# Air Force Research Laboratory


*Integrity ★ Service ★ Excellence*

# AE9 V1.50.001 Model Validation Summary Report

**28 September 2017**

**AE9/AP9/SPM Development Team**

**DISTRIBUTION A: Approved for public release; distribution unlimited. OPS-17-14998**

AFRL

# AE9 V1.50.001 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 |
| TACSAT-4 | 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.



Distribution A

# POES N15/SEM

*POES N15 data processing:*

- Electron channel fluxes are derived using geometric factors from Evans and Greer (2007), POES SEM-2 Instrument Description [https://ngdc.noaa.gov/stp/satellite/poes/docs/NGDC/MEPED%20telescope%20processing%20ATBD_V1.pdf].
- Fluxes from the two look directions for electron channels are averaged to compare to AE9 omnidirectional fluxes (see next page).

*Summary:*

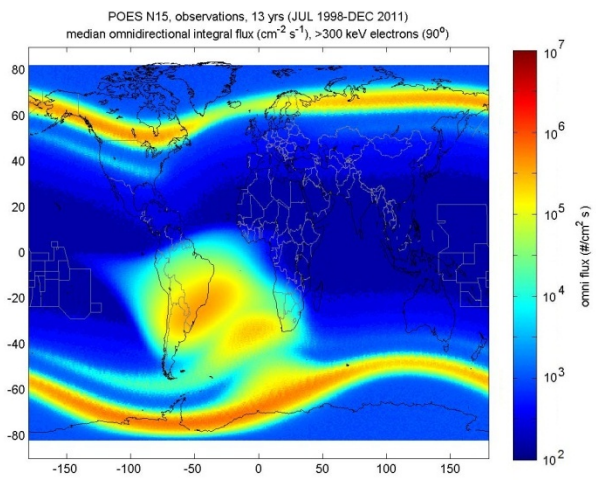
- Outer belt electrons at high latitudes are similar in intensity and structure in AE9 and POES data, apart from the latitudinal extent being more narrow in AE9.
- AE9 mean and 95th CL are more intense near SAA than POES data, and AE9 does not reproduce the multipeaked inner zone structure seen in POES data, likely representing look direction limitations and proton contamination in SEM data.
- Range of AE9 Monte Carlo fluence results is similar to solar cycle variation of POES data, although the median in AE9 is higher than in POES data.



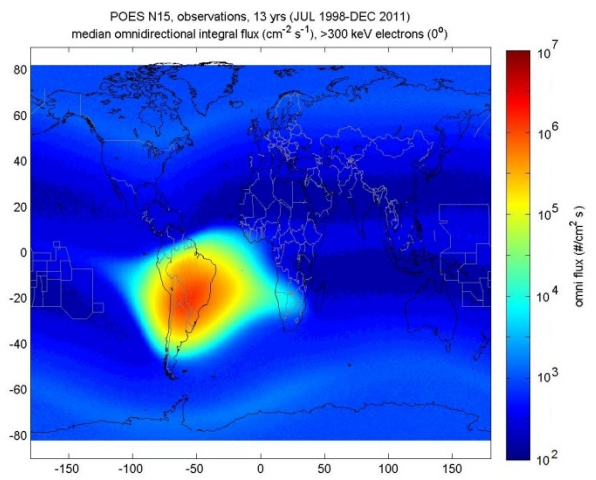
Distribution A

# POES 0 deg & 90 deg electron channels

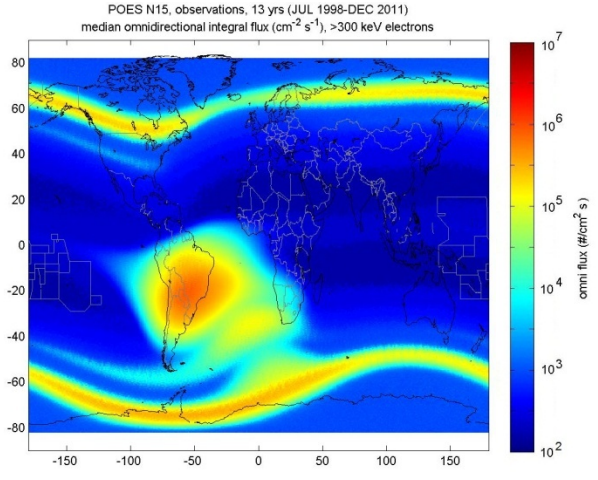
## POES N15, 13 years, 1998 - 2011




**90 deg**




**0 deg**




**ave (90 deg + 0 deg)**

## Large dependence on look angle

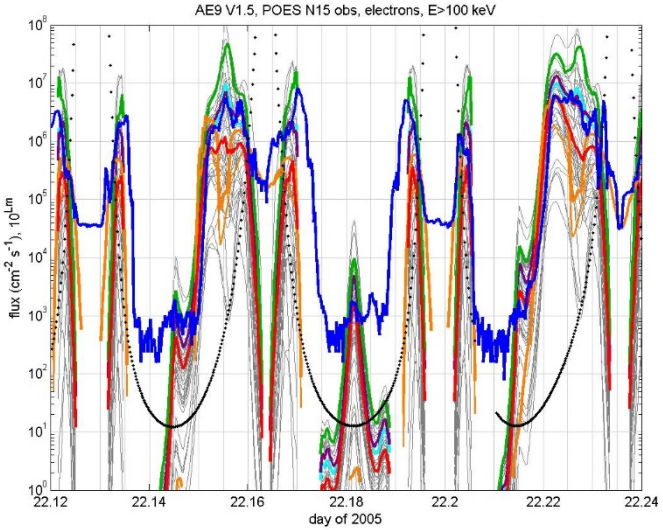
- POES MEPED electron channels have 30° field of view: one pointed toward local zenith (0°), other toward horizon opposite ram direction (90°).
- Both channels are significantly contaminated by protons in SAA.
- For validation results presented here, the average of the two channels is used for comparison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

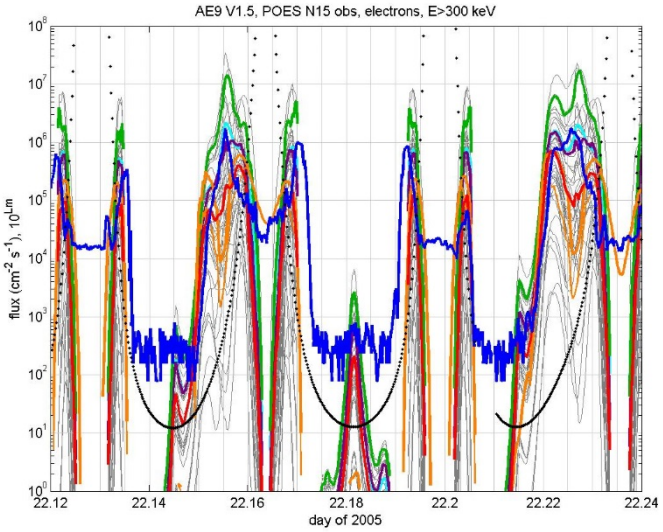


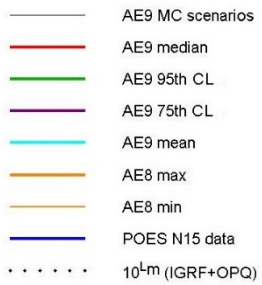
Distribution A

# POES time series (electrons)

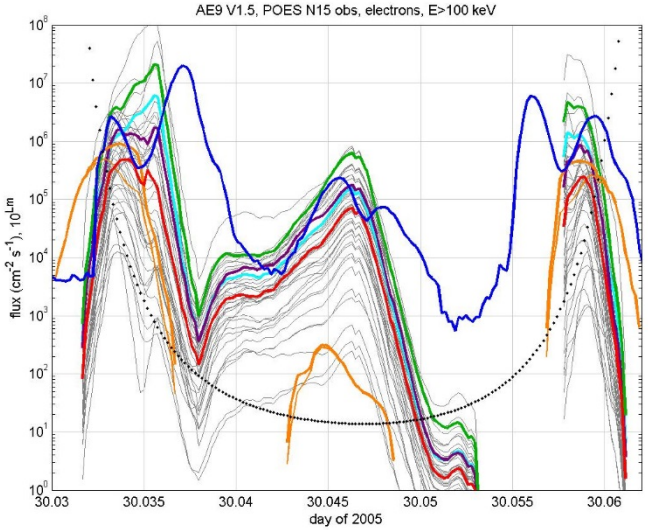
## Several orbits

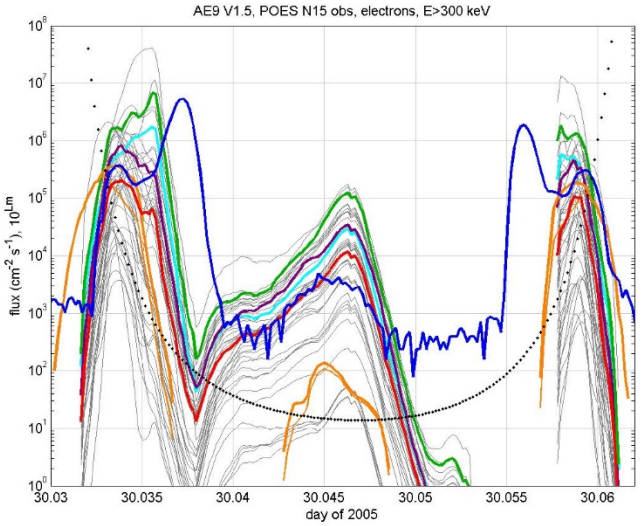



## One orbit



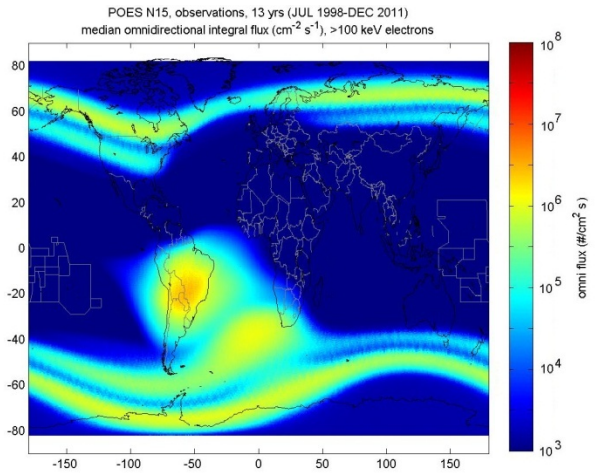



Distribution A

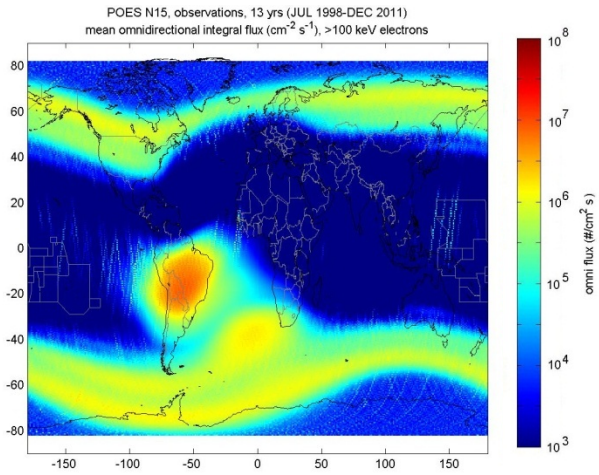
# POES > 0.1 MeV electrons

## POES N15 – 13 years, 1998 - 2011

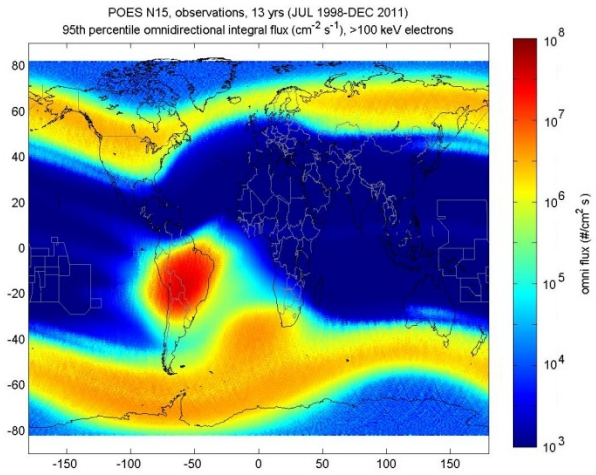
### Median



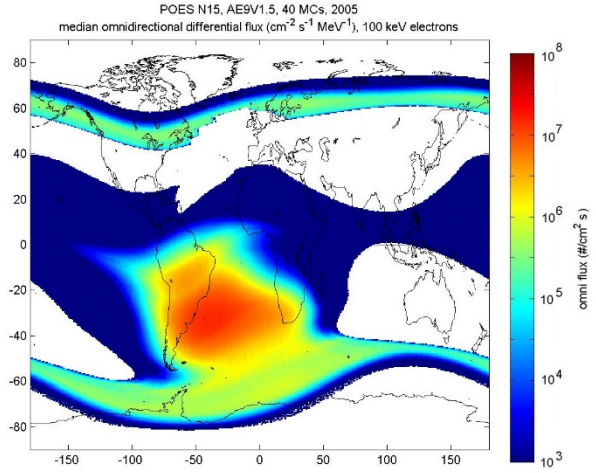

### Mean

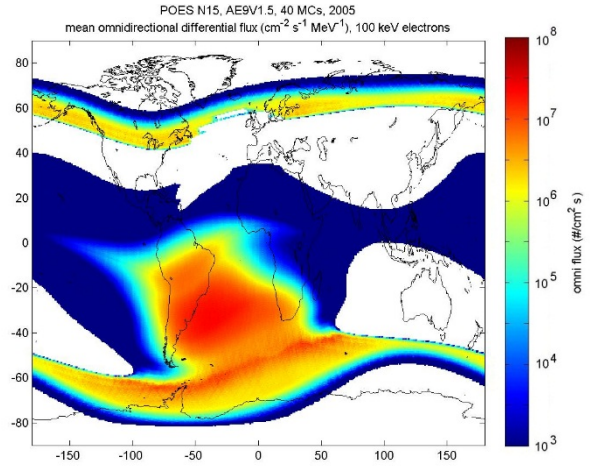


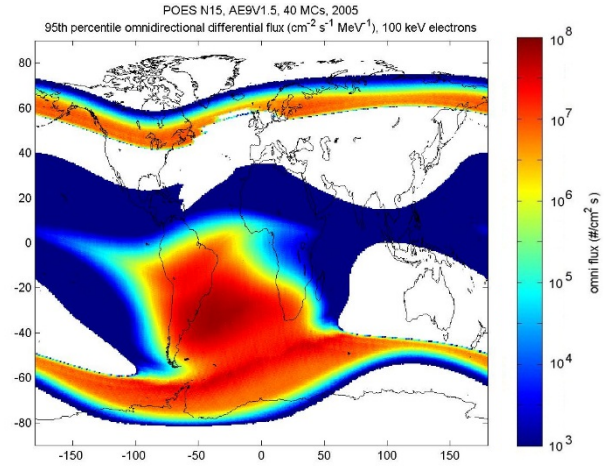

### 95th percentile




## AE9 V1.50 Monte Carlo – 1 yr (2005)



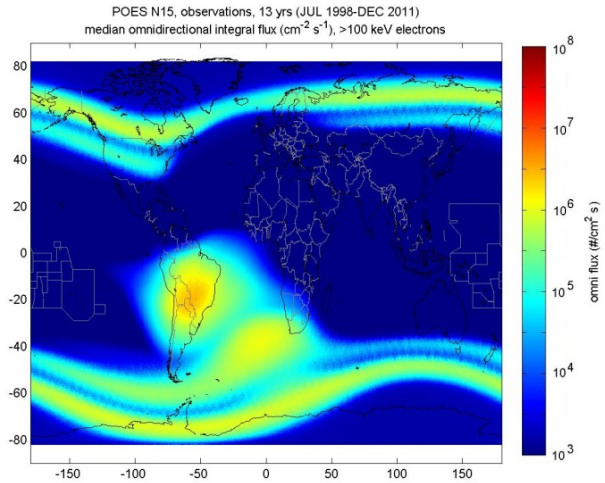



Distribution A

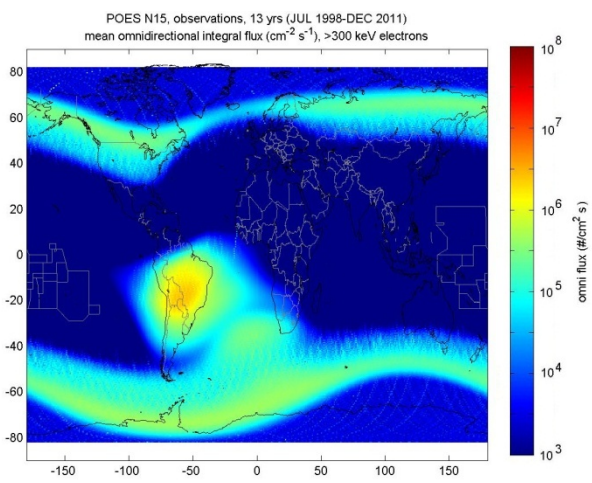
# POES > 0.3 MeV electrons

## POES N15 – 13 years, 1998 - 2011

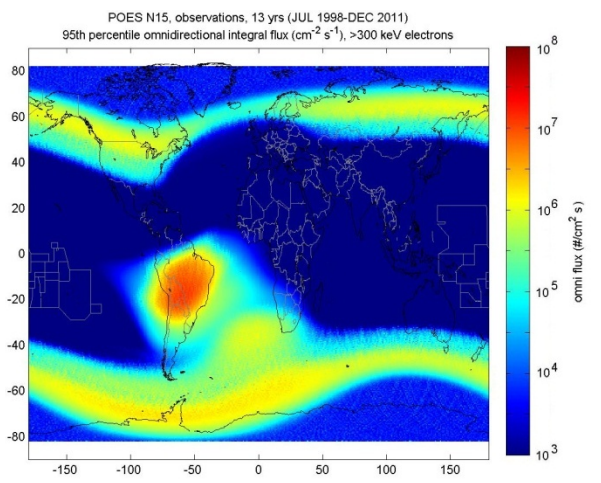
### Median



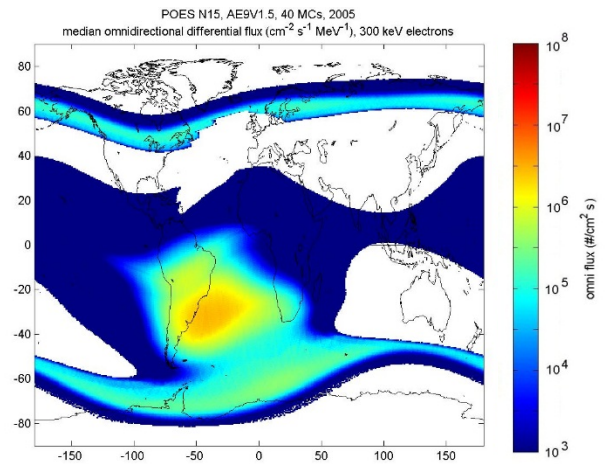

### Mean

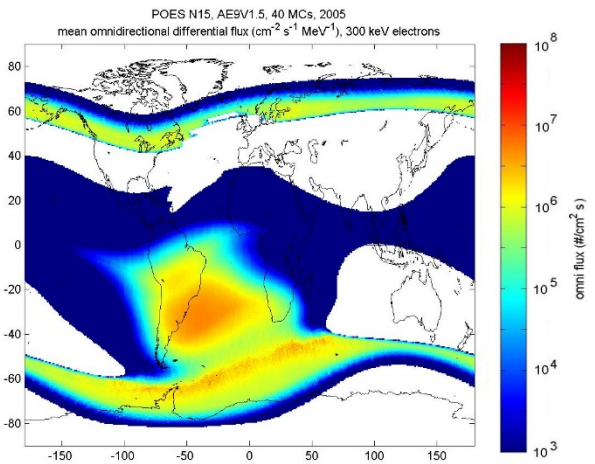


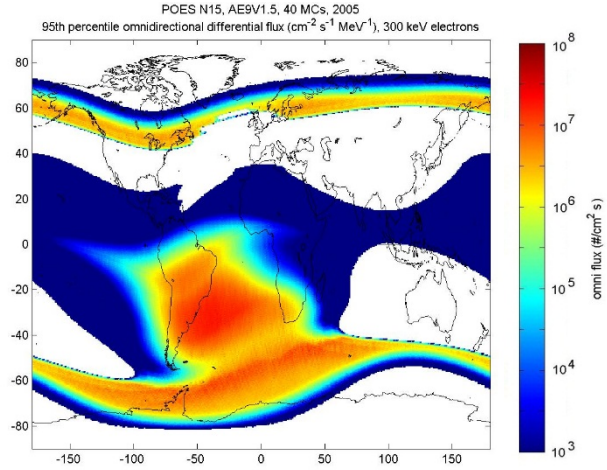

### 95th percentile




## AE9 V1.50 Monte Carlo – 1 yr (2005)



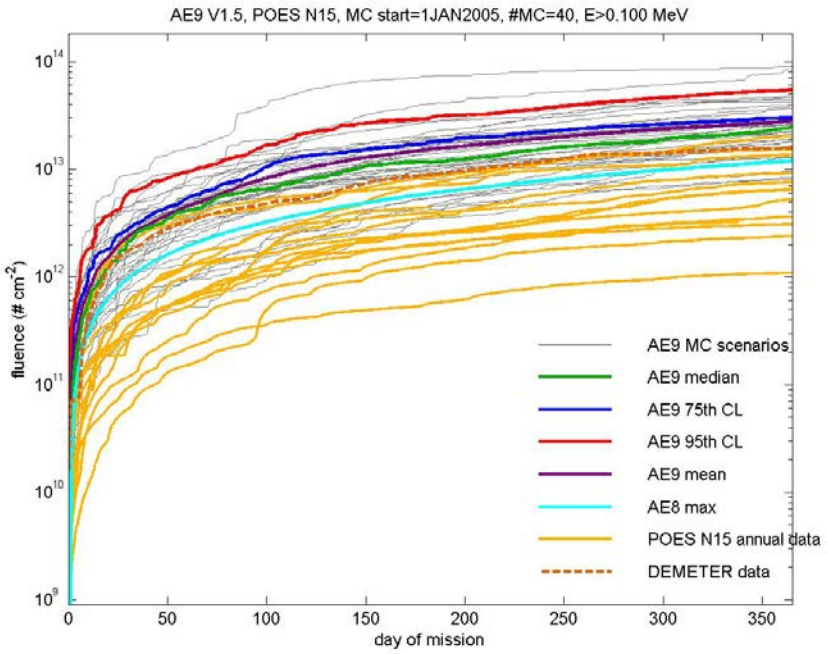



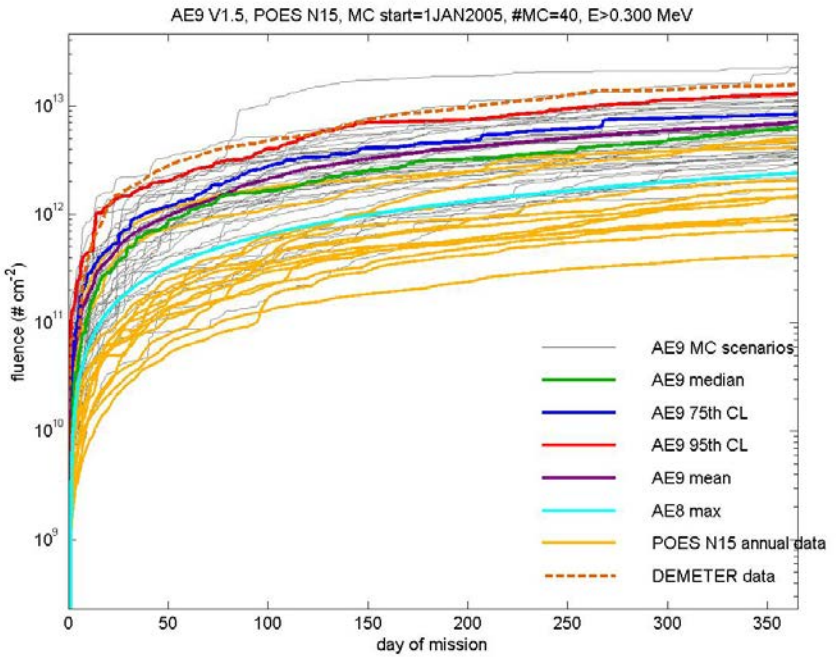






Distribution A

# POES electron fluence – 1 yr for each of 13 years



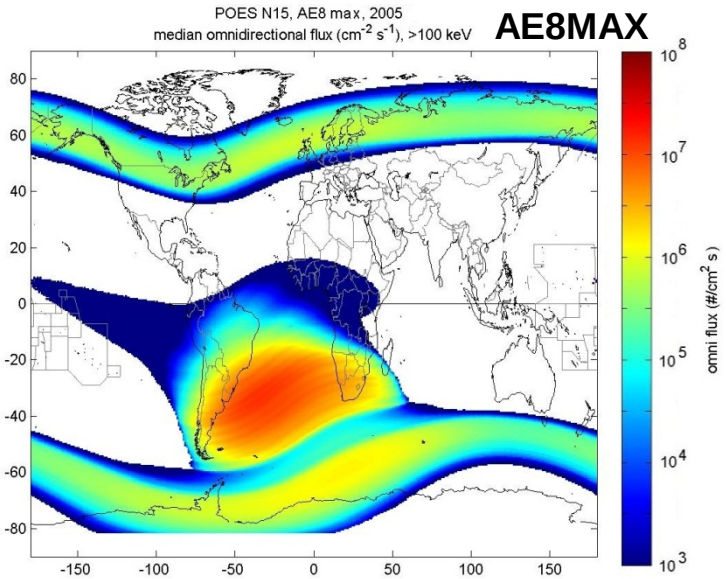

- Median of AE9 V1.50 MC results is at the high end of POES annual results.
- Range of AE9 MC results is comparable to range of individual yearly results from POES—POES range mostly results from solar cycle variation.

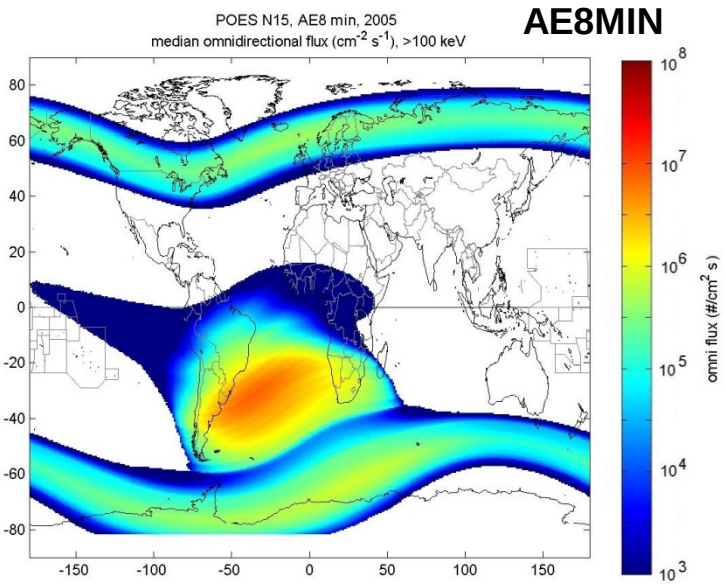


Distribution A

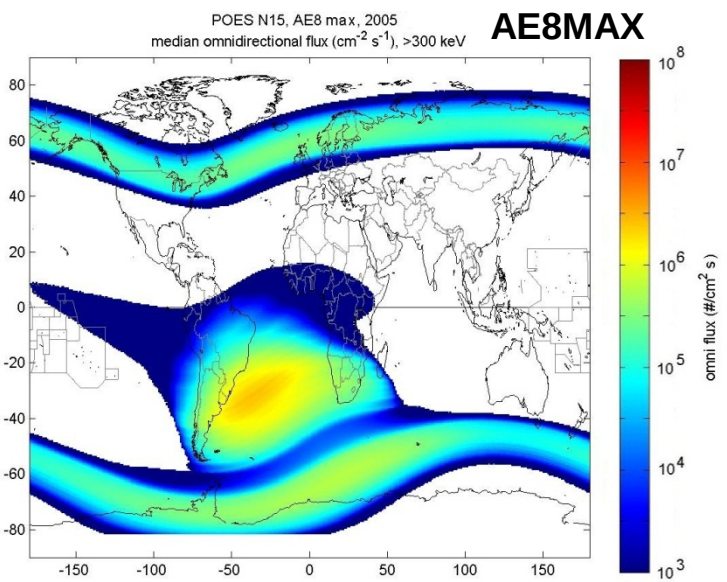
# POES — AE8

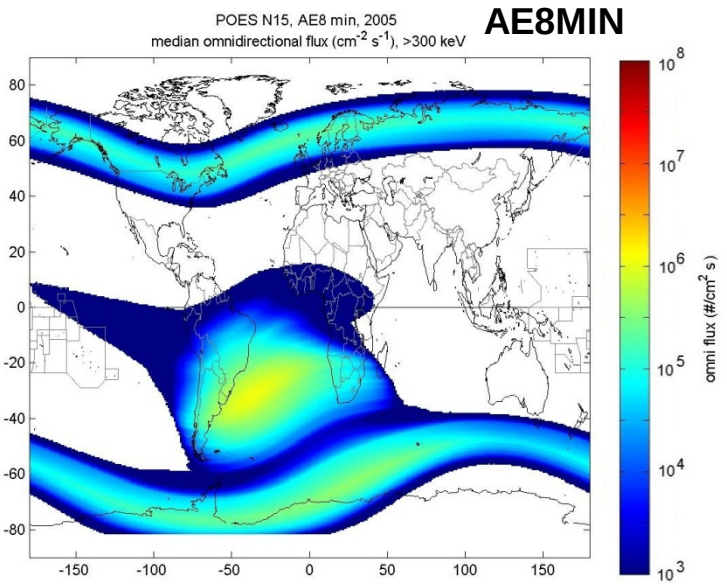
## > 0.100 MeV




## > 0.300 MeV






Distribution A

# DEMETER/IDP

*DEMETER data processing:*

- Electron differential channel data were provided by J.-A. Sauvaud (see Sauvand et al. (2006), *Planetary & Sp. Sci.*, 54:502-511), with a subset of differential channels used here.
- Electron integral channel fluxes were obtained by integrating differential channel fluxes from the stated threshold energy up to 0.8 MeV.

*Summary:*

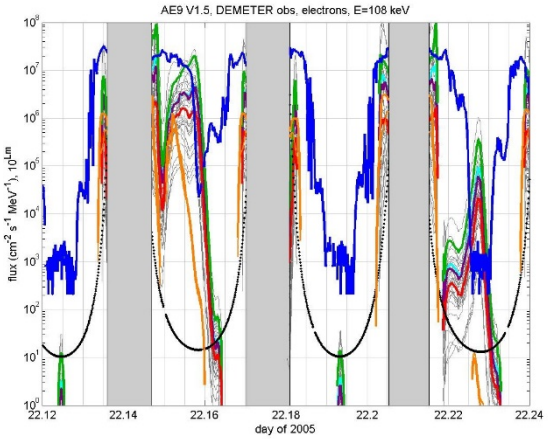
- Outer belt electrons at high latitudes are similar in intensity and structure in AE9 and DEMETER data, including similar latitudinal extent at energies other than 0.1 MeV.
- The geographic extent of inner zone/SAA electrons is similar in AE9 and DEMETER data, while the intensity is higher in AE9.
- Annual fluence results from DEMETER data (six years) show less variability than AE9 Monte Carlo results at 0.1 MeV, but are somewhat comparable at energies from 0.2 – 0.8 MeV.



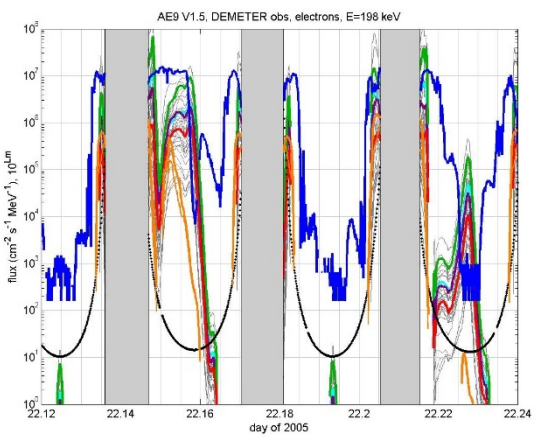
Distribution A

# DEMETER electron time series (~ 1.5 orbits)

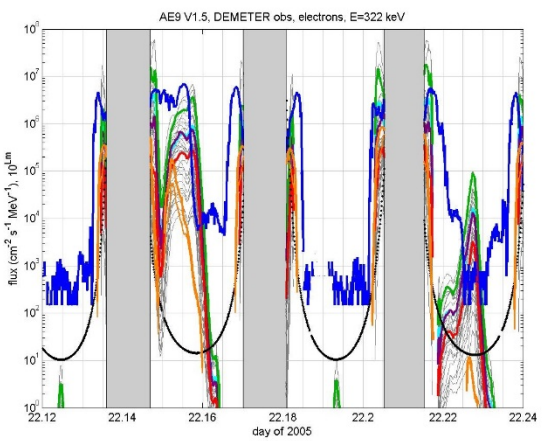
**0.108 MeV**



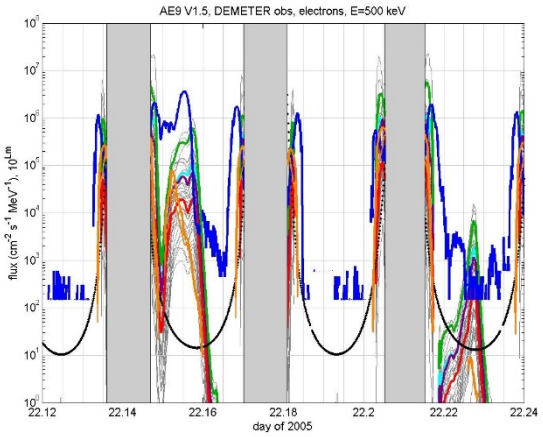

**0.198 MeV**



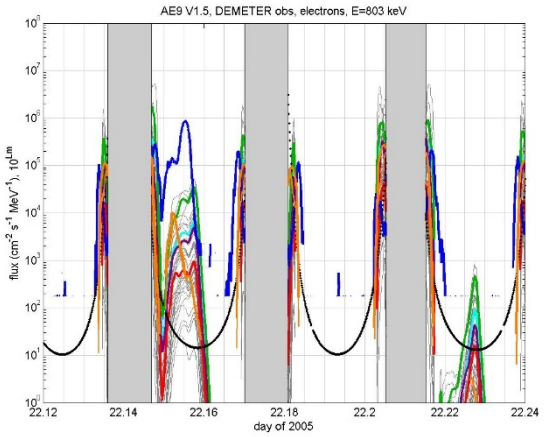

**0.322 MeV**

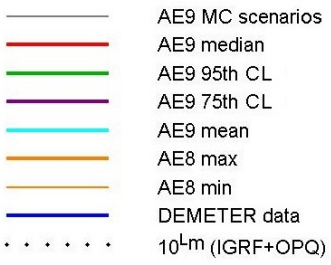



**0.500 MeV**




**0.803 MeV**




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

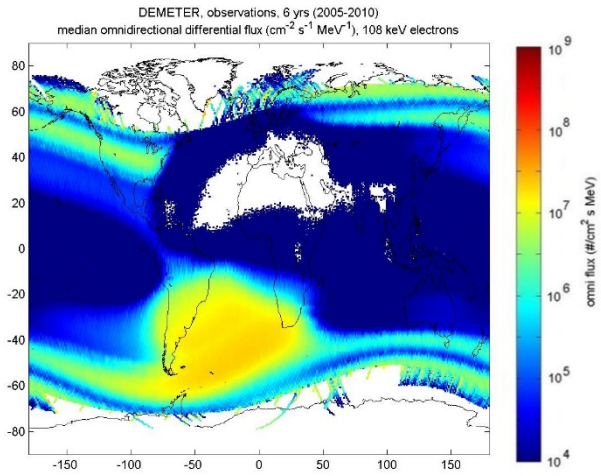


Distribution A

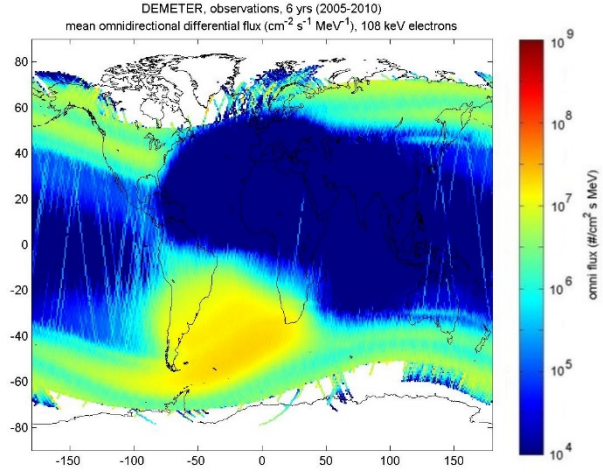
# DEMETER 0.108 MeV electrons

## DEMETER - 6 yrs (2005 – 2010)

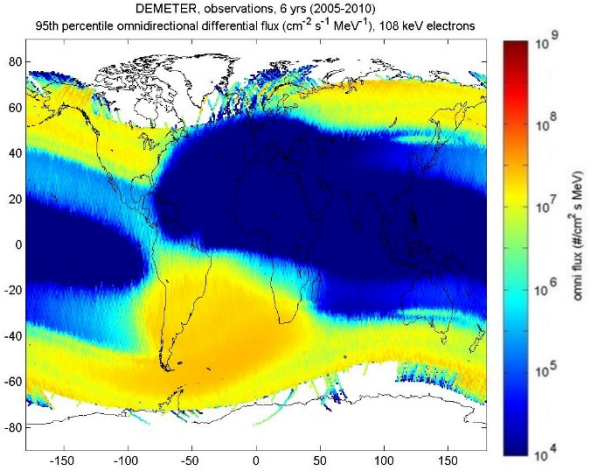
### Median



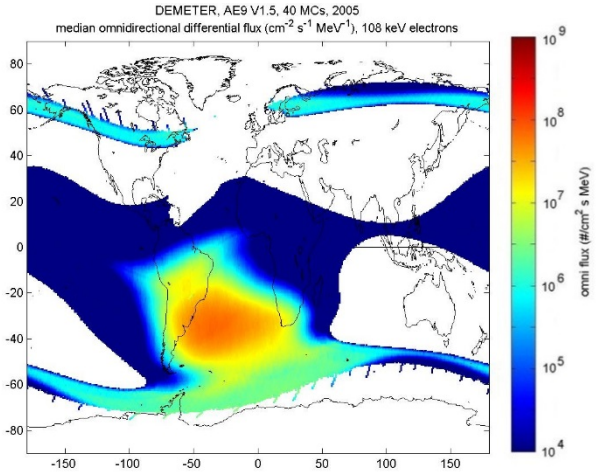

### Mean

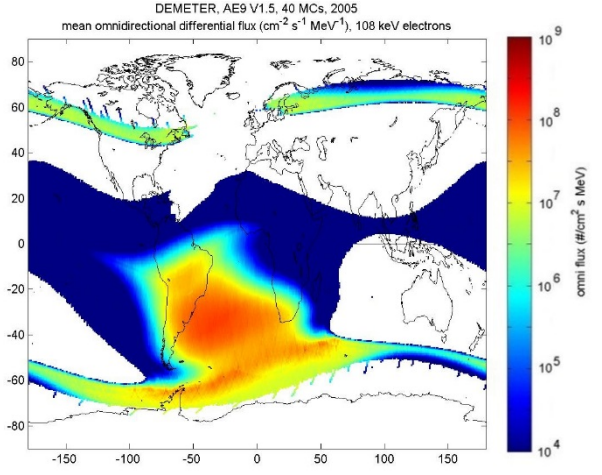


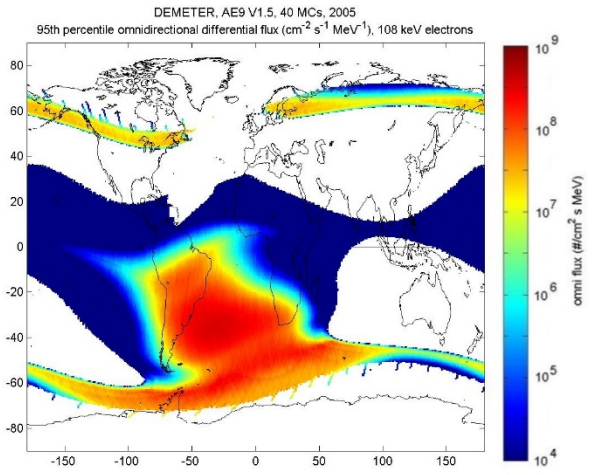

### 95th percentile




## AE9 V1.50 Monte Carlo - 1 yr (2005)



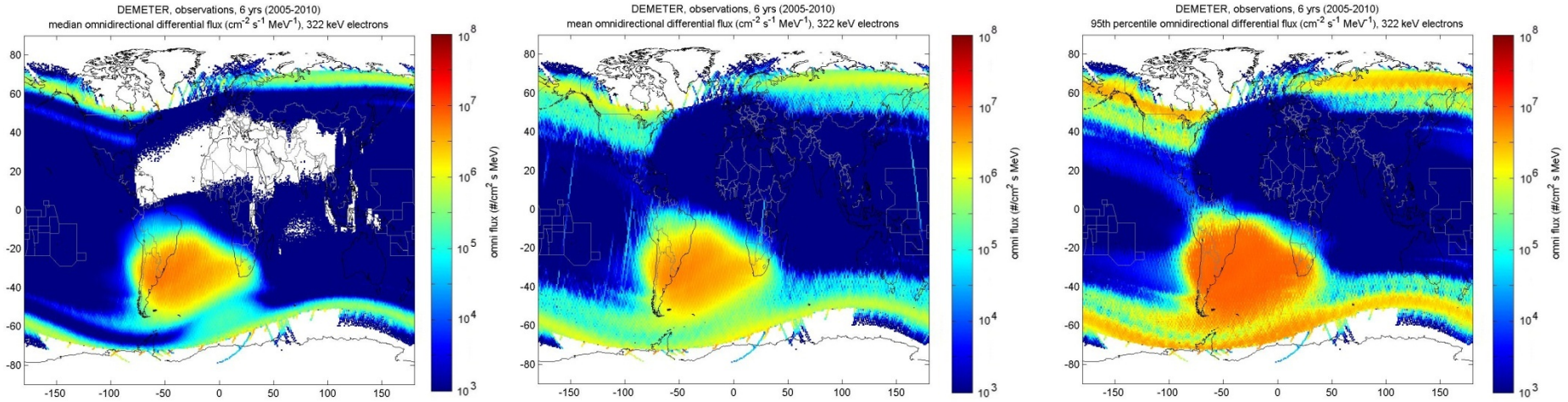



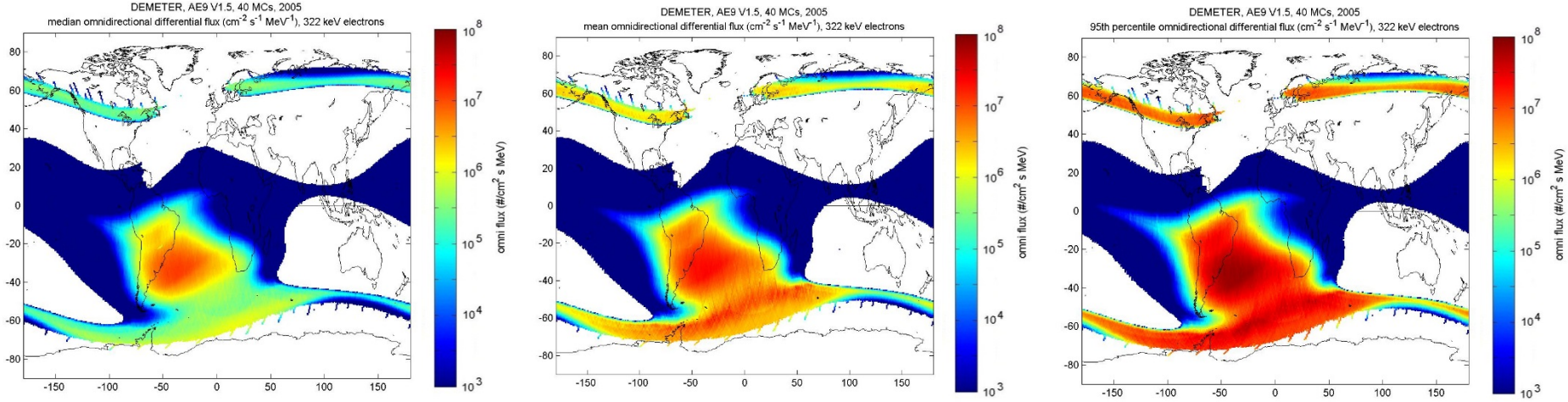
# DEMETER 0.322 MeV electrons

## DEMETER - 6 yrs (2005 – 2010)

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




## AE9 V1.50 Monte Carlo - 1 yr (2005)



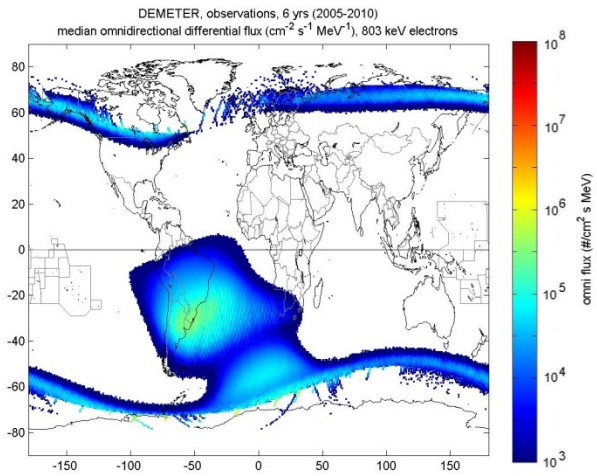


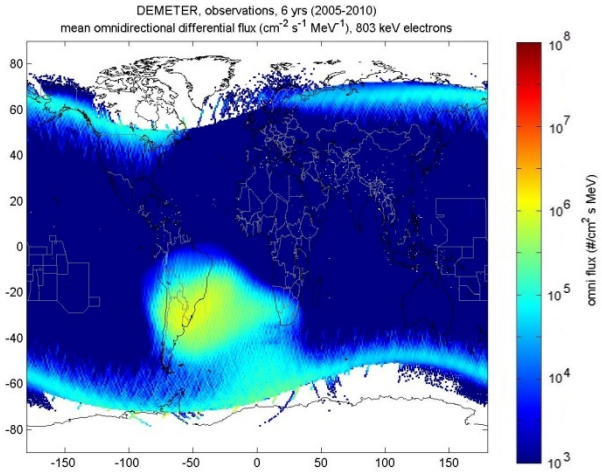

Distribution A

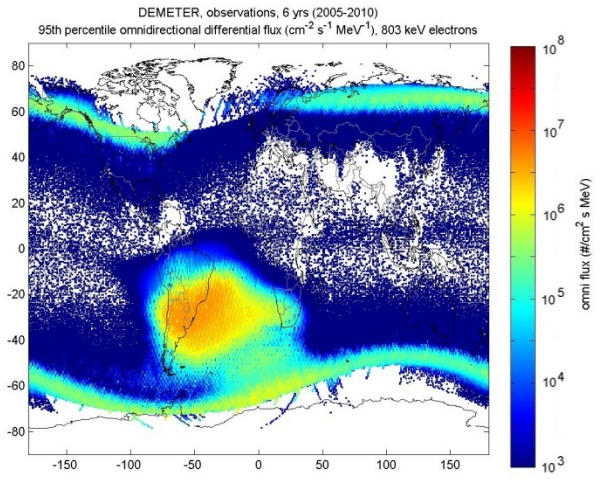
# DEMETER 0.803 MeV electrons

## DEMETER - 6 yrs (2005 – 2010)

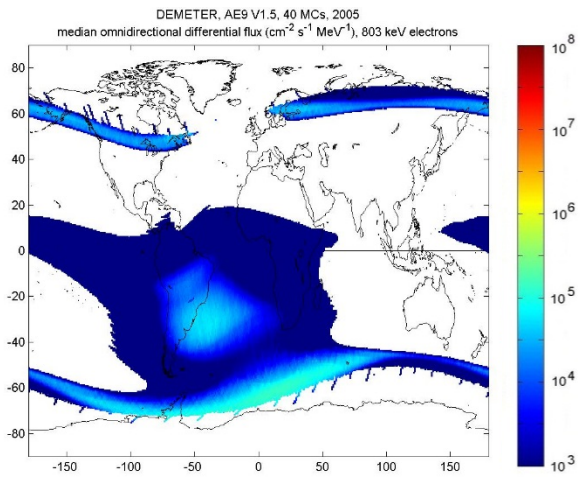
**Median** | **Mean** | **95th percentile**

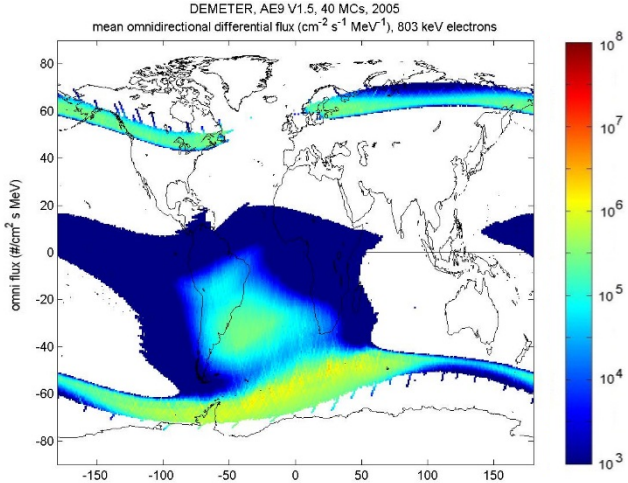


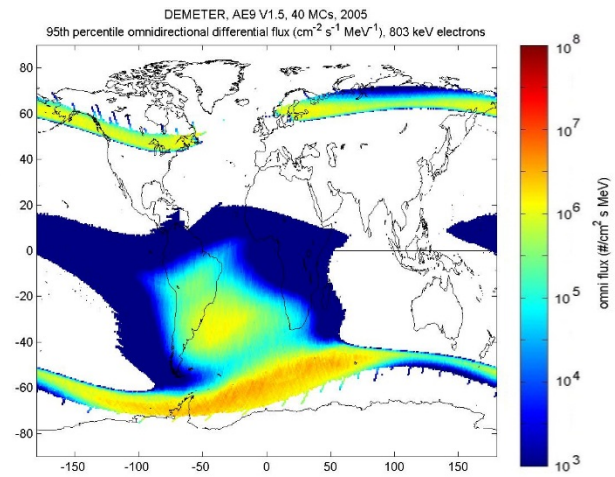




## AE9 V1.50 Monte Carlo - 1 yr (2005)



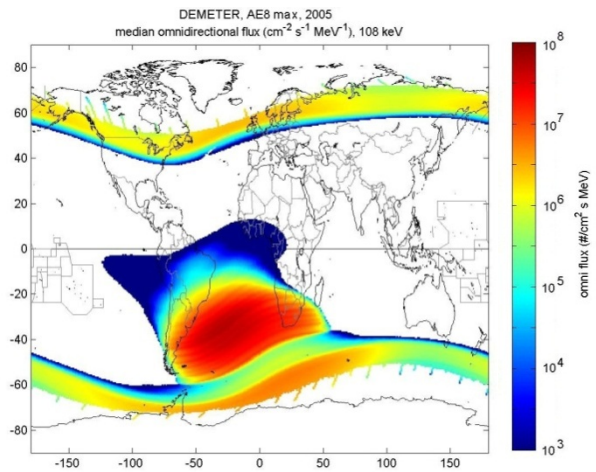



Distribution A

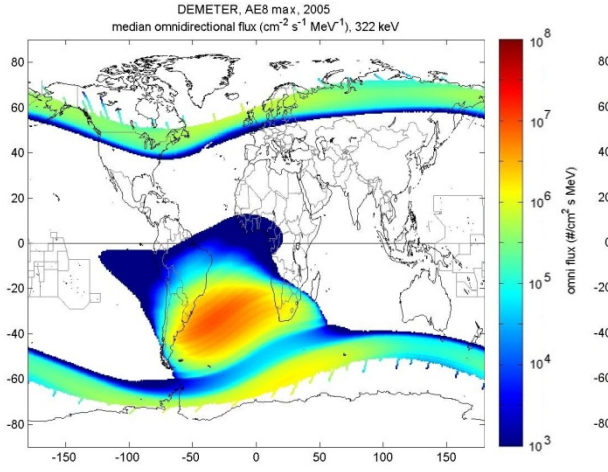
# DEMETER electrons (2005)

## AE8MAX

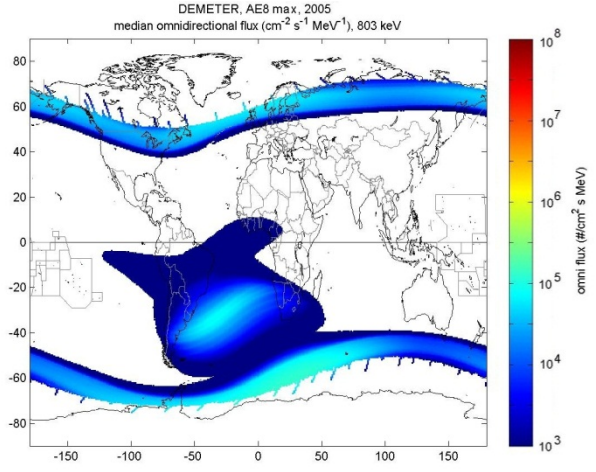
### 0.108 MeV




### 0.322 MeV

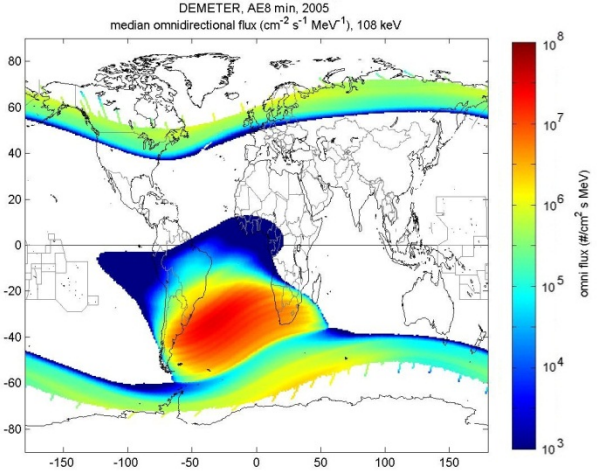



### 0.322 MeV

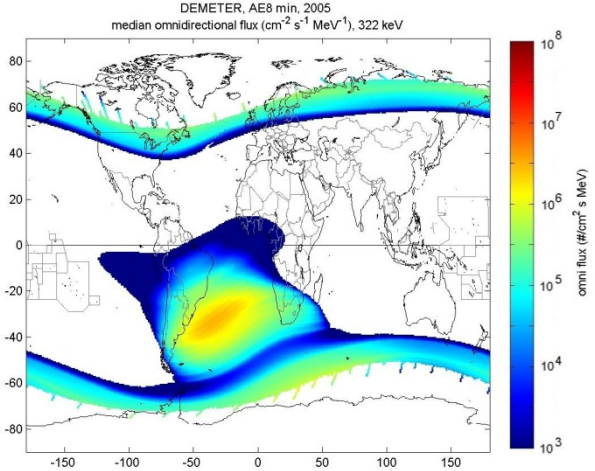



## AE8MIN

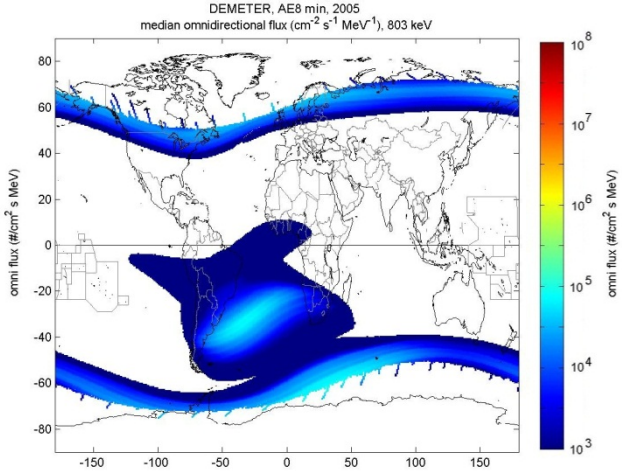
### 0.108 MeV




### 0.198 MeV




### 0.322 MeV

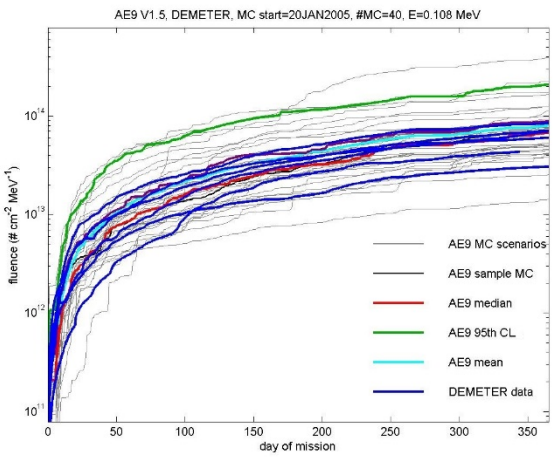




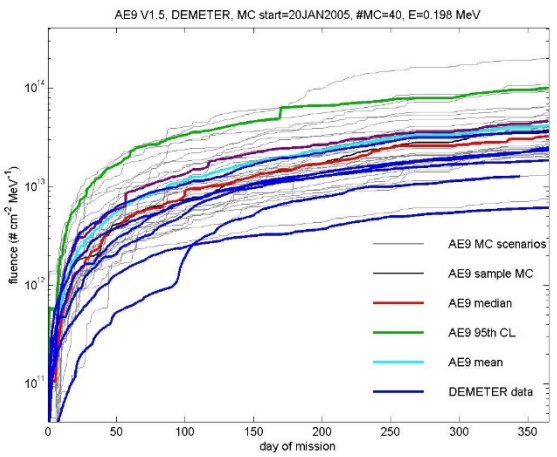

Distribution A

# DEMETER electron fluence - 1 yr for each of 6 years

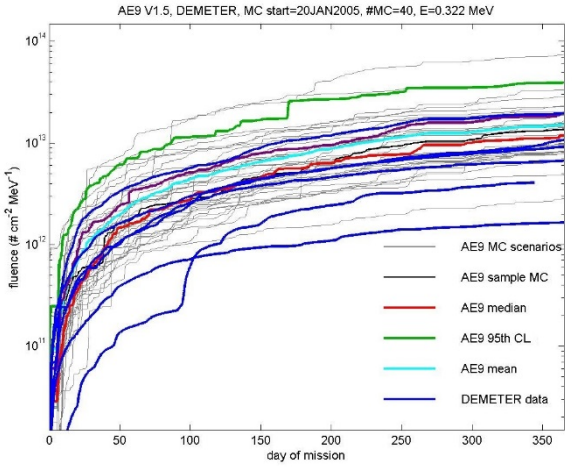
**0.108 MeV**



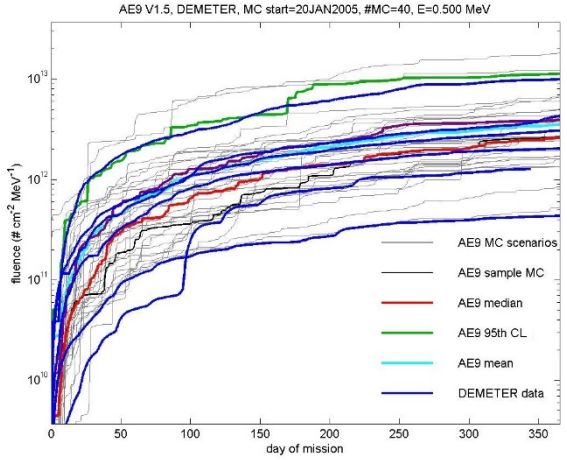

**0.198 MeV**



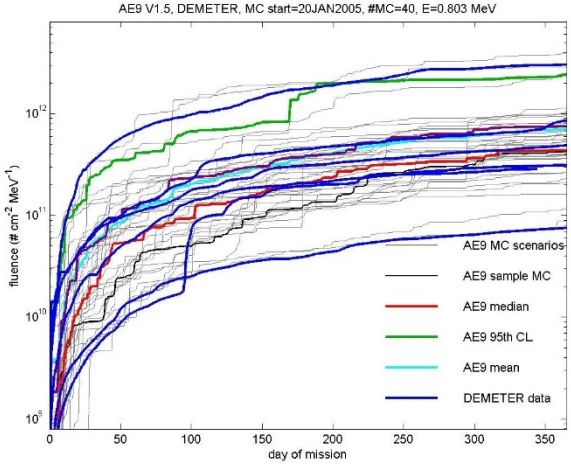

**0.322 MeV**




**0.500 MeV**




**0.803 MeV**






Distribution A

# POES/SEM 2 vs DEMETER/IDP

*Summary:*

- These charts compare POES and DEMETER data, given the similar geographic coverage 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 (particularly regarding look direction as previously discussed regarding POES).

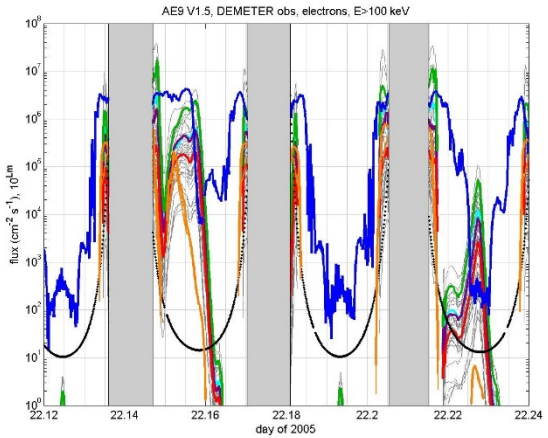


Distribution A

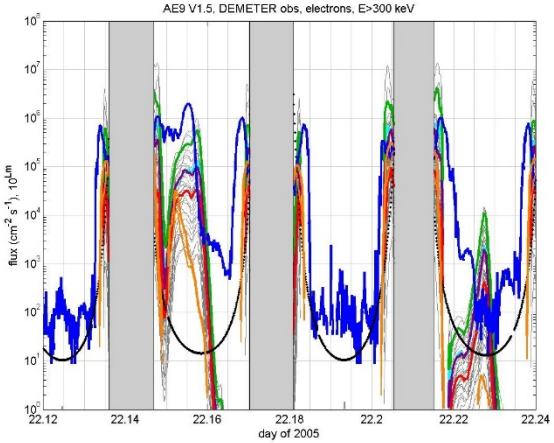
# DEMETER and POES electron flux during same period

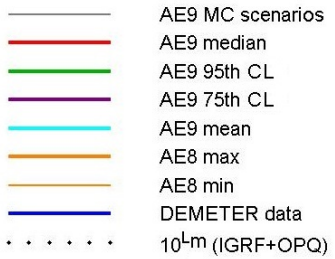
## DEMETER

### > 0.100 MeV (equivalent POES channel)



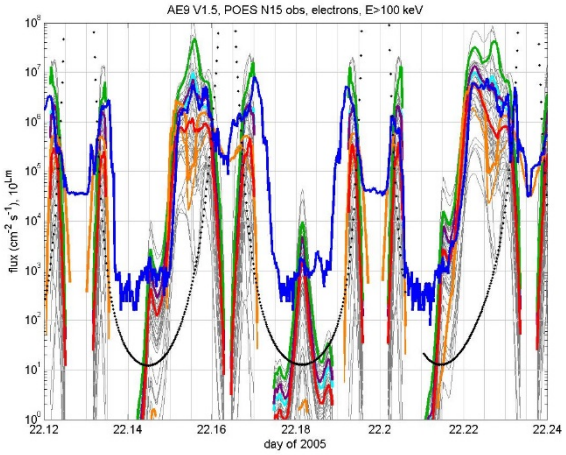

### > 0.300 MeV (equivalent POES channel)



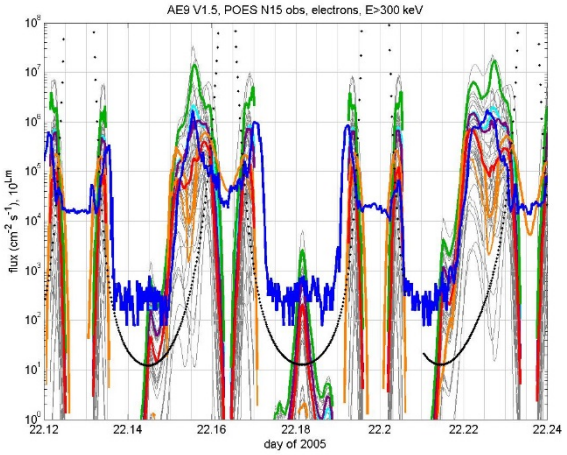



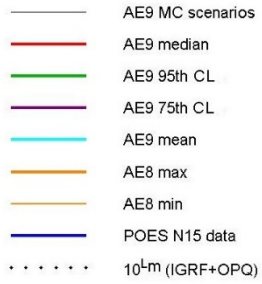

## POES

### > 0.100 MeV




### > 0.300 MeV



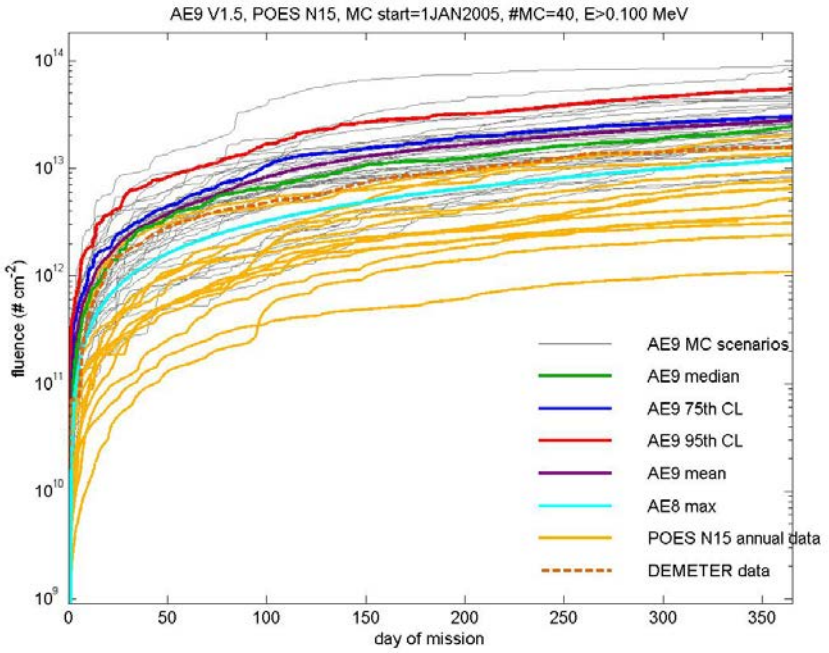





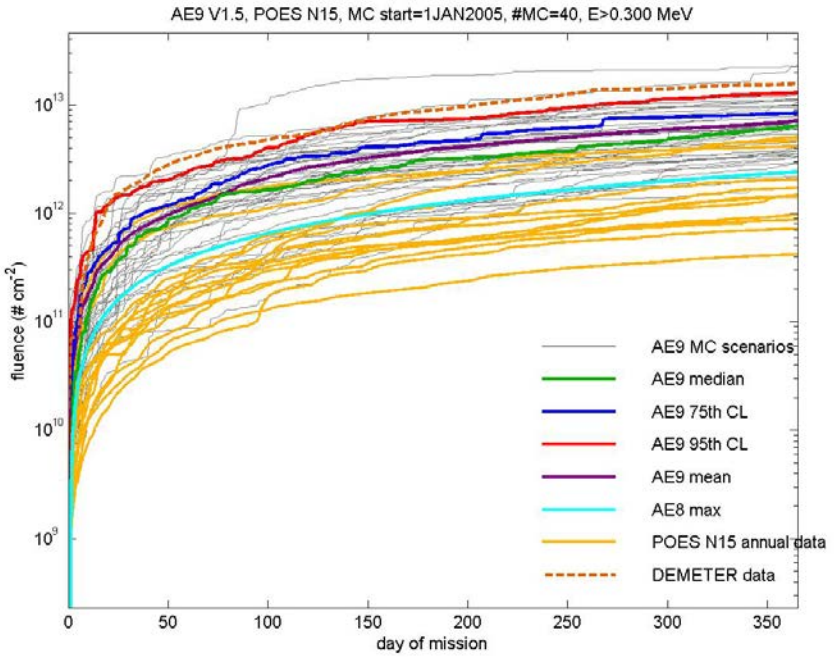

Distribution A

# DEMETER and POES electron fluence

## > 0.100 MeV




## > 0.300 MeV

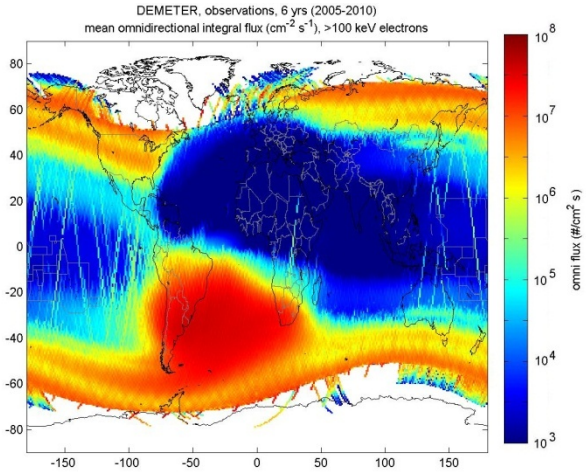


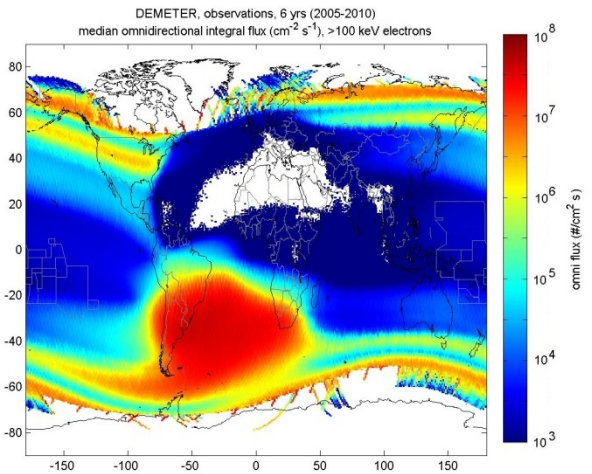


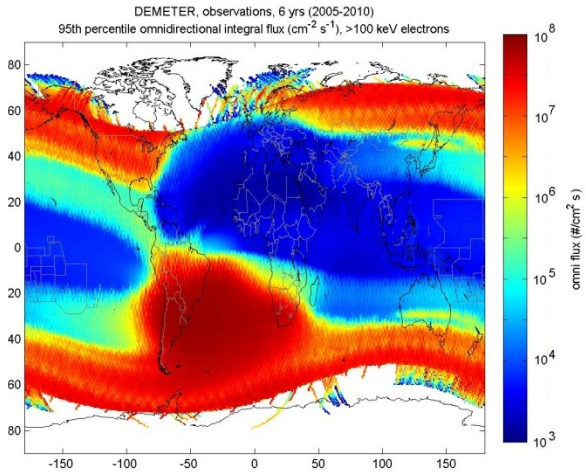

Distribution A

# DEMETER > 0.100 MeV electrons (POES equivalent)

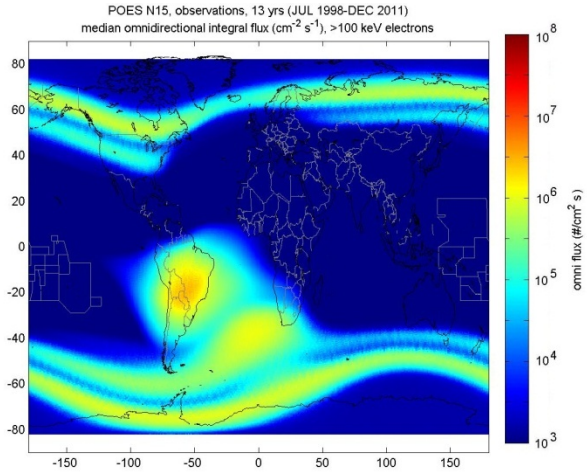
## DEMETER, 6 years (2005-2010)

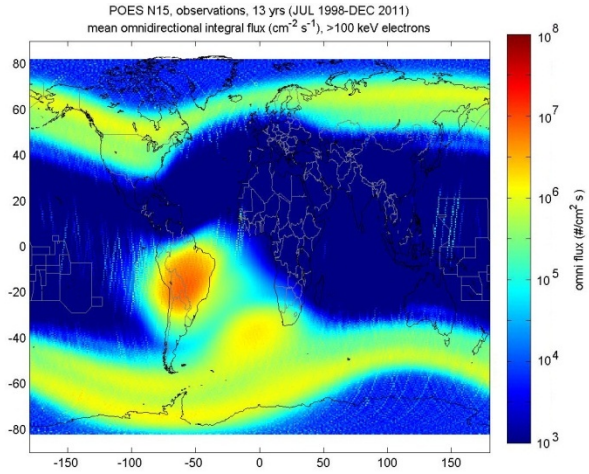


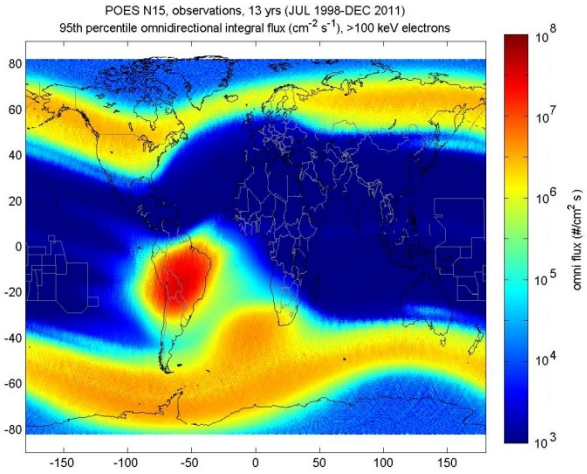




## POES N15 – 13 years, 1998 - 2011



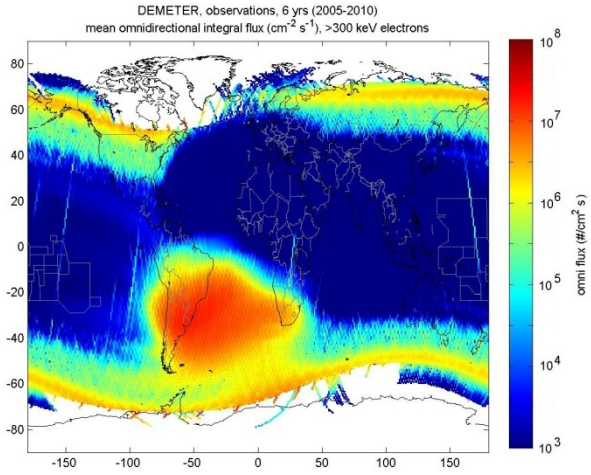



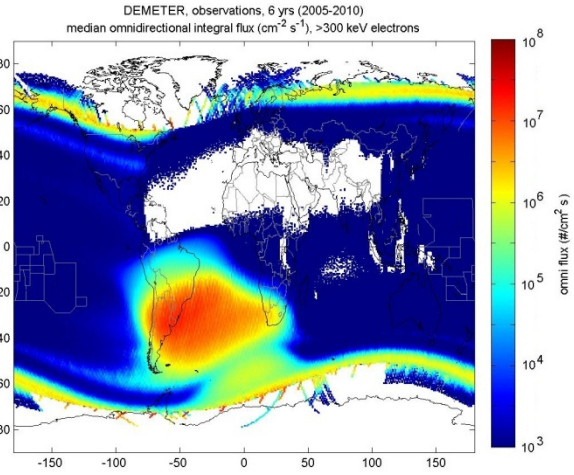


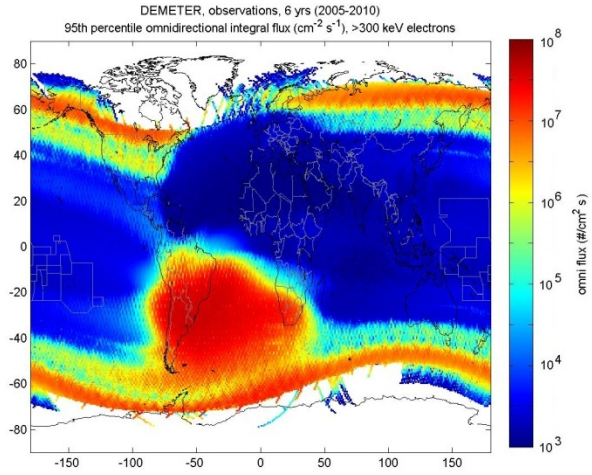

Distribution A

# DEMETER > 0.300 MeV electrons (POES equivalent)

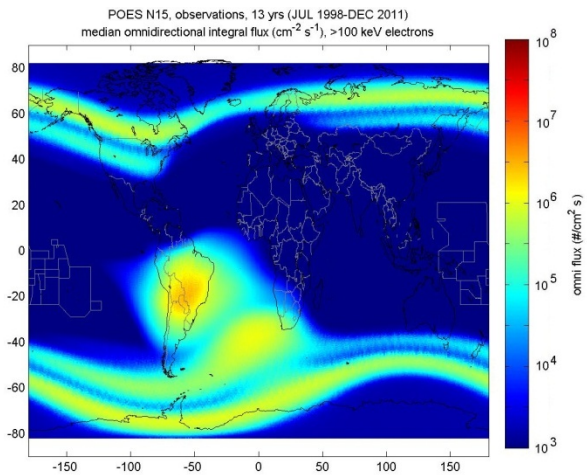
## DEMETER, 6 years (2005-2010)

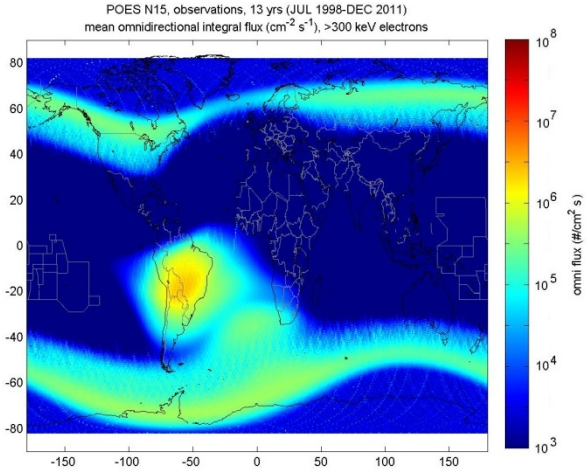


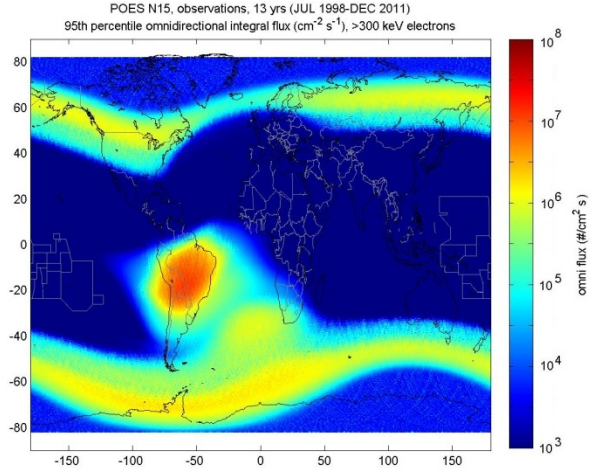




## POES N15 – 13 years, 1998 - 2011






Distribution A

# GOES10/SEM

*GOES10 data processing:*

- Electron channel fluxes are derived using geometric factors from Space Systems Loral (1996), GOES I-M DataBook, DRL 101-08 rev 1 [https://goes.gsfc.nasa.gov/text/databook/databook.pdf].

*Summary:*

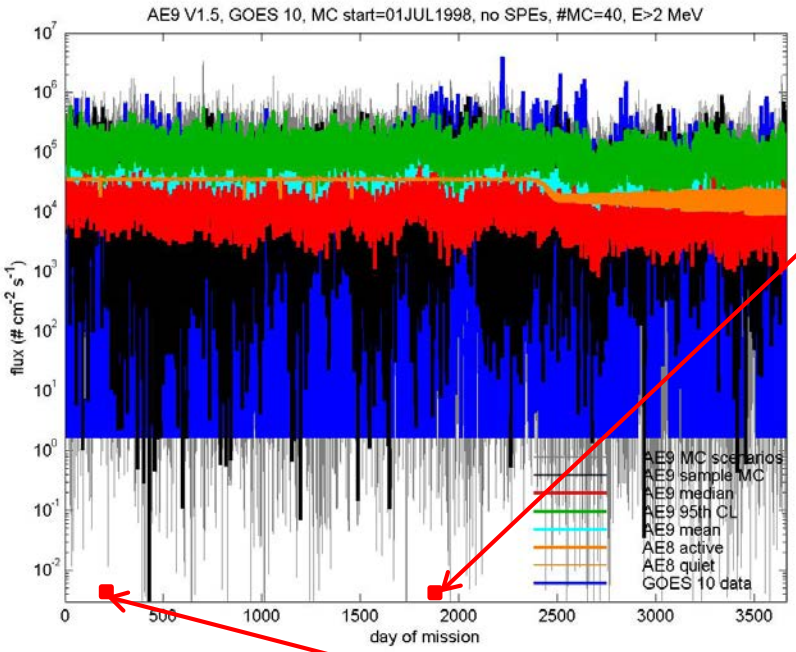
- Diurnal variation of flux observed by GOES is replicated in AE9.
- GOES-observed high and low flux periods are within the ranges represented by AE9 Monte Carlo scenarios.
- GOES-observed fluence is similar to the AE9 median once most of a solar cycle is represented.
- Cumulative flux distribution observed by GOES is generally at the low side of AE9 results, but similar for the highest 20% of fluxes.



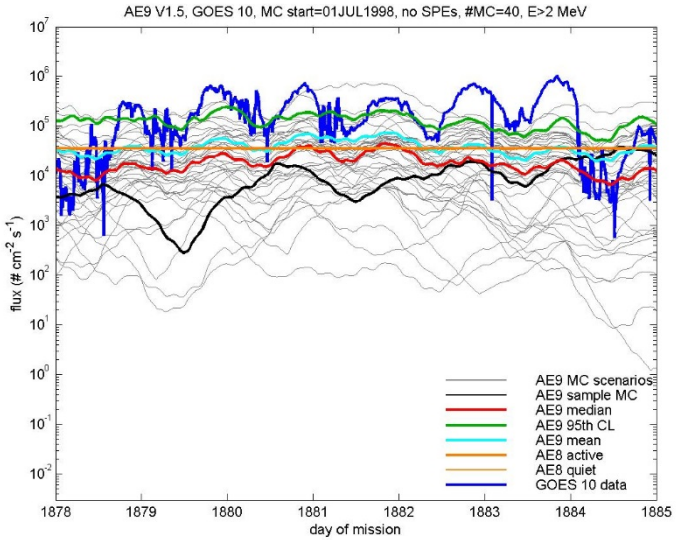
Distribution A

# GOES electron time series

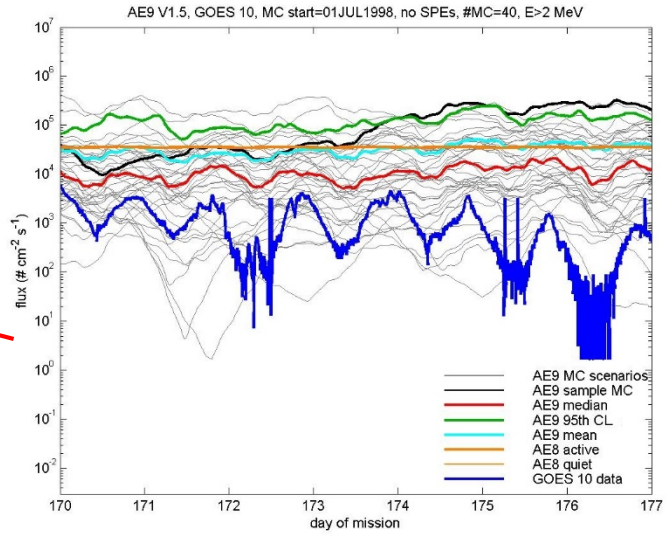
**Ten years (1998 – 2008)**




**1 week (high flux period)**




**1 week (low flux period)**

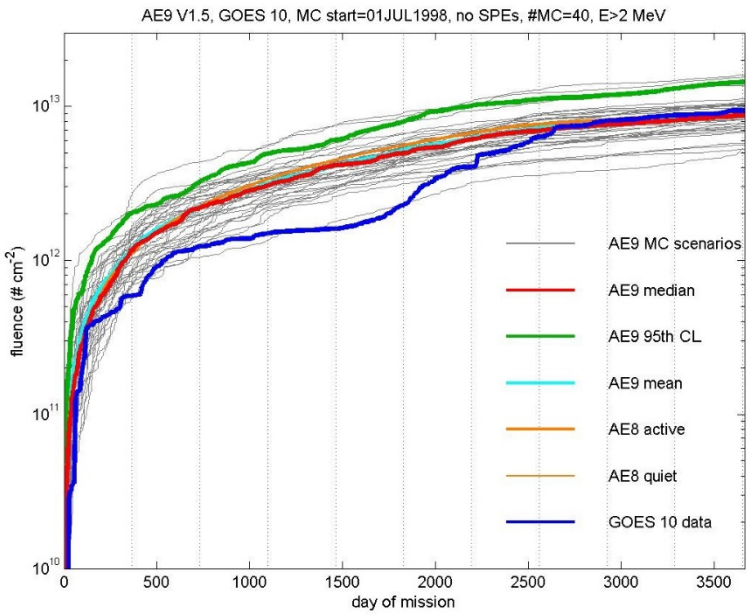




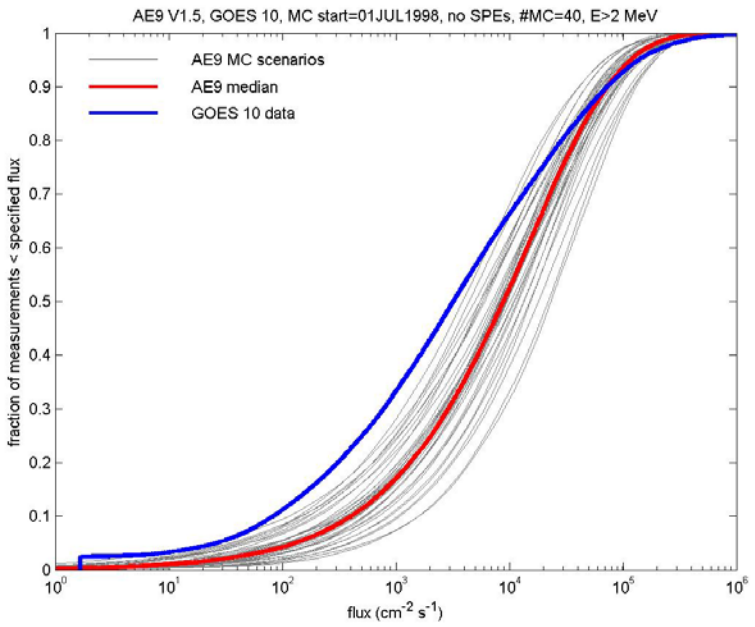

Distribution A

# GOES electron fluence and 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

*DSP21 data processing:*

- Electron fluxes for CEASE standard dosimeter and telescope channels are derived using geometric factors from Brautigam (2008), Compact Environmental Anomaly Sensor (CEASE): Geometric Factors, DTIC Report ADA514447.

*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, with good agreement at all percentiles for 0.37 – 1.5 MeV; at 2.0 MeV AE9 is close to DSP21 levels in the highest 20% of conditions and is lower at lower percentiles.

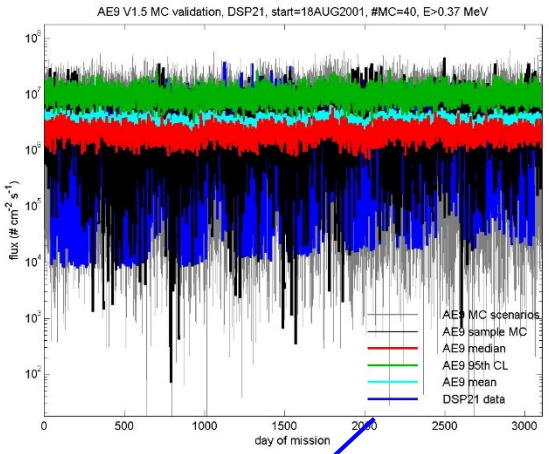


Distribution A

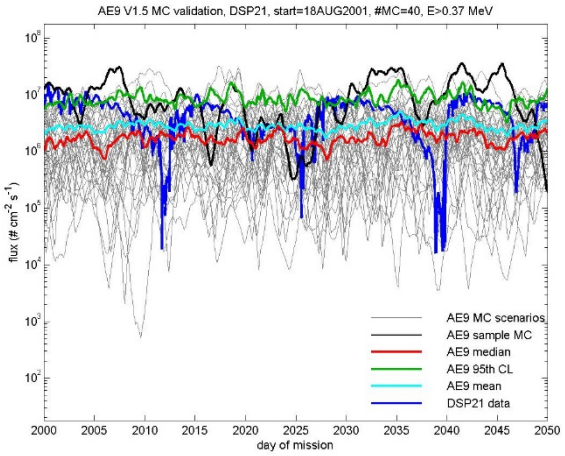
# DPS21 electron time series

## T03 > 0.37 MeV

### 10 years

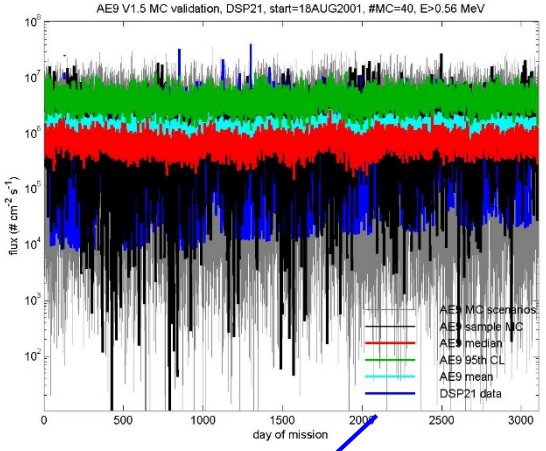



### 50 day

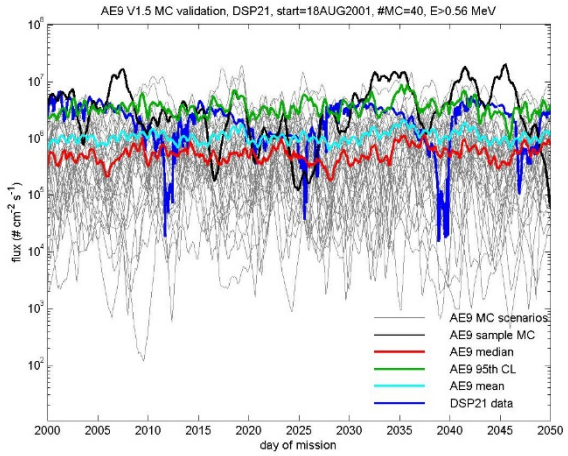



## T04 > 0.56 MeV

### 10 years

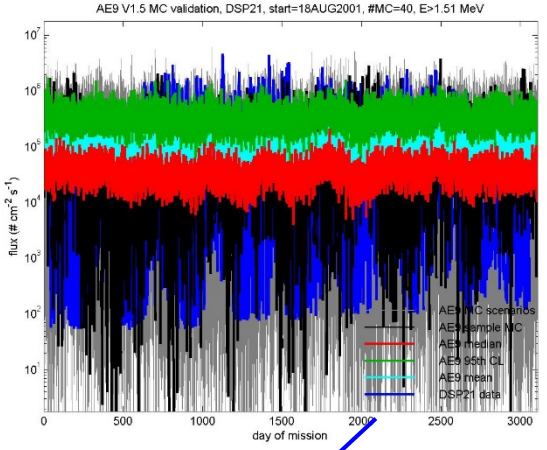



### 50 day

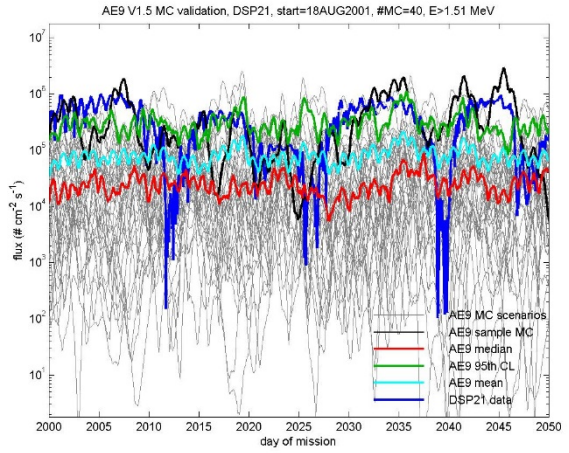



## D01 > 1.51 MeV

### 10 years




### 50 day



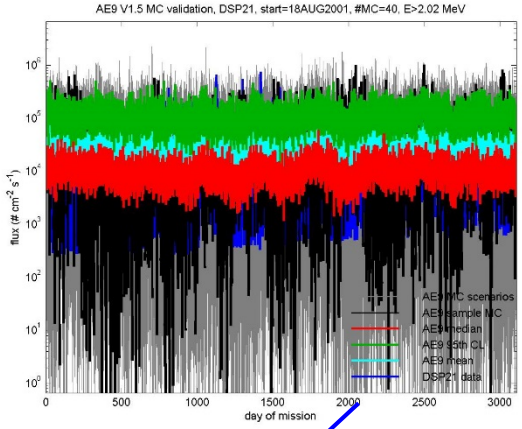



Distribution A

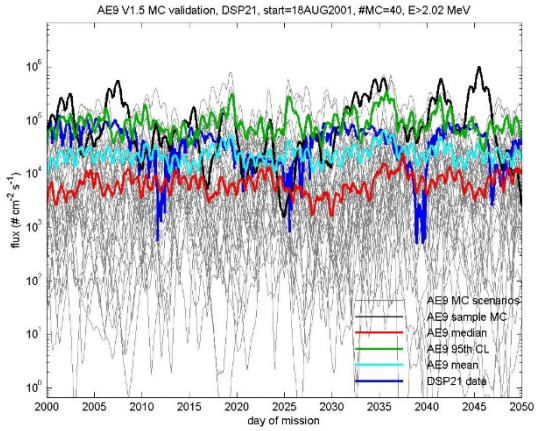
# DPS21 electron time series

## D03 > 2.02 MeV

### 10 years




### 50 day



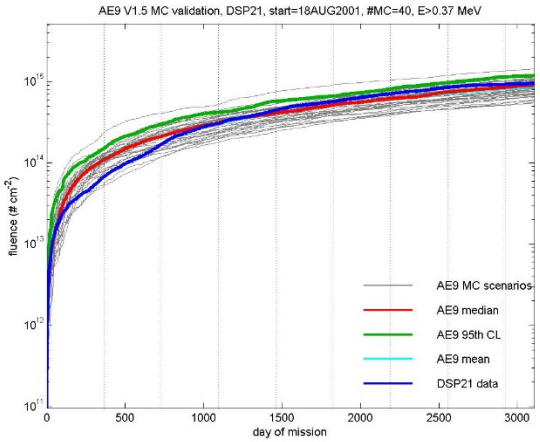



Distribution A

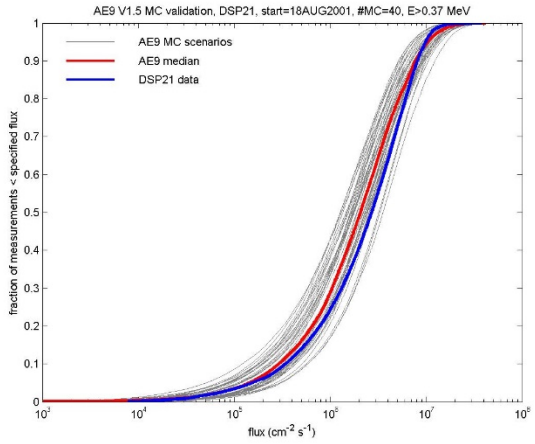
# DPS21 electron fluence and cumulative distribution (9 years, 2001 - 2010)

## T03 > 0.37 MeV

### Fluence

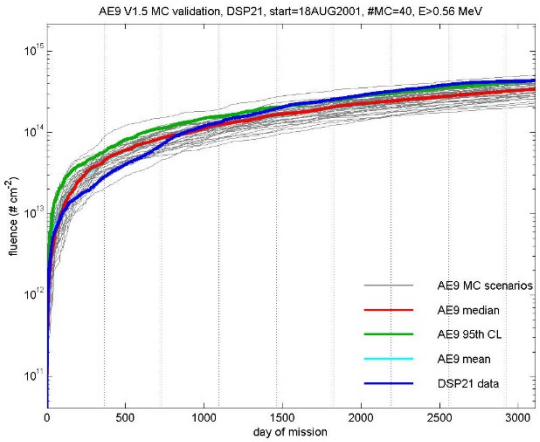



### Cumulative flux distribution

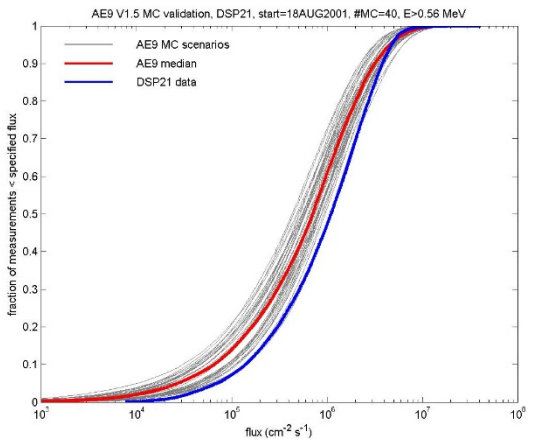



## T04 > 0.56 MeV

### Fluence

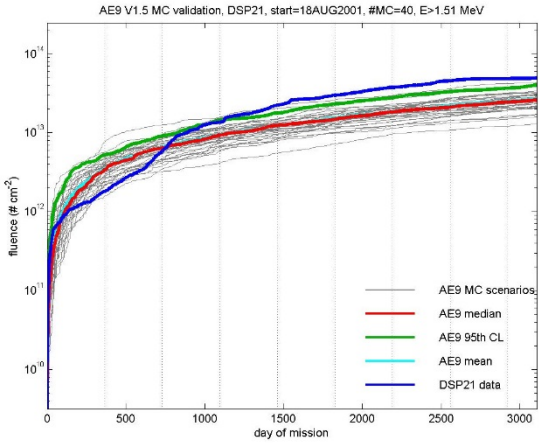



### Cumulative flux distribution

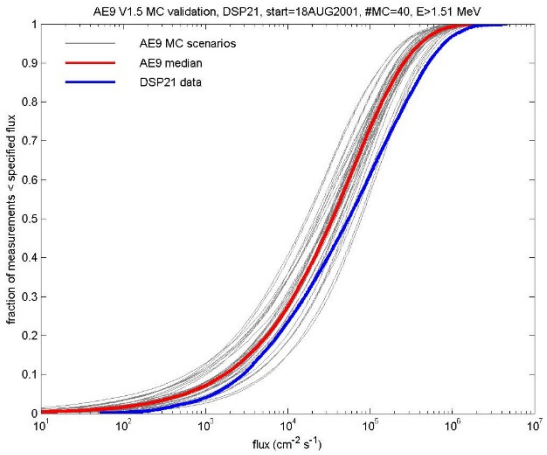



## D01 > 1.51 MeV

### Fluence




### Cumulative flux distribution



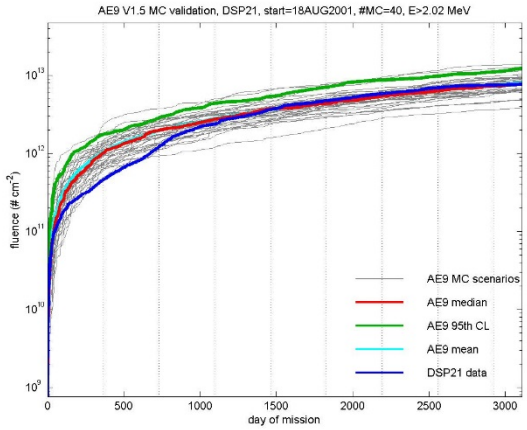



Distribution A

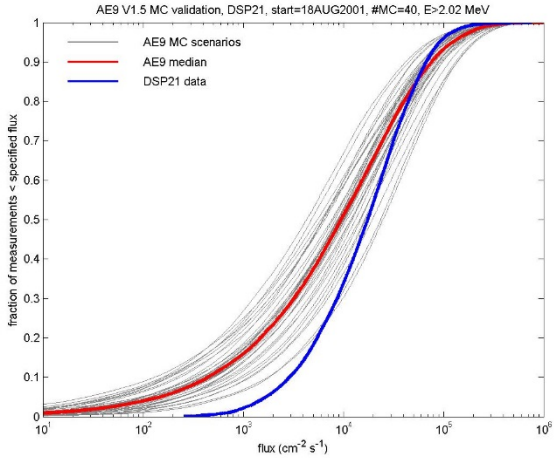
# DPS21 electron fluence and cumulative distribution (9 years, 2001 - 2010)

## D03 > 2.02 MeV

### Fluence




### Cumulative flux distribution






Distribution A

# TACSAT-4/CEASE

*TacSat-4 data processing:*

- Electron fluxes for CEASE standard dosimeter and telescope channels are derived using geometric factors from Brautigam (2008), Compact Environmental Anomaly Sensor (CEASE): Geometric Factors, DTIC Report ADA514447.

*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 three energy channels (0.56, 2.0, 2.4 MeV), near the 95$^{th}$ CL for two channels (0.14, 0.17 MeV), and at the low end of Monte Carlo results for two channels (0.37, 1.5 MeV).

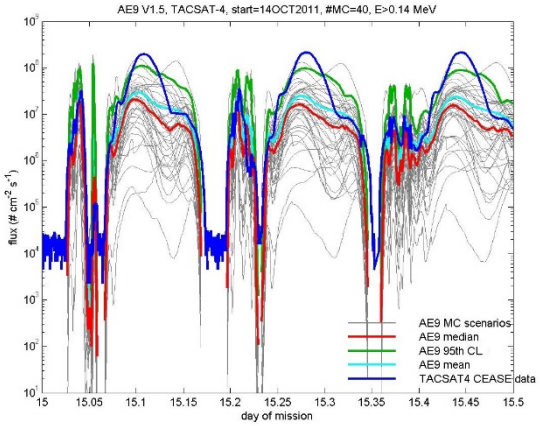


Distribution A

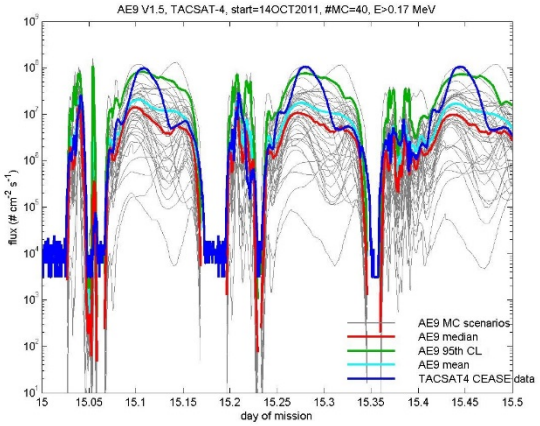
# TACSAT-4/CEASE electron flux time series and fluence

## Flux

### T01 > 0.14 MeV

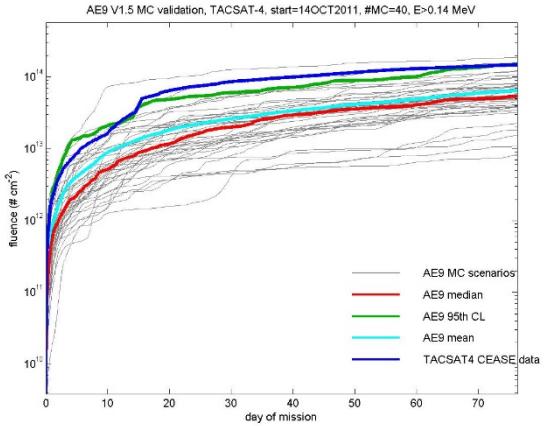



### T02 > 0.17 MeV

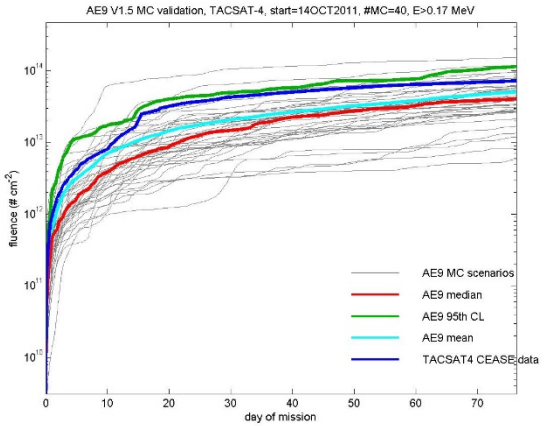



## Fluence

### T01 > 0.14 MeV




### T02 > 0.17 MeV



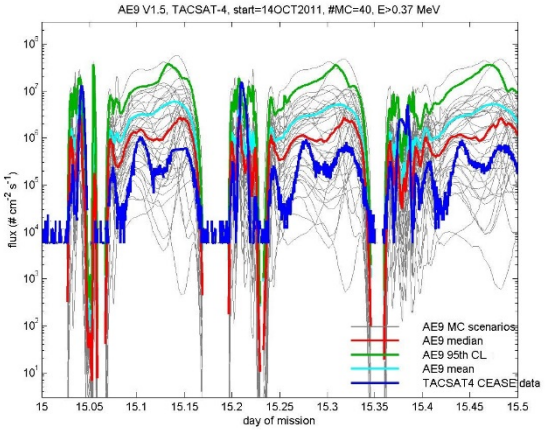



Distribution A

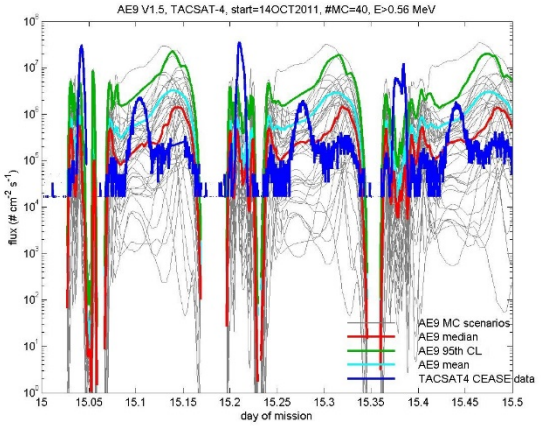
# TACSAT-4/CEASE electron flux time series and fluence

## Flux

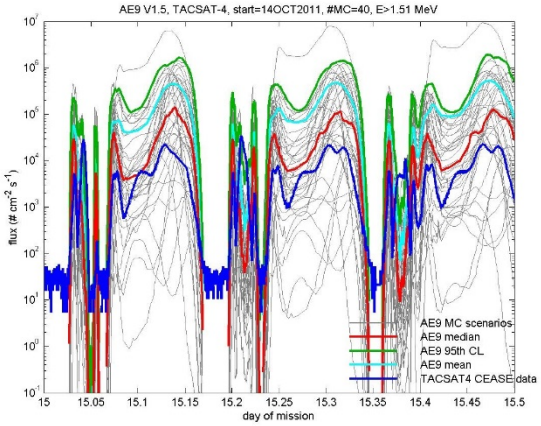
### T03 > 0.37 MeV




### T04 > 0.56 MeV

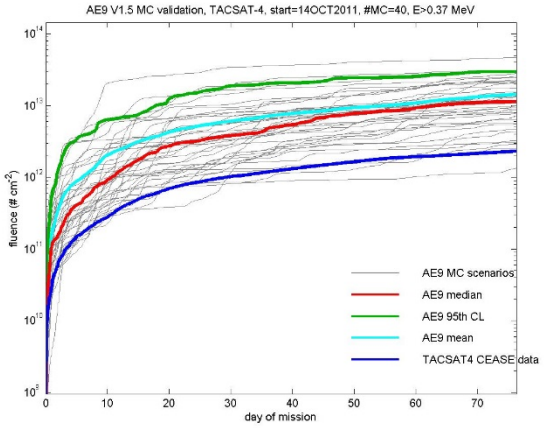



### D01 > 1.51 MeV

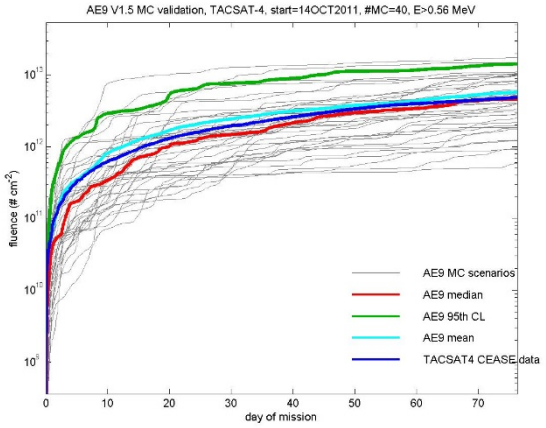



## Fluence

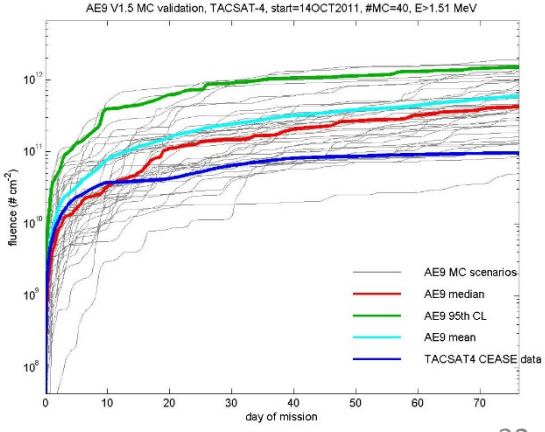
### T03 > 0.37 MeV




### T04 > 0.56 MeV




### D01 > 1.51 MeV



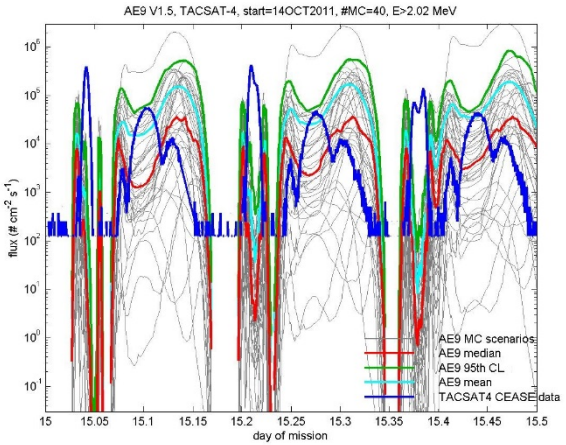



Distribution A

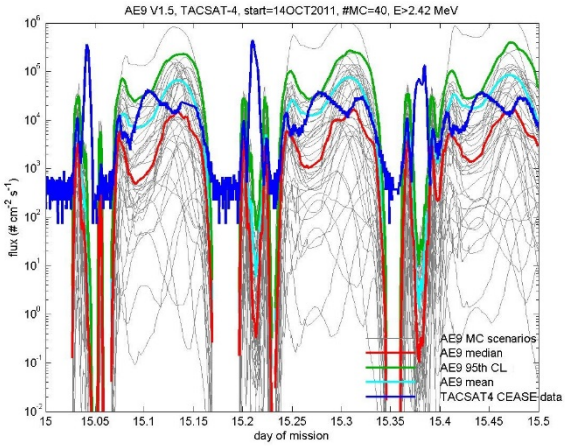
# TACSAT-4/CEASE electron flux time series and fluence

## Flux

### D03 > 2.02 MeV

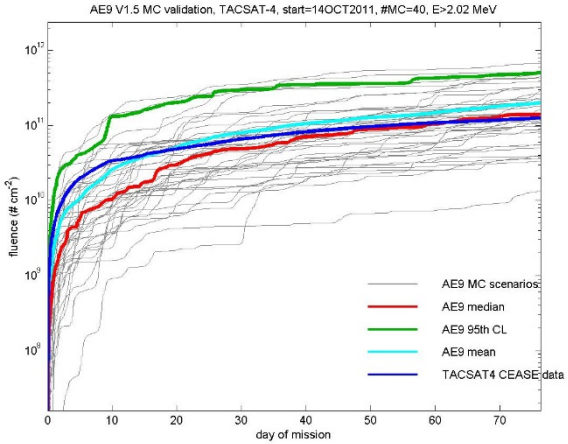



### D02 > 2.42 MeV

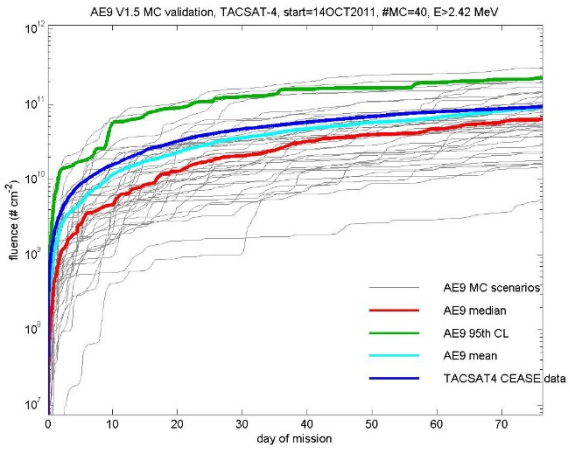



## Fluence

### D03 > 2.02 MeV




### D02 > 2.42 MeV






Distribution A

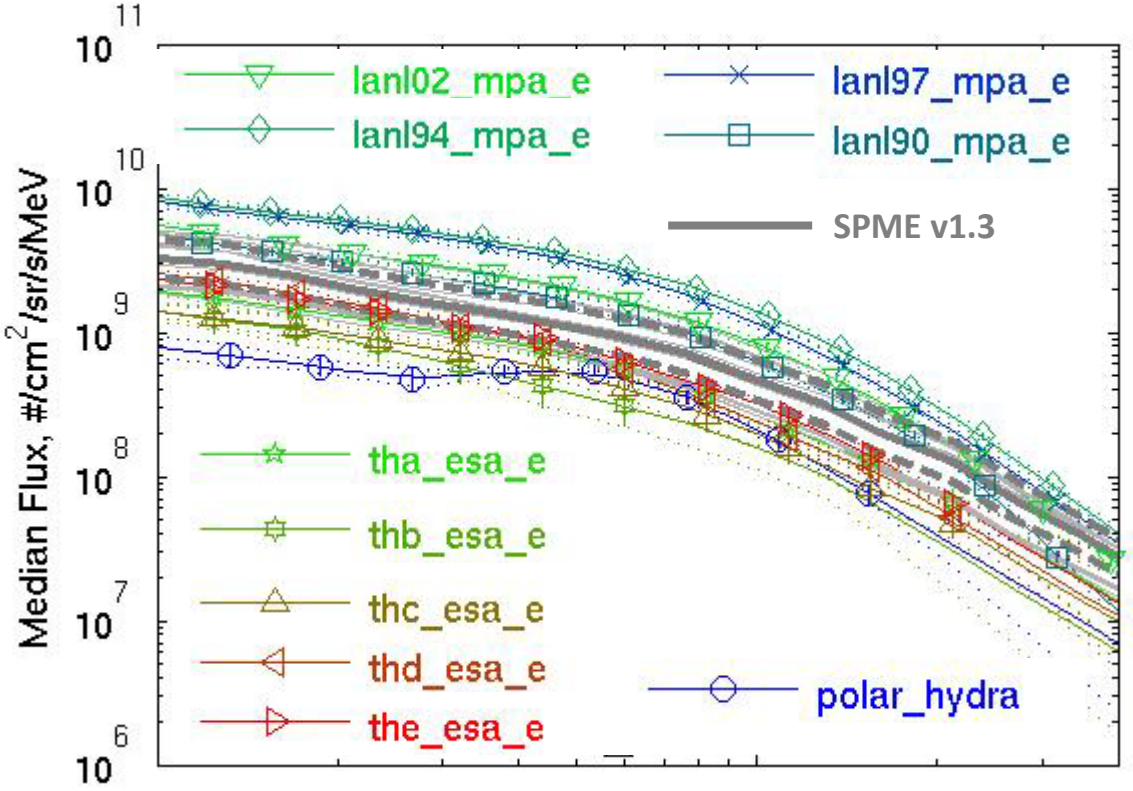
# Comments on Model/Data Comparisons



Distribution A

# 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.

*We do not expect any individual data set to fall within the model error bars.*



Distribution A