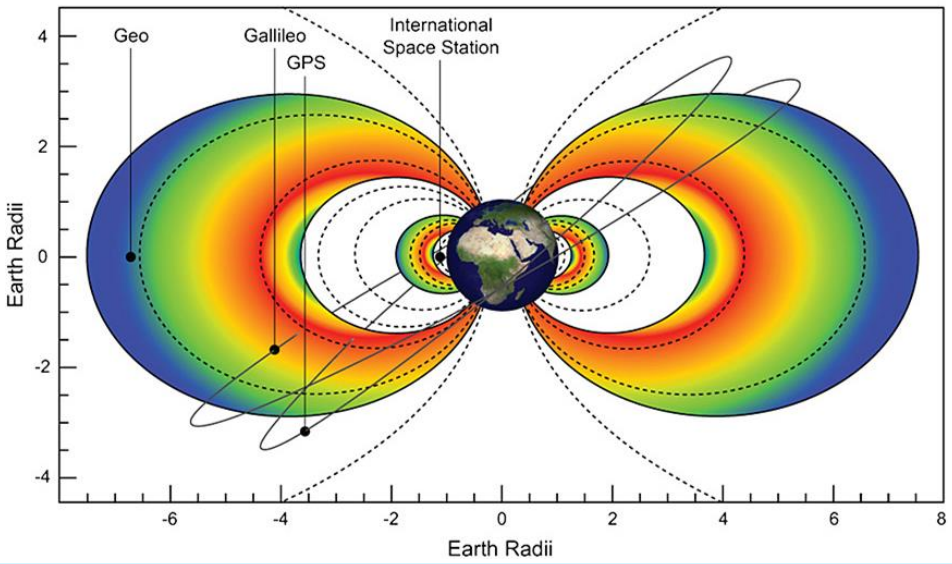
Trade Space: Orbits

- Options: LEO, MEO, GEO, and HEO.
- Magnetic field measurements: needed in all key orbits.
- Particle flux measurements: needed in all user orbits.
  - Low-energy: surface charging
  - Medium and high energy: internal charging, SEEs
- Launch costs based on NASA experience.
- Orbit to be considered: Earth-Moon Lagrange 1 for space exploration-related objectives.

Magnetic field magnitude ratios



Energetic electron flux (shading) and sample orbits



Trade Space: Users

- An operational space weather user seeks one or more types of information:
  1. Data products (e.g., NOAA Level 3 and higher)
  2. Output of global models (Enlil, Geospace) for situational awareness
  3. Output of regional or tailored models (Kp/Dst, SEAESRT) if the models describe the user's system.
- Users of magnetospheric weather information are divided in 5 categories [Abt Associates, 2019]:

User Category	Data Products	Global model	Regional/Tailored Models
#2. Satellite operators	(✓)	✓	✓
#4. Commercial aviation		✓	✓
#1. Electric power grid #5. Emergency managers		✓	
#3. GNSS operators	(✓)	✓	✓

- Users in #2 and 4 operate systems deployed in space and use all 3 or most types of information.
- Users in #1, 3, and 5 operate terrestrial systems so they only need situational awareness that is generally obtainable from global models.

Summary - Magnetospheric Reqs
(Preliminary trade space evaluation)

- Preliminary studies have examined B-field and particle-flux objectives in the POR 2025 and SPRWG -- and synergies with SWORM 2.1 and the summer NAS workshops.
- Considered: KPPs and an MOE based on improvements on accuracy and availability, but not on latency (small), along with standard instruments supporting required range & energy/spatial/temporal resolution;
  - And eight configurations for LEO, GEO, and select MEO & HEO options
- Optimal configuration - 2xLEO satellites, 2xMEO satellites (GPS-like orbits), 1xGEO satellite, 1xGEO-XO hosted payload, and 2xHEO (tundra or Molniya)
- GEO-XO Program - Preliminarily configuration:
  - Instruments on GEO satellites; particle detectors for low-, medium, and high-energy ion & electron flux -- continuation of the SEISS instrument
  - Optional: Instruments on tundra satellites; If the GEO-XO program includes such satellites, particle-flux and B-field detectors would be beneficial--as extended trade space topic.
- Refinements to technical benefits, cost estimates and risks also ongoing

References

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SWPC Storm Scales: https://www.swpc.noaa.gov/noaa-scales-explanation

SWPC Community Dashboards: https://www.swpc.noaa.gov/dashboards