



# Air Force Research Laboratory



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SCIENCE & TECHNOLOGY

## The AE9/AP9 Radiation and Plasma Environment Models

4 May 2017

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on behalf of the AE9/AP9 team

***Integrity ★ Service ★ Excellence***





# Outline

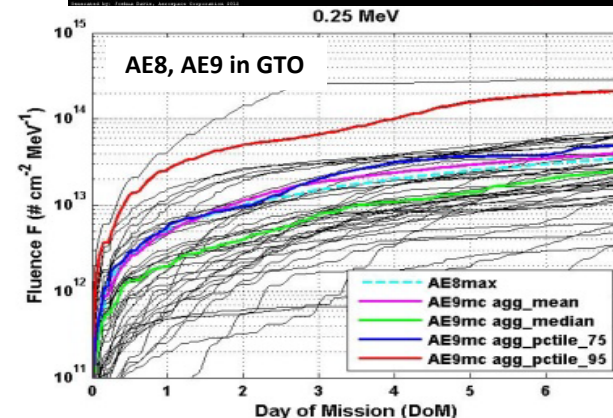
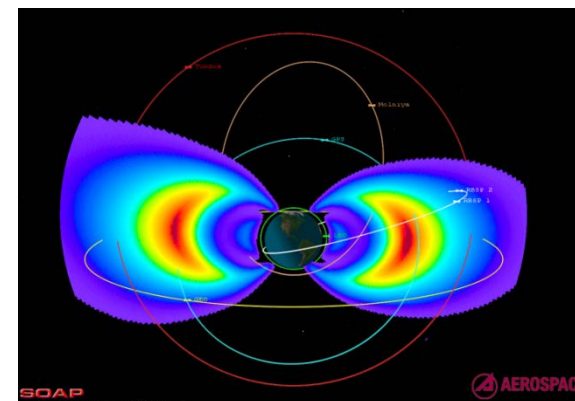


- Background on AE9/AP9/SPM model
- Summary of updates through V1.35
- Version 1.50 update
- Future version plans
- Dedicated web site for model distribution



# What is AE9/AP9/SPM?

- AE9/AP9/SPM specifies the natural trapped radiation environment for satellite design and mission planning
- It improves on legacy models to meet modern design community needs:
  - Uses 37 long duration, high quality data sets
  - Full energy and spatial coverage—plasma added
  - Introduces data-based uncertainties and statistics for design margins (e.g., 95<sup>th</sup> percentile)
  - Dynamic scenarios provide worst case estimates for hazards (e.g., SEEs)
  - Architecture supports routine updates, maintainability, third party applications
- Version 1.00 released in 2012
- Version 1.20 released in March 2015
- Version 1.30 released in February 2016





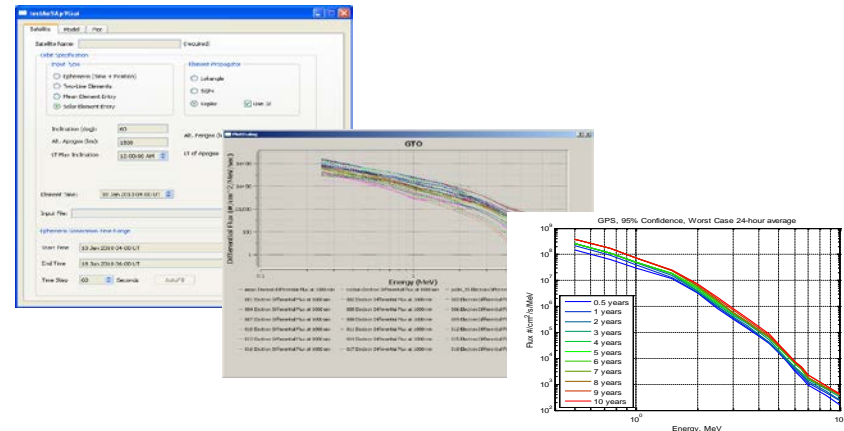
# Coverage and Application



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

- Model provided with GUI and CmdLine access
- Documentation includes recommended modes for typical use cases





# Data Sets—Temporal Coverage



Incorporates  
37 data sets from  
1976-2013

- Chosen for high quality and coverage

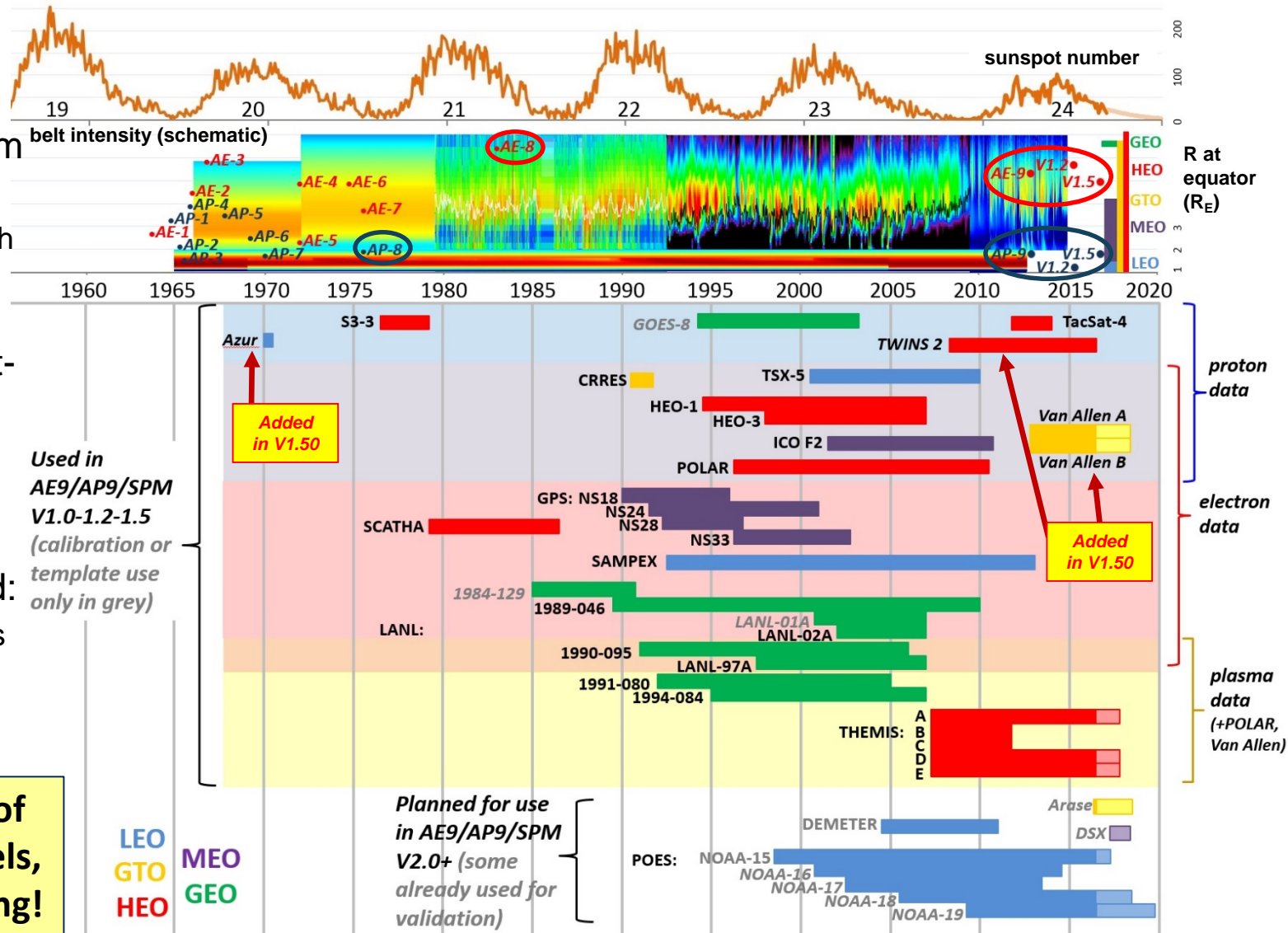
300+ instrument-years of data

- 10x more than AE8+AP8

All solar cycle phases sampled:

- 16 sets >10 yrs
- 26 sets >5 yrs

10x the data of previous models, and still growing!

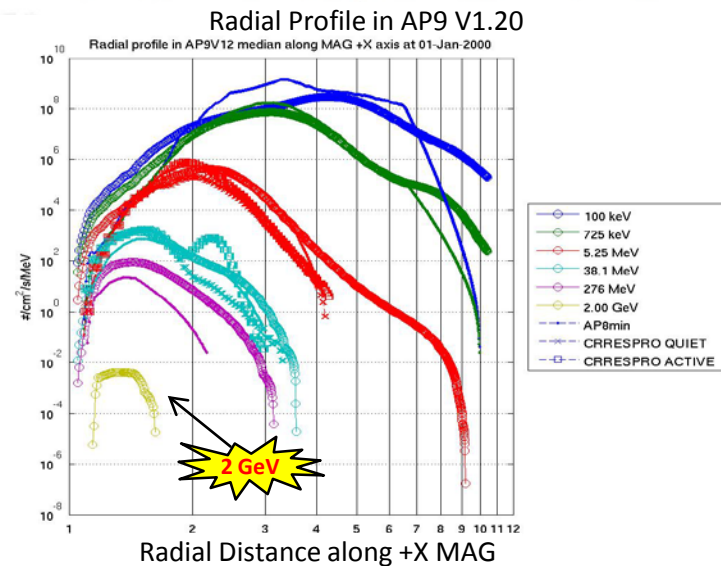
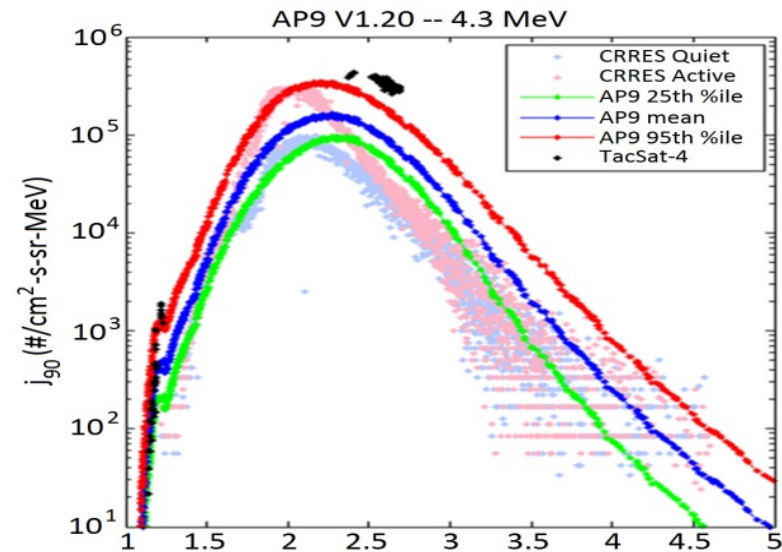




# Version 1.20 – Database Updates



- New data set (first new data to be added):
  - TacSat-4/CEASE proton data—captures new observations of elevated 1-10 MeV protons
  - Additional plasma data: THEMIS/ESA
- New electron templates
  - Improvements for inner zone electrons and for >3 MeV spectra
- New proton templates
  - Incorporate  $E/K/\Phi$  and  $E/K/h_{\min}$  profiles observed by Van Allen Probes/Relativistic Proton Spectrometer (RPS)
  - Extend proton energies to 2 GeV
- Low altitude taper
  - Force fast fall-off of flux for  $h_{\min} < 100$  km.
  - Cleans up radial scalloping at altitudes below ~1000 km



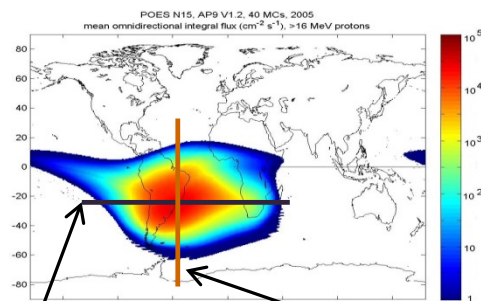


# AP9 V1.20 Validation—SAA

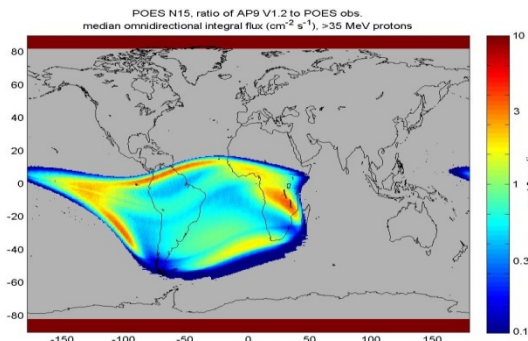


>35 MeV protons

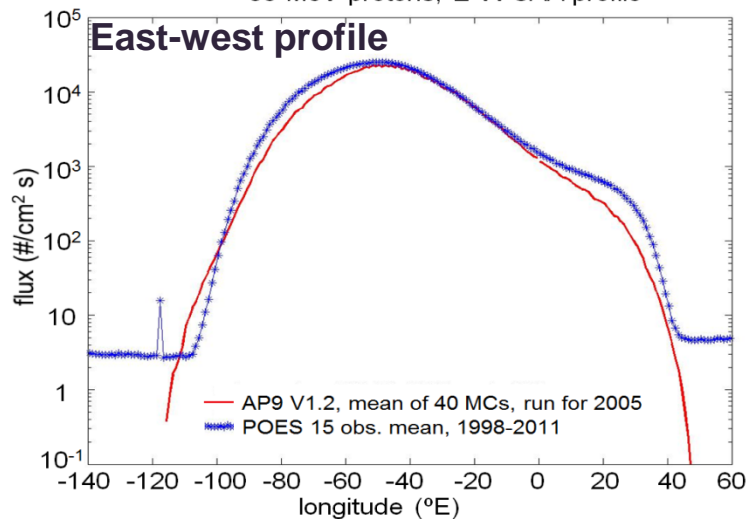
SAA flux profiles are improved in V1.20 as compared to POES observations



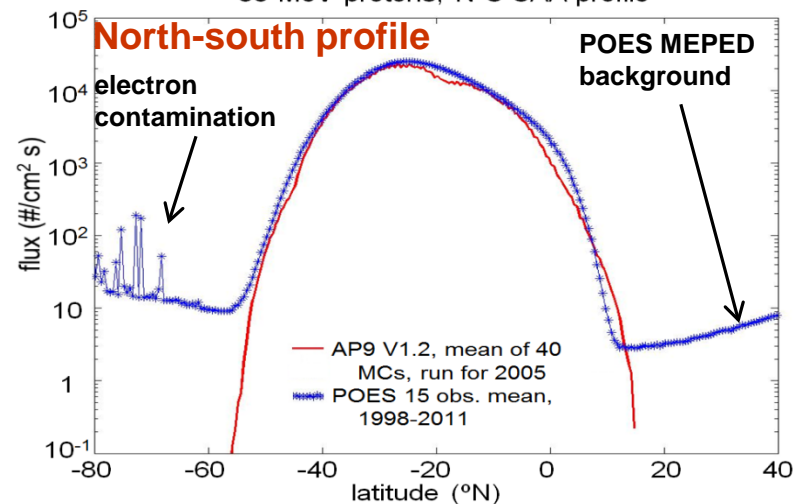
Ratio of AP9 V1.20 median to POES data



>35 MeV protons, E-W SAA profile



>35 MeV protons, N-S SAA profile

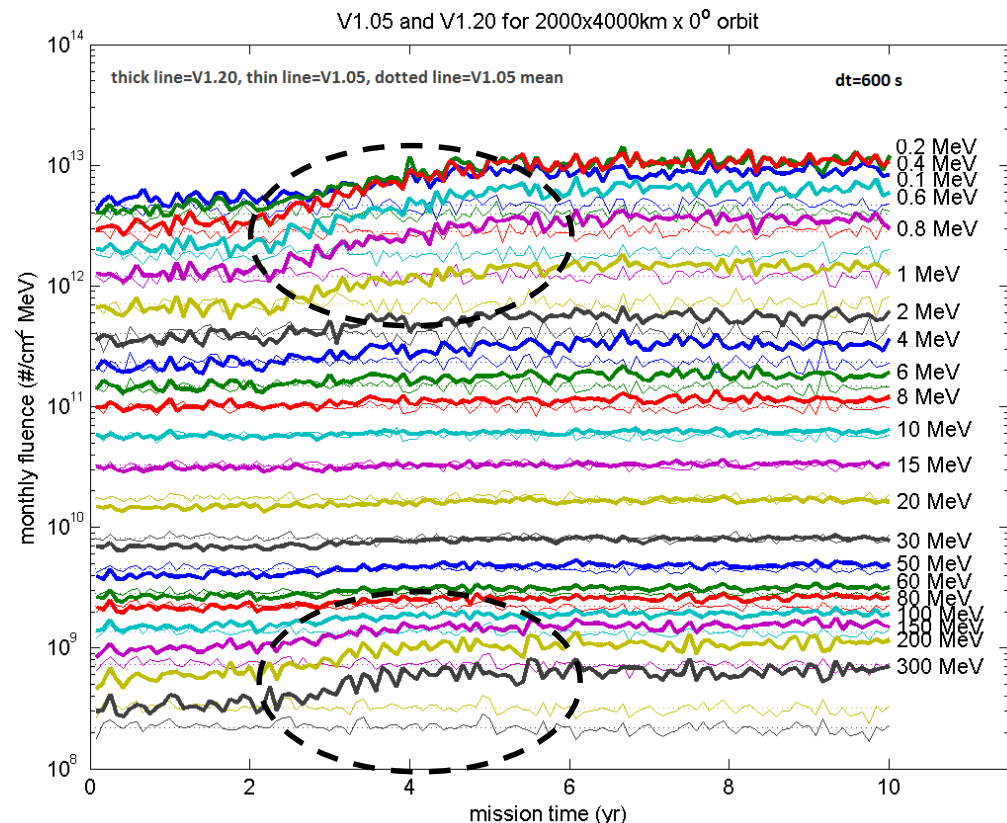




# Version 1.30 – Monte Carlo Fix



- Fixes Monte Carlo instability in AP9 V1.20
  - (AP9 MC Runs would “explode” after a few years)
- V1.30 updates Monte Carlo tables and algorithms to ensure long run fluence converges to perturbed mean
- Affects AE9 and AP9 Monte Carlo runs
- Mean and Perturbed Mean calculations are unchanged from V1.20 for AE9/AP9/SPM





# Version 1.35



- Released Jan 2017
- Supports parallelization
  - Uses MPI, supports multiple platforms and parallel environments
  - Use multiple cores on Windows via GUI
  - Use Linux Clusters via Command Line Utility
- Fix flux-to-fluence calculations to cover variable time steps—supports optimizing time steps for shorter run times
- Better calculation of combined proton and electron dose confidence levels
- All flux and fluence results match V1.30\*  
*(with some minor exceptions due to new numerics)*



# Forthcoming Versions



<b>V1.50 (2017)</b>	New data for electrons, protons
<b>V1.55(?) (2017-18)</b>	Kernels for faster effects calculations
<b>V2.00 (2018-19)</b>	New architecture New modules—solar protons, sample solar cycle New data sets
<b>V2.50(?) (2019)</b>	New data sets (DSX, ERG)



# Changes in AE9/AP9 V1.50



- AP9 and AE9: new data from NASA's Van Allen Probes mission
- AP9: data added from Azur and TWINS 2
- AP9 and AE9: other revisions to flux maps (addressing gradients and other aspects of data set merging)
- Limited feature changes with this release—most significant will be new accumulator options (e.g., fluence accumulation intervals)

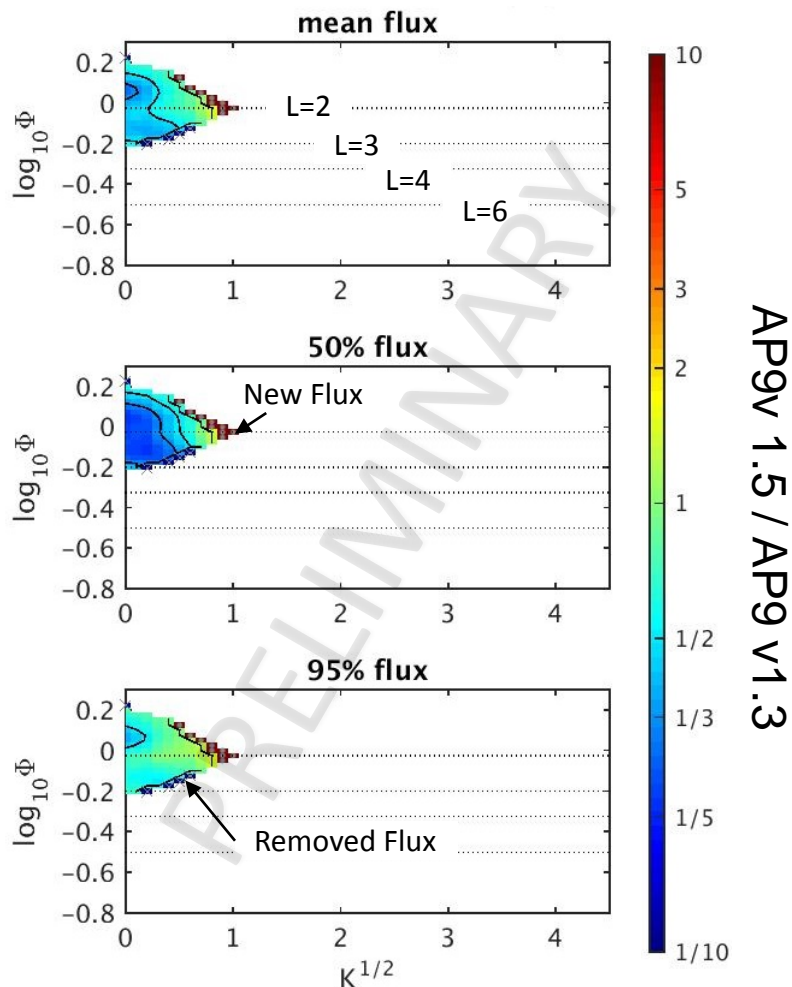
satellite	orbit	time period	instrument	species	energy
Van Allen Probes A & B	GTO (800 x 30600 km, 10°)	Aug 2012 – Dec 2016	RPS (Relativistic Proton Spectrometer)	protons	>58 MeV -- ~2 GeV
			REPT (Relativistic Electron Proton Telescope)	protons	20 – 100 MeV
				electrons	1.5 – 30 MeV
			MagEIS	electrons	30 keV – 7 MeV
Azur	384 x 3145 km, 103°	Nov 1969 – Mar 1970	EI-88 telescope	protons	1.5 – 104 MeV
TWINS 2	Molniya (1000 x 39500 km, 63°)	Apr 2008 – Nov 2016	HiLET	protons	6 – 30 MeV



# V1.50 Changes – AP9 Flux Maps



## 200 MeV Proton Flux Ratios



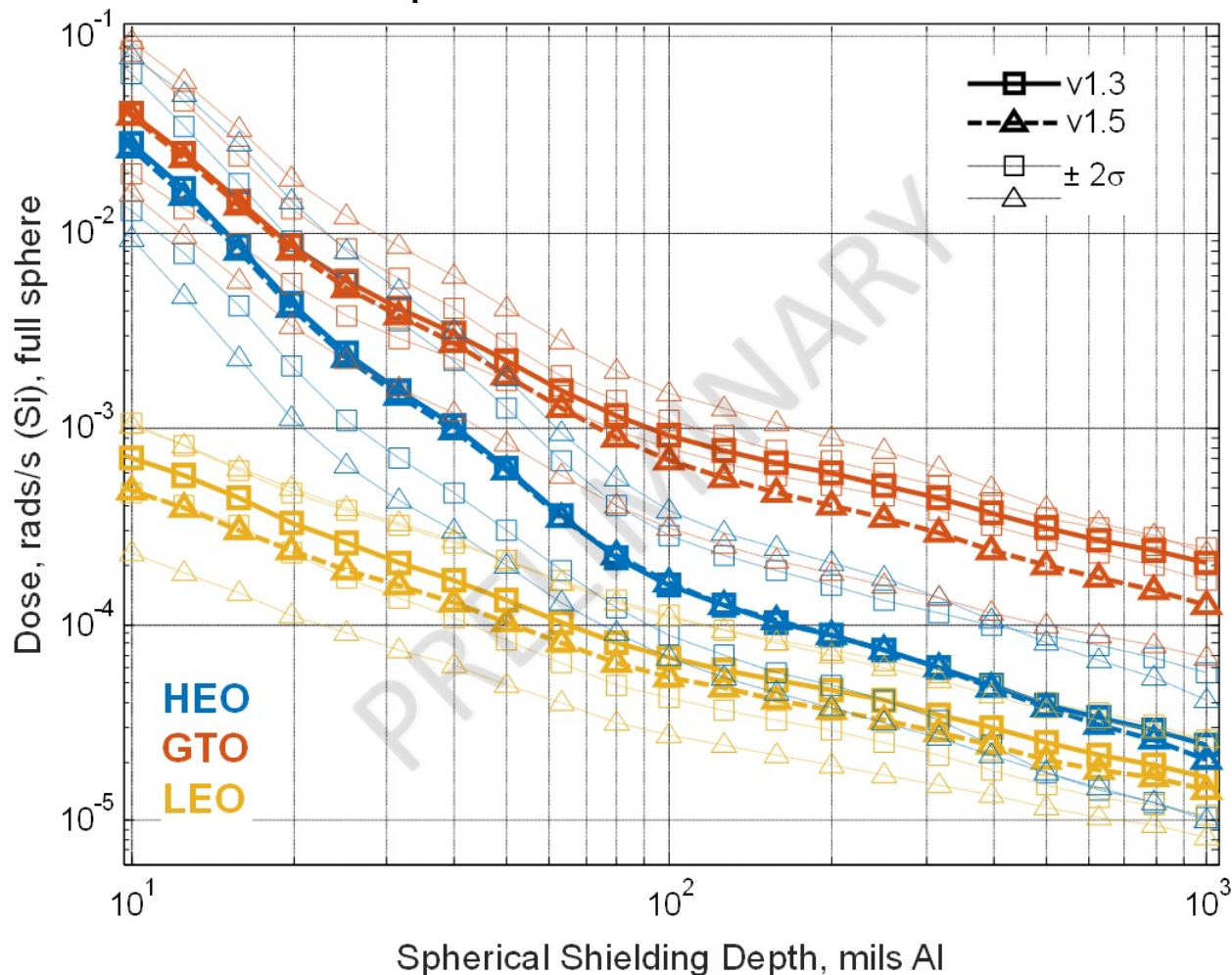
- AP9 adds Azur, HiLET and Van Allen Probes data
- These new data generally bring down the inner zone fluxes
- Especially large changes  $>150$  MeV where RPS data represent the first clean observations in the inner zone up to 2 GeV



# V1.50 Changes – AP9 Dose



Dose Comparison for Protons in AP9 v1.3 and v1.5



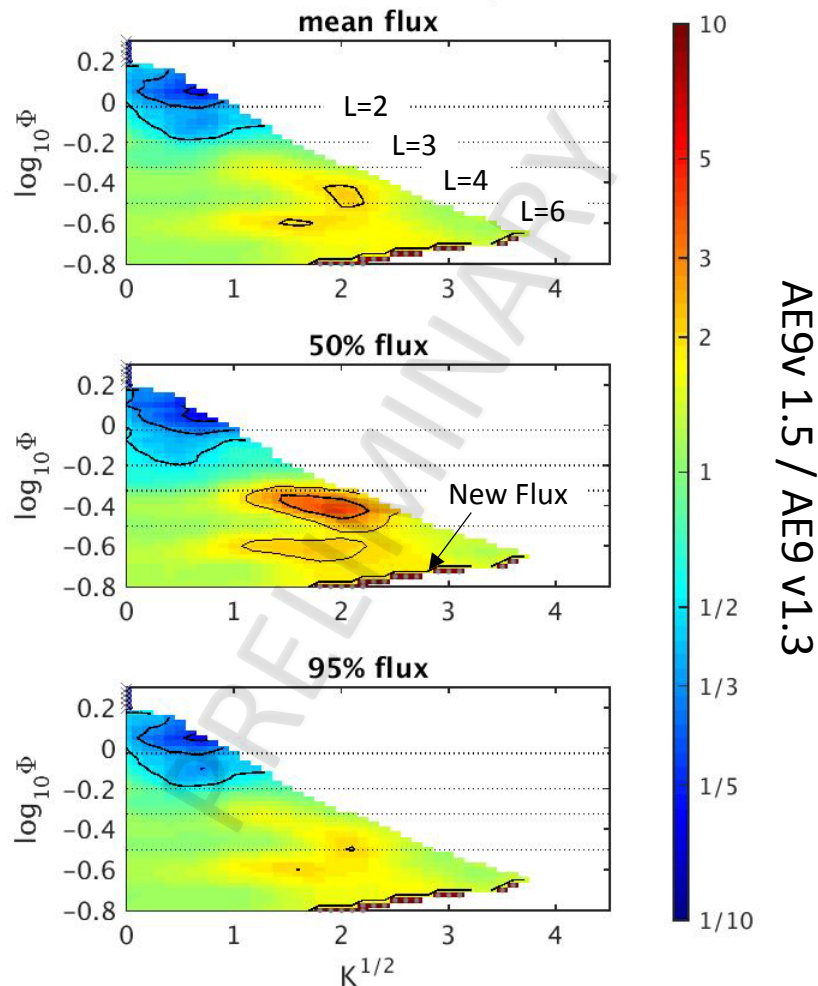
- Similar dose in HEO orbit
- Lower dose in GTO for depths >30 mils
- Lower dose in LEO for all depths
- Larger error bars in all orbits



# V1.50 Changes – AE9 Flux Maps



## 1 MeV Electron Flux Ratios



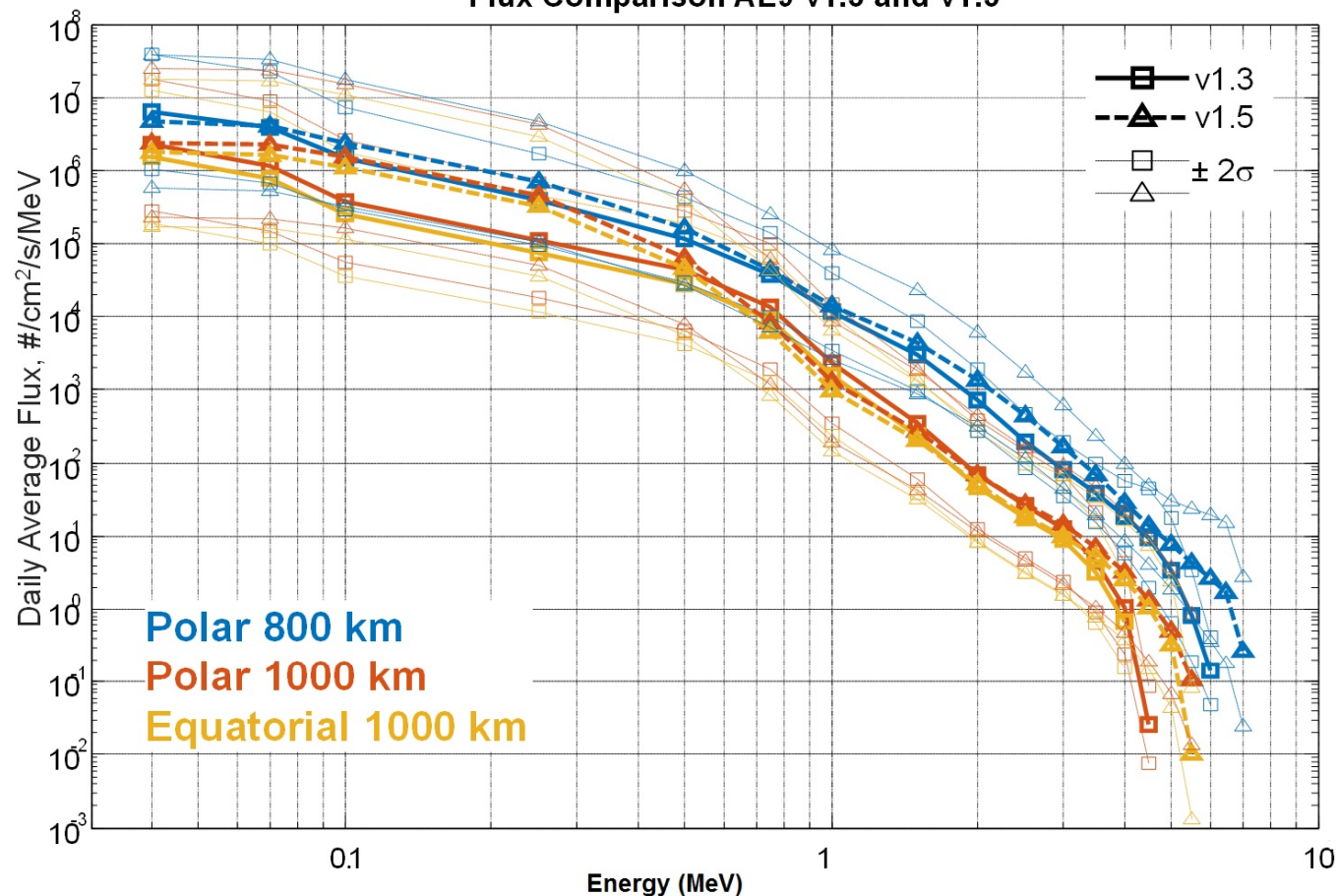
- AE9 adds Van Allen Probes data
- These new data generally bring down the inner zone fluxes
- Some localized higher fluxes



# V1.50 Changes – AE9 in LEO



Flux Comparison AE9 v1.3 and v1.5



- Fluxes are higher <300 keV for both 1000 km orbits
- Fluxes are a bit higher at all energies in 800 km orbit
- Error bars are larger



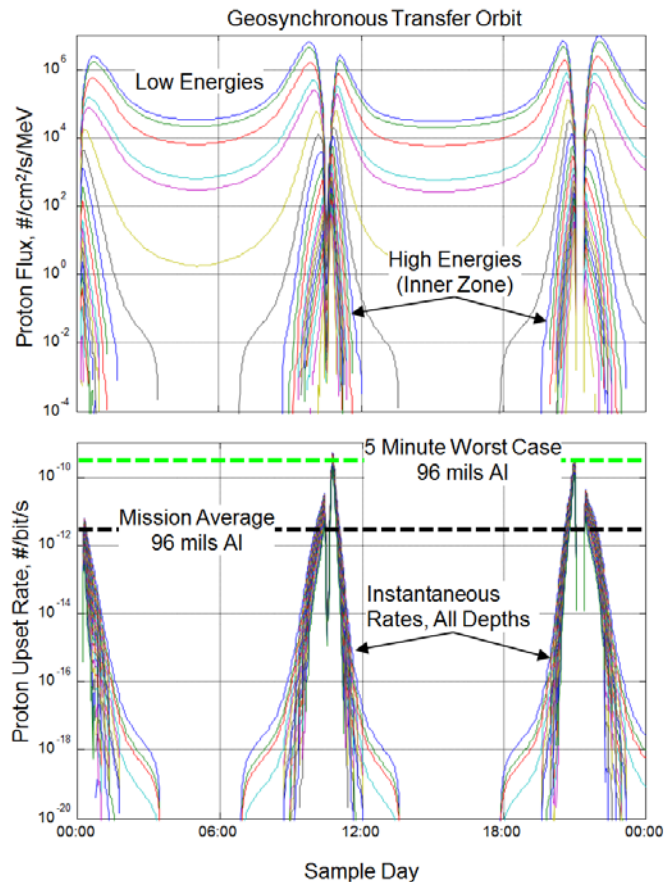
# IRENE



- Starting with V1.50, AE9/AP9 now includes international contributions (Azur data)
- To recognize the internationalization of the model, we will begin transition to a new name: **International Radiation Environment Near Earth (IRENE)**
- AE9/AP9 v1.5 is then also known as AE9/AP9-IRENE
- We will use both names for a few releases, and eventually switch to IRENE only
- In addition to Azur data, ESA is working hard to produce a Monte Carlo solar proton model that we can integrate with AP9



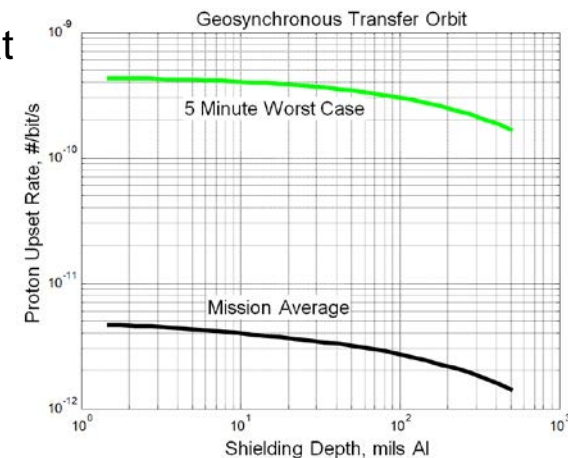
# Kernel-Based Effects Calculation



- Proton SEE rate calculation, proton displacement damage, electron internal charging currents, etc.

## Example: Proton SEE rate calculation

- User provides Weibull or Bendel Parameters and desired shielding depths
- Utility computes “kernel” that transforms proton flux to SEE rate behind shielding
- Model will be able to output
  - Instantaneous SEE rate
  - Mission average SEE rate
  - Worst case SEE rate on desired timescale





# Version 2.00



- Major feature changes:
  - Sample solar cycle—introduces a full solar cycle reanalysis as a flythrough option
  - New module frameworks for e.g. plasma species correlations, SPM stitching with AE9/AP9, auroral electrons, additional coordinates for MLT variation in SPM
  - AP9 improvements: solar cycle variation in LEO, east-west effect
  - Incorporate untrapped solar protons with statistics
- New data
  - Van Allen Probes/RPS, MagEIS & REPT protons and electrons
  - PAMELA protons—addresses high energy proton spectra
  - Other international data sets: possibilities include Cluster/RAPID-IIMS, ESA SREMs, CORONAS, NINA, Akebono/EXOS-D, SAC-C, Jason2, PROBA-V/EPT



# 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

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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

Home of Virtual Distributed Laboratory

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# Summary



- AE9/AP9/SPM provides radiation environment specification to meet the needs of modern designers
- Successive releases demonstrate maintainability
- Future releases will include new data sets and new features, driven by user needs
- **Comments, questions, etc. are welcome and encouraged!**
- Please send feedback, requests for model or documentation, etc., to (copy all):
  - Bob Johnston, Air Force Research Laboratory, [AFRL.RVBXR.AE9.AP9.Org.Mbx@us.af.mil](mailto:AFRL.RVBXR.AE9.AP9.Org.Mbx@us.af.mil)
  - Paul O'Brien, Aerospace Corporation, [paul.obrien@aero.org](mailto:paul.obrien@aero.org)
- Model downloads, documentation, news are available at AFRL's Virtual Distributed Laboratory: <https://www.vdl.af.mil/programs/ae9ap9>