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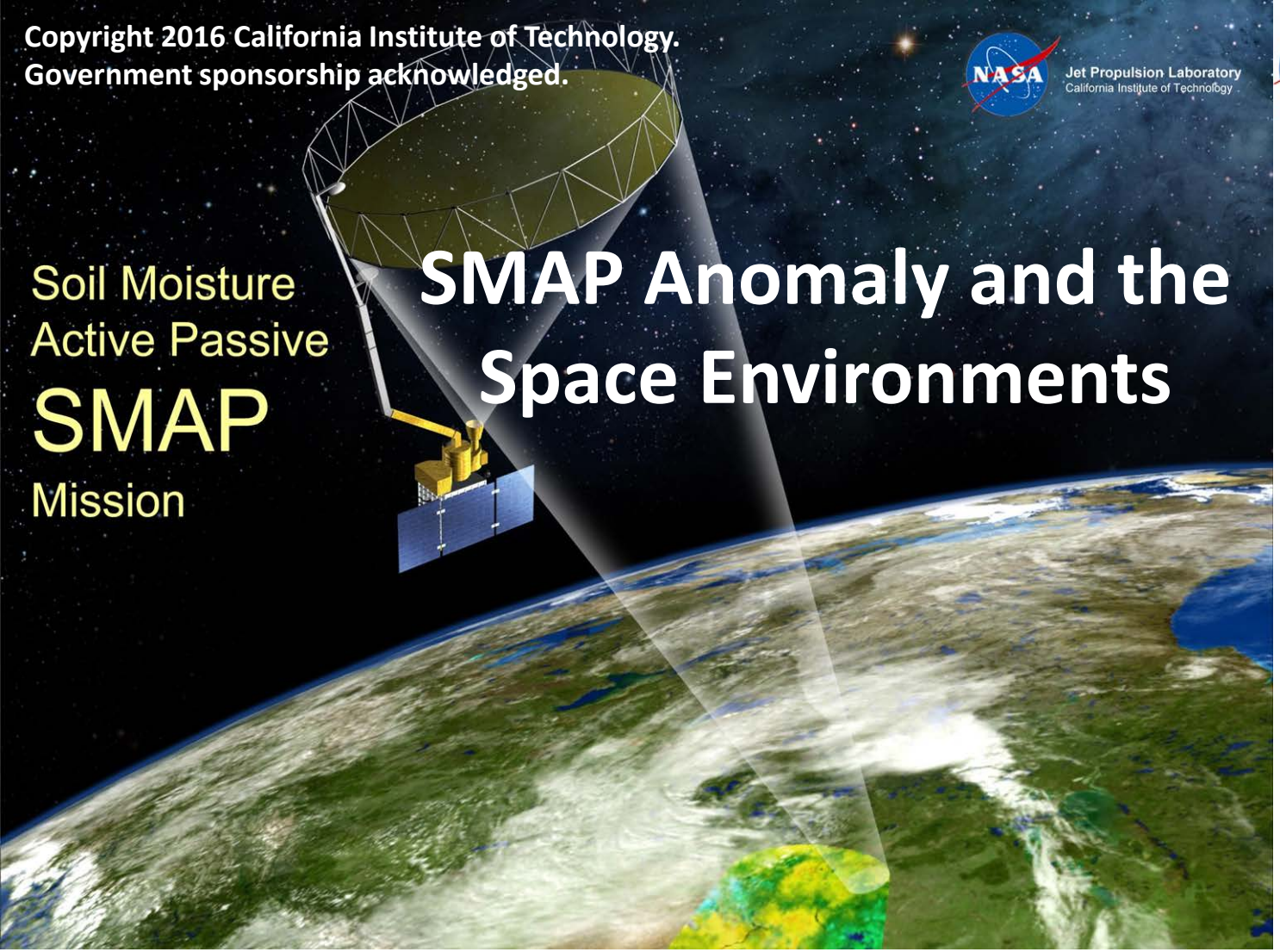

SMAP Anomaly and the Space Environments

Insoo Jun, Henry Garrett, Maria De Soria Santacruz Pich, Robin Evans, Martin Ratliff, and James Chinn

Jet Propulsion Laboratory, California Institute of Technology

SMAP Project Overview

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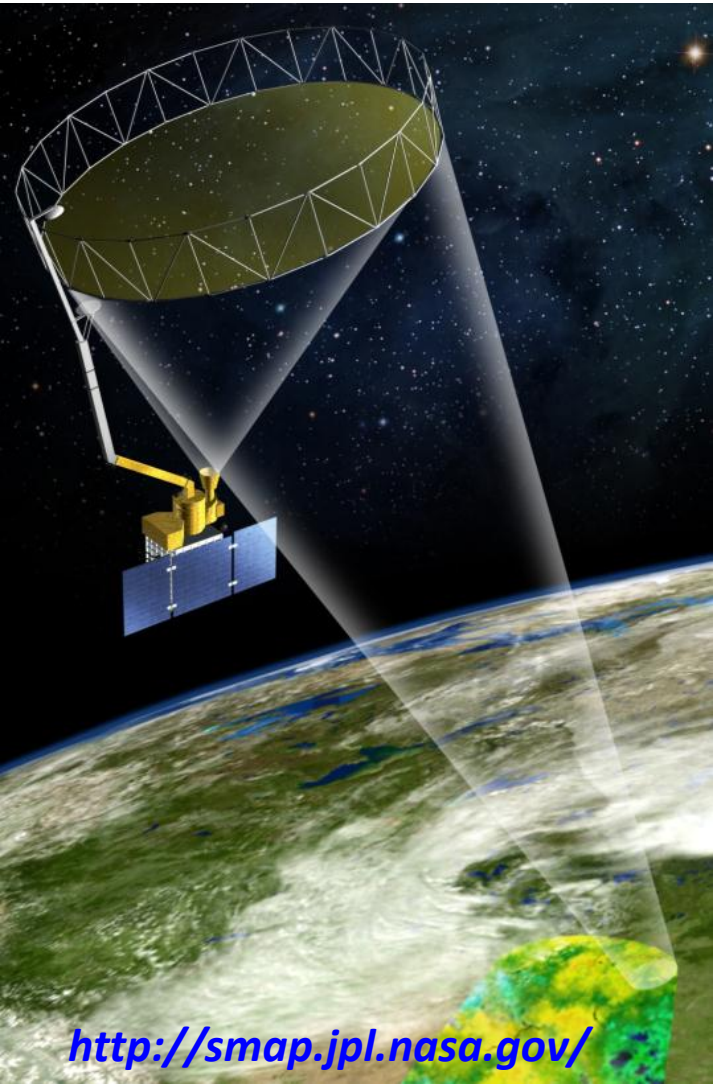

Primary Science Objectives

- Global, high-resolution mapping of soil moisture and its freeze/thaw state to
  - Link terrestrial water, energy, and carbon-cycle processes
  - Estimate global water and energy fluxes at the land surface
  - Quantify net carbon flux in boreal landscapes
  - Extend weather and climate forecast skill
  - Develop improved flood and drought prediction capability

Mission Implementation

Partners	• JPL (project & payload management, science, spacecraft, radar, mission operations, science processing) • GSFC (science, radiometer, science processing)
Risk	• NPR 7120.5E Category 2; NPR 8705.4 Payload Risk Class C
Launch	• January 31, 2015 on Delta II 7320-10C Launch System
Orbit	• Polar Sun-synchronous; 685 km altitude
Duration	• Three years
Payload	• L-band (non-imaging) synthetic aperture radar (JPL) • L-band radiometer (GSFC) • Shared 6-m rotating (13 to 14.6 rpm) antenna (JPL)

NRC Earth Science Decadal Survey (2007) recommended SMAP as a Tier-1 mission

Mission Elements

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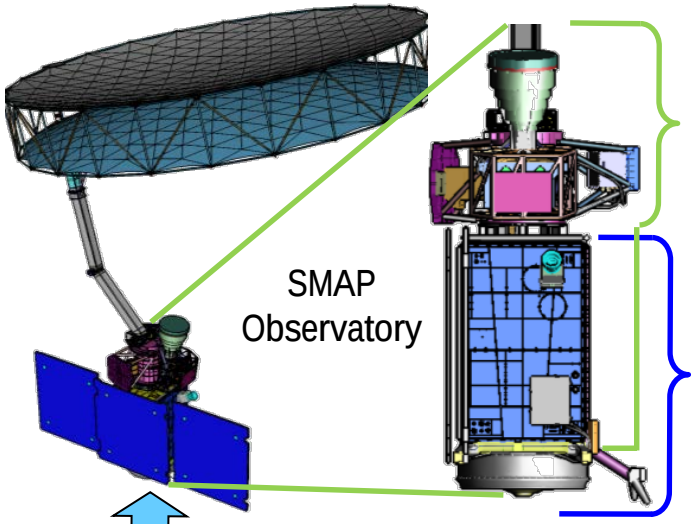
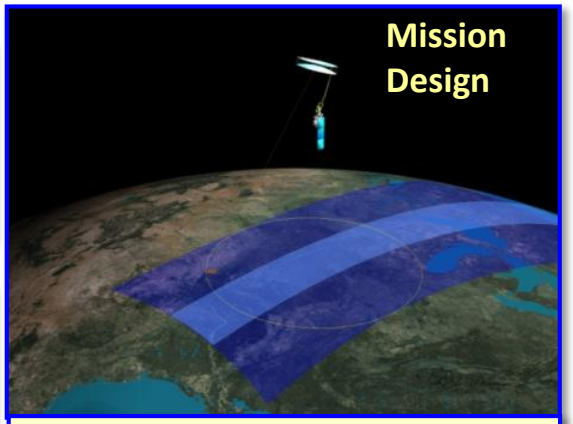


INSTRUMENT

- L-band (1.4-GHz) radiometer (GSFC)
- L-band (1.2-GHz) radar (JPL)
- Shared antenna (6-m diameter)
- Conical scan: 13–14.6 rpm; 40° incidence
- Contiguous 1,000-km swath width

SPACECRAFT (and RADAR ELECTRONICS)

- JPL developed & built
- JPL's MSAP/MSL avionics, power assys with a small number of new mission-unique card designs
- 944-kg wet mass (Observatory, measured)
- 1450-W capacity (Observatory-level)
- 81-kg propellant (measured)
- Commercial space electronics elsewhere

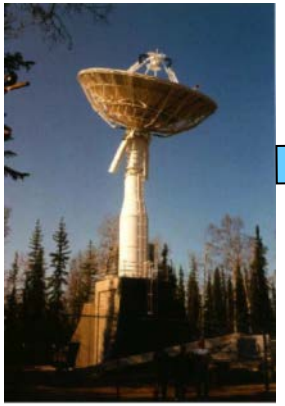


- 685-km polar orbit (Sun-sync)
- 8-day repeat ground track
- Continuous instrument operation
- 2- to 3-day global coverage
- 3-year mission duration

Delta II 7320-10C

Launched:
Jan 31, 2015

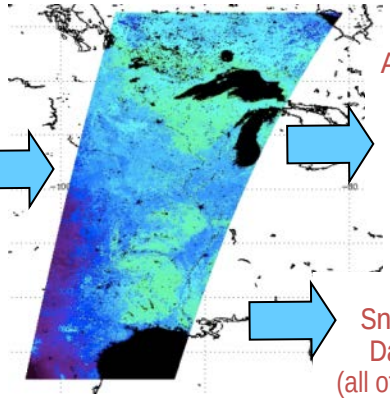
Near-Earth Network



Calibration/Validation Campaign

SMAP Mission Operations & Data Processing
(JPL, GSFC)

SCIENCE DATA PRODUCTS
Soil Moisture & Freeze/Thaw State Data Products



Alaska Satellite Facility Data Center (radar L1 products)

National Snow and Ice Data Center (all other products)

SMAP Observatory On-Orbit: Dual-Spin Architecture

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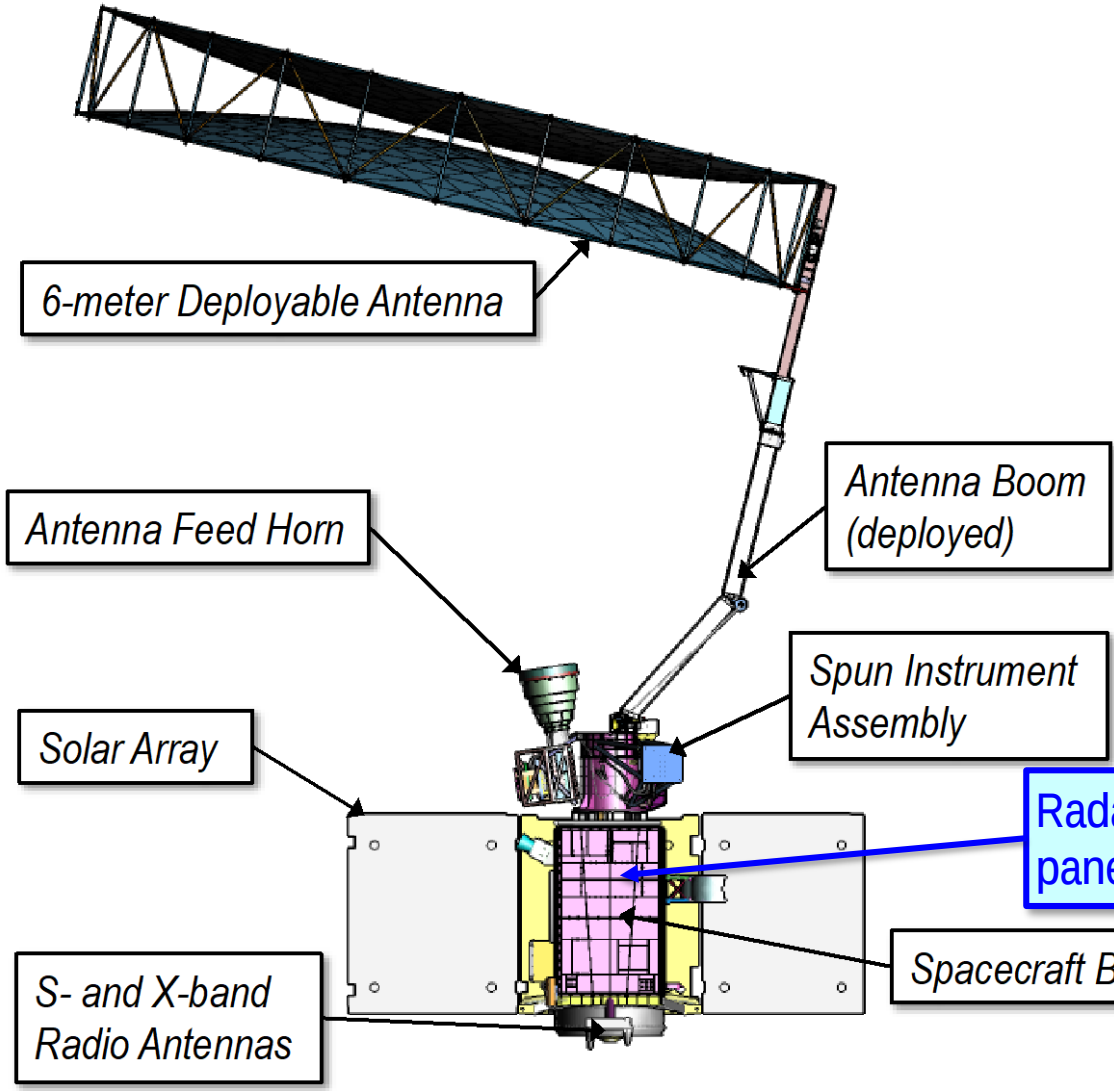

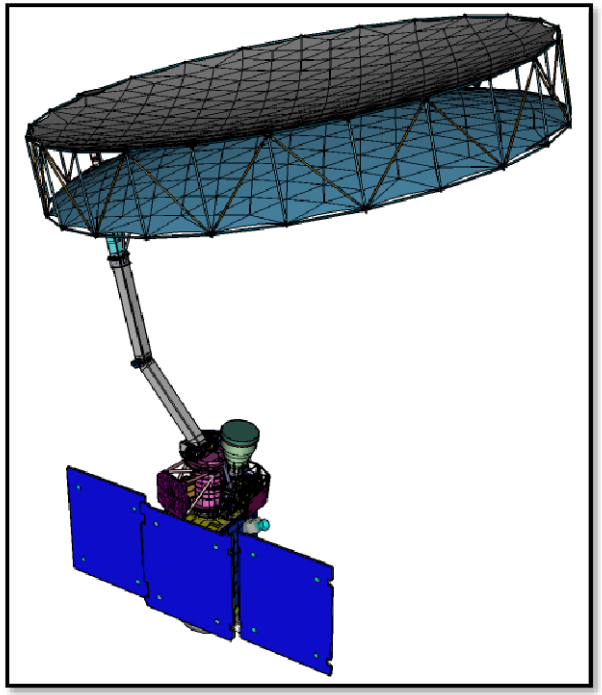

Alternative View

HPA Anomaly Summary

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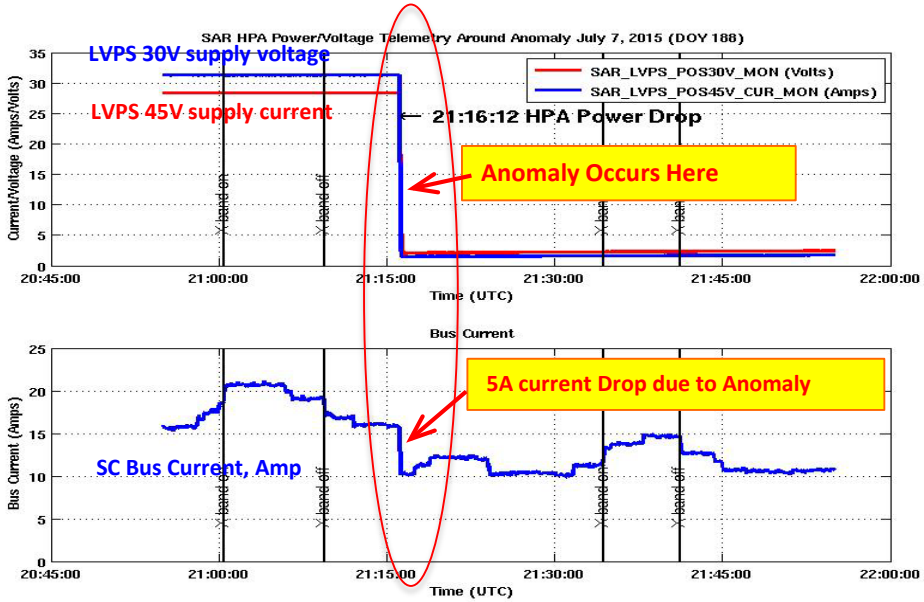
- On Tuesday, July 7 (2:16 pm PDT), DOY 188, SMAP Radar HPA suddenly stopped transmitting
  - 478 hours after last flight power cycle, 2027 transmit hours since launch, 3248 total hours
  - Flags for HPA internal under-voltage and over-current circuitry trips were high, consistent with no voltage applied to HPA and floating telemetry
  - Transmit power, current draw and temperature telemetry also consistent with HPA not transmitting
  - Radar loop-back telemetry indicated these state changes occurred abruptly
  - Observatory remained in Science Acquisition; no immediate action taken based on safe HPA assessment after anomaly



Snapshot of the SMAP Anomaly

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- SMAP launched on Jan 31, 2015 from Vandenberg AFB on a Delta II rocket
- SAR completed commissioning in May with no anomalies, minor or major
- On Tuesday, July 7, the SMAP Radar HPA suddenly stopped transmitting with no prior indications in telemetry suggesting a problem or anomaly
- An anomaly investigation team was assembled and continues to troubleshoot this radar anomaly
- The team has isolated the anomaly to the low voltage power supply (for the high power amplifier)
- Several attempts to recover the radar have not been successful. The team continues to analyze the flight and ground test data. The next attempt to power up the radar is scheduled for late August.
- The SMAP radiometer and the shared spinning reflector antenna continue to operate nominally
- The SMAP spacecraft is also healthy and operating nominally

Spacecraft and Beam Location

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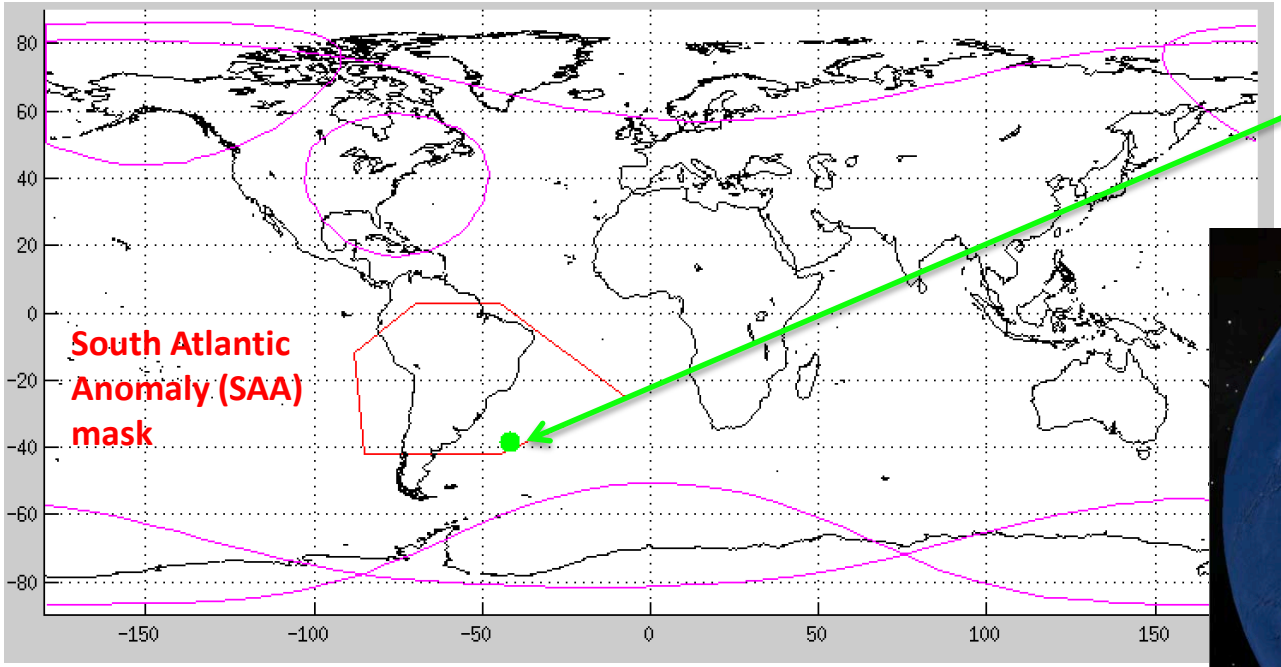
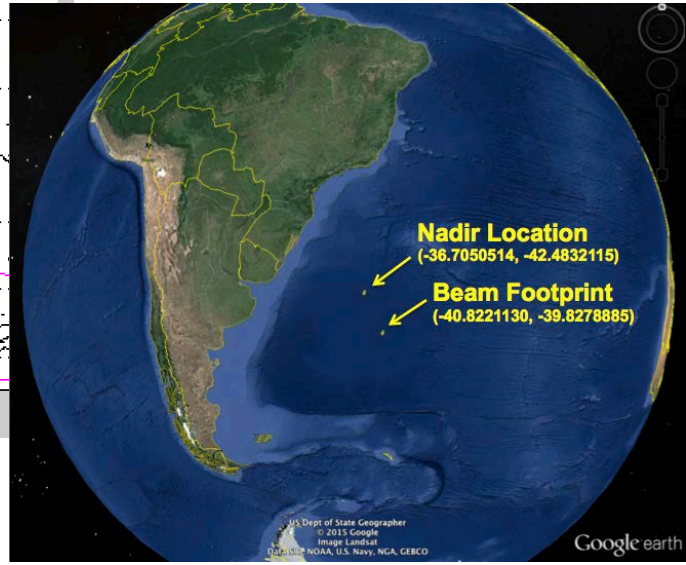


Spacecraft location at time of fault (orbit was ascending)



- The anomaly occurred during SMAP ascending orbit 1 minute into the South Atlantic Anomaly (SAA) region (green dot)
- All telemetry prior to the anomaly showed normal behavior
- Within a few seconds, the GNC SRU (stellar Reference Unit; aka Star Tracker) also experienced an ASIC overflow warning due to high-energy radiation environment (typically, this happens once per day or less during SAA region)

Space Environments and Effects

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Environment Effect	Source Particles
Total Ionizing Dose (TID) and Displacement Damage Dose (DDD)	Trapped protons in SAA; Solar protons
Surface Charging	Auroral electrons
Internal Charging (IESD)	High energy (> 1 MeV) electrons
Single Event Effects (SEE)	Trapped protons in SAA; Solar protons; Galactic cosmic ray
Structural damage	MMOD

Space Weather July 7-9, 2015

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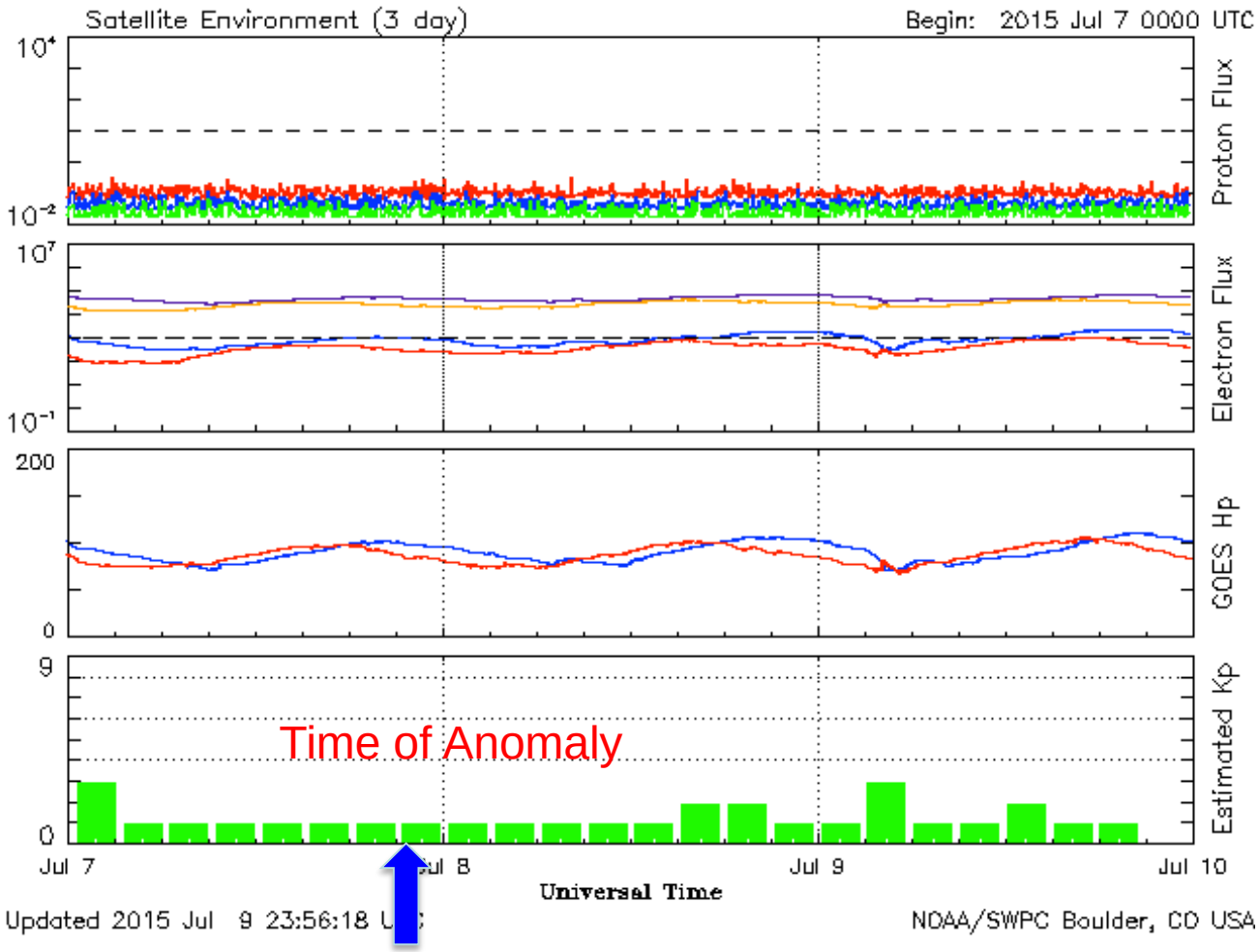
- Space weather was benign at the time of the anomaly



State of South Atlantic Anomaly

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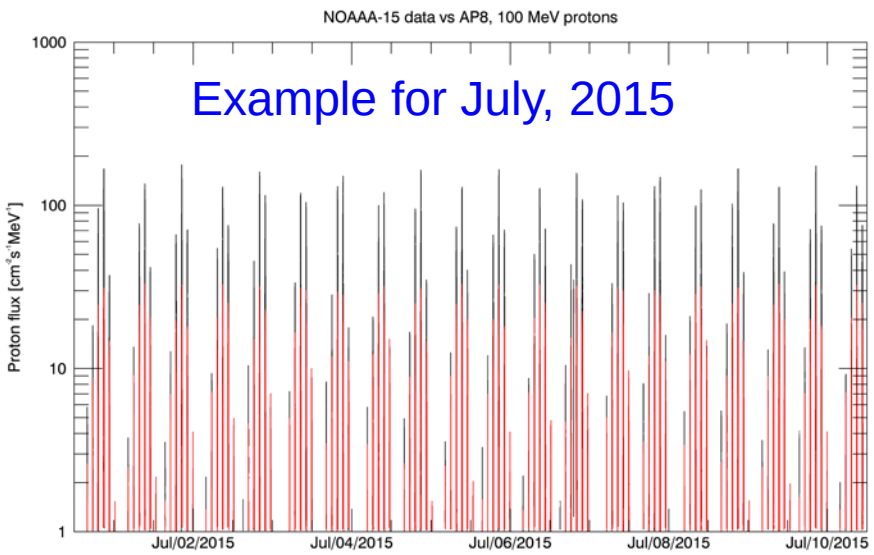
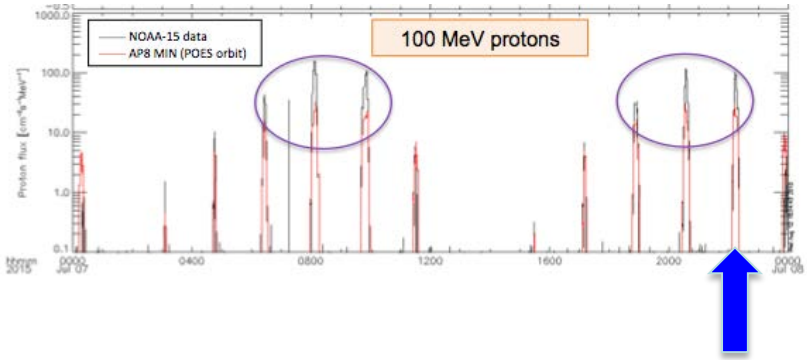
- The POES data indicate that the high energy proton environment in SAA has been consistently higher than AP8 model output for the POES orbit by a factor of 3-5 during the last few months
  - POES altitude = 850 km, inclination = 98-deg



July 7, 2015



Black line : POES
Red line: AP8

Time of Anomaly

Environments Assessments (1/3)

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- Shielding analysis has been completed using the ERD specification (scaled to 160 days) to evaluate total ionizing dose at the LVPS:
  - Parts in the LVPS have experienced <140 rad(SI), much less than 10 krad(Si), the least capable part.
  - Even if we account for higher SAA environment during the mission, the TID level incurred would be much less than the part capability.

- Worst case high-energy electron environment is too low to induce IESD events in this orbit.

IESD Hazard Zones

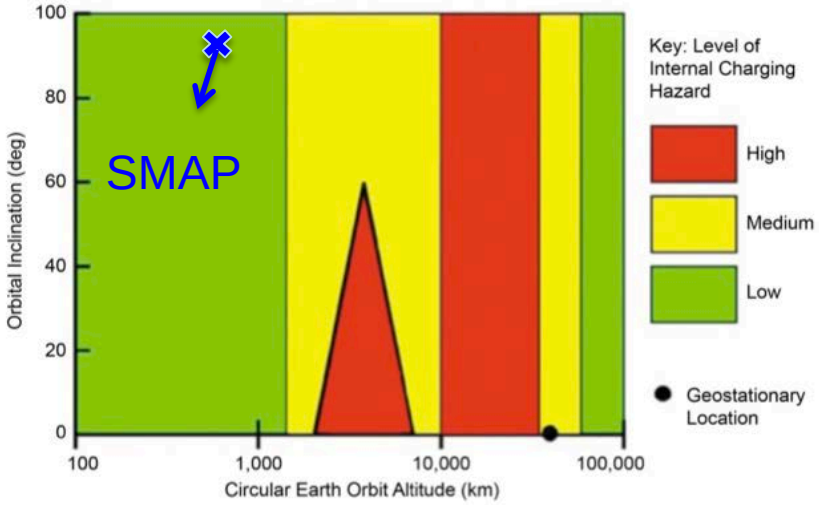

Fig. 1-2. Earth regimes of concern for on-orbit internal charging hazards for spacecraft with circular orbits.

Environments Assessments (2/3)

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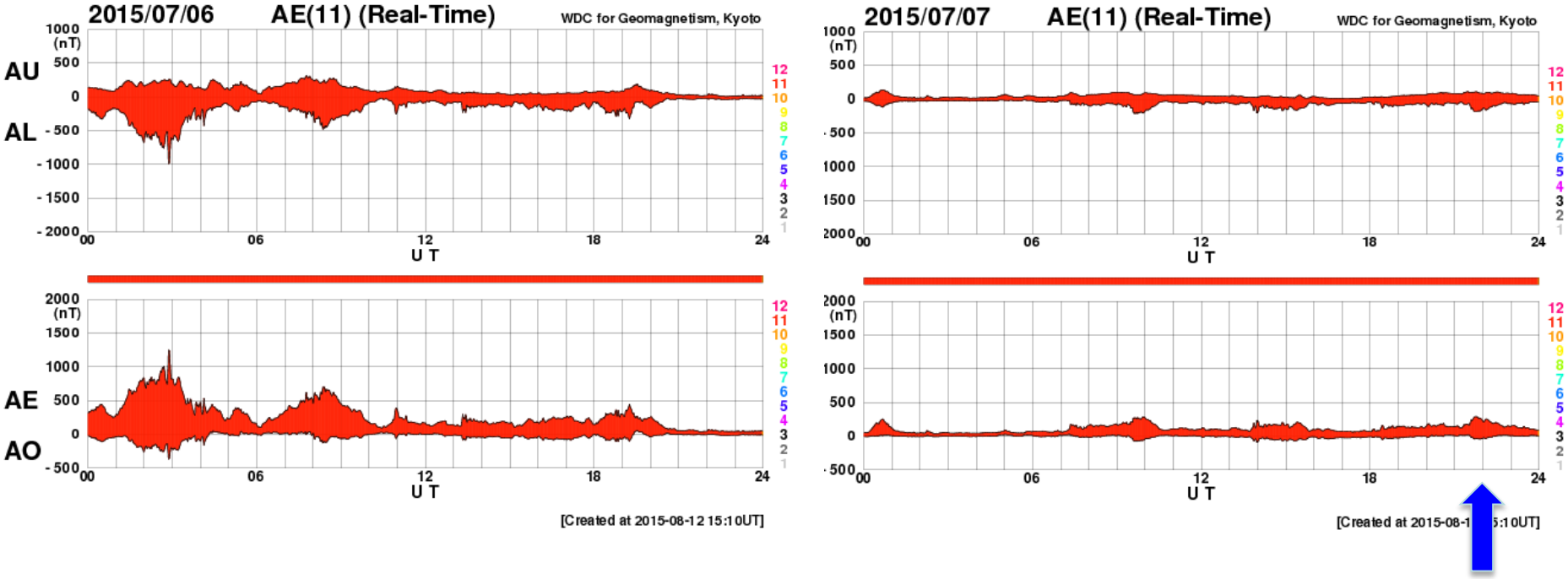
- Environment for surface charging (auroral fluxes) appears to have been moderate to low (AE index).



Time of Anomaly

Environments Assessments (3/3)

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- SEE:
  - No solar proton event
  - Both average and peak proton flux in SAA appears to have been higher than the design specification → However, at this time, there is no proton induced failure mode identified.
  - GCR is well shielded (geo-magnetically)
- MMOD: 0.0013 % impact probability due to MMOD particles
  - Probability of MMOD particles penetrating through 12 mm of aluminum [(2 mm –Y panel) + (5 mm RF chassis bottom) + (2 mm RF cover) + (3 mm LVPS chassis)]
  - No unusual attitude changes of the spacecraft at the time of anomaly
    - The GNC would have observed attitude changes if the anomaly was due to MMOD impact (i.e., the kinetic energy of a MMOD particle at which 12 mm of aluminum would be perforated is large enough to be detected)
    - Analysis package can be provided if requested.

- **OVERALL Risk Likelihood Assessment:**
  - **The likelihood of an "unusual" space-environment related phenomenon causing a failure in the LVPS is VERY LOW**

Backup

Assessment of Solar Protons

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- From Martin Ratliff:
  - I confirmed that there was no appreciable contribution to the total proton fluence from solar protons. There were only some minor events. It takes a bit more than 20 MeV for a proton to get through 0.100” aluminum, so the >30 MeV data is probably most relevant. The background level of the >30 MeV flux is about 3 orders of magnitude lower than the SAA >30 MeV flux. Considering the units on the plots in the attached file, the flux needs to get to around 100 to be similar to the SAA flux of 4.3x10^3 cm^-2 s^-1 for >30 MeV (from the ERD). But in the time period shown, it barely got above background in only two instances, and was never more than about 10, for time periods less than one day. In fact, even the >10 MeV flux only got a bit above 100 for only a part of one day.

Solar Protons

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- GOES Energetic Protons during SMAP mission: No solar energetic particle events of note.

January 2015

February

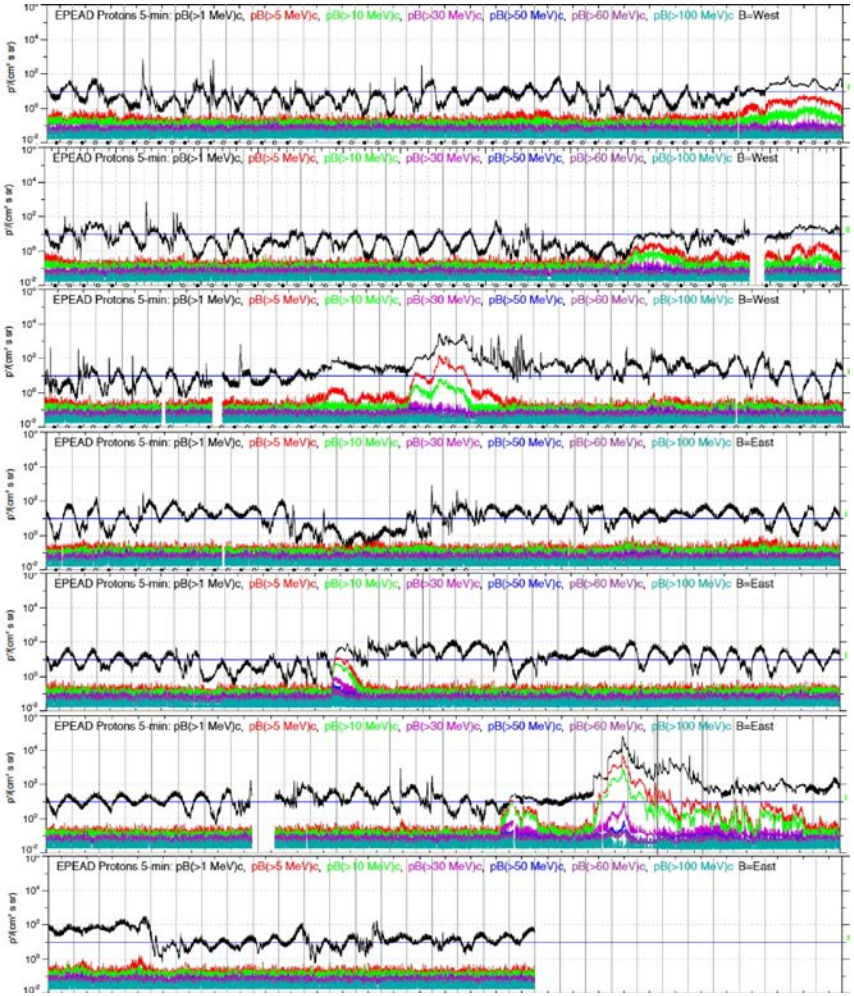
March

April

May

June

July



South Atlantic "Anomaly" – What it is

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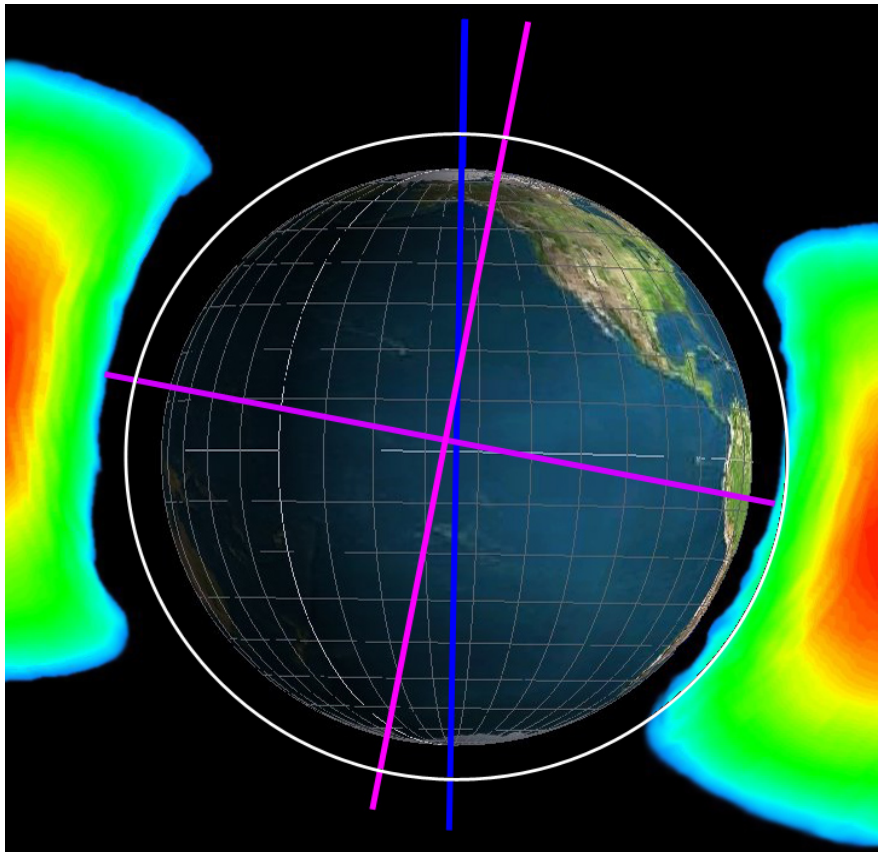
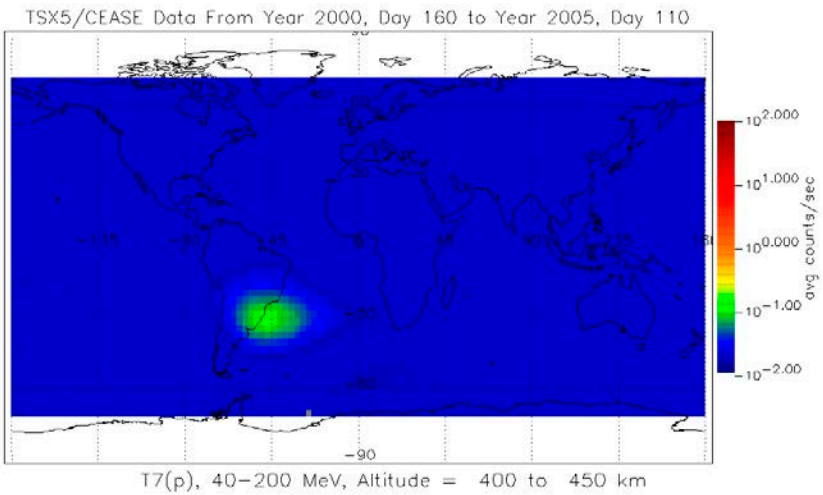


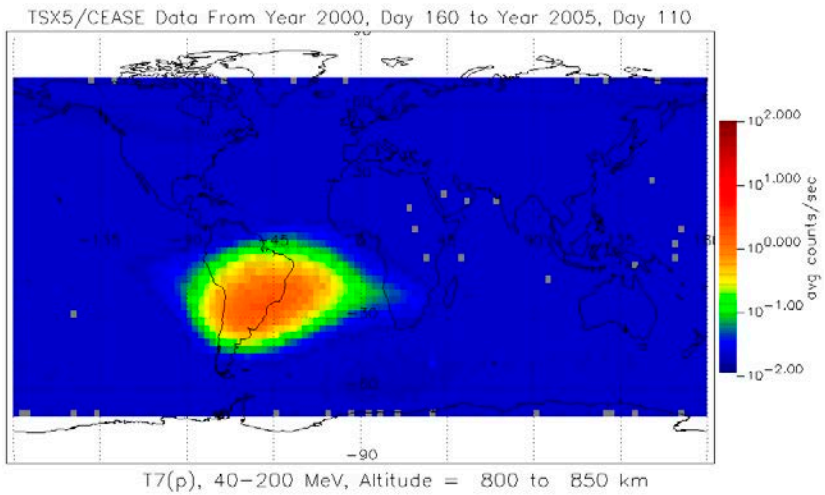
Stuart L. Huston

- Belts are roughly symmetric about magnetic dipole axis
- Tilt and offset of dipole cause lower edges of the belt to come closest to Earth near Brazil
- Also a high-altitude "anomaly" over southeast Asia (10–12,000 km)

Variation With Altitude



425 km



825 km

From:

Stuart L. Huston
Science Applications International Corporation

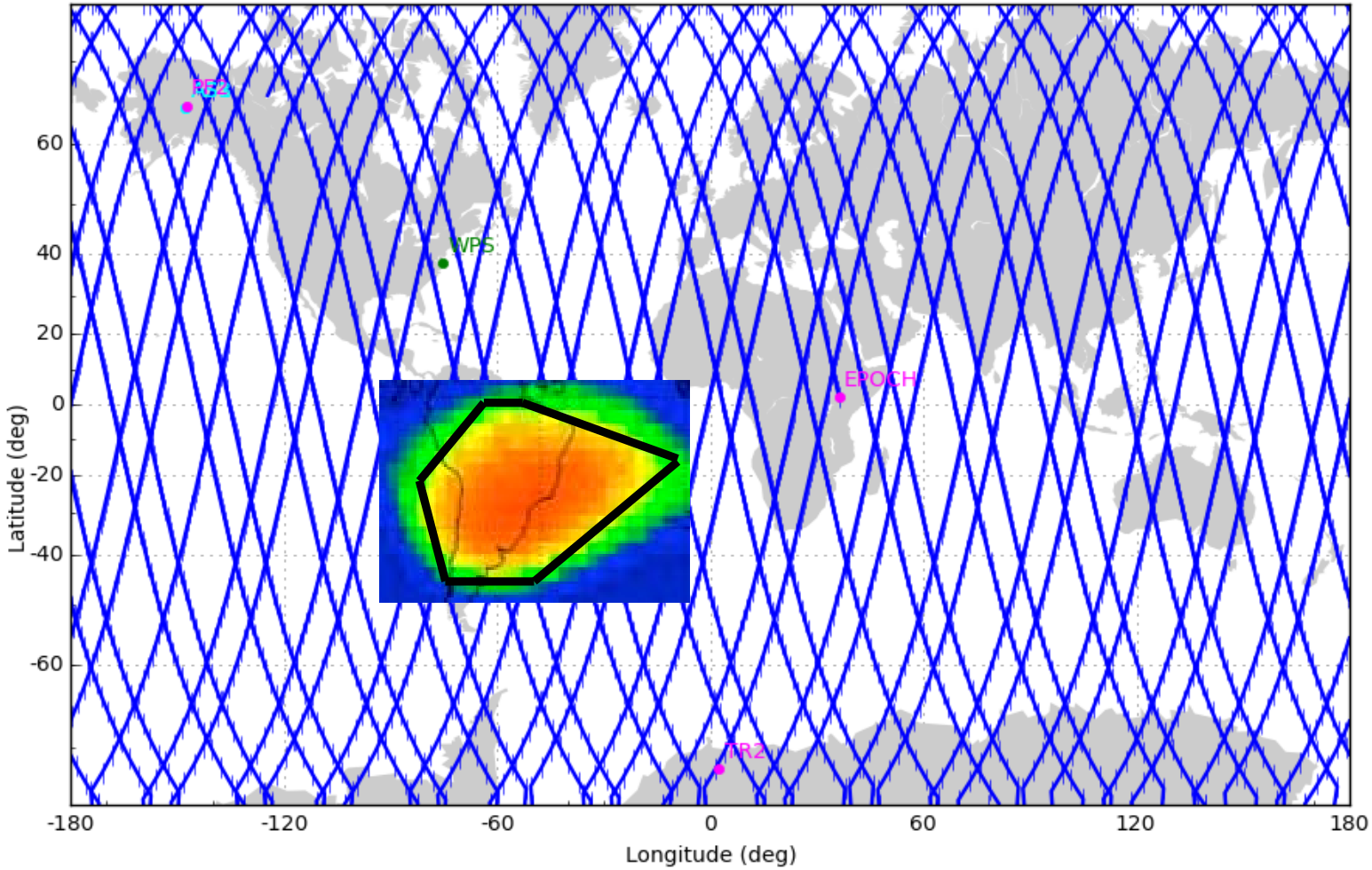
Space Technology Alliance
Space Environmental Effects Working Group
The Aerospace Corporation
El Segundo, California
2005 November 1–3

SAA polygon model

Jet Propulsion Laboratory
California Institute of Technology

Frequency: 6 passages per day

Duration: longest = 12 min 15 s
shortest = <30 s



Van Allen Probes vs AE8min

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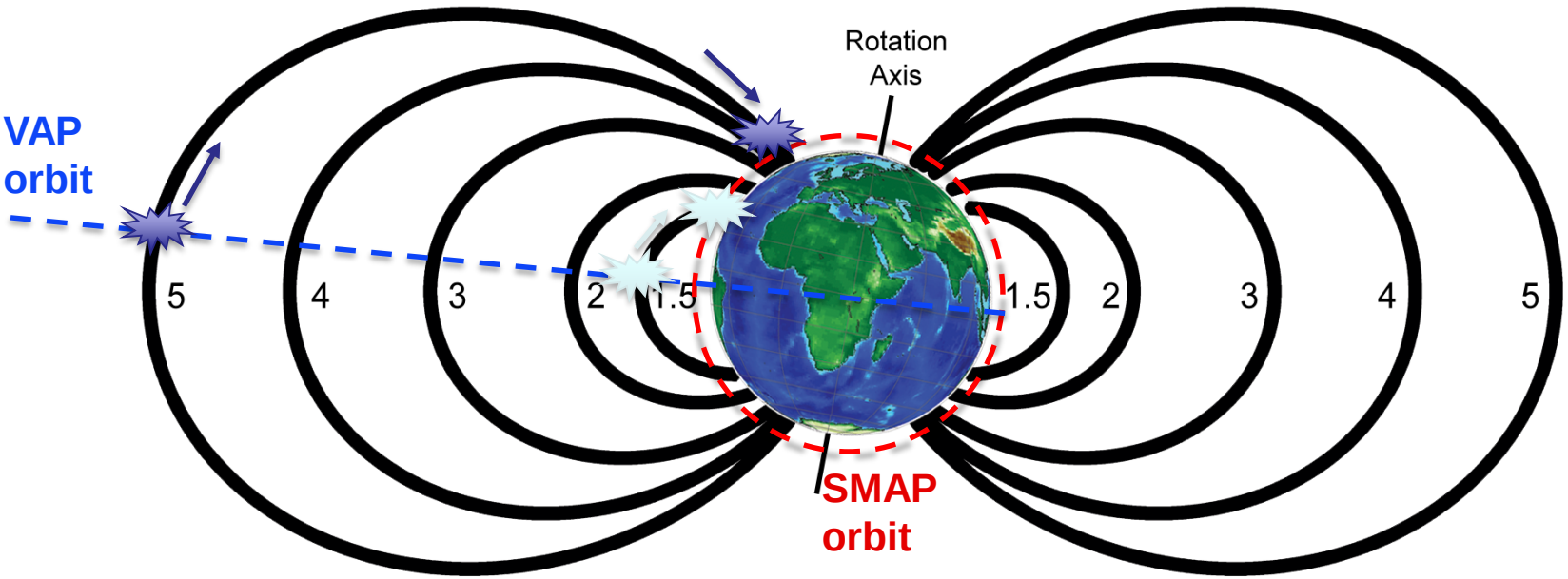
Enhancements observed by the Van Allen Probes (VAP) close to the equator can be observed by SMAP along the magnetic field lines



Energetic Electron Flux – VAP vs. AE8min

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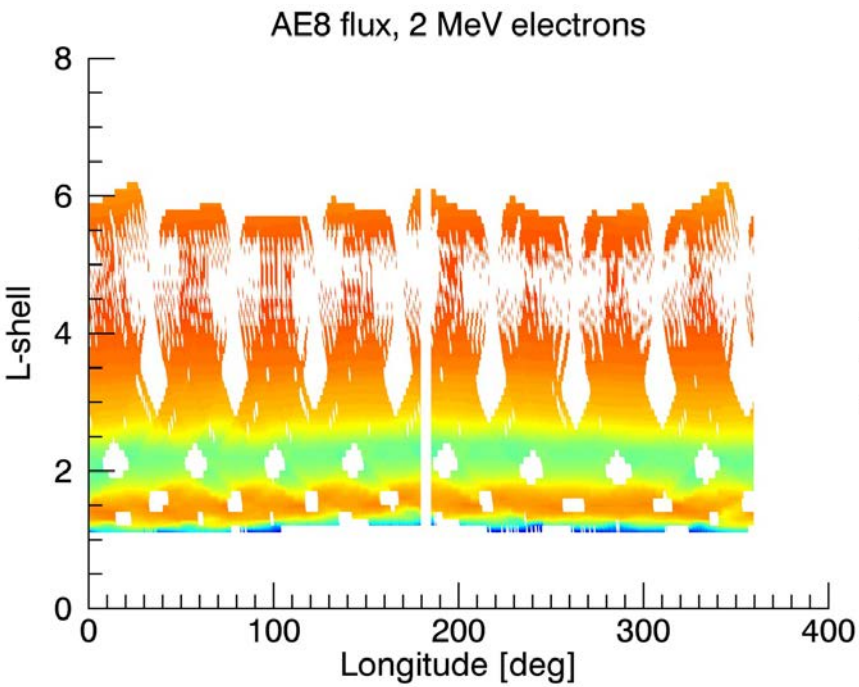
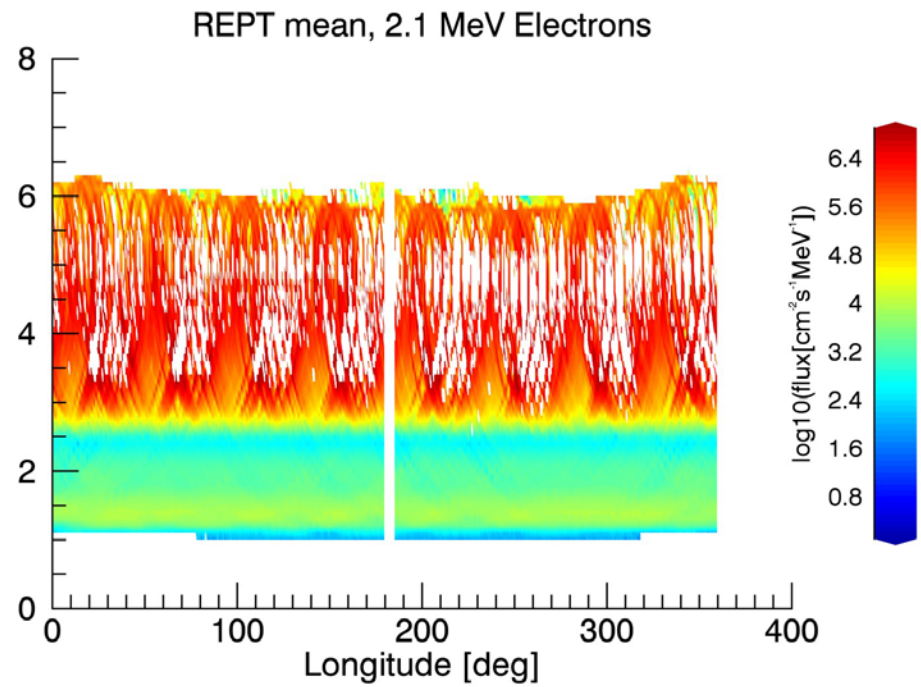
- Averaged flux from 05/01/2015 to 07/10/2015
- AE8 run for VAP orbit
- AE8 results in larger outer belt electron flux compared to REPT measurements
- AE8 results in smaller slot region electron flux compared to REPT measurements





Energetic Electron Flux – VAP vs. AE8min

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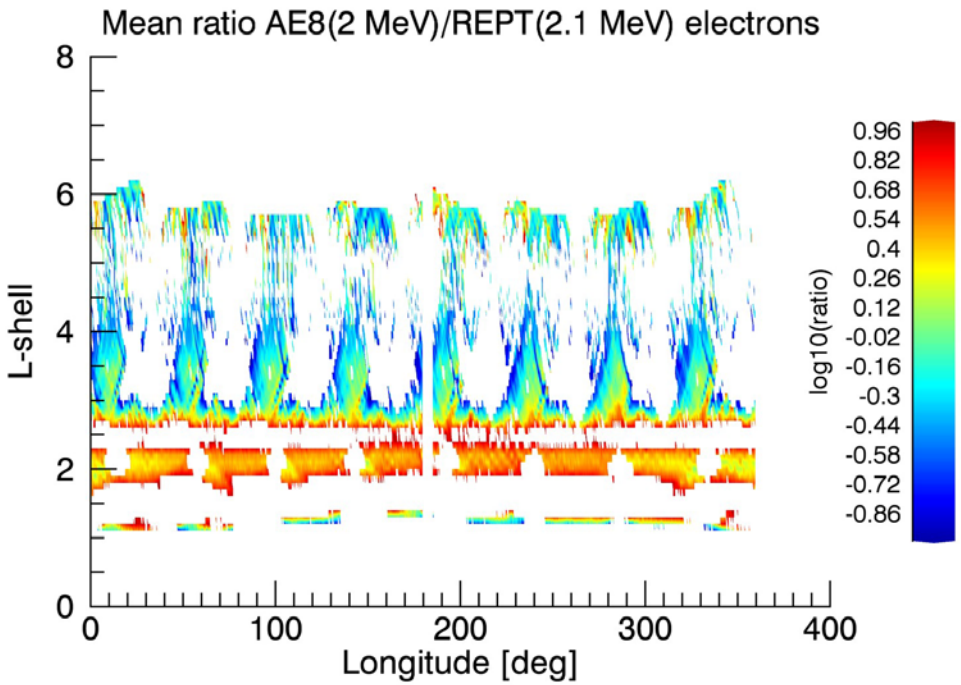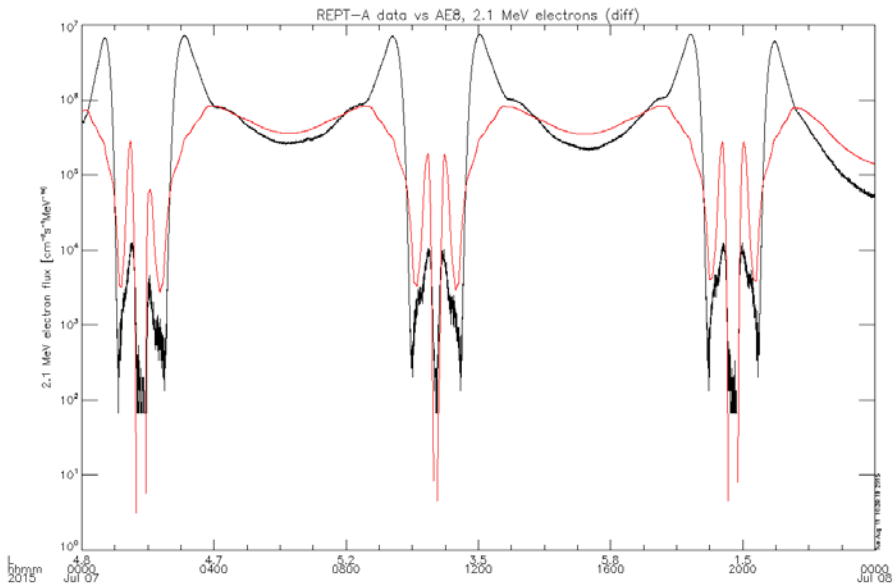
- Ratio between AE8(VAP orbit) and REPT averaged flux
- AE8 shows larger outer belt electron flux compared to REPT measurements
- AE8 shows smaller slot region electron flux compared to REPT measurements