Air Force Research Laboratory

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The AE9/AP9-IRENE Radiation and Plasma Environment Models

7 September 2017

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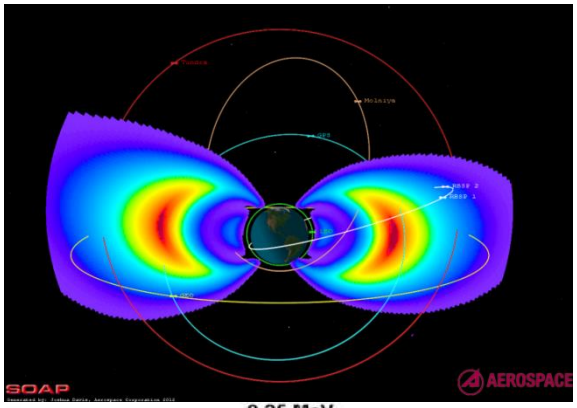
on behalf of the AE9/AP9 team

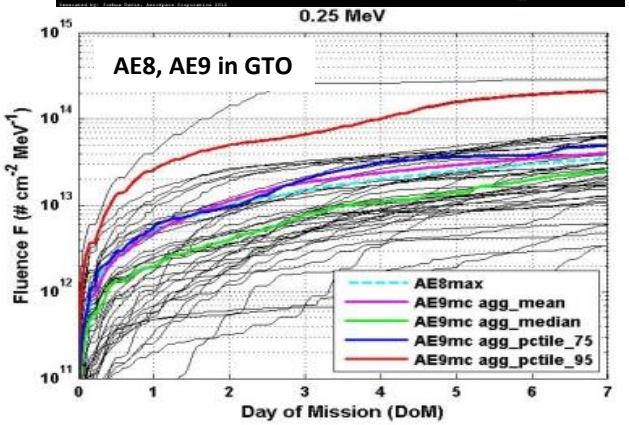
Outline

- 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., 95th 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



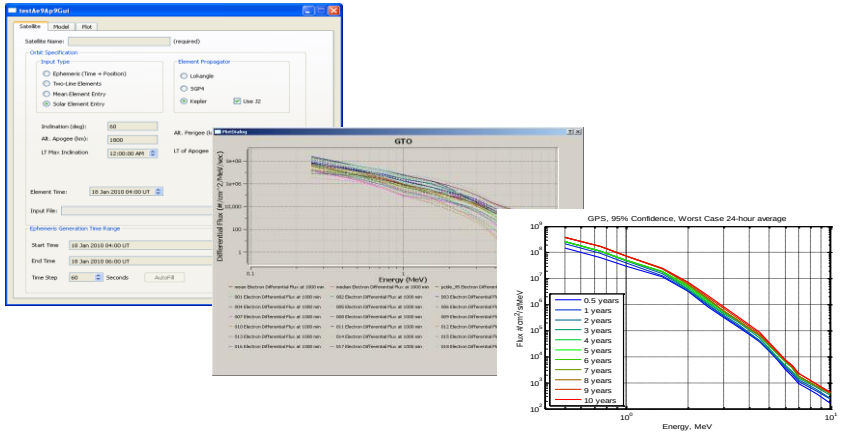


Coverage and Application

- Expanded energy coverage: keV plasma to GeV protons
- Spatial coverage for all orbit regimes, including tailored coverage for high resolution in LEO

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

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	$0.98 < L^* < 12.4$	$0.98 < L^* < 12.4$	$2 < L_m < 10$



Data Sets—Temporal Coverage

Incorporates 37 data sets from 1976-2016

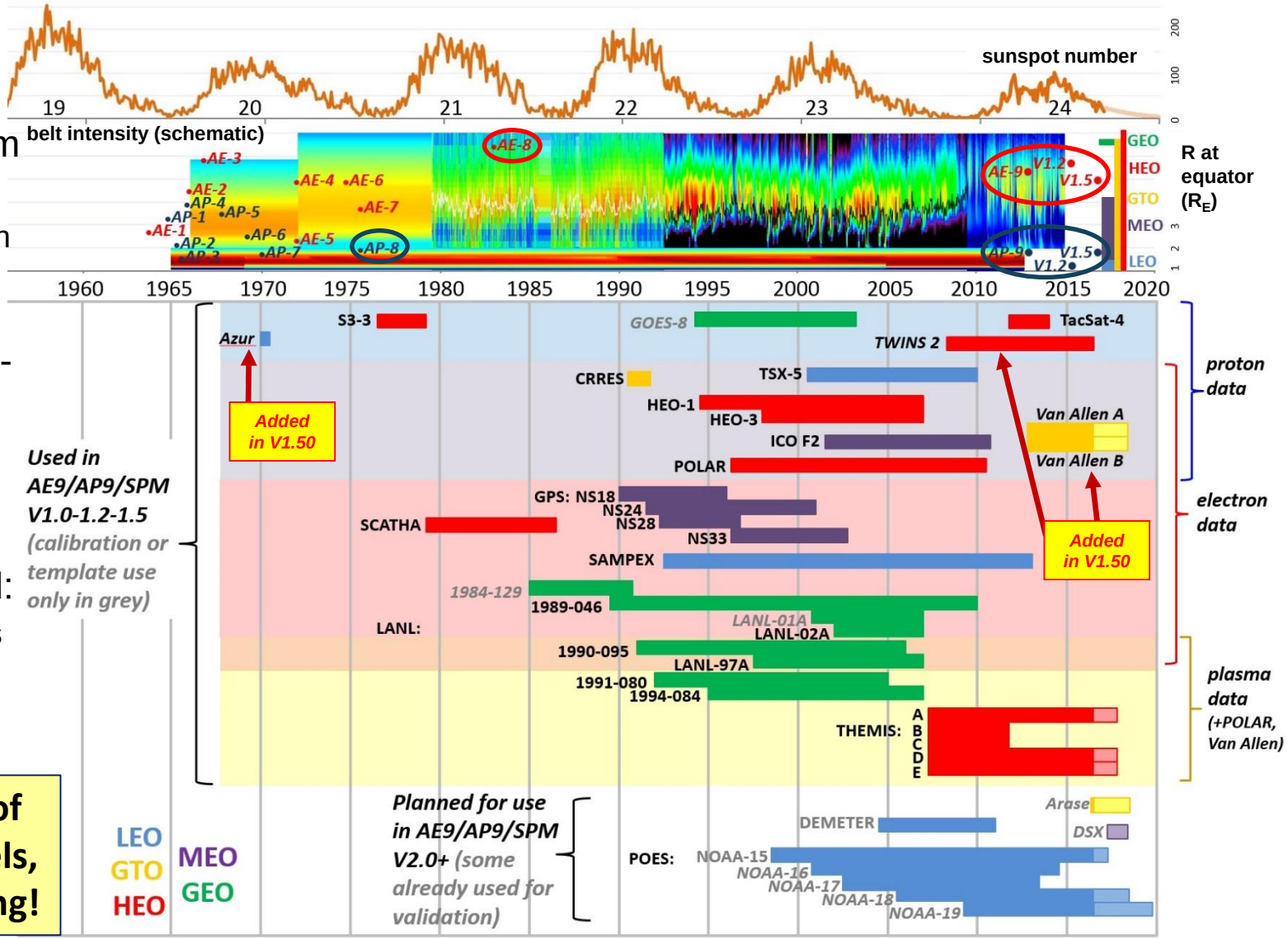
- Chosen for high quality and coverage

300+ instrument-years of data

- 10x more than AE8+AP8

All solar cycle phases sampled:

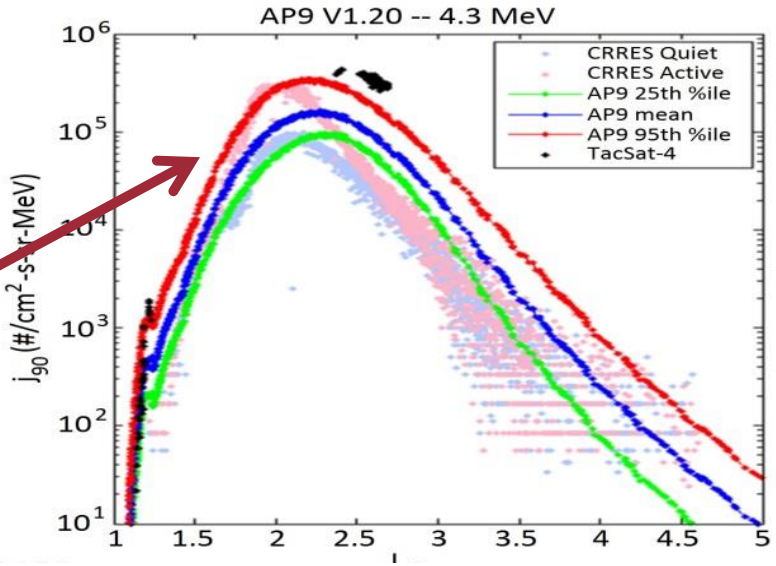
- 16 sets >10 yrs
- 26 sets >5 yrs

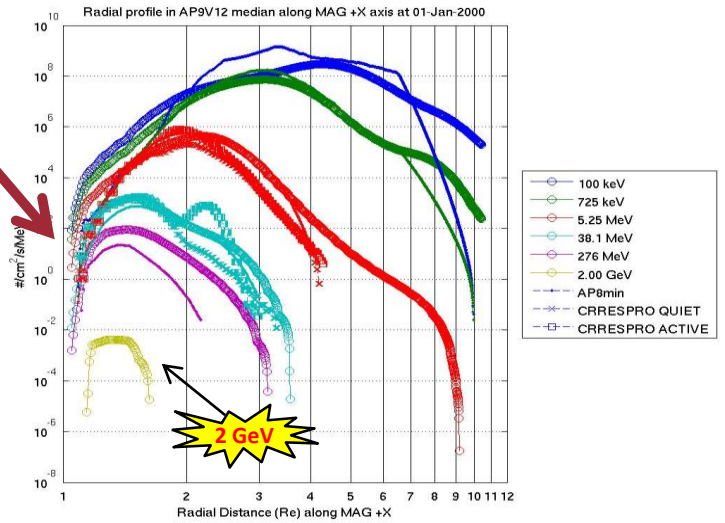


10x the data of previous models, and still growing!

Versions to Date

V1.00 (2012)	Initial release, 31 data sets
V1.20 (2015)	TacSat-4/CEASE proton data THEMIS/ESA plasma data Van Allen Probe influence to AE9 and AP9 changes more I/O options added IGRF 2015
V1.30 (2016)	Fixed instability in V1.20 AP9, AE9 Monte Carlo mode
V1.35 (2017)	Support for parallelized processing





Forthcoming Versions

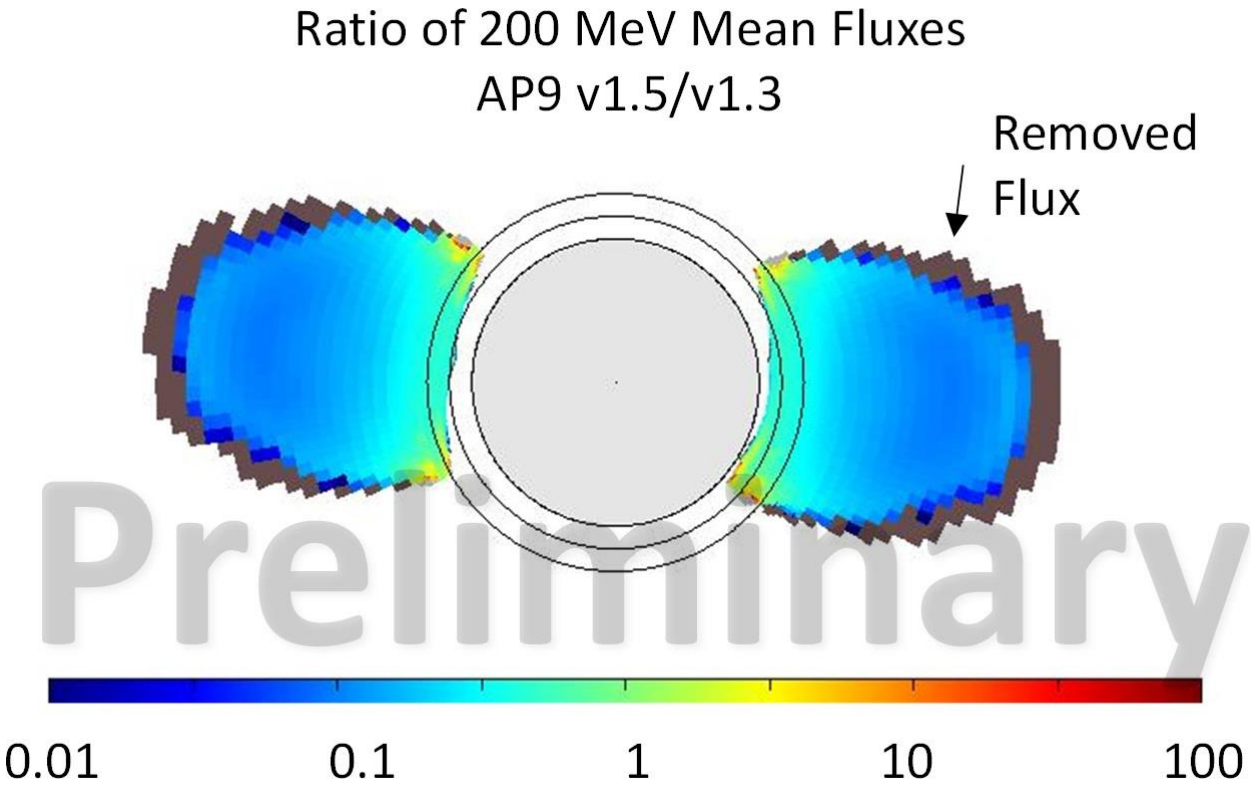
V1.50 (Sept 2017)	New data for electrons, protons
V1.55(?) (2017-18)	Kernels for faster effects calculations
V1.60 (2018)	Additional Van Allen Probes data
V2.00 (2018-19)	New architecture New modules—solar protons, sample solar cycle New data sets
V2.50(?) (2019)	New data sets (DSX, ERG)

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)

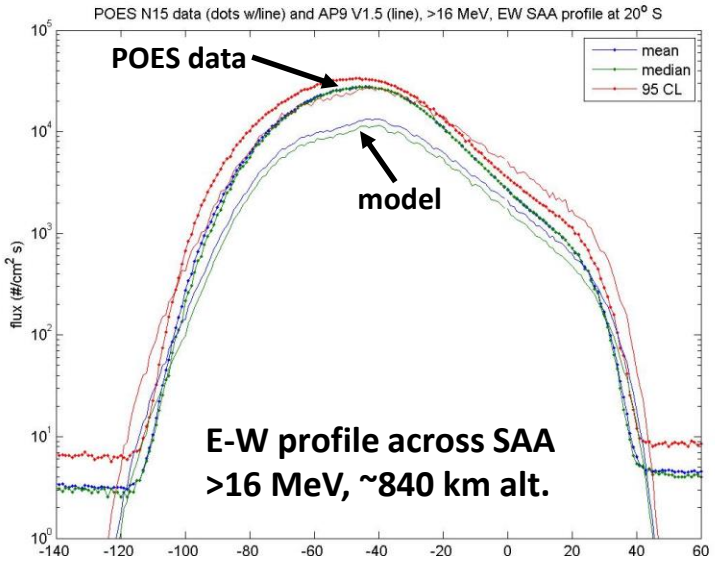
satellite	orbit	time period	instrument	species	energy
Van Allen Probes A & B	GTO (800 x 30600 km, 10°)	Aug 2012 – Dec 2016	RPS (Relativistic Proton Spectrometer)	protons	>58 MeV -- ~2 GeV
			REPT (Relativistic Electron Proton Telescope)	protons	20 – 100 MeV
			MagEIS	electrons	30 keV – 2 MeV
Azur	384 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

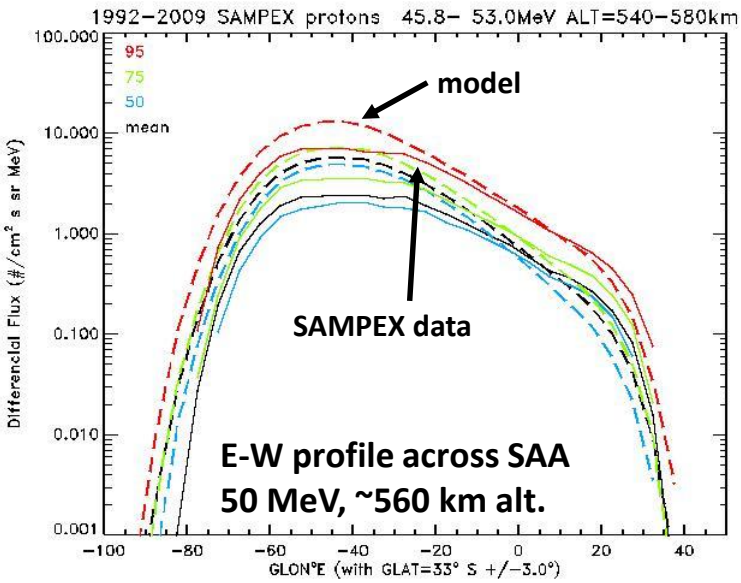
V1.50 Changes – AP9 Flux Maps

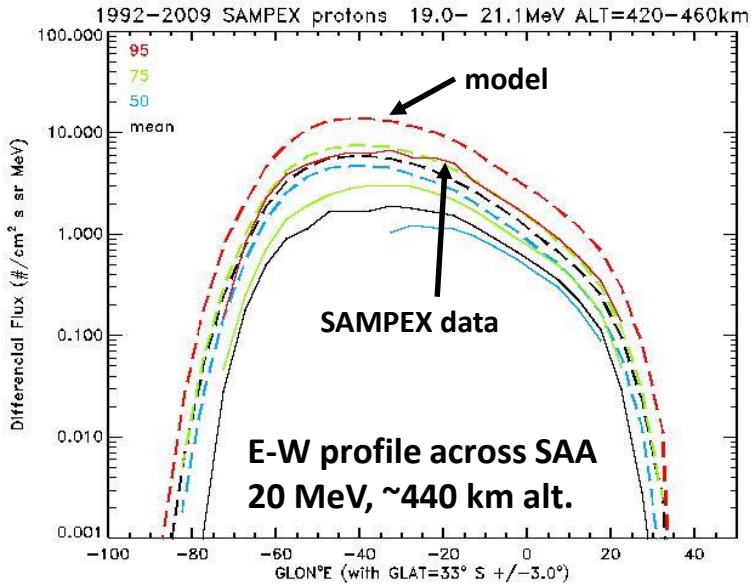


- AP9 adds Azur, HiLET and Van Allen Probes data
- These new data generally bring down the inner zone fluxes
- Especially large changes >150 MeV where RPS data represent the first clean observations in the inner zone up to 2 GeV

V1.50 AP9 Validation







- V1.50 is ~2.5-3.5x lower than POES SEM channels
- V1.50 is ~1-4x higher than SAMPEX PET channels
- Shape of SAA profile is generally consistent between model and data

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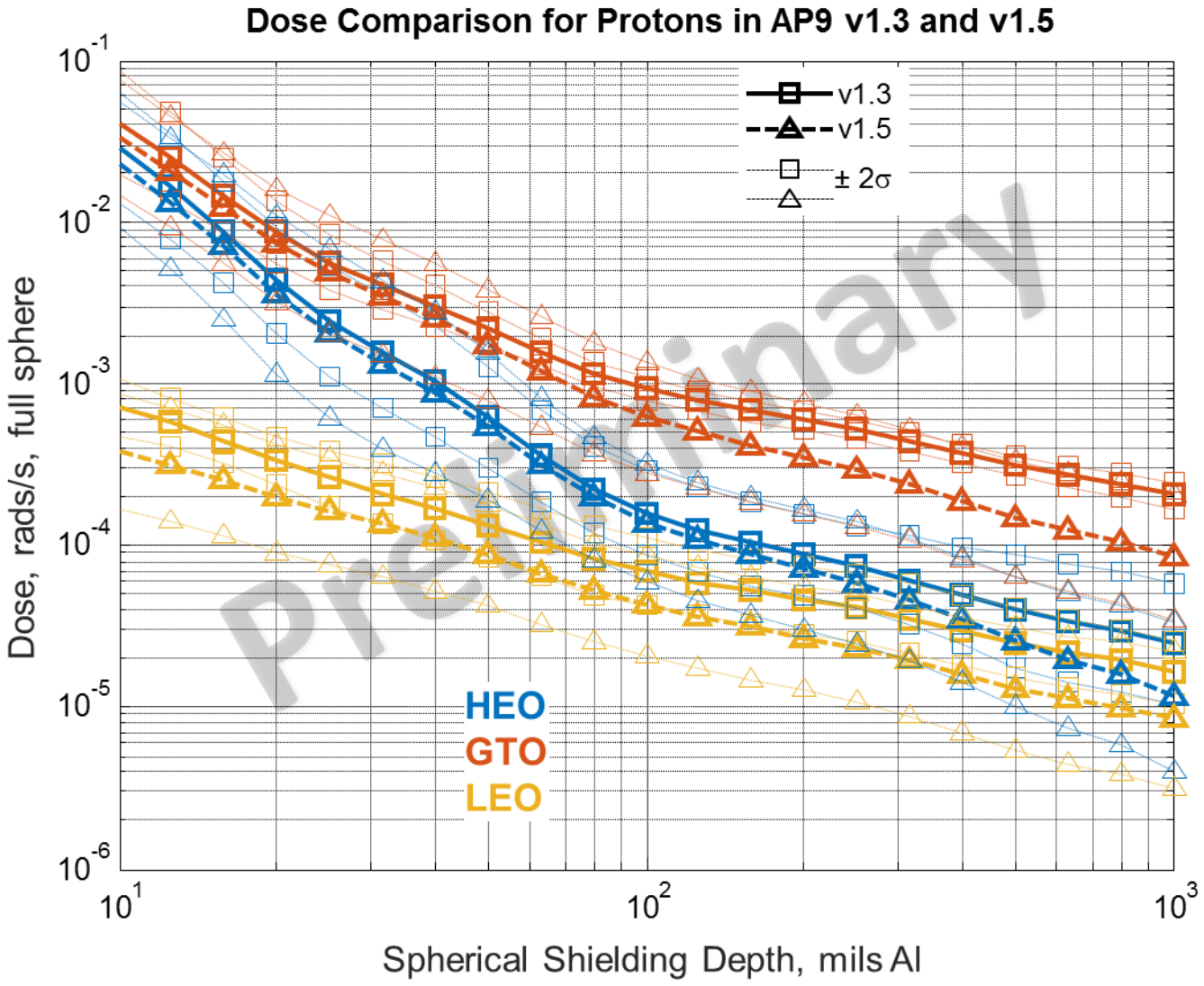
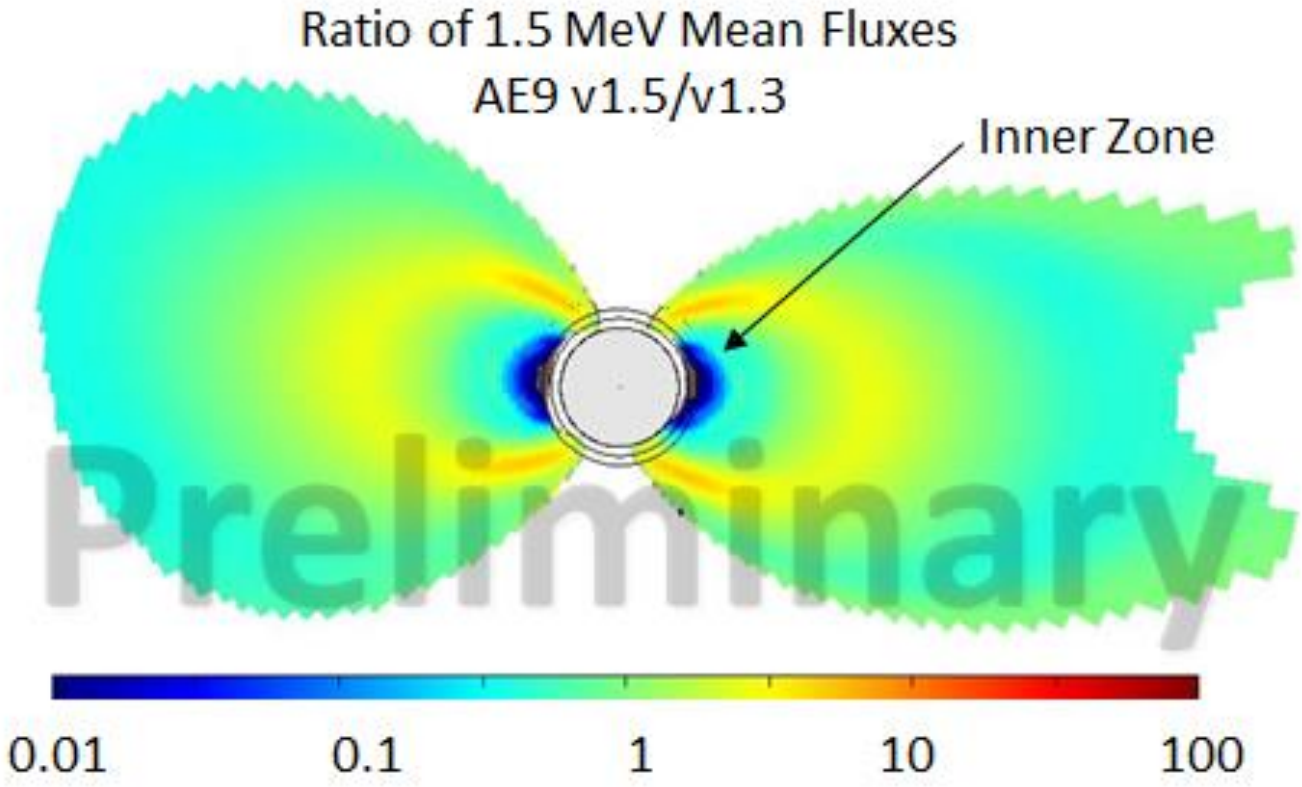
V1.50 Changes – AP9 Dose



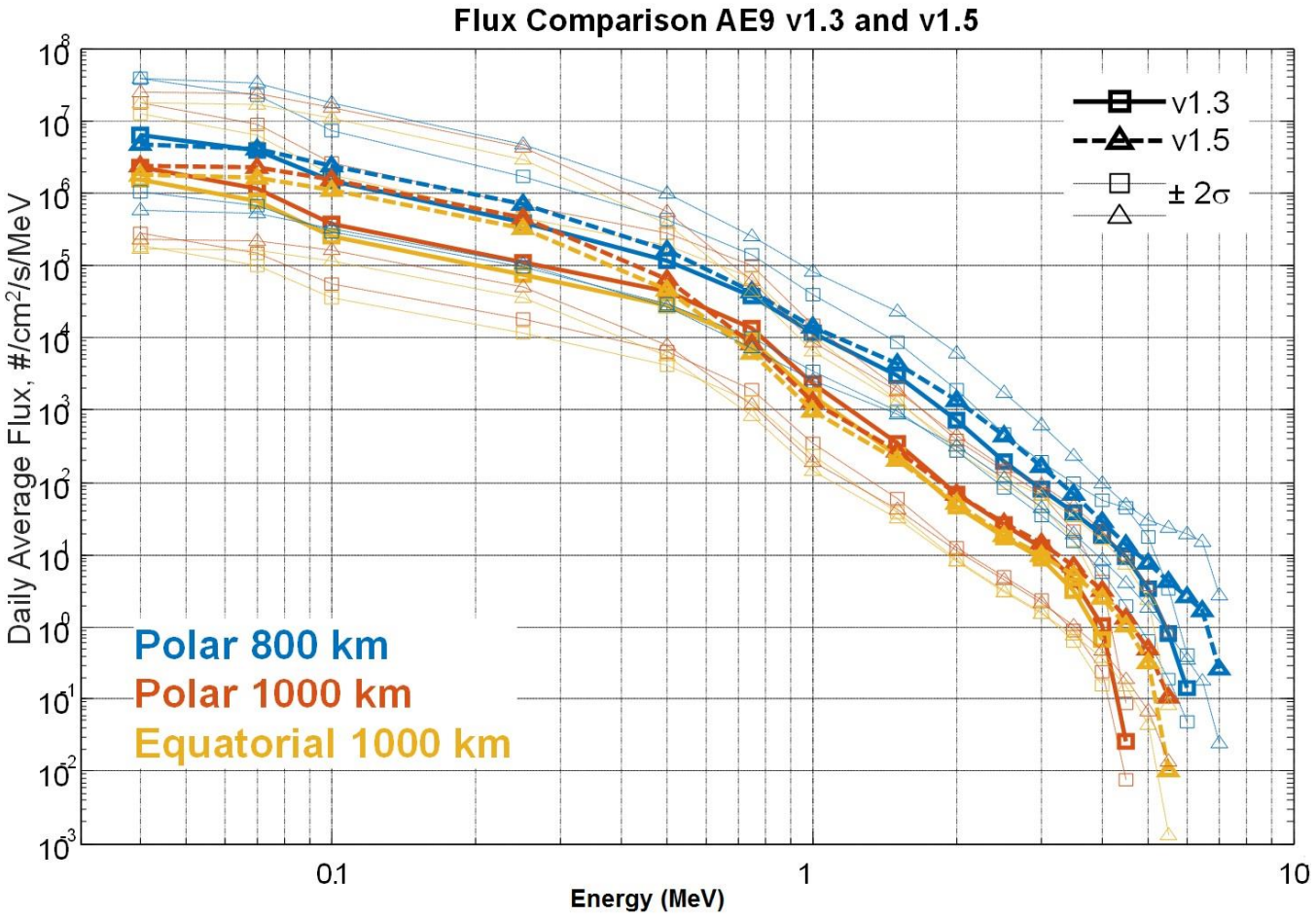
- Lower dose in all orbits
- Most pronounced in LEO at all depths and in GTO at thicker depths
- In some places, larger error bars raise 95% CL even though mean flux is lower

V1.50 Changes – AE9 Flux Maps



- 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

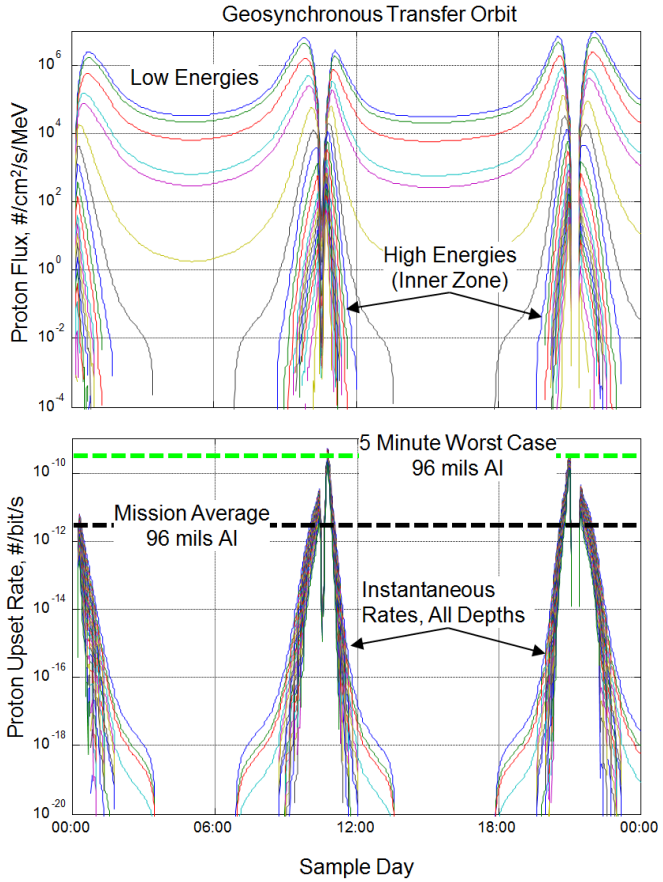


- Fluxes are higher <300 keV for both 1000 km orbits
- Fluxes are a bit higher at all energies in 800 km orbit
- Error bars are larger

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

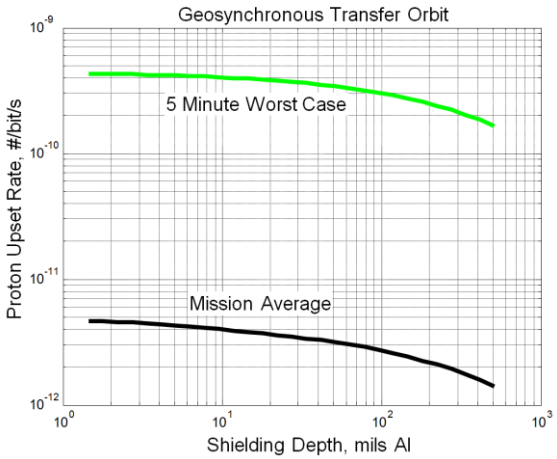
Kernel-Based Effects Calculation



- 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

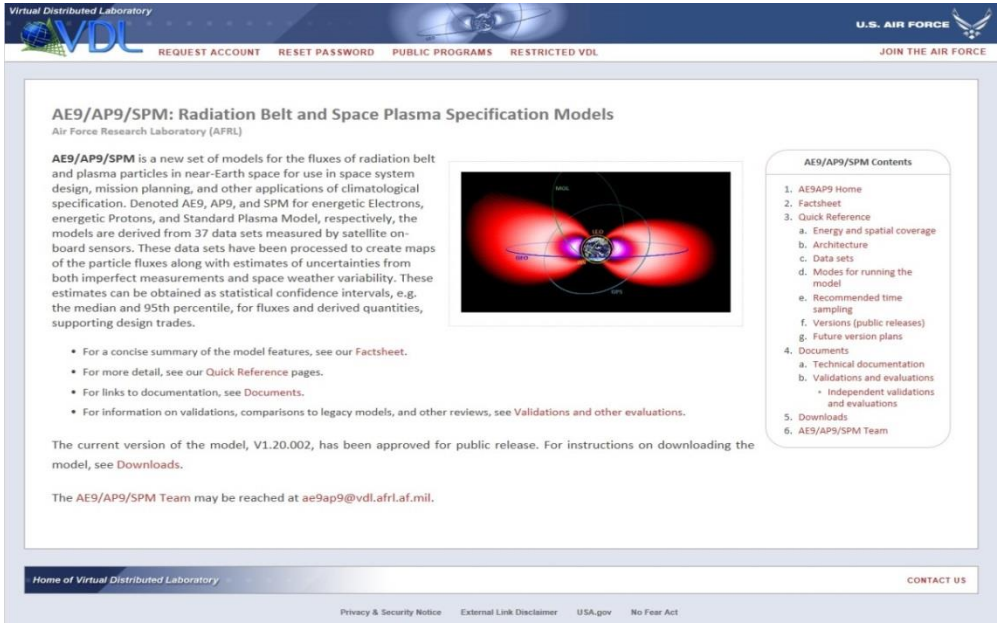


Version 2.00

- 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



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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
  - Paul O'Brien, The Aerospace Corporation, paul.obrien@aero.org
- Model downloads, documentation, news are available at AFRL's Virtual Distributed Laboratory: **https://www.vdl.afrl.af.mil/programs/ae9ap9**