Solar Energetic Particle Access to the Near-Equatorial Magnetosphere

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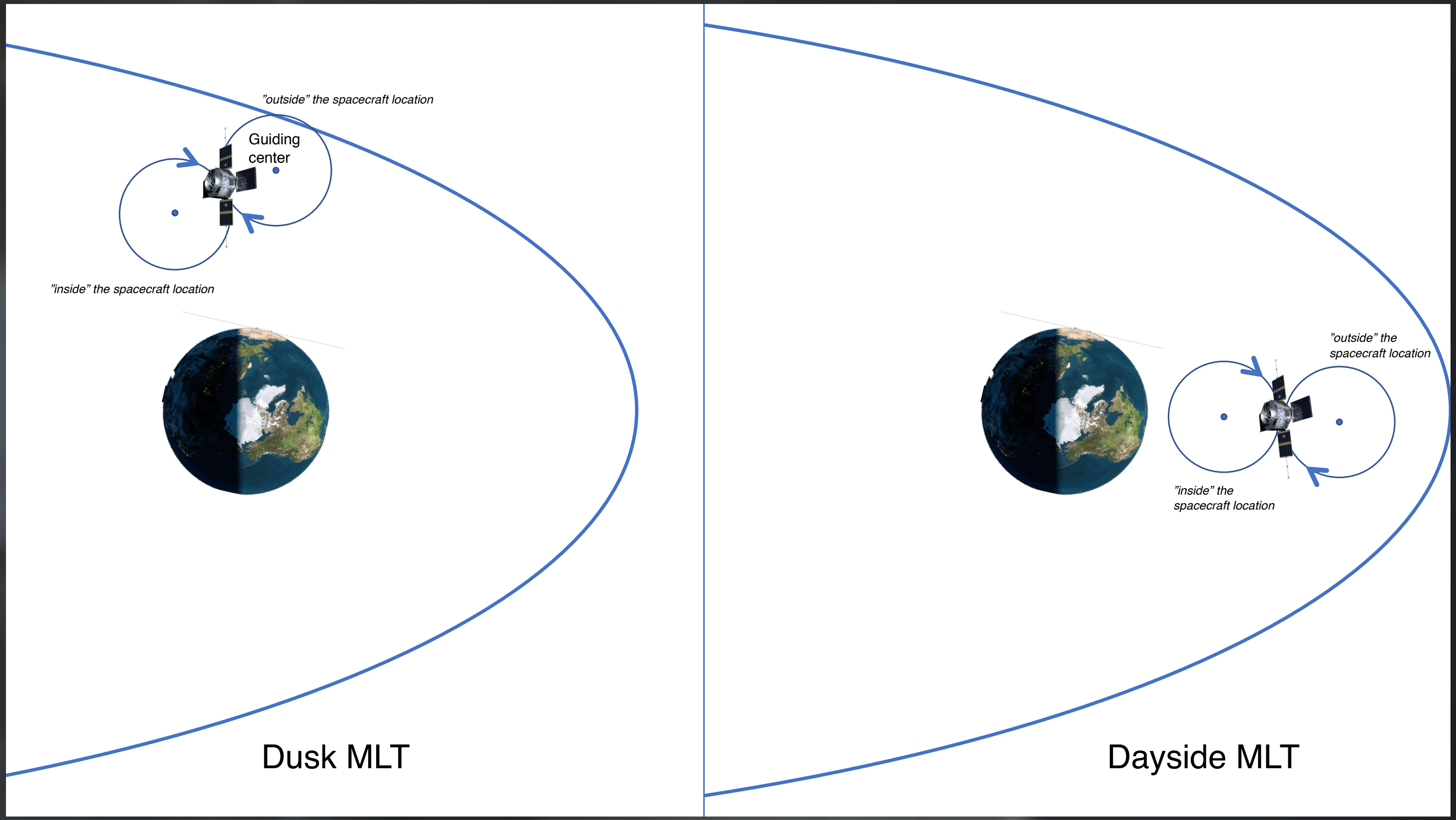
Background

For this study we use the twin Van Allen Probes (RBSP) and the ACE spacecraft to examine the proton cutoff rigidity behavior in the inner-magnetosphere. In this study we examine 4 solar energetic particle events (SEPs).

Most of the studies of cutoff rigidity are done at low earth orbit, particularly near the polar caps. By examining energetic solar particle access to the near-equatorial inner magnetosphere we can better understand the radiation threat to satellites in this area. Furthermore, by examining multiple SEPs with various characteristics we can start to understand how dynamic cutoff rigidities are. These inner-magnetosphere cutoffs have received attention in the recent literature (ex: Kress et al. (2005, 2010) and Qin et al. (2019))

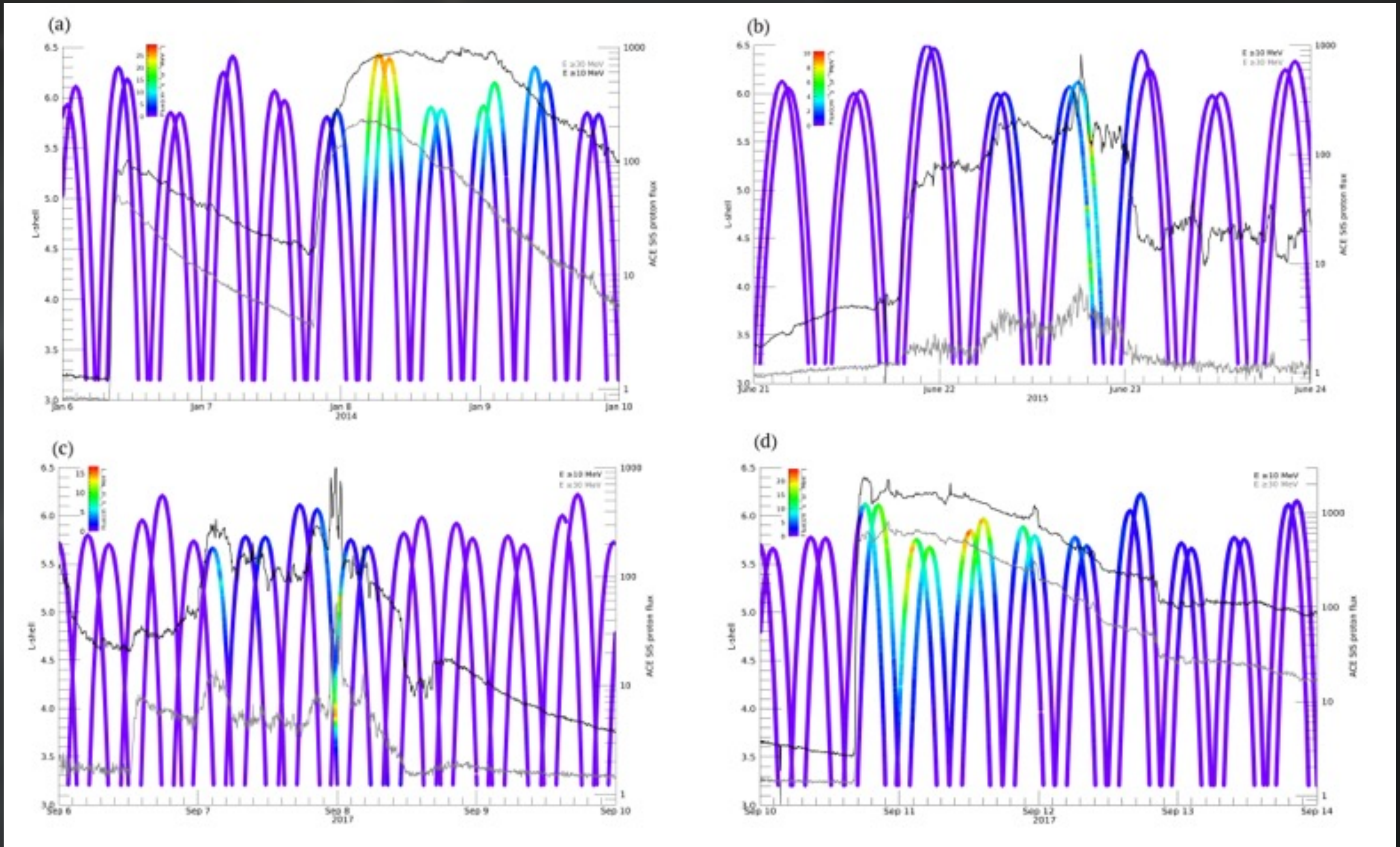
We note that in all of the following plots we do not include the inner proton radiation belt (most plots feature an L-shell lower limit of 3.2)



- East-west effect
  - Referred to generally as East-West effect because often measured by the GOES east and west facing telescopes
    - The best way to think about this is particles that have gyrocenters inside and outside of the spacecraft attitude.
    - This allows us to measure the flux difference between particles that experience a different amount of geomagnetic shielding
      - Method has been used by Rodriquez et al. (2010) and Qin et al. (2019)
    - In the graphic above the physical differences of particle gyro-orbits for various magnetic local time (MLT) for RBSP are shown

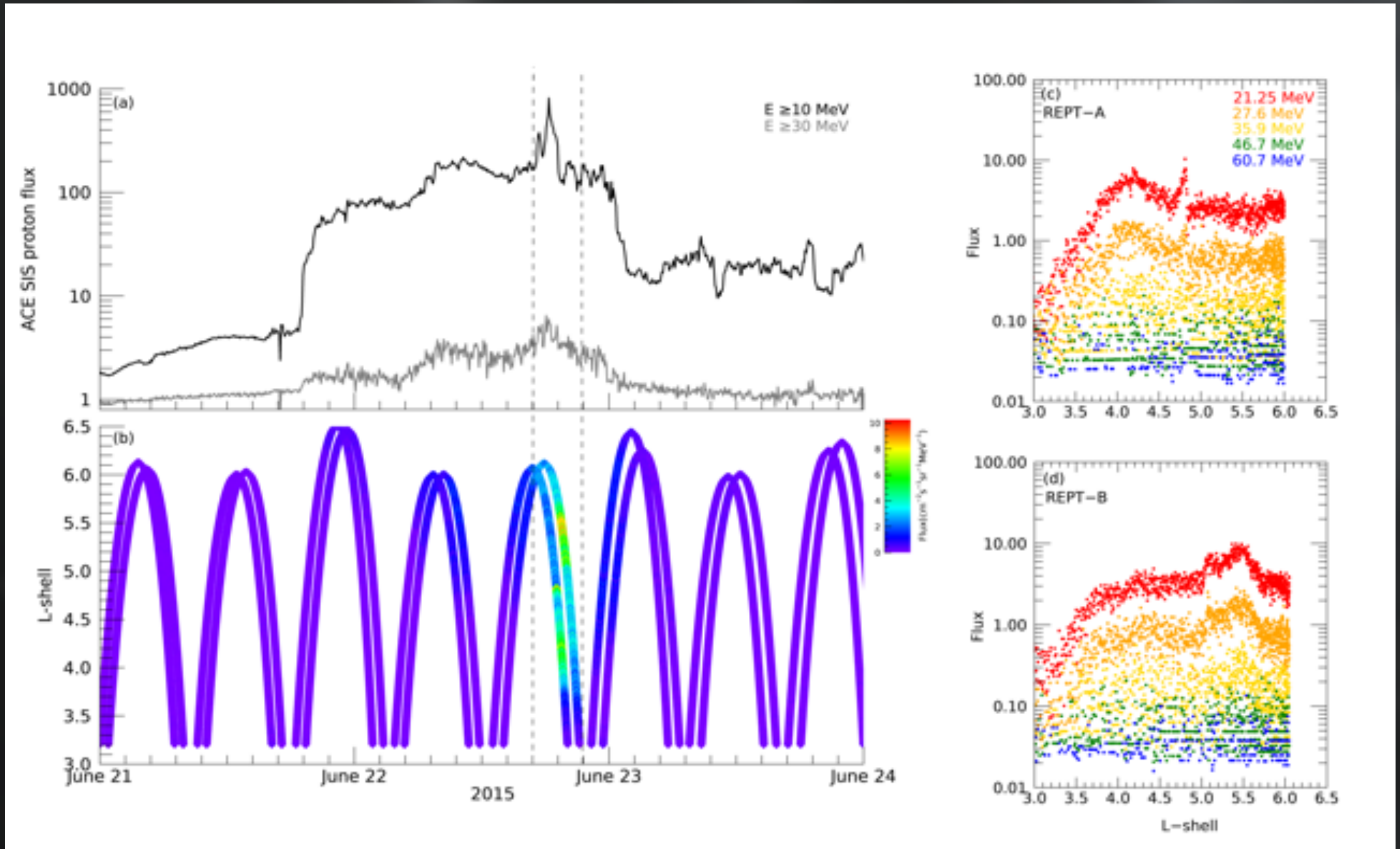
Events

- Selected 4 SEP events of the Van Allen Probes era
    - 6-10 January 2014
    - 21-23 June 2015
    - 6-10 September 2017
    - 10-14 September 2017
- Also look at the ACE proton flux >10 MeV and >30 MeV
    - Compare to the 20-200 MeV proton flux seen by REPT
- Events have a variety of flux profiles and associated geomagnetic conditions
    - Here we make no distinction between energetic solar particles from coronal mass ejections or flares



In the Figure above the 20-200 MeV proton flux is shown for the 4 SEP events in this study as a function of Van Allen Probe's L-value. The black/grey lines are the >10MeV and >30MeV ACE proton flux upstream of Earth. Here we see impulsive flux increases in the June,2015 and September 6-10, 2017, these proton flux increases match the ACE profiles quiet well.

Direct Flux Correspondence

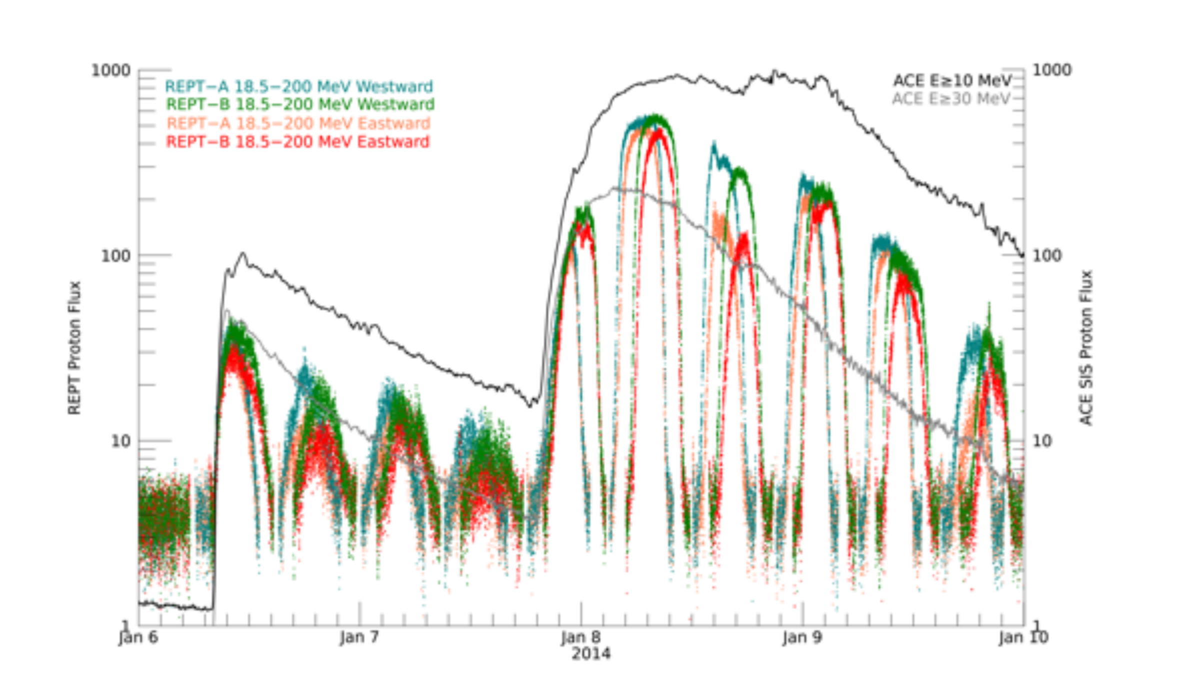


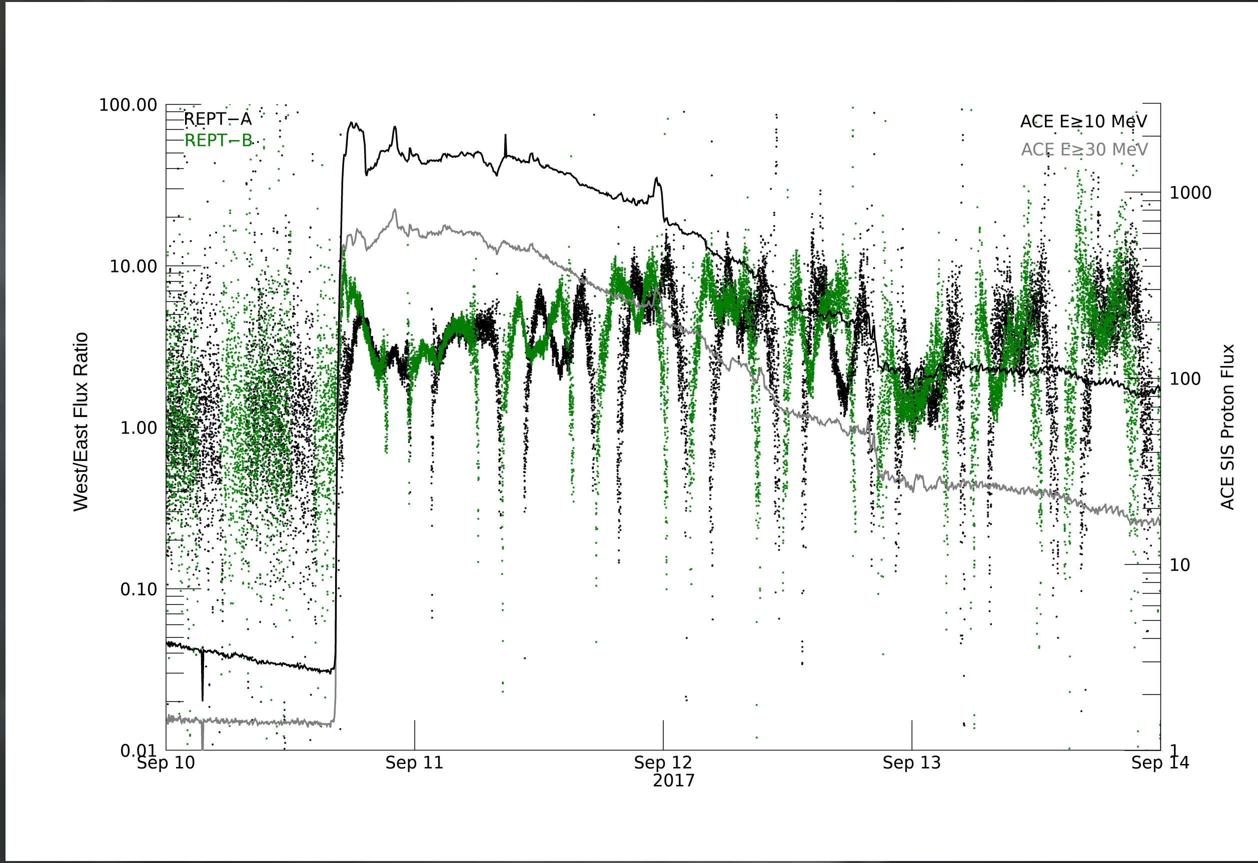
(Above) (a) shows the >10 and >30 MeV at ACE (b) shows the 20-200 MeV proton flux as a function of L-shell from RBSP. The side panels (c) and (d) show the flux profiles for the orbit between the dotted lines in (b). These flux profiles show quick changes in the inner-magnetosphere that correspond to the impulsive changes seen at ACE

Particle intensity profiles show a direct flux correspondence with the ACE proton flux

- Rapid changes in the inter-planetary medium can be seen in the equatorial inner magnetosphere
- When we examine the flux profiles for a single orbit pass (for the time within the dotted lines) we see rapid changes that correspond well to the flux changes seen at ACE
  - The flux changes in the inner magnetosphere exhibit the same energy changes (i.e. same energy particles at ACE and RBSP)
- Flux profiles show particles are able to access below L~4, this is closer to Earth than predicted by theory
  - Radial transport

East-West Effect





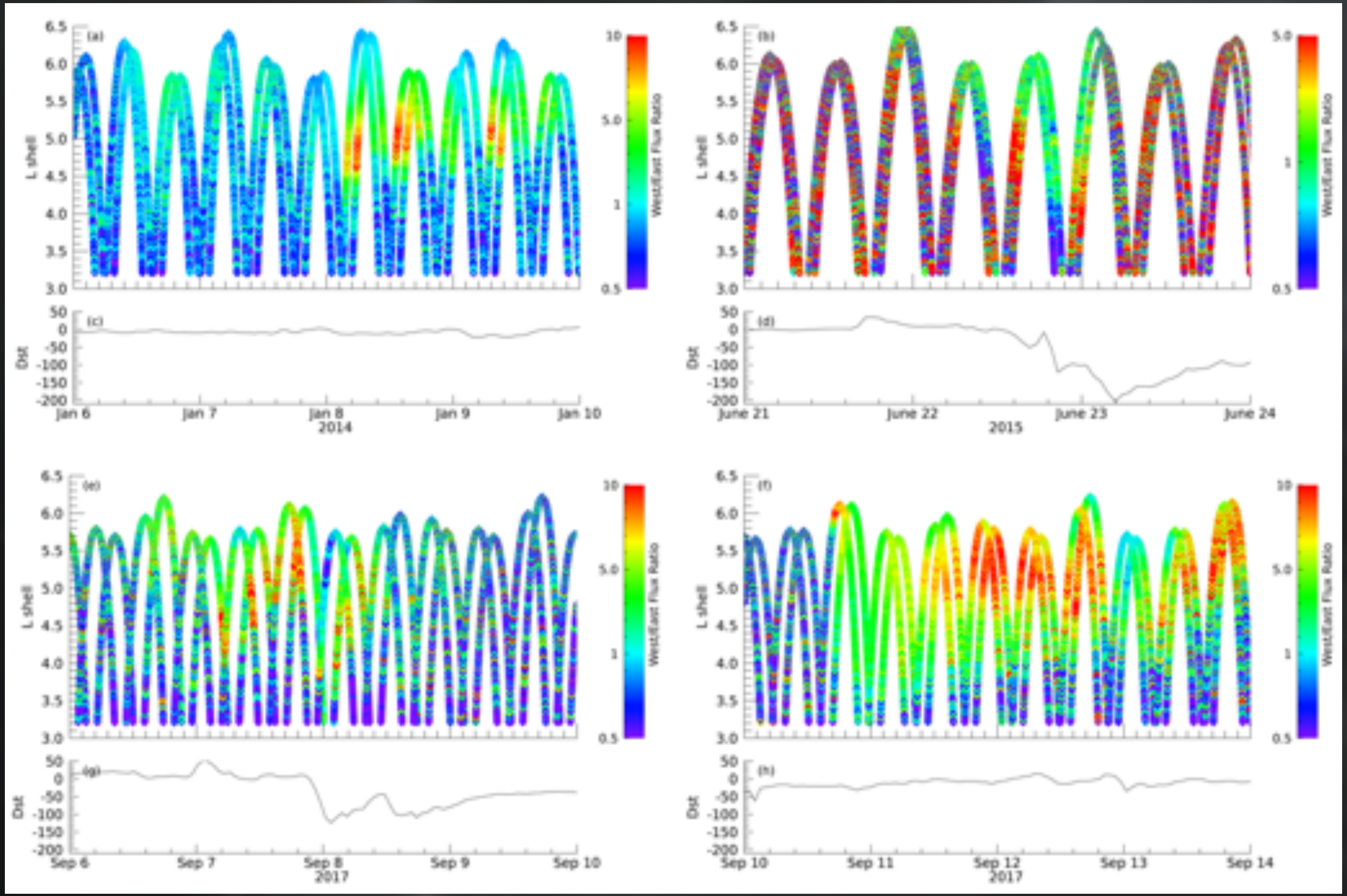
Using the east-west (i.e. gyrocenters outside-inside of orbit) can examine the variation in cutoff rigidities

- (Above) The flux from “east” and “west” (integrated 45 degrees and above east and west), this directional flux difference becomes apparent at SEP onset
- The total flux from east or west is seen to vary significantly during a single orbit, and from orbit to orbit.

We can take the ratio of West/East flux to look at a proxy for cutoff rigidity (a measure of if particles from that energy are allowed at that particular L and MLT).

- The directional flux ratio produces an ”M” shape as the spacecraft passes through Earth’s magnetic field where more particles have access, measures near isotropy of the West/East flux ratio at apogee and then comes back towards Earth.
- The West/East flux ratio has substructure, and varies orbit to orbit, implying dynamic cutoffs even during geomagnetic quiet times

East-West Effect

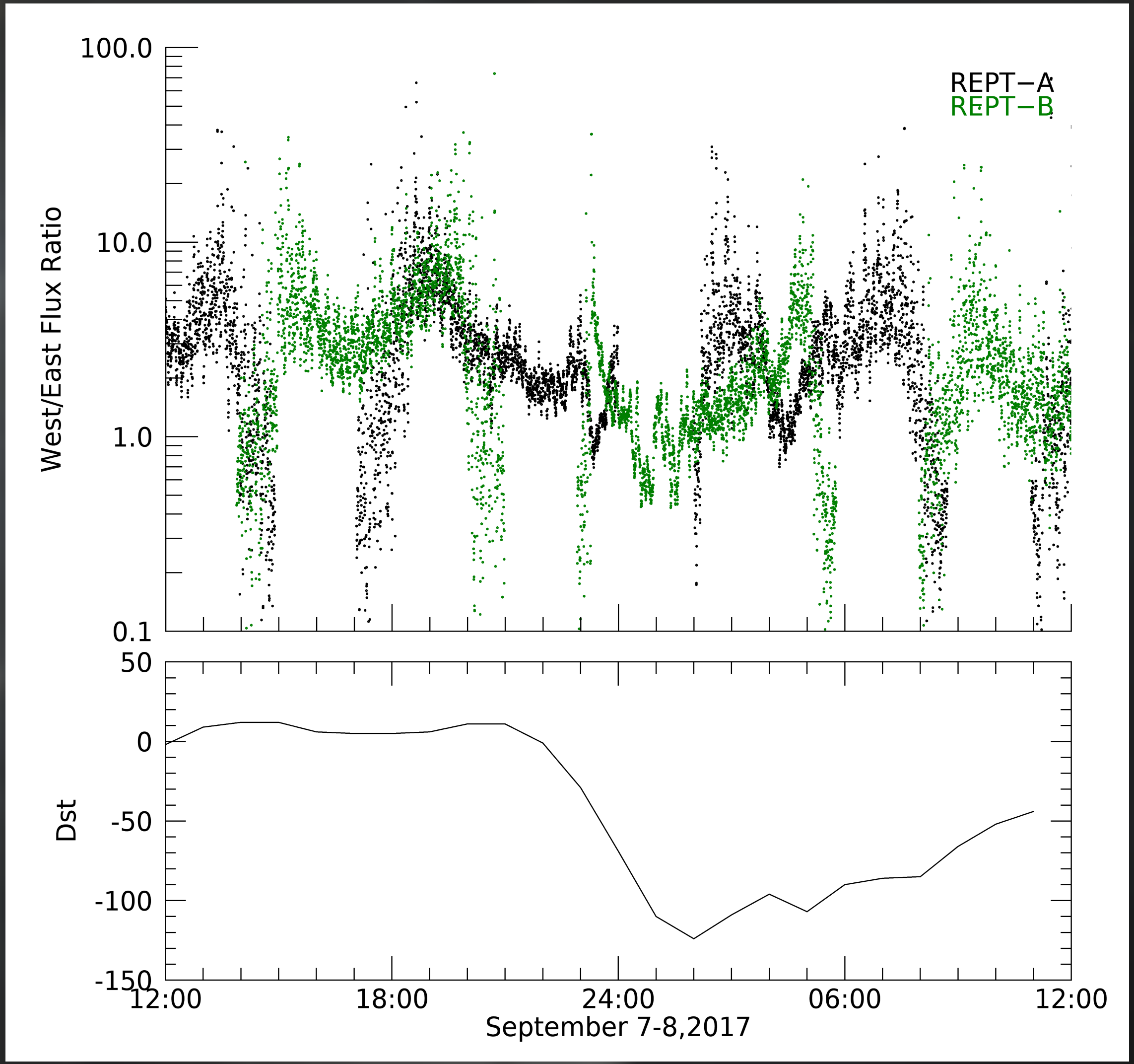


(Above) The West/East flux ratio is shown for the 4 events in this study as a function of L-shell, the concurrent Dst is also shown for each event.

- We utilized the varying L of RBSP throughout its orbit to look at West/East flux ratio (as a proxy for cutoff rigidity)
- Events from June 2015 and 6-10 September, 2017 have dramatic Dst changes which is apparent in the directional flux ratios
- January 2014 also shows dynamic cutoff rigidities
  - The peak of the flux ratio moves outward during the event, and the inbound and outbound section of orbits see varying strengths of the flux ratio
    - Could this indicate an MLT asymmetry in the cutoffs?

Dst changes

- Can examine the east/west flux ratio in more detail during active geomagnetic times
- The “M” shape seen previously is disrupted by the changing magnetic topology of the inner magnetosphere
- REPT-A (shown in black) shows a sudden flux decrease as the orbit gets closer to Earth, indicating a sudden encounter of a different magnetic topology
  - REPT-B shows less dramatic changes, but still sudden changes in the flux ratio near the apogee of it’s orbit



(Above) The west/east flux ratio for 24 hours 7-8 September, 2017, and the corresponding Dst value. The flux ratio shows dramatic changes near midnight when the Dst changes

Summary

- RBSP orbit is useful to study cutoff rigidities in the near-equatorial inner magnetosphere
- Energetic particles from SEP events can access lower L-shells (L<4) than predicted by Strömer model (1955)
- Cutoff rigidities are highly dynamic, even during magnetic “quiet” times
- Next Steps: A full statistical study of all events during Van Allen Probes, 20+ events

Thank you for your interest in this display!

The research presented here has been submitted and is under review in the Journal of Geophysical Research

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