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IRENE-AE9/AP9 Overview

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Outline

- Introduction
- Coverage and application
- Releases
- Architecture
- Data sets
- Comments on usage and limitations
- Summary

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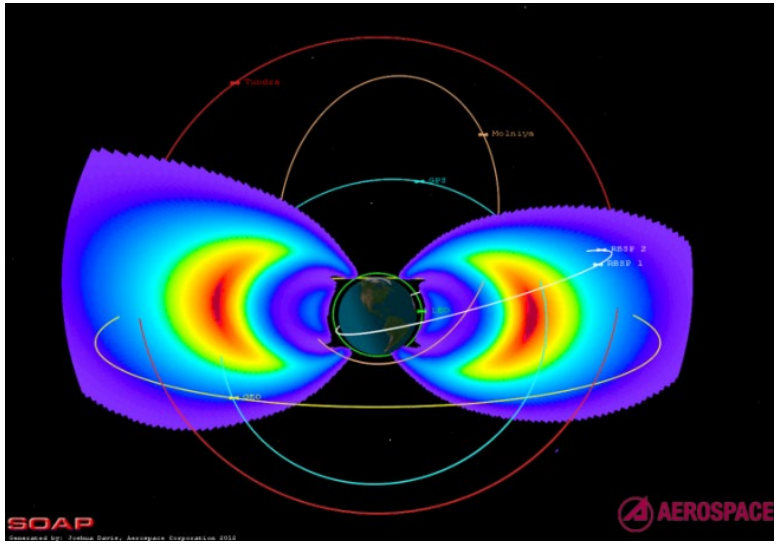
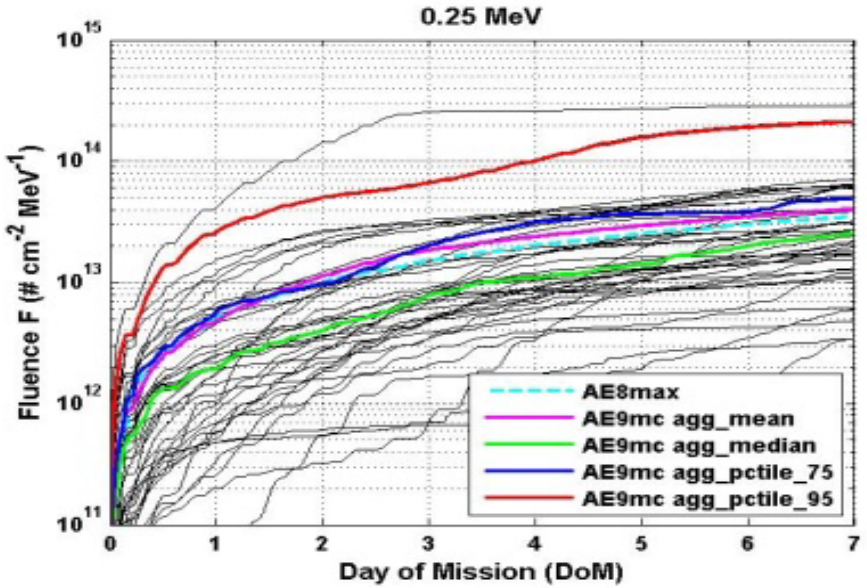
What is IRENE?

- IRENE-AE9/AP9 specifies the natural trapped radiation environment for satellite design and mission planning
- It improves on legacy models to meet modern design community needs:
  - Uses 45 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
- V1.00 released in 2012, V1.50 in Dec 2017
- V1.57 released in Oct 2022



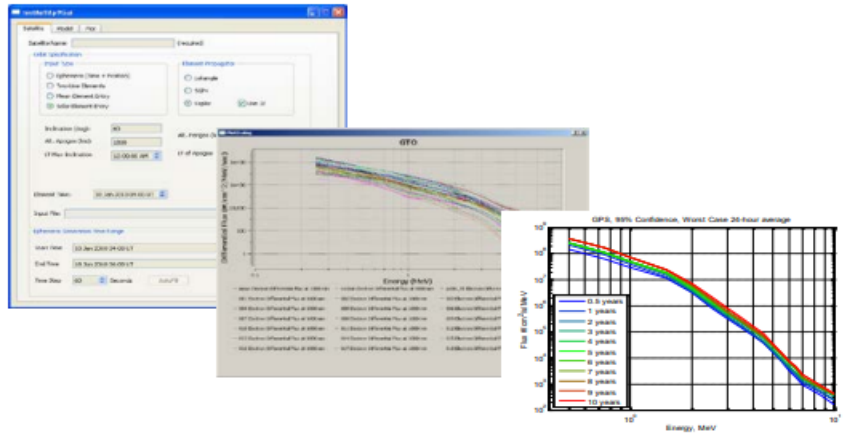


Coverage and application

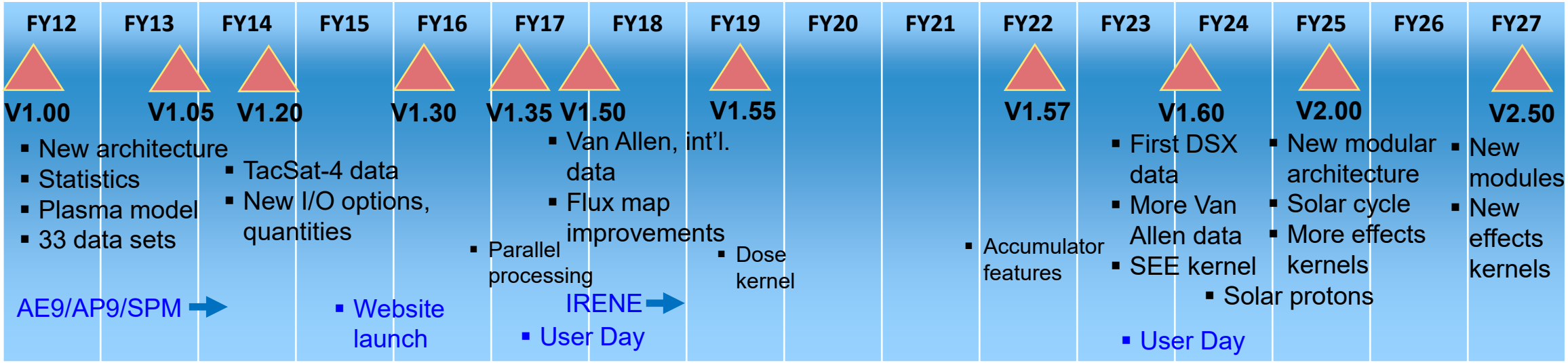
- Energy coverage from keV plasma to GeV protons
- Spatial coverage for all orbit regimes, including tailored coverage for high resolution in LEO

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

- Model provided with GUI and CmdLine access
- Distribution as Windows executable
  - Source code package available on request from AFRL for other platforms (build instructions included)
- Documentation includes recommended modes for typical use cases



IRENE-AE9/AP9 releases



Version numbering:

- **1**.00—1st digit change = new architecture
- 1.**5**0—2nd digit change = new flux maps
- 1.5**7**—3rd digit change = new features

Releases:

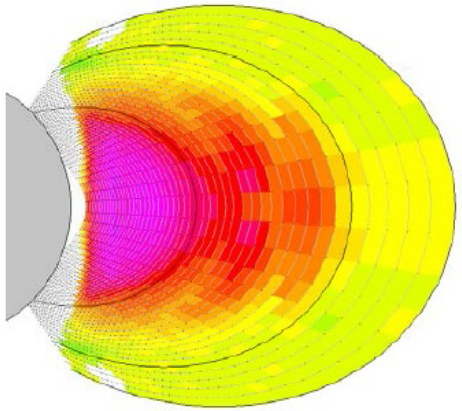
- AFRL conducts releases with public release slightly delayed from restricted release (no difference in versions)

Forthcoming:

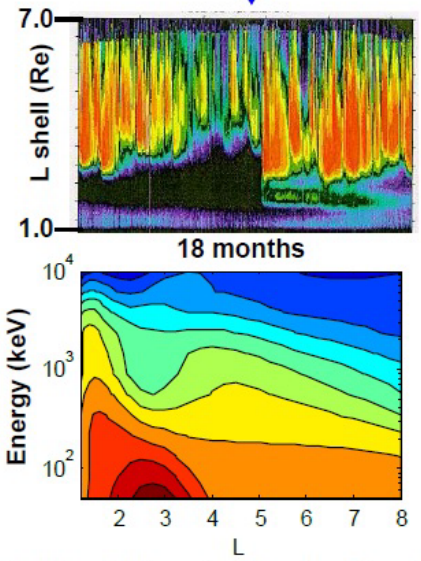
- V1.60—flux map updates, IGRF 2020
- Add solar proton module in V1.60 or V2.00
- V2.00 development
  - Architecture overhaul—tailored modules, more hazard populations
  - Kernels for SEEs, internal charging
- V2.50—more modules, kernels

Architecture

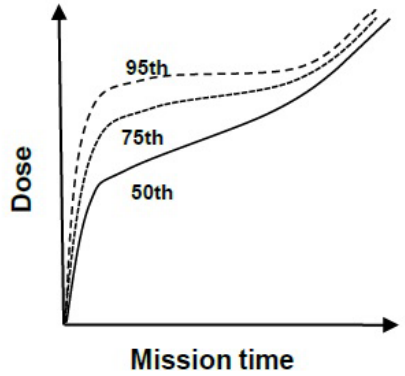
Satellite data



Satellite data & theory



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

Data sets

Incorporates 45 data sets from 1969-2016

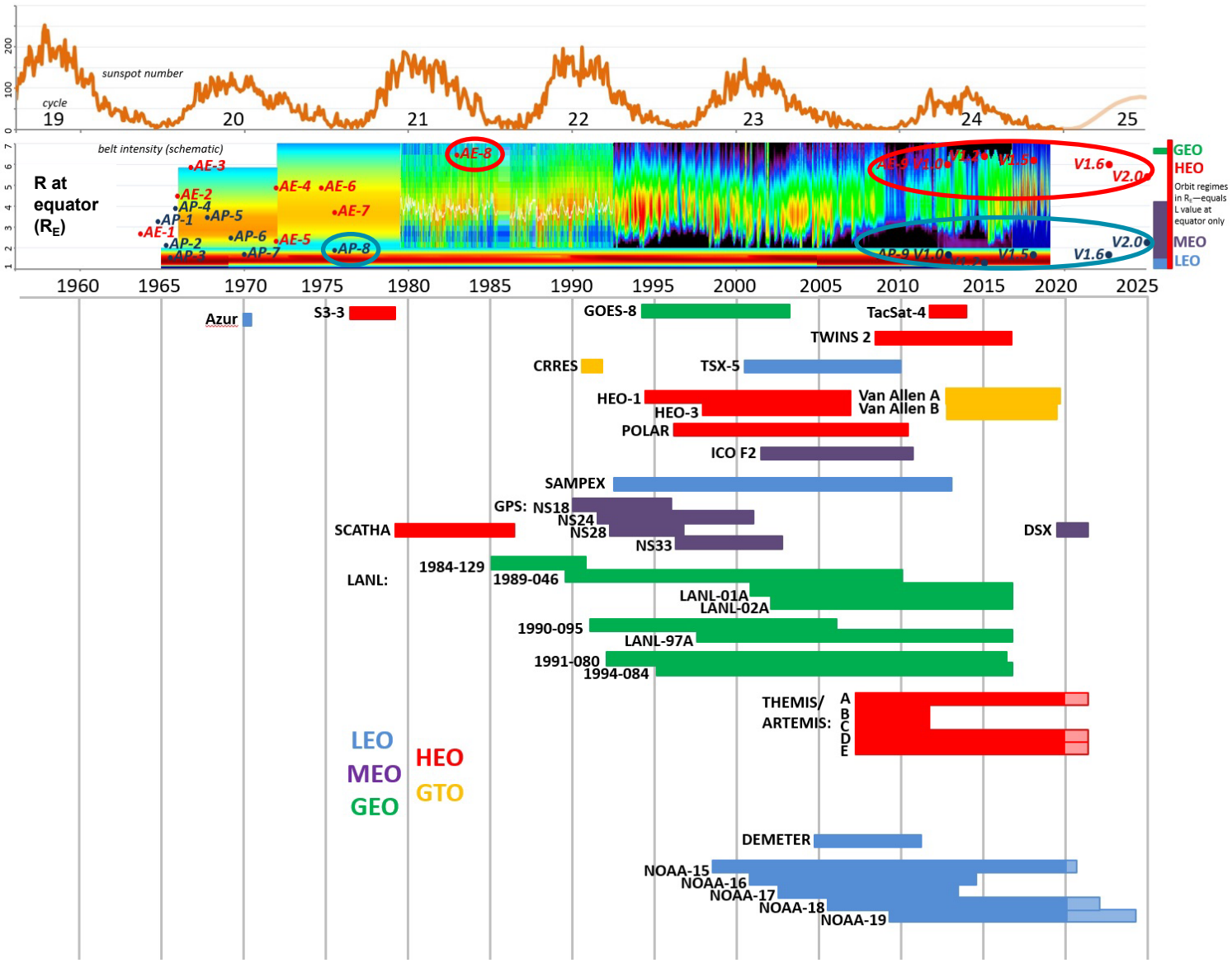
- Chosen for high quality and coverage

330+ instrument-years of data

- 10x more than AE8+AP8

All solar cycle phases sampled

- 16 sets >10 yrs
- 27 sets >5 yrs
- Long data sets yield statistics on variability

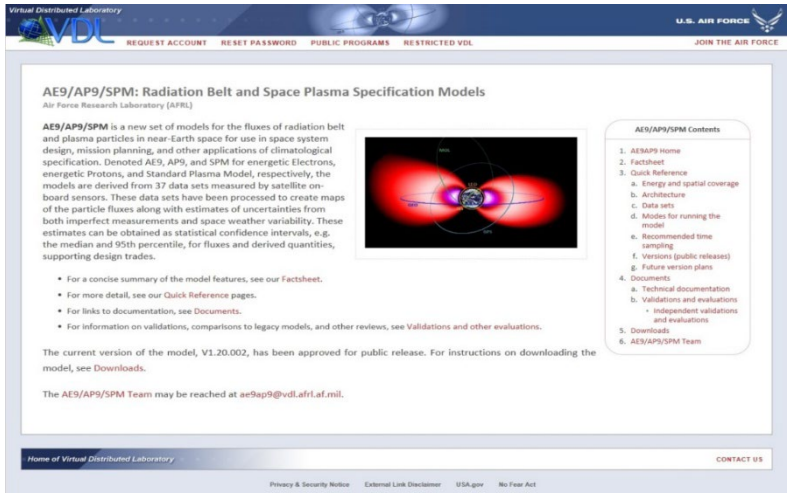


Comments

- Documentation in distribution package
  - Further documentation available on our web site **https://www.vdl.afrl.af.mil/programs/ae9ap9**
- Advice to users
  - User's guide provides recommendations for time steps, model mode and run duration for various objectives
  - See Aerospace report TOR-2022-00016, Best practices for generating space environment specifications with modern tools
- Current limitations
  - No solar protons *(forthcoming--see SAPPHIRE-2S talk)*
  - No explicit solar cycle variation *(forthcoming—see V2.0 talk)*
    - Statistics from Monte Carlo mode capture the range of expected fluxes over a solar cycle
  - Plasma model lacks local time dependence and Monte Carlo capability *(forthcoming—see V2.0 talk)*

Conclusion

- IRENE-AE9/AP9 continues to be maintained and upgraded as a comprehensive radiation environment design standard
  - Future releases will include new data sets and new features, driven by user needs
  - We seek models and data from the community to further these improvements
- **Comments, questions, etc. are welcome and encouraged!**
- Please send questions, 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



- Current model downloads, documentation, news are available at AFRL's Virtual Distributed Laboratory: **https://www.vdl.afrl.af.mil/programs/ae9ap9**

List of presentations

- IRENE overview (Bob Johnston/AFRL)
- ESA perspective (Piers Jiggens/ESA)
- V1.57 feature changes (Christopher Roth/AER)
- Kernels (Paul O'Brien/Aerospace Corp.)
- V1.60 plans (Bob Johnston/AFRL)
- SAPPHIRE-2S solar protons (Piers Jiggens/ESA)
- V2.0 plans (Paul O'Brien/Aerospace Corp.)
- Q&A / Demo (Christopher Roth/AER)