Air Force Research Laboratory

AE9/AP9 V1.30.001 Model Validation Summary Report

5 January 2016

AE9/AP9/SPM Development Team

Integrity ★ Service ★ Excellence

AFRL

AP9 V1.30.001 Validation

Satellite	Sensor	Orbit	Time Period	Energies (MeV)
POES N15	SEM2 MEPED	LEO 850 km, circular, 98.7°	Jul 1998 – Dec 2011	>16, >35, >70, >140

Distribution A

POES N15

POES data processing:

- POES data is processed based on response functions in POES/METOP SEM-2 OMNI Flux Algorithm Theory and Software Description, J. Machol, 27 Mar 2012 (see AE9/AP9 V1.30.001 Model Validation Full Report for details).
- >6.9 MeV channel not used due to significant electron contamination.
- POES results are treated as omnidirectional averages (i.e., no modeling of proton pitch angle distribution and instrument angular response).

Content:

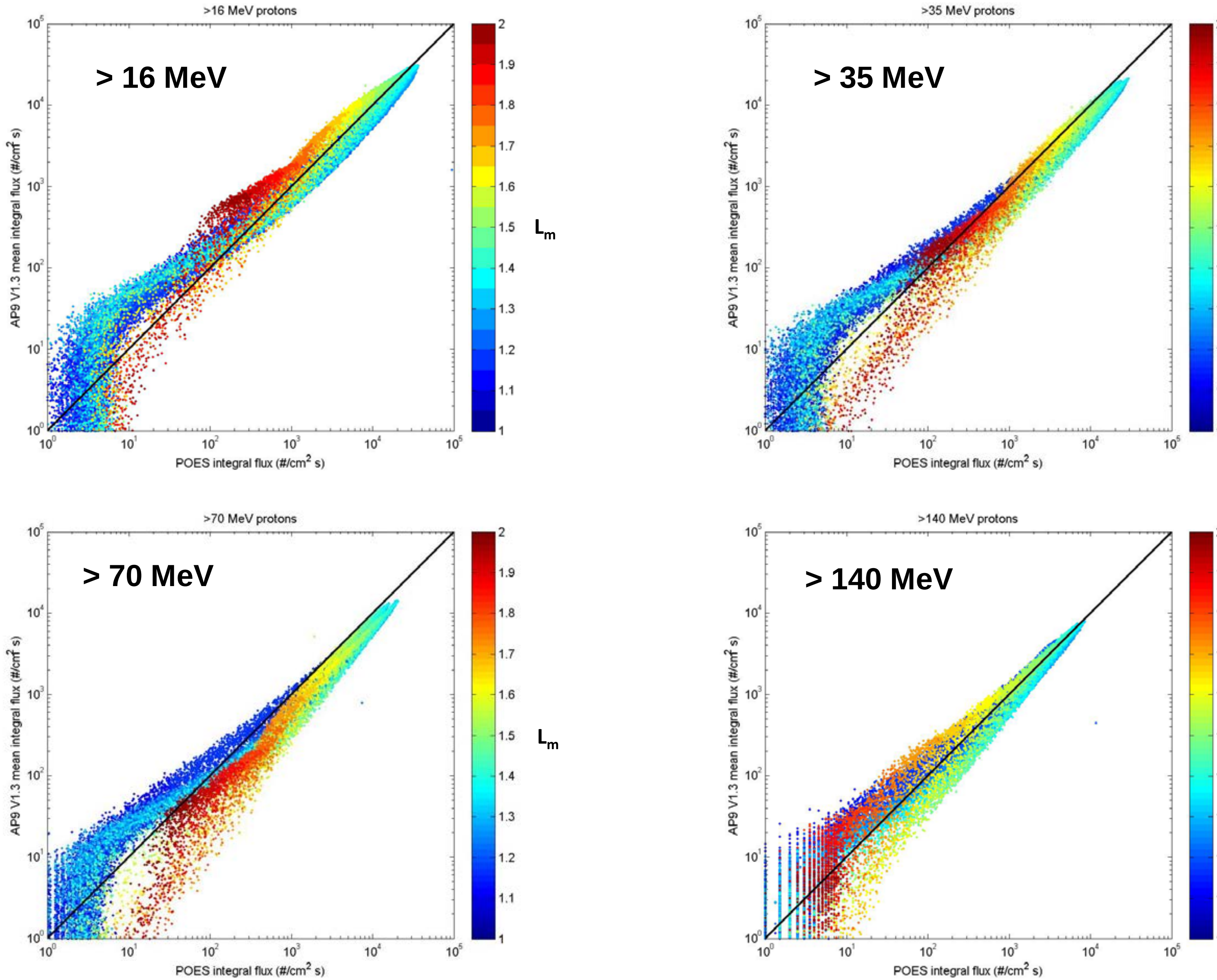
- Slides 5-10 compare AP9 V1.30 mean to POES observations from Jan 1999 (solar min) and Jan 2005 (solar max).
- Slides 11-25 compare AP9 V1.30 Monte Carlo results (40 runs) for 2005 to POES observations from Jul 1998 to Dec 2011 (full solar cycle).

POES N15

Summary:

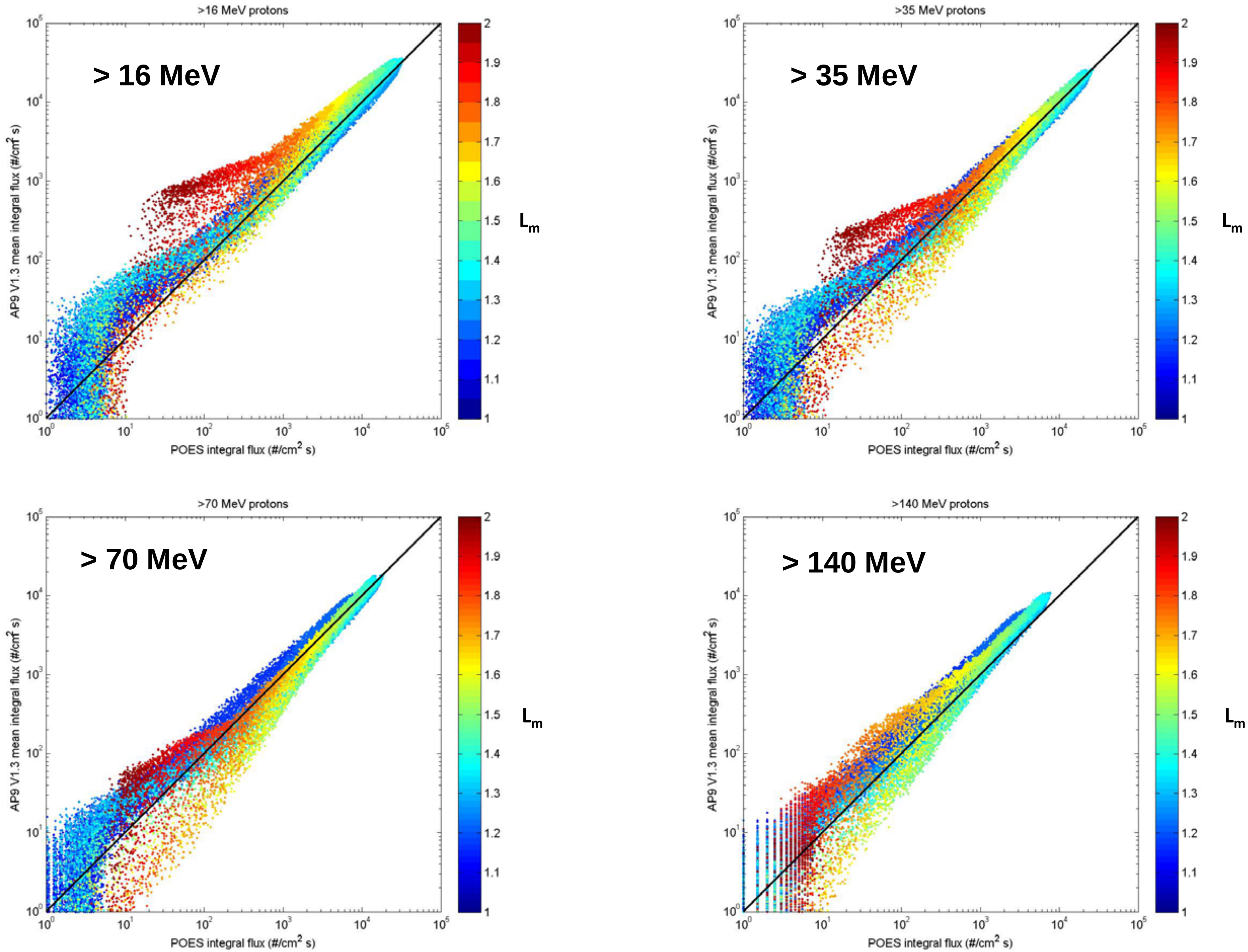
- AP9 reproduces the geographic extent of the South Atlantic Anomaly (SAA) as observed by POES
- AP9 and POES generally agree within 2x for SAA peak fluxes.
- AP9 and POES disagreements at outskirts of SAA (where fluxes are low) reach 3-10x at a some locations.
- Range of annual fluences observed by POES fall within the ranges represented by AP9 Monte Carlo results.

POES proton data and AP9 V1.30 mean flux scatter plot, Jan 1999 (after solar min)



Distribution A

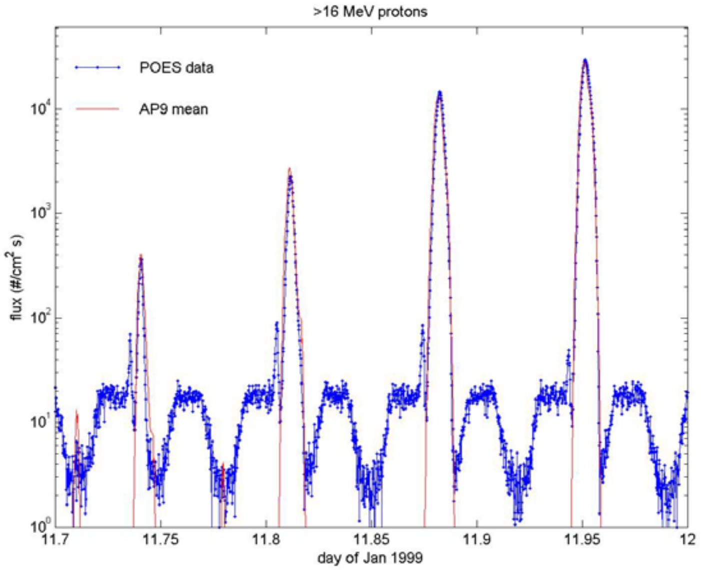
POES proton data and AP9 V1.30 mean flux scatter plot, Jan 2005 (after solar max)



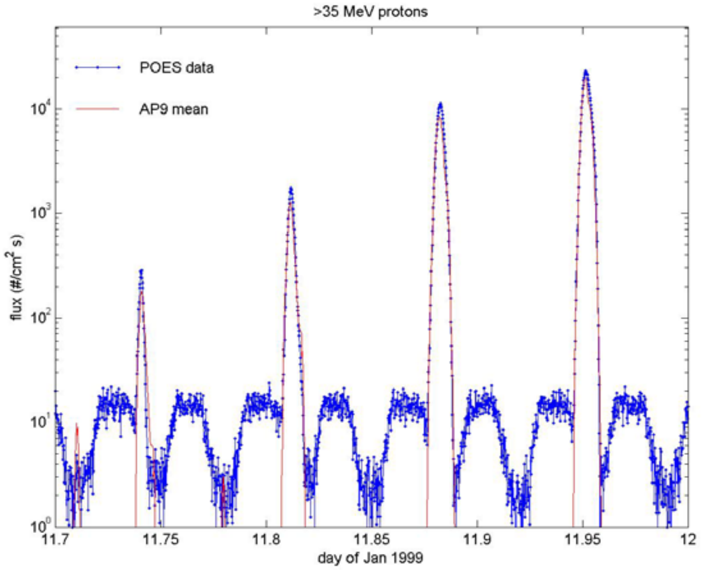
Distribution A

POES and AP9 V1.30 mean proton flux time series, Jan 1999 (after solar min)

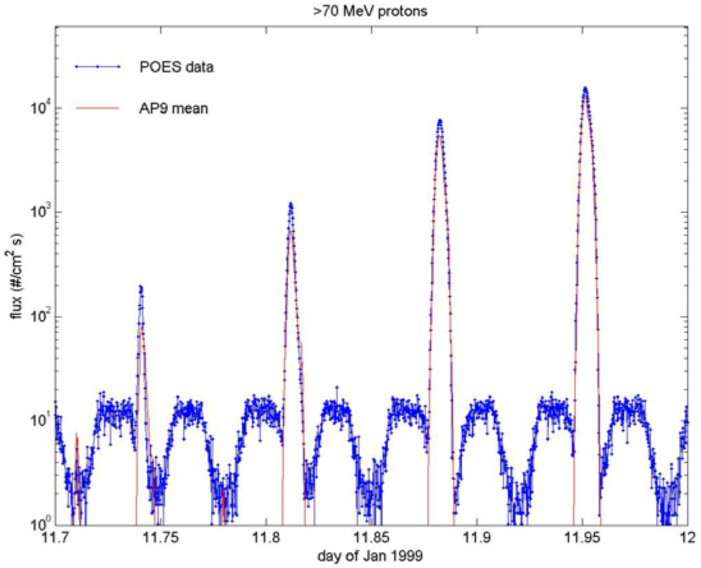
> 16 MeV



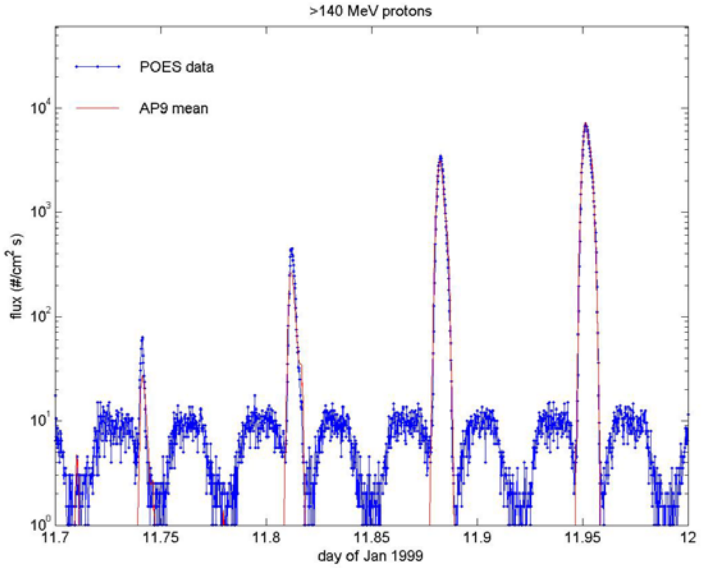
> 35 MeV



> 70 MeV



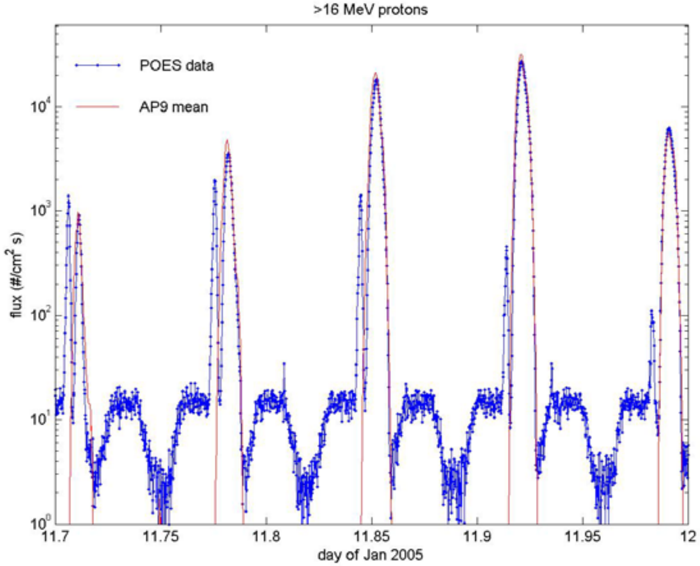
> 140 MeV



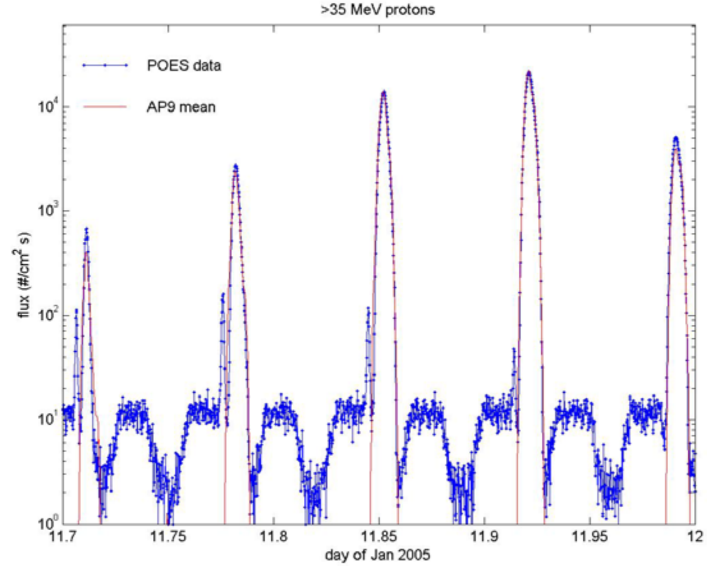
Distribution A

POES and AP9 V1.30 mean proton flux time series, Jan 2005 (after solar max)

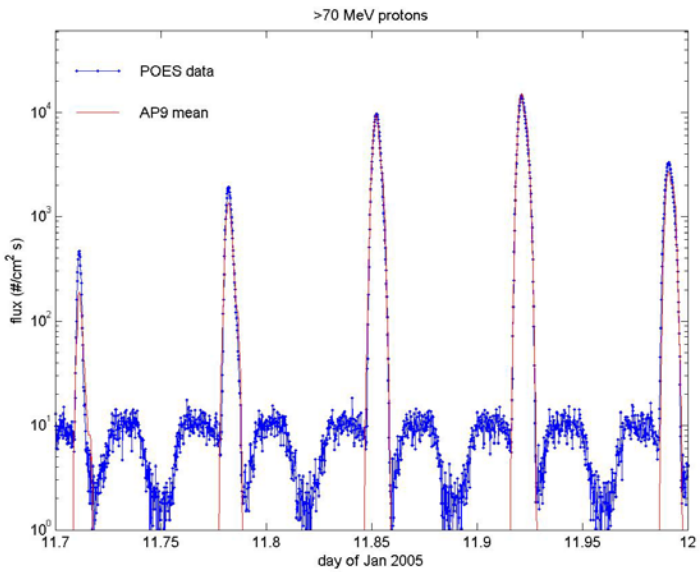
> 16 MeV



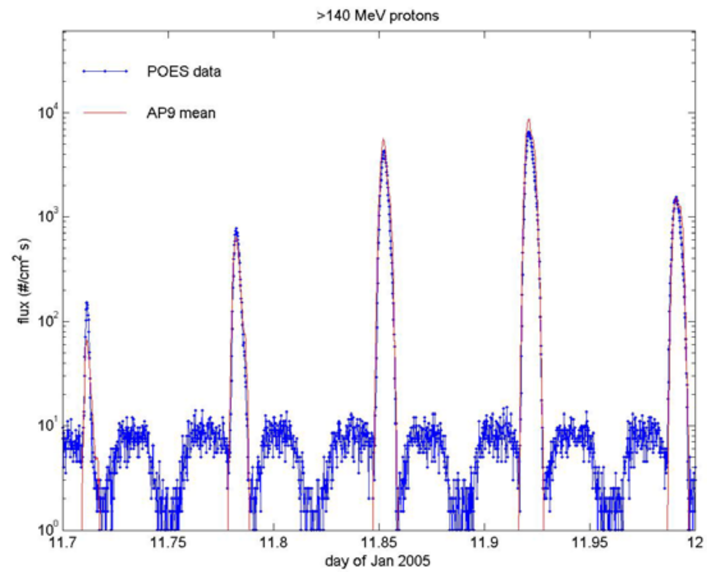
> 35 MeV



> 70 MeV

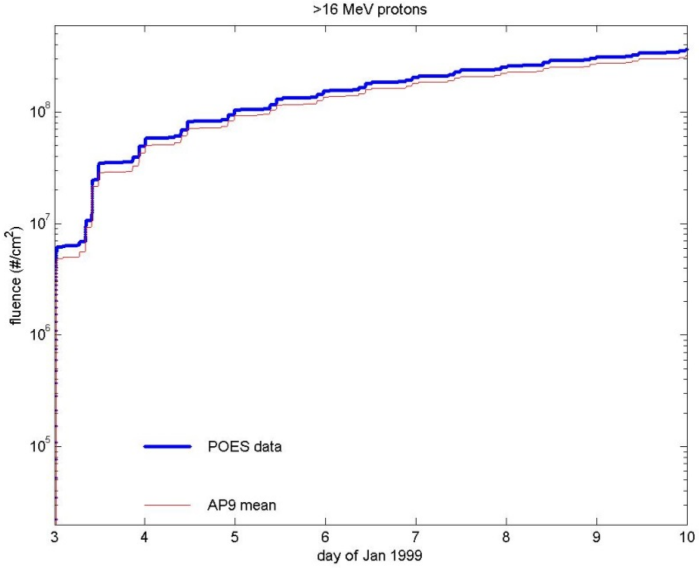


> 140 MeV

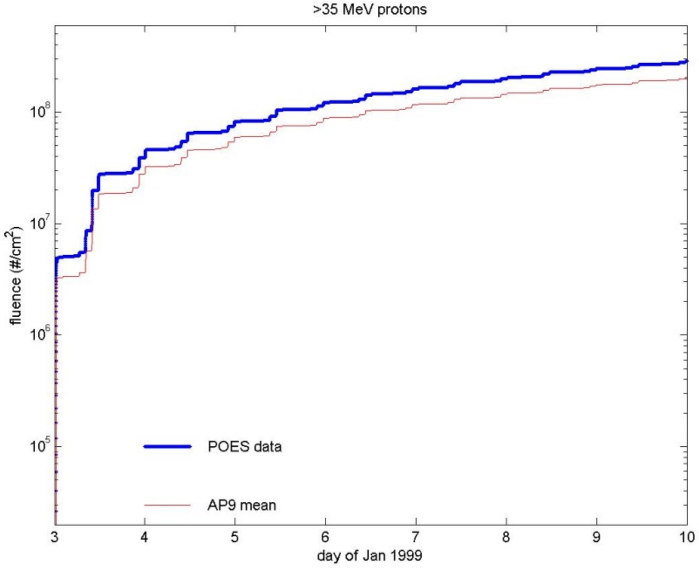


POES and AP9 V1.30 mean proton fluence time series, Jan 1999 (after solar min)

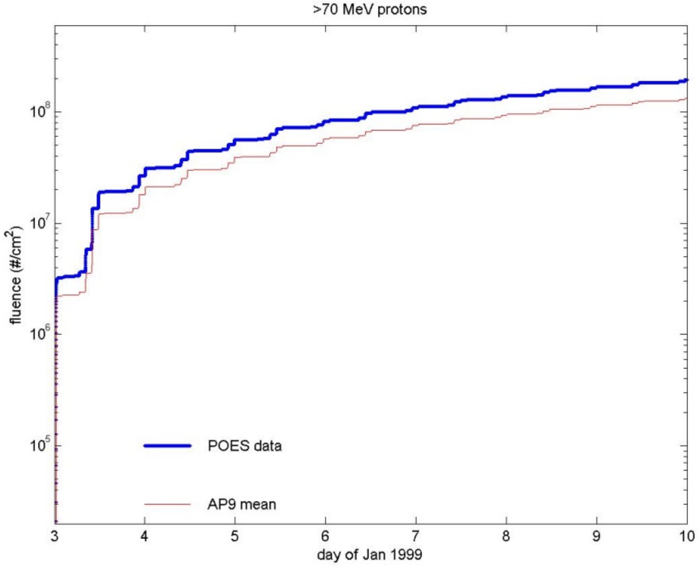
> 16 MeV



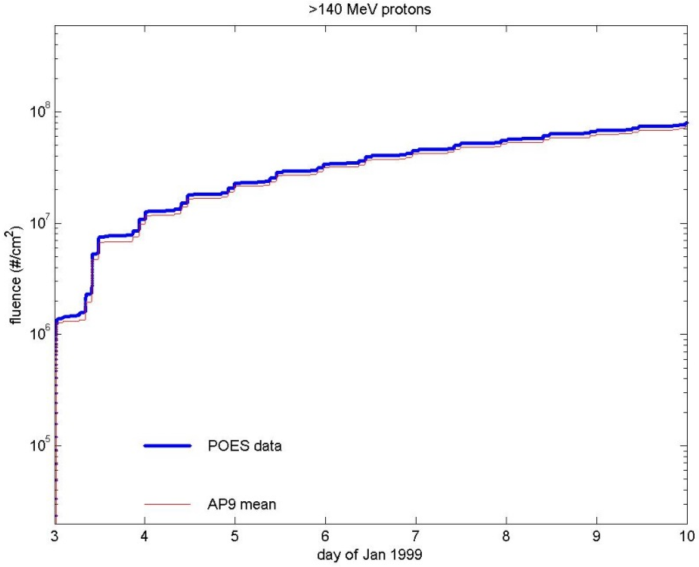
> 35 MeV



> 70 MeV



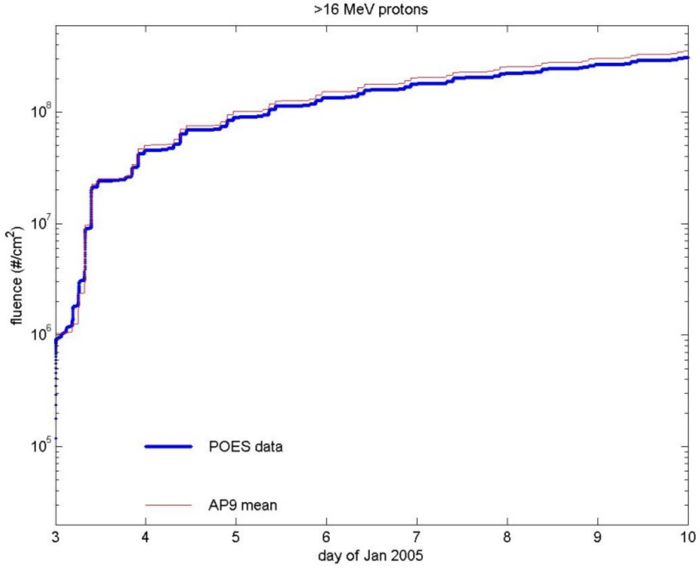
> 140 MeV



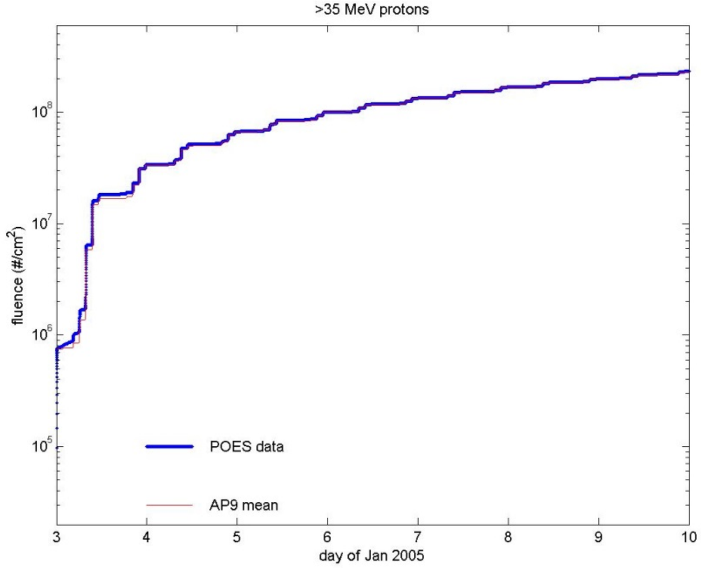
Distribution A

POES and AP9 V1.30 mean proton fluence time series, Jan 2005 (after solar max)

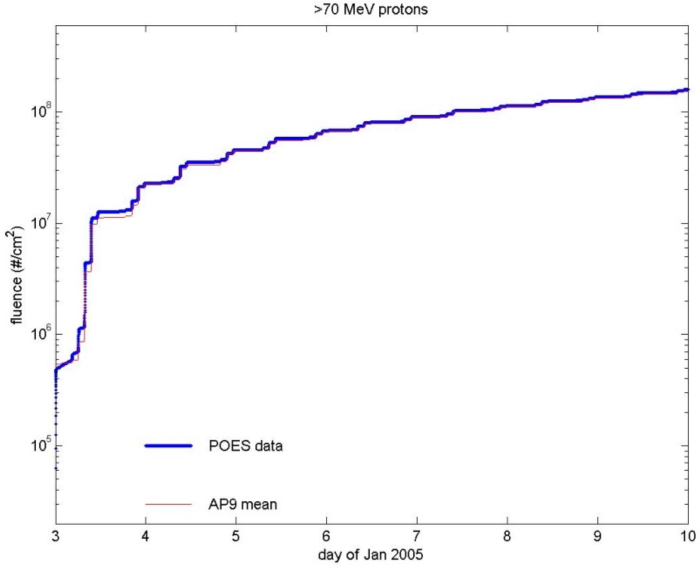
> 16 MeV



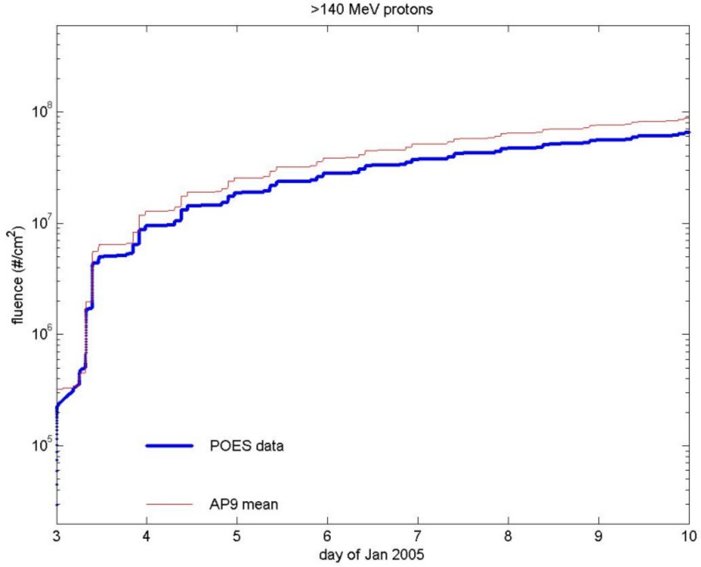
> 35 MeV



> 70 MeV



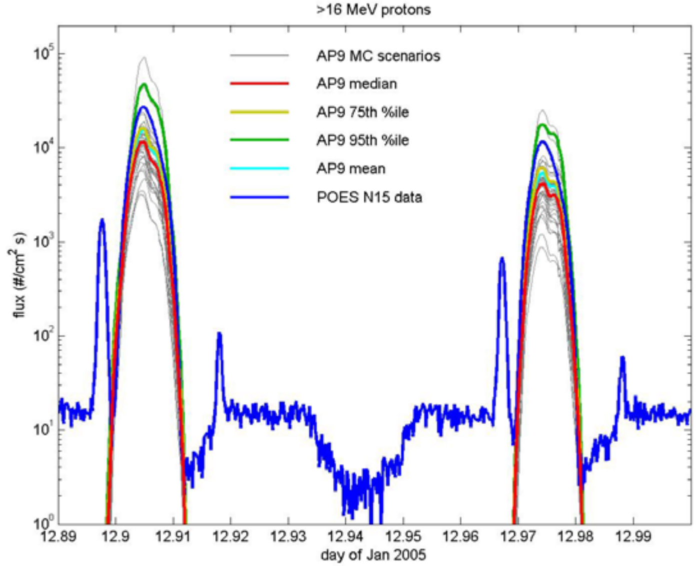
> 140 MeV



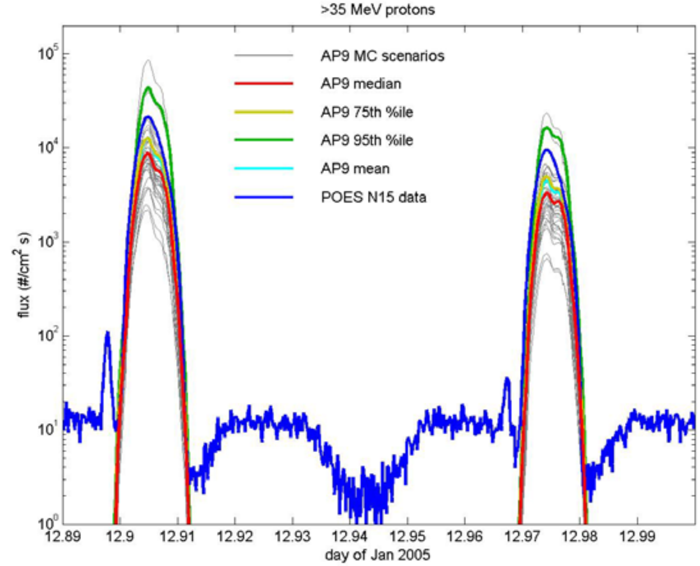
Distribution A

POES and AP9 V1.30 Monte Carlo proton flux time series, Jan 2005 (after solar max)

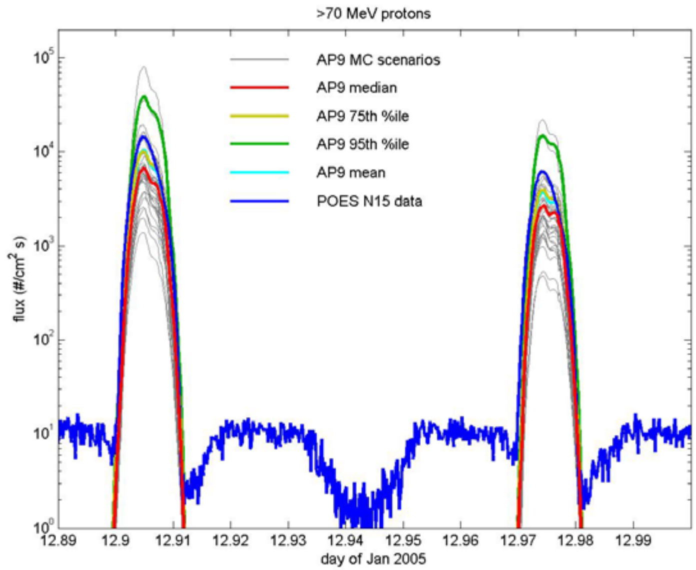
> 16 MeV



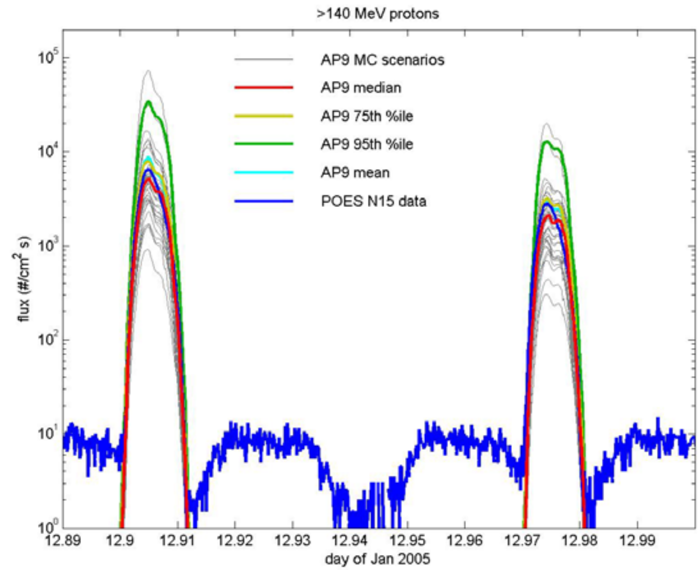
> 35 MeV



> 70 MeV

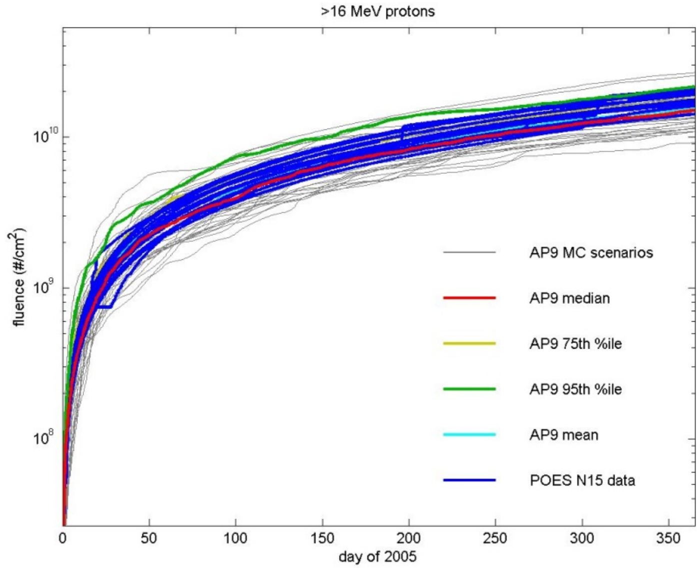


> 140 MeV

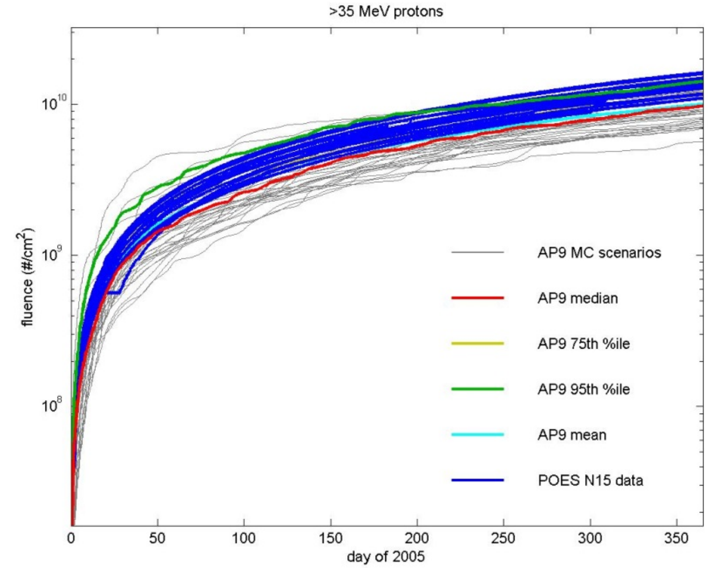


POES and AP9 V1.30 Monte Carlo proton fluence time series

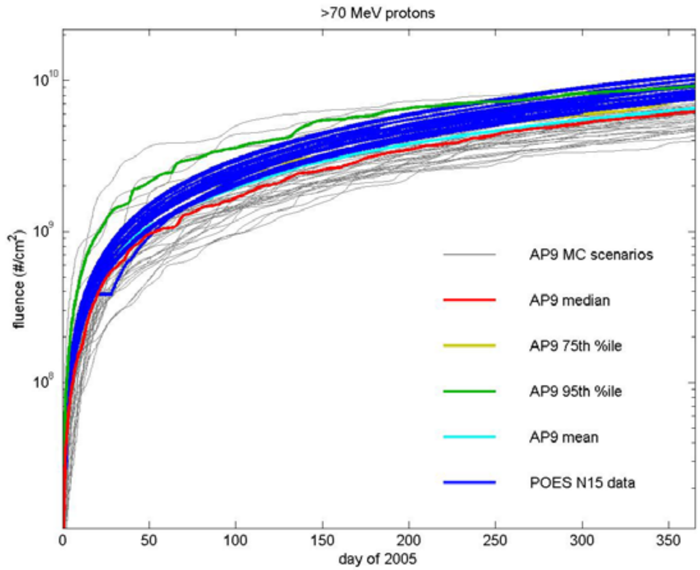
> 16 MeV



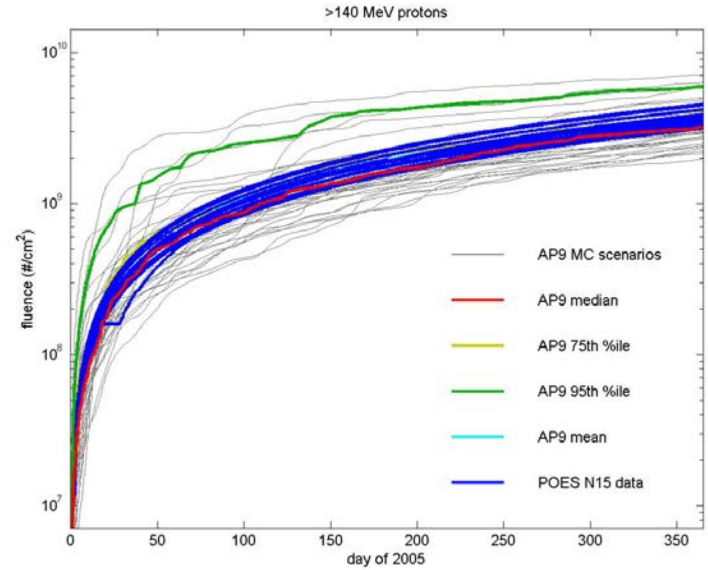
> 35 MeV



> 70 MeV

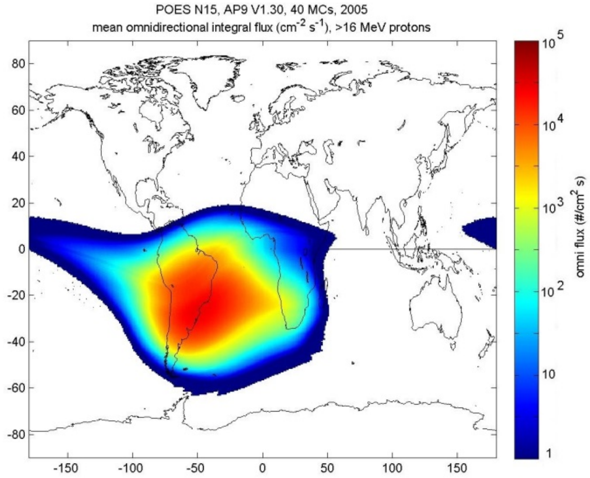


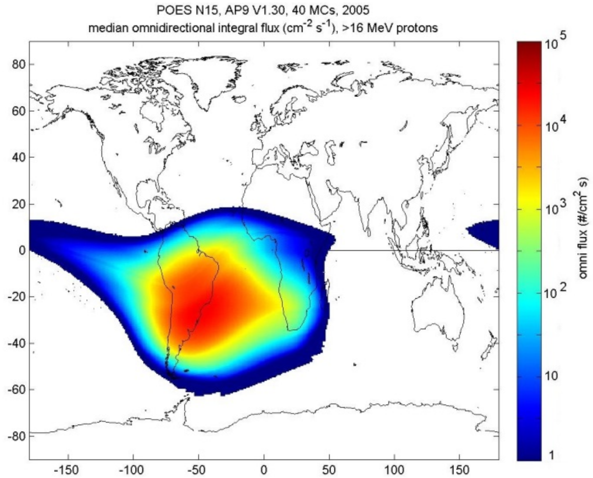
> 140 MeV

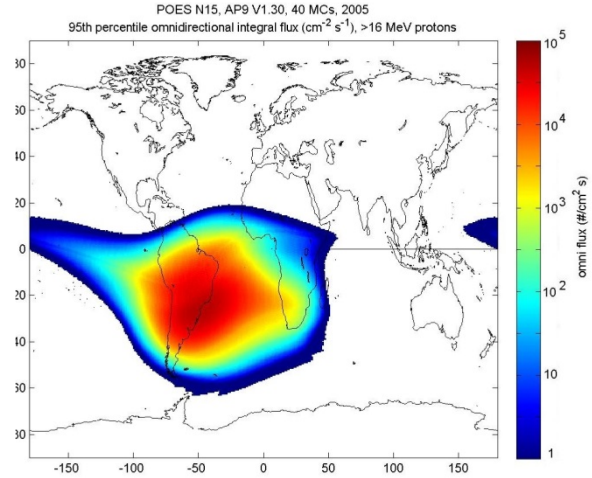


>16 MeV protons

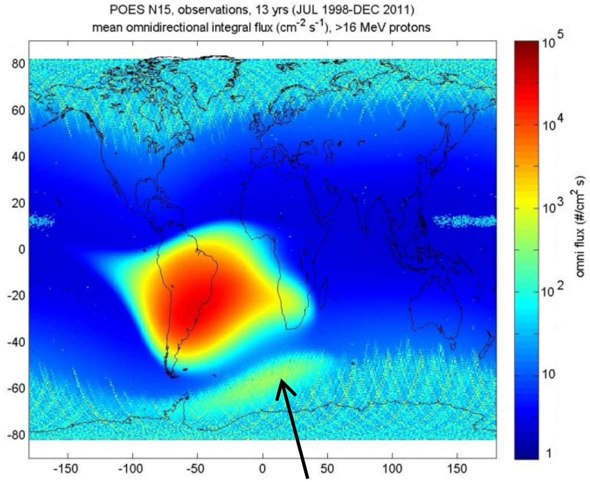
AP9 V1.30 Monte Carlo results

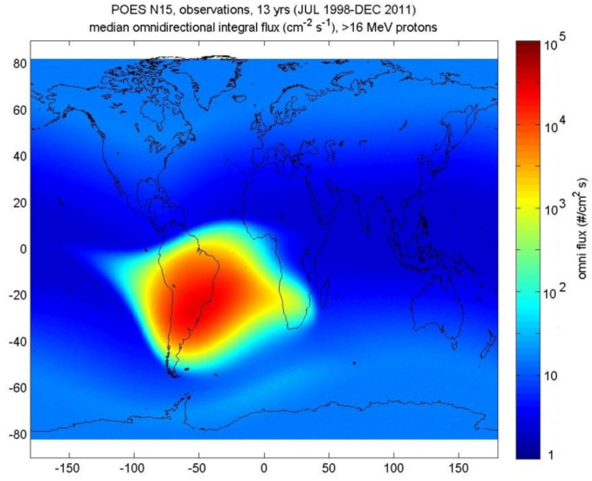


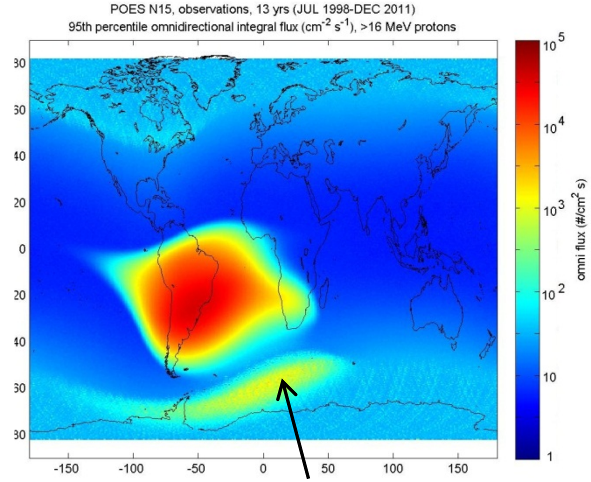




POES NOAA-15 data, 1998-2011



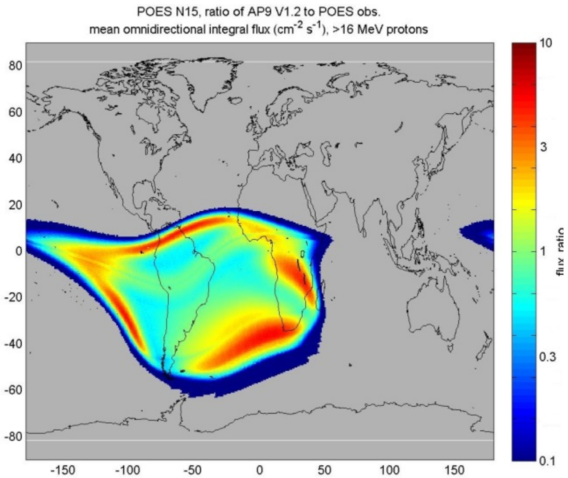


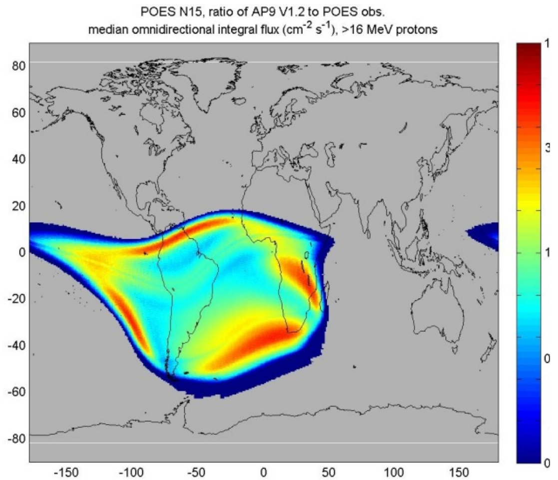


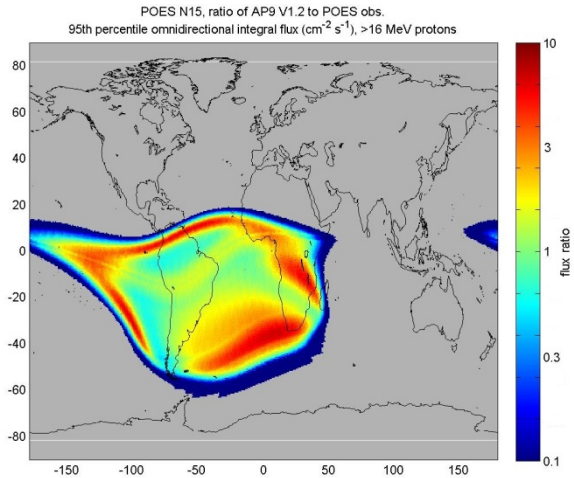
electron contamination

electron contamination

>16 MeV protons—ratio of AP9 V1.30 to POES obs.



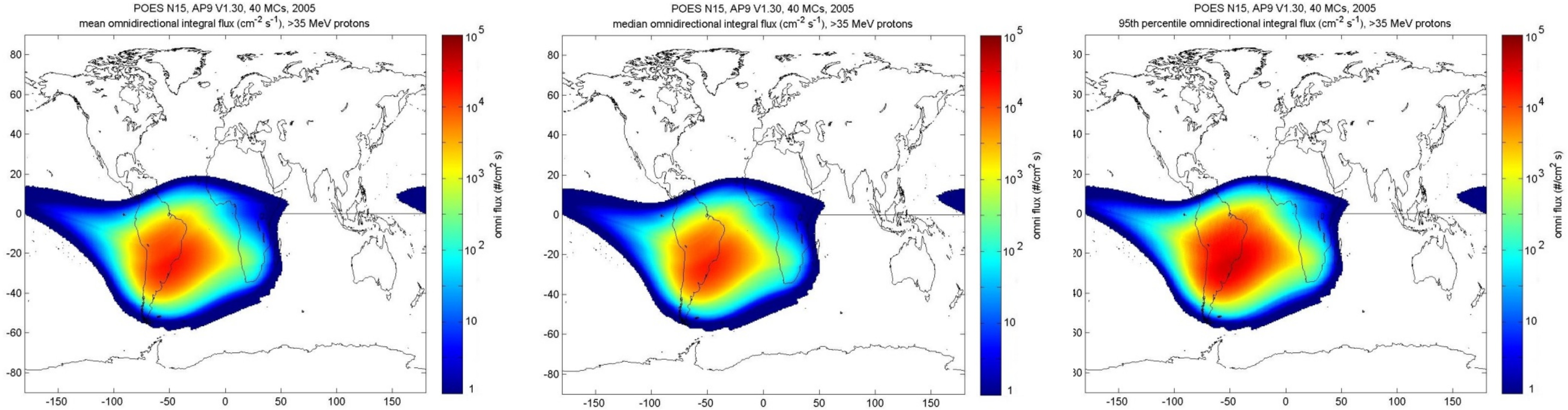




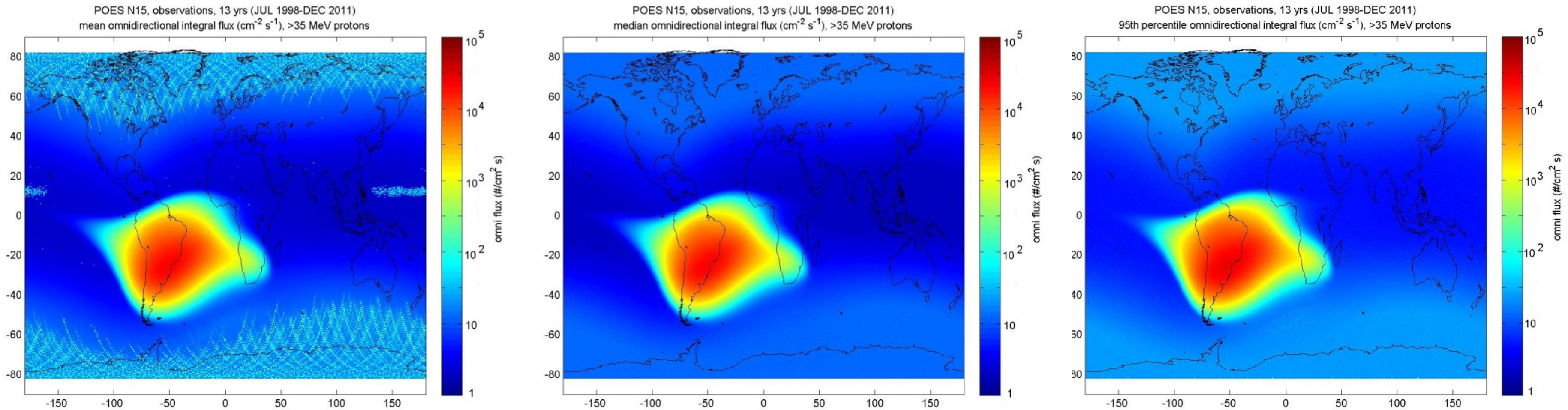
Distribution A

>35 MeV protons

AP9 V1.30 Monte Carlo results

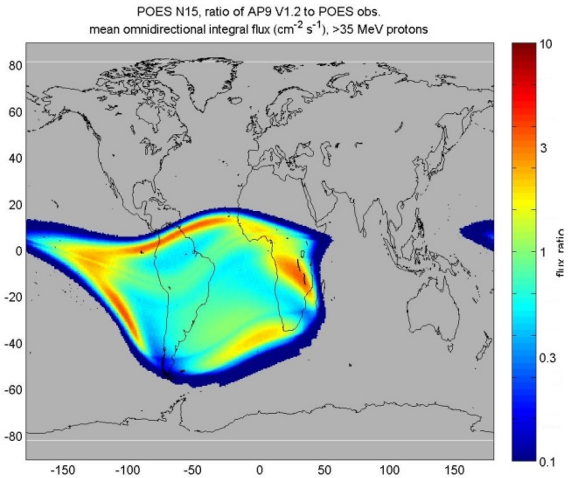


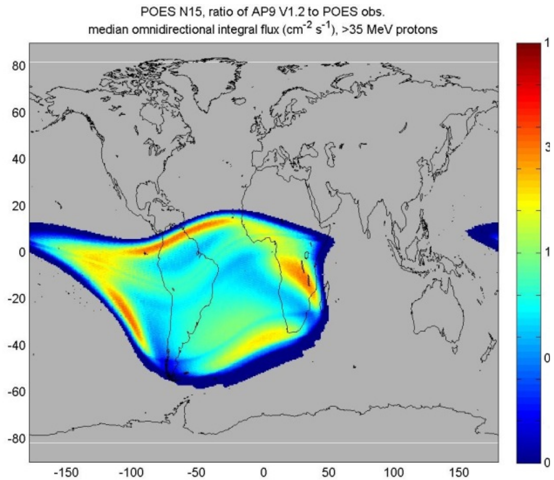
POES NOAA-15 data, 1998-2011

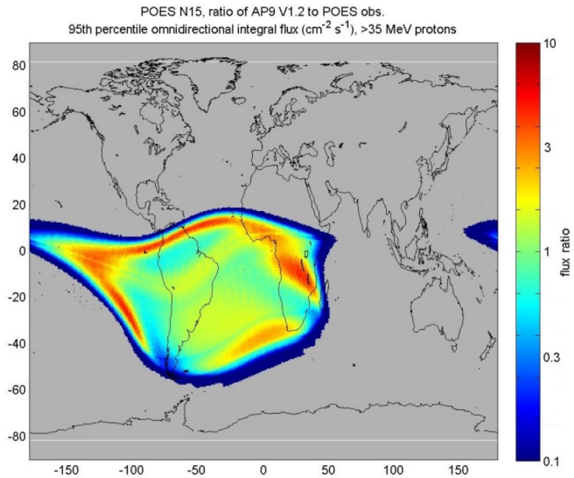


Distribution A

>35 MeV protons—ratio of AP9 V1.30 to POES obs.



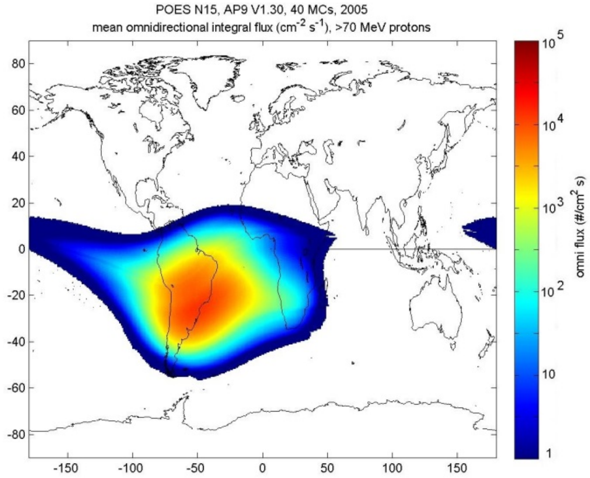


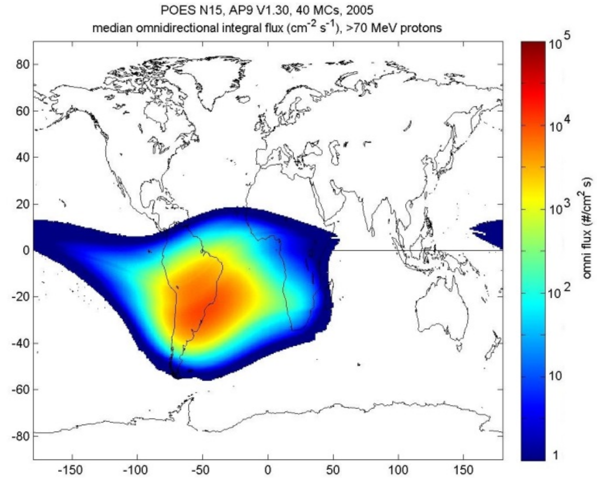


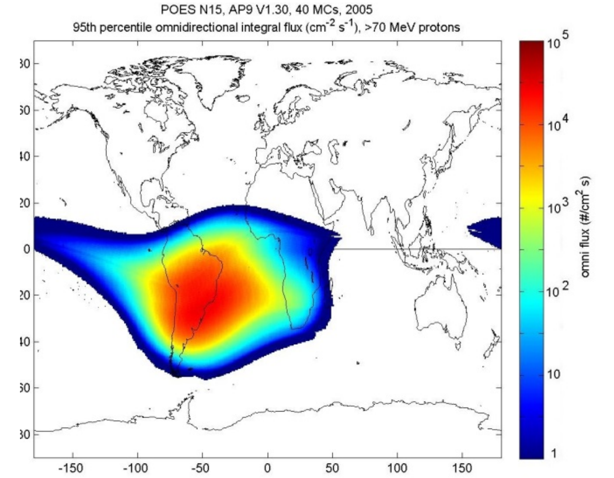
Distribution A

>70 MeV protons

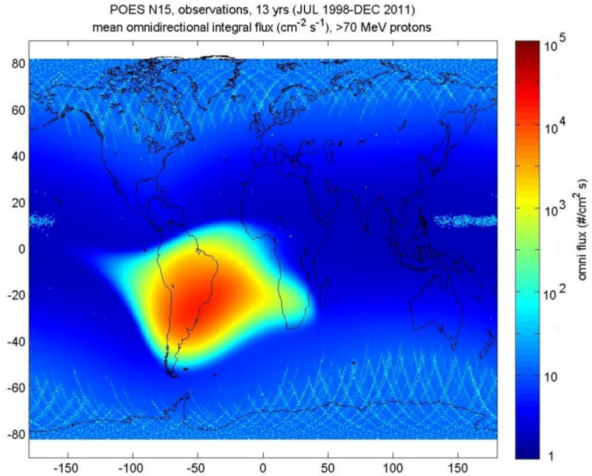
AP9 V1.30 Monte Carlo results

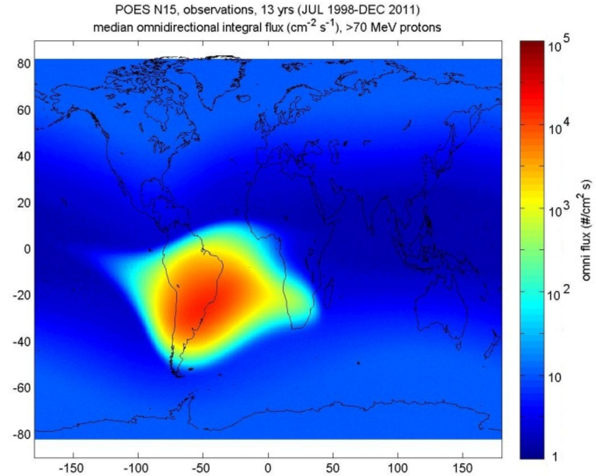


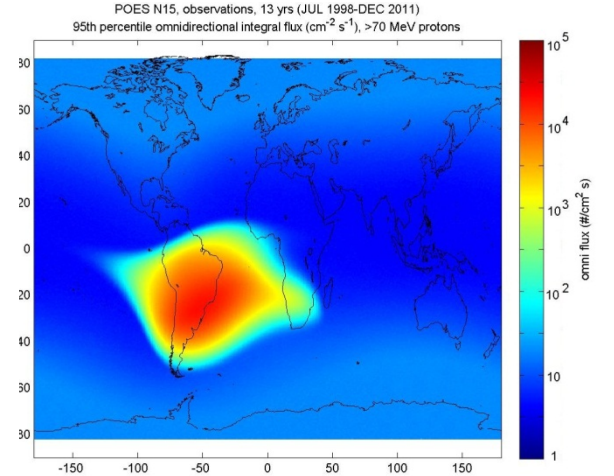




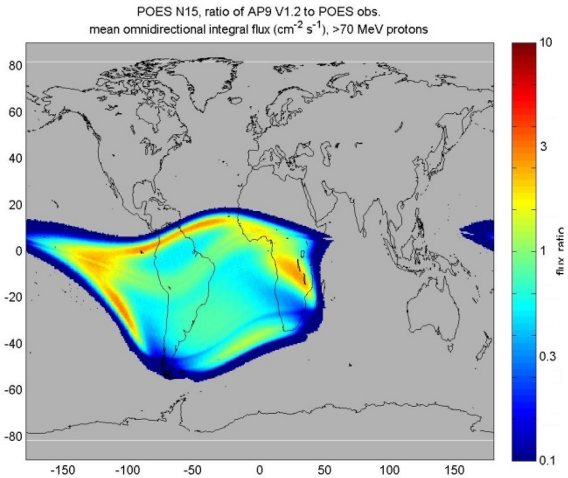
POES NOAA-15 data, 1998-2011

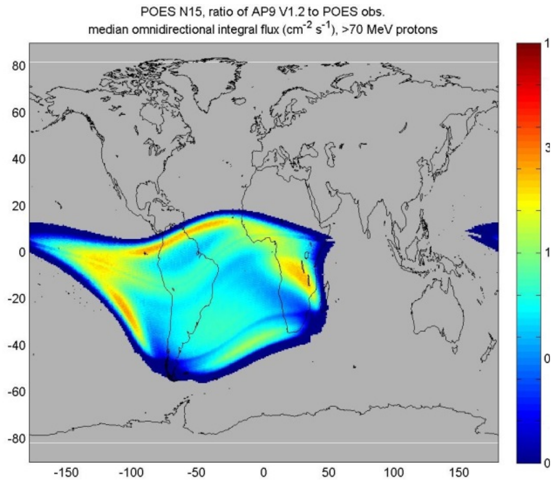


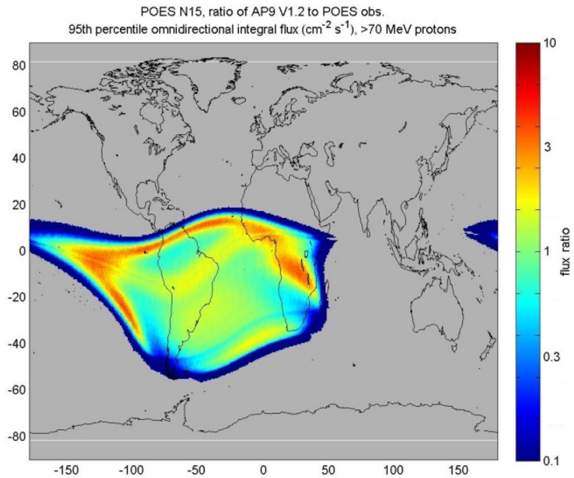




>70 MeV protons—ratio of AP9 V1.30 to POES obs.

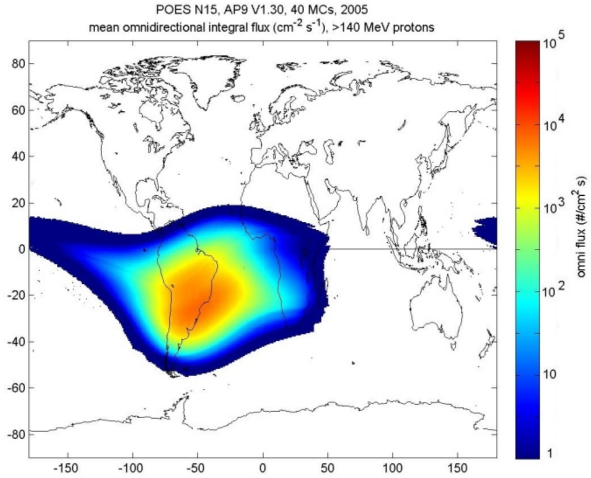


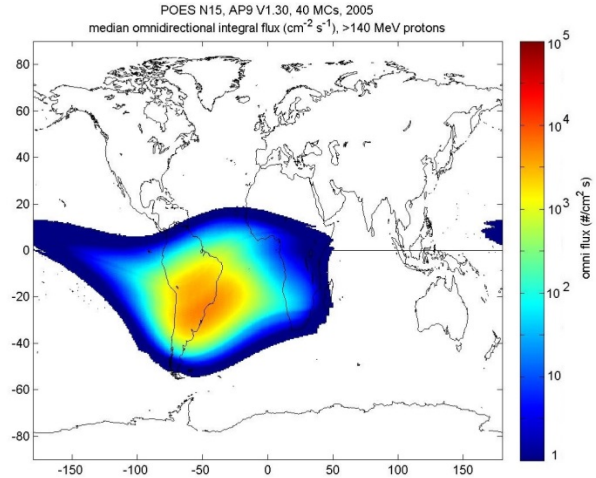


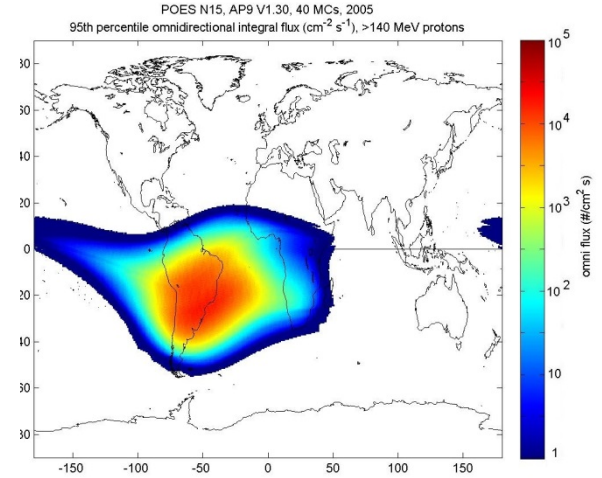


>140 MeV protons

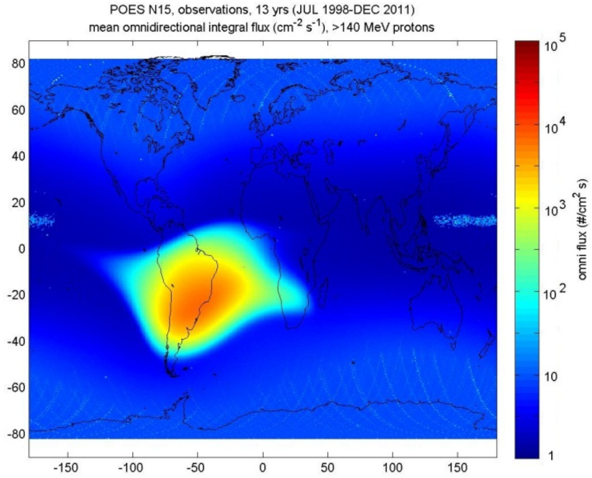
AP9 V1.30 Monte Carlo results

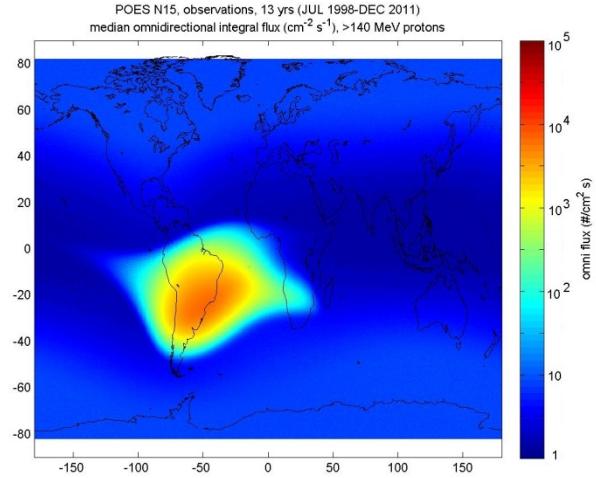


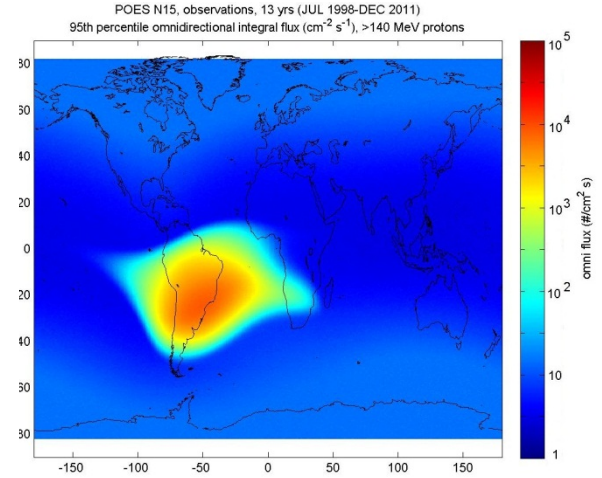




POES NOAA-15 data, 1998-2011

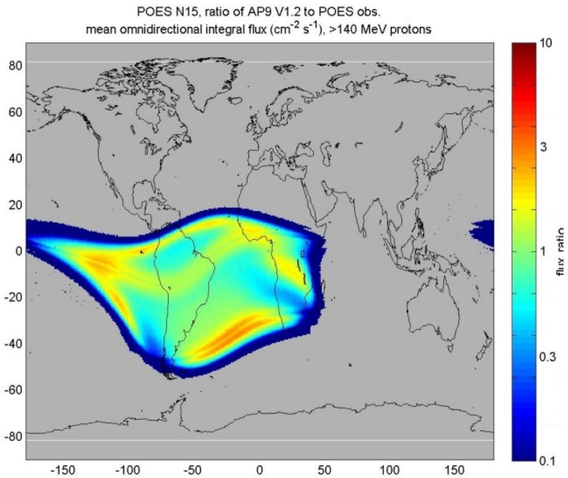


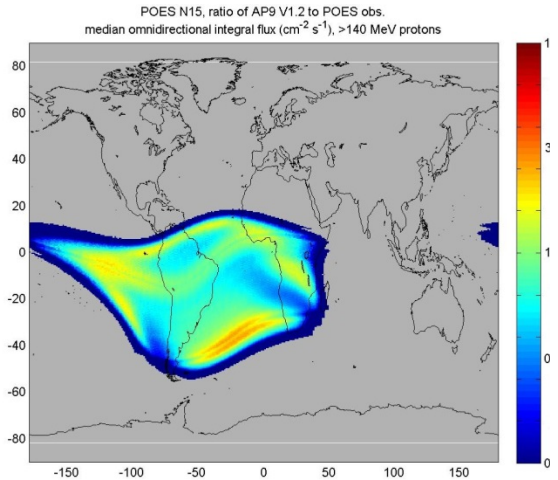


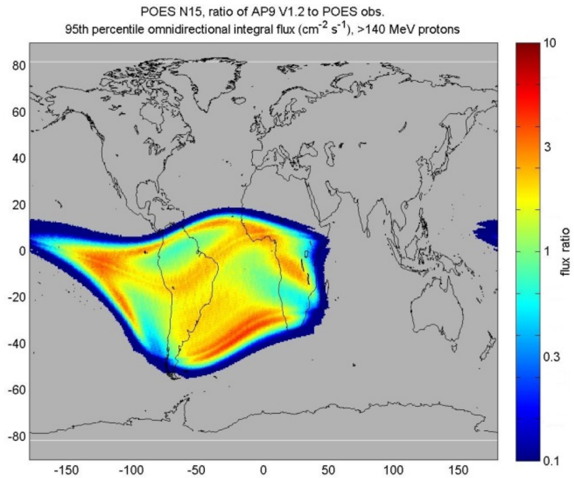


Distribution A

>140 MeV—ratio of AP9 V1.30 to POES obs.

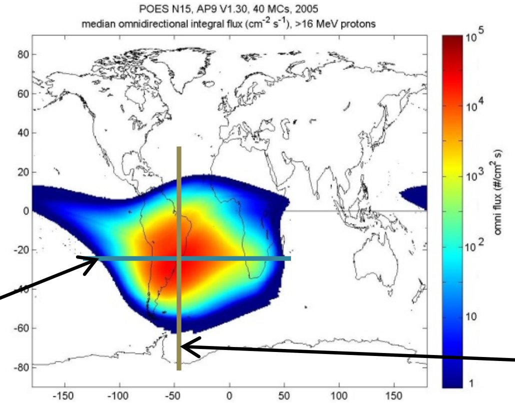




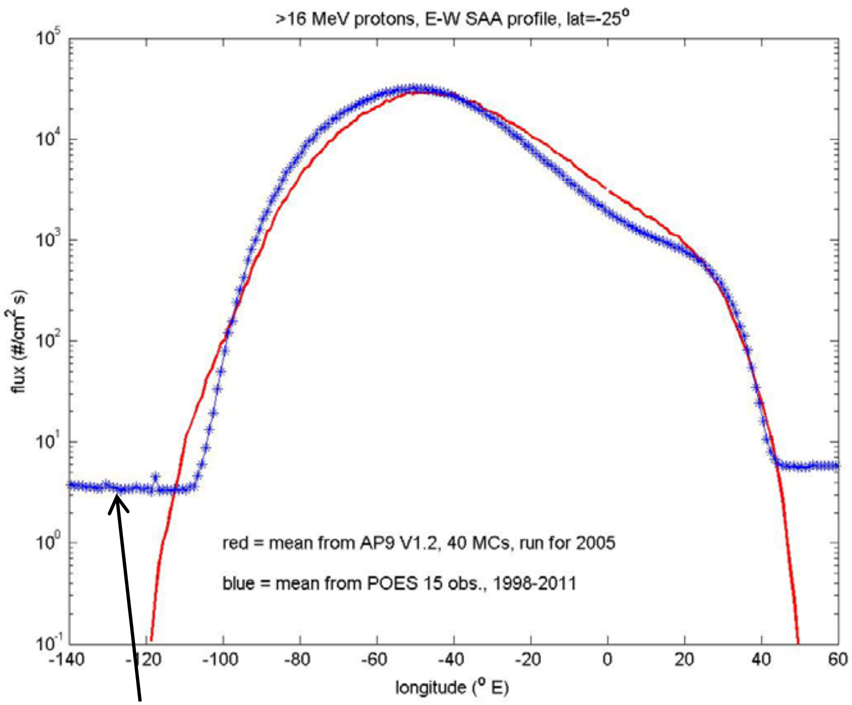


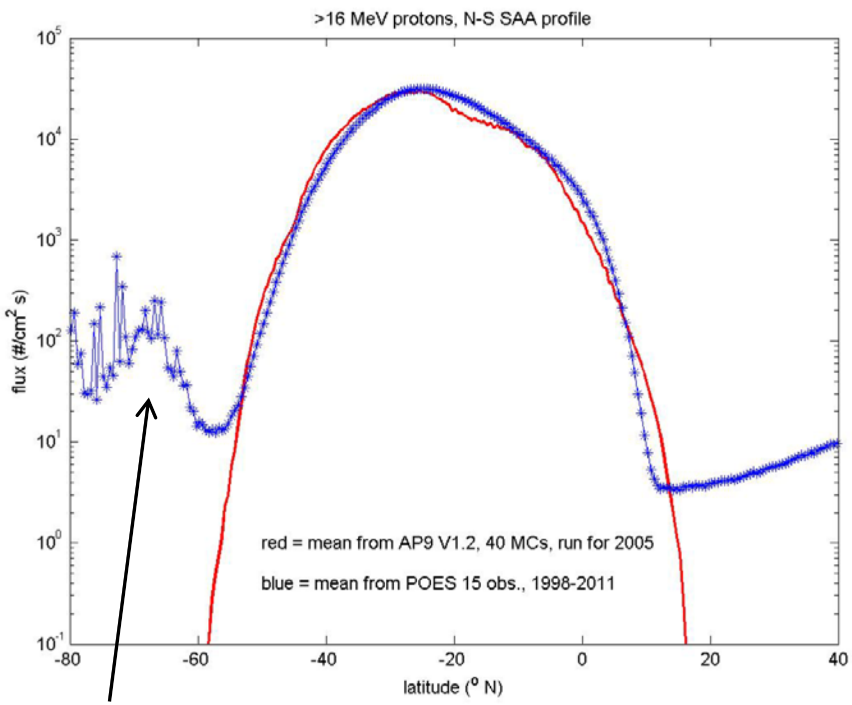
Profiles across SAA at POES orbit, >16 MeV protons

East-west profile



North-south profile





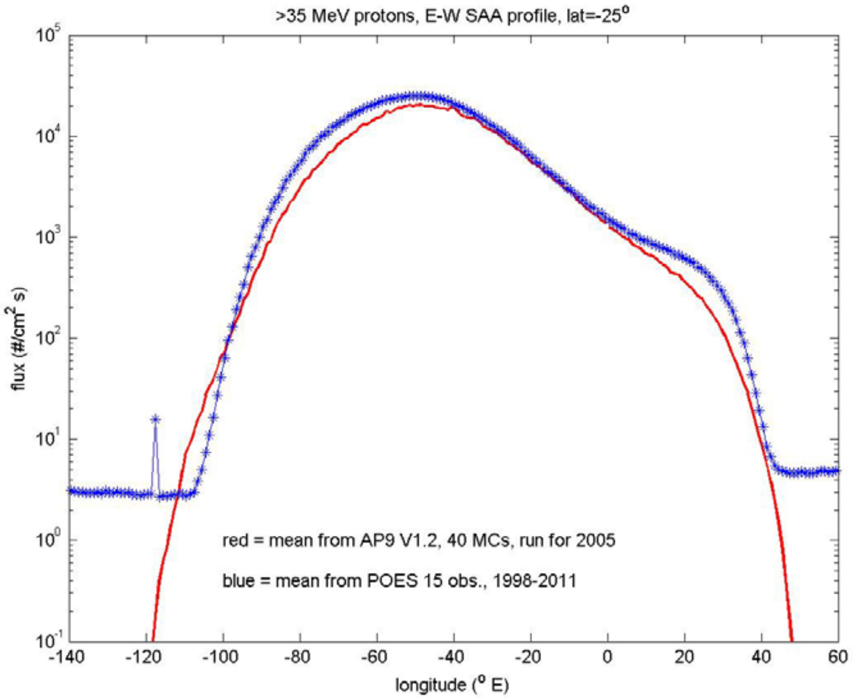
POES MEPED background

electron contamination

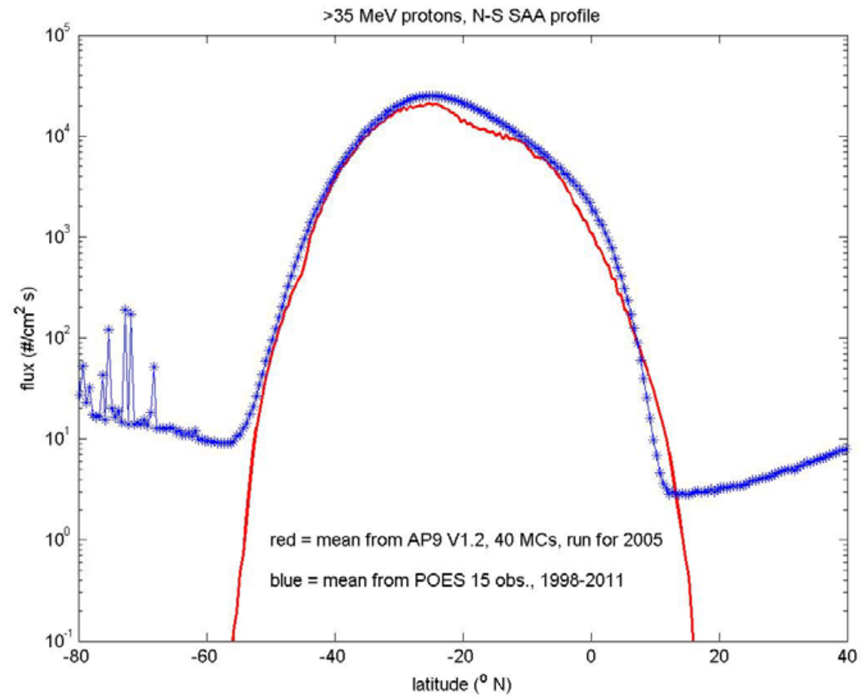
Distribution A

Profiles across SAA at POES orbit, >35 MeV protons

East-west profile

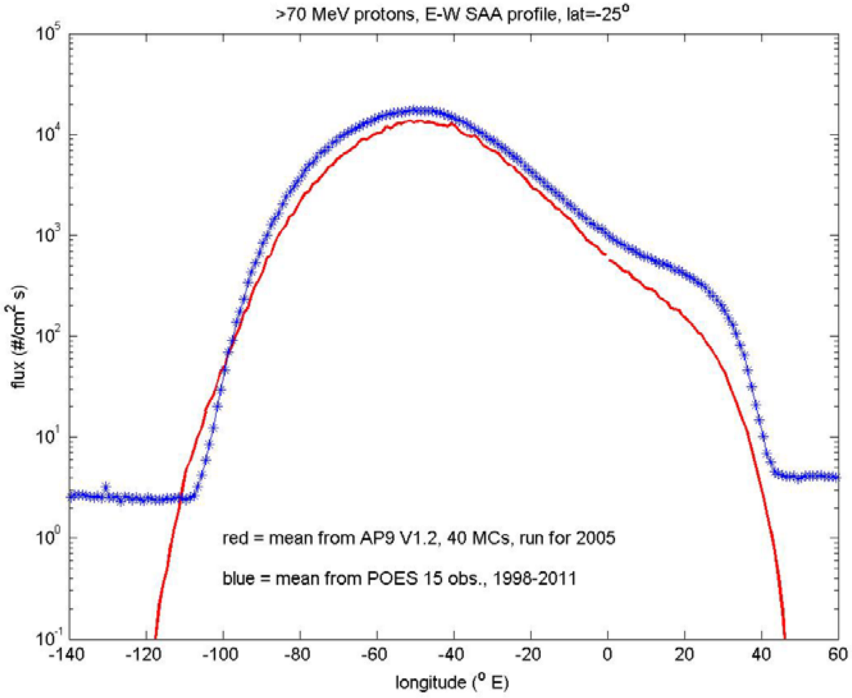


North-south profile

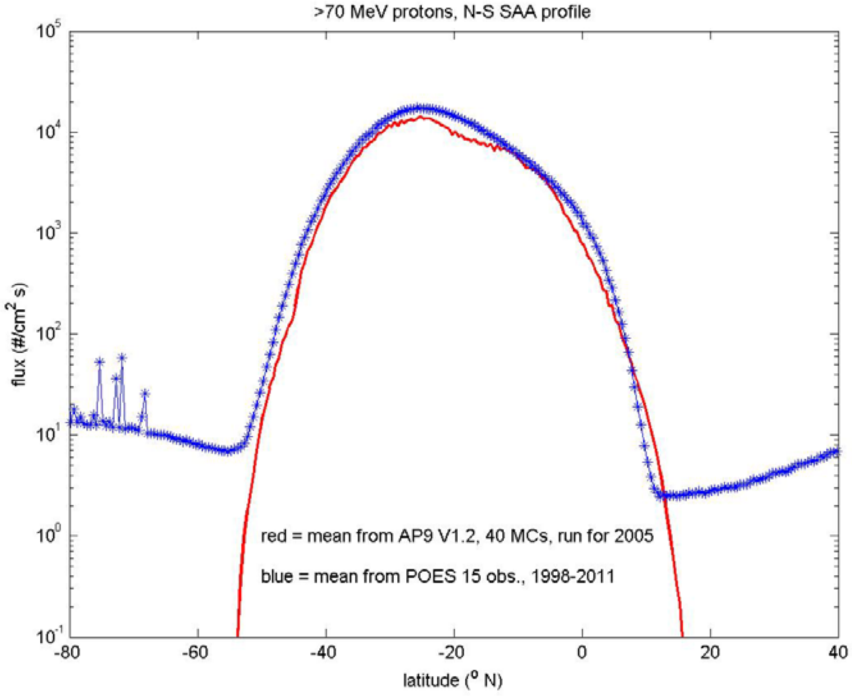


Profiles across SAA at POES orbit, >70 MeV protons

East-west profile

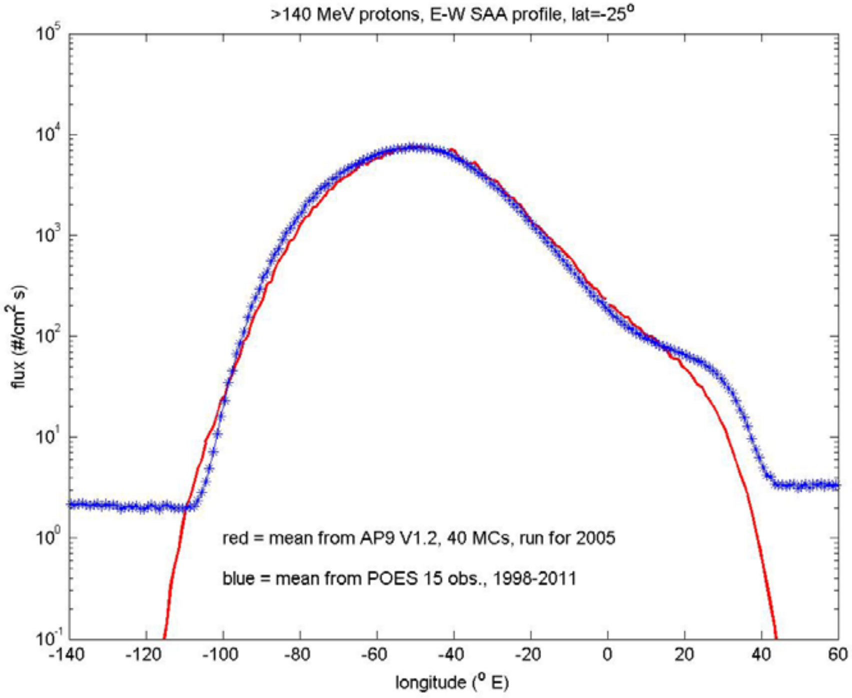


North-south profile

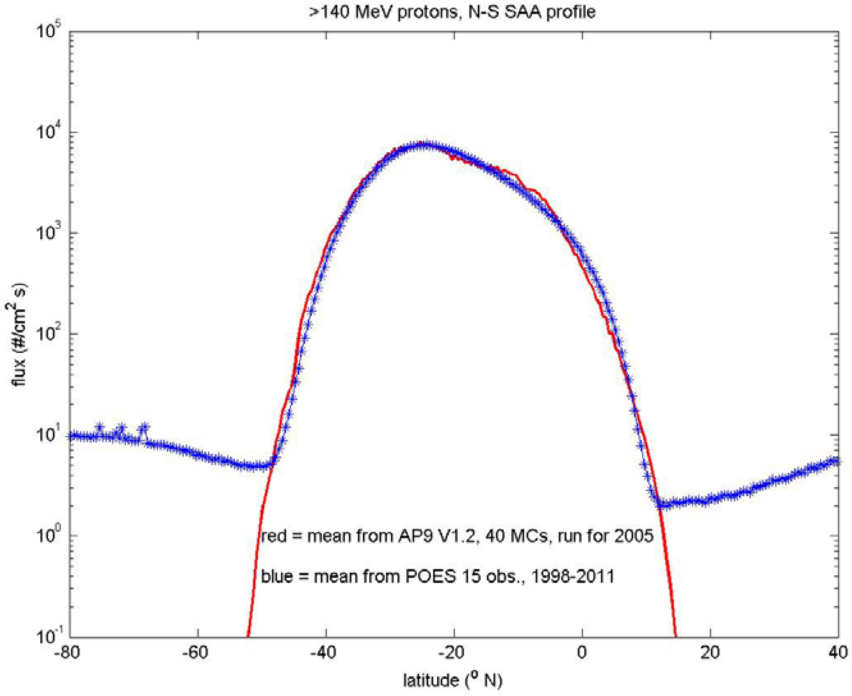


Profiles across SAA at POES orbit, >140 MeV protons

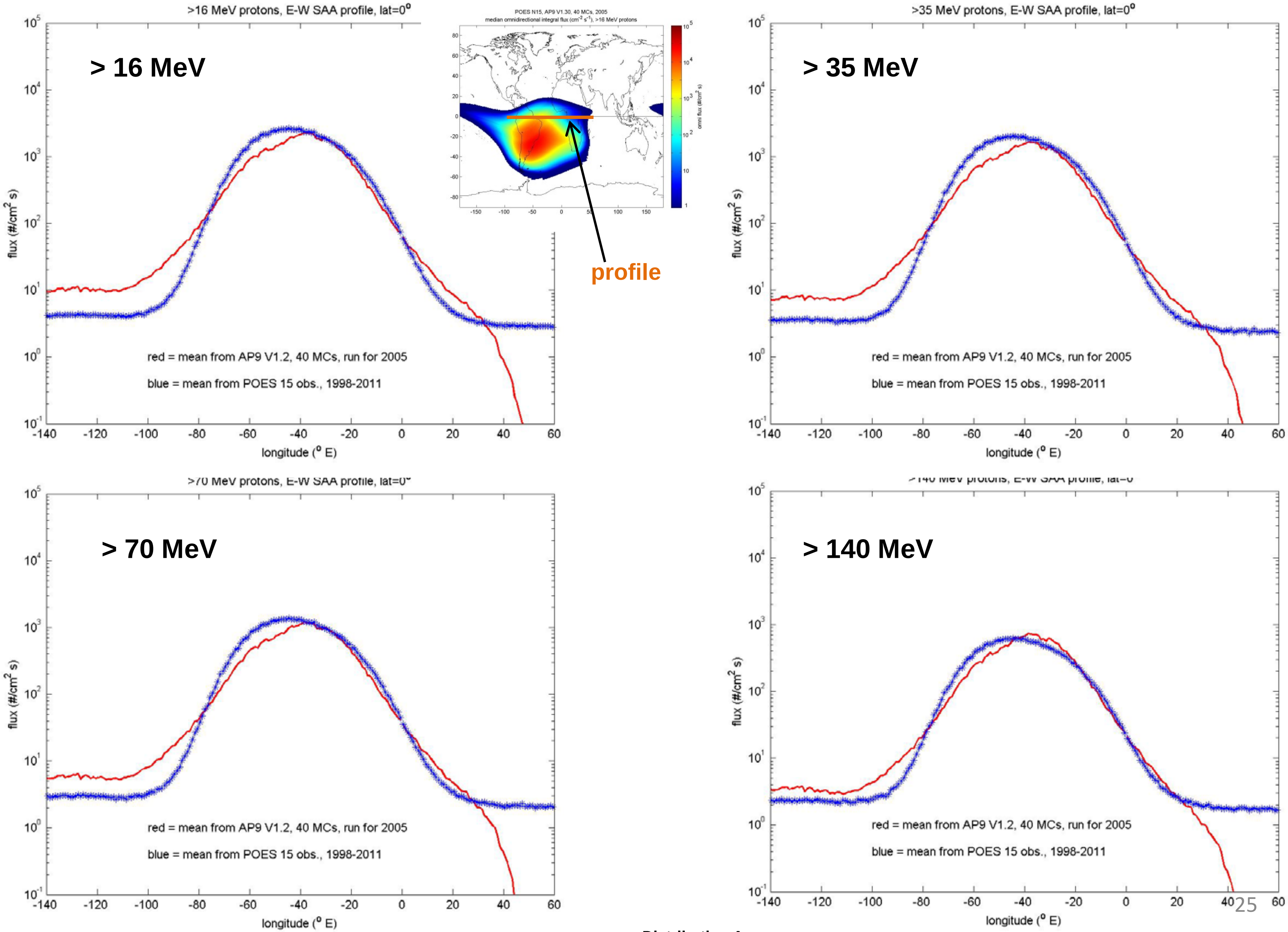
East-west profile



North-south profile



Profile across north edge of SAA at POES orbit: East-west profile at equator



Distribution A

AE9 V1.30.001 Validation

Satellite	Sensor	Orbit	Time Period	Energies (MeV)
POES N15	SEM2/ MEPED	LEO 850 km, 98.7°	Jul 1998 – Dec 2011	> 0.10, > 0.30
DEMETER	IDP	LEO 660 km, 98.2°	Jan 2005 – Dec 2010	0.108, 0.322, 0.393, 0.803
DSP-21	CEASE	GEO 35780 km, 0°	Aug 2001 – Nov 2009	> 0.37, > 0.56, > 1.51, > 2.02
GOES 10	SEM/ EPS	GEO 35780 km, 0-4°	Jul 1998 – Dec 2009	> 2.0
TACSAT4	CEASE	MEO 735 km x 12024 km, 63.5°	Oct 2011 – Dec 2011	> 0.37, > 0.56, > 1.51, > 2.02, > 2.42

- Data sets processed using standard geometric factors and algorithms obtained from source.
- No additional cleaning or cross-calibration was performed.

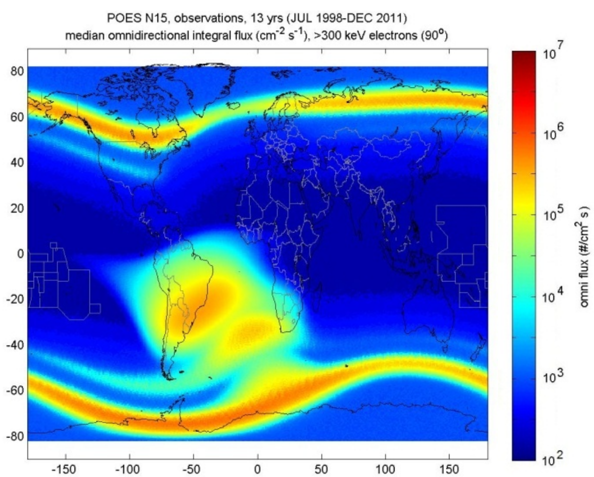
POES N15/SEM

Summary:

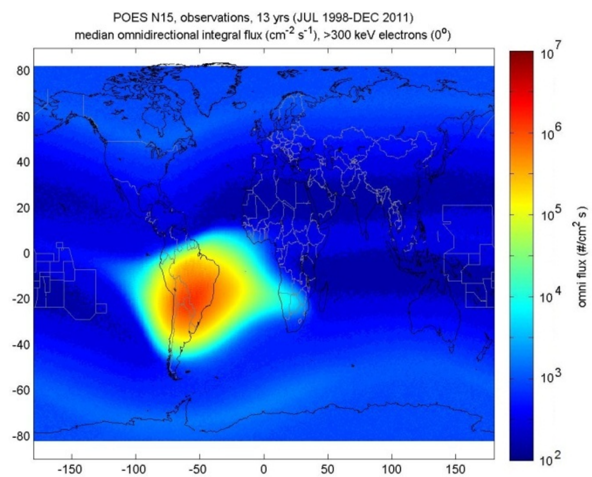
- AE9 reproduces overall morphology of electron belts observed in LEO.
- High latitude horns of outer belt in AE9 are more narrow in latitude than POES observations.
- AE9 mean and 95th percentile are more intense near SAA than POES observations.
- Range of AE9 Monte Carlo fluence results is similar to solar cycle variation of POES data.

POES 0 deg & 90 deg electron channels

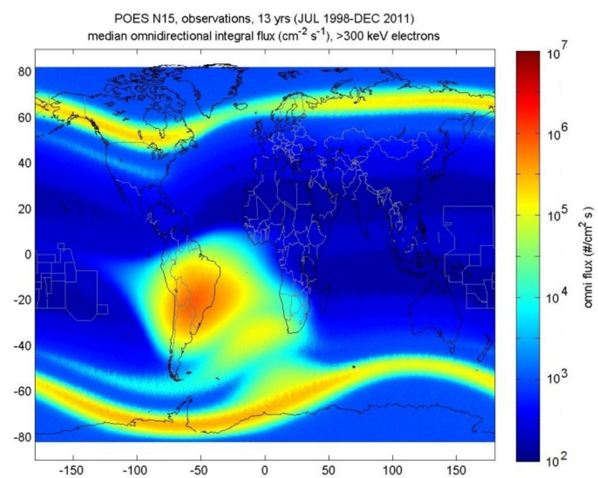
POES N15, 13 years, 1998 - 2011



90 deg



0 deg



ave (90 deg + 0 deg)

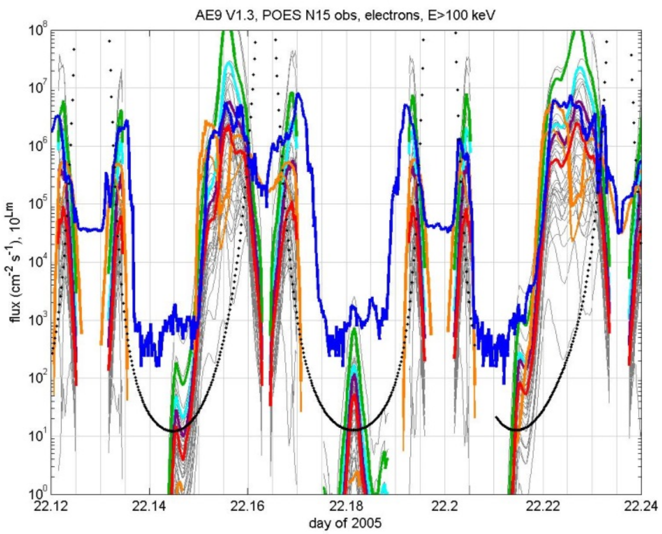
Large dependence on look angle

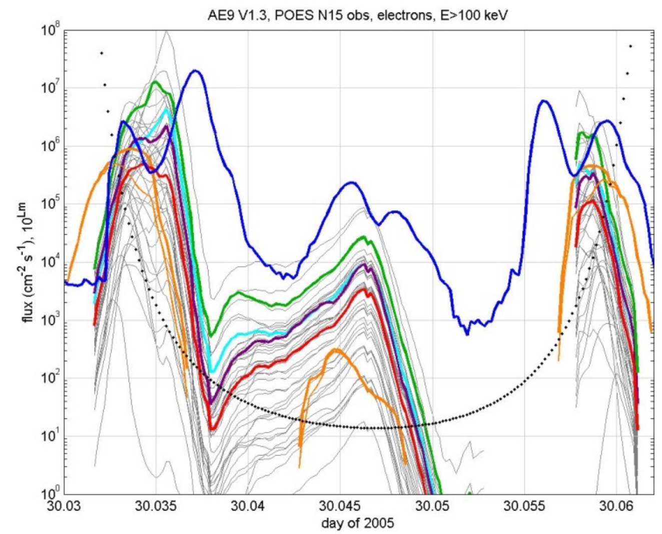
- POES MEPED electron channels have 30° field of view: one pointed toward local zenith (0°), other toward horizon opposite ram direction (90°).
- Both channels are significantly contaminated by protons in SAA.
- For validation results presented here, the average of the two channels is used for comparison to AE9 omnidirectional results.

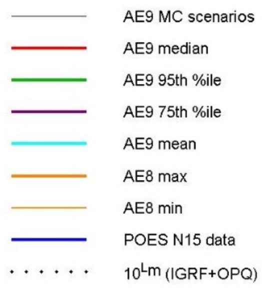
POES time series (electrons)

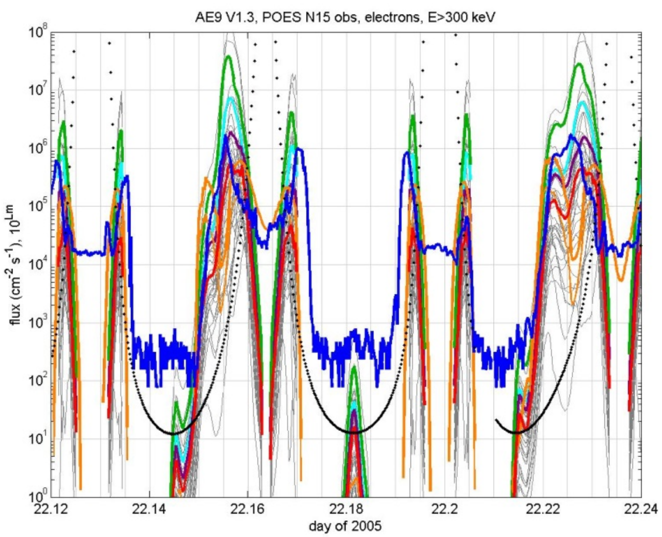
Several orbits

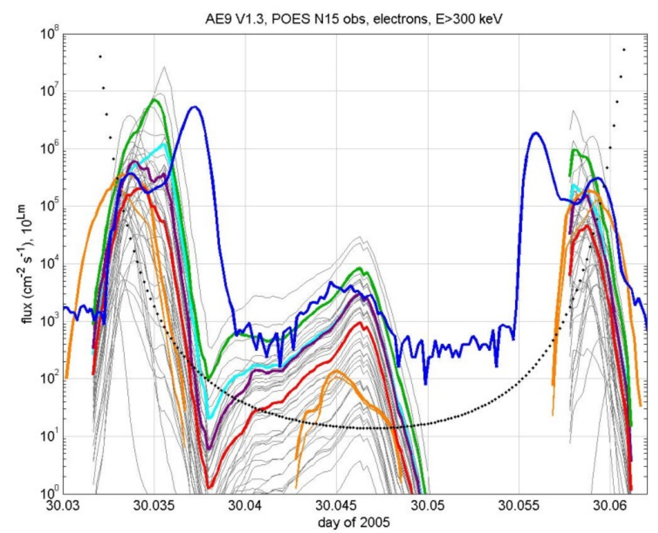
One orbit







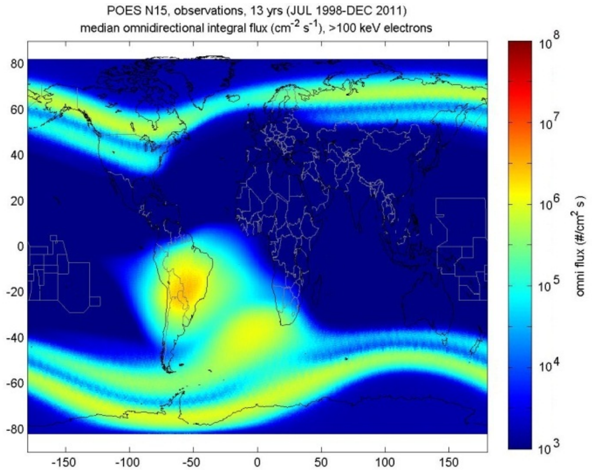


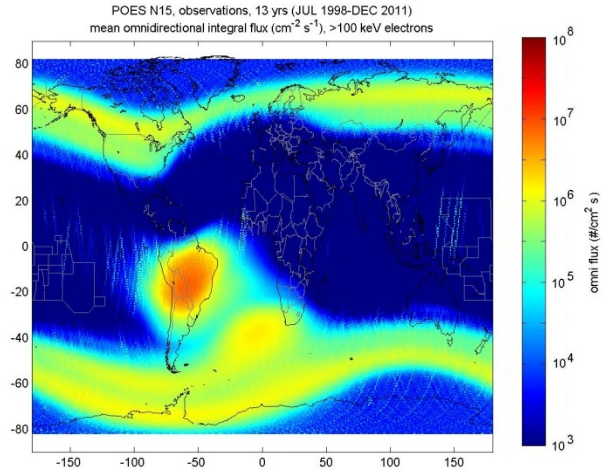


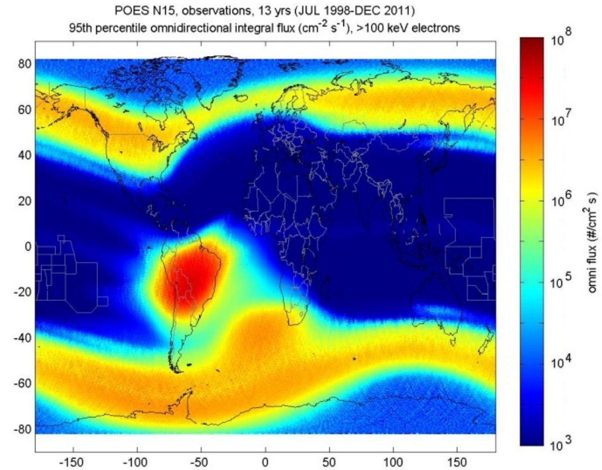
POES > 0.1 MeV electrons

POES N15 – 13 years, 1998 - 2011

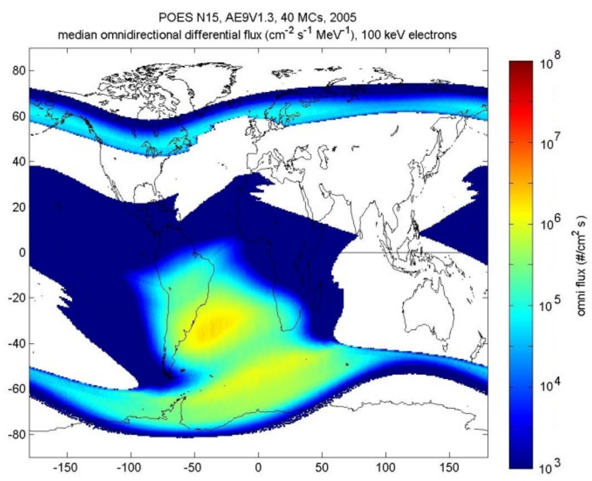
Median | **Mean** | **95th percentile**

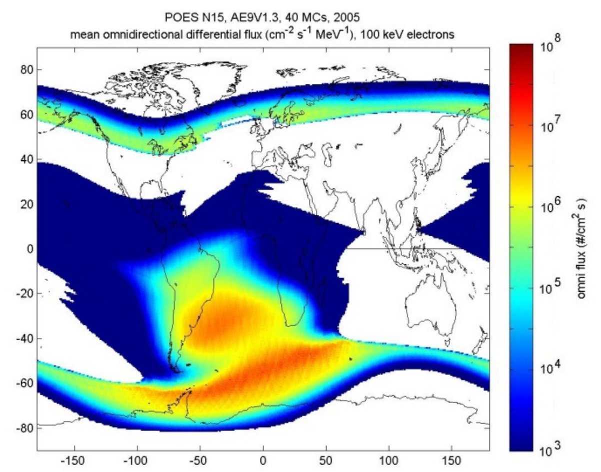


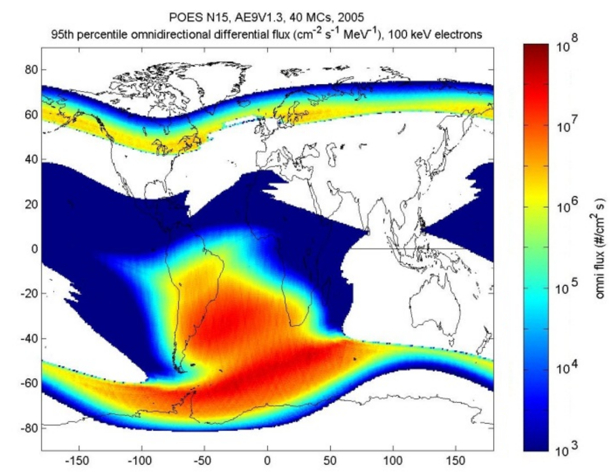




AE9 V1.30 Monte Carlo – 1 yr (2005)





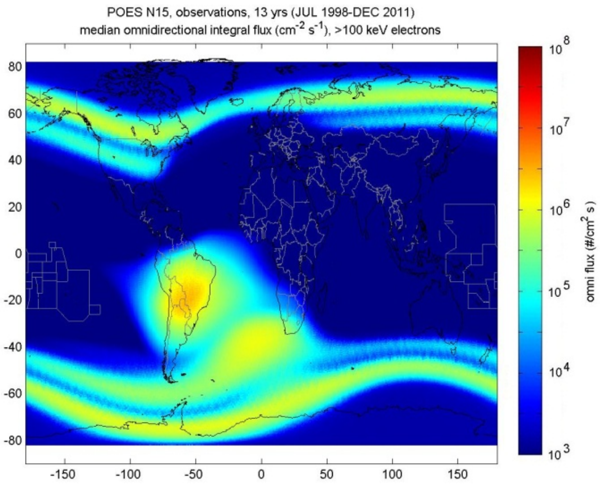


Distribution A

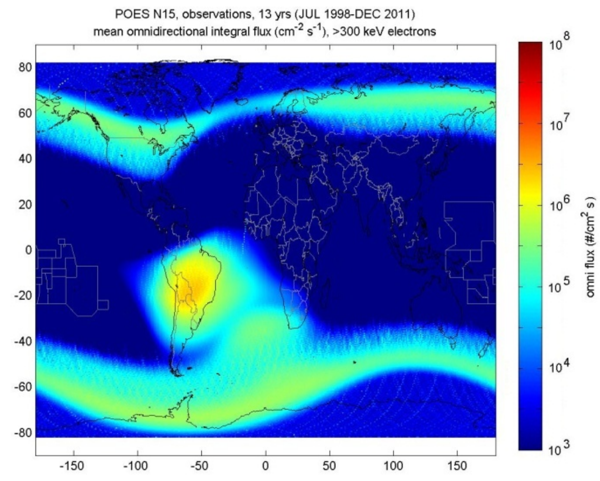
POES > 0.3 MeV electrons

POES N15 – 13 years, 1998 - 2011

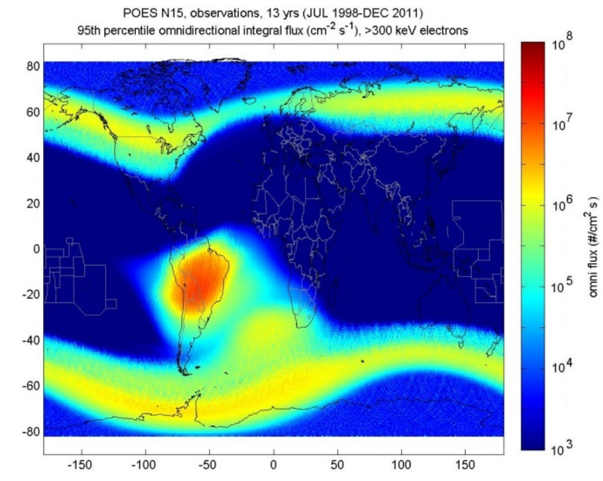
Median



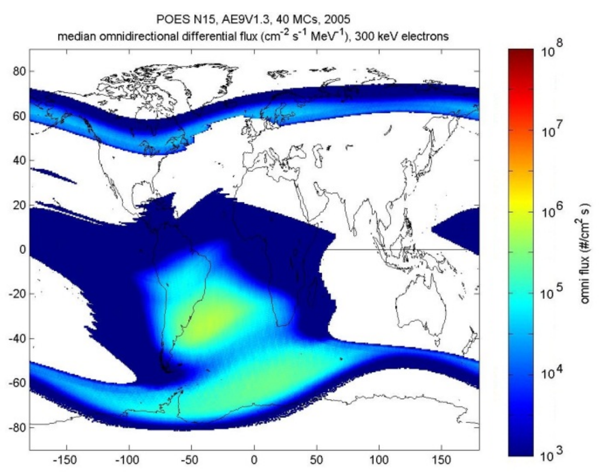
Mean

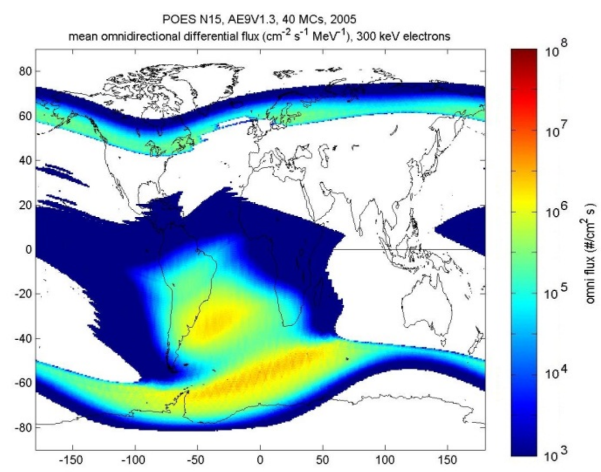


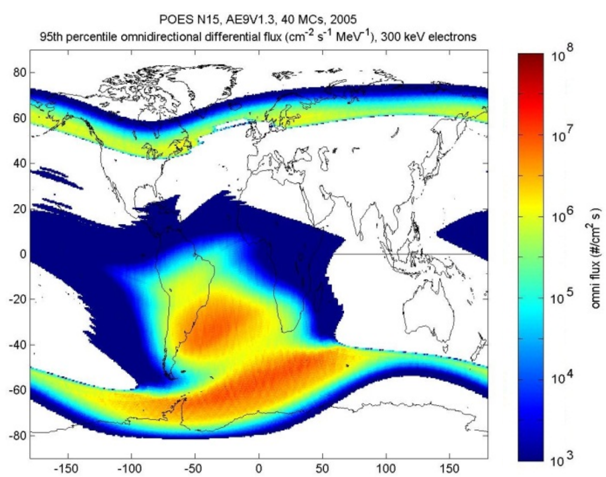
95th percentile



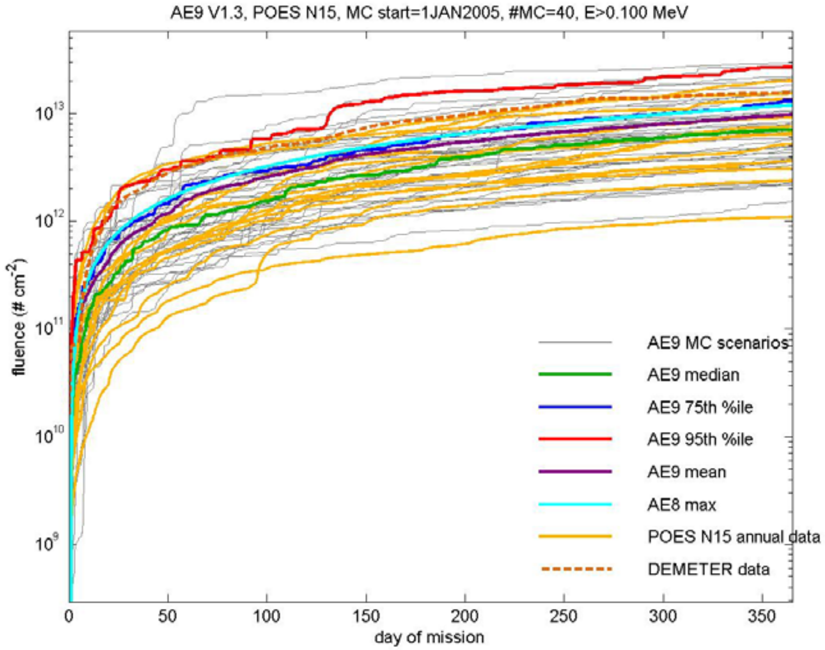
AE9 V1.30 Monte Carlo – 1 yr (2005)

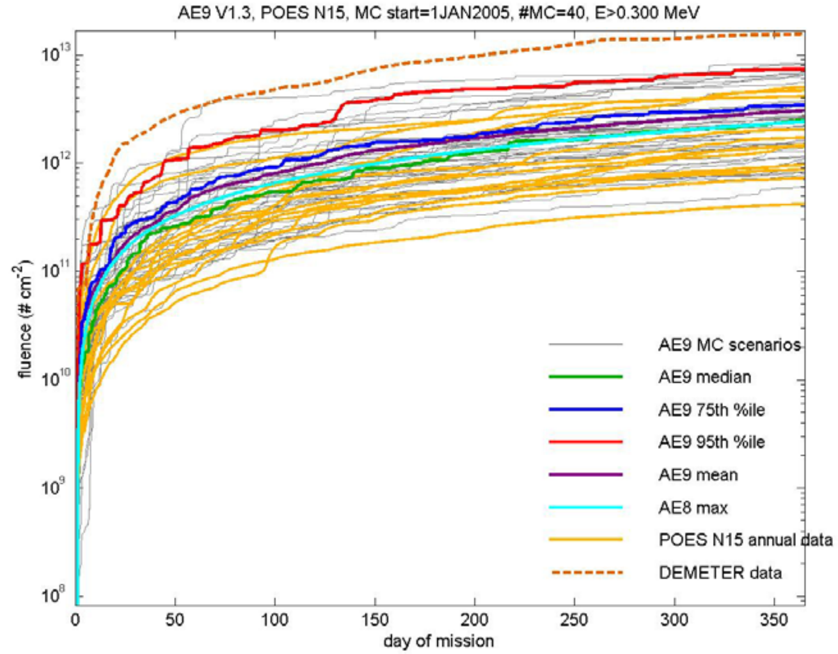






POES electron fluence – 1 yr for each of 13 years





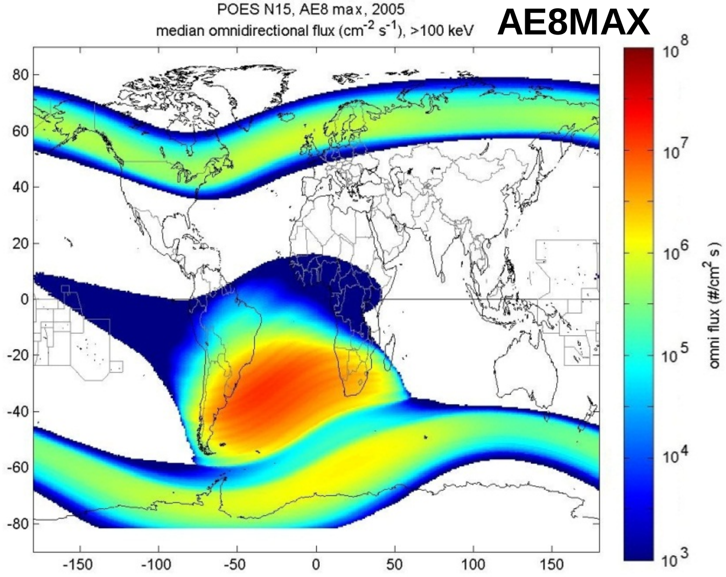
- Range of AE9 MC results is comparable to range of individual yearly results from POES—POES range mostly results from solar cycle variation.

Distribution A

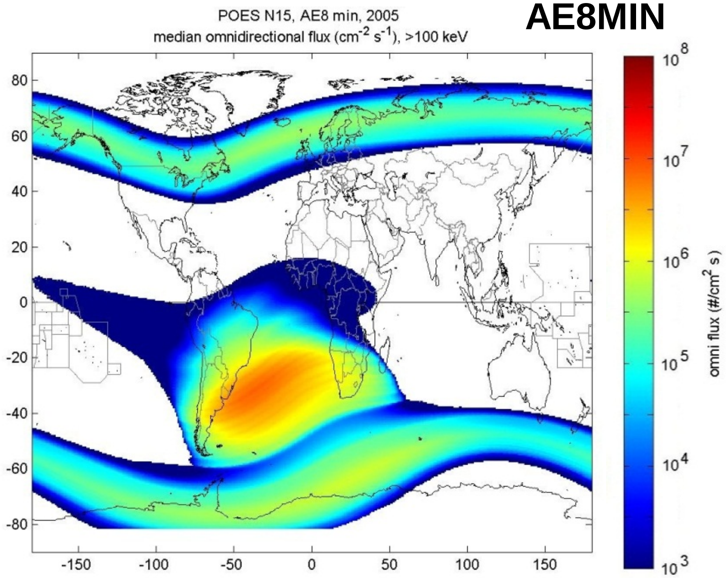
POES — AE8

> 0.100 MeV

AE8MAX

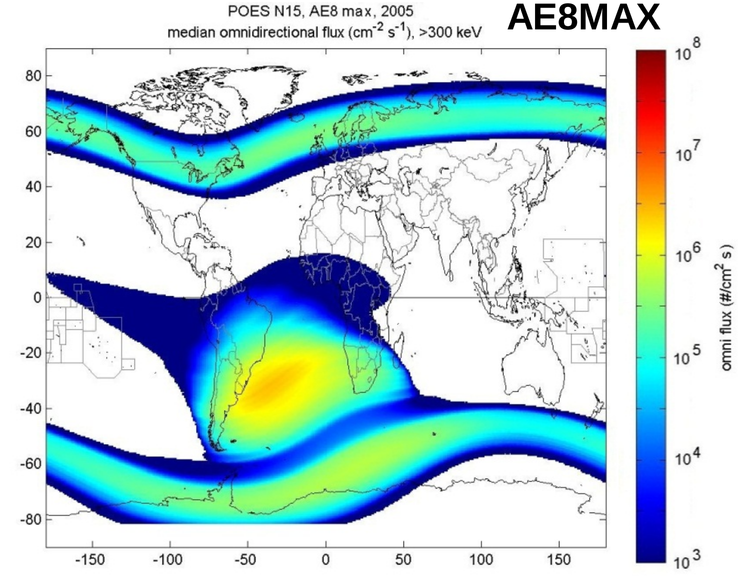


AE8MIN

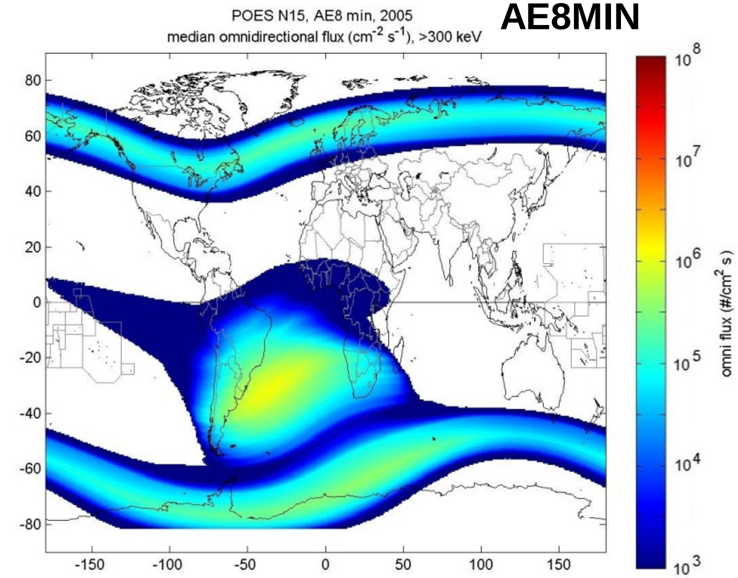


> 0.300 MeV

AE8MAX



AE8MIN



Distribution A

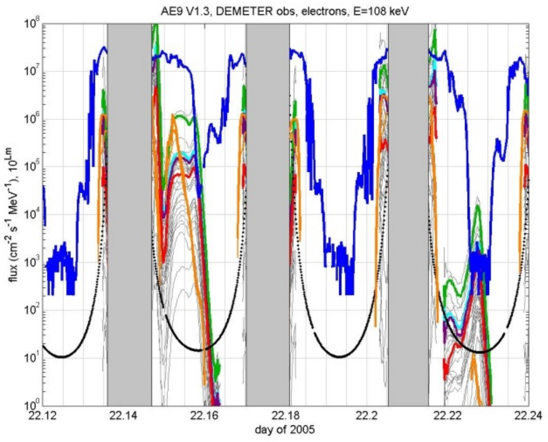
DEMETER/IDP

Summary:

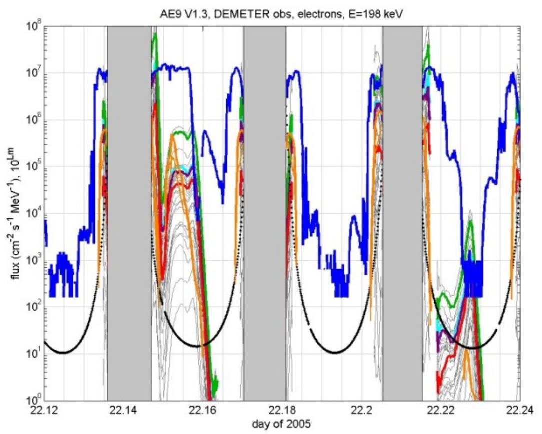
- AE9 reproduces overall morphology of electron belts observed in LEO.
- High latitude horns of outer belt in AE9 are more narrow in latitude than DEMETER observations, particularly at 0.1 MeV.
- AE9 95th percentile, relative to DEMETER data, has a more intense peak near the SAA but has a less geographically expansive region of high flux.
- Annual fluence results from DEMETER data (six years) show less variability than AE9 Monte Carlo results at 0.1 MeV, more variability at 0.8 MeV, and are somewhat comparable at intermediate energies.

DEMETER electron time series (~ 1.5 orbits)

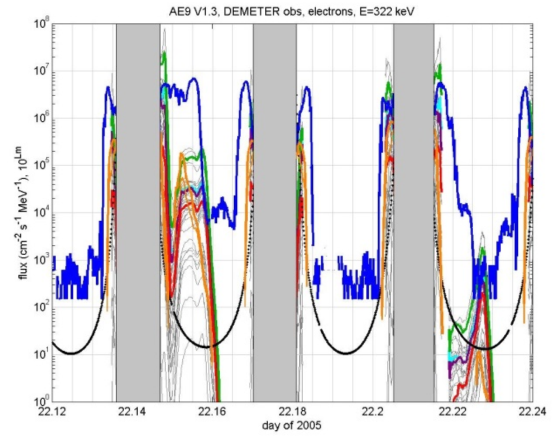
0.108 MeV



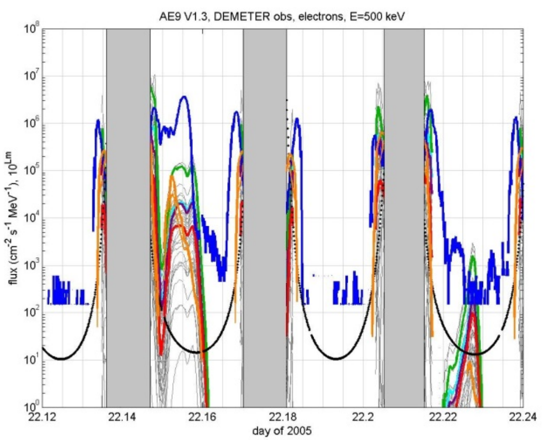
0.198 MeV



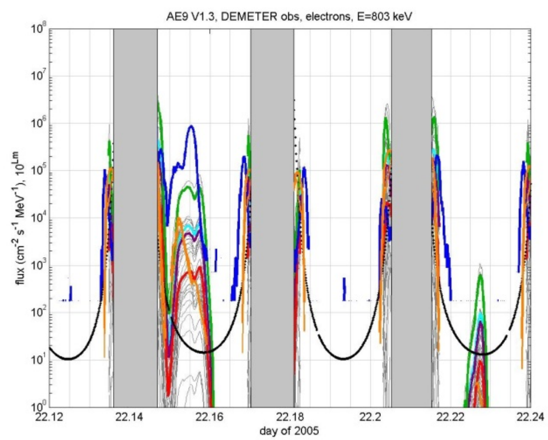
0.322 MeV



0.500 MeV



0.803 MeV



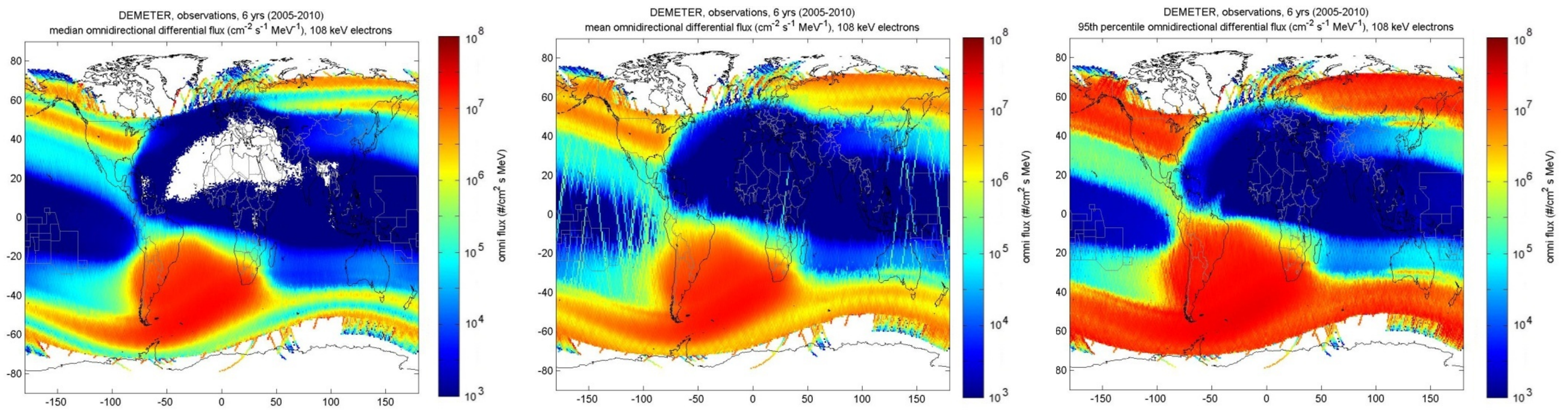
AE9 MC scenarios
AE9 median
AE9 95th %ile
AE9 75th %ile
AE9 mean
AE8 max
AE8 min
DEMETER data
10^{Lm} (IGRF+OPQ)

- Grey regions denote high latitudes where no DEMETER data are available.

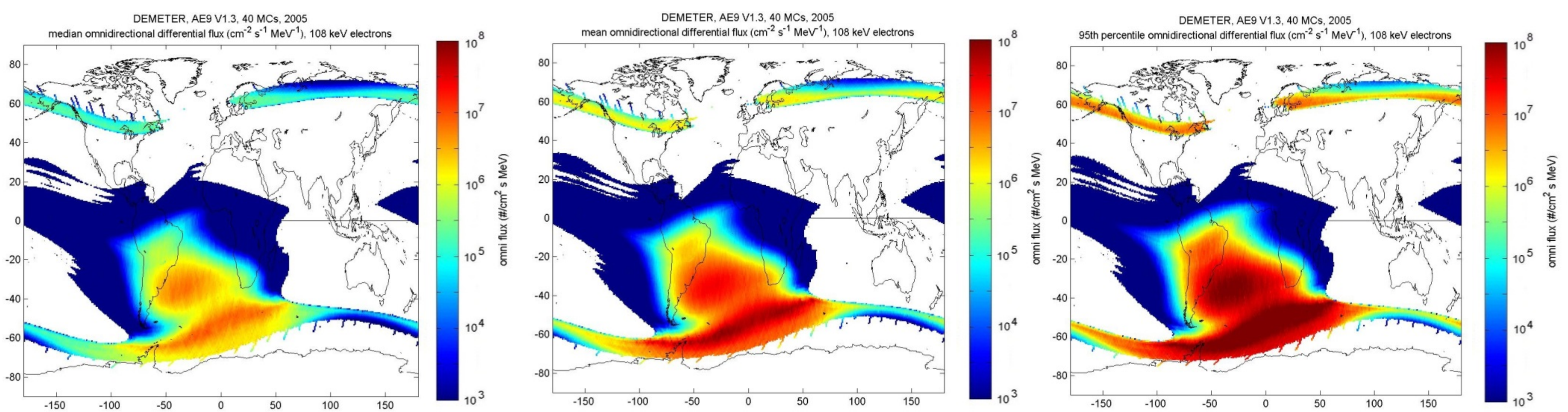
DEMETER 0.108 MeV electrons

DEMETER - 6 yrs (2005 – 2010)

Median **Mean** **95th percentile**



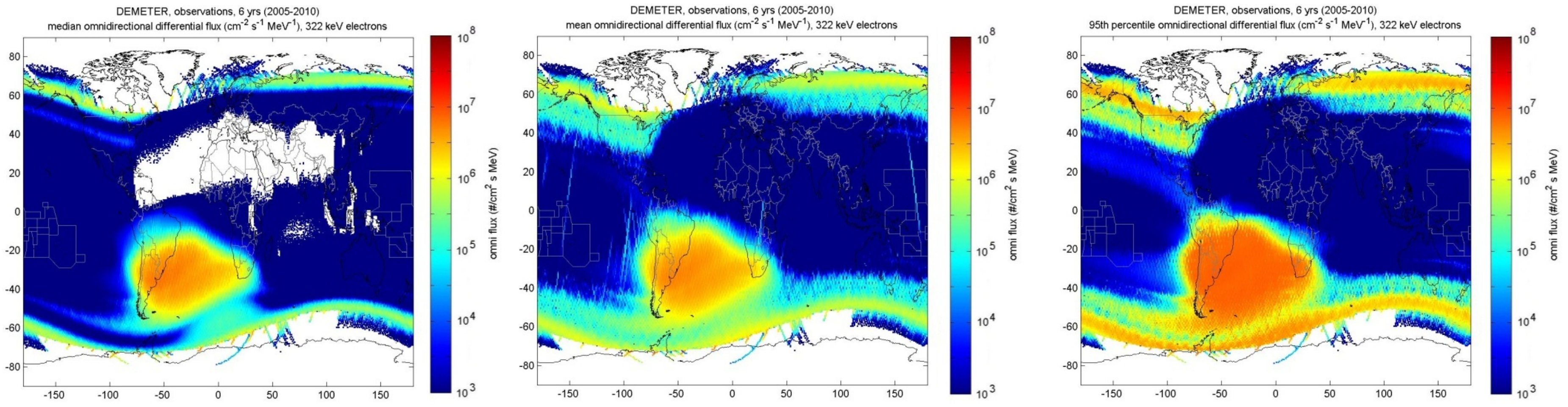
AE9 V1.30 Monte Carlo - 1 yr (2005)



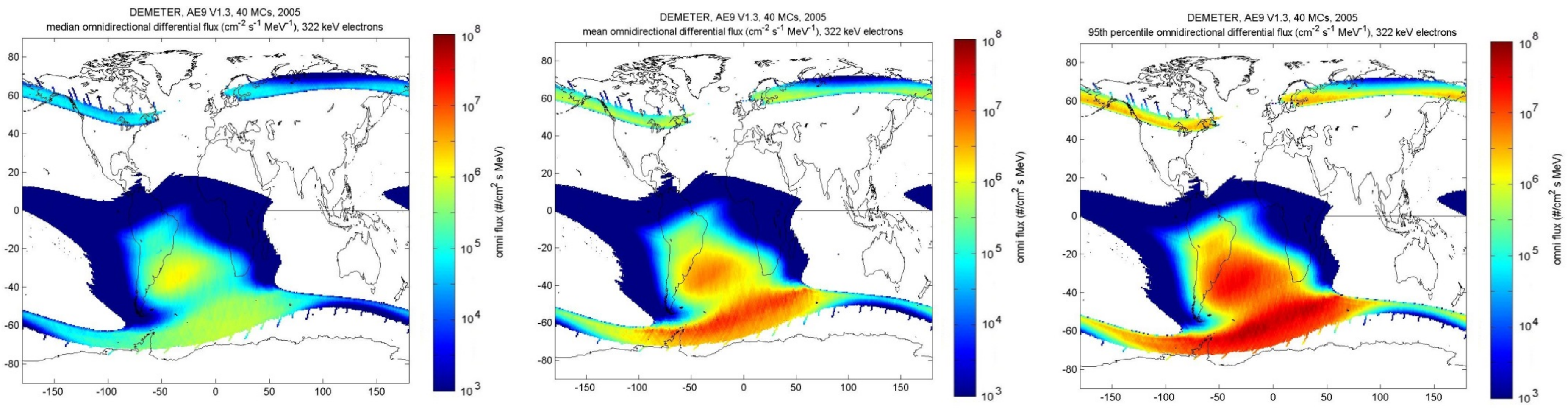
DEMETER 0.322 MeV electrons

DEMETER - 6 yrs (2005 – 2010)

Median | **Mean** | **95th percentile**



AE9 V1.30 Monte Carlo - 1 yr (2005)

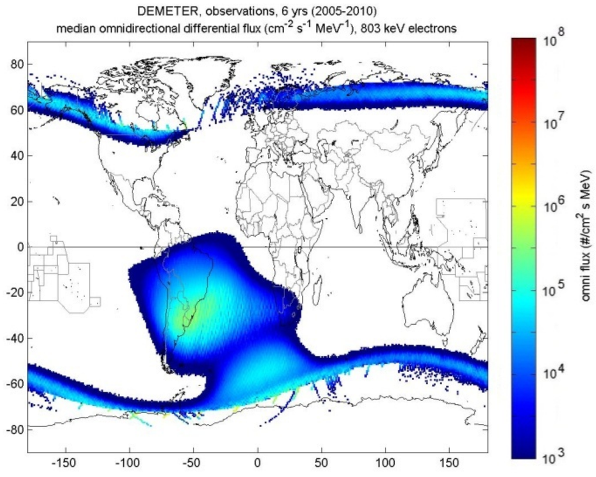


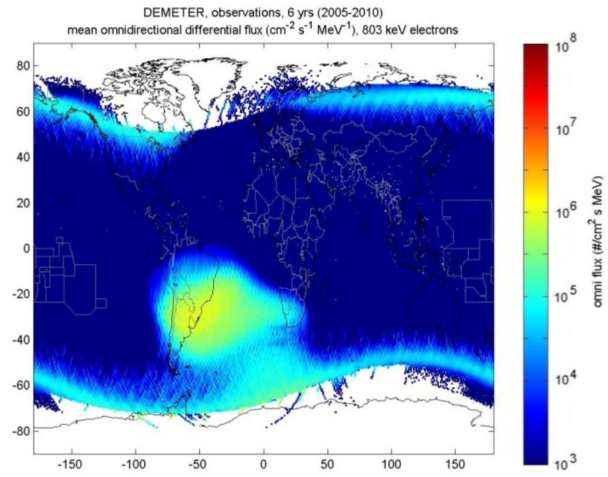
Distribution A

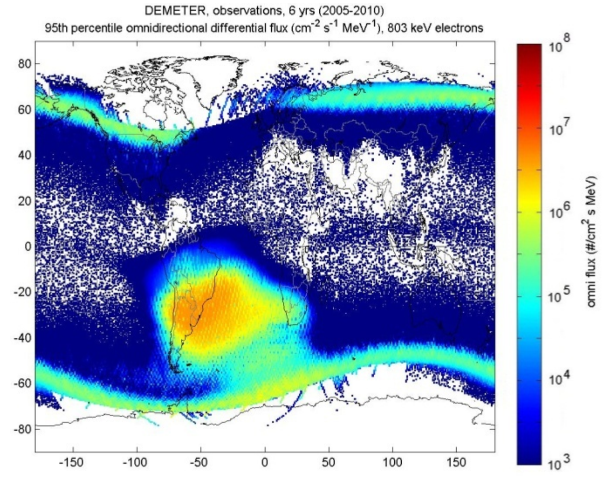
DEMETER 0.803 MeV electrons

DEMETER - 6 yrs (2005 – 2010)

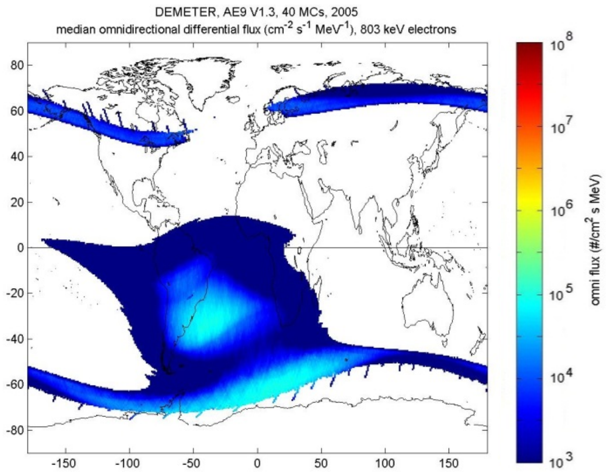
Median **Mean** **95th percentile**

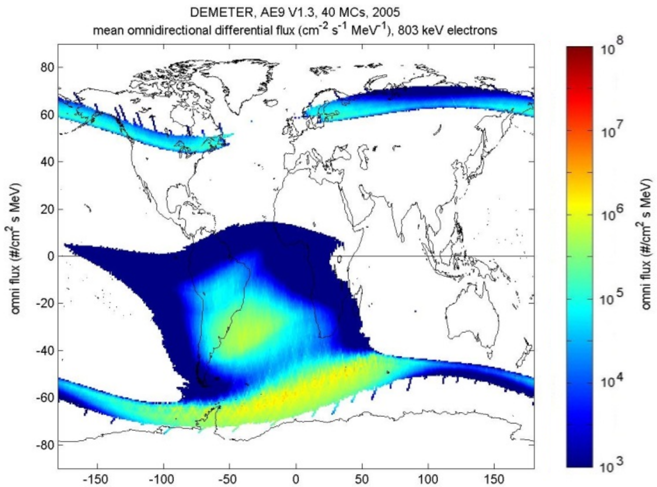


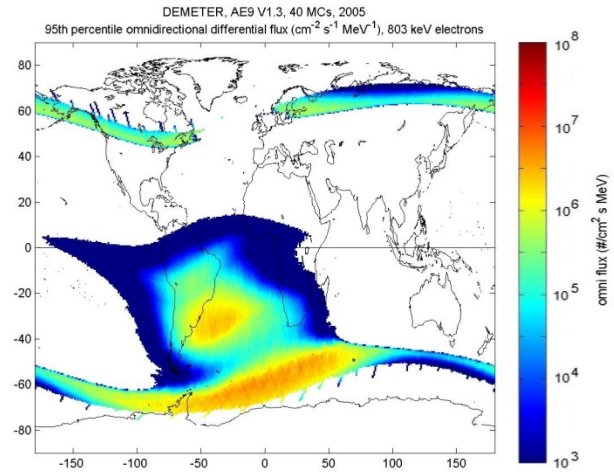




AE9 V1.30 Monte Carlo - 1 yr (2005)



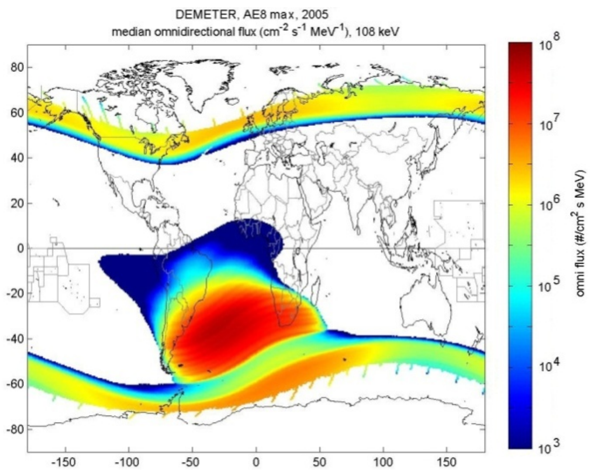




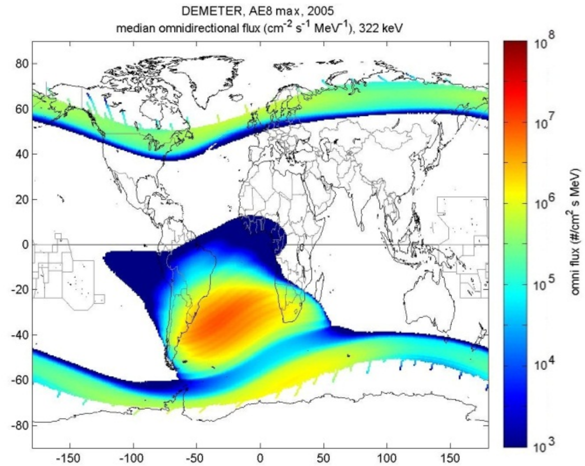
DEMETER electrons (2005)

AE8MAX

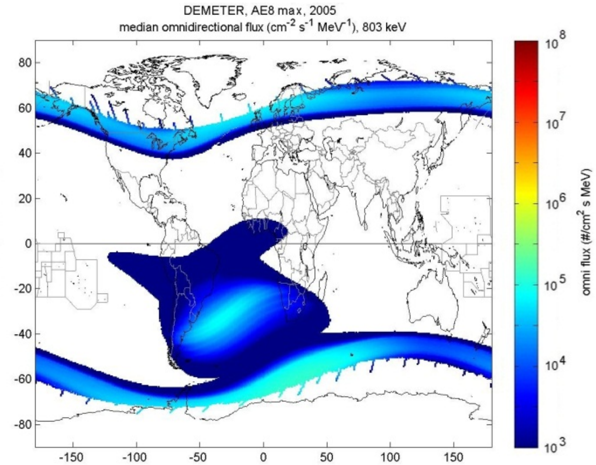
0.108 MeV



0.322 MeV

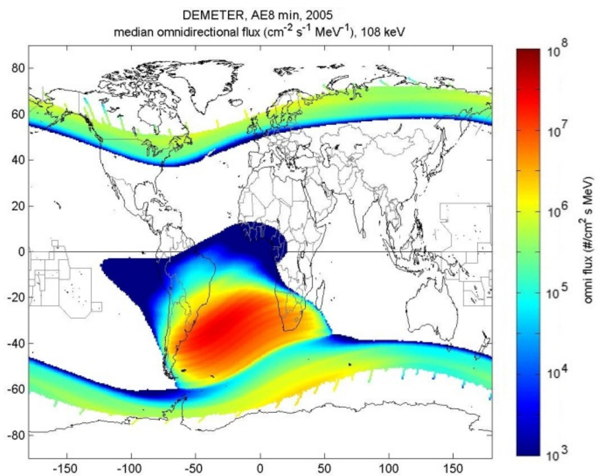


0.322 MeV

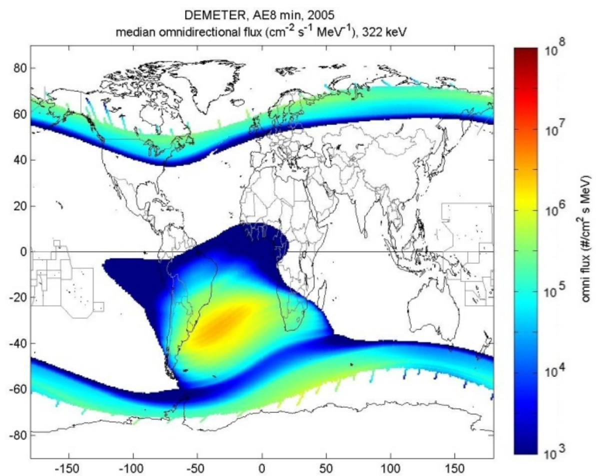


AE8MIN

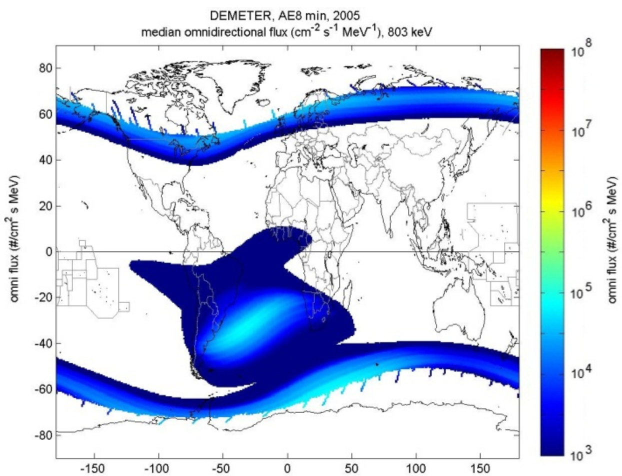
0.108 MeV



0.198 MeV



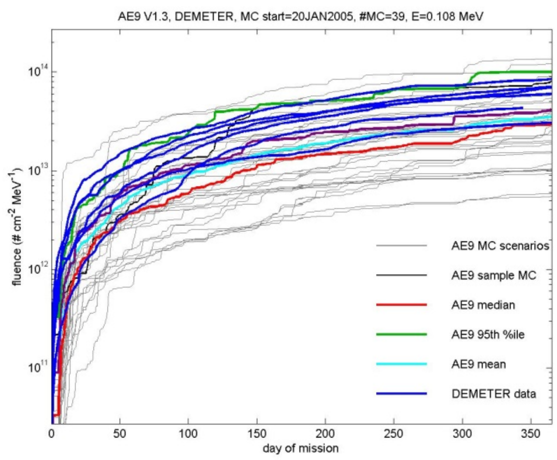
0.322 MeV



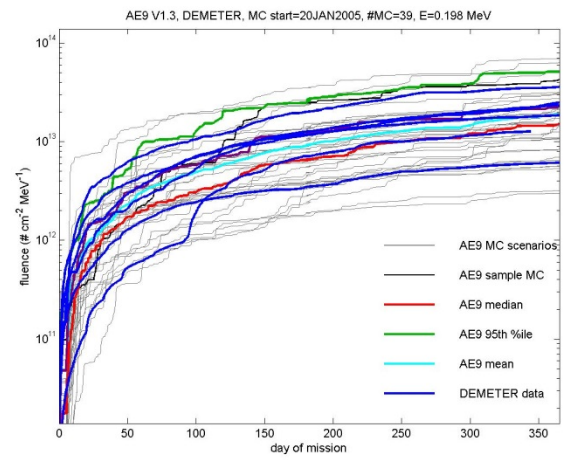
Distribution A

DEMETER electron fluence - 1 yr for each of 6 years

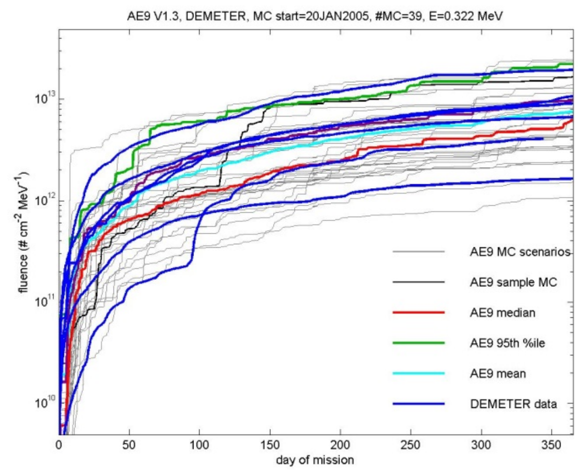
0.108 MeV



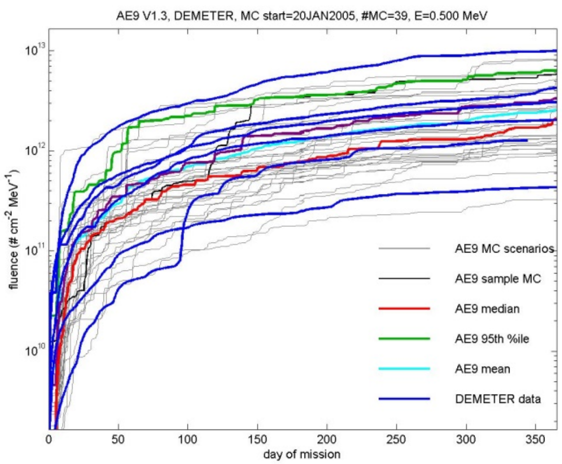
0.198 MeV



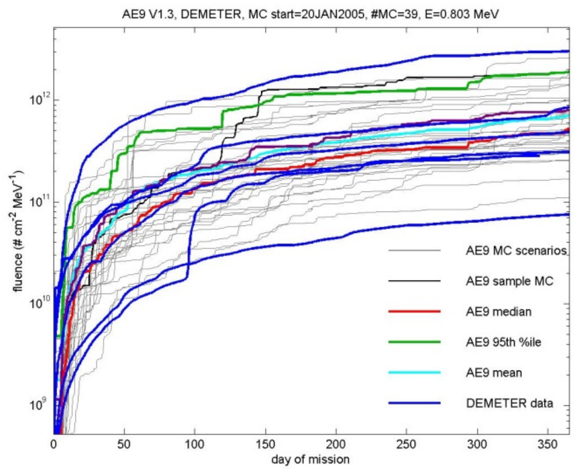
0.322 MeV



0.500 MeV



0.803 MeV



POES/SEM 2 vs DEMETER/IDP

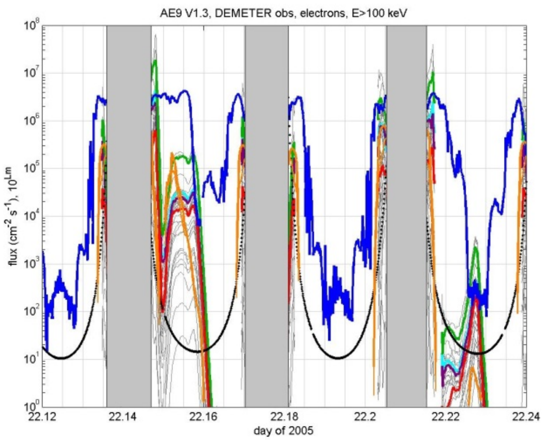
Summary:

- These charts compare POES and DEMETER results, given the similarity of their orbits (with the caveat of different altitudes, 850 km and 660 km, respectively).
- DEMETER channel data were used to construct estimates shown here for the energy coverage of the POES MEPED channels (>0.1, >0.3 MeV).
- DEMETER-based estimates are at the high end of AE9 Monte Carlo results for POES, despite DEMETER's lower altitude.
- Comparison of POES and DEMETER results for LEO show different shapes and coverage for the SAA—this is partly from the different altitudes but also from differences in the instruments.

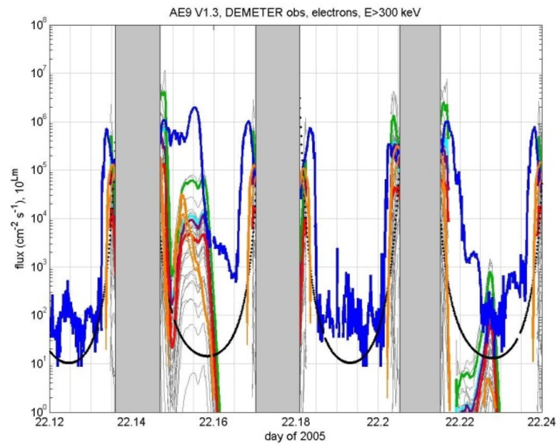
DEMETER and POES electron flux during same period

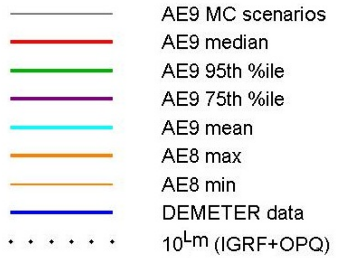
DEMETER

> 0.100 MeV (equivalent POES channel)



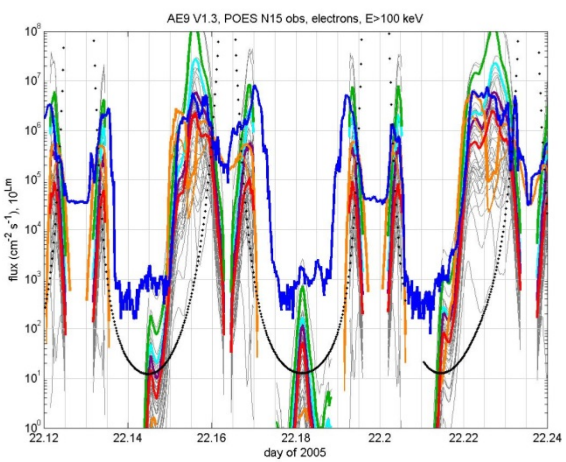
> 0.300 MeV (equivalent POES channel)



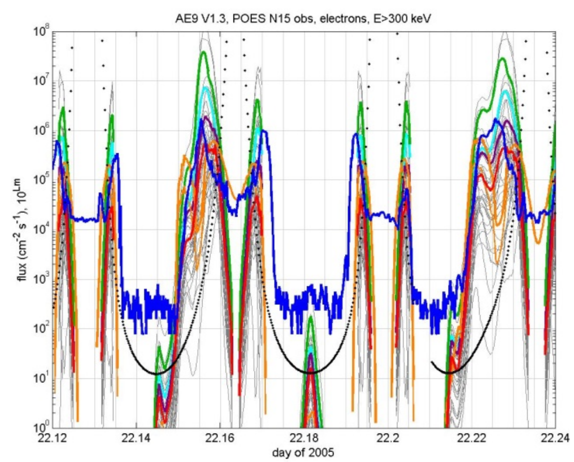


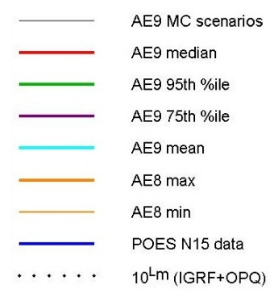
POES

> 0.100 MeV



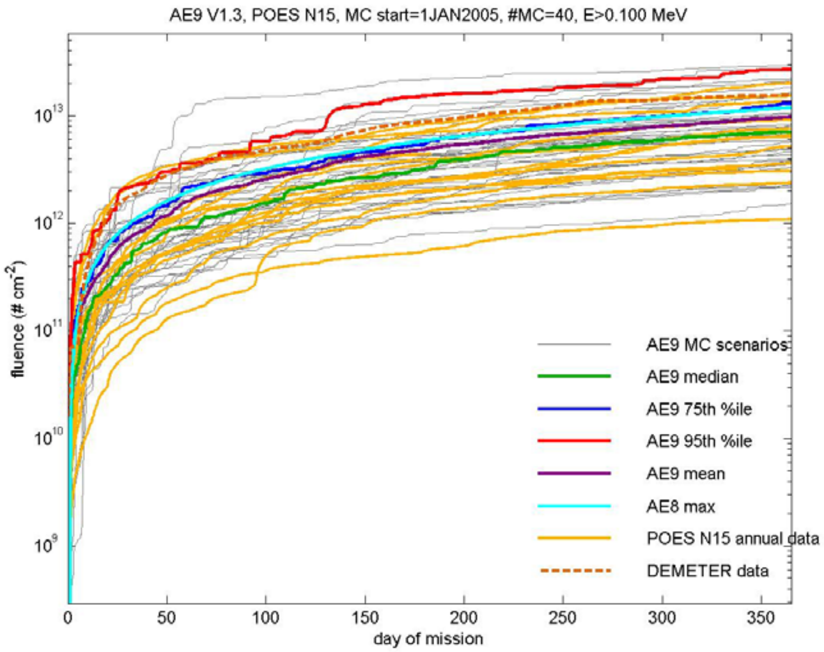
> 0.300 MeV

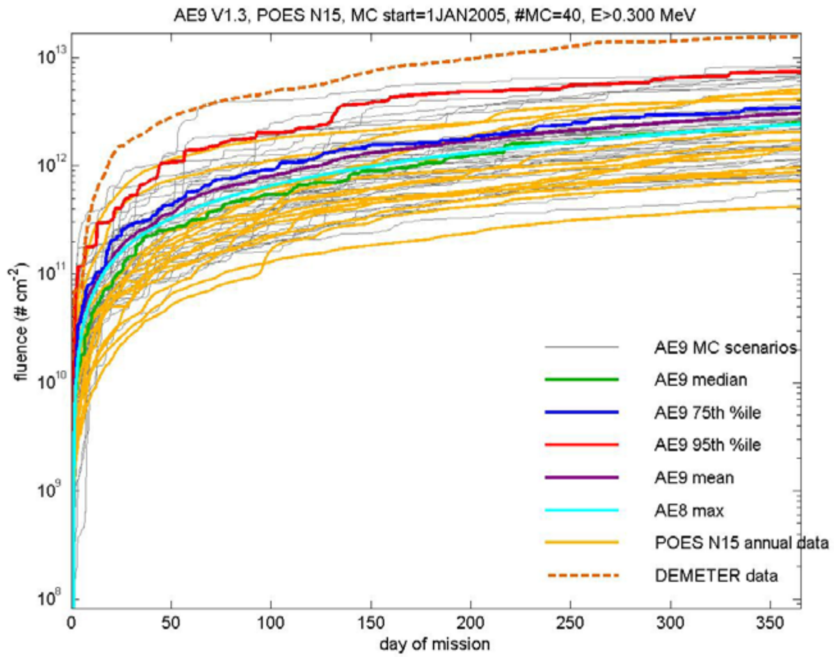




DEMETER and POES electron fluence

> 0.100 MeV **> 0.300 MeV**

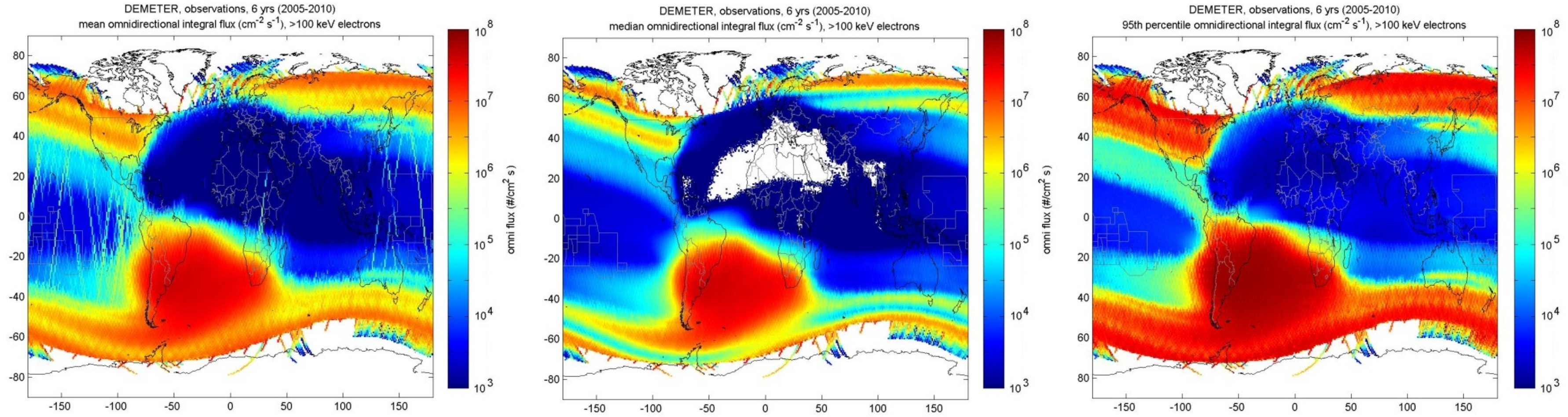




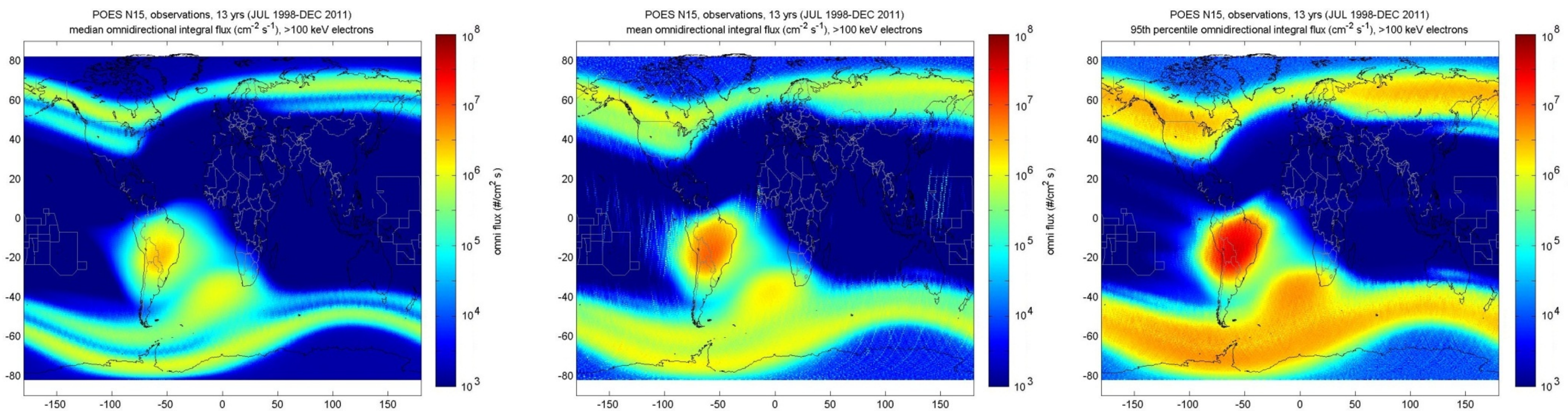
Distribution A

DEMETER > 0.100 MeV electrons (POES equivalent)

DEMETER, 6 years (2005-2010)

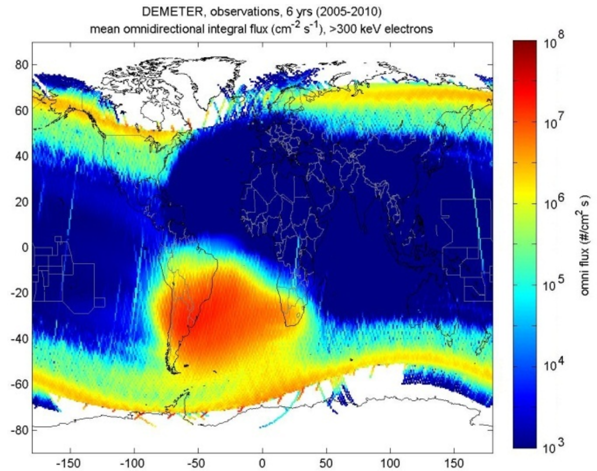


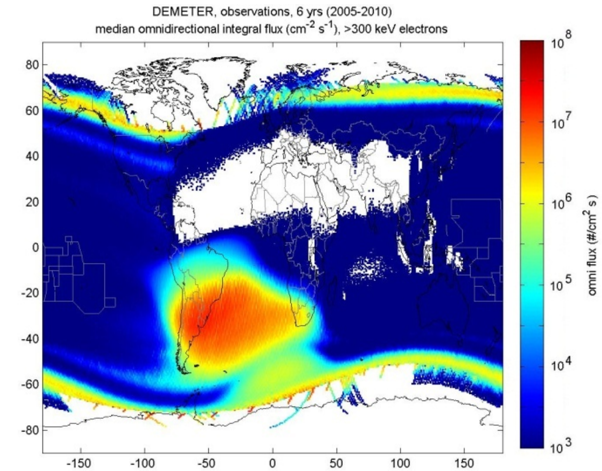
POES N15 – 13 years, 1998 - 2011

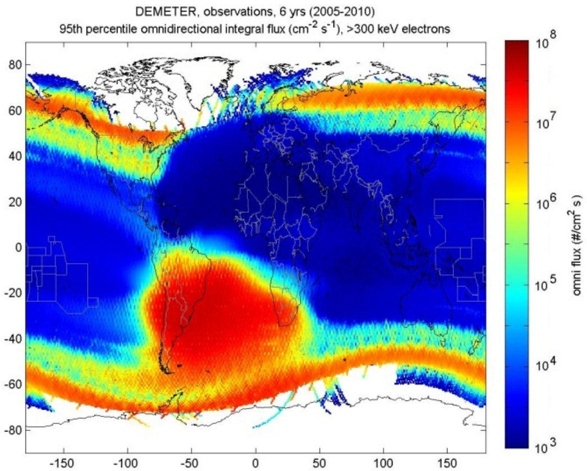


DEMETER > 0.300 MeV electrons (POES equivalent)

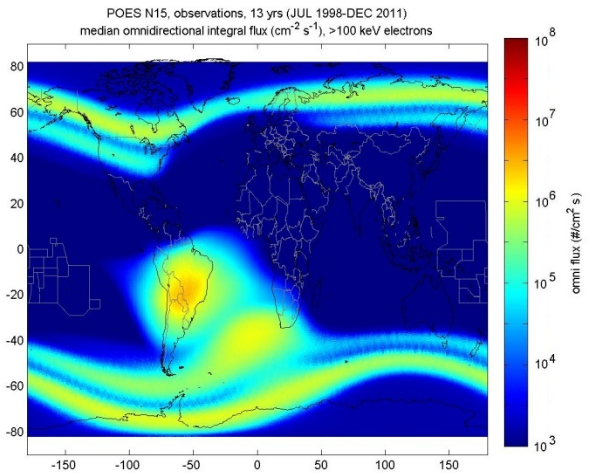
DEMETER, 6 years (2005-2010)

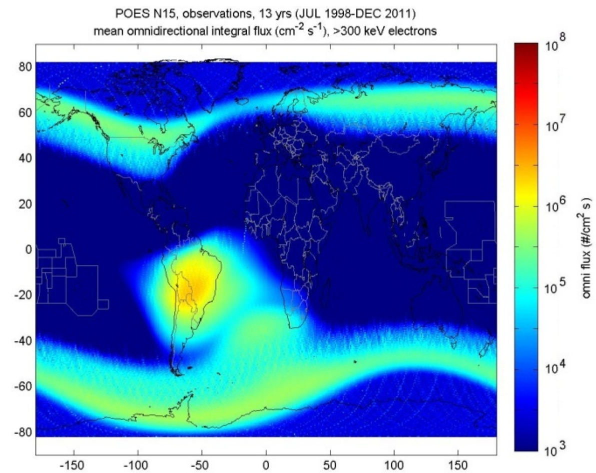


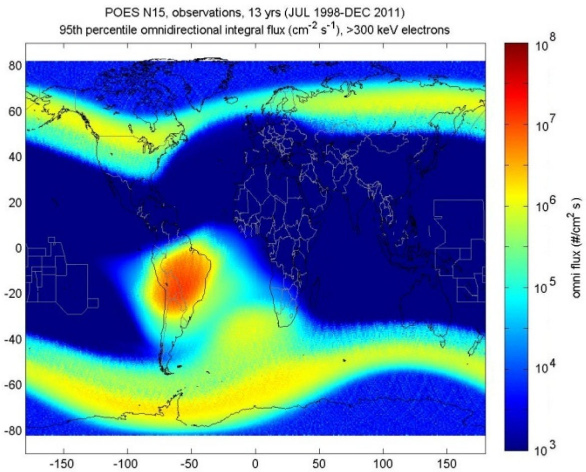




POES N15 – 13 years, 1998 - 2011







GOES10/SEM

Summary:

• Diurnal variation of flux observed by GOES is replicated in AE9.

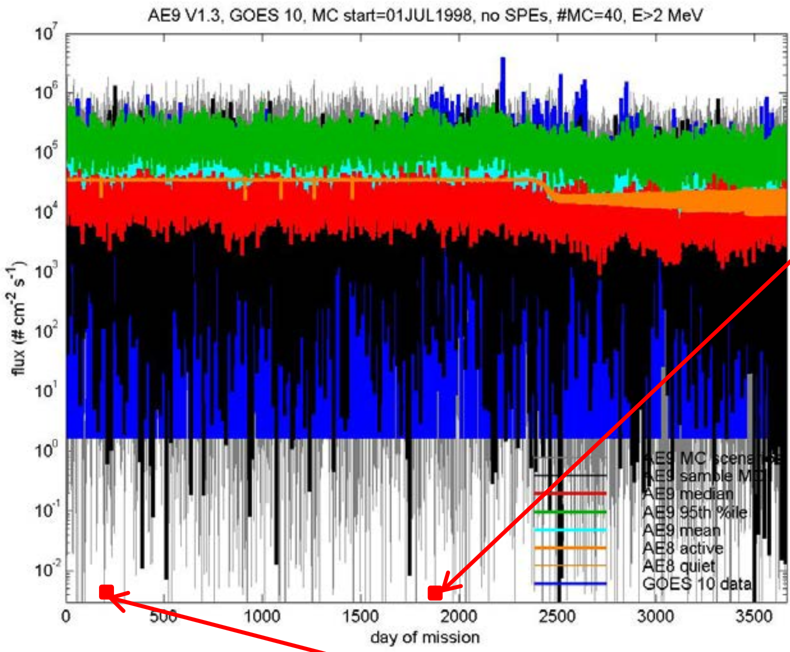
• GOES-observed high and low flux periods are within the ranges represented by AE9 Monte Carlo scenarios.

• GOES-observed fluence is similar to the AE9 median once most of a solar cycle is represented.

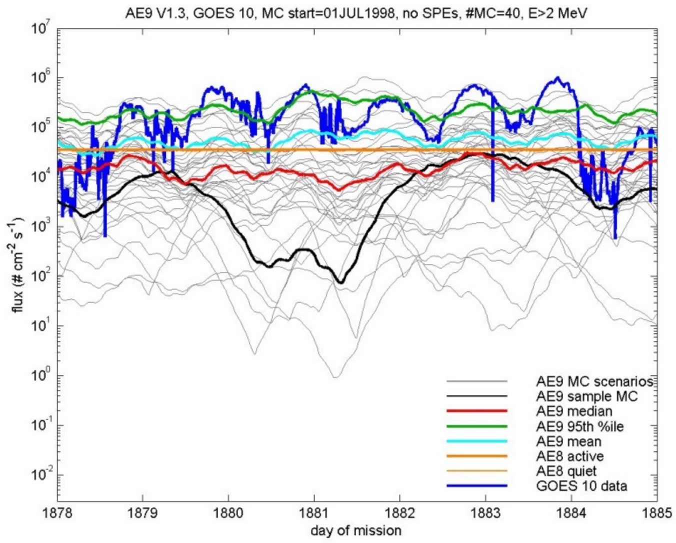
• Cumulative flux distribution observed by GOES is generally at the low side of AE9 results, but similar for the highest 20% of fluxes.

GOES electron time series

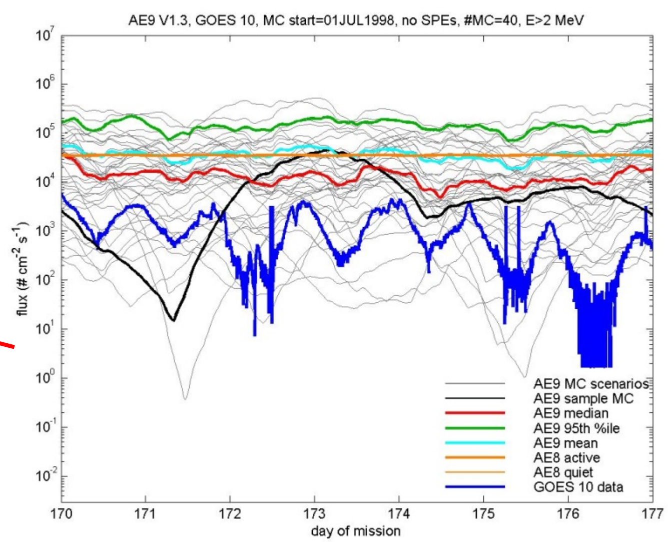
Ten years (1998 – 2008)



1 week (high flux period)



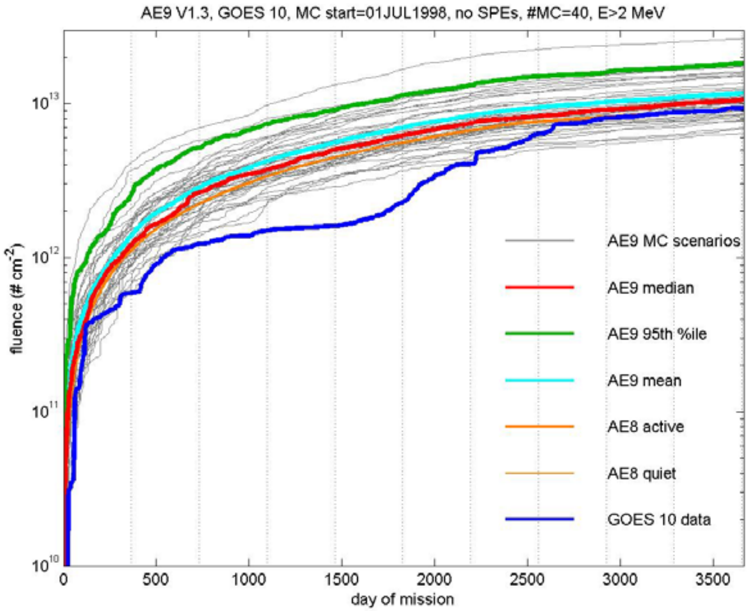
1 week (low flux period)



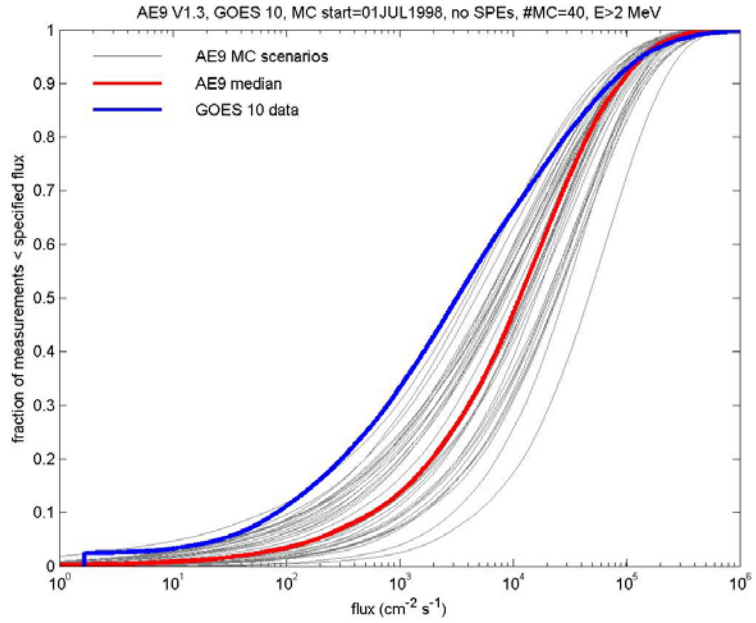
Distribution A

GOES electron fluence & cumulative distribution

Fluence - Ten years (1998 – 2008)



Cumulative flux distribution
- Ten years (1998 – 2008)



• GOES observed fluence is below AE9 results through 2003, but close to the AE9 median once most of a solar cycle has been observed. AE9 does not reproduce solar cycle phase, but it does represent the range of conditions observed through a full solar cycle.

Distribution A

DSP21/CEASE

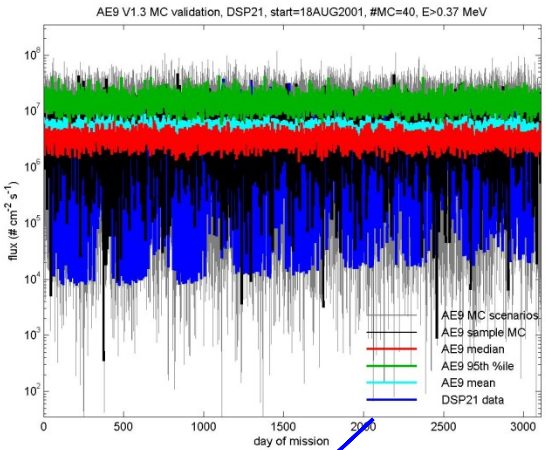
Summary:

- Short-term (1-30 day timescale) flux dynamics observed by DSP21 are comparable to those in AE9 Monte Carlo results.
- DSP21 observed fluence trends are similar to AE9 results and are very close to the AE9 median for most energy channels.
- Cumulative distribution of DSP21 observed fluxes are mostly comparable to AE9 Monte Carlo results.

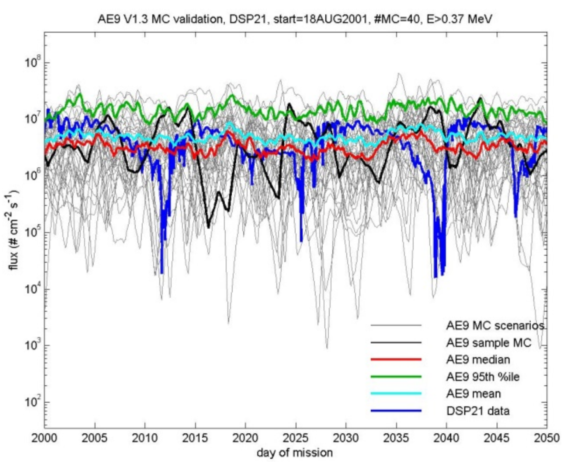
DPS21 electron time series

T03 > 0.37 MeV

10 years

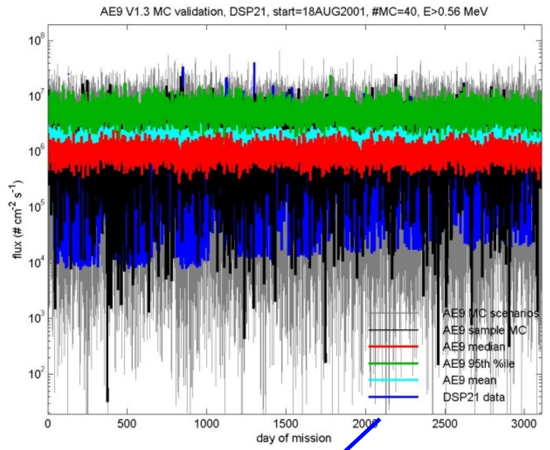


50 day

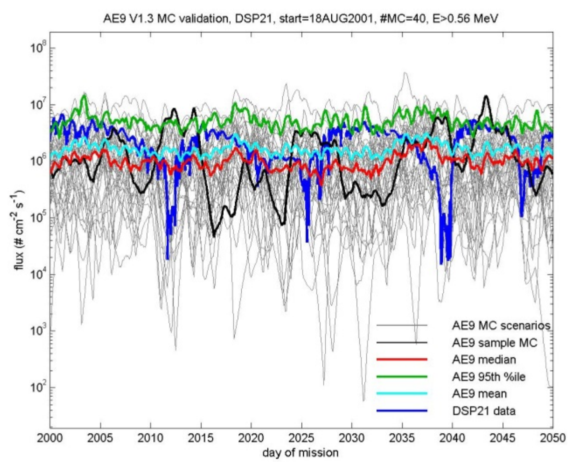


T04 > 0.56 MeV

10 years

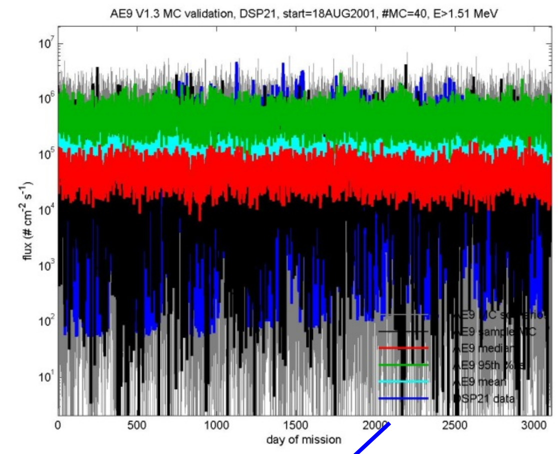


50 day

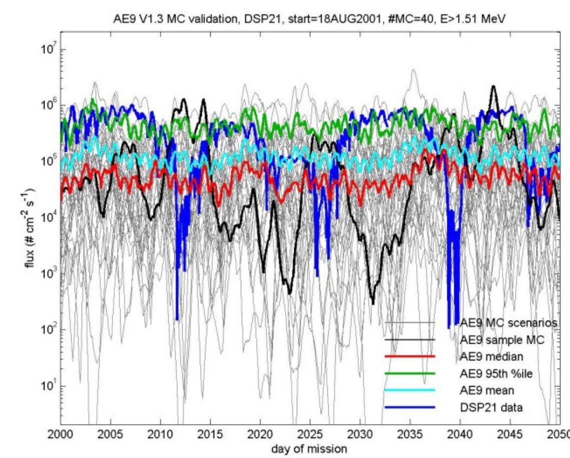


D01 > 1.51 MeV

10 years



50 day

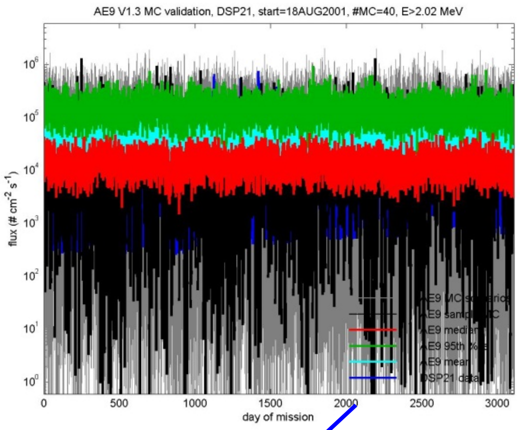


Distribution A

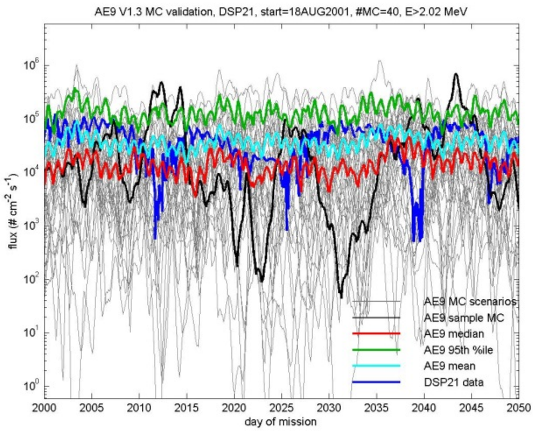
DPS21 electron time series

D03 > 2.02 MeV

10 years



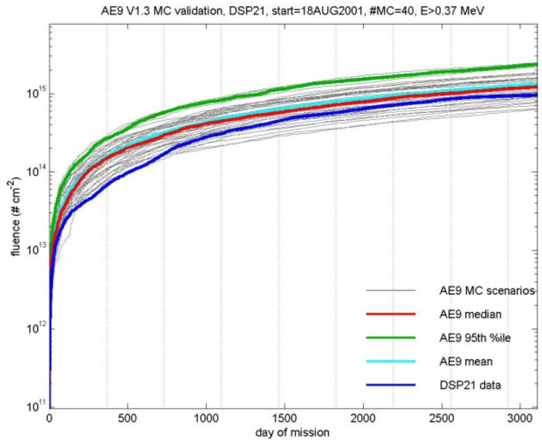
50 day

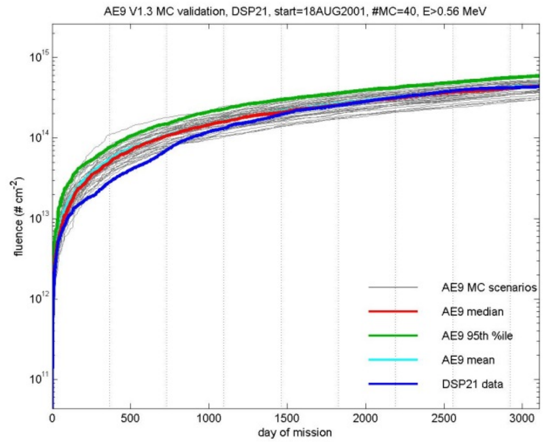


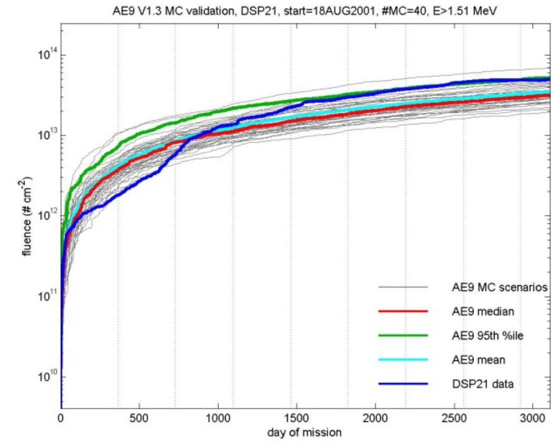
DPS21 electron fluence & cumulative distribution (9 years, 2001 - 2010)

T03 > 0.37 MeV | **T04 > 0.56 MeV** | **D01 > 1.51 MeV**

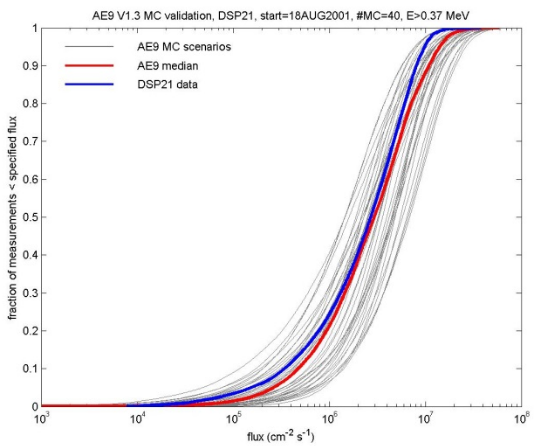
Fluence

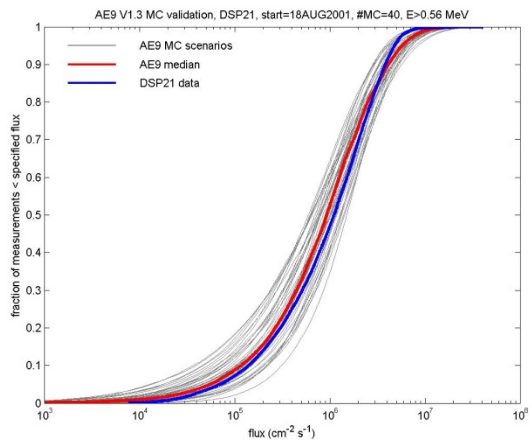


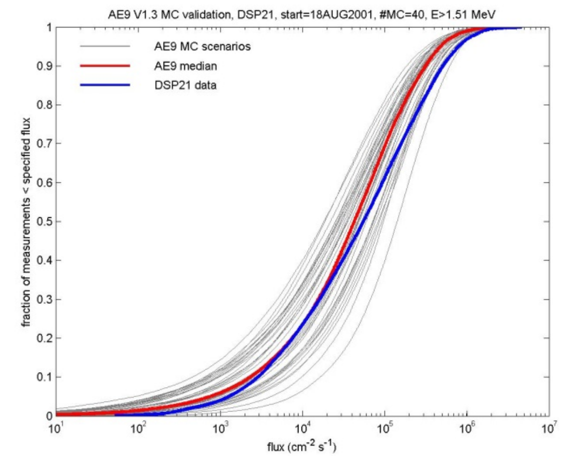




Cumulative flux distribution



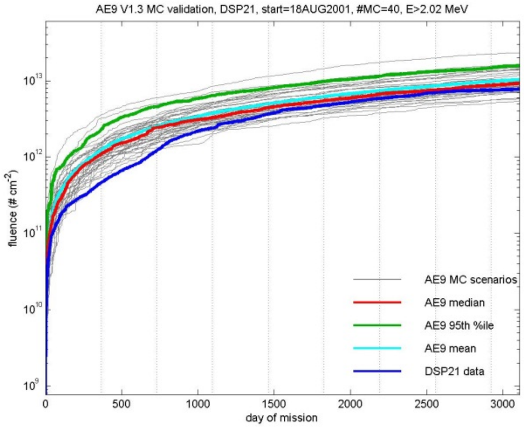




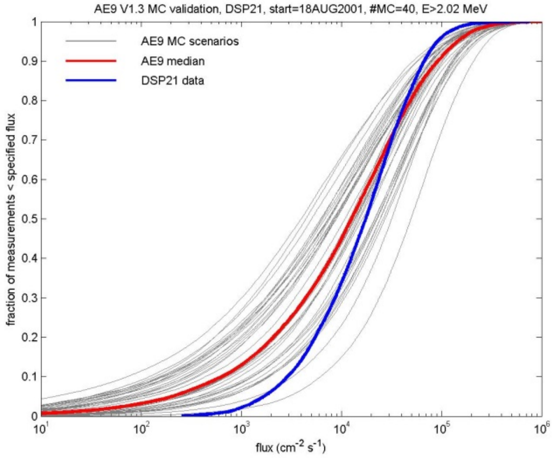
DPS21 electron fluence & cumulative distribution (9 years, 2001 - 2010)

D03 > 2.02 MeV

Fluence



Cumulative flux distribution



Distribution A

TACSAT4/CEASE

Summary:

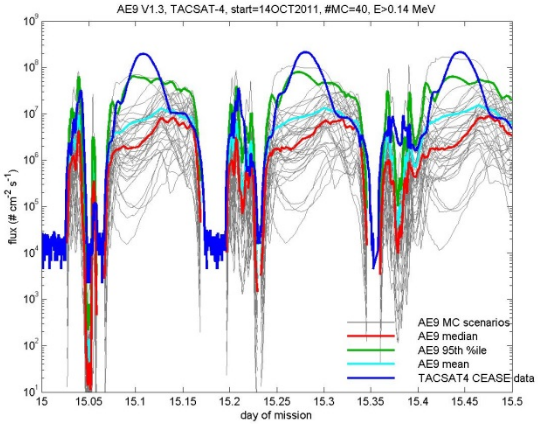
- Short timescale samples of flux vs. time observations from TacSat-4 fall within the ranges of AE9 Monte Carlo runs.
- TacSat-4 fluence results for 75 days are near the AE9 Monte Carlo median for two energy channels, near the 95^{th} percentile for three channels, and at the low end of Monte Carlo results for two channels.

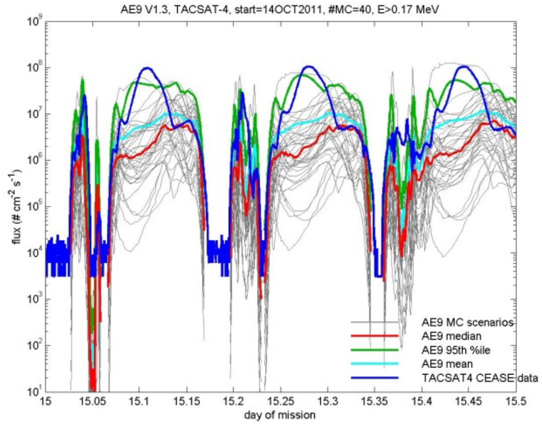
TACSAT-4/CEASE electron flux time series and fluence

Flux

T01 > 0.14 MeV

T02 > 0.17 MeV

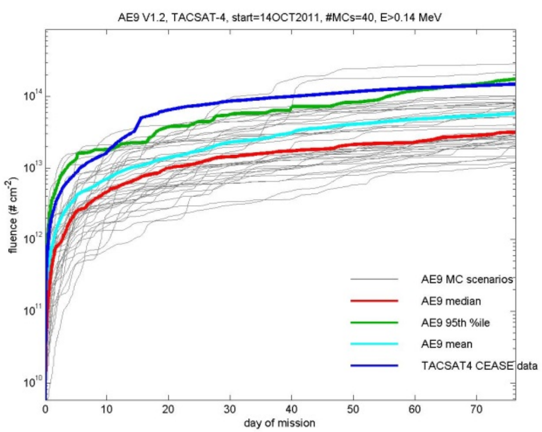


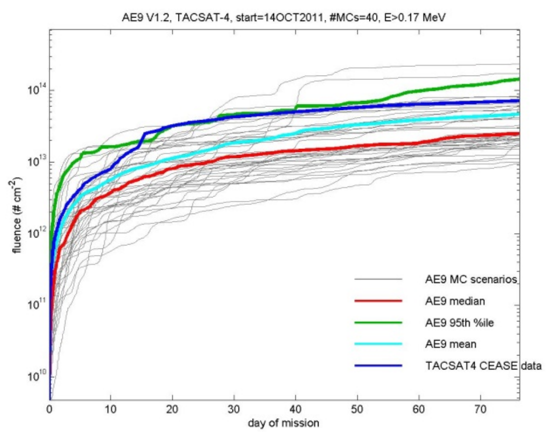


Fluence

T01 > 0.14 MeV

T02 > 0.17 MeV



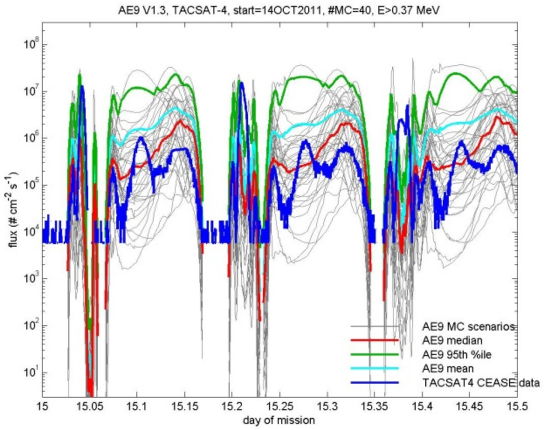


Distribution A

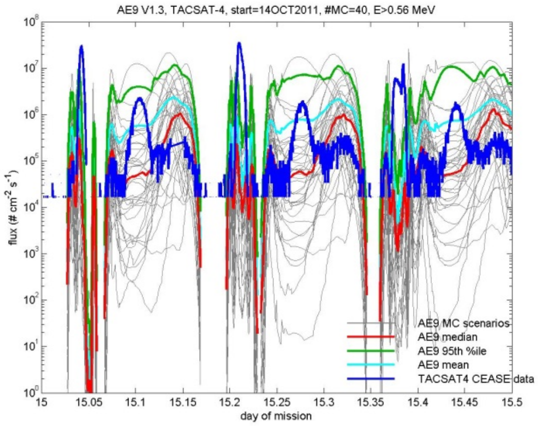
TACSAT-4/CEASE electron flux time series and fluence

Flux

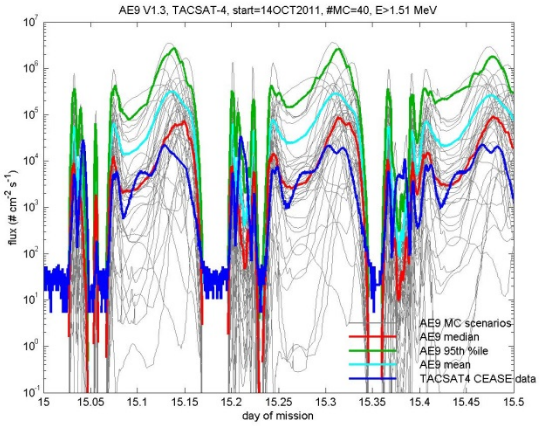
T03 > 0.37 MeV



T04 > 0.56 MeV

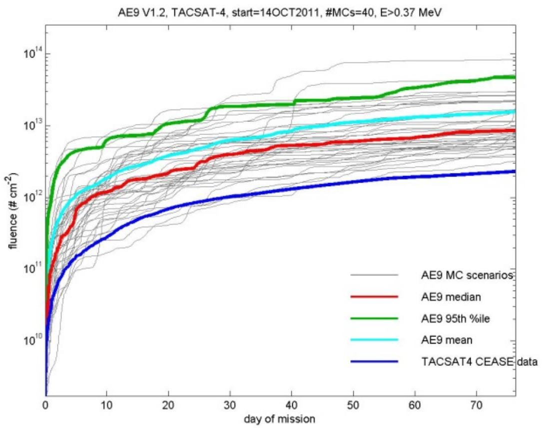


D01 > 1.51 MeV

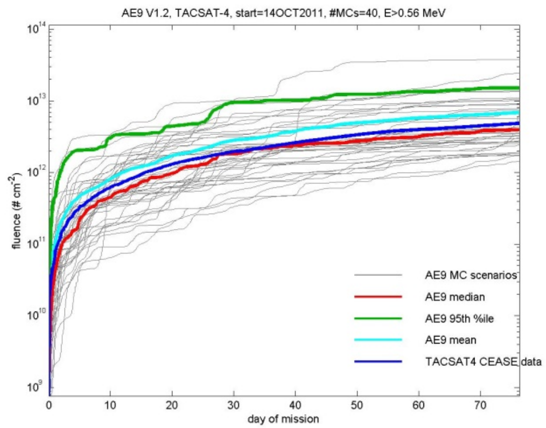


Fluence

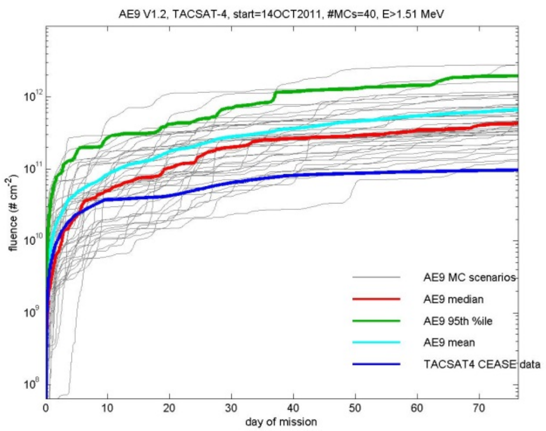
T03 > 0.37 MeV



T04 > 0.56 MeV



D01 > 1.51 MeV

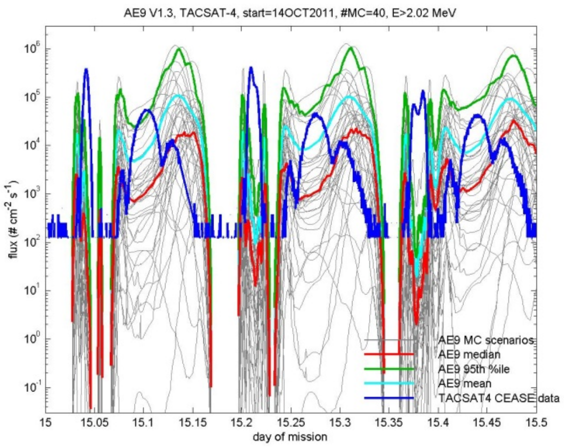


Distribution A

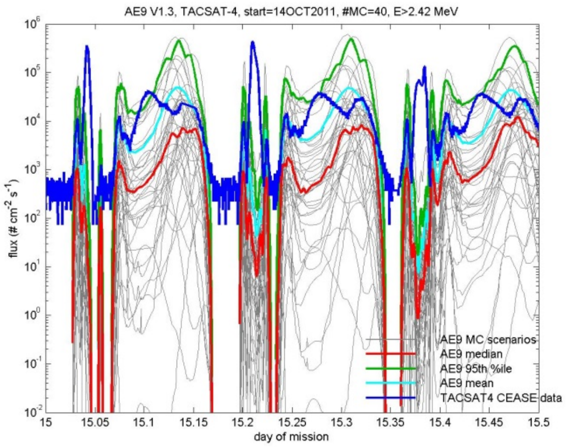
TACSAT-4/CEASE electron flux time series and fluence

Flux

D03 > 2.02 MeV

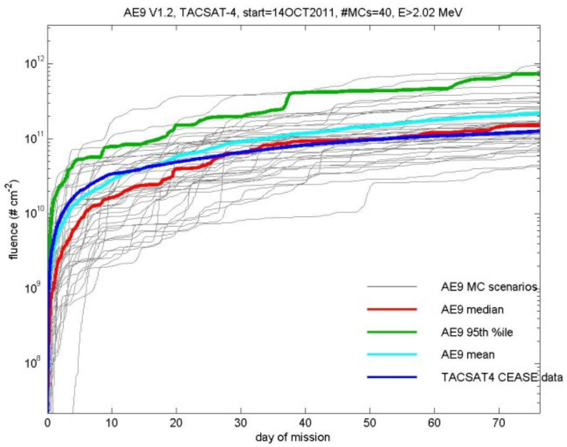


D02 > 2.42 MeV

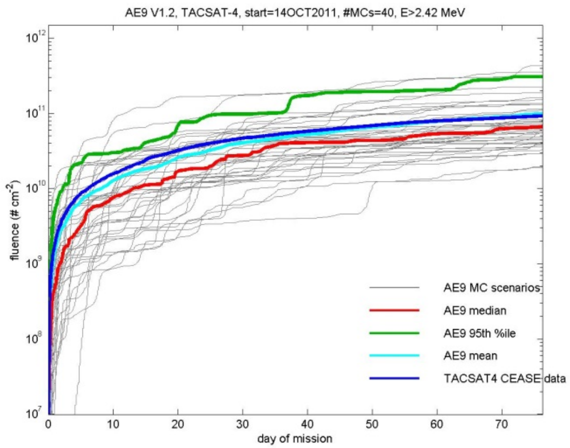


Fluence

D03 > 2.02 MeV



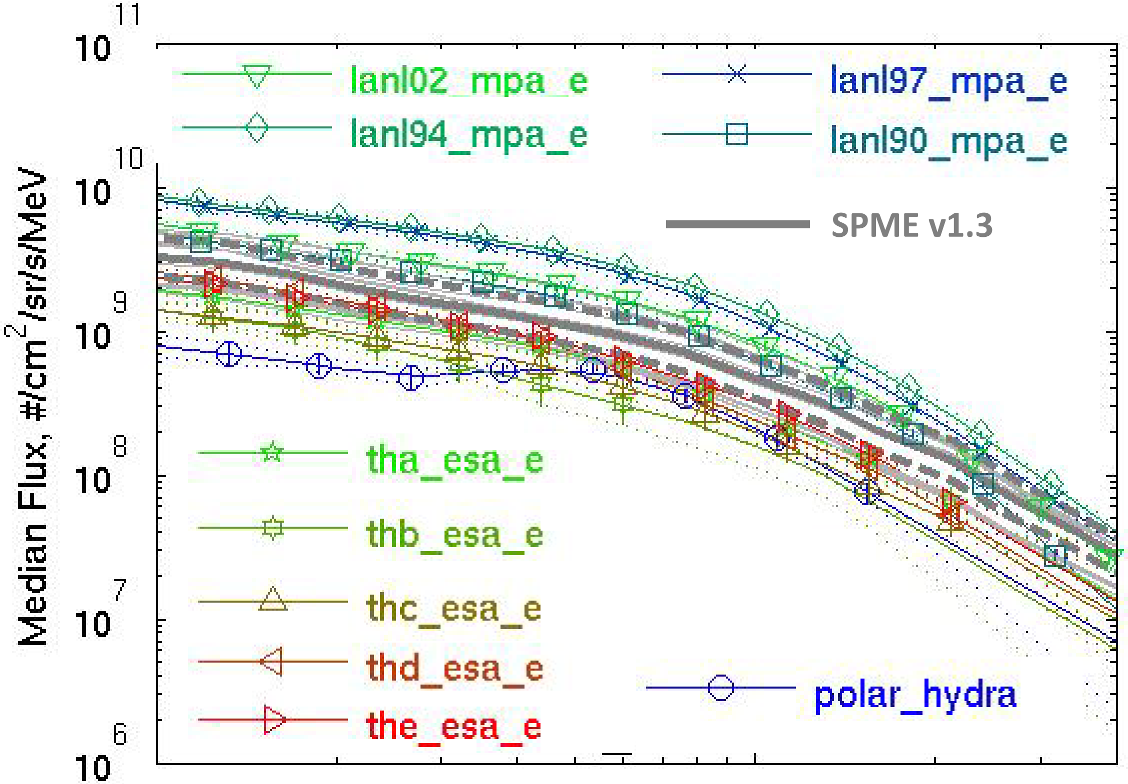
D02 > 2.42 MeV



Comments on Model/Data Comparisons

Model Error Bars versus Data Sets

Median and 1-s for each data set and the model



Electron Plasma Model (SPME), v1.3
L_m=7, a=35 (i2=4, i3=11, ired=88, ifull=94)

- The data sets spread over about a factor of 10.
- The model error is about a factor of 3.
- The model error is *small* because there are many data sets.
- If the model error covered the spread of the data *it would never shrink no matter how many data sets we added.*
- The model error bars are designed so that a model update with a new data set will still fall within the error bars of the prior model release.

<u>We do not expect any individual data set to fall within the model error bars.</u>

Distribution A