



***Integrity ★ Service ★ Excellence***

# **SOUTH ATLANTIC ANOMALY AND CUBESAT DESIGN CONSIDERATIONS**

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# South Atlantic Anomaly and CubeSat Design Considerations



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**SPIE Paper 9604-24**



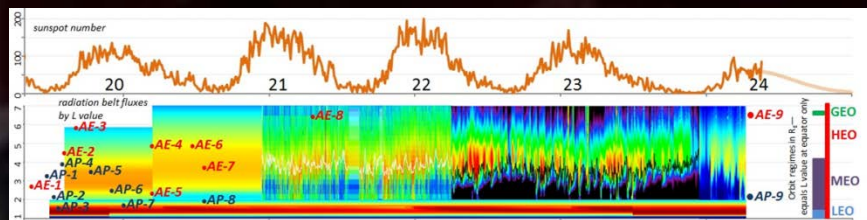
# South Atlantic Anomaly (SAA) & CubeSat Design Considerations



## 1.0 SAA Space Environment

## 2.0 Space Effects in the SAA

## 3.0 SAA Mitigation Strategies



Solar array power decrease

False stars in star tracker CCDs

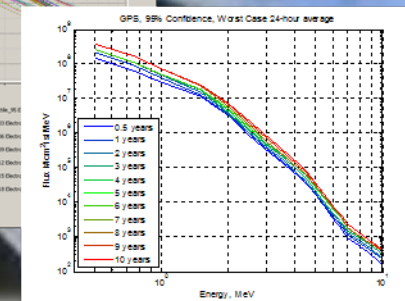
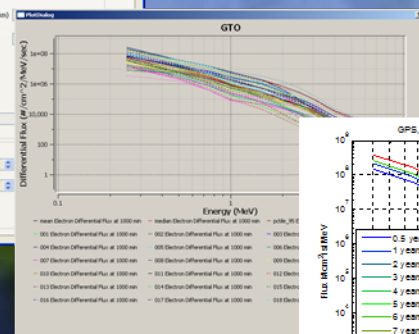
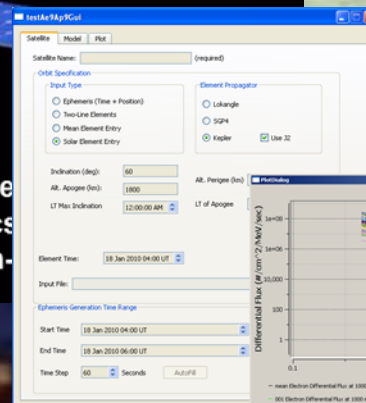
Surface degradation

EMP from vehicle discharge

Electronics degradation

Spacecraft components become radioactive

Single event electronics fatal latch



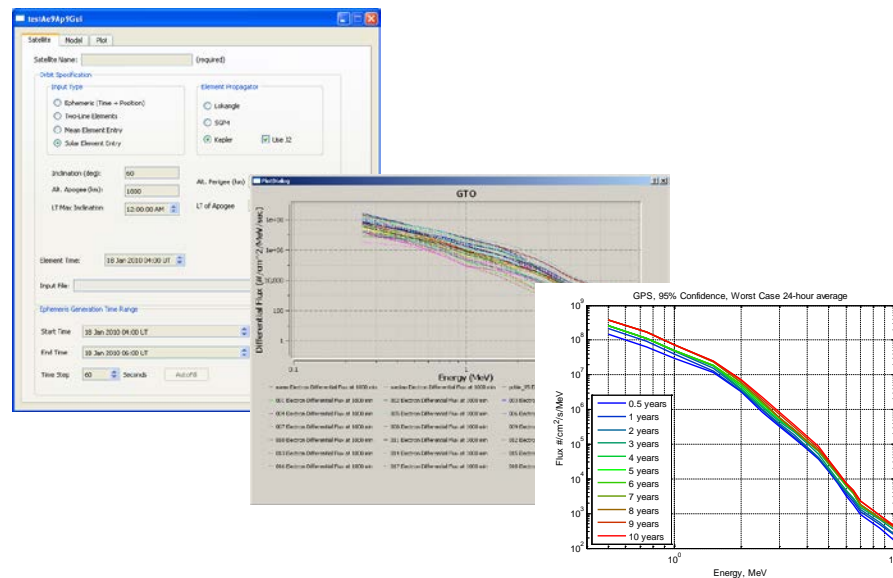


# AE9/AP9/SPM Radiation Model Design and Mission Planning



- ❑ Using a new combined set of models for the space environment determination needed for CubeSat design and mission planning
- ❑ Expanded energy coverage: keV plasma to GeV protons
- ❑ Spatial coverage for all orbit regimes, including tailored coverage for high resolution in LEO

Model	AE9	AP9	SPM
Species	$e^-$	$H^+$	$e^-$ , $H^+$ , $He^+$ , $O^+$
Energies	40 keV— 10 MeV	100 keV— 2 GeV (V1.20)	1—40 keV ( $e^-$ ); 1.15—164 keV ( $H^+$ , $He^+$ , $O^+$ )
Range in L	$0.98 < L^* < 12.4$	$0.98 < L^* < 12.4$	$2 < L_m < 10$





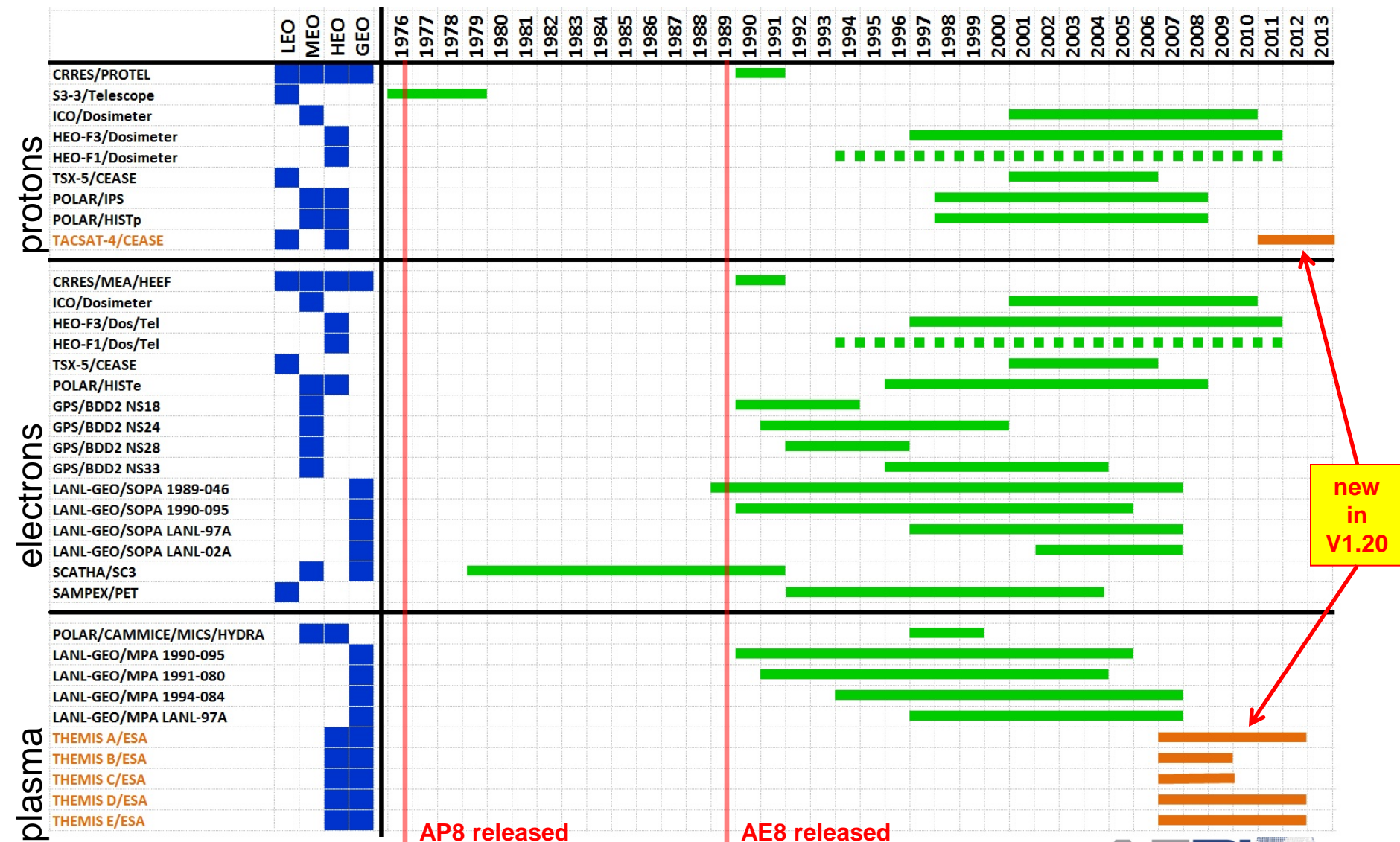
# What Type of Run

Spec Type	Type of Run	Duration	Notes
Total Dose	Perturbed Mean	Several orbits or days	SPME+AE9, SPMH+AP9+Solar
Displacement Damage (proton fluence)	Perturbed Mean	Several orbits or days	AP9+Solar
Proton SEE (proton worst case)	Monte Carlo	Full Mission	AP9+Solar
Internal Charging (electron worst case)	Monte Carlo	Full Mission	AE9 (no SPME)

- **Run 40 scenarios through either static Perturbed Mean or dynamic Monte Carlo**
- **Compute statistics by comparing results across scenarios (e.g., in what fraction of scenarios does the design succeed)**
- **Do not include plasma (SPM\*) models in worst case runs**

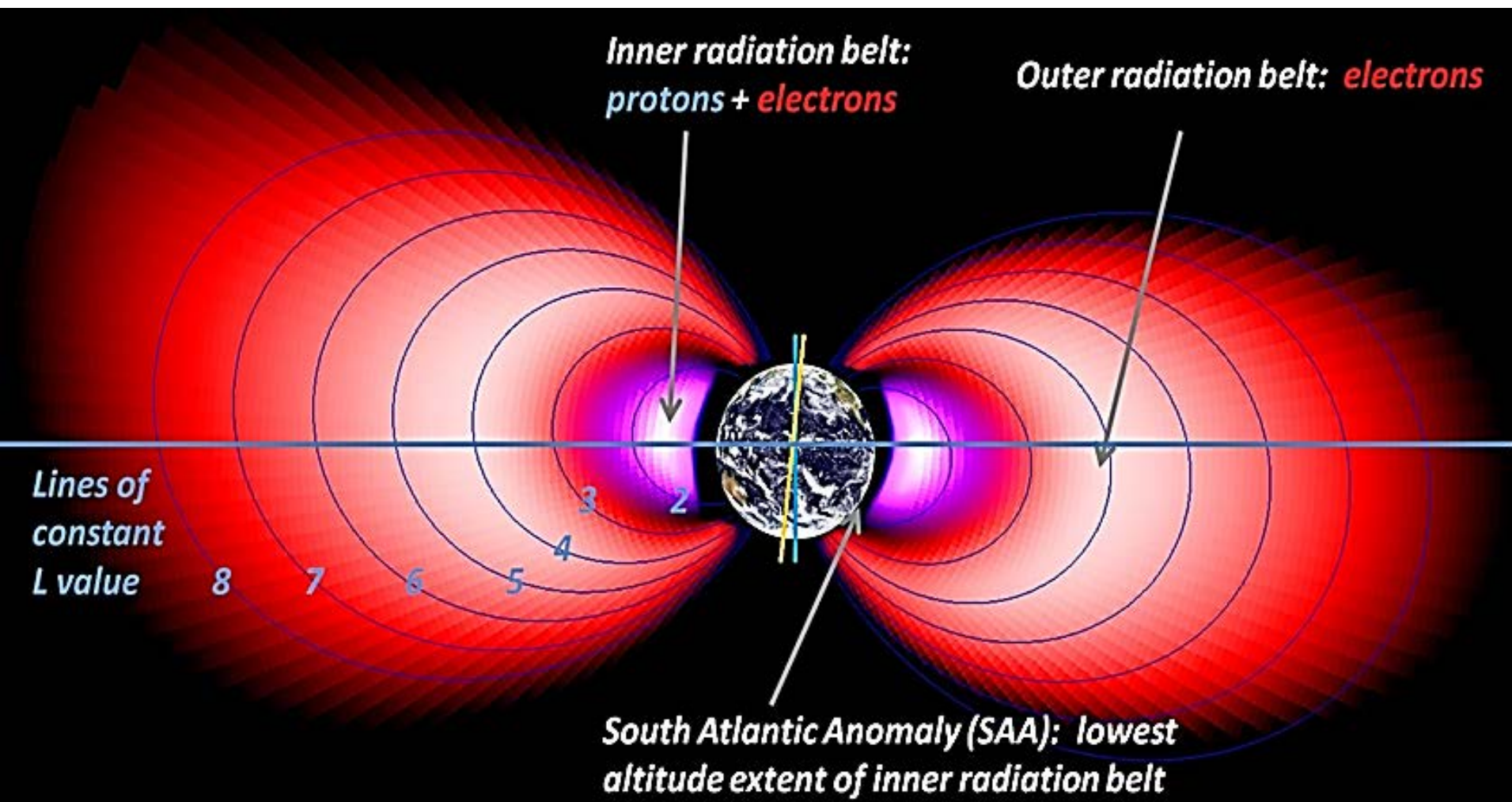


# Data Sets—Temporal Coverage





# SAA Proton Flux Source: Horn of the Inner Radiation Belt

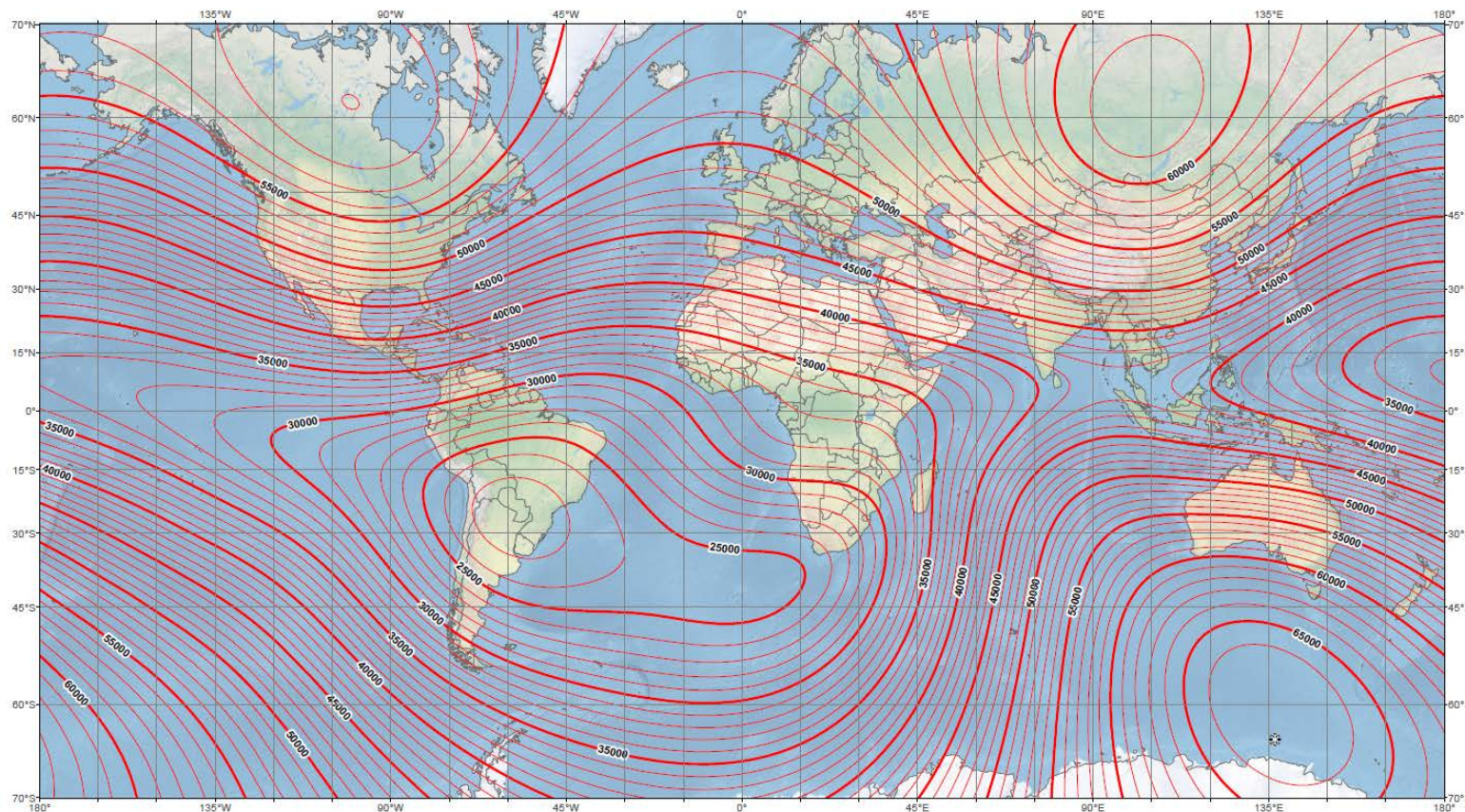




# SAA Couples Horn With a Weak Surface Magnetic Field



US/UK World Magnetic Model - Epoch 2015.0  
Main Field Total Intensity (F)



Main Field Total Intensity (F)  
Contour interval: 1000 nT.  
Mercator Projection.  
☉: Position of dip poles

Map developed by NOAA/NGDC & CIRES  
<http://ngdc.noaa.gov/geomag/WMM>  
Map reviewed by NGA and BGS  
Published December 2014

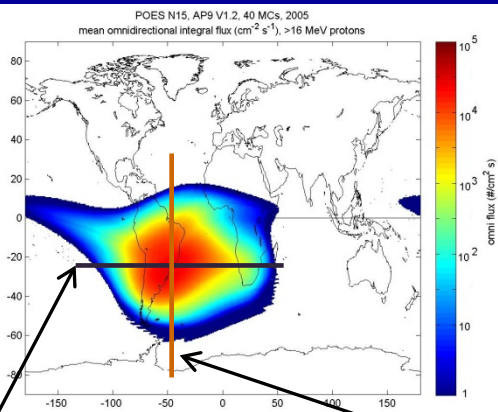


# AP9 V1.20 Validation—SAA

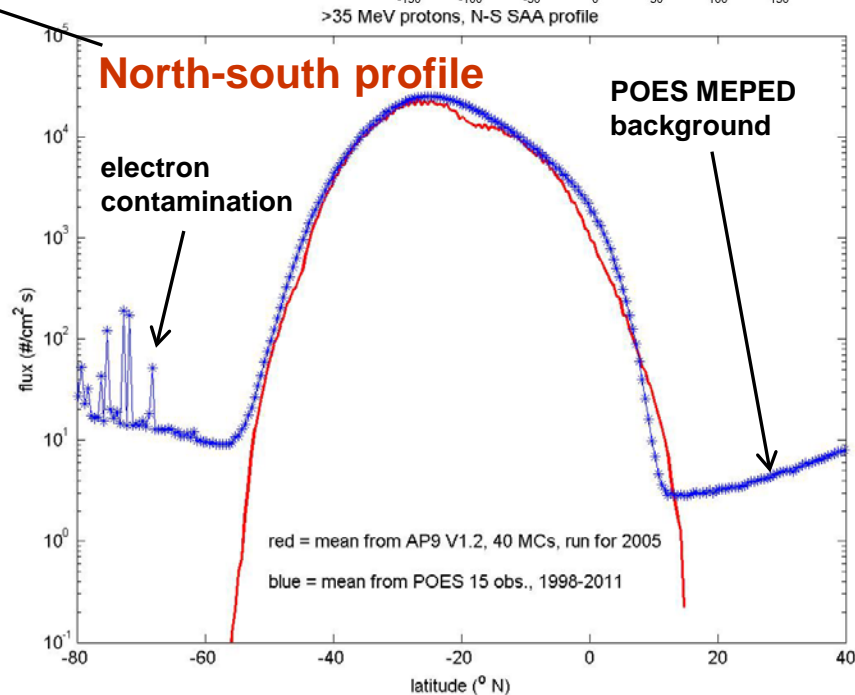
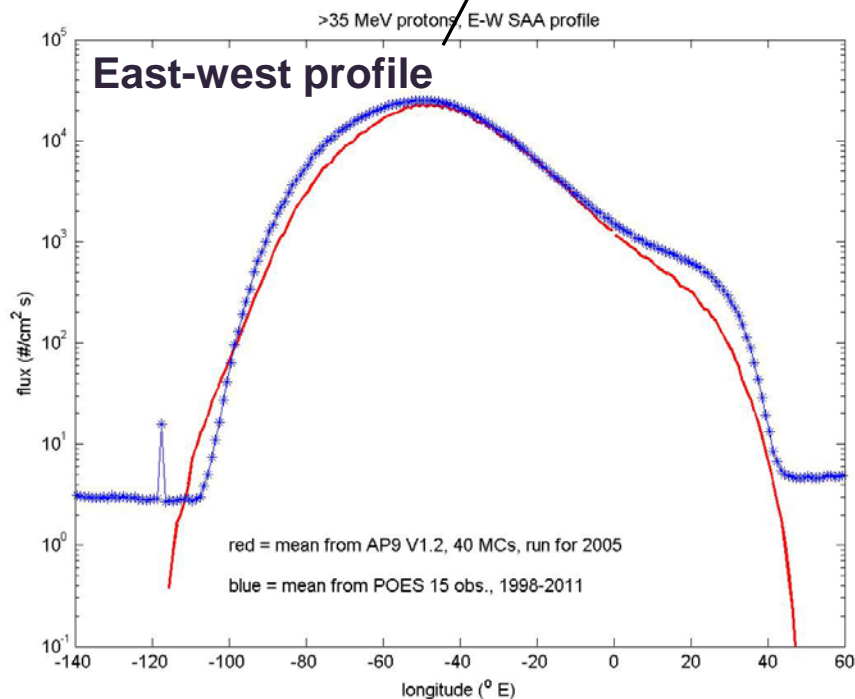
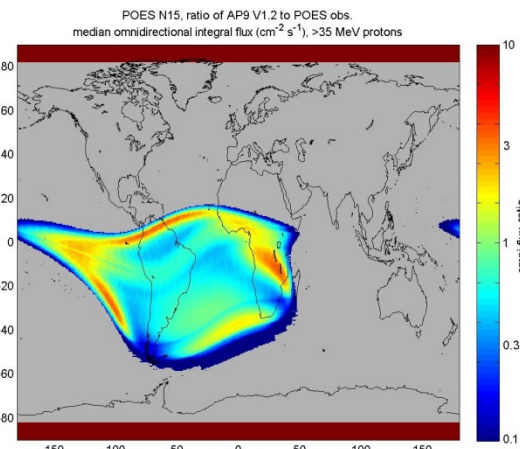


**>35 MeV protons**

SAA flux profiles are improved in V1.20 as compared to POES observations



Ratio of  
AP9 V1.20  
median to  
POES data

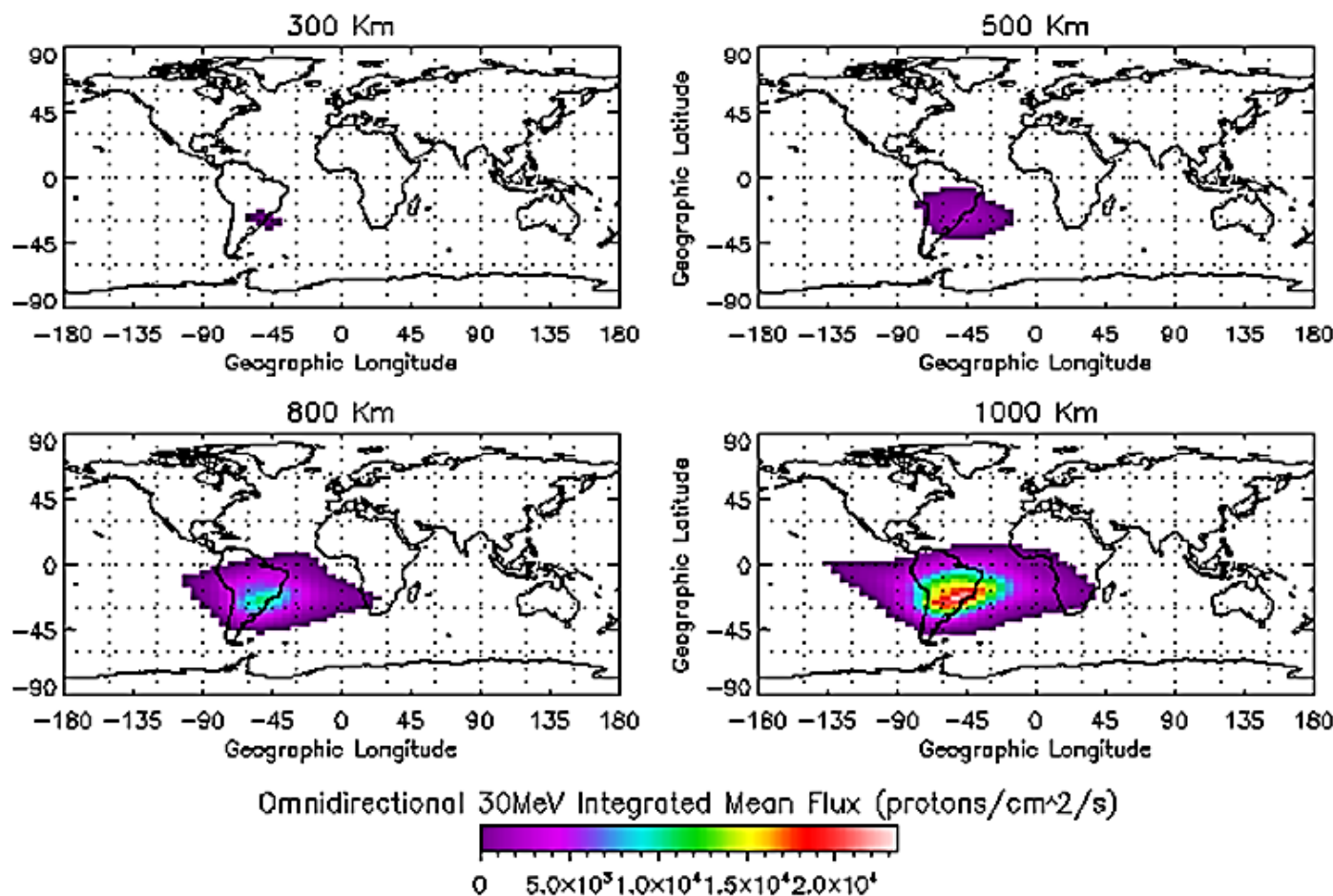




# SAA Spatial Extent: AE9/AP9/SPM Radiation Model



## Spatial Extent of SAA



Sun Jun 28 15:02:30 2015

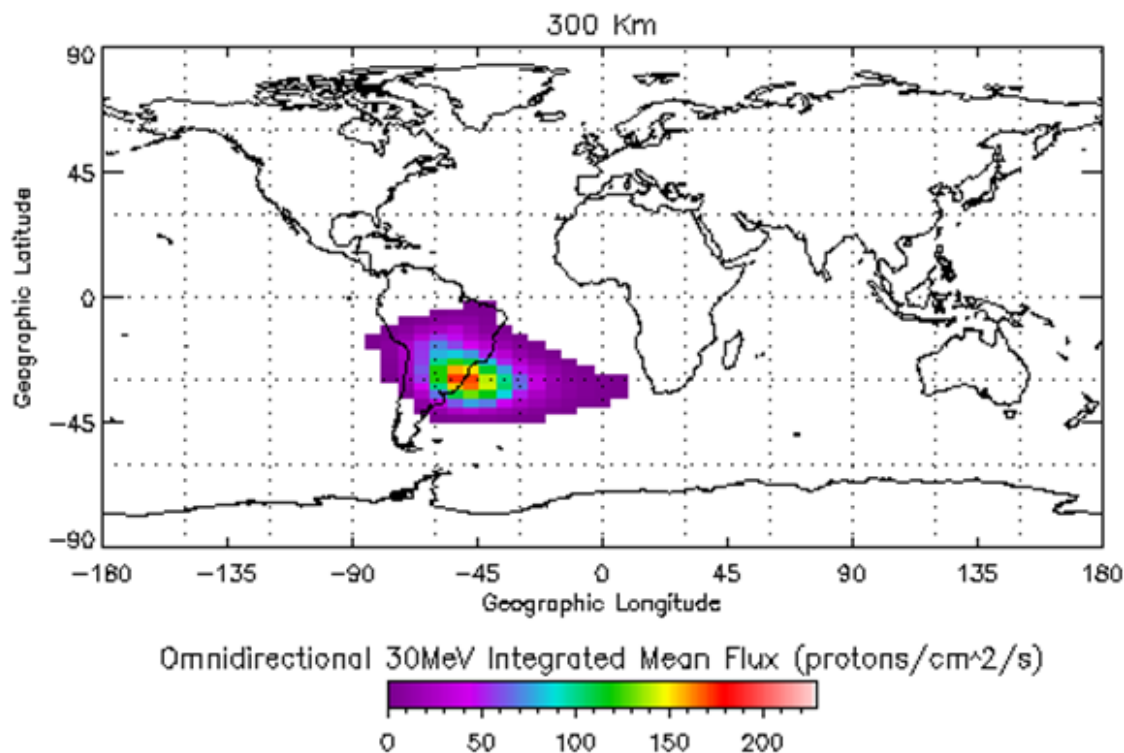




# SAA Spatial Extent (300Km): AE9/AP9/SPM Radiation Model



Spatial Extent of SAA



Sun Jun 28 15:37:12 2015



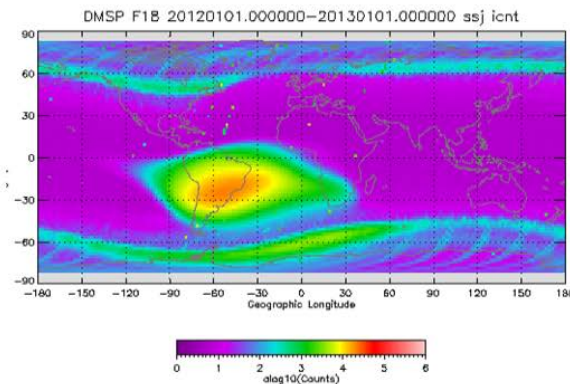
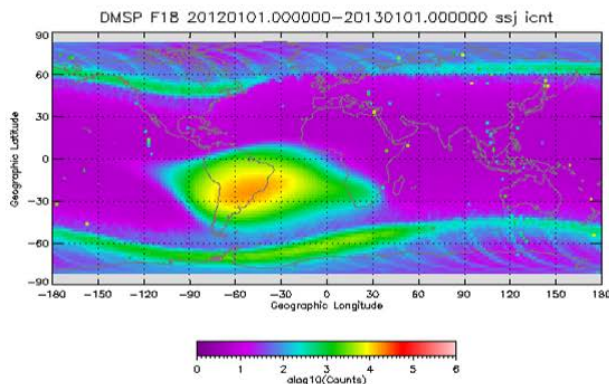
# Use Directional or Omnidirectional Fluxes?



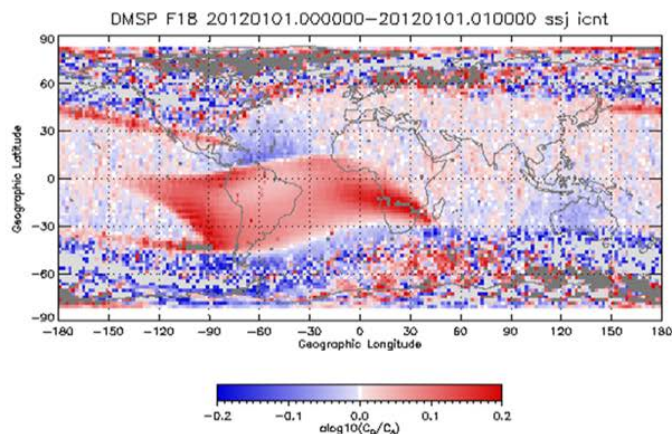
## DMSP-F18 2012 Average Background Counts

Ascending

Descending



$\log_{10}(\text{Descending/Ascending})$



- Directional Flux for Fixed Orientation with respect to Earth
- Omnidirectional Flux for Random Orientation



# SAA Drift Rate Over Time



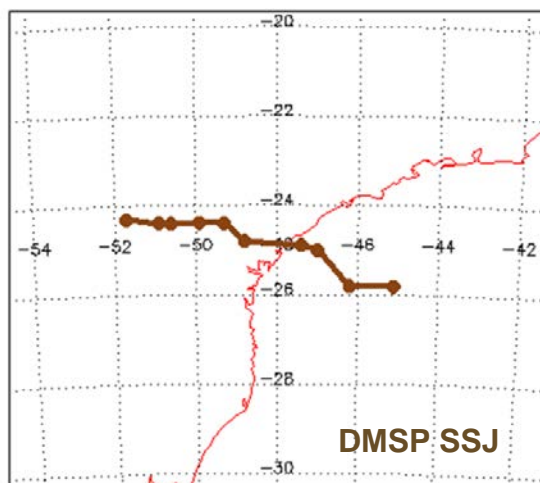
From DMSP SSJ contamination

Satellite	Year	Latitude	Longitude
F08	1989	-25.8	-45.1
F11	1993	-25.8	-46.2
F12	1998	-25.0	-47.0
F12	2001	-24.9	-47.4
F15	2004	-24.8	-48.8
F15	2006	-24.4	-49.3
F16	2008	-24.4	-49.9
F16	2010	-24.4	-50.6
F16	2012	-24.4	-50.9
F16	2014	-24.3	-51.7

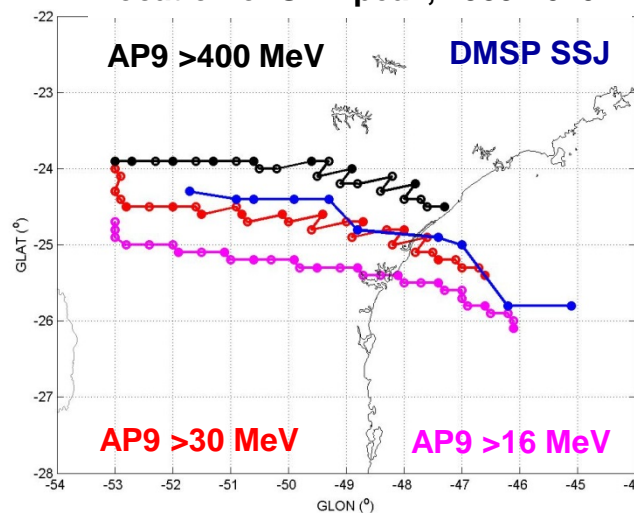
From AP9 V1.20 mean >30 MeV

Year	Latitude	Longitude
1989	-25.4	-46.6
1994	-25.1	-47.5
1997	-25.0	-48.2
2000	-24.9	-48.9
2003	-24.8	-49.6
2006	-24.6	-50.1
2009	-24.5	-50.9
2012	-24.5	-52.0
2014	-24.5	-52.8
2020	-23.9	-53.0

location of SAA peak, 1989-2014



location of SAA peak, 1989-2020





# AE9/AP9 Website



- We have launched a dedicated web site for the AE9/AP9 project hosted by AFRL's Virtual Distributed Laboratory:  
<https://www.vdl.afrl.af.mil/programs/ae9ap9>
- The latest version of the model may be downloaded from this site after creating an account
- Summaries and model documentation are also available (no account needed)
- Future news and releases will be announced through the website

**Virtual Distributed Laboratory** U.S. AIR FORCE

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### AE9/AP9/SPM: Radiation Belt and Space Plasma Specification Models

Air Force Research Laboratory (AFRL)

AE9/AP9/SPM is a new set of models for the fluxes of radiation belt and plasma particles in near-Earth space for use in space system design, mission planning, and other applications of climatological specification. Denoted AE9, AP9, and SPM for energetic Electrons, energetic Protons, and Standard Plasma Model, respectively, the models are derived from 37 data sets measured by satellite on-board sensors. These data sets have been processed to create maps of the particle fluxes along with estimates of uncertainties from both imperfect measurements and space weather variability. These estimates can be obtained as statistical confidence intervals, e.g. the median and 95th percentile, for fluxes and derived quantities, supporting design trades.

- For a concise summary of the model features, see our [Factsheet](#).
- For more detail, see our [Quick Reference](#) pages.
- For links to documentation, see [Documents](#).
- For information on validations, comparisons to legacy models, and other reviews, see [Validations and other evaluations](#).

The current version of the model, V1.20.002, has been approved for public release. For instructions on downloading the model, see [Downloads](#).

The AE9/AP9/SPM Team may be reached at [ae9ap9@vdl.afrl.af.mil](mailto:ae9ap9@vdl.afrl.af.mil).

**AE9/AP9/SPM Contents**

1. AE9AP9 Home
2. Factsheet
3. Quick Reference
  - a. Energy and spatial coverage
  - b. Architecture
  - c. Data sets
  - d. Modes for running the model
  - e. Recommended time sampling
  - f. Versions (public releases)
  - g. Future version plans
4. Documents
  - a. Technical documentation
  - b. Validations and evaluations
    - Independent validations and evaluations
5. Downloads
6. AE9/AP9/SPM Team

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