Air Force Research Laboratory

A Comparison of Solar Energetic Particle Flux Mapping Models

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Integrity ★ Service ★ Excellence

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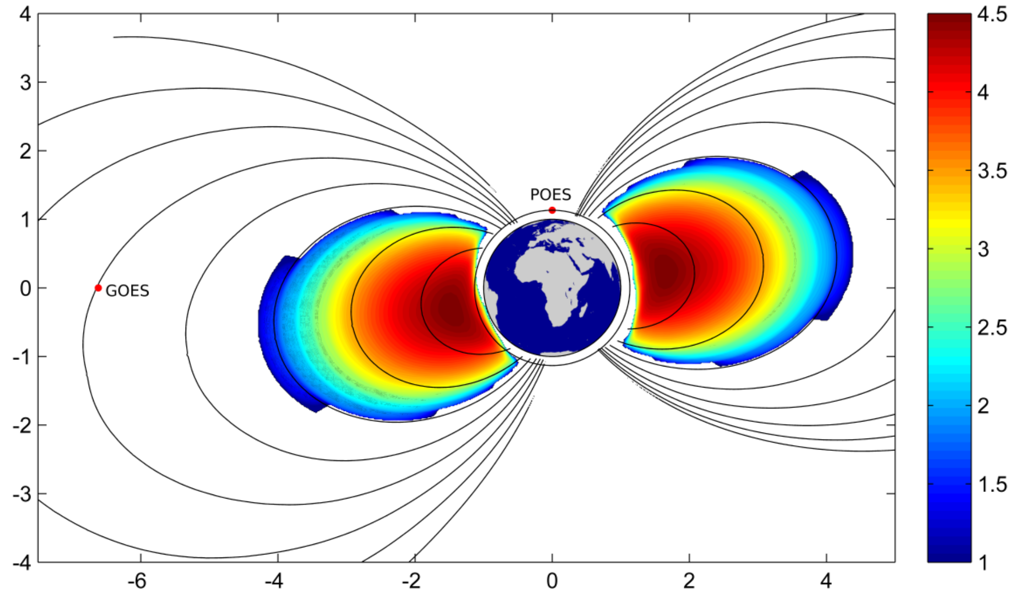
Outline

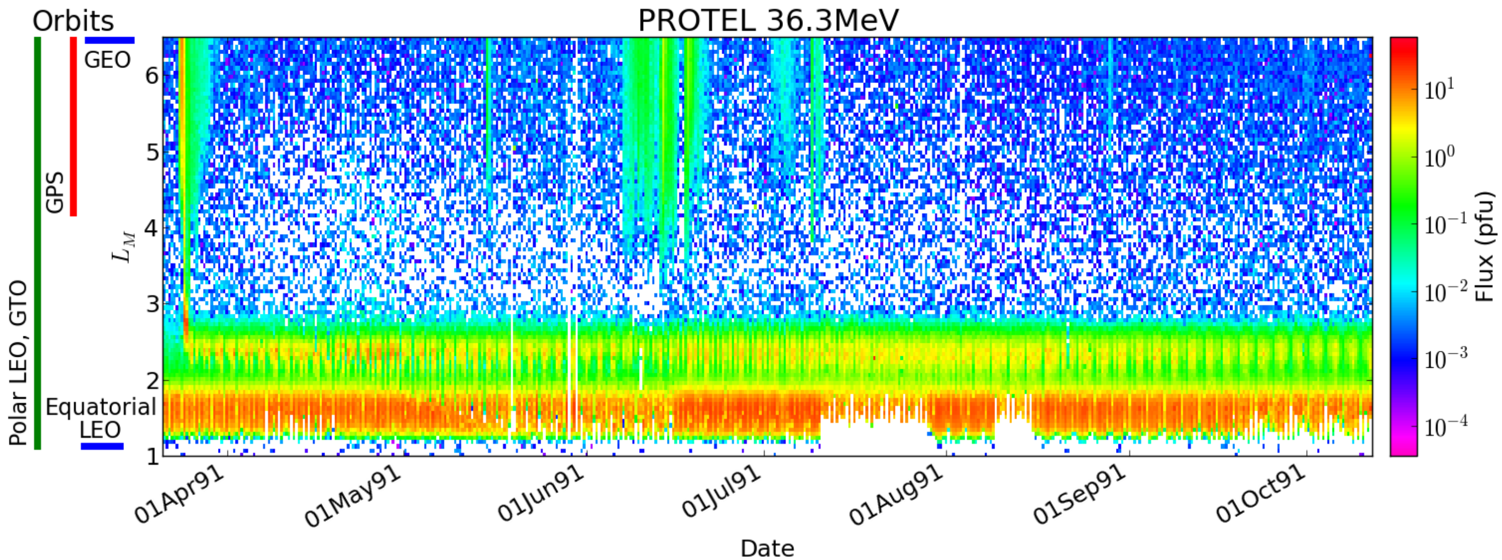
- The Current Capability
- Mapping from GEO
- Mapping from LEO
- Comparison
- Conclusions

Current Capability



- GOES continuously monitors the interplanetary SEP flux
  - Operational warnings/alerts are based on observations.
- POES observes the interplanetary SEP flux in the polar regions and the low altitude trapped SEPs in the SAA.
  - POES **single event effects index** for LEO orbits is derived from these observations.

Does it meet our needs?



- GOES and POES observations are relevant to GEO and LEO orbits.
- For satellites in other orbits application of GOES and POES observations has limitations.

Approaches to Improved Capability

- Map interplanetary flux observations inside GEO
- Map LEO observations outward
- Put a sensor on every satellite

Map from GEO

Mapping the interplanetary spectrum (IPS) inside GEO

Assumptions:

- We see the hazardous portion of the IPS (usually good)
- The interplanetary flux is isotropic

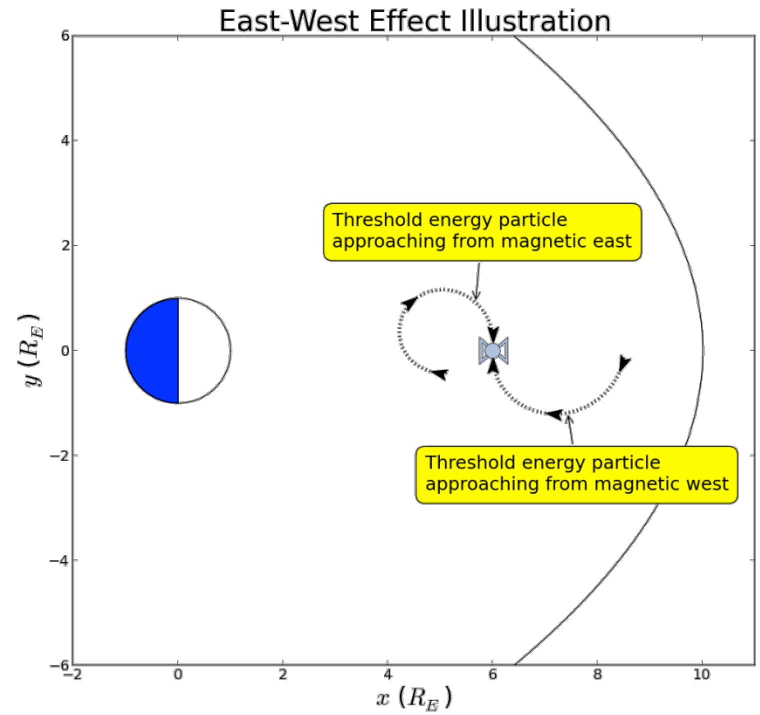
High level algorithm:

- Calculate shielding inside GEO
- Invoke Liouville's theorem

Particle Access

$$R_C = \frac{M}{L^2}\left(\frac{1}{1+\sqrt{1+\cos\alpha\cos^3\lambda}}\right)^2$$

- α is the angle between magnetic west and the particle velocity.
- λ is the latitude
- L is the dipole L parameter.



Application to Geospace

- Cutoffs vary with MLT
- Cutoffs at location depend on magnetospheric configuration
- Electric fields affect particle access.
- The solid Earth blocks some particle trajectories creating a shadow or penumbra.

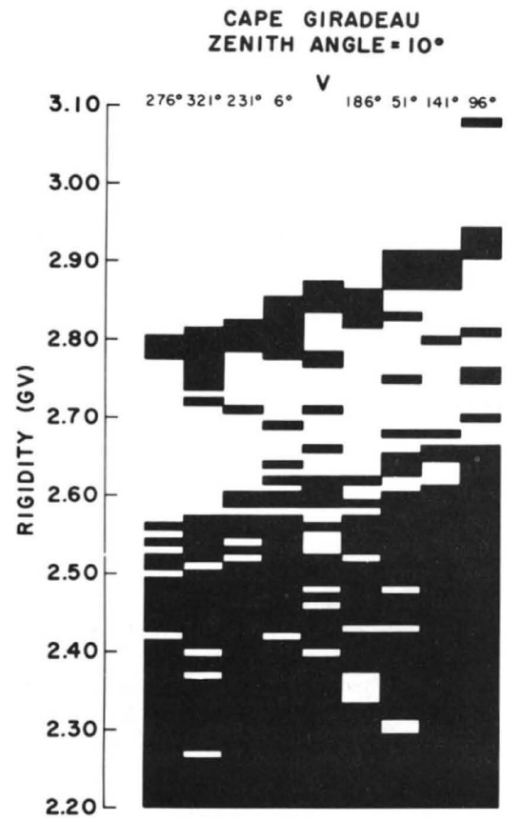


Figure 7. Illustration of the persistence of the first forbidden band (called the primary band by N. Lund of the Danish Space Research Institute). This feature is shown for a balloon flight location.

Taken from Smart and Shea 1994

Numerical Cutoff Calculations in Geospace

- Lorentz force equations integrated backward in time.
- "Allowed" trajectories escape, "forbidden" trajectories don't.
- Search rigidity space for penumbra.
- Increase sampling resolution in penumbra to calculate density of allowed trajectories.
- Lower bound is the threshold density determined by application.

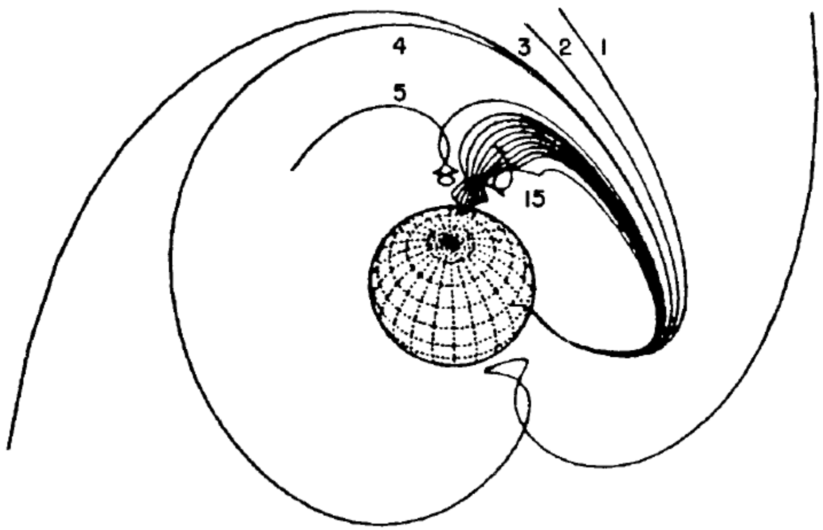


Figure taken from Smart et al. 2000

We calculated west, vertical and east cutoffs and interpolated to determine cutoffs in other directions using dipole cutoff like functions to increase calculation speed.

Initial Results (CRRES)

- For $L^* \geq 4.5$ the model compares well with observations, and best for $L^* \geq 5$.
- Below L^* of about 3 the comparison is with AP9.
- Between $L^* = 3$ and $L^* = 4.5$ the agreement is poor and the median observations are not hazardous, but hazardous flux levels were observed.

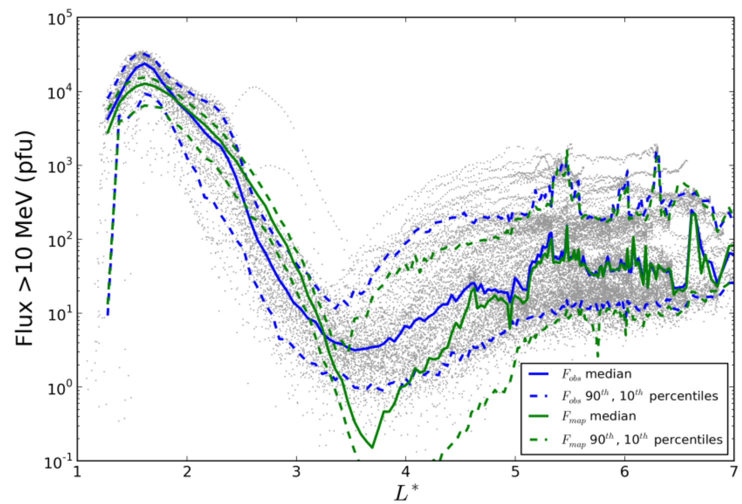
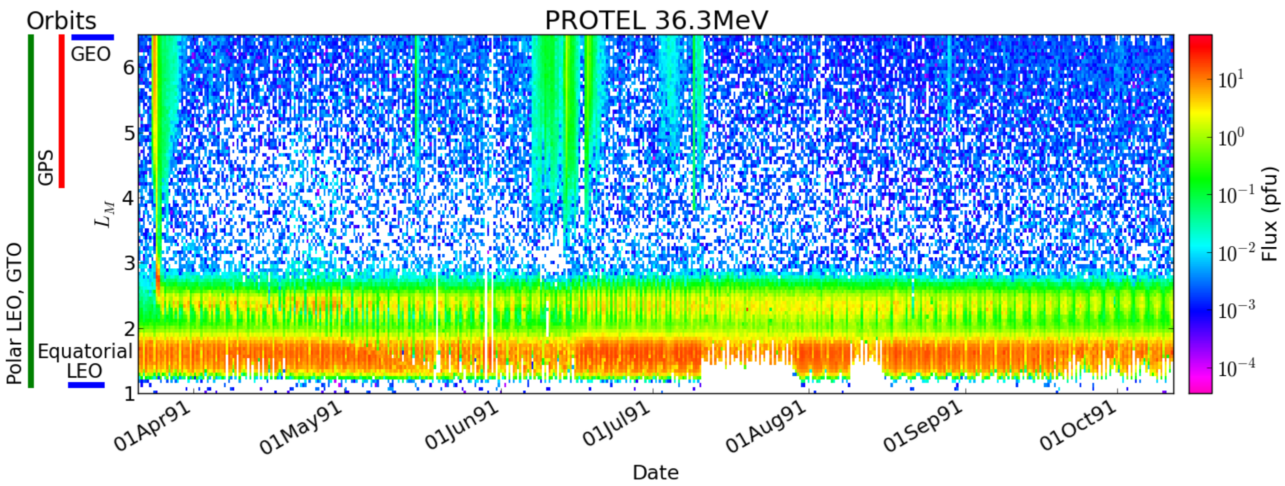
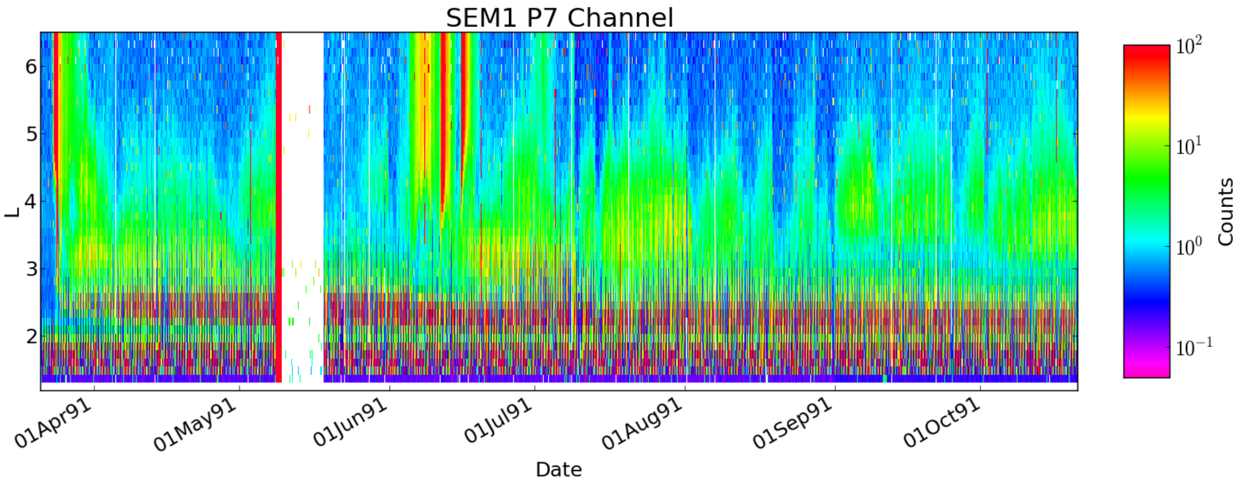


Figure:

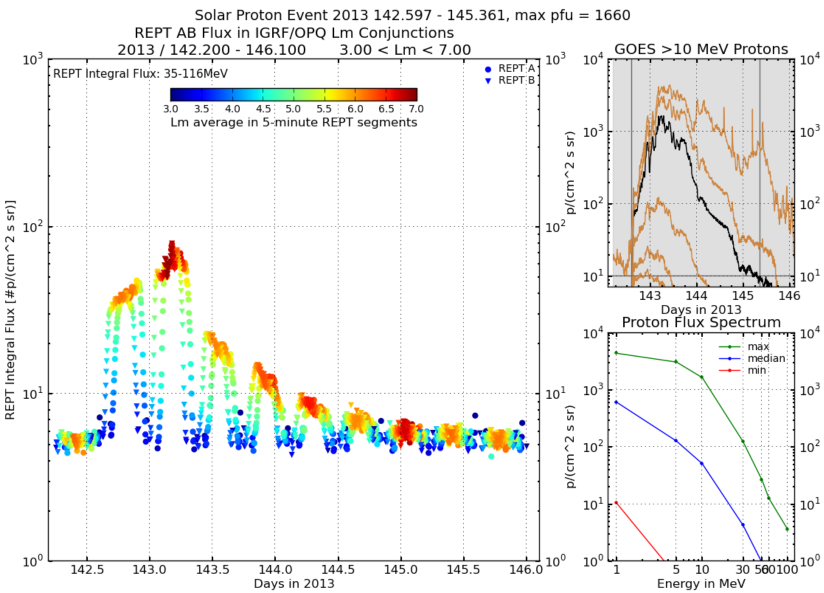
- Gray dots are individual observations
- Solid lines are observed/mapped medians
- Dashed lines are 10^{th} and 90^{th} percentiles.
- Blue represents observed
- Green represents mapped (individual mapings not shown)
- 16 events, 105 passes through belts.

Mapping LEO Observations – What is possible?

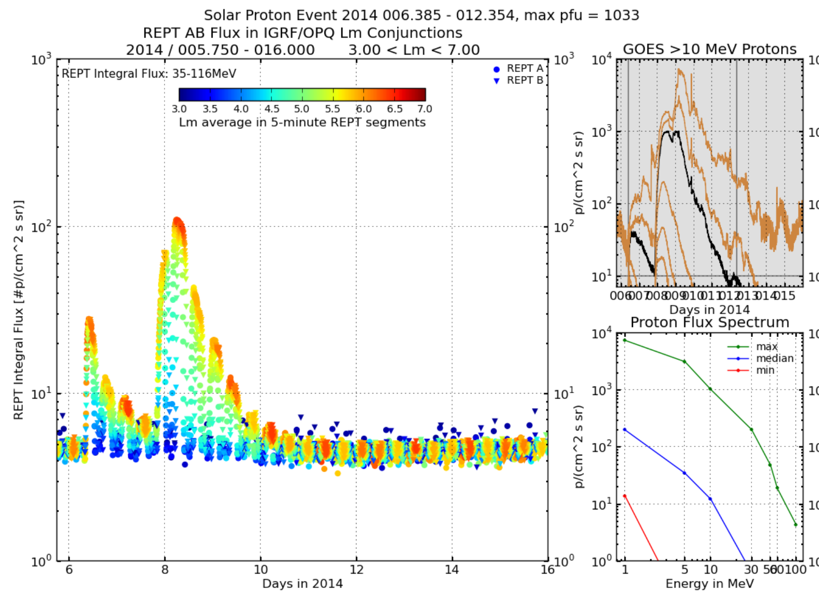




SEP Events



May 22-25, 2013 SEP event



January 6-10, 2014 SEP events

The only two events with significant >35 MeV fluxes during the Van Allen Probes mission during our study. Color coding represents L_M in the large panels, where REPT data are displayed. The small panels on the right show GOES data (top) and mean spectrum (blue), max spectrum (green) and minimum spectrum (red) in bottom panel.

Mapping IPS from POES

- Empirical model based on comparisons between observations at POES and the Van Allen Probes

$$F(L_M) = 0.619 C_{P7}(L_M) + 1.85.$$

- Model relates POES SEM-2 P7 counts to a REPT 35-100 MeV integral flux.
- Based on the May 23-25, 2013 and the January 6-10, 2014 events – and tested against the same events.

Models

CISM-Dartmouth-TS05

Calculates reverse trajectories and the effective cutoffs on-the-fly using the Tsyganenko TS05 magnetic field model.

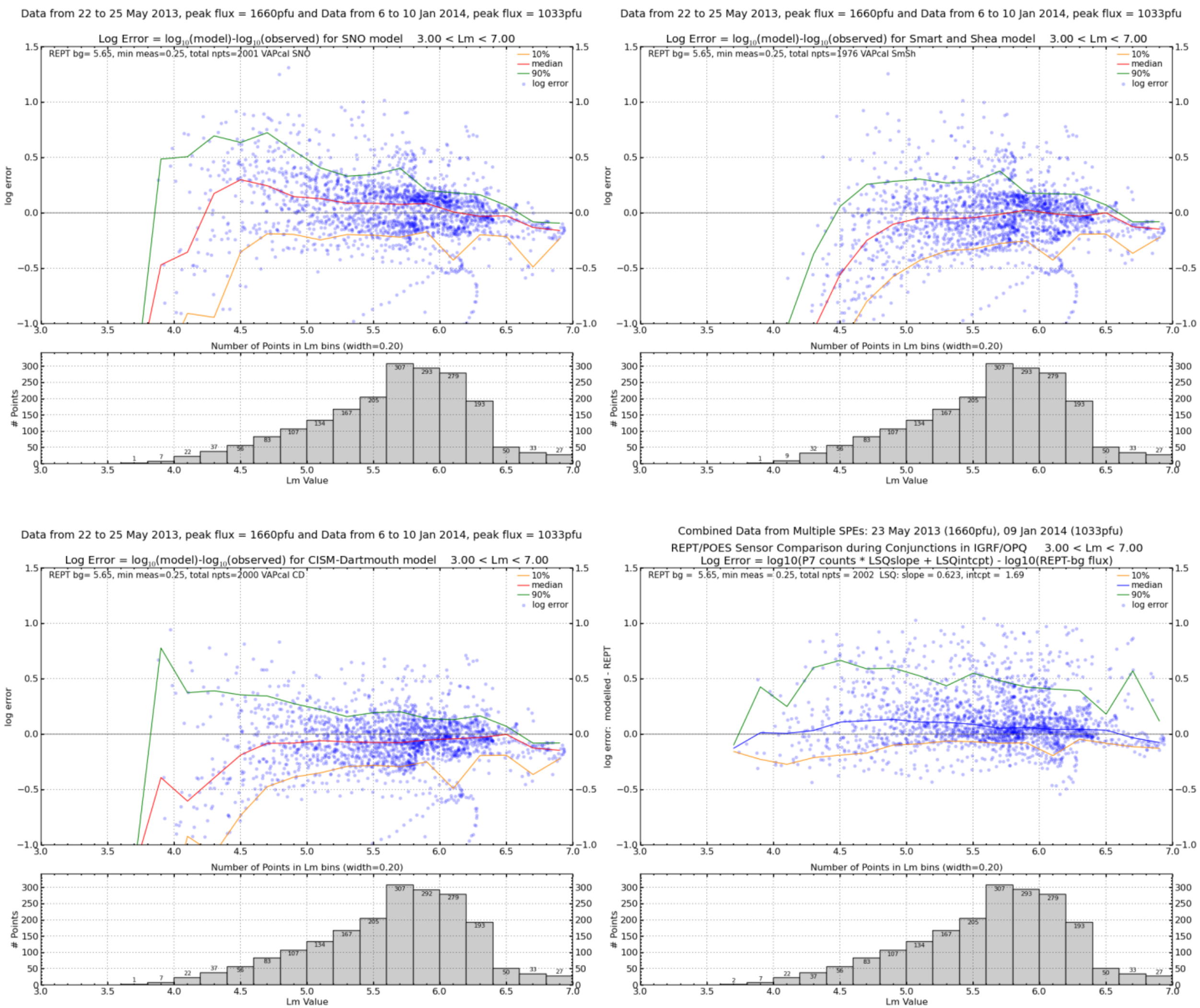
Smart and Shea

Interpolates/Extrapolates from a table of pre-calculated cutoffs at an altitude of 450 km

Selesnick-Neal-Ogliore (SNO) model

Extrapolates Ogliore’s SAMPEX observation based cutoff model in space using TS05-LANLstar and Neal’s Kp dependent POES based model.

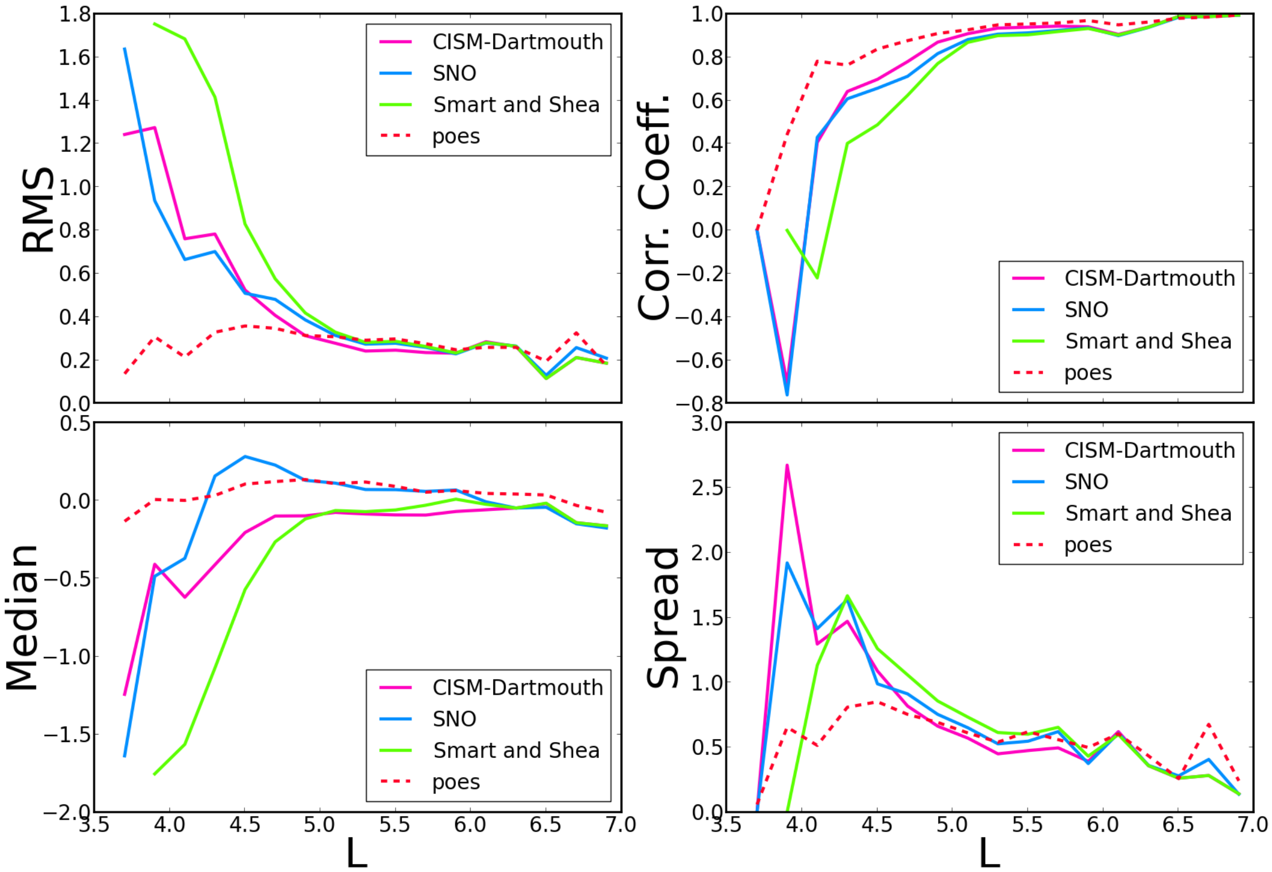
Model Comparison



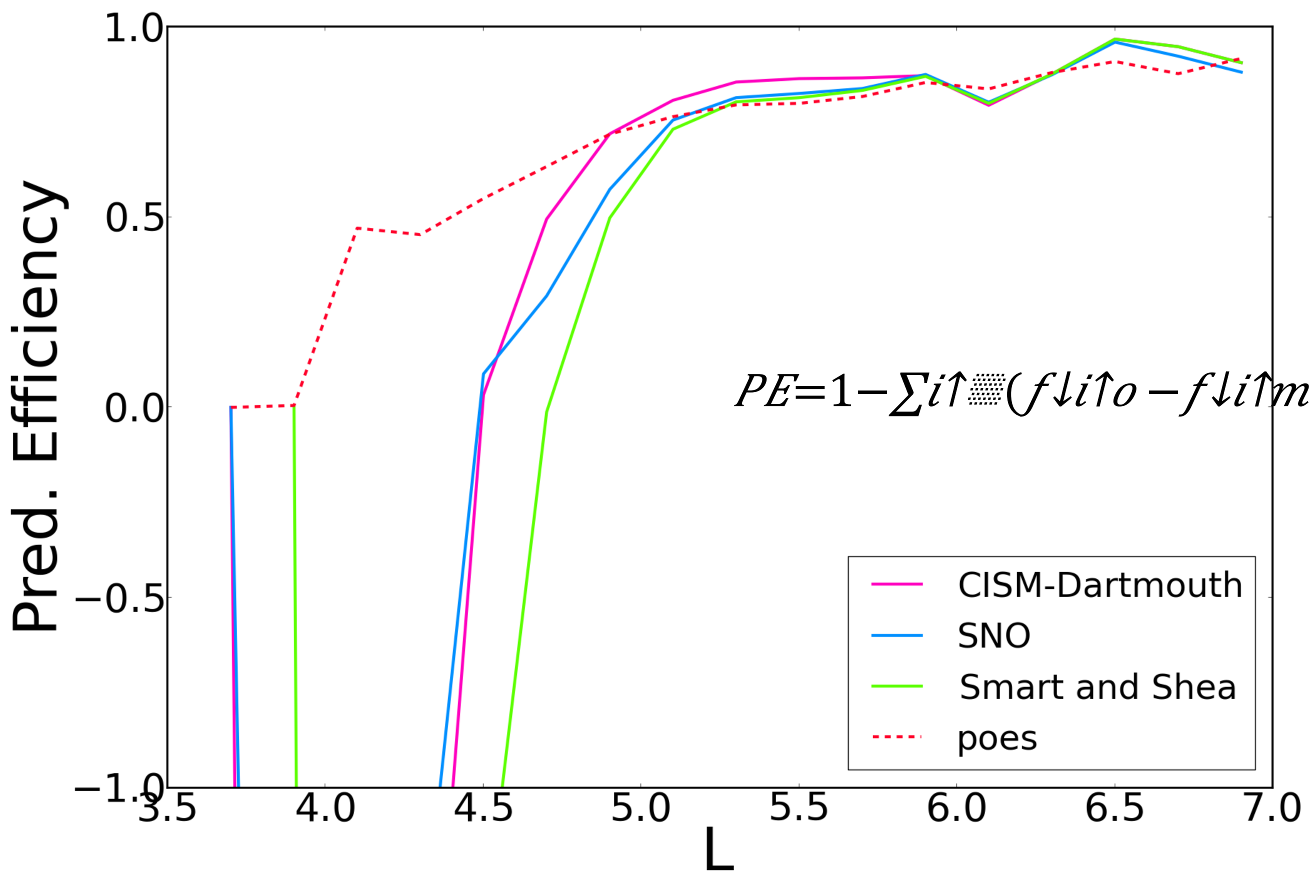
Log$_{10}$ Error Plots

- Results of mapping techniques are similar at high L↓M.
- GOES maps appear to do somewhat better at high L↓M, but the POES mapping may be more accurate at low L↓M.
- Note the low

More statistics



Prediction Efficiency



PE=1−∑i↑▒(f↓i↑o −f↓i↑m)↑2 /∑j↑▒(f↓j↑

Conclusions: POES Mapping Technique

- The POES mapping did comparatively well using this simple mapping model; more sophisticated models may do better.
- The current mapping is from POES to the equator with no activity dependence. Further development is required for off equatorial locations and to add activity dependence.
- These results are based on only two events, more events are necessary to improve and understand the model’s accuracy.
- Improved POES SEM-2 response functions should improve results.
- The POES mapping is good for specifications, but loses any advantage for forecasting.

Conclusions: GOES Mapping Technique

- Magnetic field cutoffs depend on the magnetic field's configuration and its activity level.
- The static fields used here do not model the electric fields seen during active time periods.
- More accurate magnetic field models are required to map IP fluxes deep inside the magnetosphere.
- The IPS mapping technique can be used for forecasting so further development is important.

¿Questions?