RADIATION MODELS FOR TRAPPED PARTICLES

Jakub Řípa (ELTE), Giuseppe Dilillo (Udine U.),
Riccardo Campana (INAF), Gábor Galgóczi (ELTE)

Overview

- Models of near-Earth trapped radiation environment are investigated
- Aim is to have a readily available library of models to be used for HERMES (and other LEO missions) simulations
- Models AE8 MAX / AP8 MIN and AE9 / AP9 (MC 50% & 90% CL) were compared
- 3 different altitudes: 500, 550 and 600 km
- 12 inclinations: 0°, 5°, 10°, 15°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°
- Obtained differential and integral fluxes (summed flux of particles with energy > E) of trapped particles and orbit averaged spectra
- Computed maps of the trapped particle regions
- Estimate duty cycles at different flux and energy thresholds
- Models are compared with published measurements by the BeppoSAX and PAMELA instruments
- Results were summarized in HERMES-SP Technical Note and an abstract was submitted for SPIE 2020 conference in Yokohama.

Trapped Particles Models

AE8 MAX / AP8 MIN

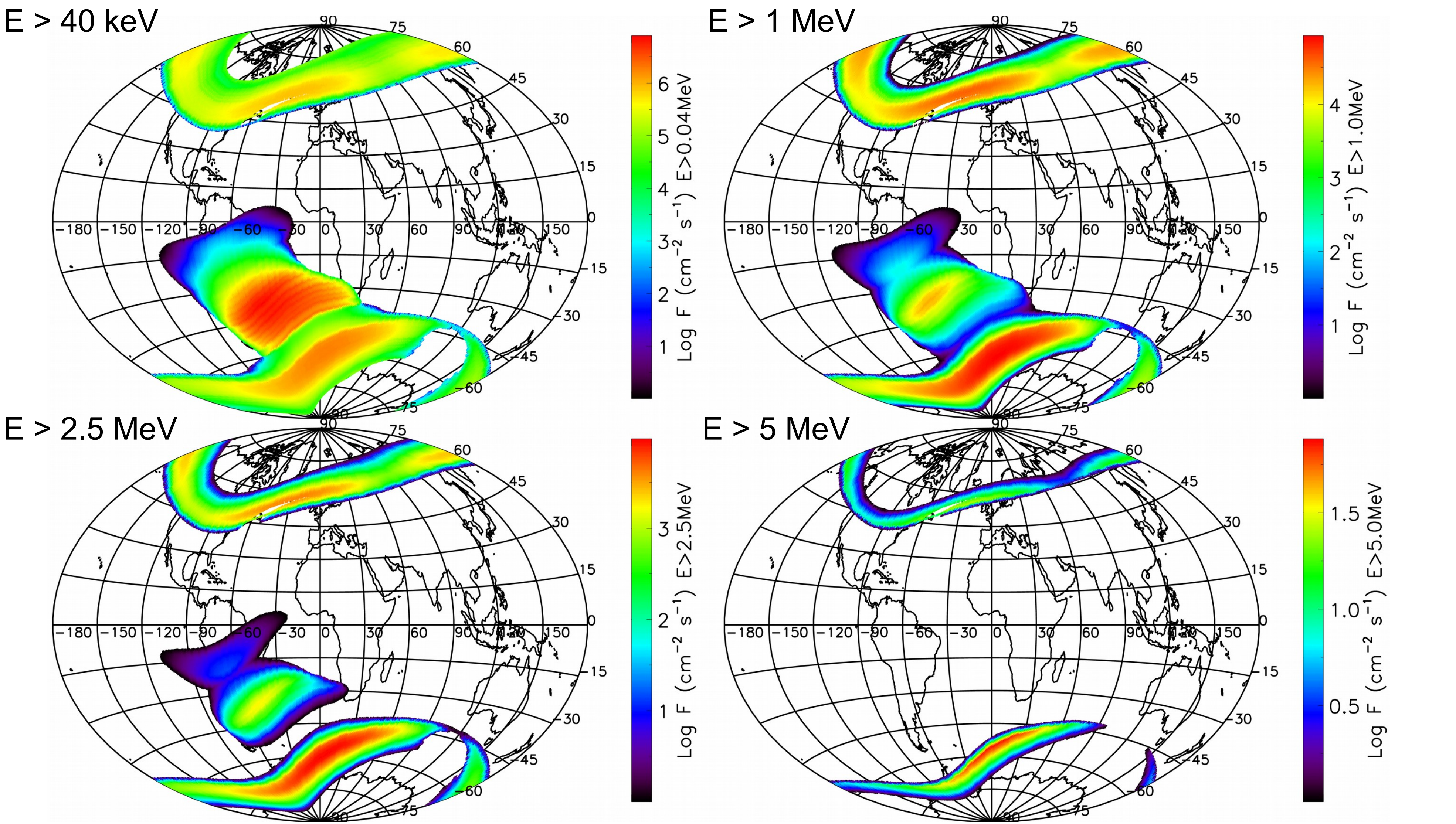
- NASA's model based on data from more than 20 satellites
- Based on data from early 60s to the mid-70s
- Used as as a standard model of trapped particles
- MIN and MAX for solar cycle minimum and maximum

AE9 / AP9

- More recent, but so far recommended only for evaluation purposes
- Based on 33 satellite datasets from 1976 to 2011
- Contain uncertainties due to the statistical variations, instrument errors, and variations due to the space weather
- We used Monte Carlo (MC) mode (100 runs) which account for these variations
- 50% and 90% confidence levels (CL) were obtained

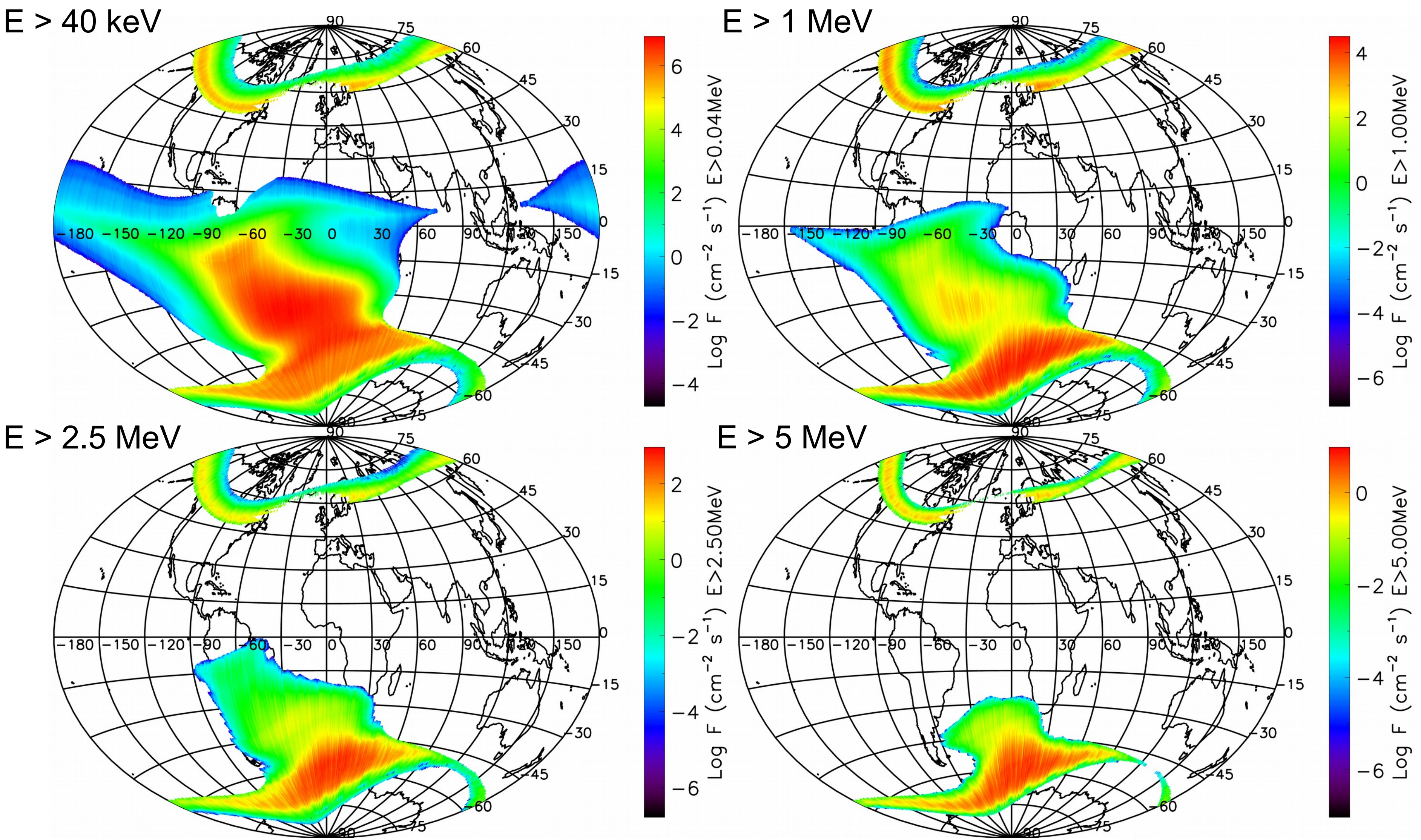
- The official software developed by the U.S. Air Force Research Laboratory (www.vdl.afrl.af.mil/programs/ae9ap9) was used to calculate the fluxes given by the AE8/AP8 and AE9/AP9 models.

Maps of Trapped Electrons
AE8 MAX



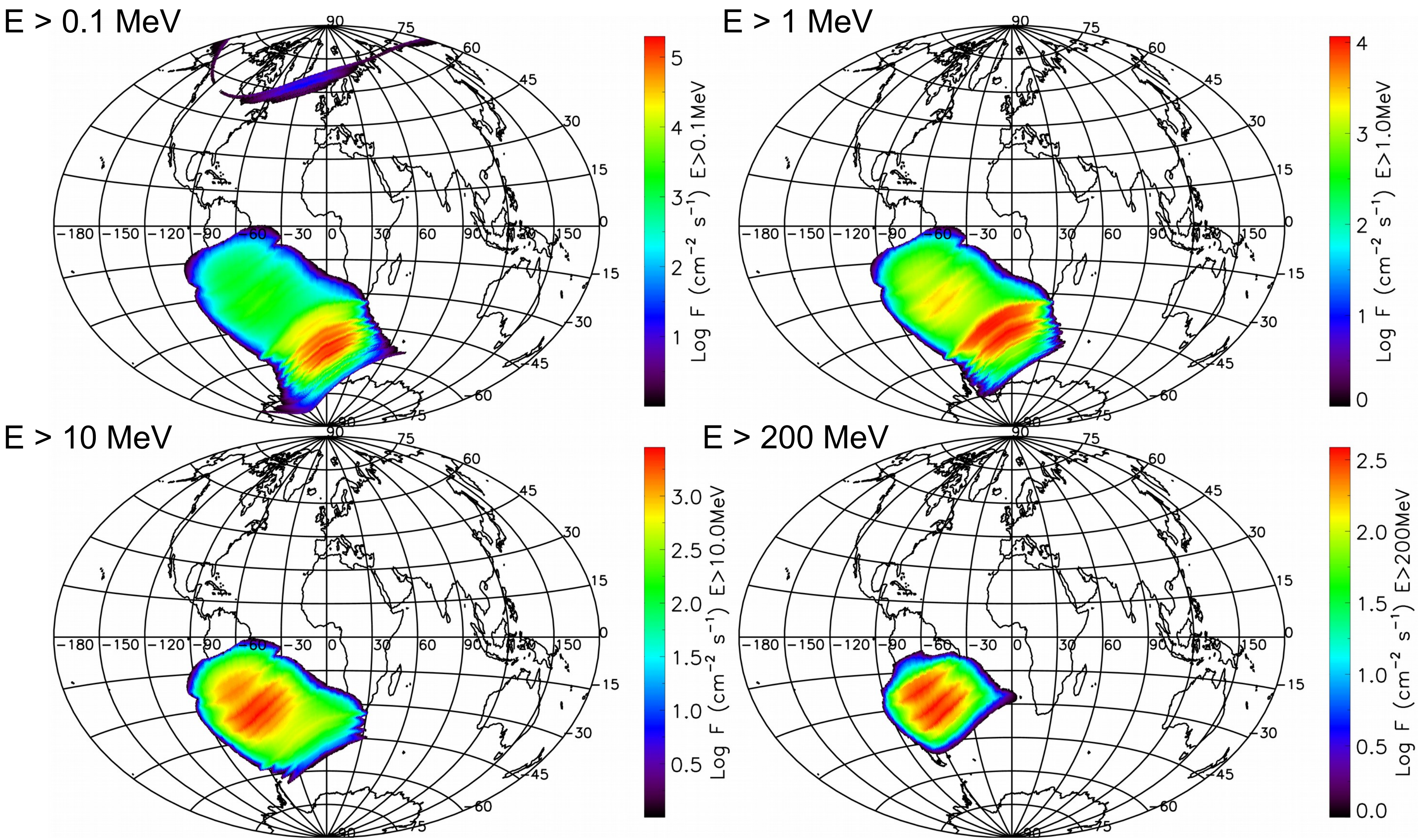
Integral flux maps of trapped electrons for AE8 MAX model and different low energy thresholds

Maps of Trapped Electrons AE9 (50% CL)



Integral flux maps of trapped electrons for AE9 50% CL model and different low energy thresholds

Maps of Trapped Protons
AP8 MIN



Integral flux maps of trapped protons for AP8 MIN model and different low energy thresholds

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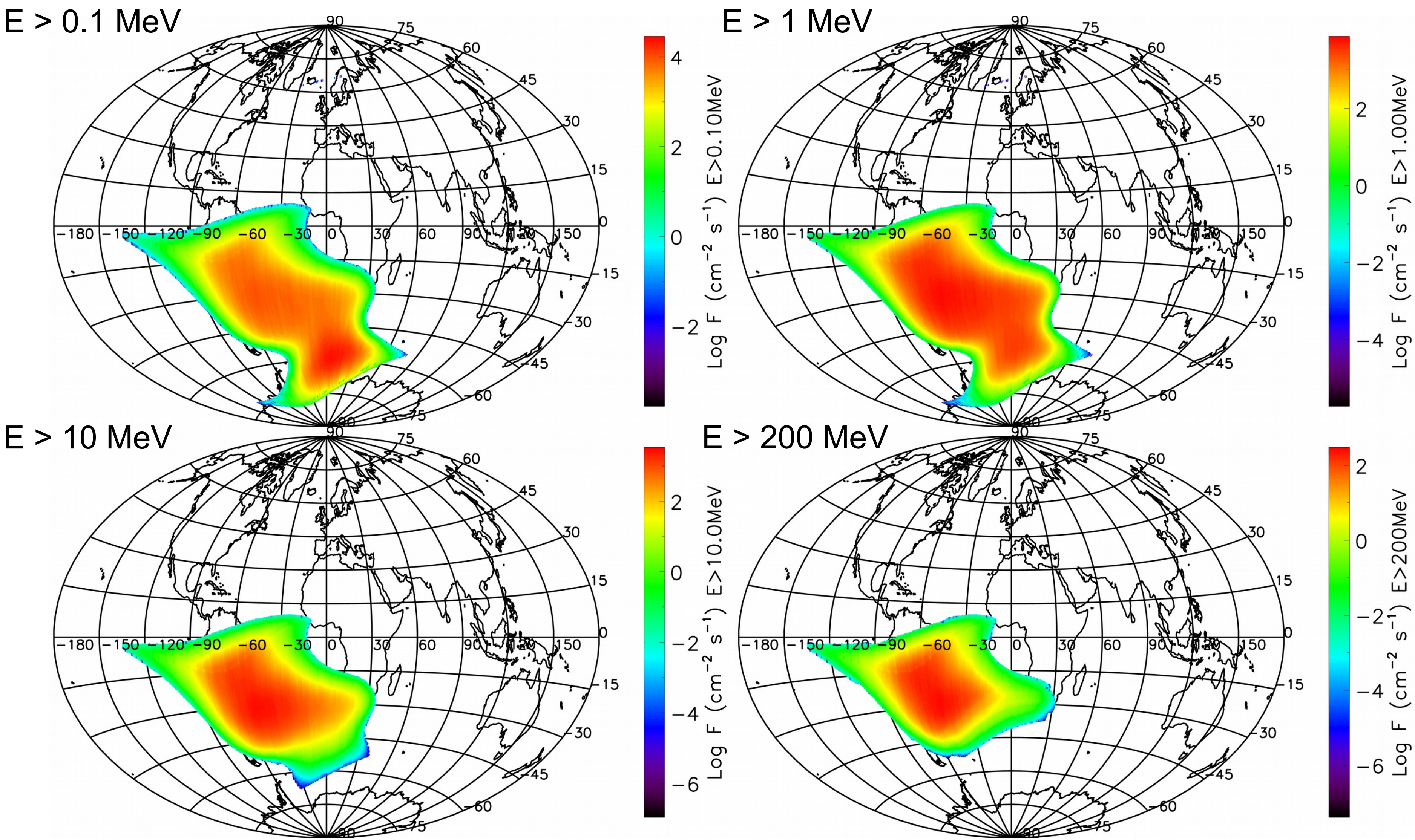
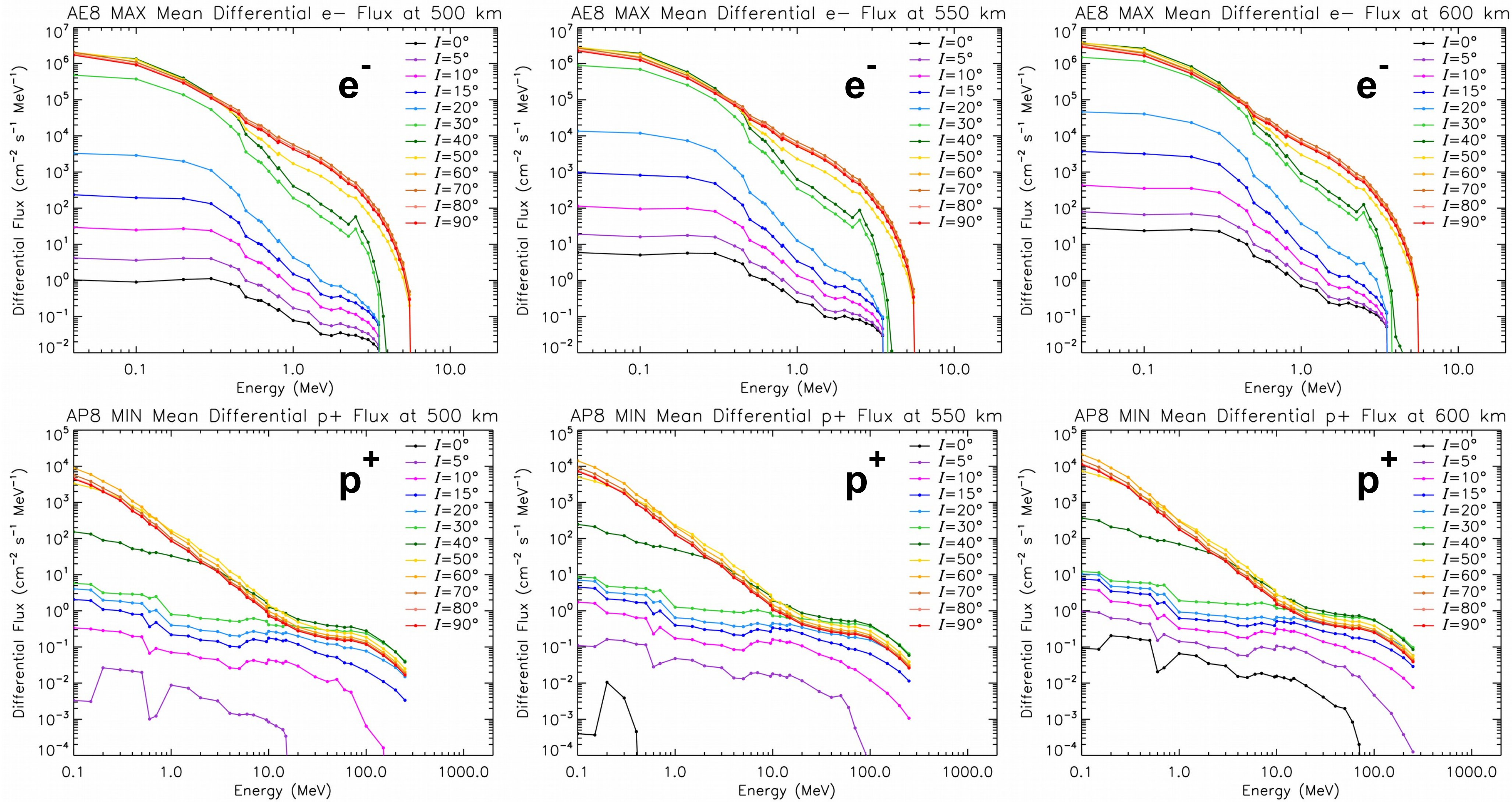
Maps of Trapped Protons AP9 (50% CL)



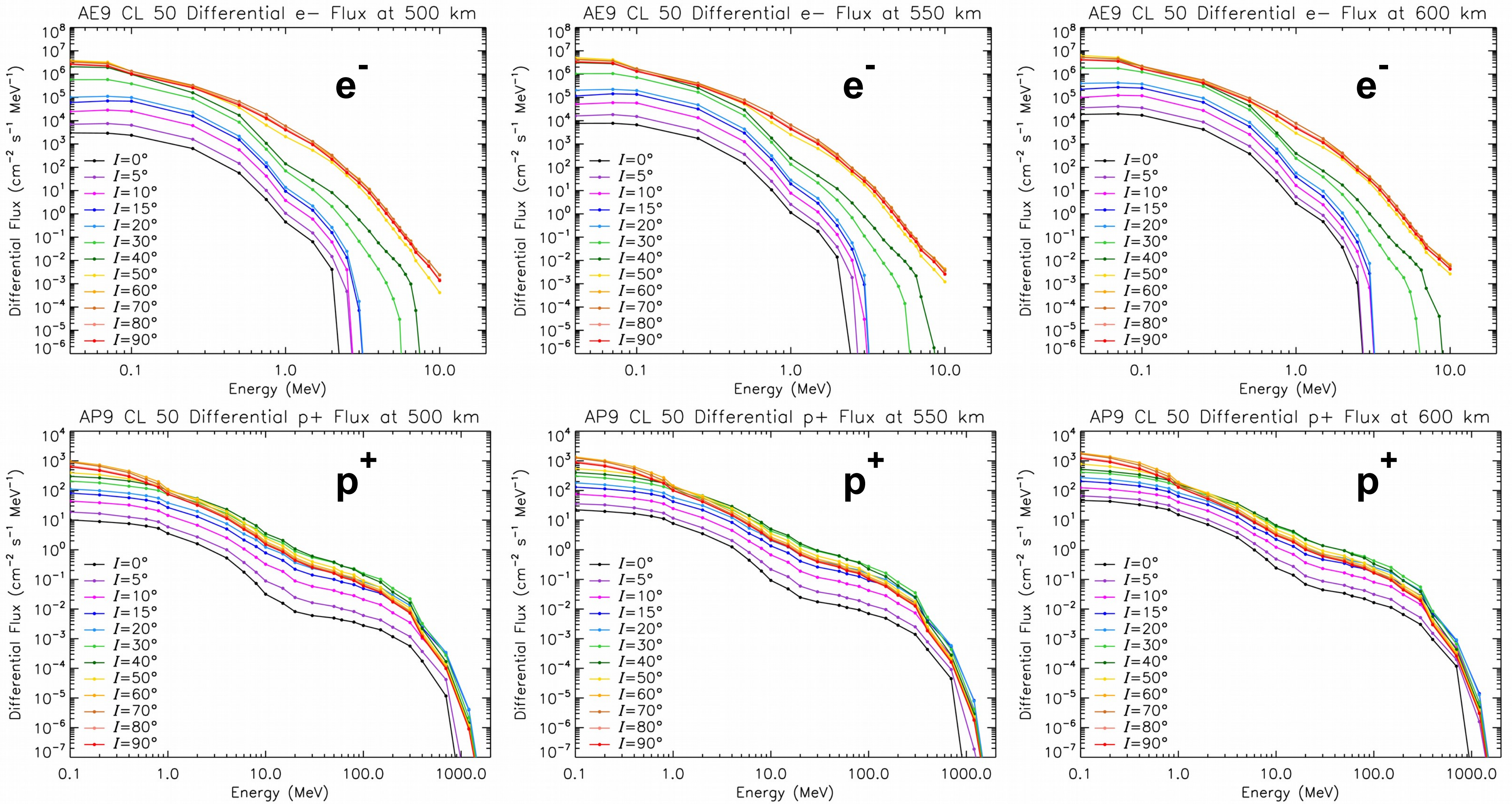
Integral flux maps of trapped protons for AP9 50% CL model and different low energy thresholds

Differential Spectra
AE8 MAX and AP8 MIN



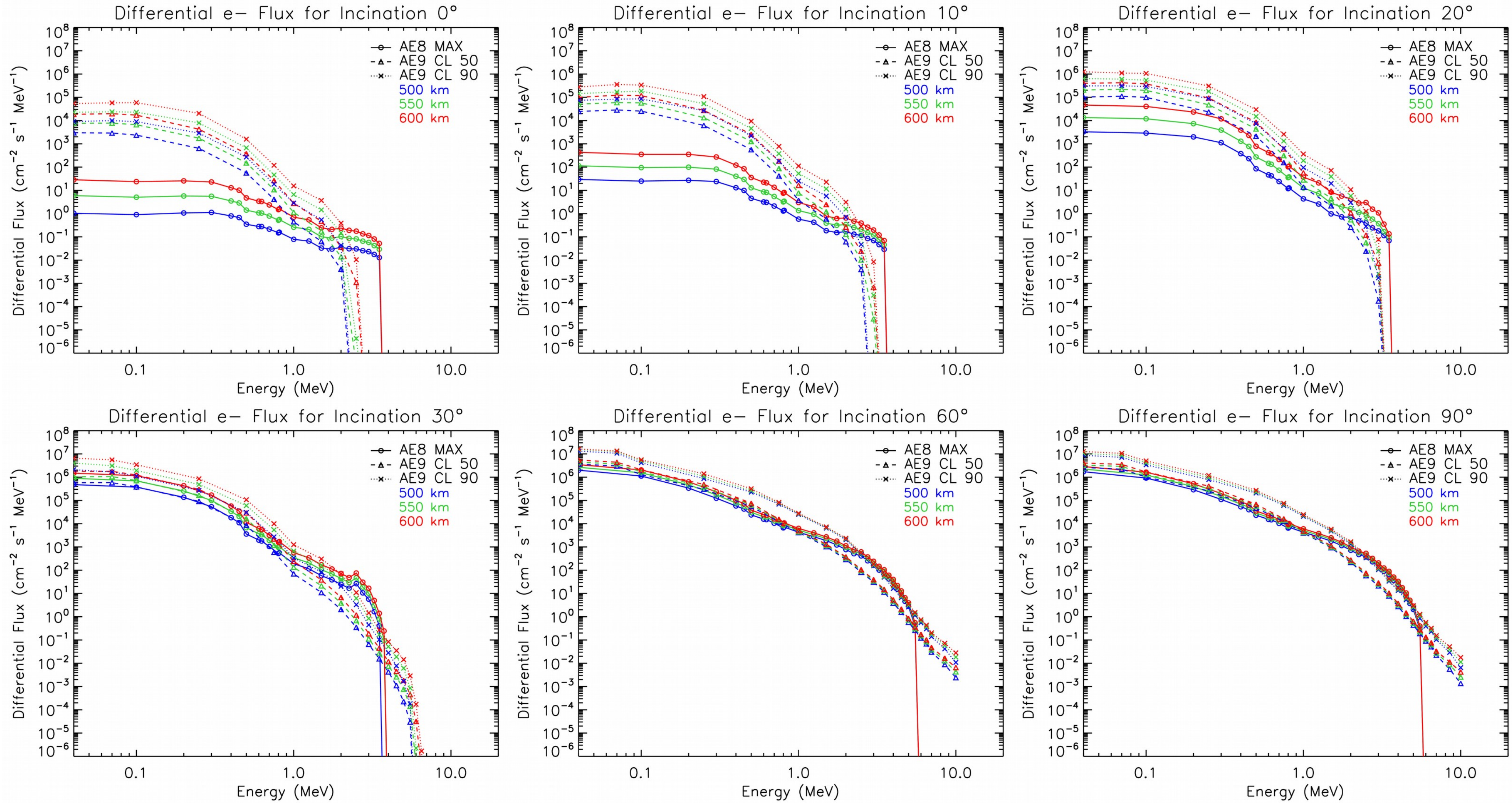
Mean differential fluxes of trapped electrons and protons for AE8 MAX and AP8 MIN models

Differential Spectra
AE9 and AP9 (50% CL)



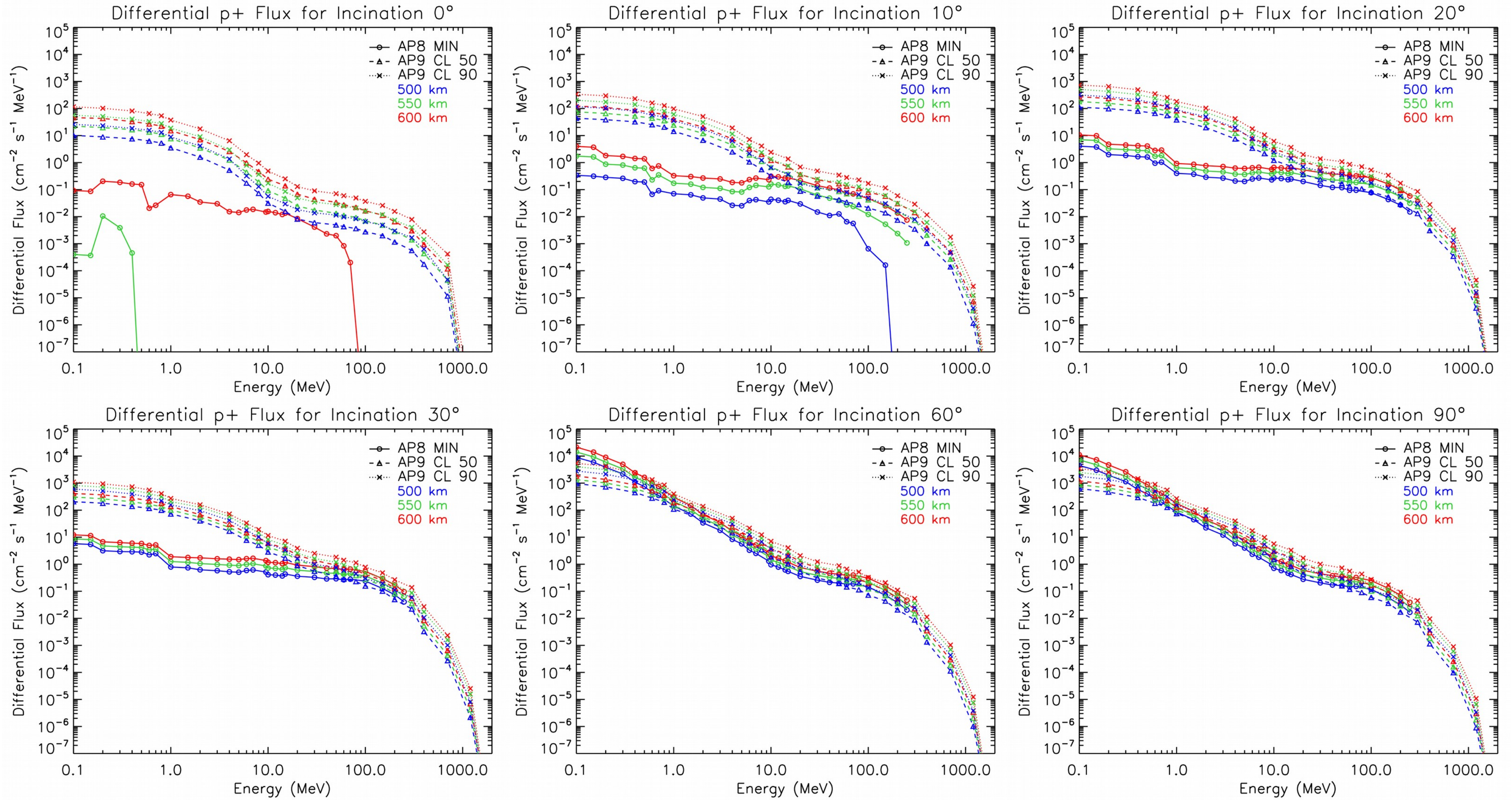
Differential fluxes (50% CL) of trapped electrons and protons for AE9 and AP9 models

Differential Spectra - Electrons
AE8 MAX, AE9 (50%, 90% CL)



Comparison of differential fluxes of trapped electrons for AE8 MAX, AE9 (50%, 90% CL) models.

Differential Spectra - Protons
AP8 MIN, AP9 (50%, 90% CL)



Comparison of differential fluxes of trapped protons for AP8 MIN, AP9 (50%, 90% CL) models.

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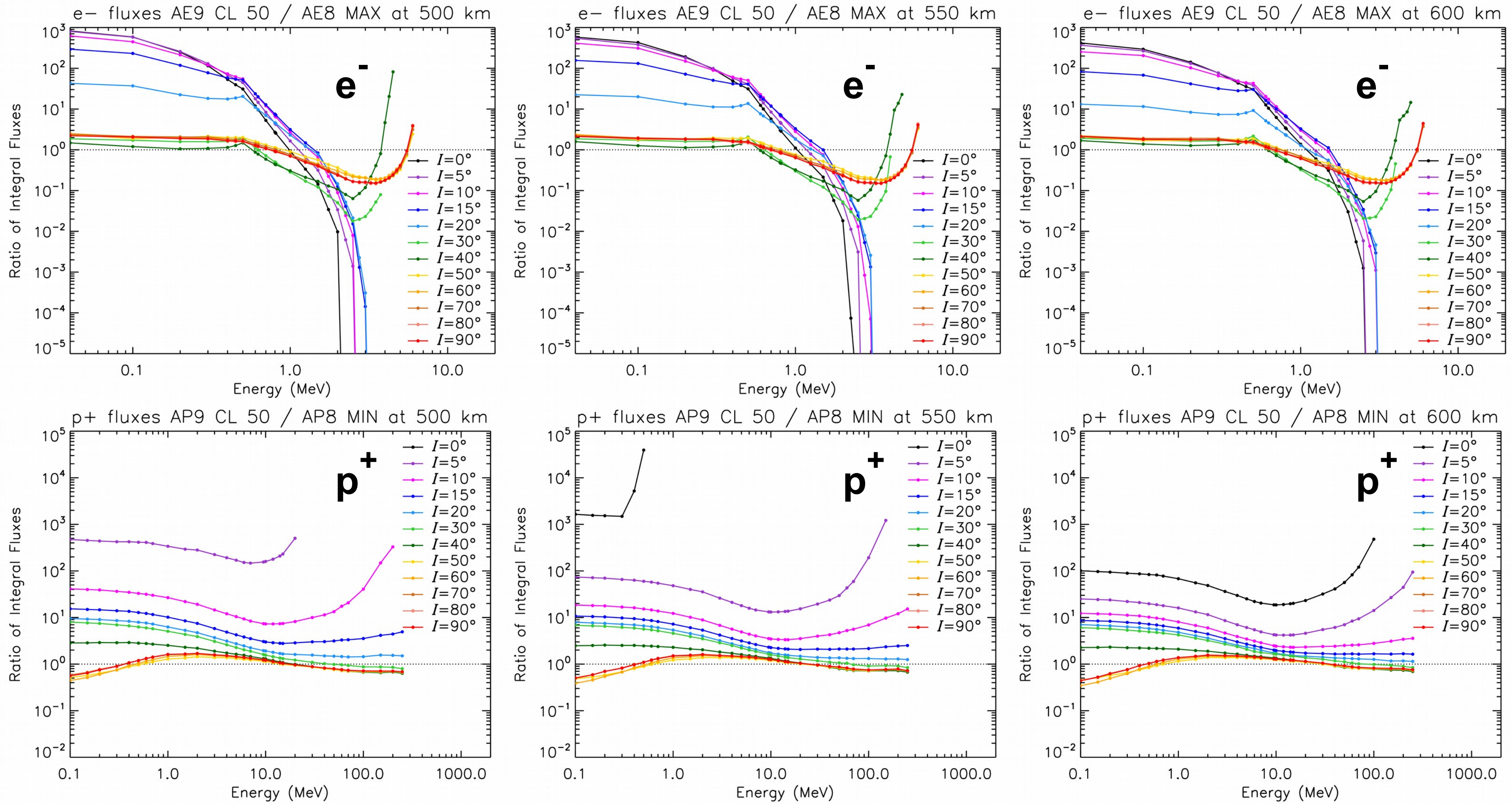
Ratio of Integral Spectra

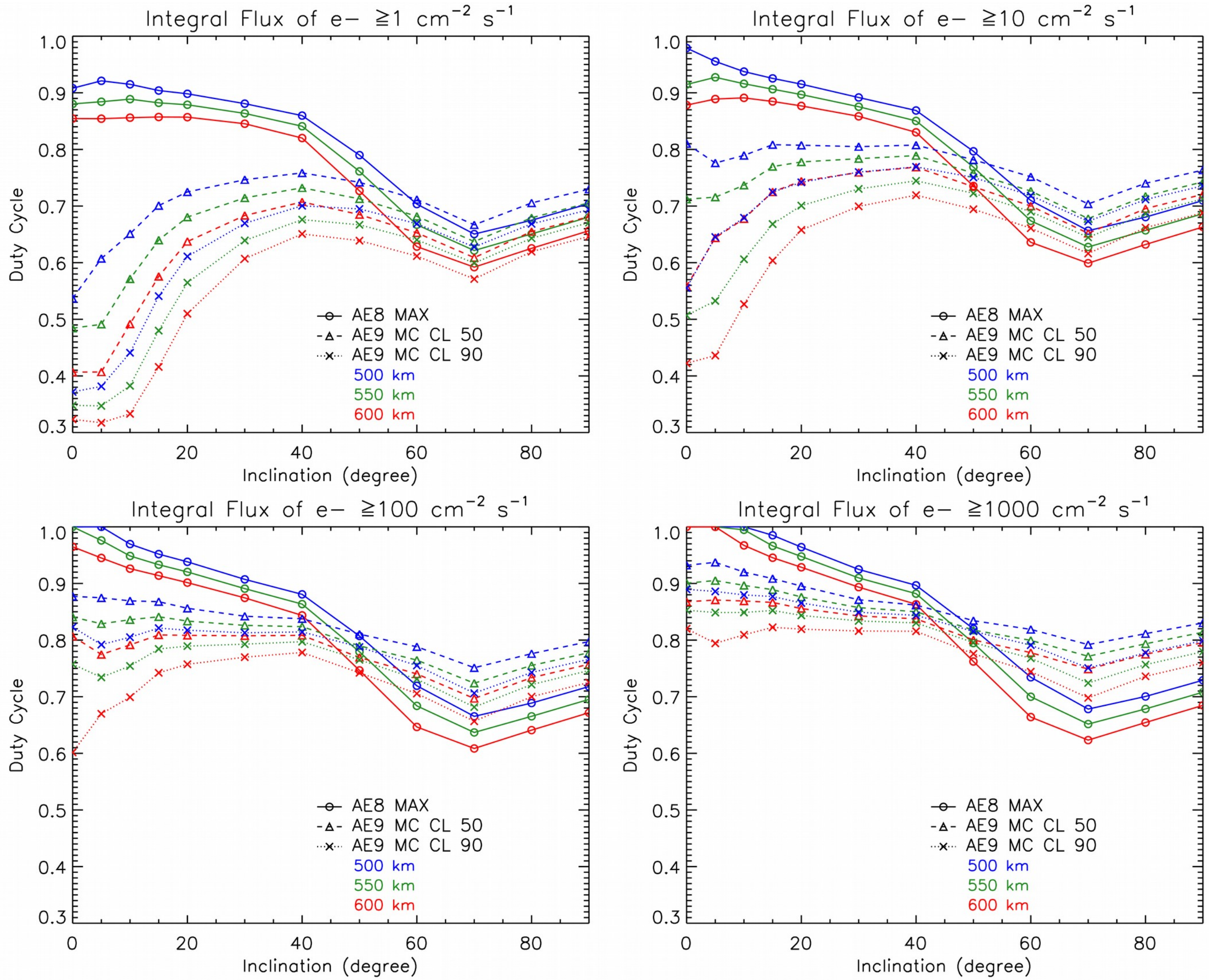


Ratio of integral fluxes of trapped electrons (AE9 50% CL / AE8 MAX) and protons (AP9 50% CL / AP8 MIN).

Duty Cycle

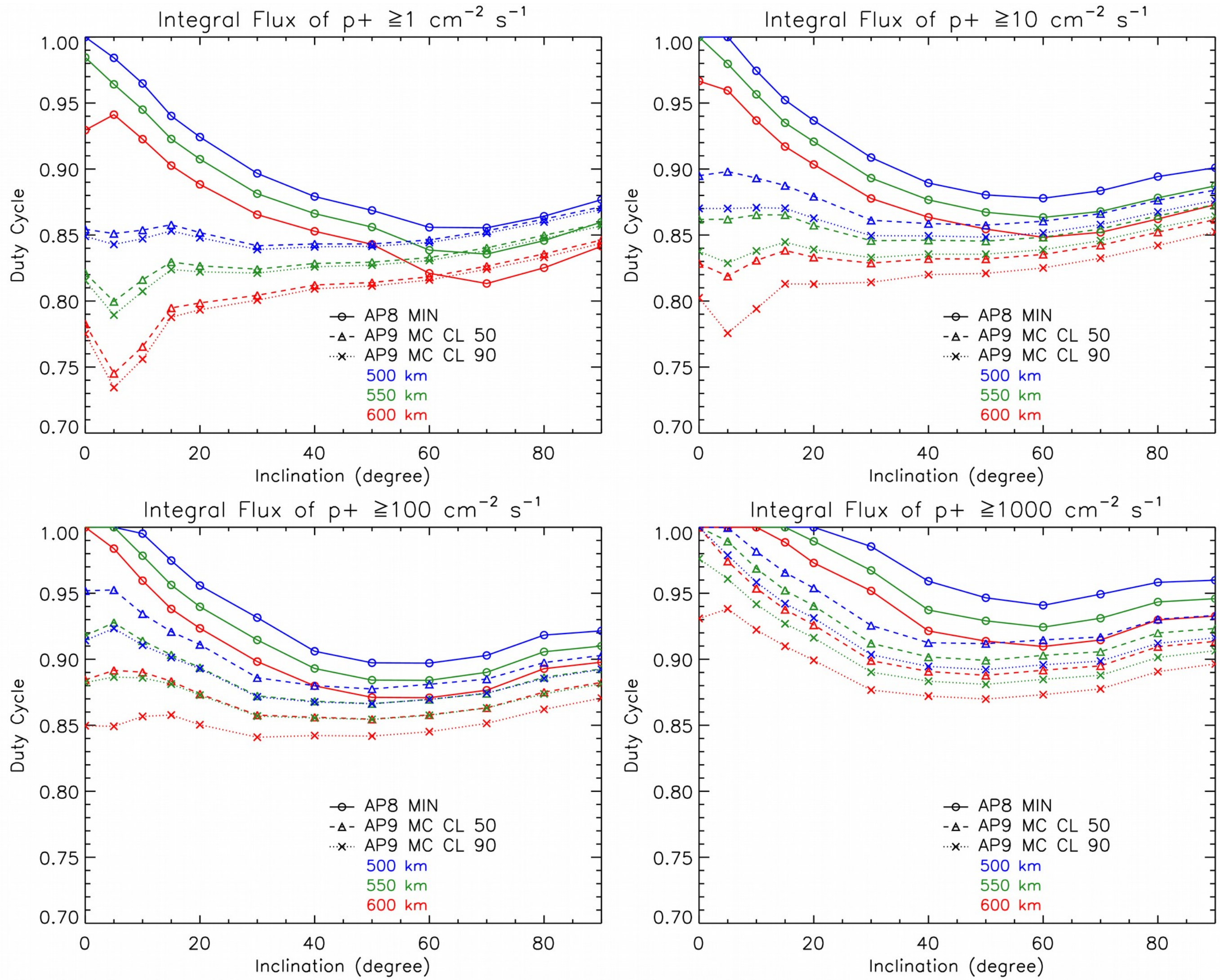
- Duty cycle was calculated as the fraction of time the satellite spends in the area with an integral flux of particles ≥ a given flux level threshold.
- Applied flux level thresholds of 1, 10, 100 and 1000 $cm^{-2}\ s^{-1}$
- Duty cycle was calculated as a function of inclination
- For altitudes 500 km, 550 km and 600 km
- For electron fluxes (models AE8 MAX, AE9 50% and 90% CL)
- For proton fluxes (models AP8 MIN, AP9 50% and 90% CL)
- For different low-energy thresholds (fluxes of particles of energy ≥ low-energy threshold)

Duty Cycle - Electrons
AE8 MAX, AE9 (50%, 90% CL)



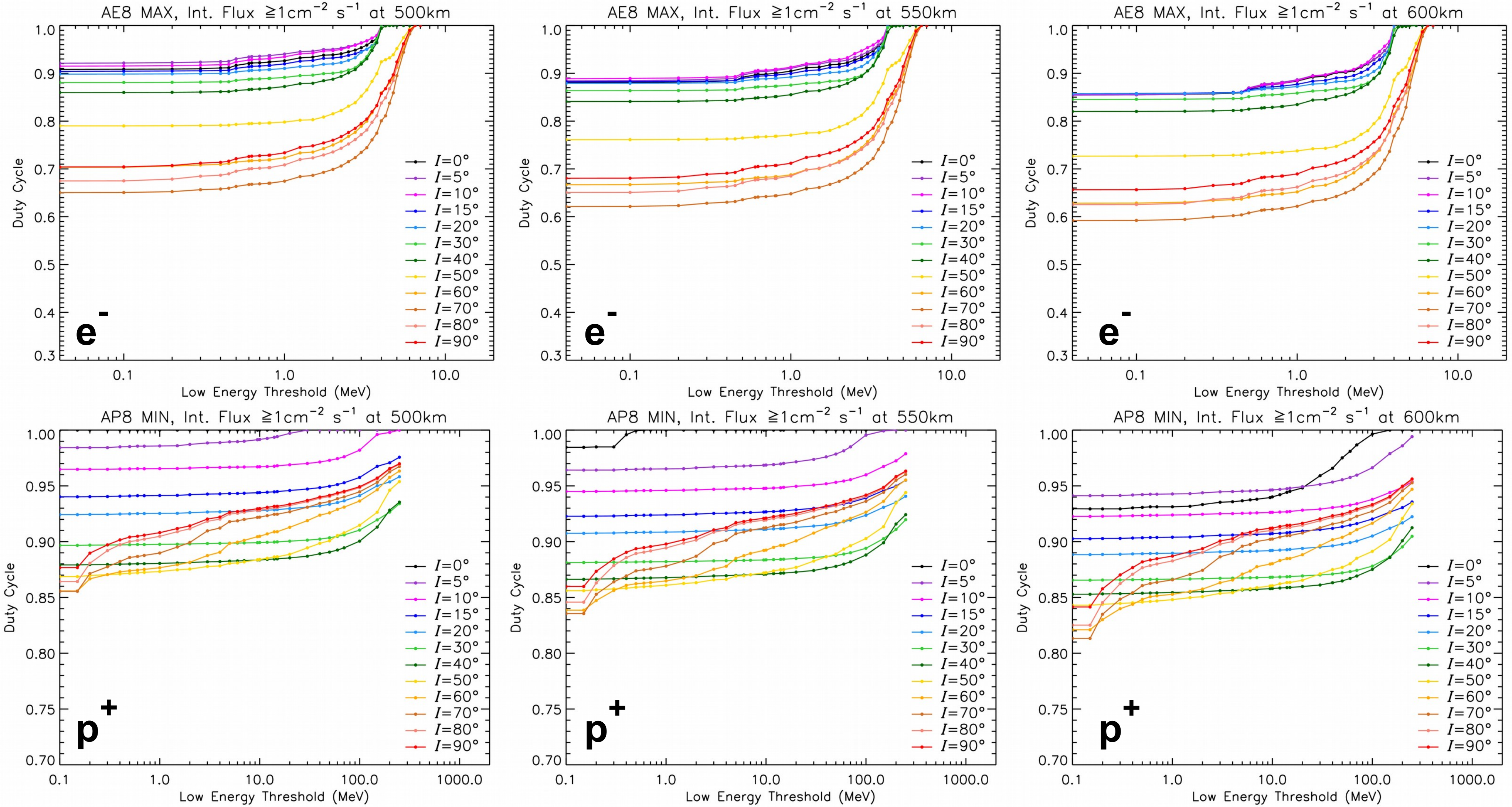
Comparison of duty cycle for different models of trapped electrons for low-energy threshold of 0.04 MeV and for different flux thresholds and altitudes.

Duty Cycle - Protons
AP8 MIN, AP9 (50%, 90% CL)



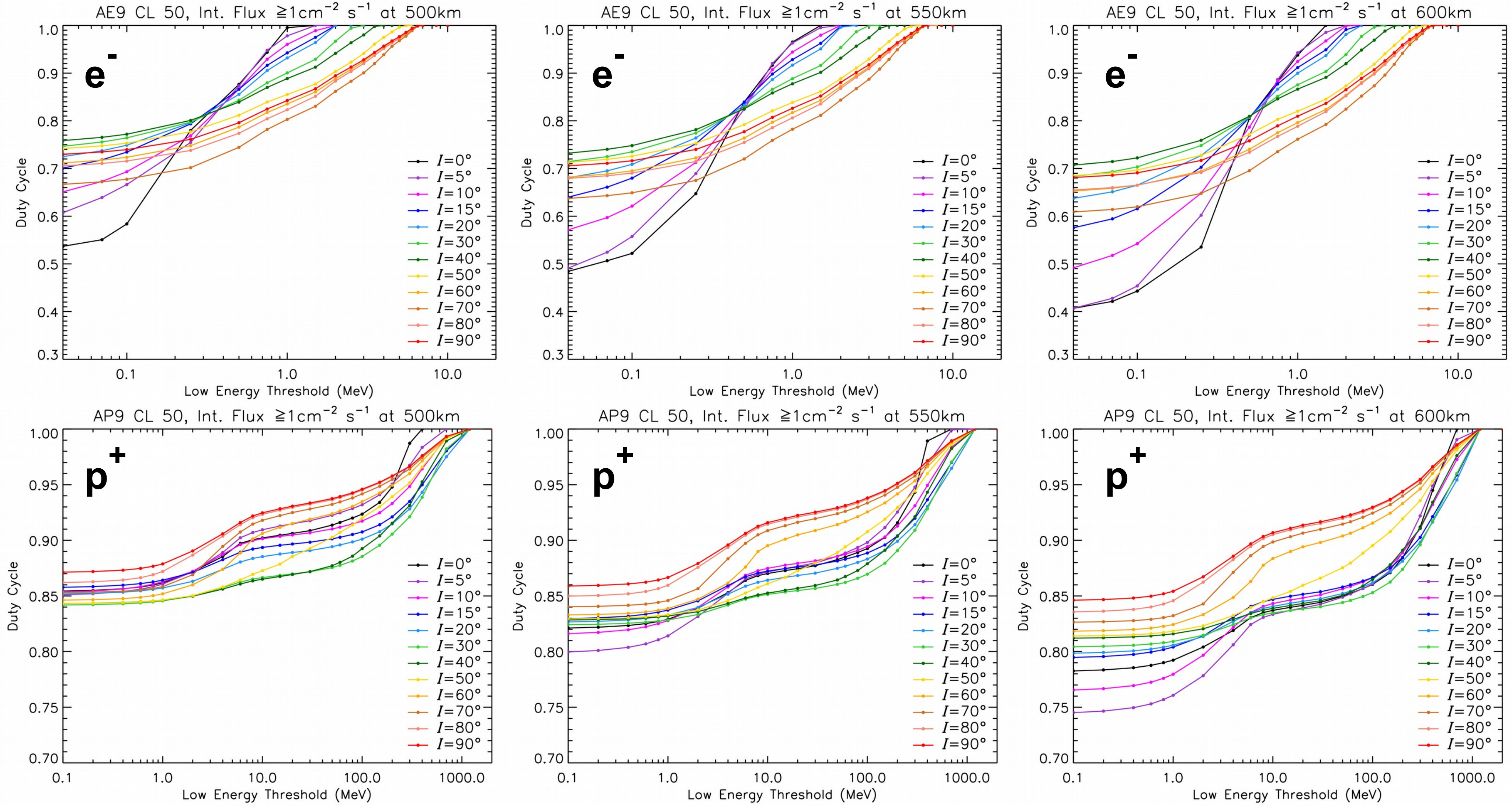
Comparison of duty cycle for different models of trapped protons for low-energy threshold of 0.1 MeV and for different flux thresholds and altitudes.

Duty Cycle - Function of Low-Energy Threshold (AE8 MAX, AP8 MIN)



Duty cycle for integral flux threshold of 1 cm^{-2} s^{-1} as a function of the low-energy threshold.

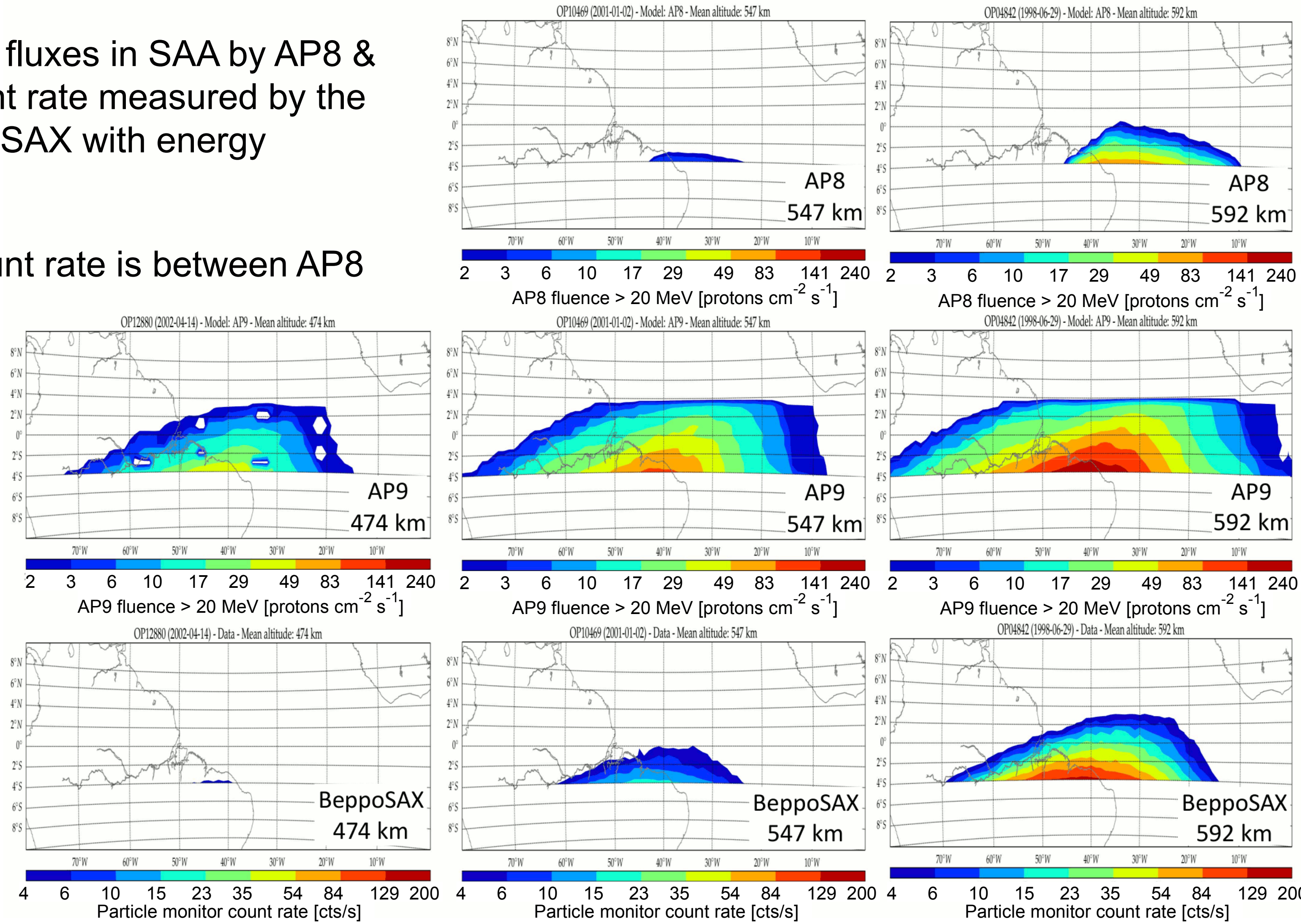
Duty Cycle - Function of Low-Energy Threshold (AE9, AP9 50% CL)



Duty cycle for integral flux threshold of 1 cm^{-2} s^{-1} as a function of the low-energy threshold.

Comparison of AP8 & AP9 with BeppoSAX measurement

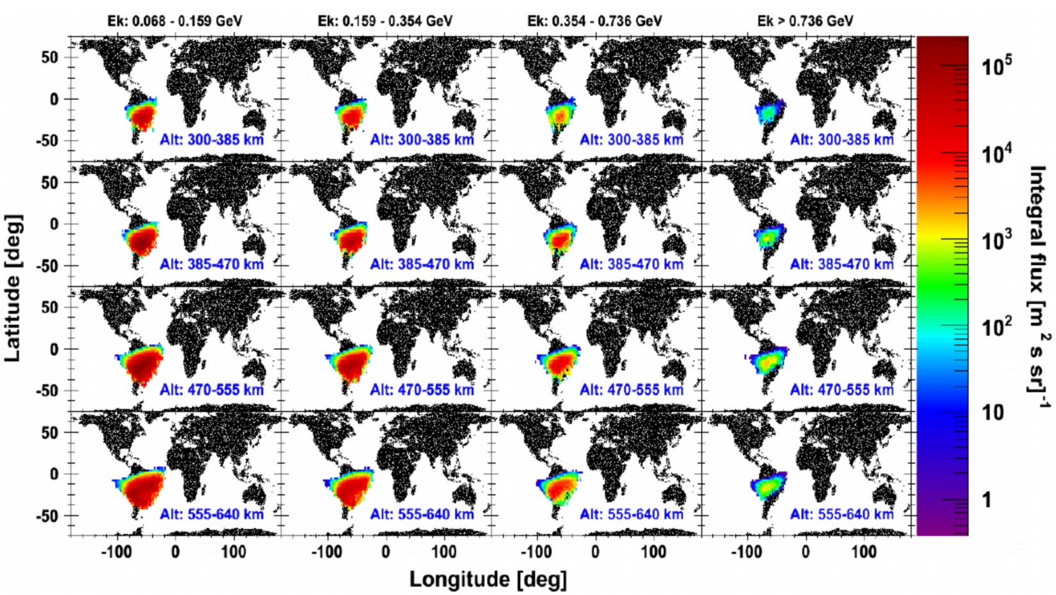
- Comparison of the proton fluxes in SAA by AP8 & AP9 models with the count rate measured by the particle monitor on BeppoSAX with energy threshold 20 MeV.
- BeppoSAX measured count rate is between AP8 and AP9.



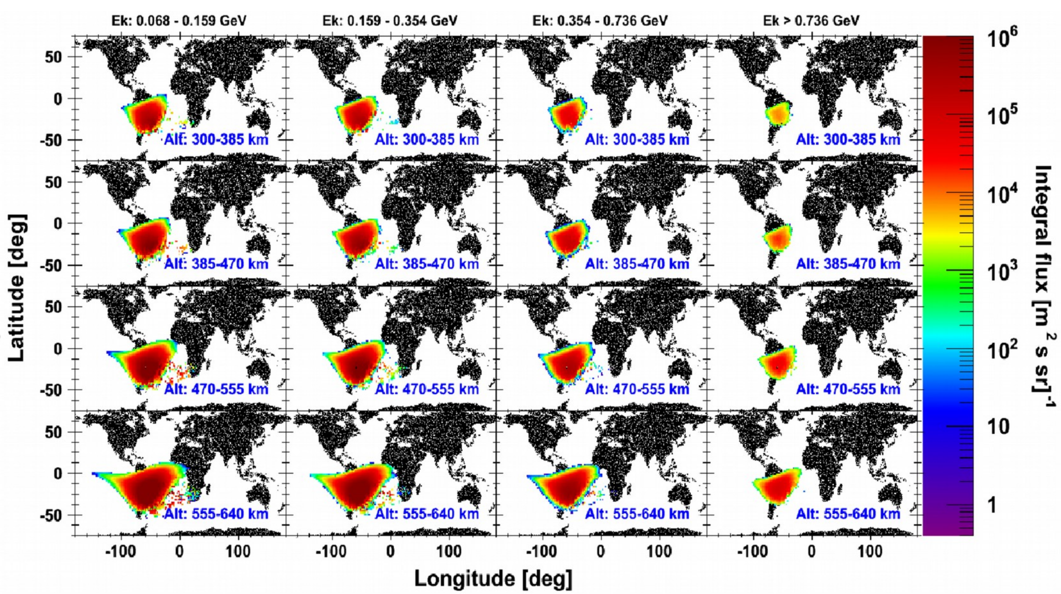
Credit: R. Campana+ 2014; R. Campana 2014 (presentation at INAF)

Comparison of AP9 with PAMELA measurement

- Mean AP9 model gives higher fluxes at SAA then PAMELA measurements



Pitch-angle averaged fluxes measured by PAMELA.



Mean AP9 fluxes averaged over the local pitch-angle range available to PAMELA.

Credit: O. Adriani+ 2015; A. Bruno & F. Cafagna 2017 (presentation)

Summary

- Models comparison:
  - AP8 MIN and AP9 models give dramatically different particle fluxes
  - Especially for low *i* (≤20° for e^- , ≤30° for p^+) and low *E* ($\lesssim$1MeV for e^- , $\lesssim$10MeV for p^+)
  - For low *i* and low *E,* AE9 50% CL gives ~10x–3000x higher flux of e^- than AE8 MAX
  - For low *i* and low *E,* AP9 50% CL gives ~10x–50 000x higher flux of p^+ than AP8 MIN
  - For $i \gtrsim 40°$ different models give comparable results (within one order of magnitude).

- Average fluxes:
  - Higher alt. gives higher flux, 50 km difference gives ~2x different average integral flux (for the same *i*)
  - *i* = ~30–50° have deepest SAA passing
  - Orbits with $i \gtrsim 50°$ (for e^-) or $\gtrsim 30°$ (for p^+) face highest average fluxes of particles (up to 6 orders of magnitude higher than near equator).

- Duty cycle:
  - For e^- by AE8 MAX model, typical duty c. = 60–90%, max. at $i \lesssim 20°$, min. at *i* = ~60–80°.
  - For p^+ by AP9 MIN model, typical duty c. = 80–100%, max. at $i \lesssim 20°$, min. at *i* = ~40–70°.
  - AE8 and AE9 models give very different duty cycles for low i and low flux thresholds because AE9 has excess of low-energy, low-flux e^- near equator compared to AE8.

- Models compared to measurements:
  - BeppoSAX and PAMELA measurements suggest that AP9 might overestimate the actual flux for altitudes <600km and low inclinations, while AP8 MIN might underestimate the actual flux.
  - We are searching for other measurements to be compared with AP8/AP9 models.