A Directional Trapped Proton Model for the International Space Station Orbit

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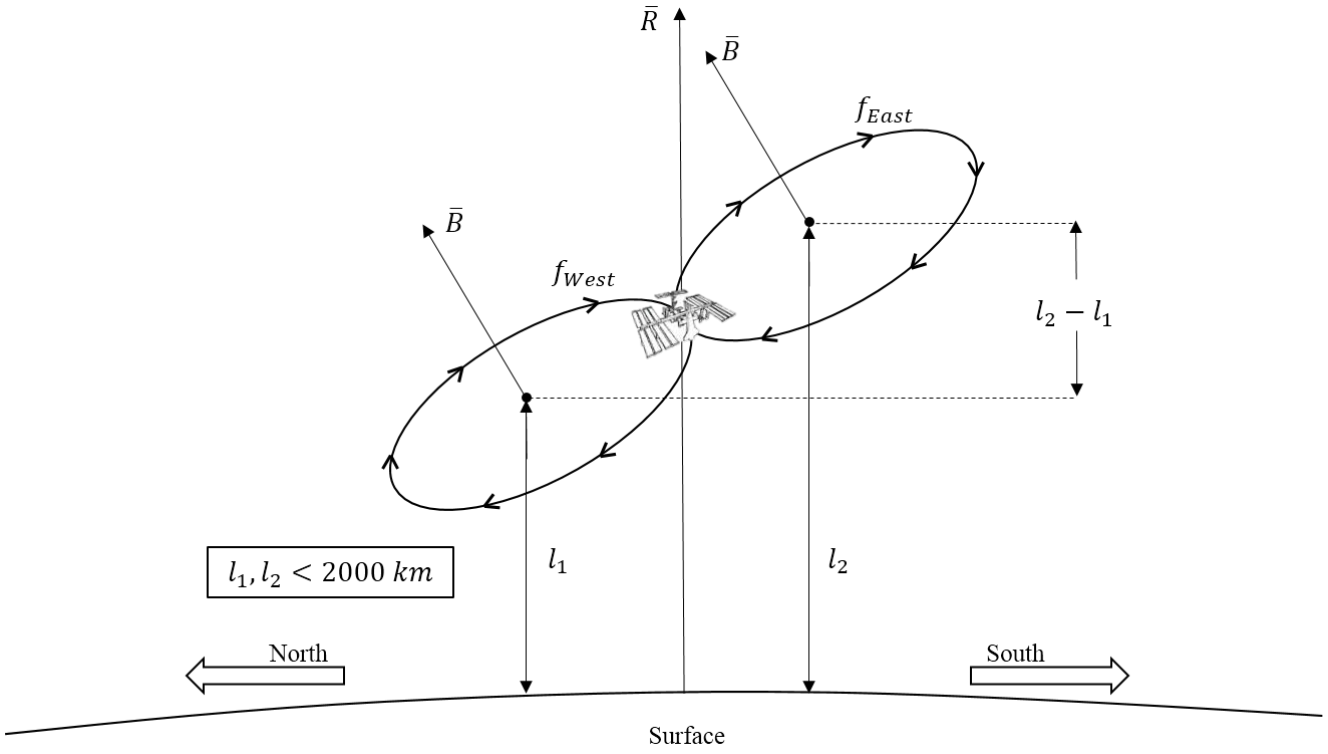
Outline

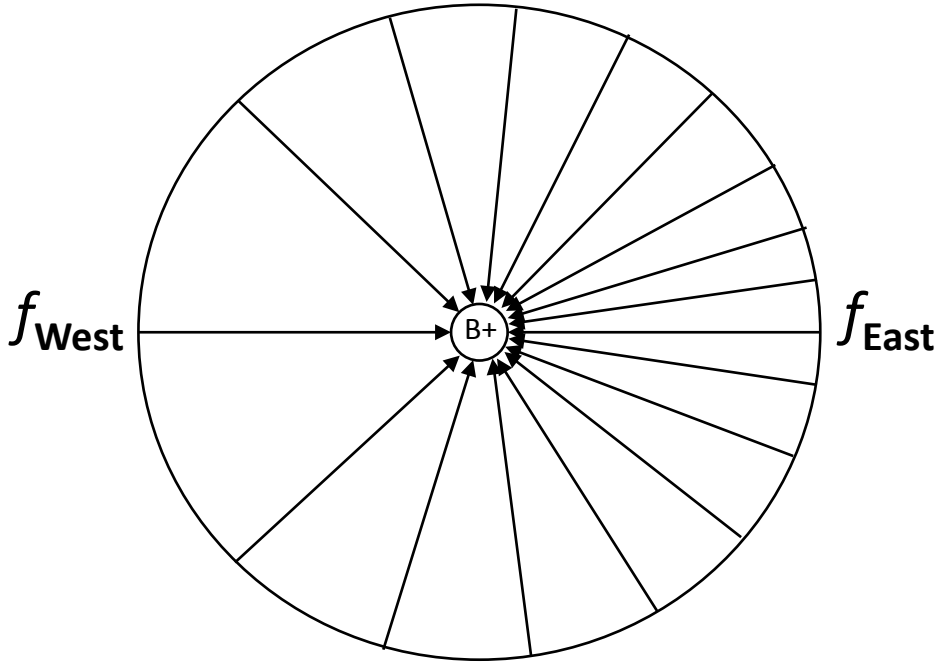
- Describe an angular model to account for proton flux anisotropy (directionality) at Low Earth Orbit (LEO) inside/outside the South Atlantic Anomaly (SAA) region
- Using US Air Force Tri-Service Experiment 5 (AF-TSX5) satellite measurements and the omni-directional trapped proton models AP8/AP9, validate the angular model at three locations within SAA
- Using Crew Quarter (CQ) of Zvezda Service Module (SM) ray-traced geometry of ISS, and the trapped models AP8/AP9, apply the angular model to proton anisotropy **dosimetric simulation** of ISS within SAA, and compare the simulation with ISS daily measurement
- Summary

“East – West effect” of Proton Anisotropy within SAA (100 – 2000 km)

$flux_{East} > flux_{West}$

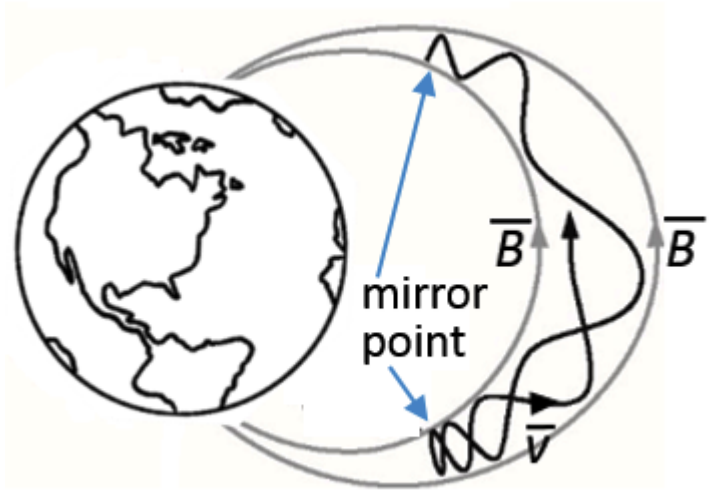


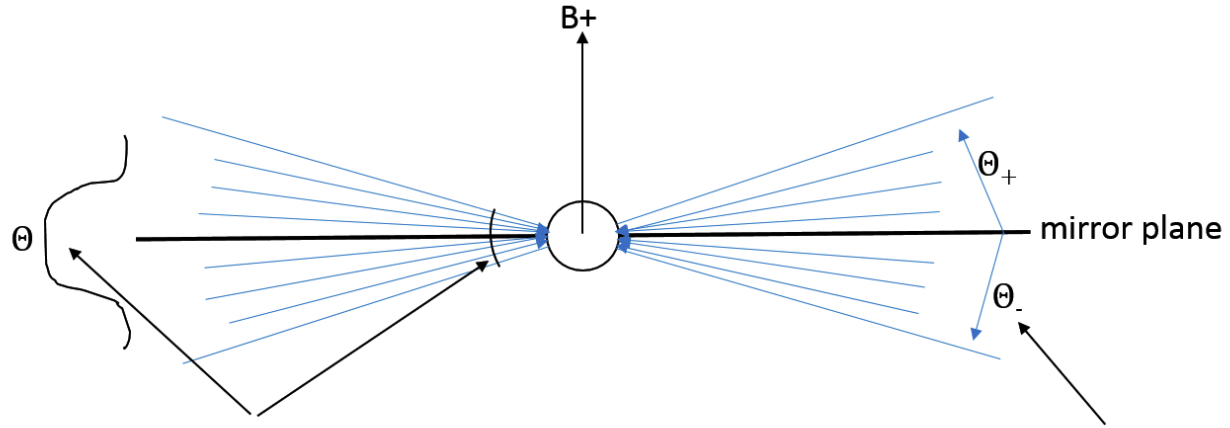
Side view



Top view

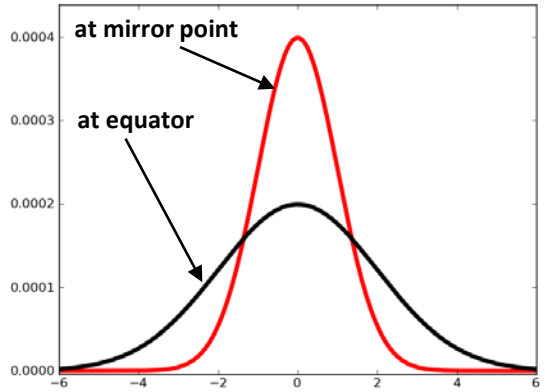
“Pitch Angle Distribution Effect” of Proton Anisotropy Near Mirror Point within SAA



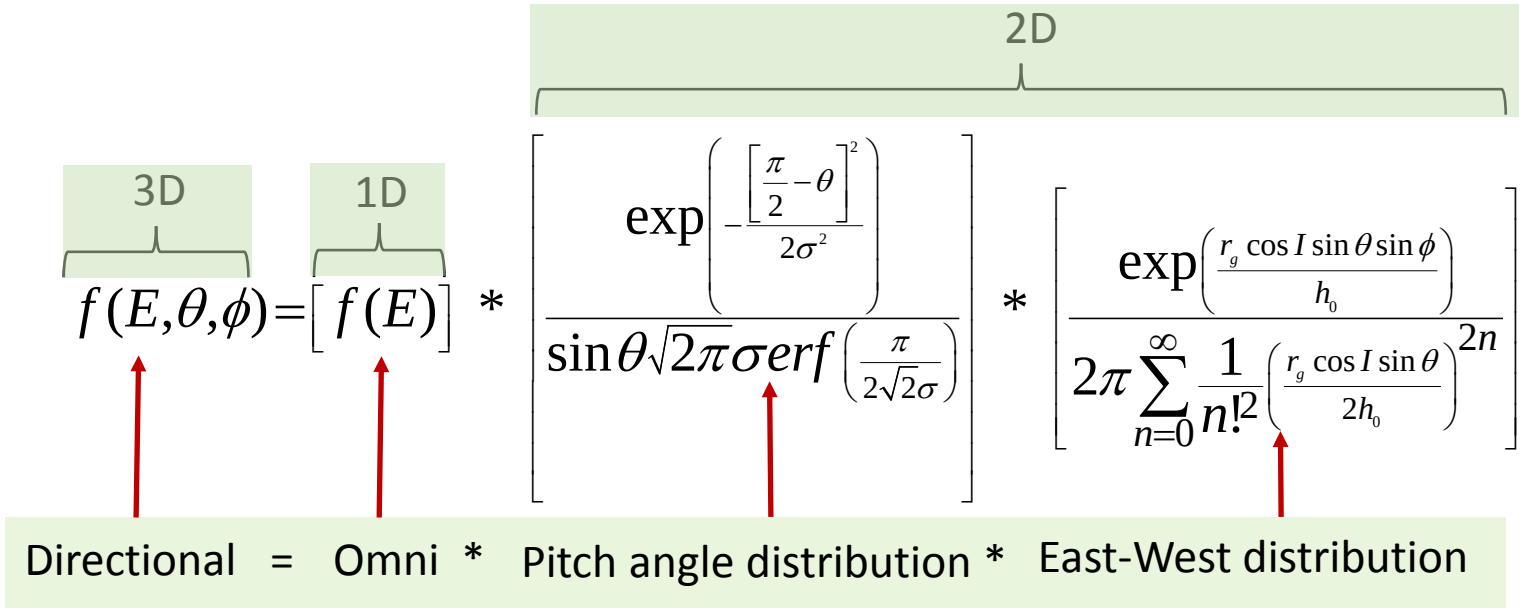


Θ: Pitch angle distribution has a Gaussian profile

Θ: Pitch angle variation near mirror point



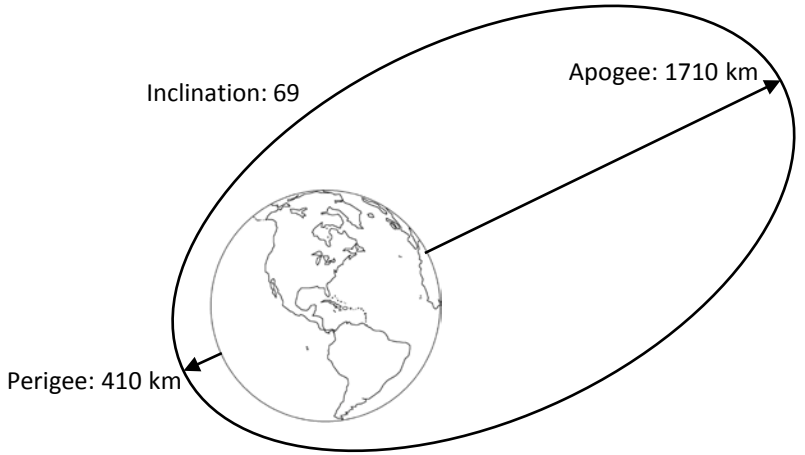
Combined “East - West” and “Pitch Angle” Distribution Effects Formalism Describing Proton Anisotropy within SAA



- h_0 (300 – 2000 km) is atmospheric scale height (ISS = 80 km)
- I is magnetic dip angle between B field and Earth surface (ISS I = 42˚)
- σ is pitch angle standard deviation (h_0, I, R, ISS σ = 8˚)
- r_g is proton gyro-radius (km)
- ϕ is azimuth (0 - 2π)
- θ is pitch angle near mirror point

AF-TSX5 Satellite Orbit Description

[Ginet] AF-TSX5 satellite (2001 - 2006)

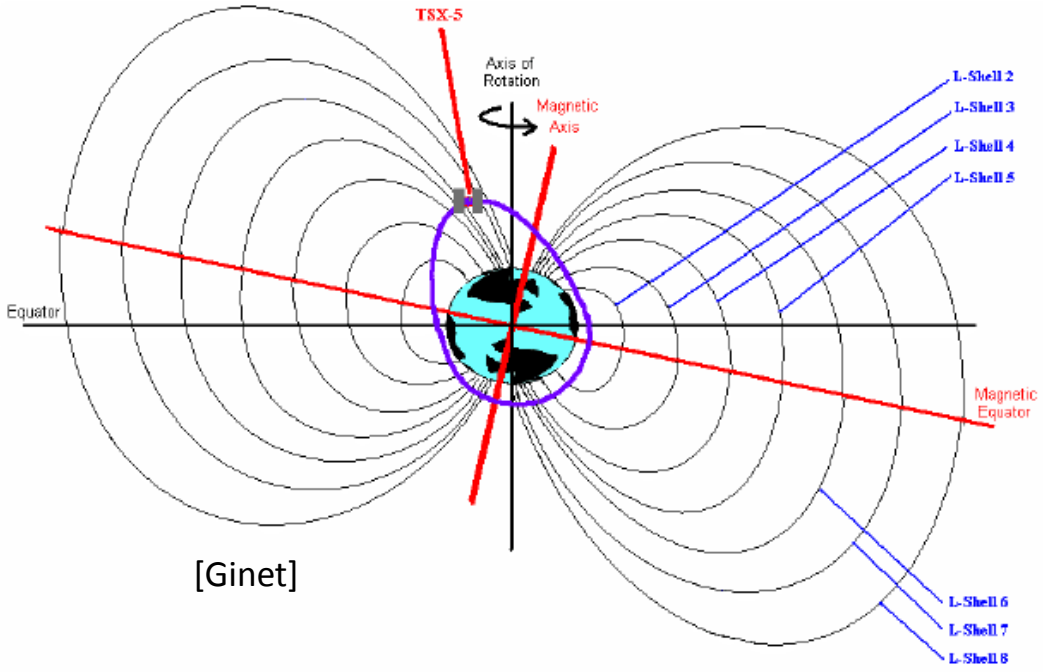


[Ginet]

- 69˚ inclination allows coverage of many L shells (2 - 8) in a single orbit
- 410 - 1710 km altitude range allows coverage of atmospheric density variation within thermosphere and low exosphere (ionosphere)

Ginet, et al., Proton flux anisotropy in low earth orbit, IEEE Trans. Nucl. Sci. 54 (6) (2007) 1975–1980

AF-TSX5 Compact Environment Anomaly SEnsor (CEASE) Particle Detector



[Ginet]

Single orbit crossing of AF-TSX5 in B - L geomagnetic coordinate for L shells 1 - 8

[Dichter]

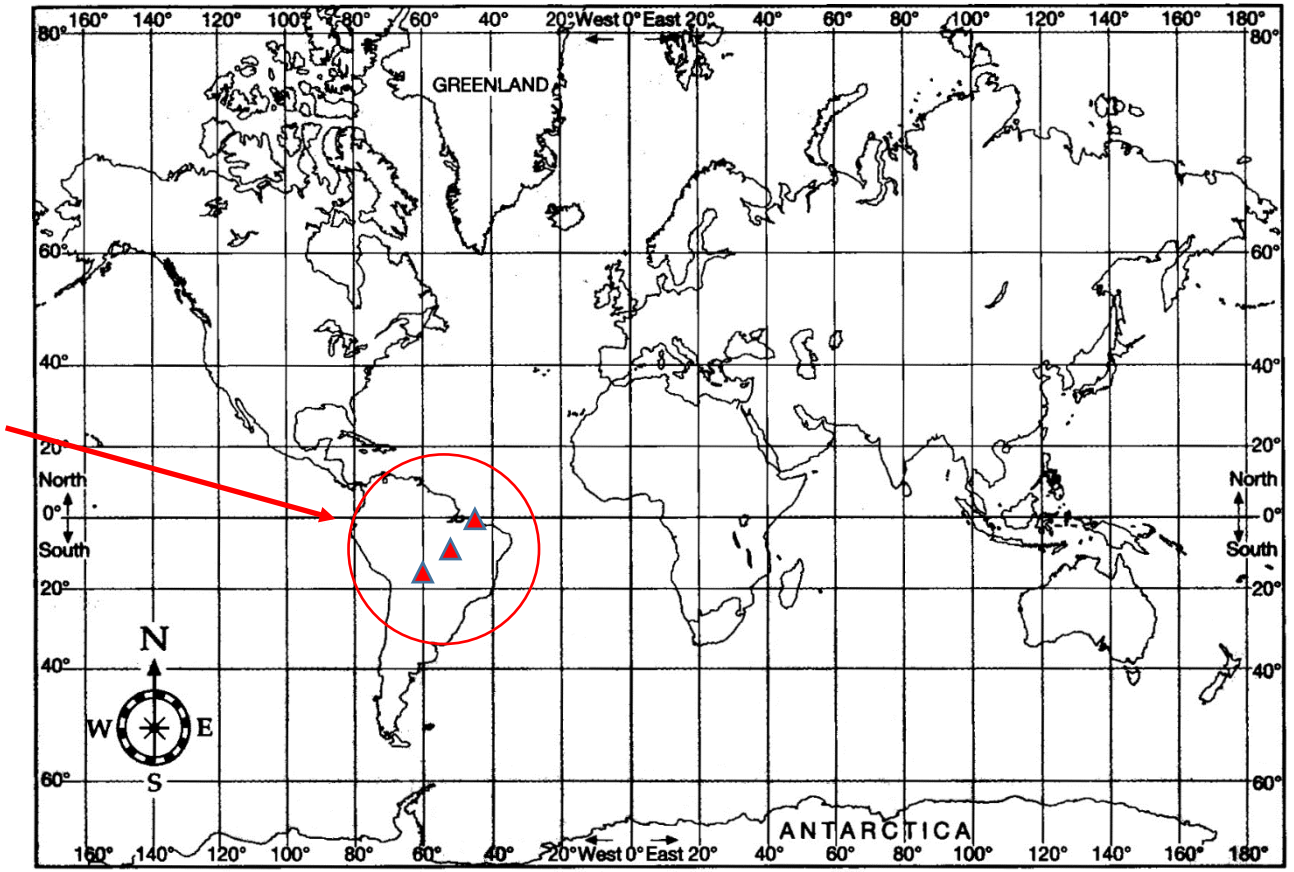
CEASE (Compact Environment Anomaly SEnsor) instrument. Small, light weight and low power particle detector (1.7 W)

Ginet, et al., Proton flux anisotropy in low earth orbit, IEEE Trans. Nucl. Sci. 54 (6) (2007) 1975–1980

Dichter, et al., Compact environmental anomaly sensor (cease): a novel spacecraft instrument for in situ measurement of environmental conditions, IEEE Trans. Nucl. Sci. 45 (6) (1998) 2758–2764.

AF-TSX5 Compact Environment Anomaly SEnsor (CEASE)
Particle Detector Data Acquisition Attitude

Here, longitude and latitude are fixed and altitude changes between 400 - 1700 km



SAA orbital crossing of AF-TSX5 for L shells 1 - 8

Proton Anisotropy within SAA at a Geographic Point with a Specific Look Direction

Becomes constant

Has only one variable

$$f(E,\theta,\phi) = [f(E)] * \left[\frac{\exp\left(-\frac{\left[\frac{\pi}{2} - \theta\right]^2}{2\sigma^2} \right)}{\sin\theta\sqrt{2\pi}\sigma erf\left(\frac{\pi}{2\sqrt{2}\sigma}\right)} \right] * \left[\frac{\exp\left(\frac{r_g \cos I \sin\theta \sin\phi}{h_0}\right)}{2\pi \sum_{n=0}^{\infty} \frac{1}{n!^2} \left(\frac{r_g \cos I \sin\theta}{2h_0}\right)^{2n}} \right]$$

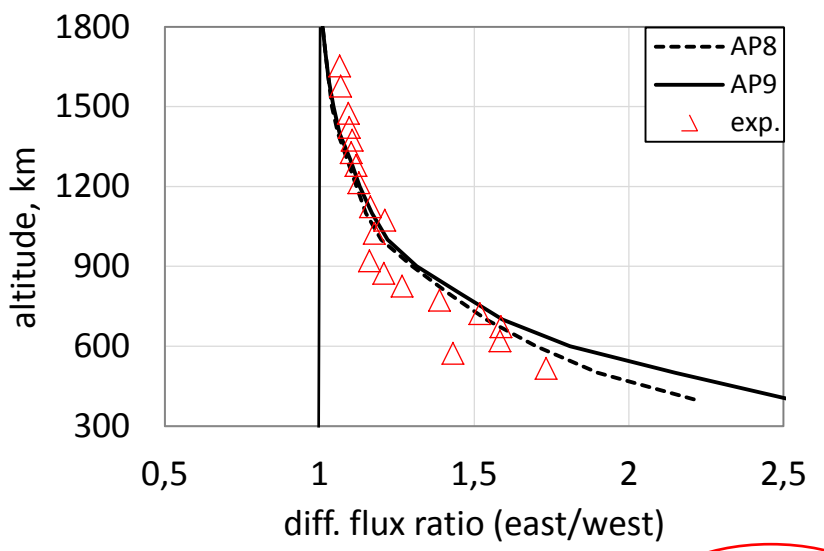
= are constants

= are variables

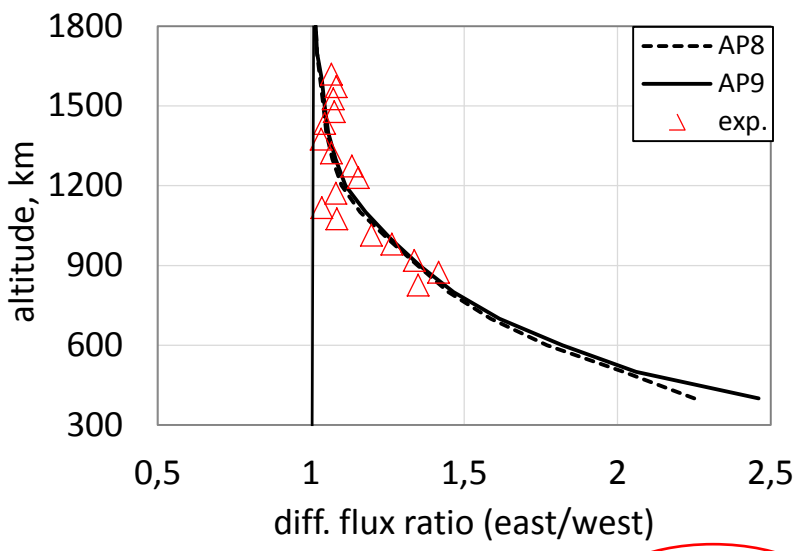
$$r_{g,p} \propto \frac{E_p}{B}$$

I want to look at only E and W directions, so I make azimuth angle φ to be either 90° or 270° degree

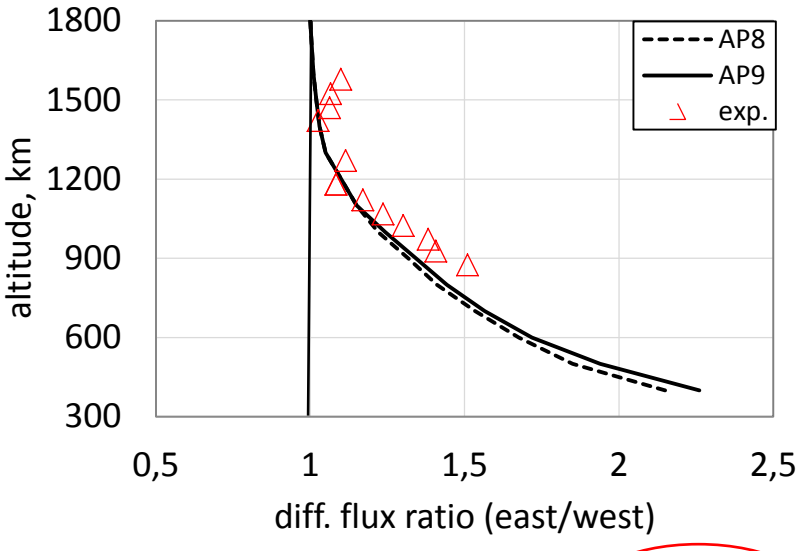
AF-TSX5 CEASE Differential Flux (40 MeV) Proton Validation of AP8/AP9 Trapped Models



40 MeV flux ratios (east/west) at 18°S, 300°E

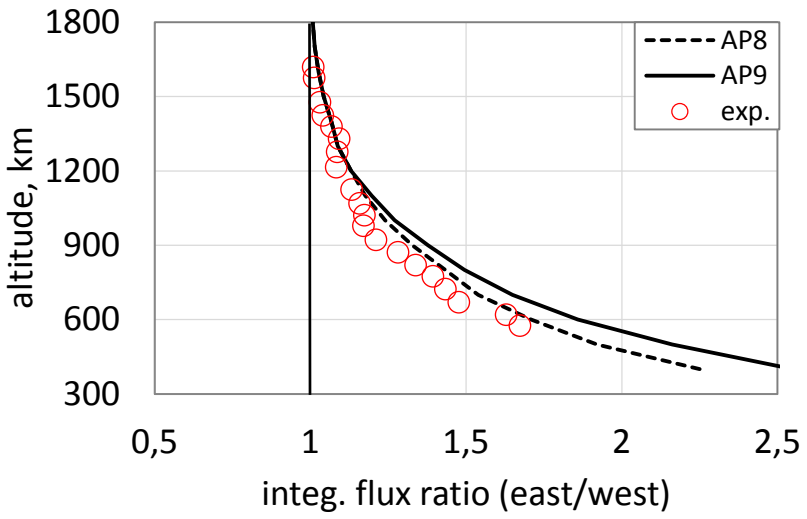


40 MeV flux ratios (east/west) at 9°S, 309°E

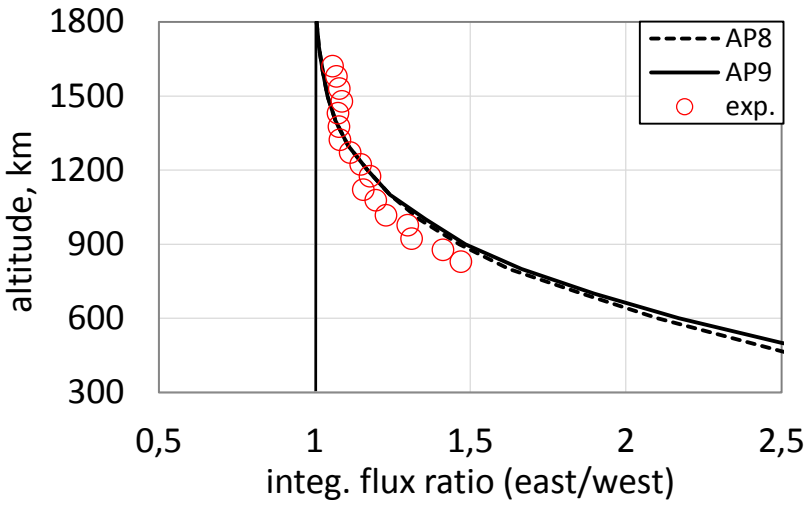


40 MeV flux ratios (east/west) at 0°S, 315°E

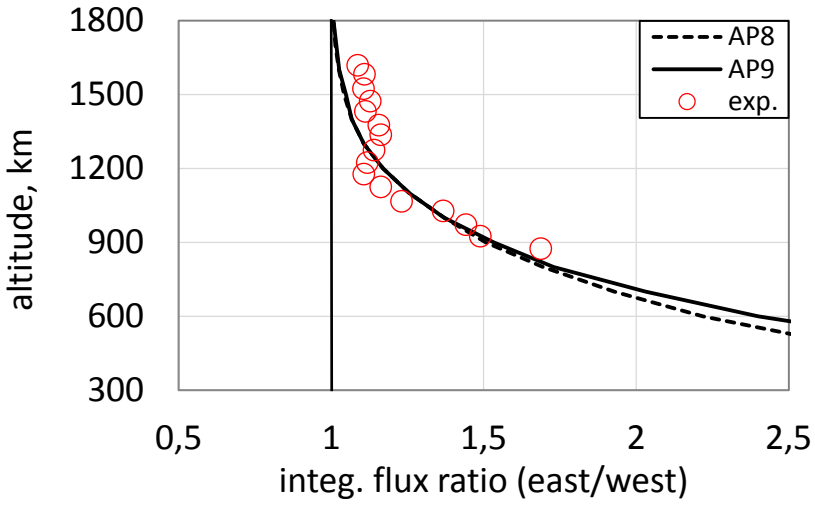
AF-TSX5 CEASE Integral Proton Flux (>40 MeV) Validation of AP8/AP9 Trapped Models



>40 MeV flux ratios (east/west) at 18°S, 300°E

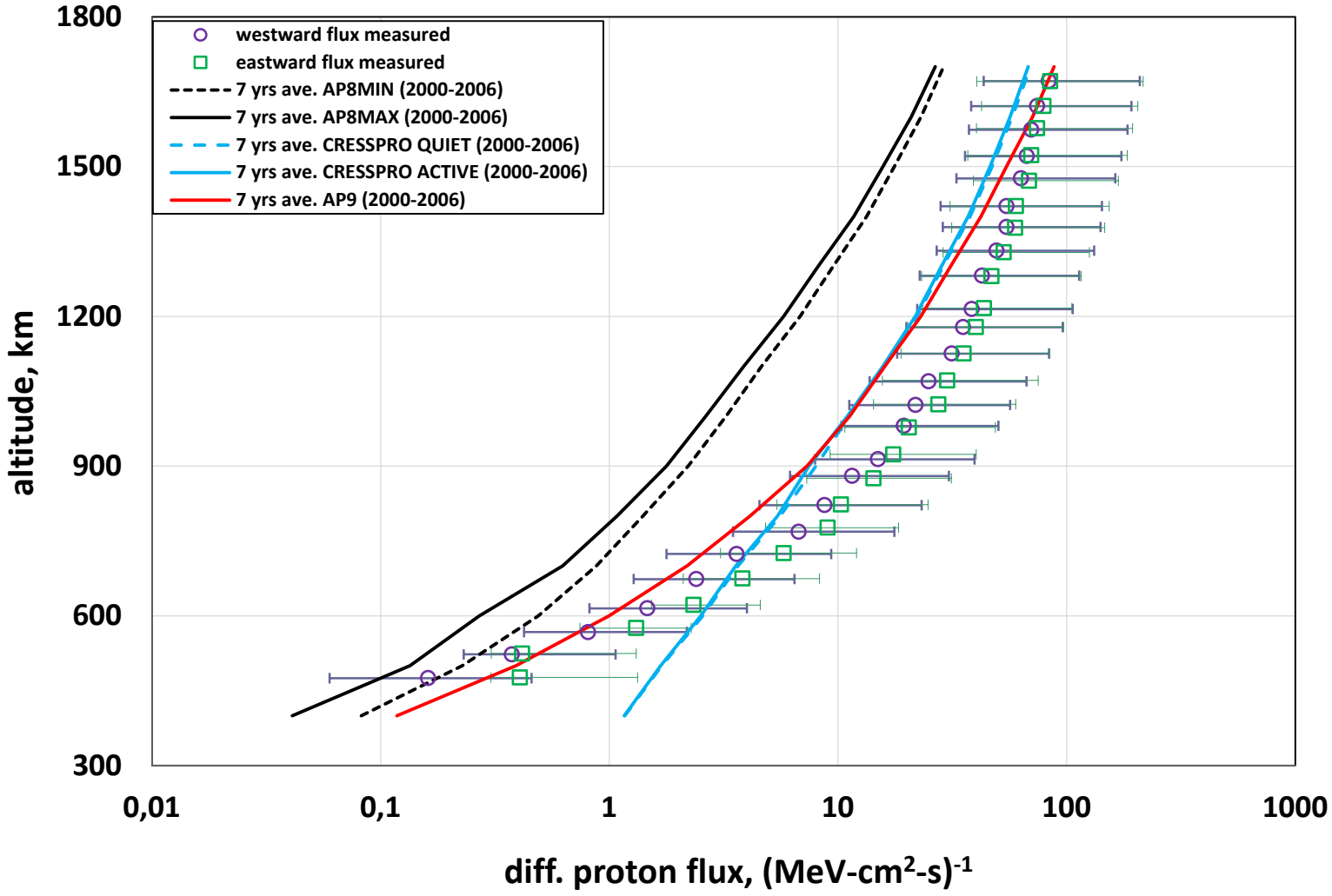


>40 MeV flux ratios (east/west) at 9°S, 309°E

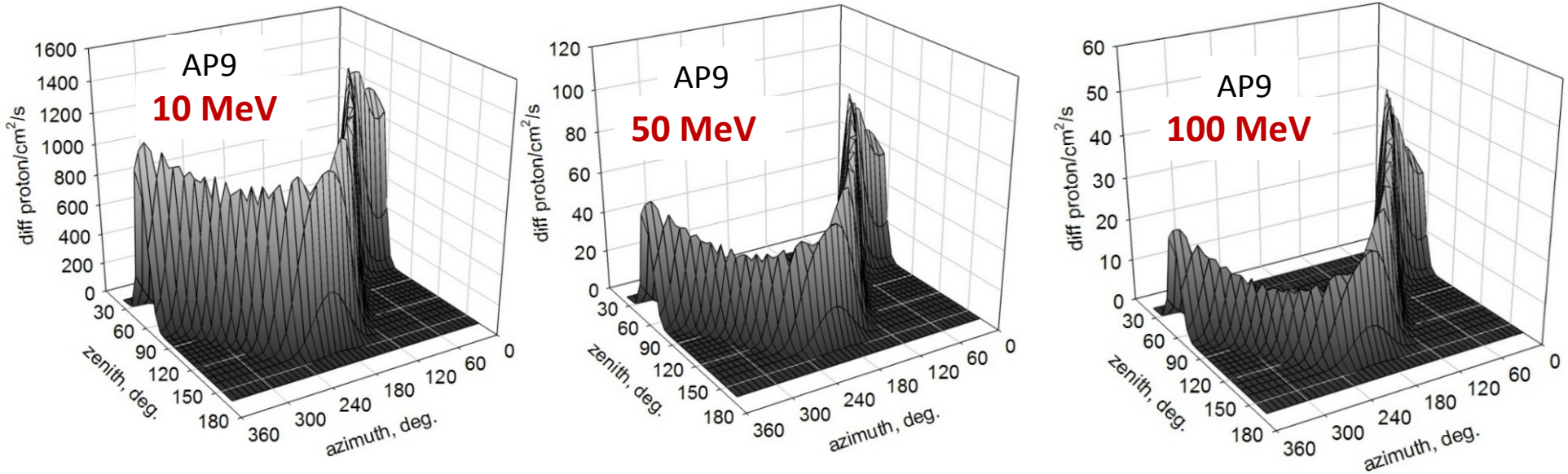


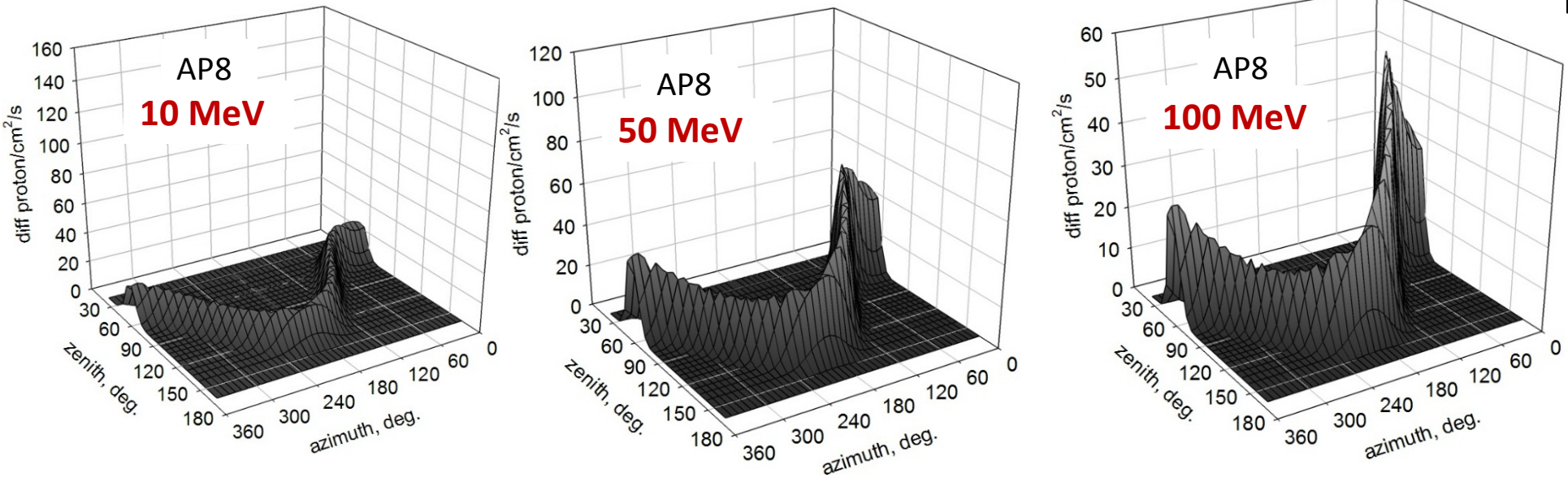
>40 MeV flux ratios (east/west) at 0°S, 315°E

AF-TSX5 CEASE Validation of AP8/AP9/CRESSPro Trapped Models



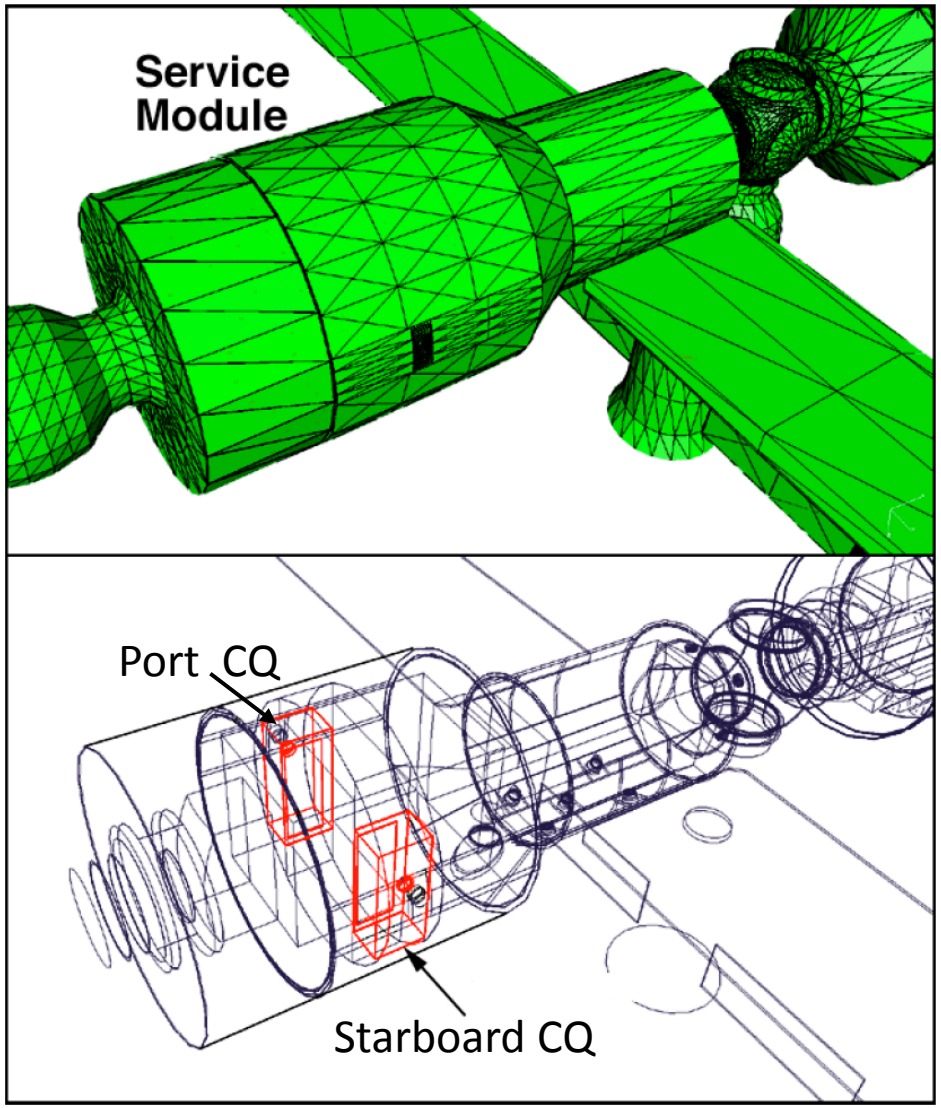
ISS Ascending Node Anisotropic Proton Flux Distributions from AP8/AP9 Trapped Models at the Center of SAA

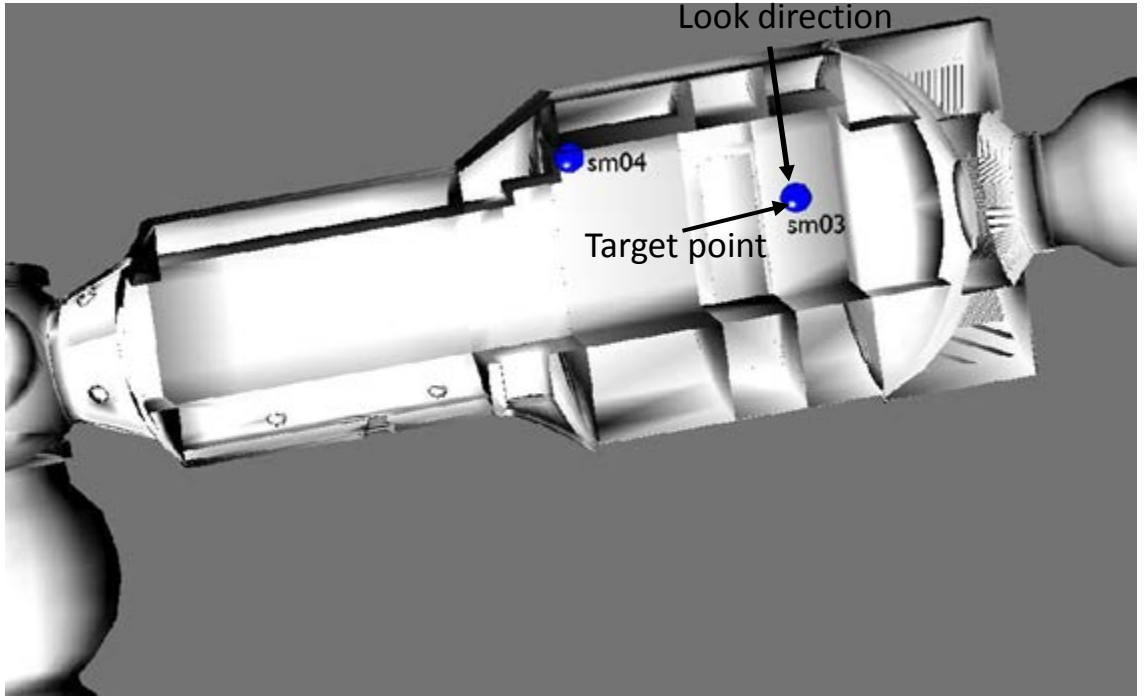




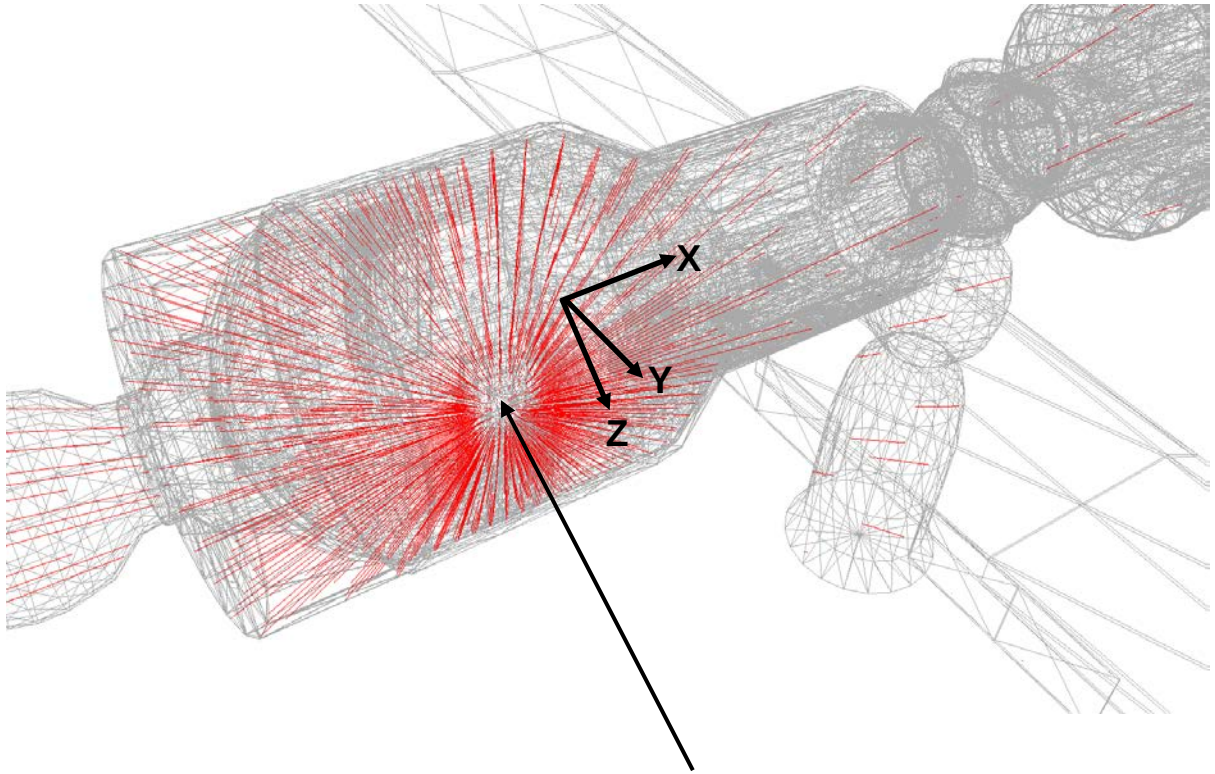
Here, azimuth and zenith are in ISS internal coordinate

ISS Dosemetric Target Point Definition

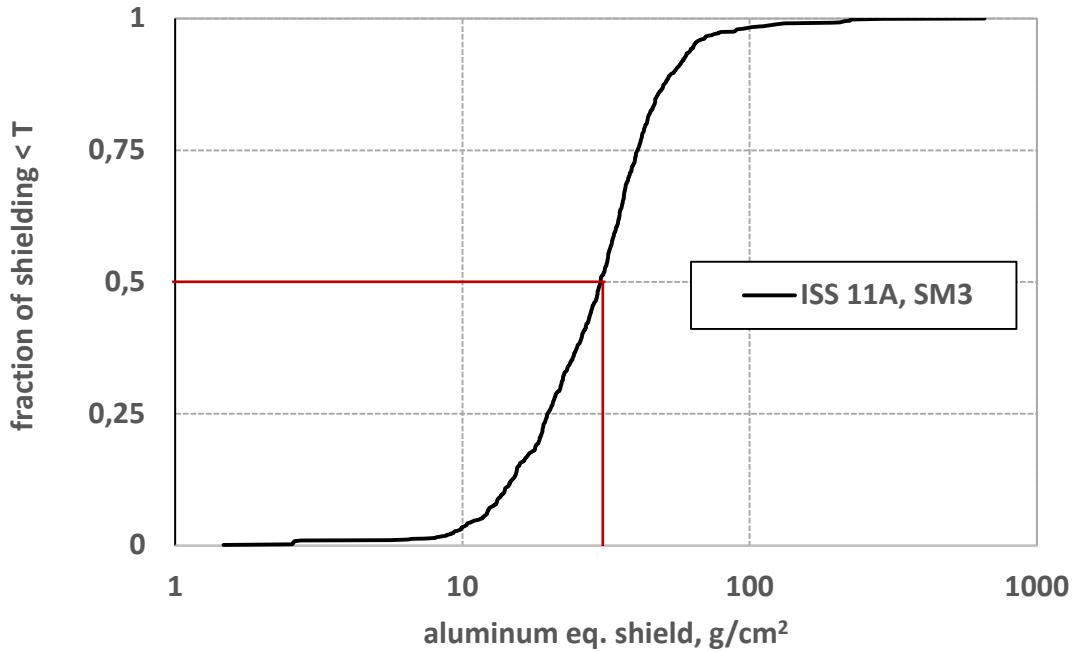




ISS Dosemetric Target Point Definition

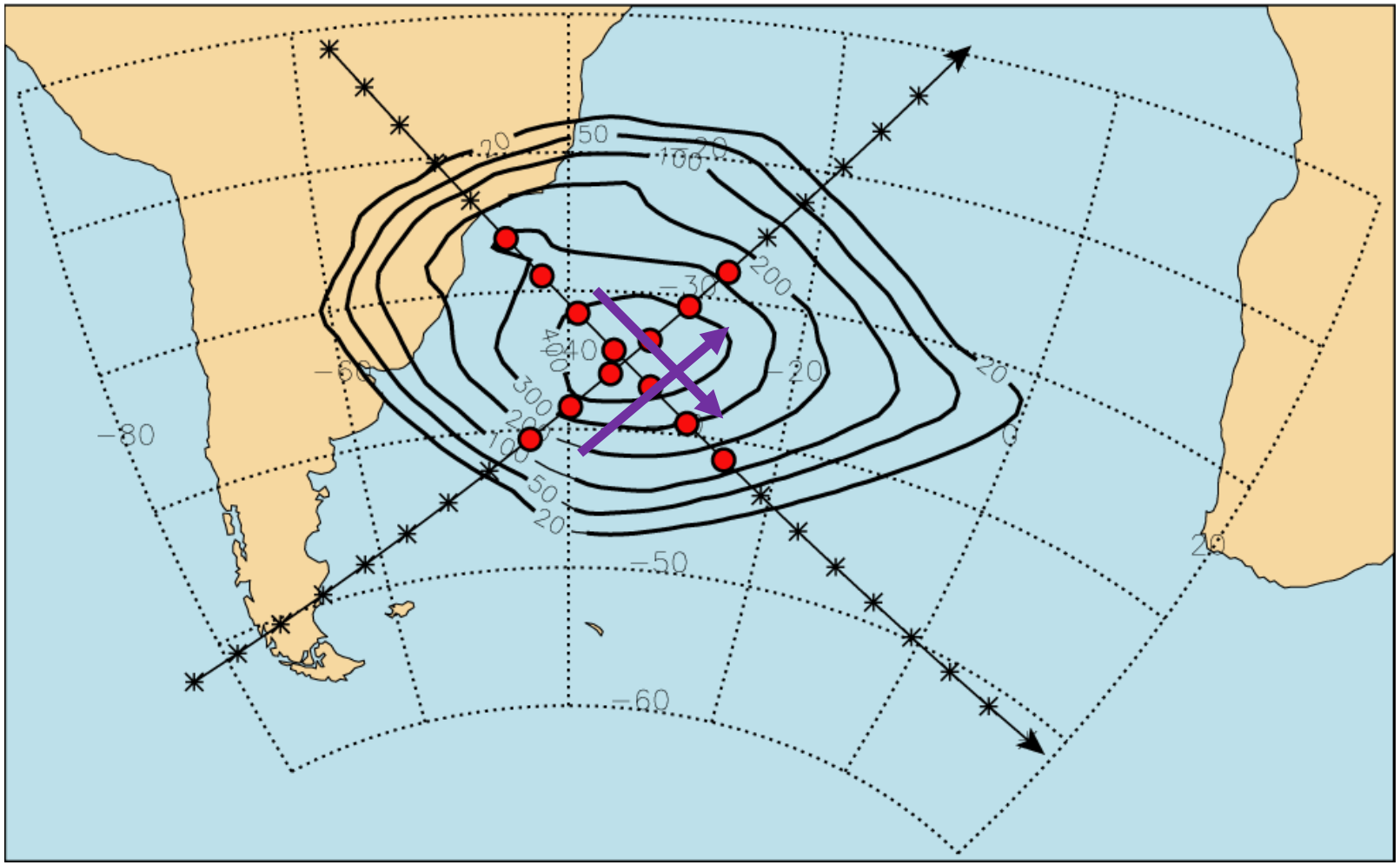


CQ ray traced at SM3 target pt.



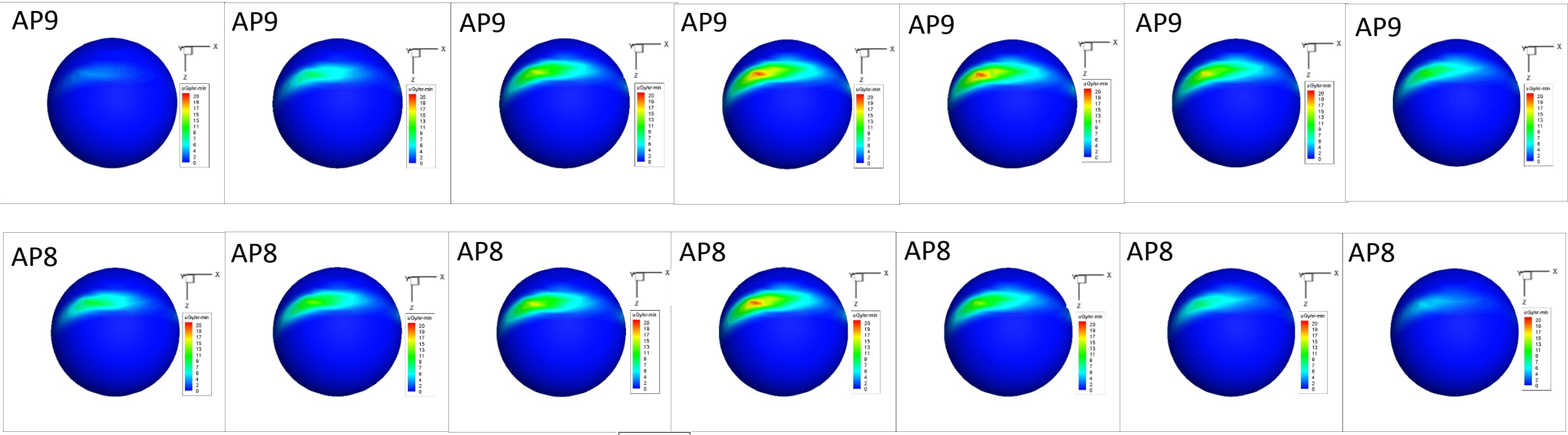
SM3 target pt. thickness dist. of CQ (50% ~ 20 g/cm²)

ISS Ascending and Descending Nodes within SAA



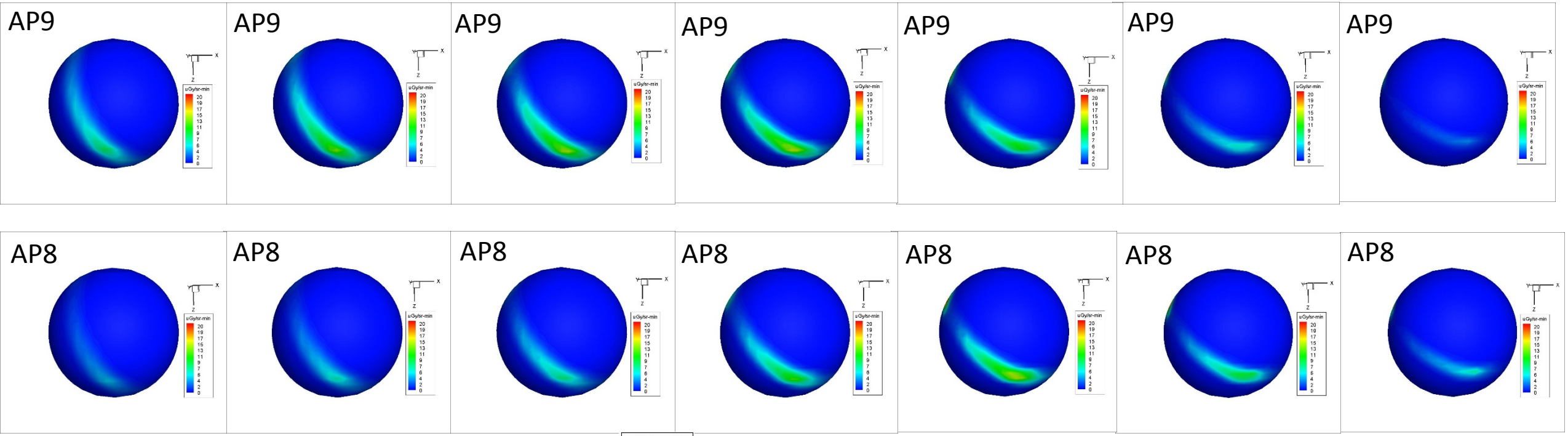
ISS Ascending Node AP8/AP9 Comparison within SAA

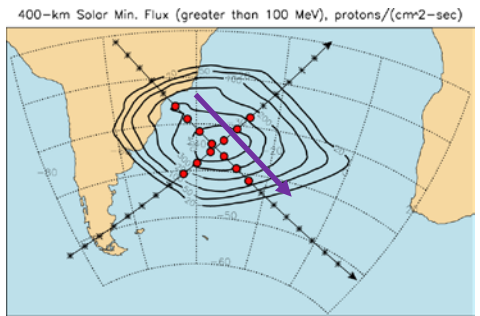
SM3 target pt. directional dose (μGy/sr/min) in a Silicon detector

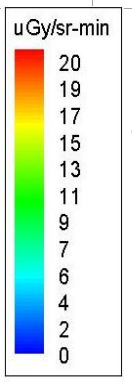


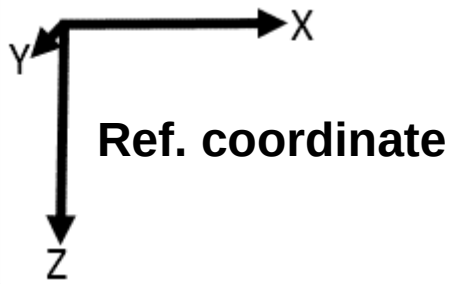
ISS Descending Node AP8/AP9 Comparison within SAA

SM3 target pt. directional dose (μGy/sr/min) in a Silicon detector





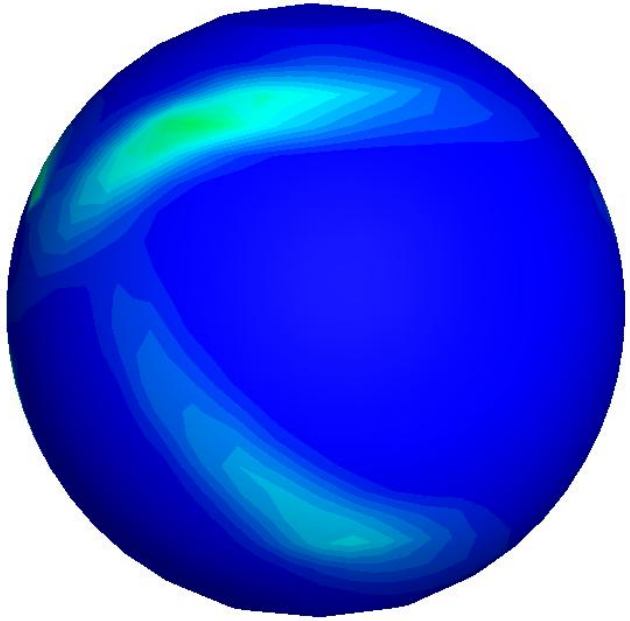


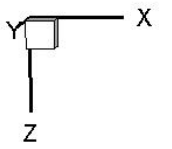


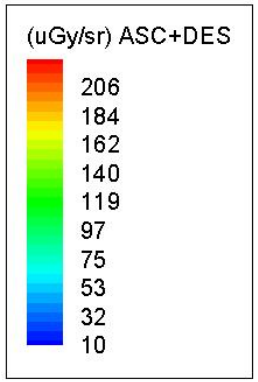
ISS Combined Nodes AP8/AP9 Comparison within SAA

Ascending+descending nodes CQ-SM3 target pt. exposure for 7 mins (µGy/sr)

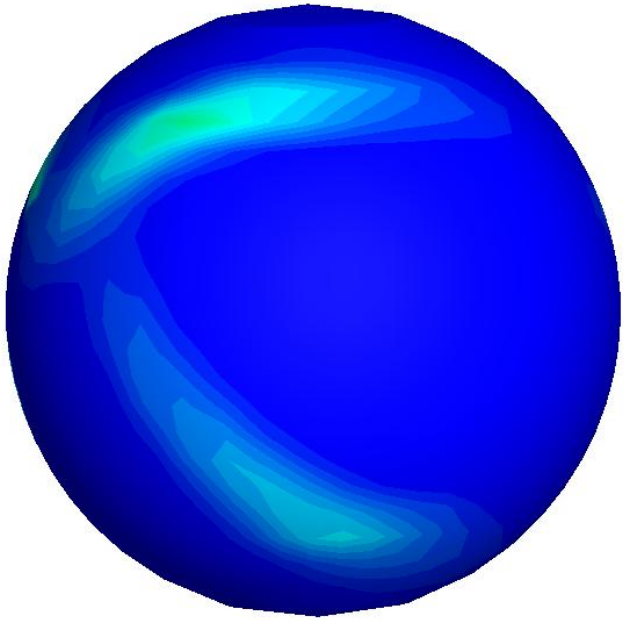
AP9

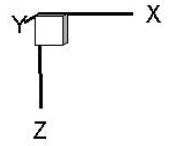


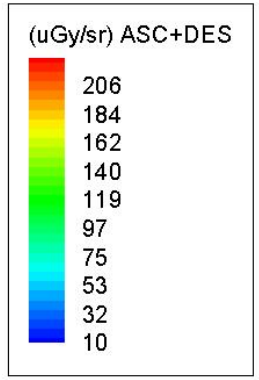


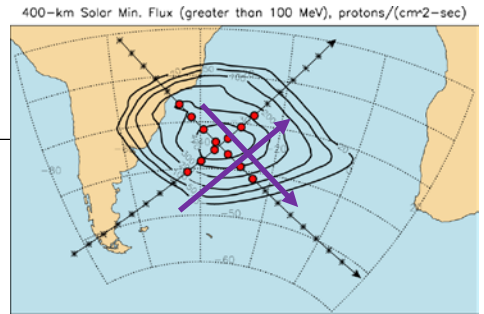


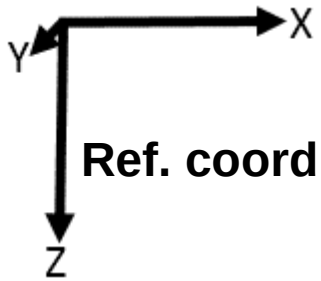
AP8









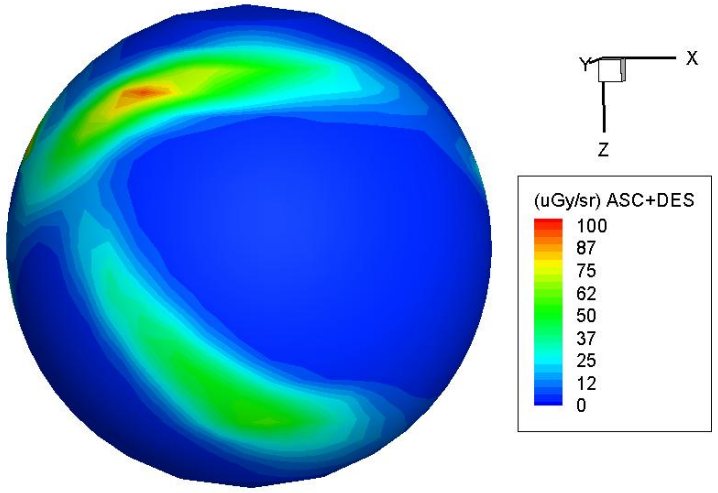


Ref. coordinate

ISS Combined Nodes AP8/AP9/GCR Comparison within SAA

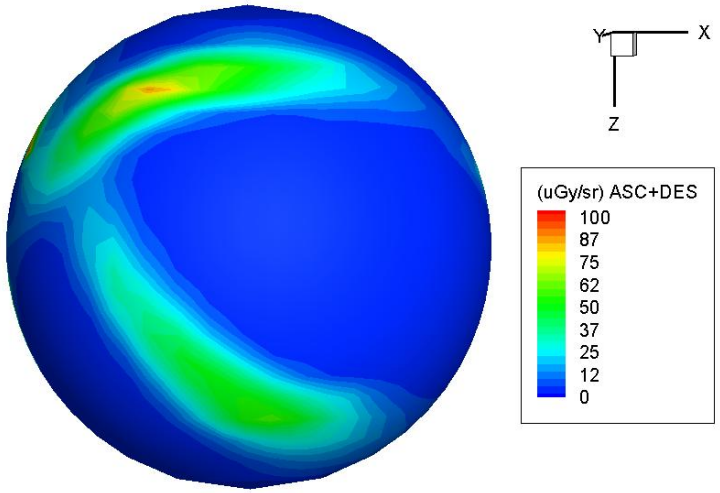
Ascending+descending nodes CQ-SM3 target pt. exposure for 7 mins (µGy/sr)

AP9



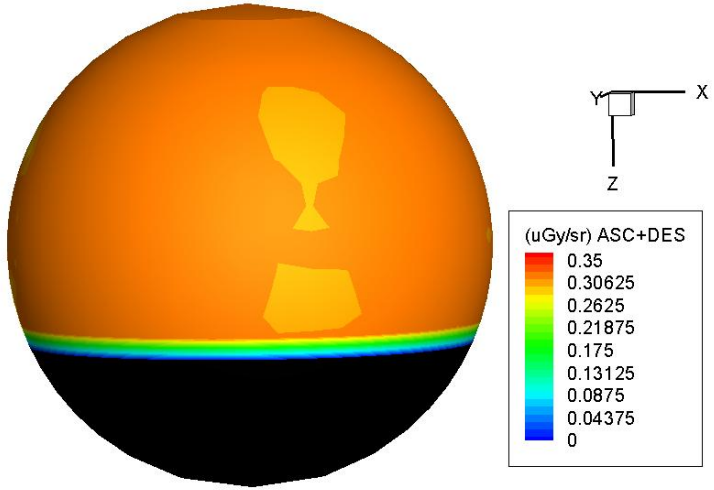
[2.6µGy/sr/orbit * 5 orbits/day *4π_sr]=161 µGy/day

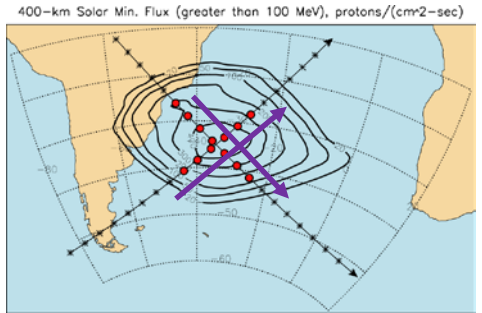
AP8

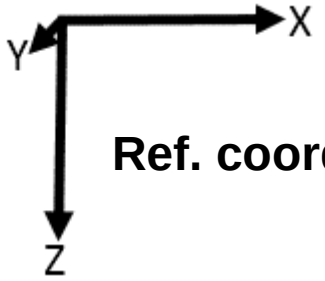


[2.2µGy/sr/orbit * 5 orbits/day *4π_sr]=142 µGy/day

GCR







Ref. coordinate

Simulation: SM3 pt. (2003) AP8=142 µGy/d, AP9=161 µGy/d
Measurement: G. Reitz (DOSMAP-2005) : 74 ~ 215 µGy/d

Summary

- Described an angular model to account for proton flux anisotropy at LEO. The angular model has not been tested for the **difficult to analyze** inner electron belt yet

- Using the omni-directional trapped models AP8/AP9, validated the angular model for AF-TSX5 satellite proton measurements at three locations within SAA

- Using CQ of Zvezda-SM ray-traced geometry of ISS and the trapped models AP8/AP9, applied the angular model to proton anisotropy **dosimetric simulation** of ISS within SAA and compared with ISS daily measurement

Q/A