IRENE: AE9/AP9/SPM Radiation Environment Model

Release Notes

Version 1.50.001

The IRENE (International Radiation Environment Near Earth): (AE9/AP9/SPM) model was developed by the Air Force Research Laboratory in partnership with MIT Lincoln Laboratory, Aerospace Corporation, Atmospheric and Environmental Research, Incorporated, Los Alamos National Laboratory and Boston College Institute for Scientific Research.

IRENE (AE9/AP9/SPM) development team: Wm. Robert Johnston[1] (PI), T. Paul O'Brien[2] (PI), Gregory Ginet[3] (PI), Stuart Huston[4], Tim Guild[2], Christopher Roth[4], Yi-Jiun Su[1], Rick Quinn[4], Michael Starks[1], Paul Whelan[4], Reiner Friedel[5], Chad Lindstrom[1], Steve Morley[5], and Dan Madden[6].

To contact the IRENE (AE9/AP9/SPM) development team, email ae9ap9@vdl.afrl.af.mil .

The IRENE (AE9/AP9/SPM) model and related information can be obtained from AFRL's Virtual Distributed Laboratory (VDL) website: https://www.vdl.afrl.af.mil/programs/ae9ap9

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[1] Air Force Research Laboratory, Space Vehicles Directorate
[2] Aerospace Corporation
[3] MIT Lincoln Laboratory
[4] Atmospheric and Environmental Research, Incorporated
[5] Los Alamos National Laboratory
[6] Boston College Institute for Scientific Research

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Highlights

Please refer to the 'Ae9Ap9_v1_35_001_ReleaseNotes' document for a full description of the *significant* revisions and enhancements of the model software since v1.30.001.

The package name of "IRENE" (International Radiation Environment Near Earth) was introduced in the documentation.

The AE9 and AP9 model databases were updated with the inclusion of new data sets from: NASA's Van Allen Probes mission (AE9 and AP9), the Azur satellite (AP9 only), and the HiLET sensor on TWINS 2 (AP9 only). Additional updates to AE9 and AP9 flux maps improved low altitude gradients.

A new utility script was added for converting ASCII model output files to the Microsoft Excel file format.

The GUI application was enhanced to retain all user selections and specifications between uses, and be able to load these settings from previously-generated model run input files. The plots were revised to improve their clarity.

Several improvements and additions were made in the model- and application-level API methods.

Several software bug fixes and enhancements were implemented.

Database Changes

The AE9 and AP9 runtime model databases were updated to include several new satellite particle sensor data sets. These new data sets substantially improve the coverage in areas where it was previously lacking: the inner zone and slot. In some locations, the addition of the new data sets actually results in larger error bars on the mean environment because data sets from different decades disagree significantly.

- Three data sets from each of the Van Allen Probes have been included (more will follow in later versions). The Magnetic Electron Ion Spectrometer (MagEIS) instrument provides electrons from 35 keV to 890 keV, the Relativistic Electron-Proton Telescope (REPT) provides protons from ~20 MeV to ~80 MeV, and the Relativistic Proton Spectrometer (RPS) provides protons from ~60 MeV to 2 GeV. The Van Allen Probes mission consists of two identically-instrumented satellites in 800 x 30600 km orbits with 10° inclination, passing through both the inner and outer radiation belts. The data that were incorporated spans the August 2012 through December 2016 time period.

- The Azur data set provides proton observations from the EI-88 telescope, covering energies from 1.5 MeV to 104 MeV during the November 1969 through March 1970 time period. This data set was substantially cleaned and improved by the European Space Agency (ESA) prior to its incorporation, marking the first major inclusion of an international data source in the model. The Azur satellite was in a 384x2145 km, sun synchronous orbit, with a 103° inclination.
- The High Linear Energy Transfer (HiLET) sensor data set provides protons from 5 to 30 MeV,with temporal coverage from April 2008 to November 2016. The HiLET sensor resides on the same host vehicle as the Two Wide-Angle Imaging Neutral-Atom Spectrometers (TWINS-2) NASA experiment. The spacecraft is in a 1000 x 39500 km orbit with 63° inclination.

Several changes were made to the processing of data sets into flux maps, in particular for AP9 where greater weight is given to local data in the low altitude grid. See the last few pages in this document for more details on these changes.

Software Changes

CmdLineAe9Ap9 application (and its associated 'helper' applications):

- Fixed a program execution failure on Windows platforms when the model software package was installed in a directory that included spaces in the name.
- Corrected an issue with the use of the Boxcar accumulation 'increment' parameter specification.
- Eliminated an inconsistency in the report frequency of the accumulation interval values.
- Changed the *default* accumulation mode from 'Cumulative' to 'Interval' for 1-day periods.
- Revised the Dose Accumulation calculations to be more accurate.
- Improved the behavior of multi-threaded Windows-based CmdLineAe9Ap9 'helper' applications, and updated the Windows Intel MPI Library to the latest version.
- Corrected an issue with the multi-threaded processing of an input ephemeris file that is output in a different coordinate system.
- Improved the support of environment variables, now accepting the Windows-style references (ie, `%DATADIR%`), in addition to the Linux-style references (ie, `$DATADIR`).
- Added a new parameter to enable multi-threaded file I/O when using RAID-5 disk units.

Ae9Ap9Gui application:

- Replaced the 'Ae9Ap9GuiDBConfig.txt' configuration file with an automatically-generated (and user-specific) 'ini' file. This new configuration file also enables the GUI item states to be retained from one use of the application to the next.
- Added a new 'configuration' menu, enabling the user to control the retention of the GUI item states, reset all to their default states, adjust the database specifications, and customize application settings.

- Added a new feature, enabling the application to load the GUI item states from a set of previously-generated model run input files.
- Improved the support of environment variables, now accepting the Windows-style references (ie, `%DATADIR%`), in addition to the Linux-style references (ie, `$DATADIR`).
- Changed the colors and line thicknesses used in the data value plots, making the plotted lines more distinct from each other.
- Changed the default Accumulation Interval time to be 1 day.
- Revised several user interface control labels and tooltip messages for clarity.

New utility application:

- Developed the new 'ConvertToXlsx.py' Python script, added to the executable directory.
    - This script will convert the specified model run output files, and/or GUI plot output files, to their equivalent forms in a Microsoft Excel file format.
    - Use of this script requires that the end-user's machine has the Python scripting language installed, plus the 'Numpy' and 'XlsxWriter' Python modules.

API library:

- Added two new 'convertCoordinates' methods to the 'model-level' API EphemModel and AdiabatModel classes.
- Added the new 'setNumFileIo' method to the 'application-level' API Application class.
- Several methods were revised or added to the 'model-level' API AccumModel class.
- Several accumulation methods were removed from the 'model-level' API DoseModel class.
- Changed the return value of the 'computeEphemeris' method, in the 'model-level' API EphemModel class, to be the number of returned data records when zero or larger; any negative value indicates an error.
- Added the support of environment variables to the 'model-level' API classes, accepting both the Windows-style references (ie, `%DATADIR%`) and the Linux-style references (ie, `$DATADIR`).
- Updated the sample programs using the API, 'DemoApp' and 'DemoModel' (formerly named 'TestApp' and 'TestModel', respectively), to reflect recent changes and provide clearer demonstrations of the API usage.

Ae9, Ap9, SPM model:

- The perturbation method being used in the "Perturbed Mean" and "Monte Carlo" flux mode calculations was changed. During these calculations, the flux maps are perturbed using random variables drawn from a specified distribution, with different statistical distributions having their own advantages and disadvantages. All prior versions of the model releases had used a 'Gaussian' distribution for the perturbations; in order to limit the possibility of unrealistic extreme perturbations, the method was changed to use a 'Uniform' distribution. This change alters the individual "Perturbed Mean" and "Monte Carlo" scenario outputs. This also affects their associated confidence level outputs, tending to compact the extreme confidence levels (higher 5%, lower 95%), but with only minor effects near the median. This change does *not* affect the "Mean" or static "Percentile" flux mode calculations.

Build Scripts:

- Revised the C++ compiler flags to eliminate benign compiler warnings.
- Made several minor software modifications to prevent other types of benign compiler warnings.
- Built the pre-compiled Windows binaries using the latest update of the Intel MPI Library; the associated Runtime Environment files (included in the distribution) were also updated.

Documentation Changes

- The package name of 'IRENE' (International Radiation Environment Near Earth) was added into the main distribution documents.
- The *User's Guide* document was revised, updating the description of the GUI application configuration settings, adding a description of the new ConvertToXlsx.py Python script, and adding the new 'Installation Tips' and 'Troubleshooting' appendices.
- The *Application Programming Interface* (API) document was updated, adding descriptions for several new methods, including 'convertCoordinates', and removing those for outdated methods related to dose accumulation. Descriptions for many of the existing methods were improved for clarity.
- The license information for the Windows Intel MPI Library files was updated for the newer version.

General

- Due to the changes in the AE9 and AP9 runtime model databases, the results produced for these models will be different from those of the previous software release.

Changes in Supporting Files

- The current set of 'unit test' model run input/expected output files was expanded to include those for the 'legacy' model results.
- The "old" set of 'unit test' input/expected output files was removed. This was superseded by the current set of unit test files, which is much more comprehensive.

Version Numbering Scheme: **V***a.bc.ddd*

The '*a*' digit changes with major new architecture or feature changes in the model.
The '*b*' digit changes with updates of the model database files.
The '*c*' digit changes with minor new features in the model and/or interface software.
The '*d*' digits change with bug fixes and trivial feature tweaks.

Review of database changes in V1.50

Changes in results from AP9 V1.50 relative to V1.30:

- High energy fluxes (≥100 MeV) are reduced at most locations, by a factor of 2-3 for 100-300 MeV, and by a factor of 3 or more for higher energies (Figure 1).
- Fluxes are reduced at altitudes below 1500 km for E<50 MeV (Figure 1).
- Collectively, this produces a factor of 3 drop in fluxes at POES orbit for E>16-140 MeV.

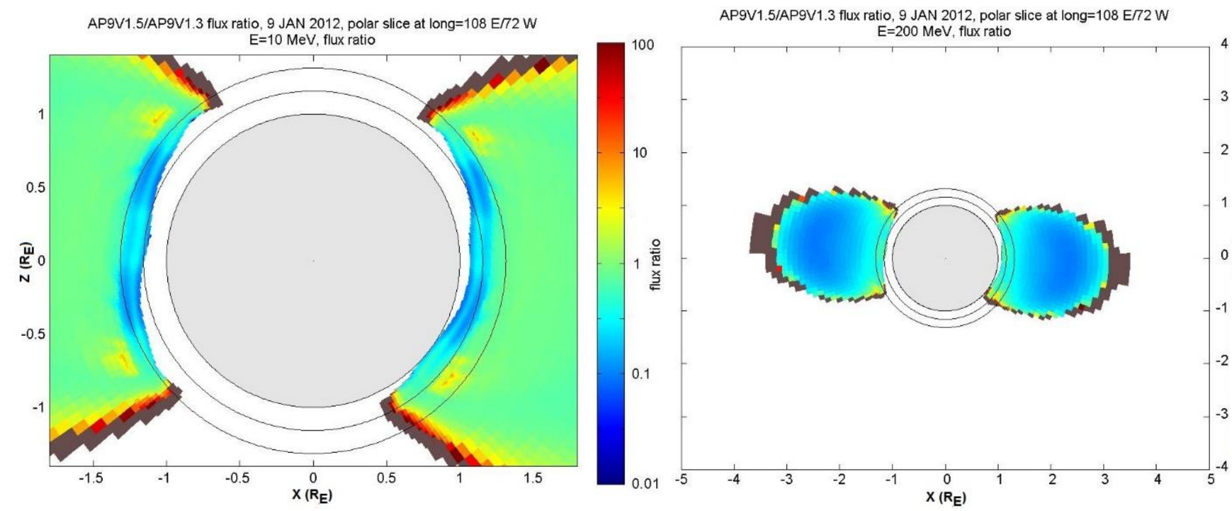

Figure 1. Left, ratio of AP9 V1.5 to V1.35 mean 10 MeV fluxes, low altitudes. Right, ratio of AP9 V1.5 to V1.35 mean 200 MeV fluxes.

Changes in results from AE9 V1.50 relative to V1.30:

- High energy fluxes (>3 MeV) are significantly reduced in the inner zone (Figure 2).
- Low to mid energy fluxes (≤300 keV) are increased by about a factor of 3 in inner zone (L<3.5) with higher increases (up to a factor of 10) at the lowest altitudes (Figure 2).
- Resulting changes to requirements for LEO should be limited: most dose contribution is driven by inner zone protons, not electrons.

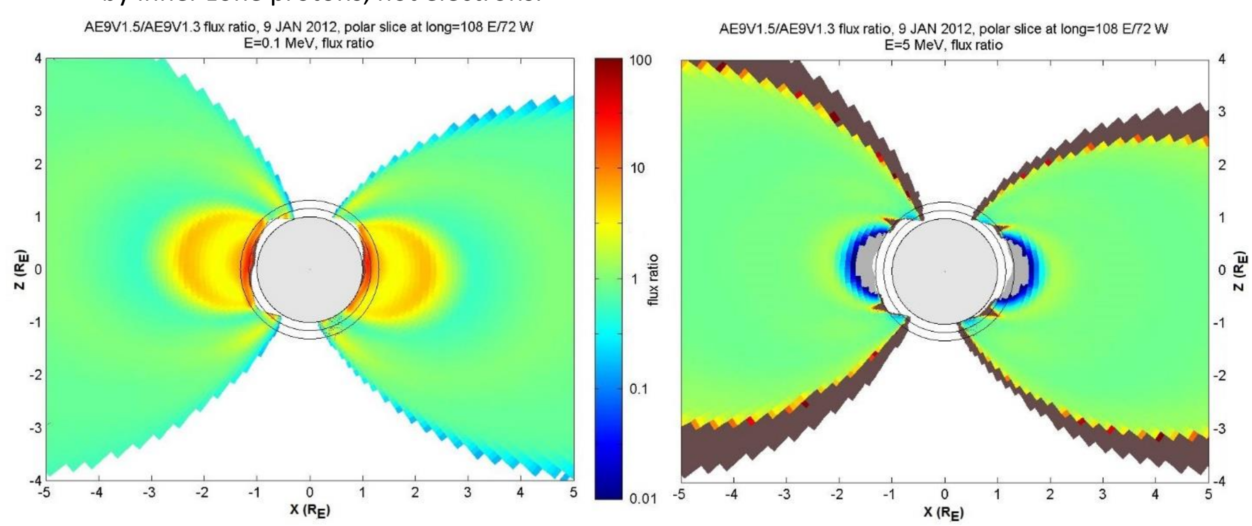

Figure 2. Left, ratio of AE9 V1.5 to V1.0 mean 0.1 MeV fluxes, showing inner zone. Right, ratio of AE9 V1.5 to V1.0 mean 5 MeV fluxes, showing inner zone.

See the accompanying documents "AE9/AP9 V1.50.001 Model Comparison Summary Report: Standard Orbit Comparisons" and "AE9/AP9 V1.50.001 Model Comparison Summary Report: Spatial Comparisons" for more complete change results.

Causes of changes in V1.50 results and checks of their validity

Generally, V1.50 shows notable changes in proton and electron fluxes in LEO resulting from the addition of new data sets (Van Allen Probes and others) plus changes in templates and algorithms that tend to increase the influence of local data sets.

AP9: The reduced AP9 fluxes for energies ≥100 MeV resulted from inclusion of Van Allen RPS data. At energies below 30 MeV, the reduced fluxes are largely due to the inclusion of the Azur data, which measured significantly lower fluxes than earlier versions of AP9. Also, new templates used to fill in gaps in the data were better informed by low altitude data sets such as POES and Azur. Increasing the influence of low altitude proton data in the low altitude maps has also reduced fluxes at altitudes below 1500 km and energies below 30 MeV.

The new AP9 results for V1.5 are lower than POES typically by a factor of 3, whereas V1.3 showed good agreement with POES (generally within a factor of 1.5). POES/SEM data have a high uncertainty (~2x) in counts-to-flux conversion for trapped protons. While V1.5 is now lower than POES, it is mostly higher than SAMPEX/PET data at these energies for a similar time period, for the 400-700 km altitudes observed by SAMPEX (Figure 3). Note that SAMPEX data interpretation here uses pitch angle distribution assumptions based on AP9, but otherwise uses fluxes as reported by the SAMPEX data center website.

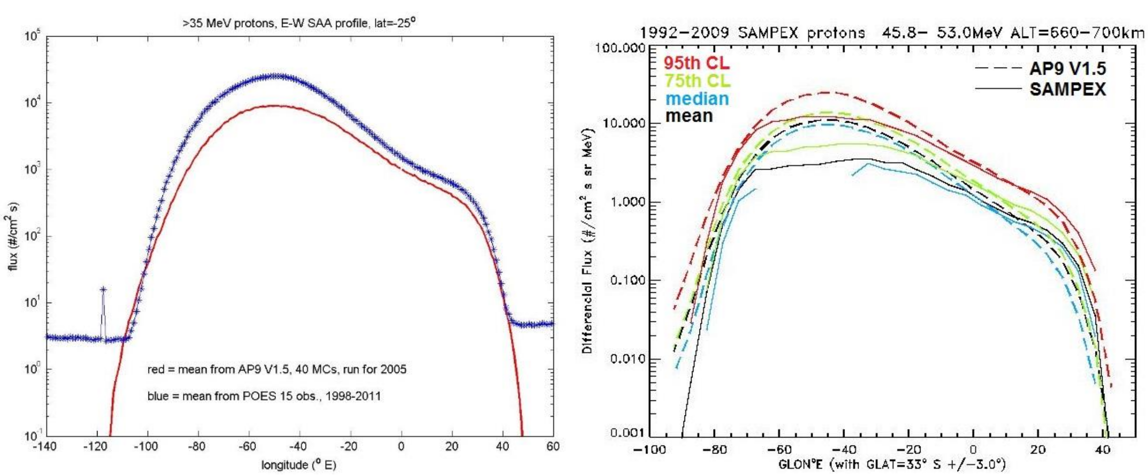

Figure 3. East-west profiles across the SAA: Left, >35 MeV protons from AP9 V1.5 and POES N15 observations; Right, 46-53 MeV protons from AP9 V1.5 and SAMPEX observations.

AP9 low altitude gradients are largely consistent with LEO data used in the model. Also, gradients are consistent with SAMPEX/PET gradients based on data sorted by altitude (given the range of altitudes covered over the course of the mission).

AE9: The AE9 V1.5 fluxes are higher in LEO for L<3 relative to both POES/SEM and DEMETER. Regarding POES, V1.5 shows agreement for L<1.27 and L>3, while intermediate L values may be poorly sampled by the two look directions for 100 and 300 keV channels. Note that V1.5 and V1.3 generally agree (2x or better) for L>2.5. The V1.3 to V1.5 change is limited to L=1.27 to 2.5 and is ~3x for the mean and 95th confidence level, and ~5-10x for the median.

AE9 changes result from inclusion of MagEIS data and associated template changes. Changes to flux map production algorithms (and resulting effects) were minimal for AE9. MagEIS inner zone data is higher for E<300 keV than the prior model version (V1.3). MagEIS observed no multi-MeV electrons in the inner zone, in contrast to some prior missions. This discrepancy could represent either proton contamination in prior data sets or climatological differences between the Van Allen era and long-term norms, or both. Low altitude gradients remain highly uncertain but are somewhat consistent with the limited LEO data available.

More complete model-data comparisons are provided in the accompanying documents "AP9 V1.50.001 Model Validation Summary Report" and "AE9 V1.50.001 Model Validation Summary Report".

Summary of updates to flux map development in V1.50

update	***AP9***	***AE9***
New data sets— Van Allen Probes	REPT RPS	MagEIS (low and medium only, 35 keV-890 keV)
New data sets— other	Azur/EI-88 (LEO, short) TWINS 2/HiLET	No change
Prior data sets	No change	Additional filtering of CRRES HEEF (inner zone, multi-MeV electrons)
Templates	K-Φ and K-H_{min} templates amended based on new data sets K-H_{min} altitude gradients informed by POES/SEM	Prior K-Φ CRRES templates amended in inner zone based on MagEIS New K-H_{min} templates based on MagEIS and REPT
Explicit filled map influence tapering	Added	Added, but with weak energy correlation
Splicing of K-Φ and K-H_{min} grids	Polynomial fit around transition in H_{min}	No change
Merging sequence	Combine with same template on all sensors first	No change
Monte Carlo statistics	Changed from Gaussian to uniform	Changed from Gaussian to uniform
K-H_{min} grid data influence	Data constrains absolute fluxes more directly	No change

(No updates to SPM databases)

Template and algorithm updates: For a full explanation of the use of templates and algorithms in generating flux maps, see Ginet et al. (2013) (the 'AE9AP9SPM_SSR_Overview' file in the "documents" directory). Template updates are summarized above. For AP9, the merging sequence has been modified to first combine data sets with the same template, then merge across templates. The influence of each data set within the energy-spatial grids is now explicitly tapered with distance from bins populated with data, though with weaker energy correlation in AE9 than in AP9. In V1.3 (and in

AE9 V1.5), data binned in the low altitude grid informs the gradients in this region, while the absolute values are based on overlap with the high altitude grid. AP9 V1.5 now additionally constrains absolute flux values in the low altitude grid if binned data is present. The assumed statistical distribution driving Monte Carlo variability was Gaussian in V1.0-V1.3; in V1.5 this is changed to uniform distribution.

Contact Information

Please send any questions, comments and/or bug reports to: ae9ap9@vdl.afrl.af.mil

The IRENE (AE9/AP9/SPM) model package and related information can be obtained from AFRL's Virtual Distributed Laboratory (VDL) website: https://www.vdl.afrl.af.mil/programs/ae9ap9