Solar Energetic Particle (Proton) Cutoffs

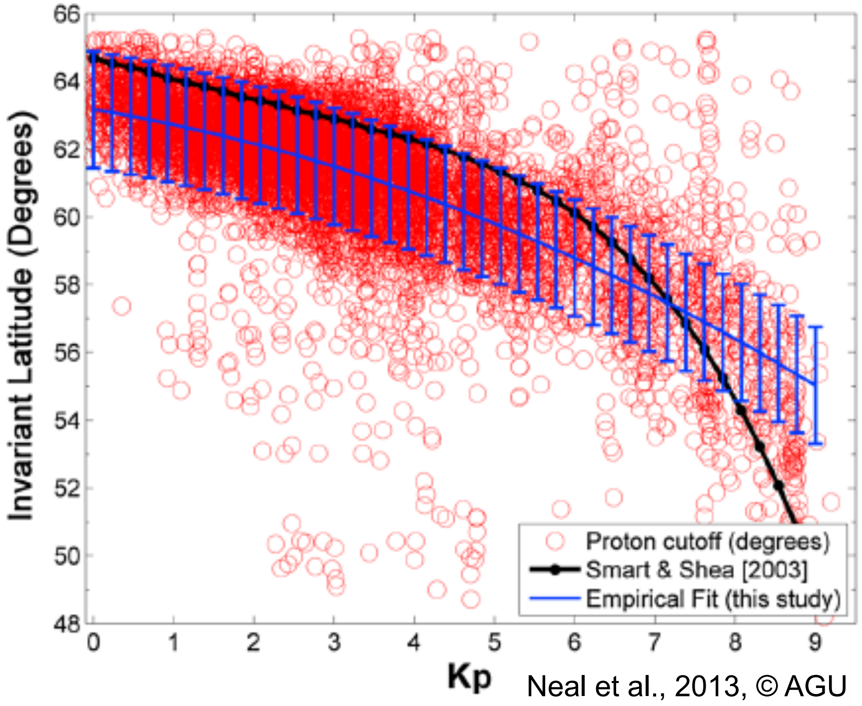
T. Paul O'Brien[1] and W. Kent Tobiska[2]
[1]Space Sciences Department, The Aerospace Corporation
[2]Space Environment Technologies

SEP Cutoffs

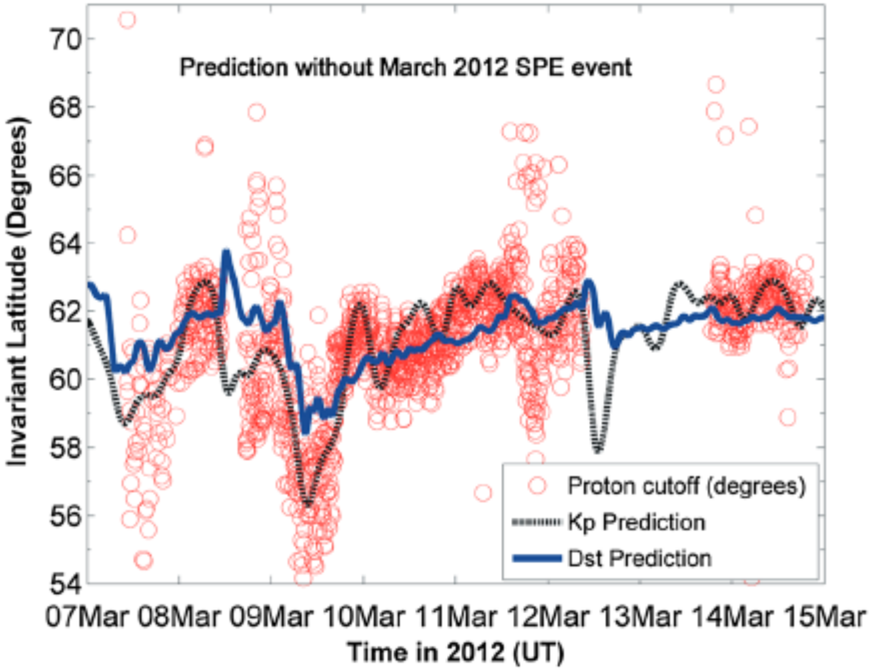
- Cutoff depends on rigidity (momentum / charge) and angle of incidence
- Usually look at “vertical” cutoffs which is probably relevant for atmospheric and ground-based observations, but hard to use in space
- Most of what we have are (integral or broadband) omnidirectional proton measurements
- Climatological models show lower cutoff latitude (lower L shell) at stronger magnetic activity (Dst, Kp, etc)
- However, storms also have idiosyncratic temporal evolution and local time variation [Fanselow et al., 1972; Leske et al., 2001]
- Suggested approach:
  - *Use POES and/or REACH to monitor proton cutoffs in real time*
  - *Use empirical models to relate LEO cutoffs to high altitude*

Rigidity

- Rigidity is $R = p/q = momentum/charge$
- Usually expressed in MV (dropping a factor of *c*)
- Can model cutoff rigidity vs L: (From Ogliore et al., 2001, ICRC)
  - $R = 15.062 \cos^4 \Lambda_c - 0.363\ GV$
  - $R = 15.062/L^2 - 0.363\ GV$
- Often invert these to get cutoff *L* or latitude Λ_c at fixed *R*, which can be observed by a satellite in polar or elliptical orbit:
  - $\Lambda_c = AK_p^2 + BK_p + C$ *(From Neal et al., 2013, Space Weather)*



Neal et al., 2013, © AGU

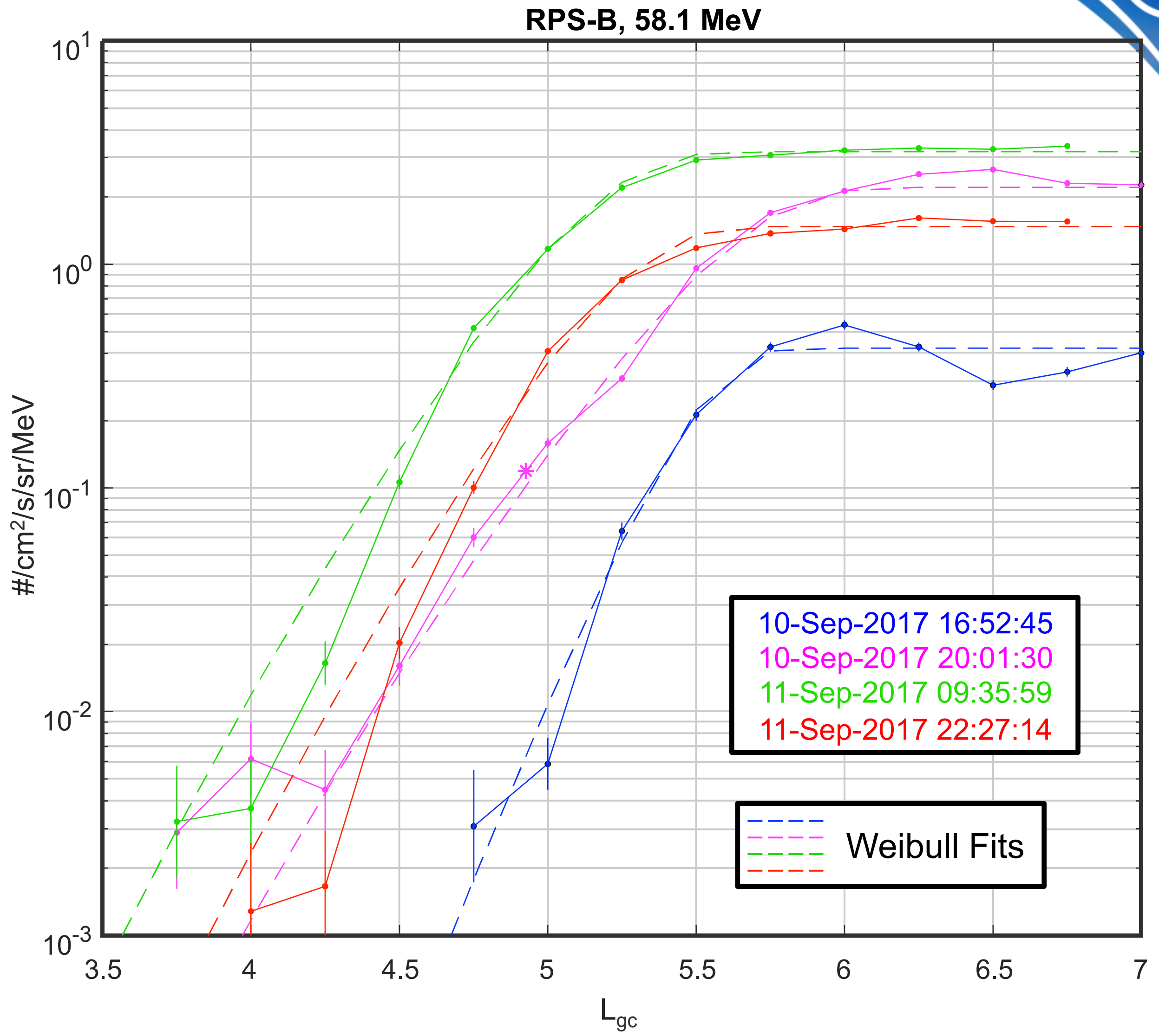


Climatological models

- A recent paper examined cutoffs in POES data [Neal et al., Space Weather, 2013. doi:10.1002/swe.20066]
- Climo models have >~2 degrees error in invariant latitude, or ~0.5 L near L~4-6 (60-66°)
- Lots of idiosyncratic variation

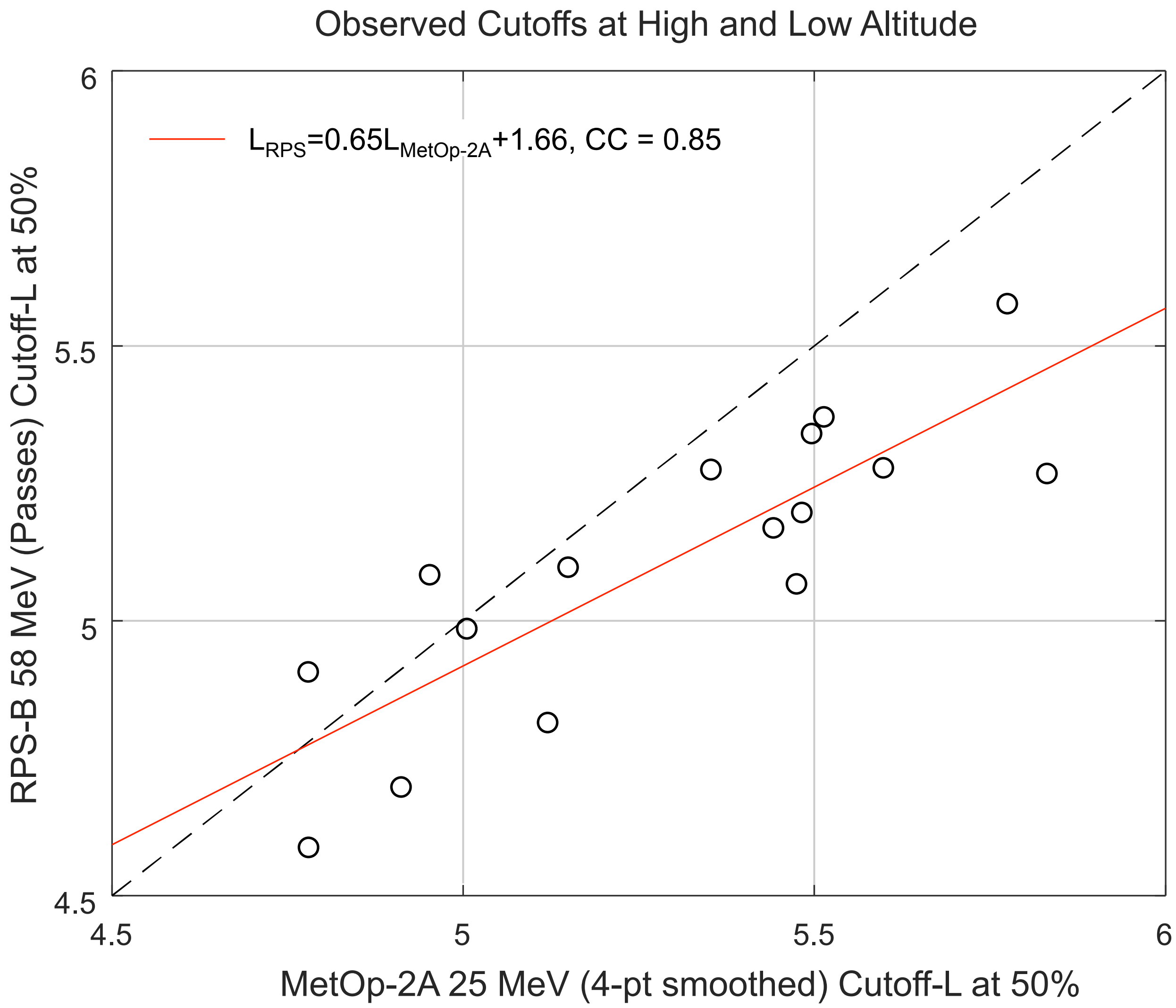
"Real" Cutoffs

- These cutoffs from Van Allen Probes RPS are adjusted for angle of incidence and there is ***still*** a smooth cutoff
- We use a Weibull function
  $j(L)=j_{\infty}\left(1-\exp\left[-\left(L/L_0\right)^{\gamma}\right]\right)$
  - j_{∞} = *free space flux*
  - L_0 = *cutoff at 63% flux*
  - γ = *steepness*
  - *Works for different kinds of fluxes (omnidirectional, unidirectional, integral, differential)*

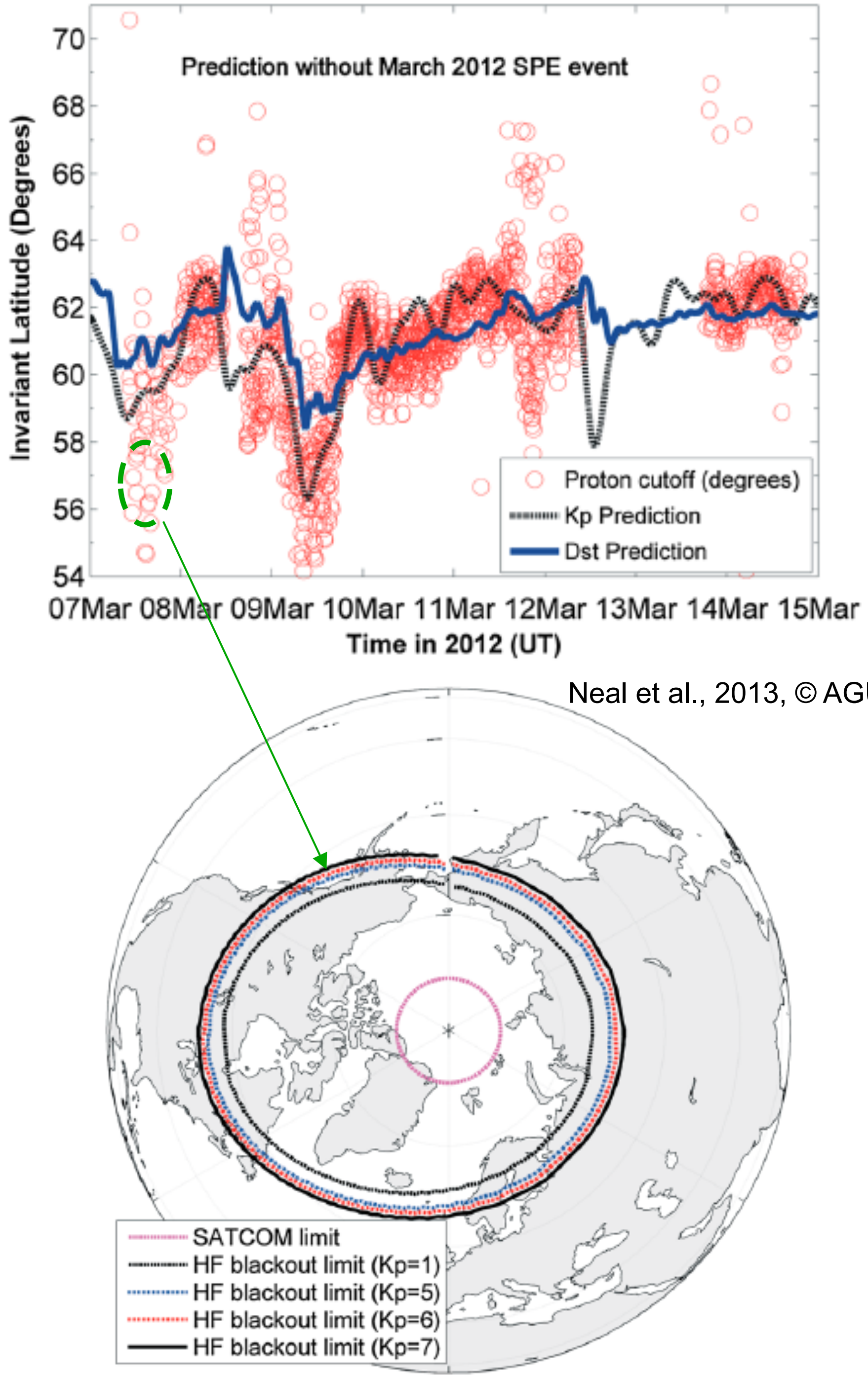


Suggested Approach: Real Time LEO Monitoring

- Use POES/MetOp and/or REACH to monitor proton cutoffs in real time
- Use empirical models to relate LEO cutoffs to high altitude

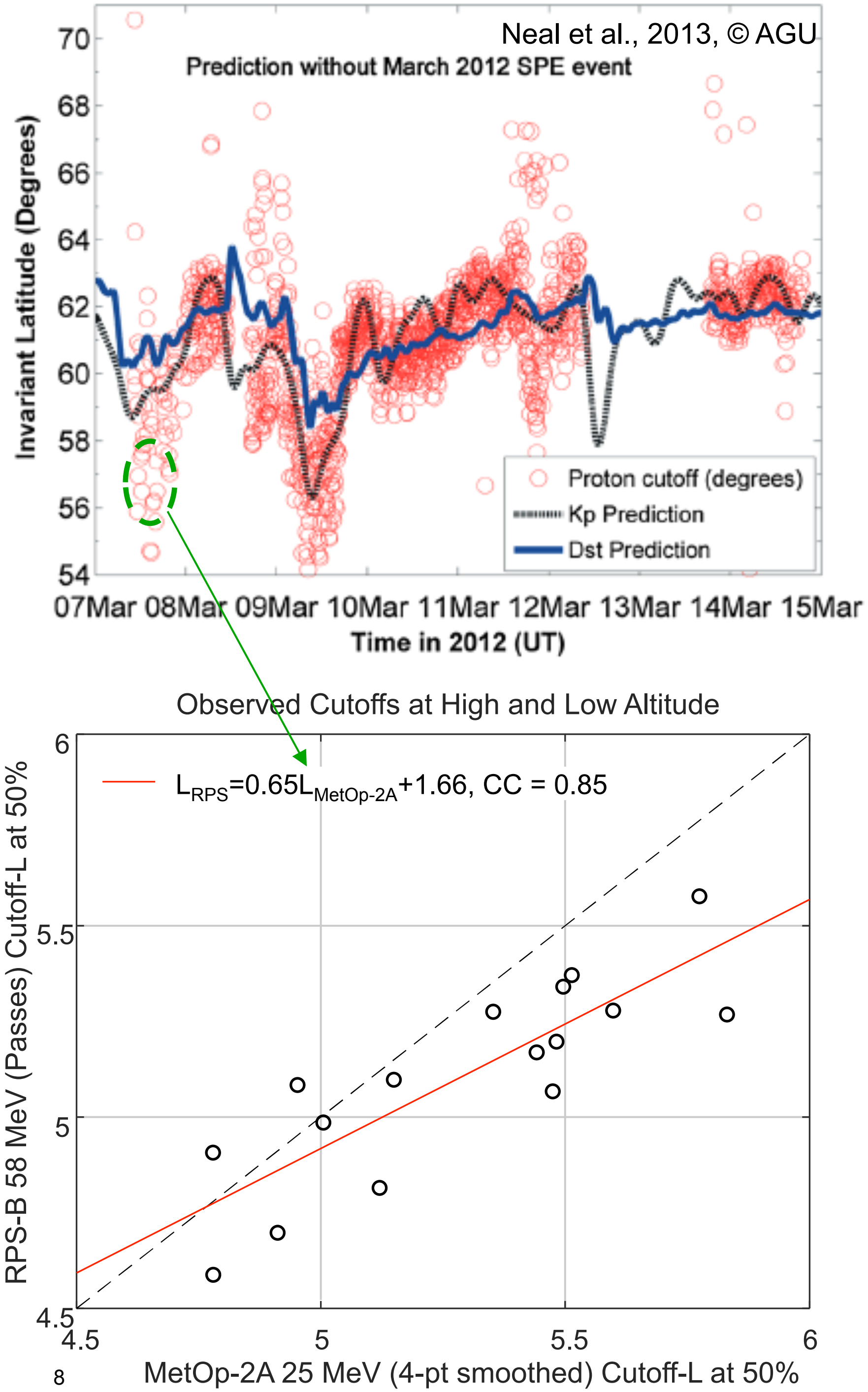


Suggested Approach: Real Time LEO Monitoring



Neal et al., 2013, © AGU

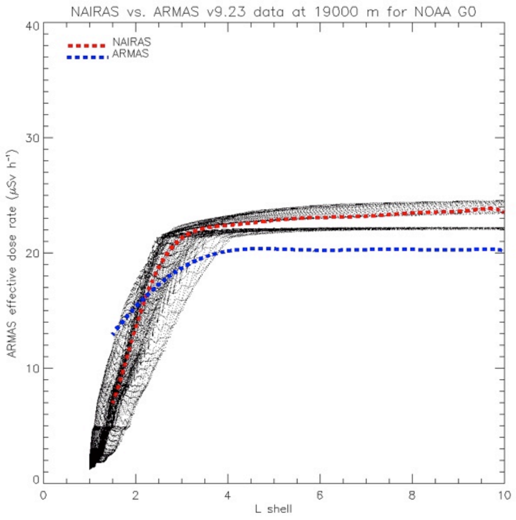
- Use POES/MetOp and/or REACH to monitor proton cutoffs in real time
- Use empirical-physical models to “spread” cutoff around in longitude / local time

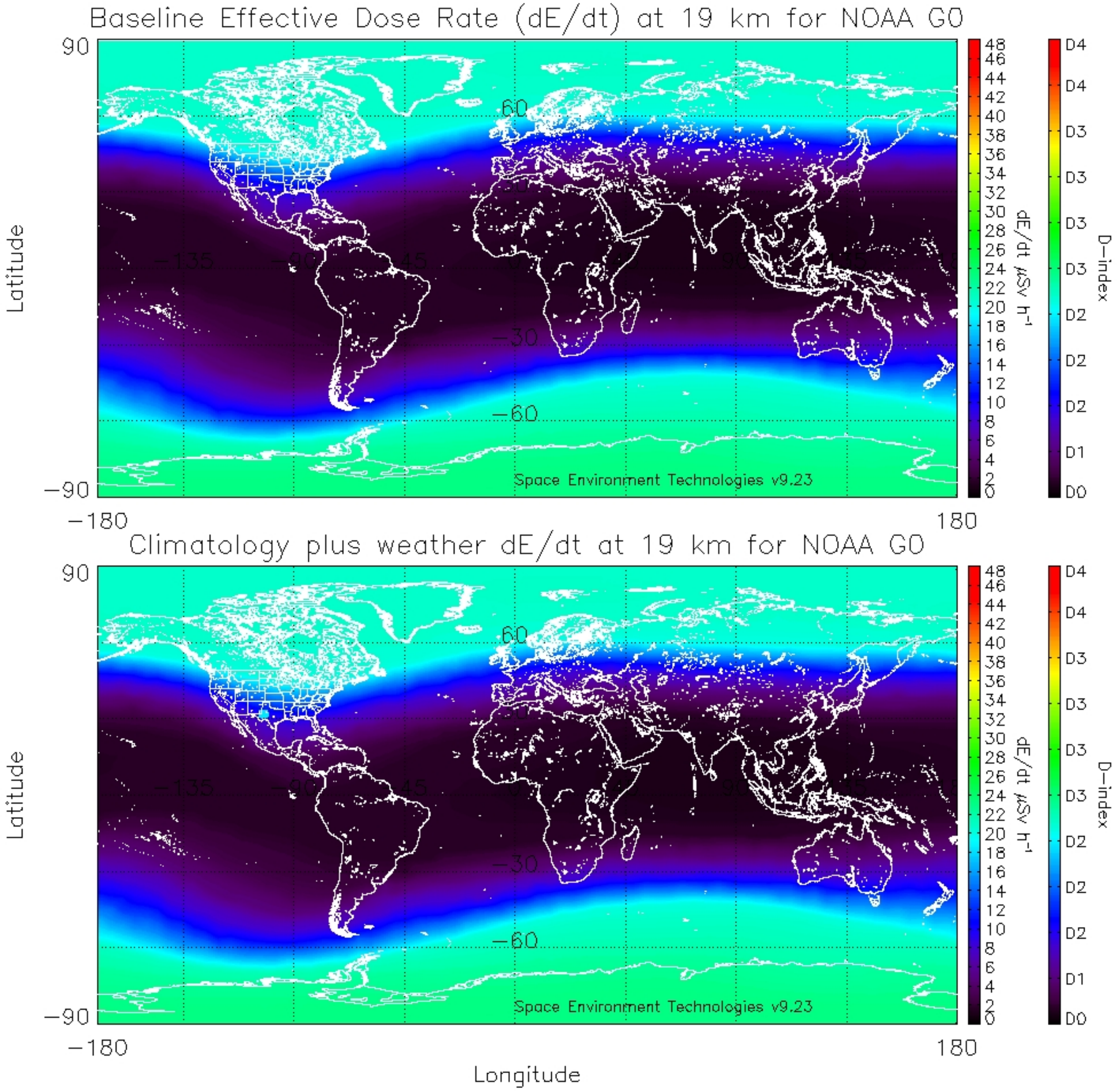


Suggested Approach: Real Time LEO Monitoring

- Use LEO cutoffs to project to high altitude
- Much better than climatological model
- Support satellite anomaly resolution: single event effects, event total dose
- Will need to account for local time, activity level, energy
- Apply proton cutoff rigidity to heavy ions (SEE risk)

NAIRAS climatology (red and black) vs. ARMAS (blue) statistical for effective dose rate vs. L-shell at 19 km





Cutoff effects at 19 km

modeled (top panel) and measurements (bottom panel) for NOAA G0 and G4

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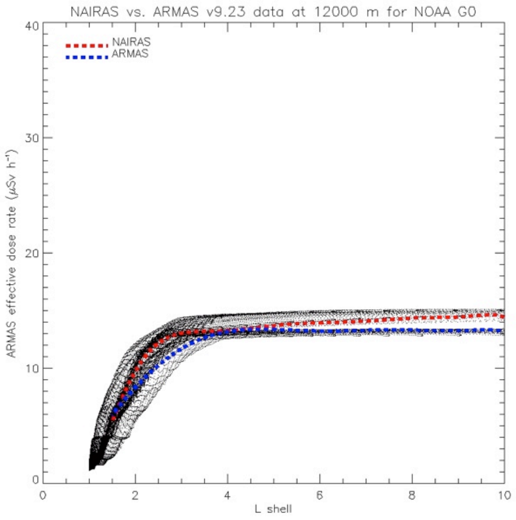

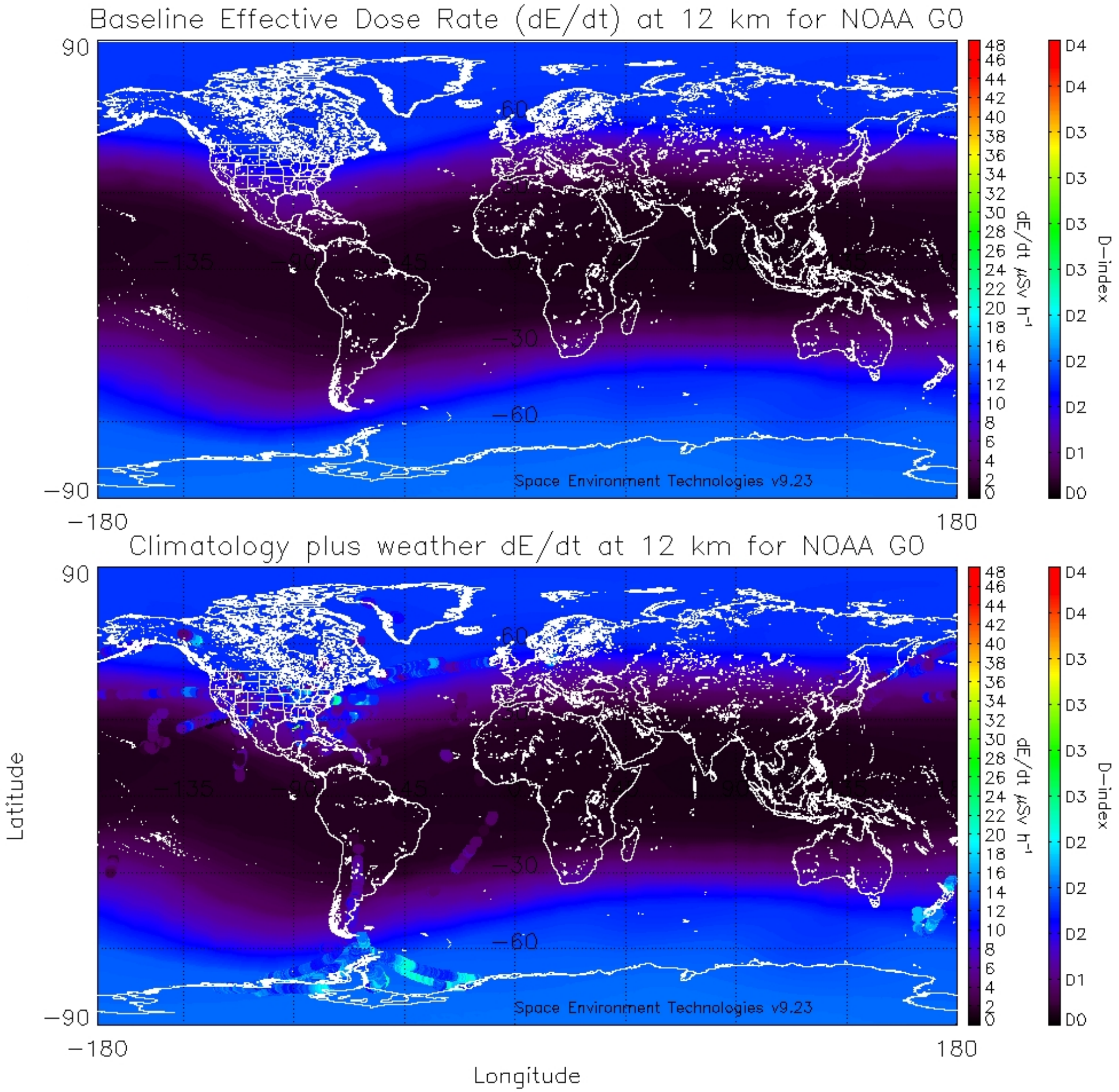

Cutoff effects at 12 km

modeled (top panel) and measurements (bottom panel) for NOAA G0 and G1

Cutoff effects >8 km in the atmosphere

measurement ratio to model for NOAA G0 and G1