Air Force Research Laboratory

Comparisons of AE9 and AP9 With Legacy Trapped Radiation Models

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Integrity ★ Service ★ Excellence

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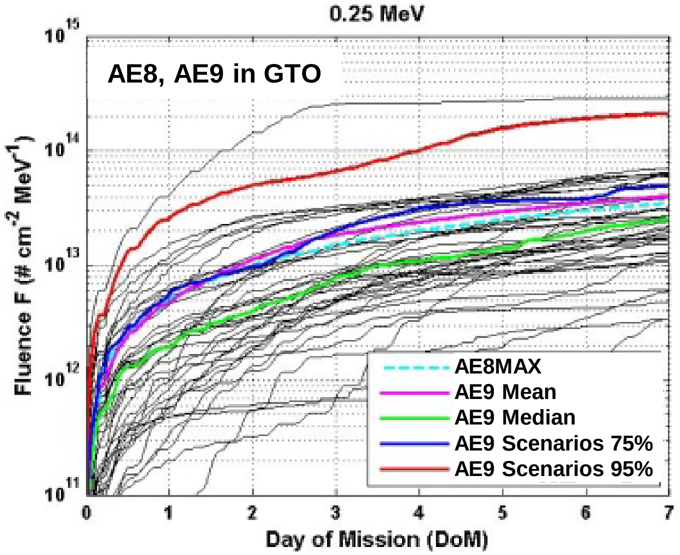
Introduction

- Trapped electron and proton models AE8/AP8 (or Ax8) have been *de facto* industry standards for > 30 years
- Industry practice has used large design margins to compensate for uncharacterized uncertainties in flux predictions
- New AE9/AP9 models specify uncertainty, leading to the possibility of more meaningful margins

- Objective of this talk is to provide an idea of the differences and similarities between Ax8 and Ax9
  - Global comparisons of fluxes
  - Orbital comparisons: flux spectra, dose vs. depth

What is AE9/AP9?

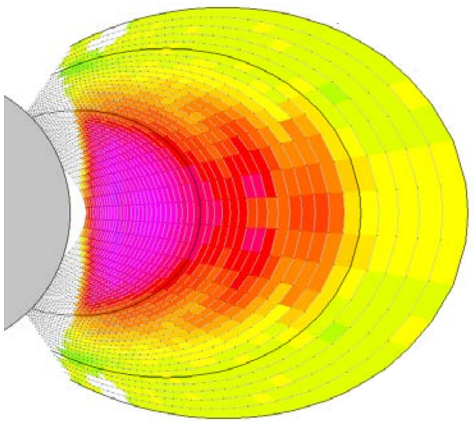
- AE9/AP9 specifies the natural trapped radiation environment for satellite design
  - Energetic electrons, protons, plasma
- Its unprecedented coverage in particles and energies address the major space environmental hazards
- Newer, high-quality data sets with extensive cross-calibration, validated against independent data sets
- AE9/AP9 includes uncertainties and dynamics that have never been available for use in design
  - The uncertainty allows users to estimate design margins (95 percentile rather than arbitrary factors)
  - Dynamic scenarios allow users to create worst cases for internal charging, single event effects, and assess mission life



- "Turn-Key" system for ingesting new data sets ensures that the model can be updated easily
- V1.0 cleared for public release on 5 September 2012
  - Current version is 1.04, version 1.1 expected in July 2013

Architecture Overview

Satellite data



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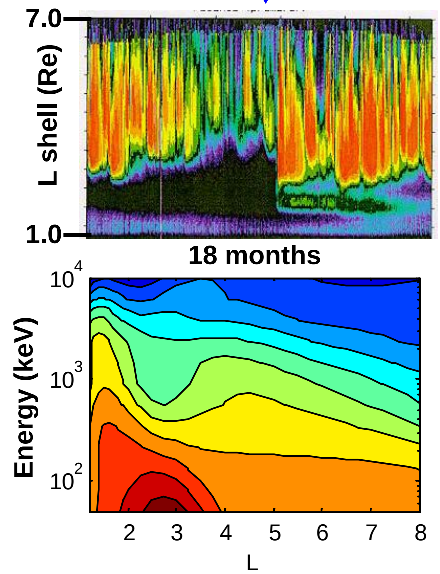
Satellite data & theory



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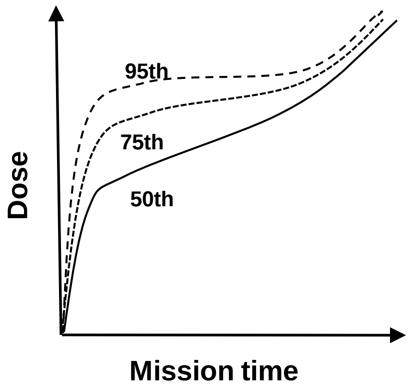
User's orbit



Flux maps

- Derive from empirical data
  - Systematic data cleaning applied
- Create maps for median and 95th percentile of distribution function
  - Maps characterize nominal and extreme environments
- Include error maps with instrument uncertainty
- Apply interpolation algorithms to fill in the gaps

Statistical Monte-Carlo Model

- Compute spatial and temporal correlation as spatiotemporal covariance matrices
  - From data (V 1.0)
  - Use one-day (protons) and 6 hour (electrons) sampling time (V 1.0)
- Set up Nth-order auto-regressive system to evolve perturbed maps in time
  - Covariance matrices give SWx dynamics
  - Flux maps perturbed with error estimate give instrument uncertainty

User application

- Runs statistical model N times with different random seeds to get N flux profiles
- Computes dose rate, dose or other desired quantity derivable from flux for each scenario
- Aggregates N scenarios to get median, 75th and 90th confidence levels on computed quantities

What Type of Run

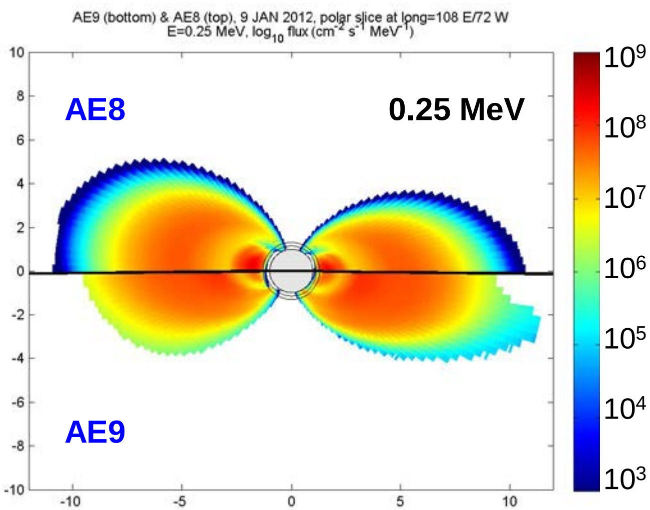
Spec Type	Type of Run	Duration	Notes
Total Dose	Perturbed Mean	Several orbits or days	SPME+AE9, SPMH+AP9+Solar
Displacement Damage (proton fluence)	Perturbed Mean	Several orbits or days	AP9+Solar
Proton SEE (proton worst case)	Monte Carlo	Full Mission	AP9+Solar
Internal Charging (electron worst case)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

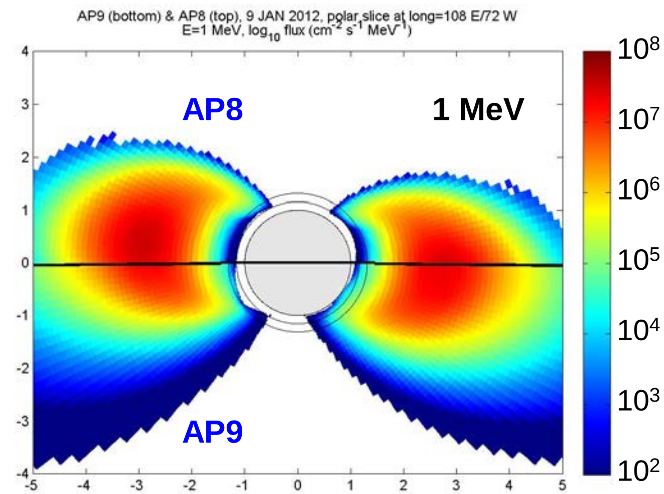
- Run 40 scenarios through either static Perturbed Mean or dynamic Monte Carlo
- Compute statistics by comparing results across scenarios (e.g., in what fraction of scenarios does the design succeed)
- Do not include plasma (SPM*) models in worst case runs

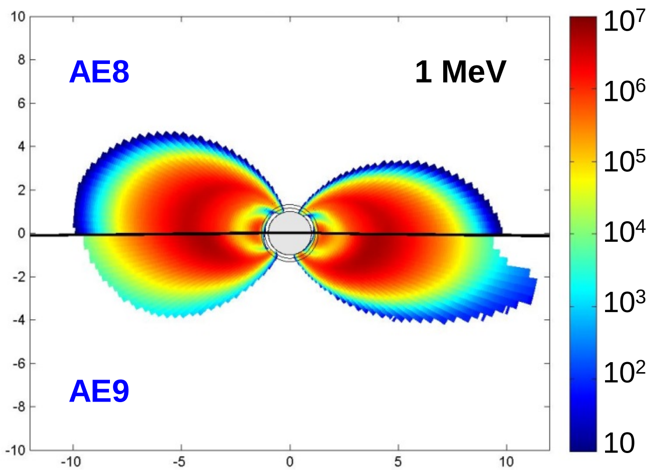
Types of Comparisons

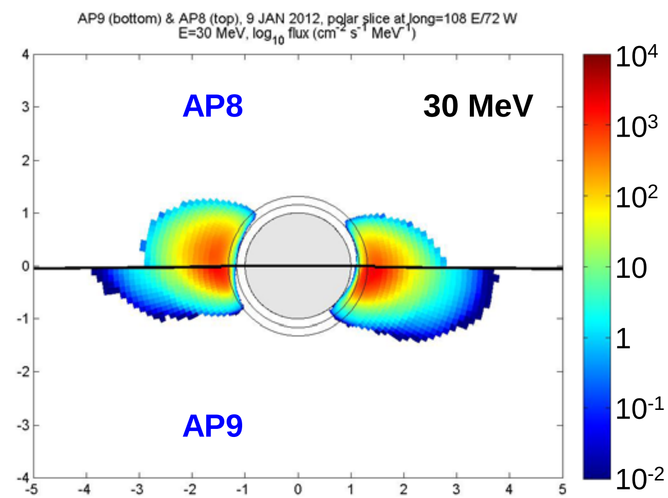
- Global plots
  - Meridional slices showing Ax8 vs. Ax9
  - Meridional slices showing ratio Ax9/Ax8
- Orbital integration for representative orbits
  - Monte Carlo fluence spectra
  - Comparison of Ax9 to Ax8 and CRRESELE/CRRESPRO
  - Dose vs. Depth

AE9/AP9 Compared to AE8/AP8

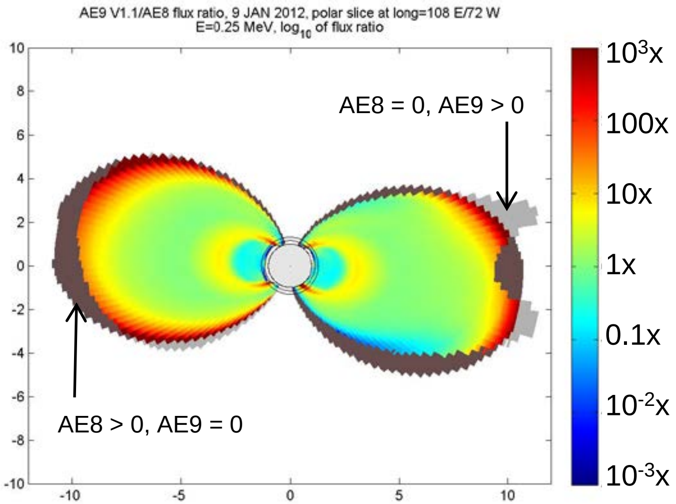


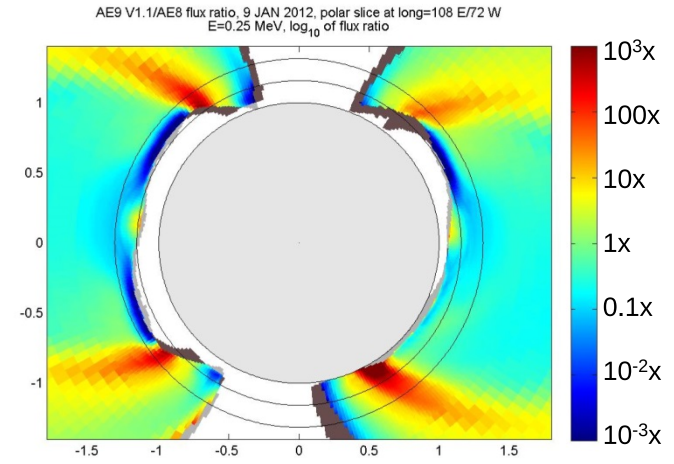




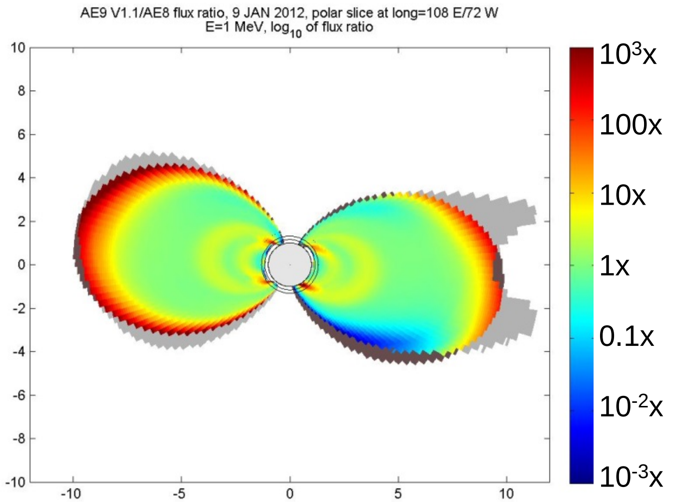


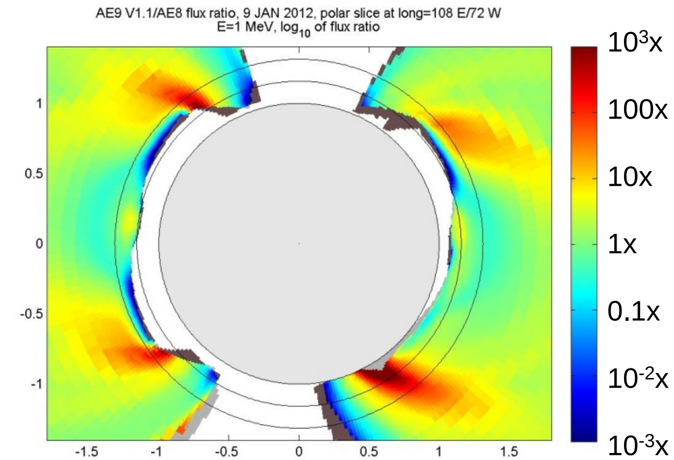
AE9-to-AE8 flux ratio





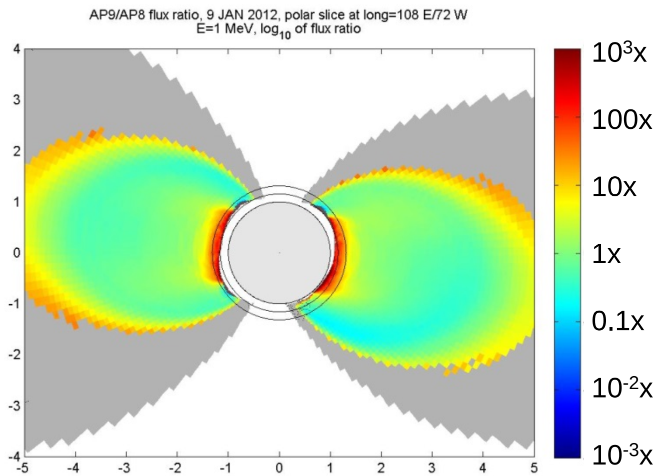
0.25 MeV

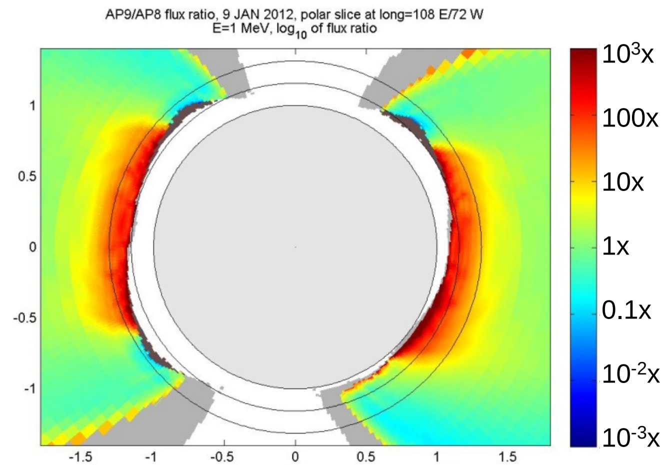




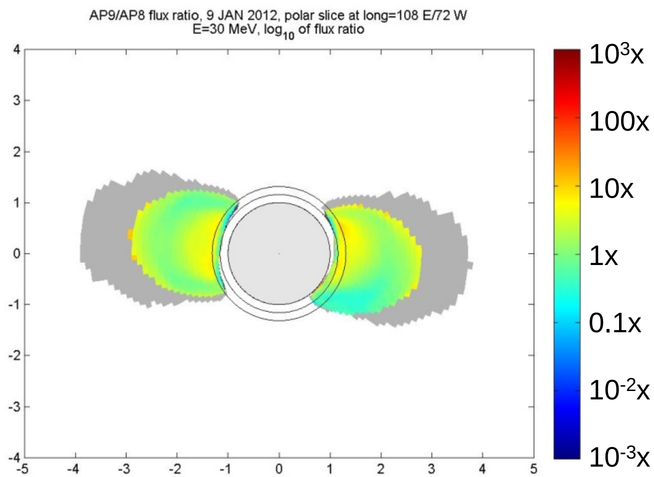
1 MeV

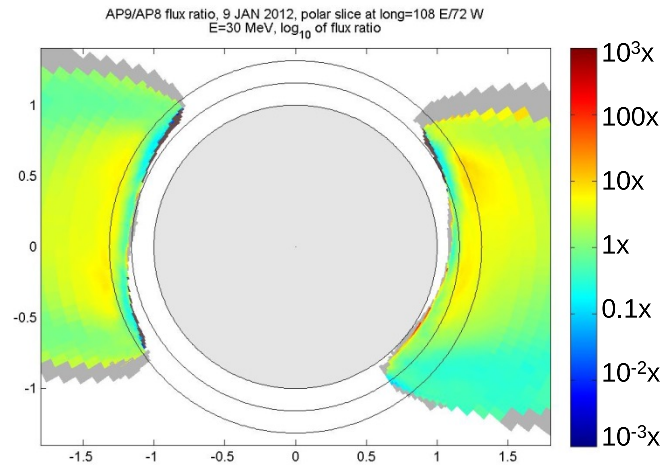
AP9-to-AP8 flux ratio





1 MeV



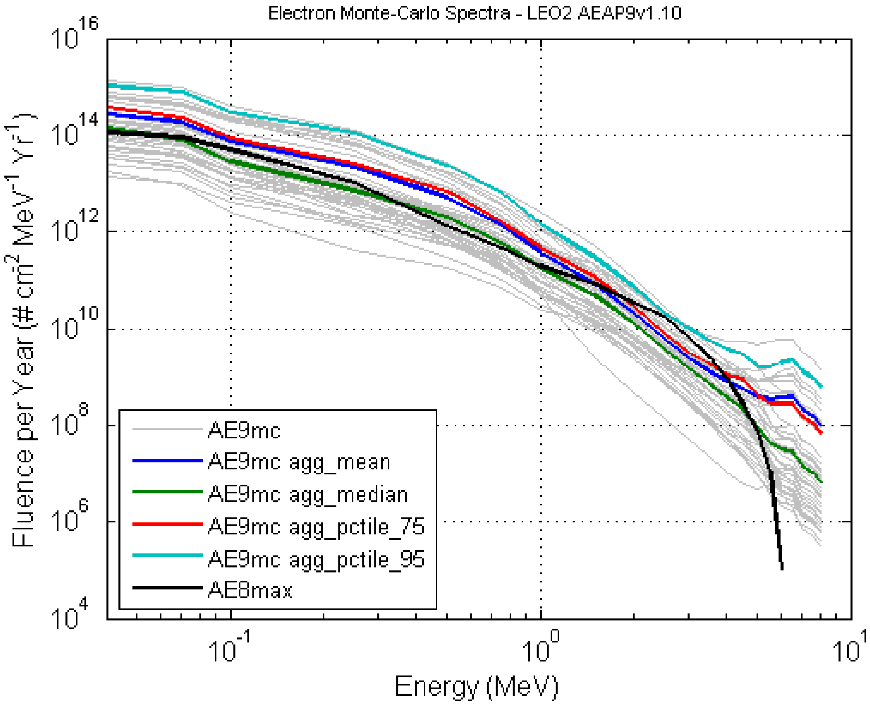


30 MeV

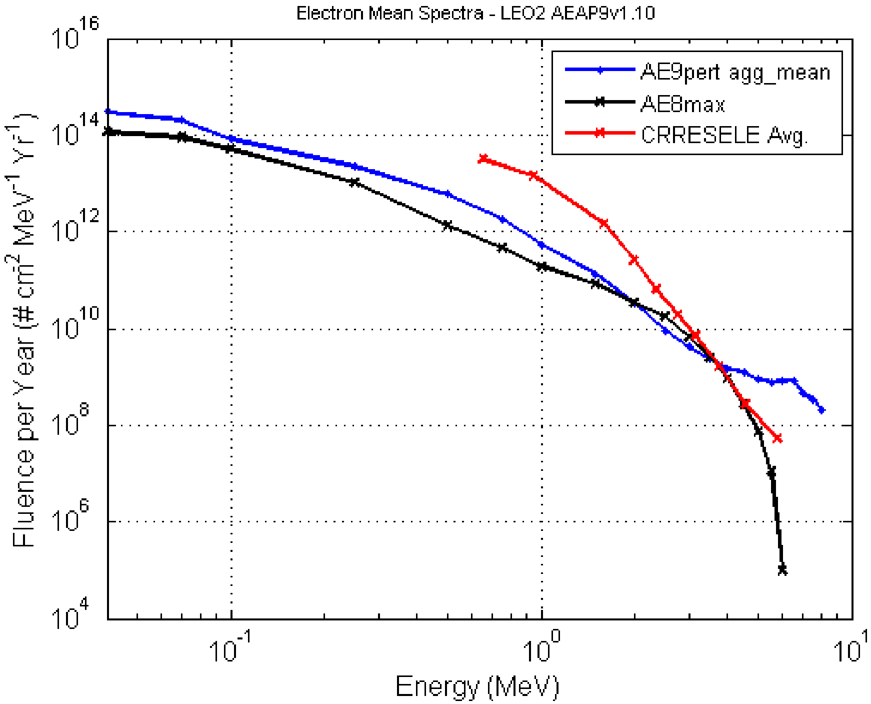
Electron Spectra: LEO

800 km x 800 km x 90°

Monte Carlo Fluence Spectra



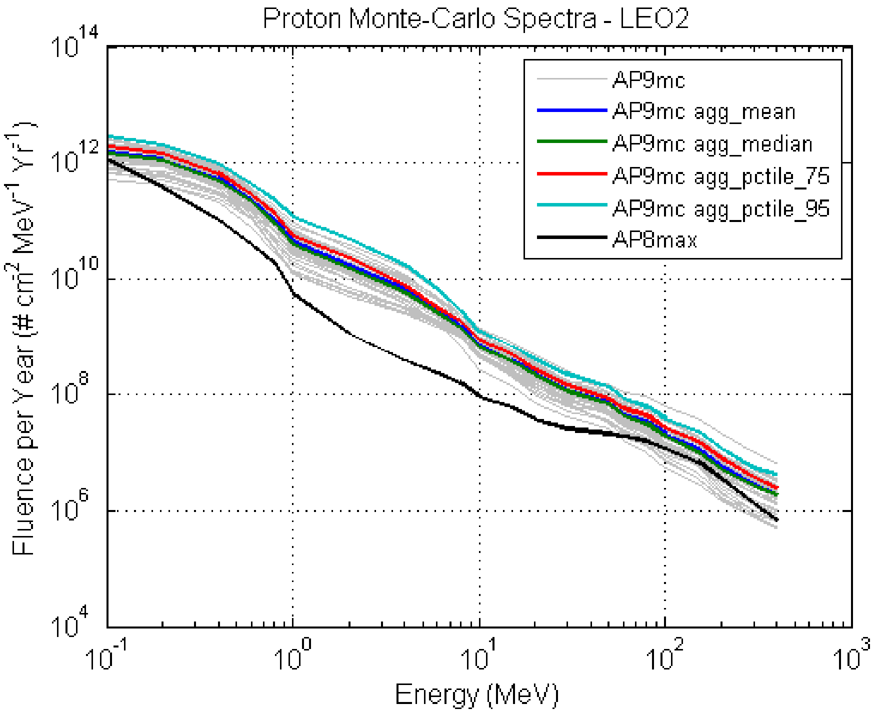
Mean Fluence Spectra



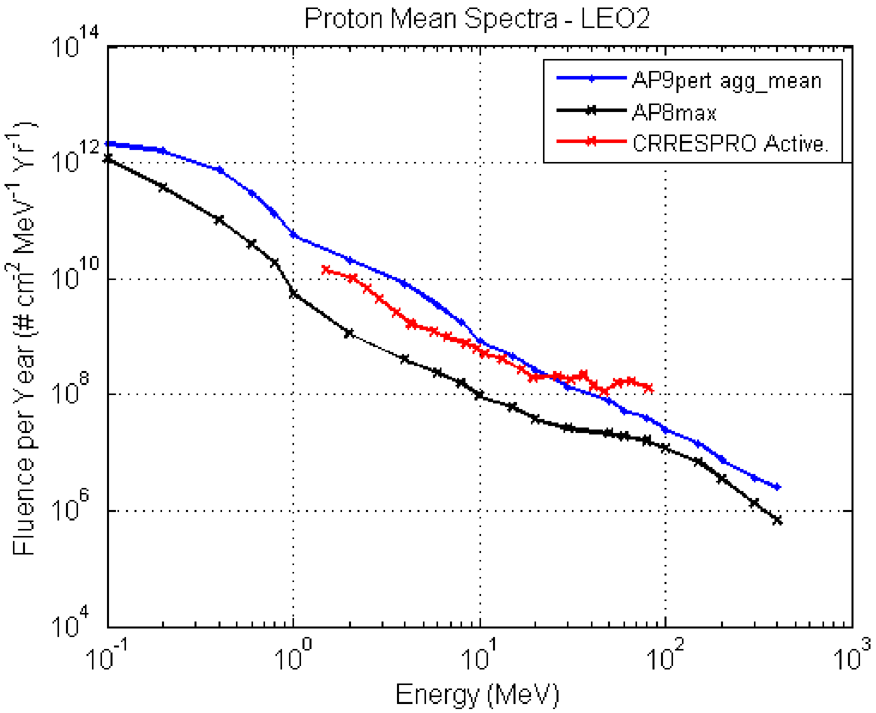
Proton Spectra: LEO

800 km x 800 km x 90°

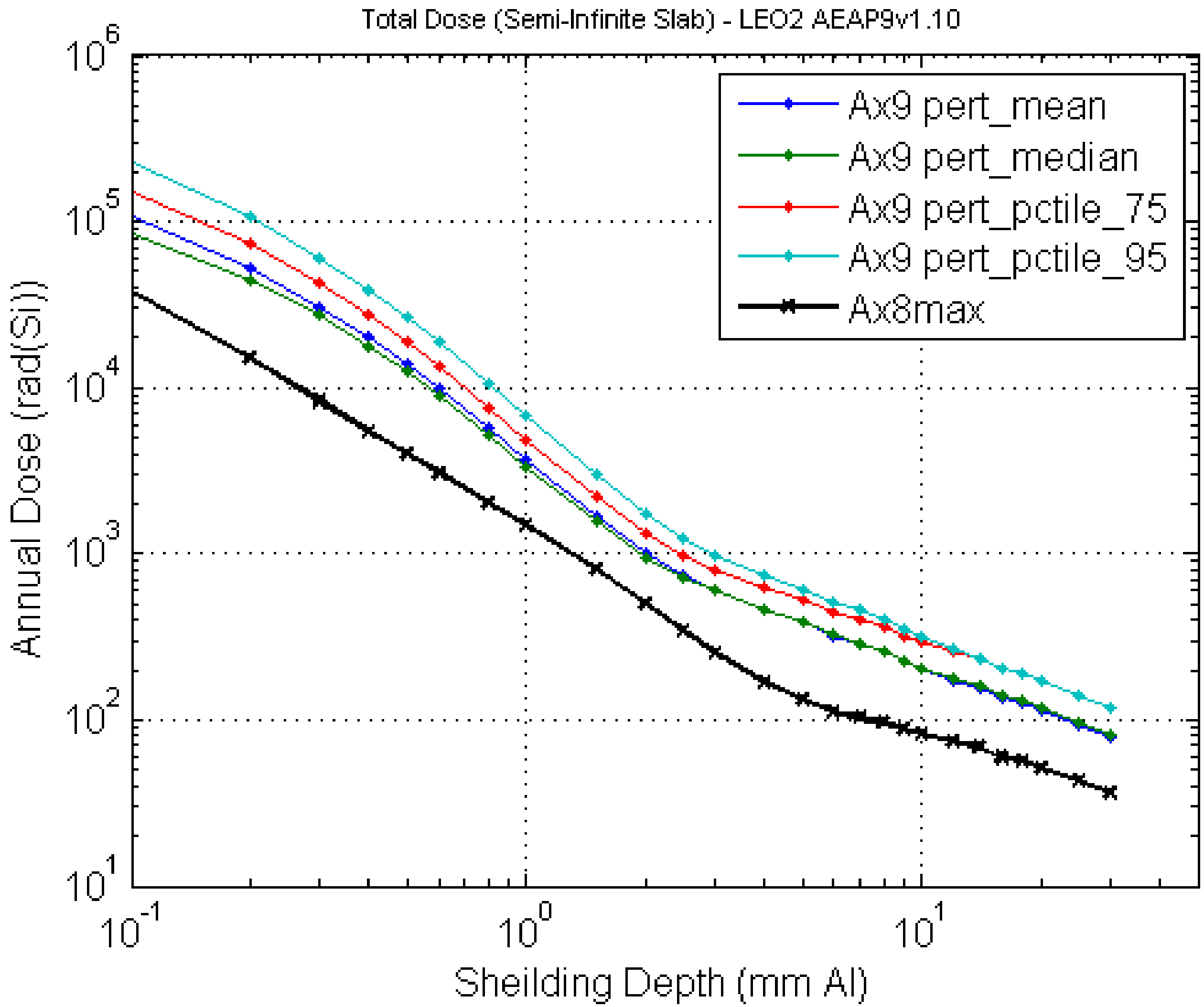
Monte Carlo Fluence Spectra



Mean Fluence Spectra



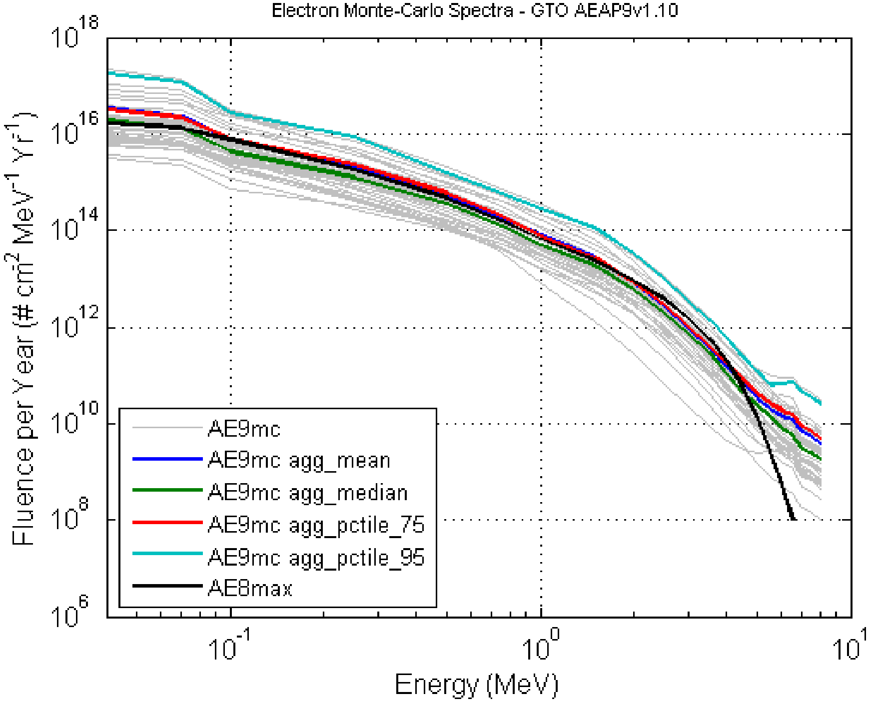
Dose vs. Depth: LEO



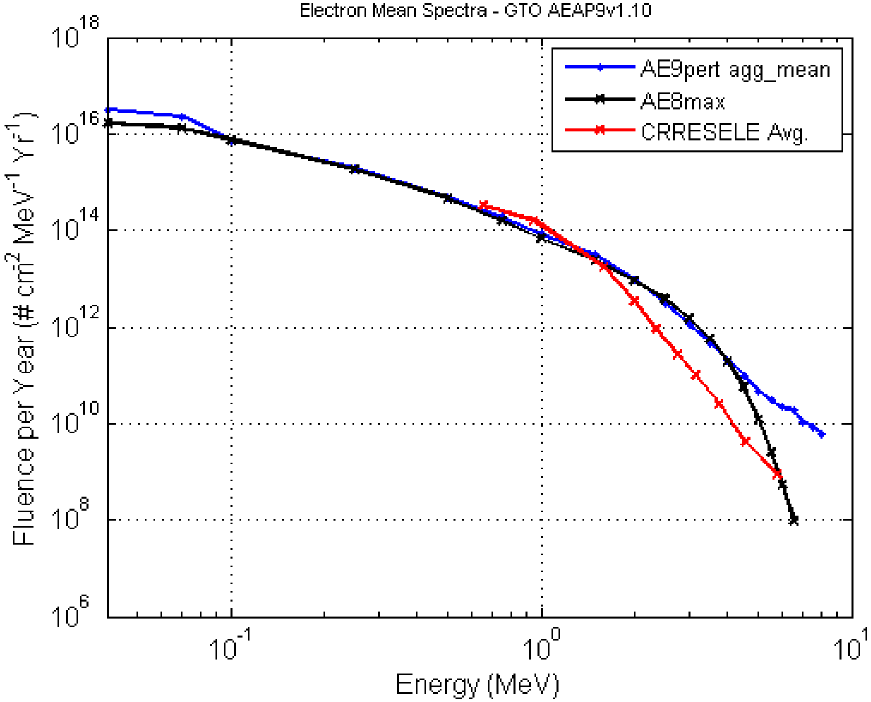
Electron Spectra: GTO

30,600 km x 500 km x 10°

Monte Carlo Fluence Spectra



Mean Fluence Spectra



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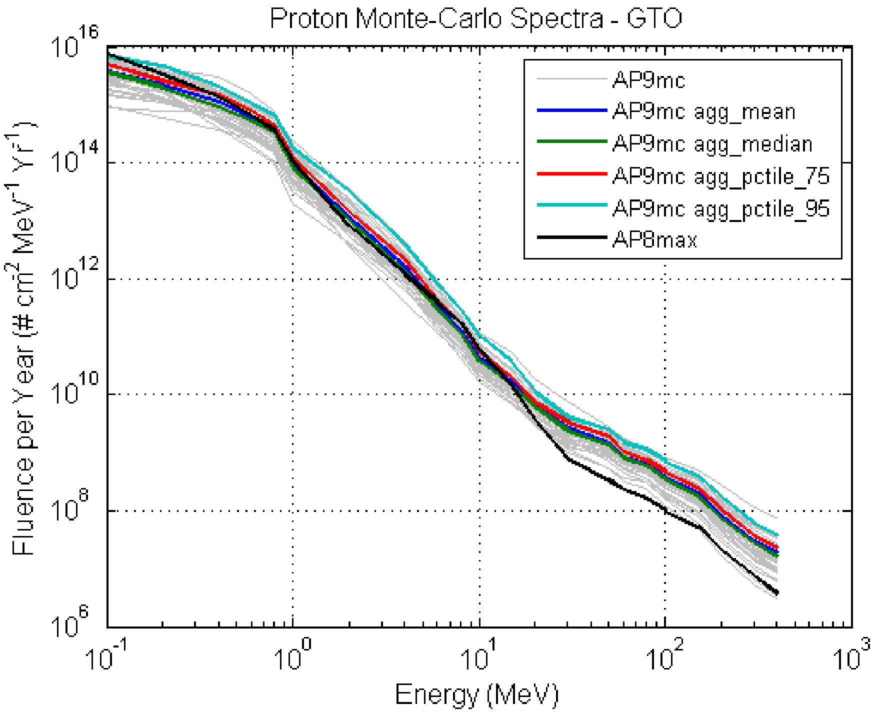
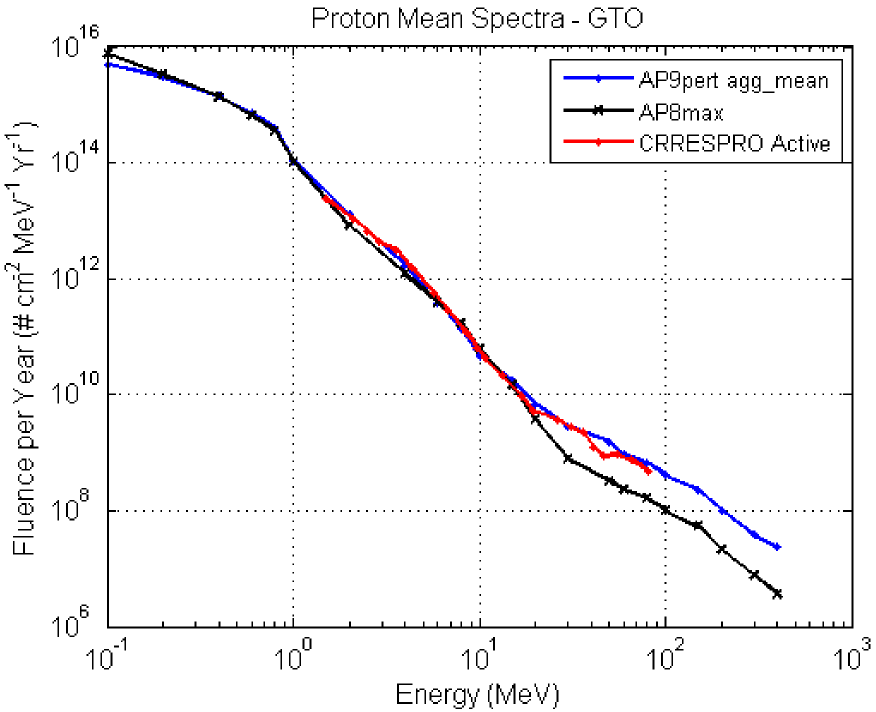
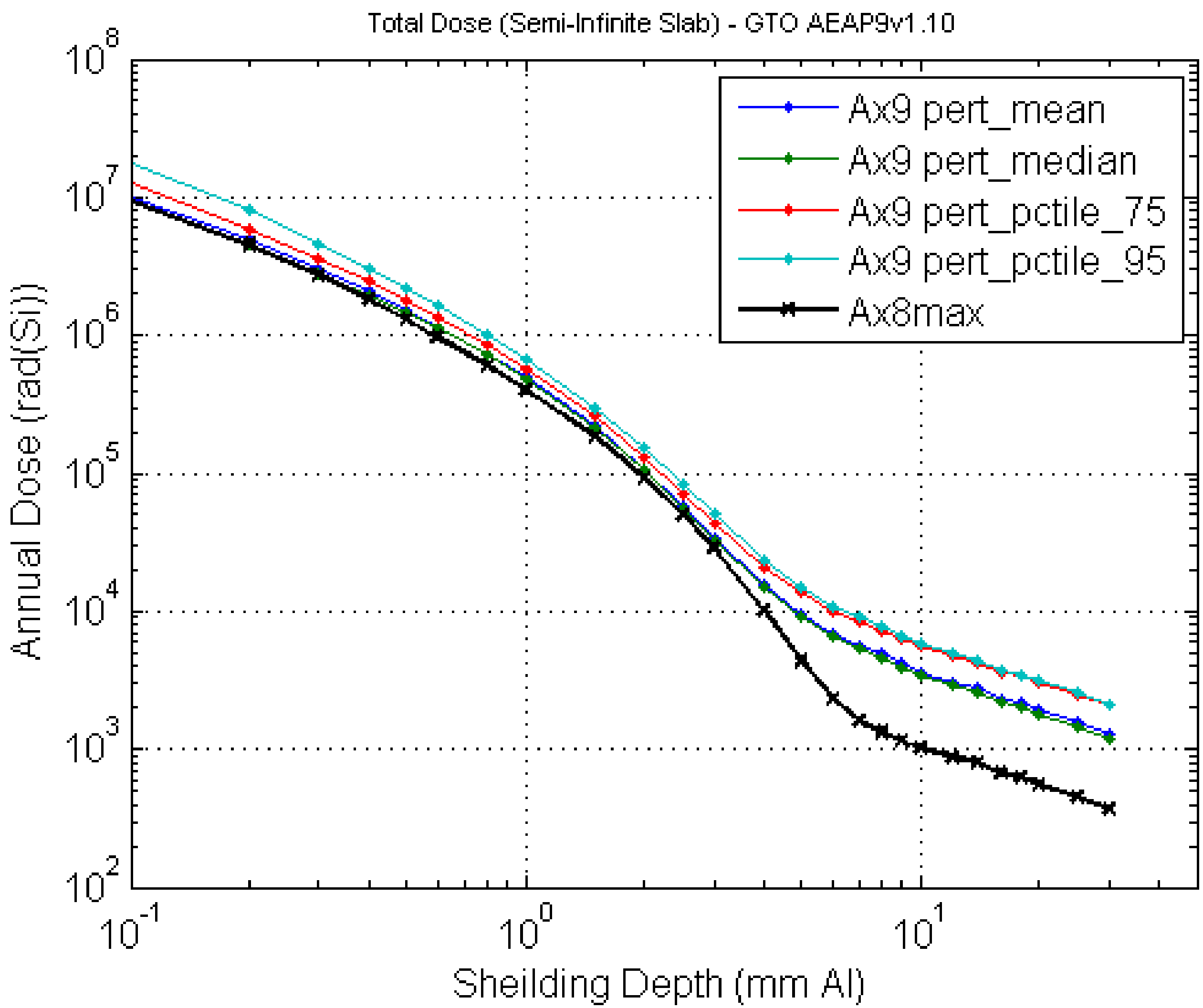


Mean Fluence Spectra



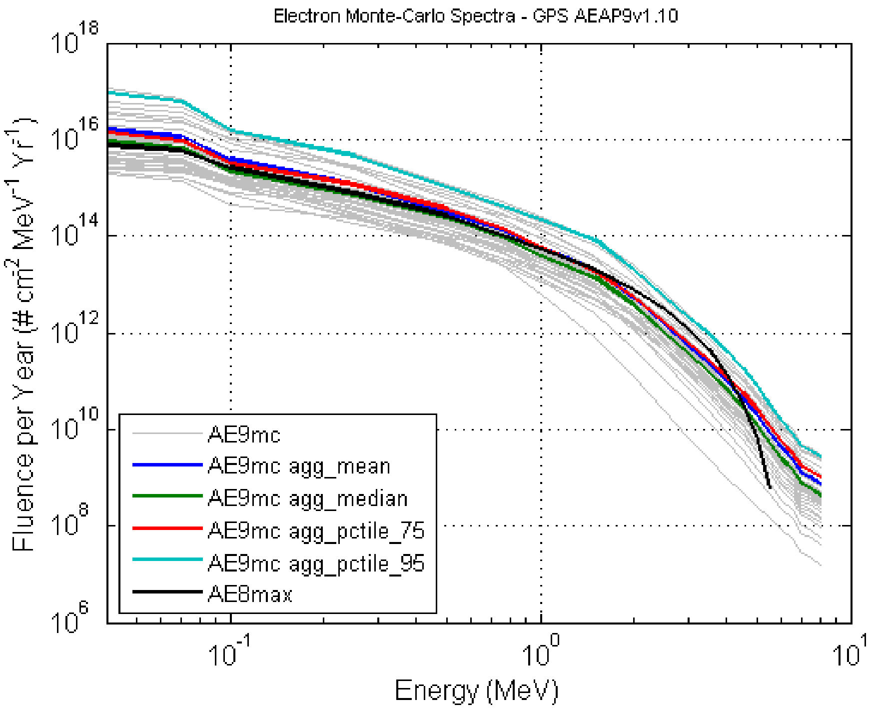
Dose Vs. Depth: GTO



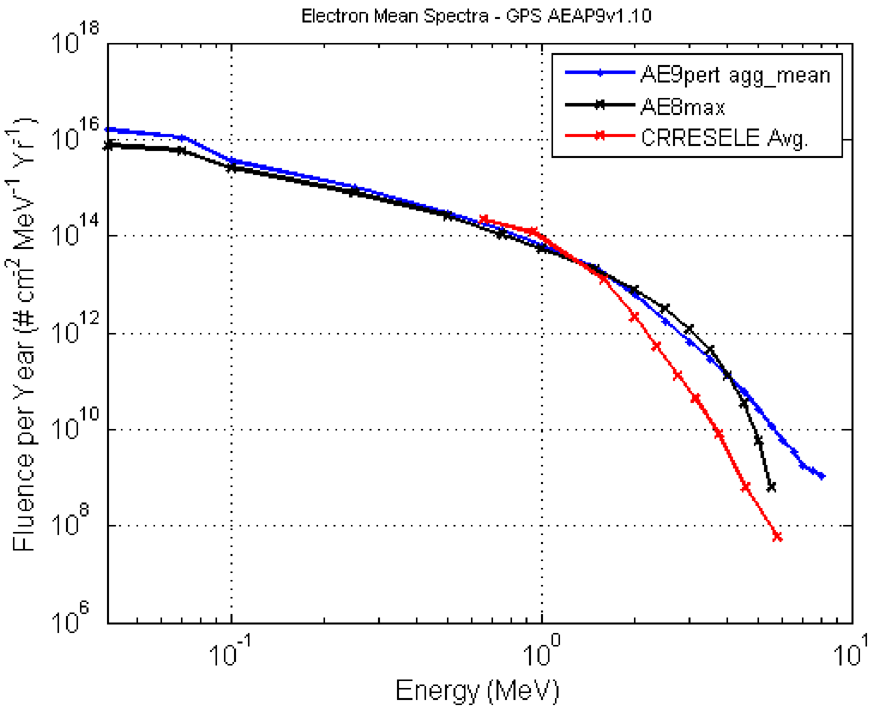
Electron Spectra: GPS

20,200km x 20,200km x 55°

Monte Carlo Fluence Spectra



Mean Fluence Spectra



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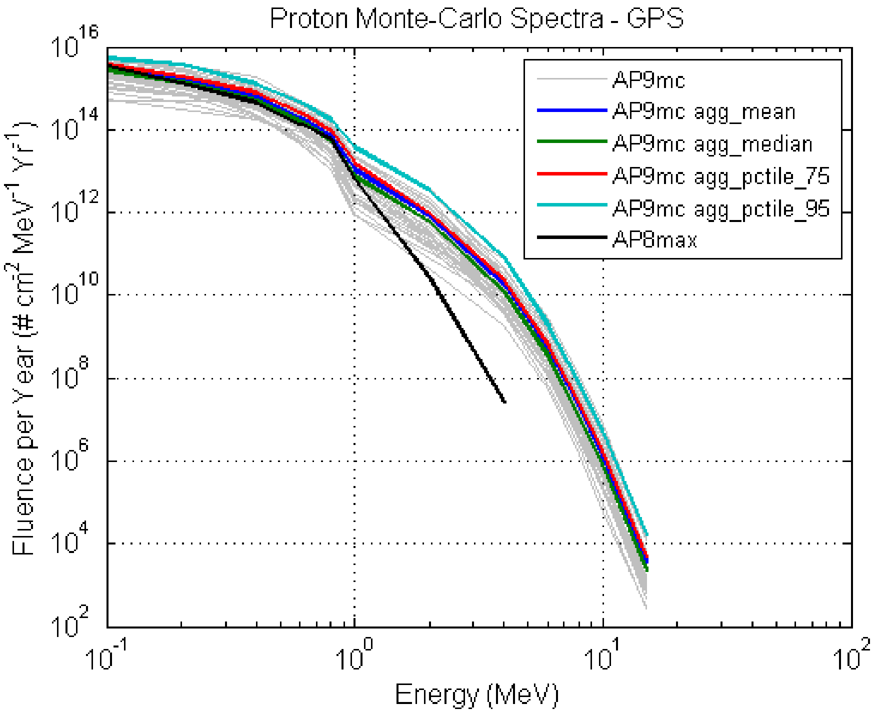
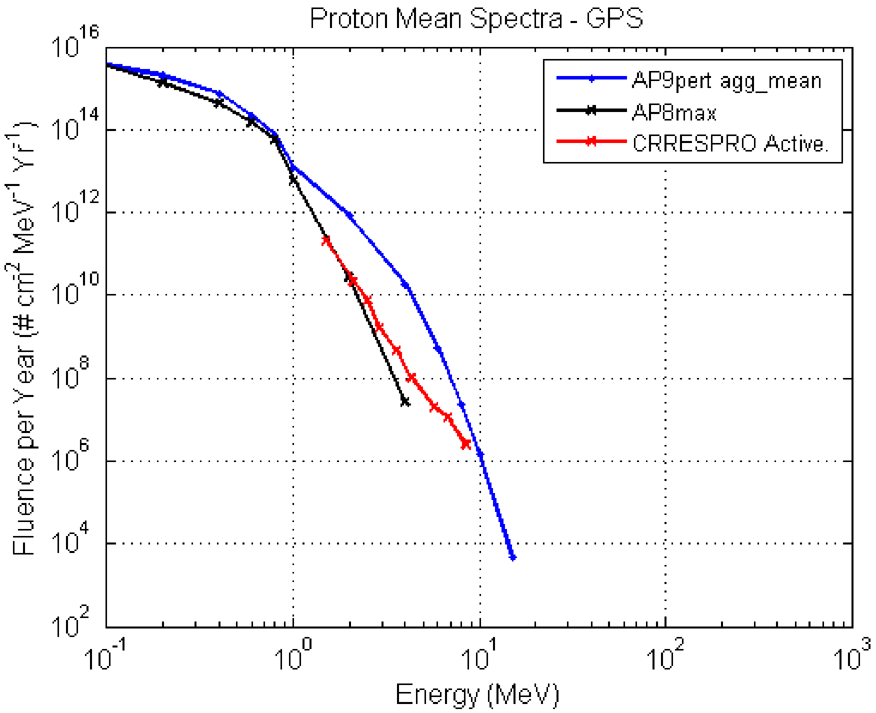
Proton Spectra: GPS

20,200km x 20,200km x 55°

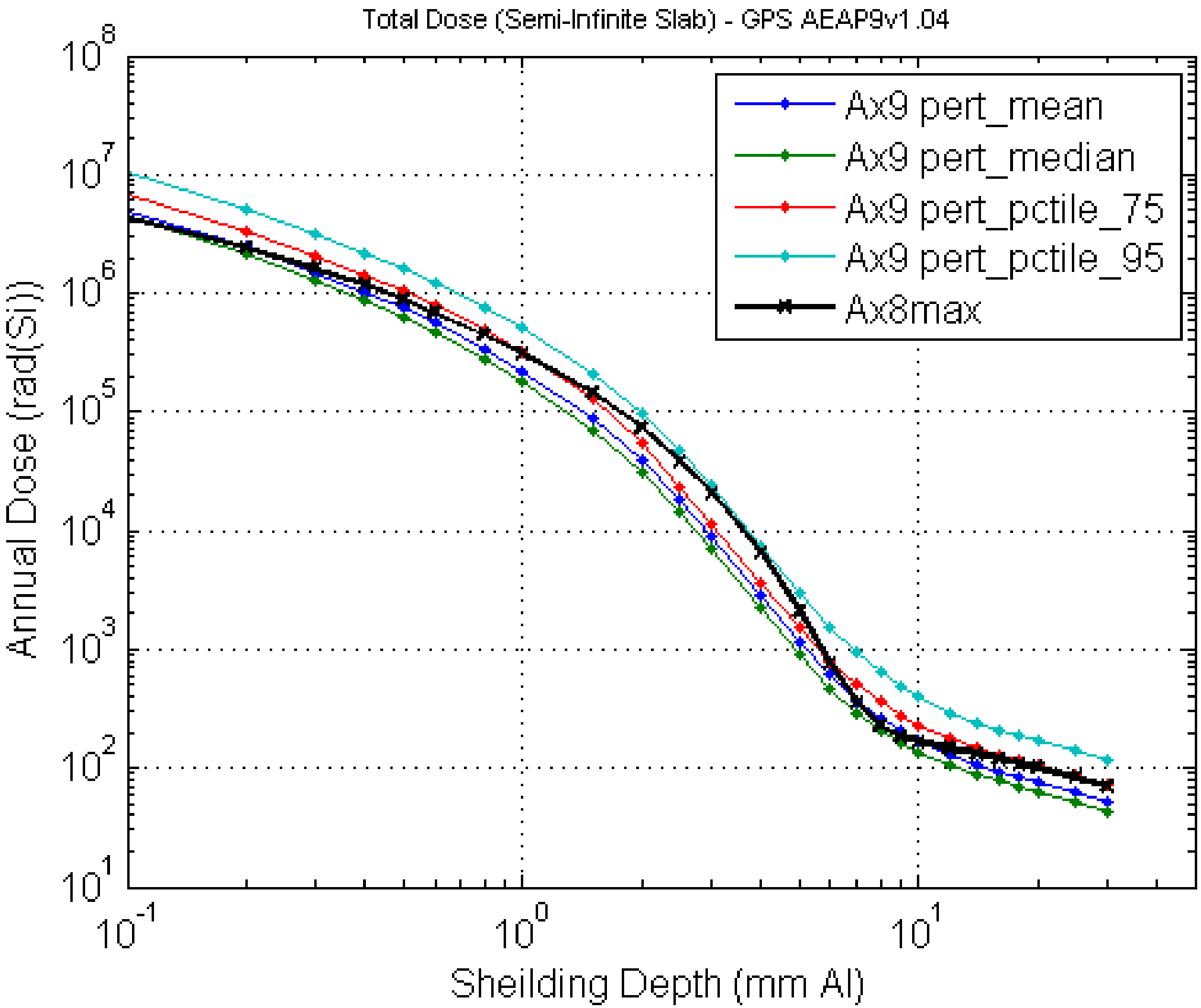
Monte Carlo Fluence Spectra



Mean Fluence Spectra



Dose vs. Depth: GPS



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Discussion (1)

- Differences depend on individual orbit
- General morphology (AE9):
  - AE9 outer zone more intense, extends closer to Earth
  - AE9: more intense outer zone horns at low altitude
  - AE9 higher at higher energies (> 3 – 4 MeV)
  - **Largest differences are in regions of lowest fluxes**
- General morphology (AP9)
  - AP9 fluxes generally higher, especially at low altitude
    - Low energies consistent w/measurements by Vampola
    - High energies validated through extensive cross-calibration and comparison w/independent data sets
  - AP9 higher in heart of inner zone
  - **Largest differences are in regions of lowest fluxes**

Discussion (2)

- There are large differences at LEO (electrons & protons)
  - Direct comparisons are difficult here (large spatial gradients)
  - Generally higher fluxes of electrons and protons
  - Differences are generally consistent with measurements (e.g., POES protons, DEMETER electrons)
  - Location of SAA is important (e.g. for low inclination orbits)
- Dose at depth generally higher with Ax9
  - largest difference in LEO
- Uncertainty in flux due to space weather and measurement uncertainty can be a factor of 5 - 10
- Model uncertainty estimates provide ability to trade risk vs. shielding mass, etc.

Discussion (3)

- Models will be periodically updated with new data
  - TacSat-4 (MEO, LEO protons)
  - Van Allen Probes (GTO, electrons, protons)
  - International data sets
- Review paper published in Space Science Reviews: http://link.springer.com/article/10.1007/s11214-013-9964-y
- Please send feedback to (copy all):
  - Bob Johnston, Air Force Research Laboratory, AFRL.RVBXR.AE9.AP9.Org.Mbx@kirtland.af.mil
  - Paul O'Brien, Aerospace Corporation, paul.obrien@aero.org
  - Gregory Ginet, MIT Lincoln Laboratory, gregory.ginet@ll.mit.edu
- Information and discussion forum available on NASA SET website:
  - http://lws-set.gsfc.nasa.gov/radiation_model_user_forum.html

Thank You