Statistics of Longitudinal Splitting of the Proton Aurora during Substorms

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Abstract

The isotropy boundary, i.e. the lower limit of significant proton precipitation into the ionosphere, moves equatorward as the geosynchronous magnetic field elevation angle decreases. At the beginning of the substorm expansion phase, the magnetic field is highly stretched (low elevation angle) except in a very azimuthally localized region (the substorm current wedge). As reconnected flux continues to pile up, the substorm current wedge grows both azimuthally and radially. Using a combination of 264 high quality events imaged by the spectrographic imager onboard the IMAGE spacecraft and global MHD simulations, we show that the proton aurora often has a significant decrease in intensity (split) at local times that map into the substorm current wedge. The splitting is much more likely to happen for substorms with lower AL. Other parameters such as the width and expansion speed of the split region also correlate with the AL index.

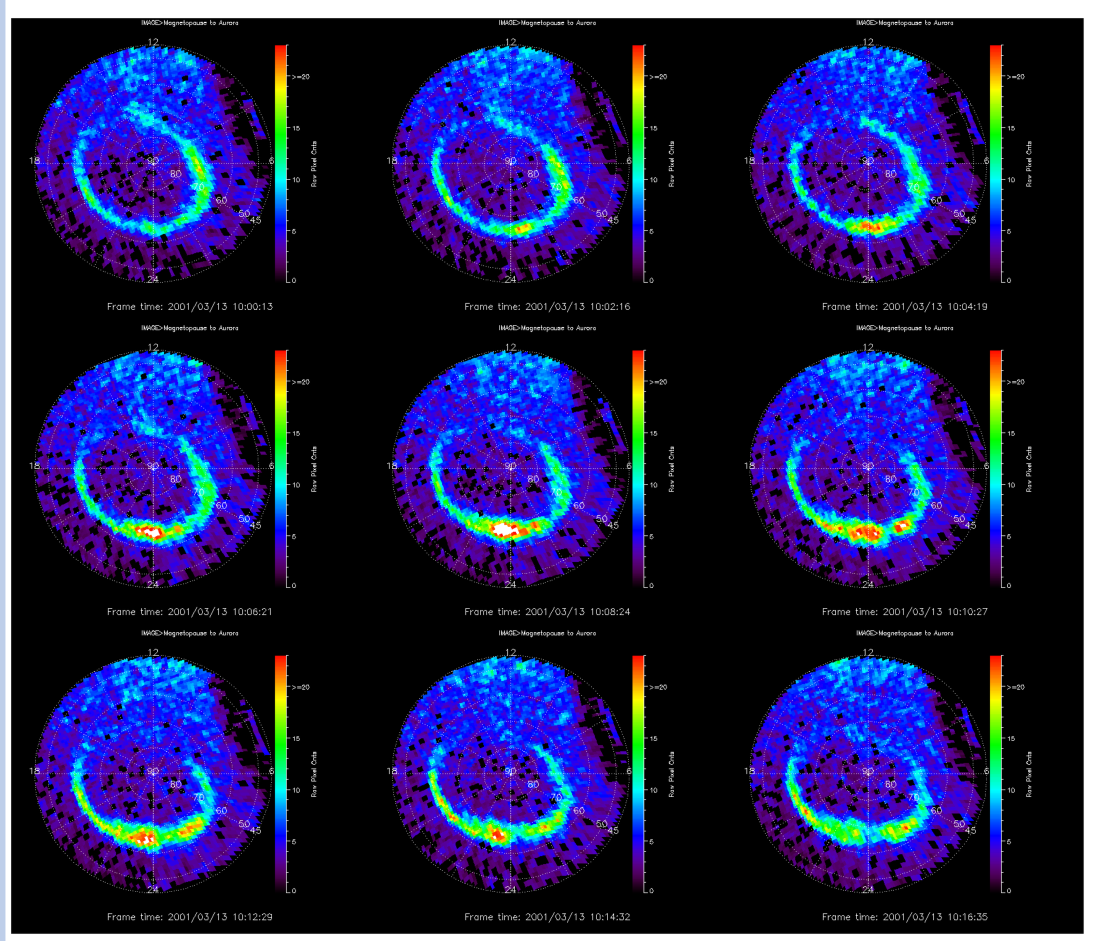
Event Selection Criteria

Events were selected from the list provided in *Frey et al.* [JGR - 2004]. They list was then reduced by the following criteria:

1. **Isolated**: No substorm onsets within 90 minutes
2. **Good Coverage**: The auroral oval had to be in the field of view of the camera for the entire period, and no more than two consecutive missing frames
3. **Clearly Distinguishable**: The substorm onset brightening had to be clearly distinguishable from the background in both the WIC and SI-12 imagers.
4. **No Limb Distortion**: The pixel size near the enhanced auroral precipitation could not be severely distorted due to a poor viewing angle

This left 356 events from the original 2400.

Longitudinal Splitting Example



- 9 consecutive frames from IMAGE SI-12 instrument (proton aurora) arranged from left to right and top to bottom
- Longitudinal splitting starts in the 4th frame very close to the onset meridian
- "Clear " precipitation maxima on either side of the precipitation minimum
- Common feature in the substorms observed by SI-12 instrument

Quantification of the Splitting

- Each event was first inspected to determine whether or not it looked like it developed a "clear" precipitation minima near the onset location.
- The events were binned as split (developed precipitation minima) or not-split.
- For the split events, the width and time of the split was recorded relative to the onset.

To better quantify what is meant by "splitting", the following procedure was then developed:

- Extract the data along meridians every 1° in longitude
- Fit each scan to a function of the form:

$$Counts(\phi_i) = A(\phi_i)e^{\frac{(\lambda-\lambda_{max}(\phi_i))^2}{2\sigma(\phi_i)^2}} + B(\phi_i)$$

- Scans with $\sigma(\phi) > 20°$ were discarded as bad fits
- The background counts for each frame were estimated as:

$$\bar{B} = \sum_{i=1}^{N} \frac{B(\phi_i)}{N}$$

- The raw data along each meridian was integrated (and normalized by scan length in degrees) and plotted as a function of longitude
- The integrated data (I) was then smoothed and searched for well defined peaks.
- The splitting index (SI) was then calculated as:

$$\Delta I_{west,east} = I_{west,east} - I_{min}$$
$$SI = \frac{\min(\Delta I_{west,east})}{\bar{B}}$$

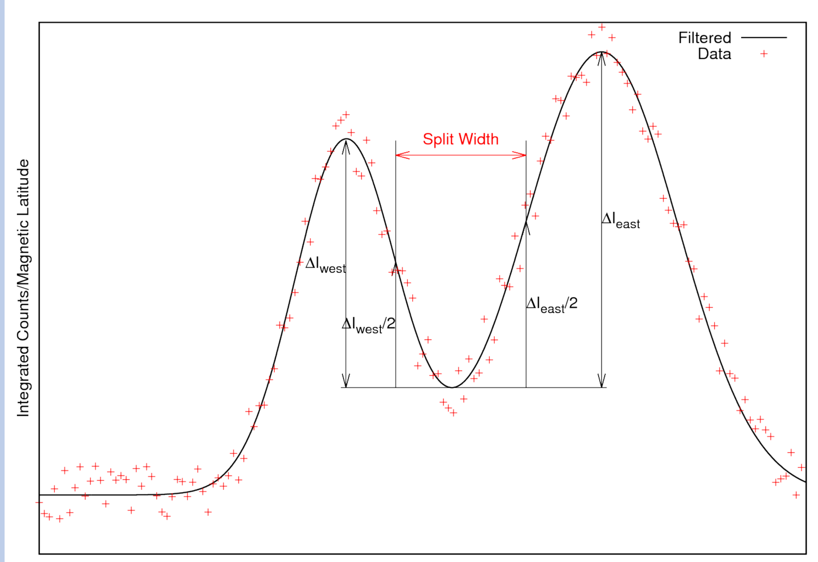


Figure: Example of the splitting index

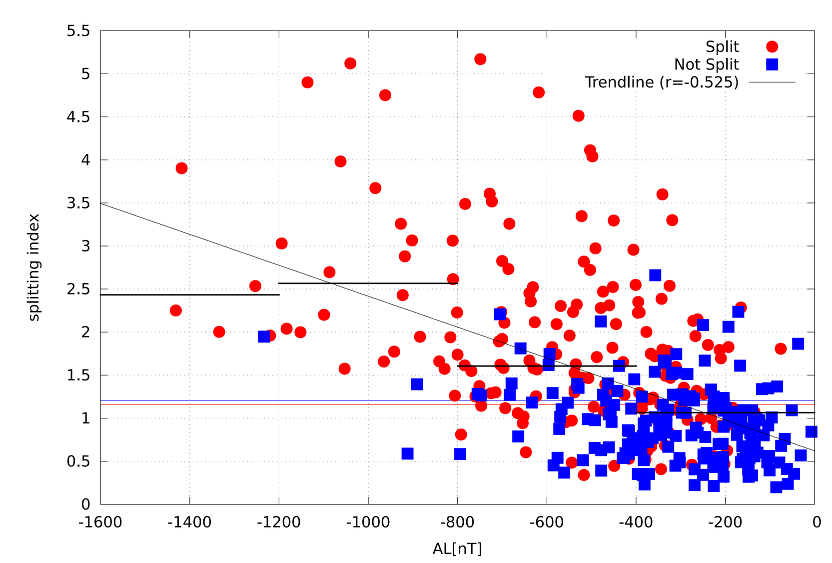
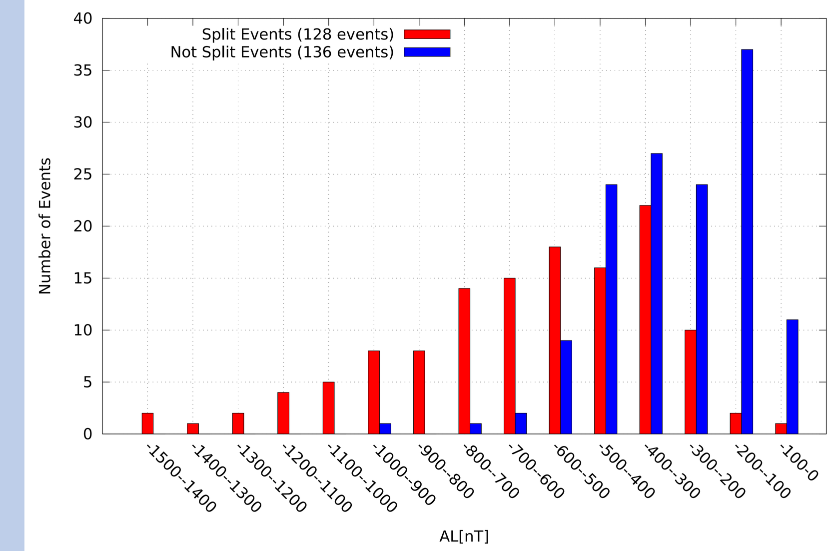


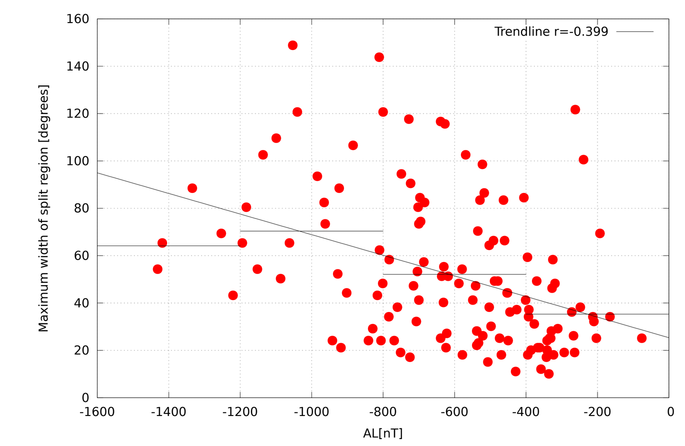
Figure: SI vs AL. Split events (red circles) and not-split events (blue squares) determined by visual inspection.

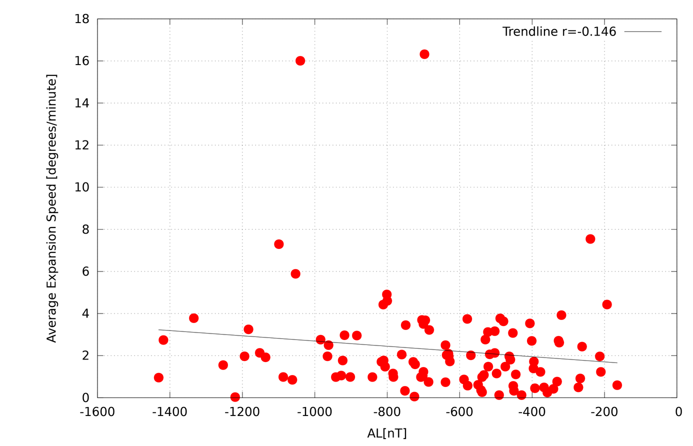
- Lower quartile of split events and upper quartile of not-split events were removed from the study
- 264 events remained. The boundary between split and not-split events was placed at SI=1.2

AL Dependence



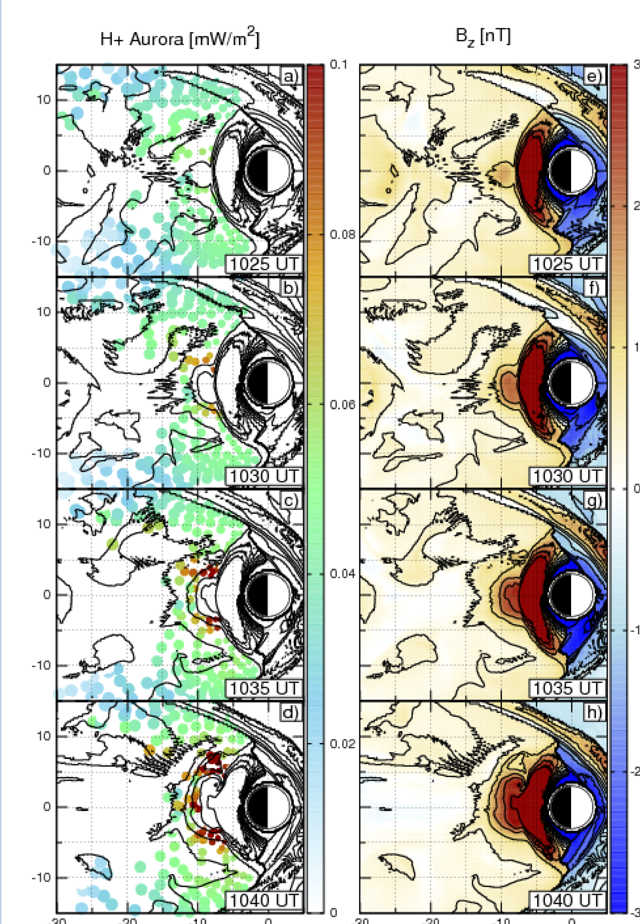
- Stronger substorms (lower AL) split more frequently
- Stronger substorms produce wider split regions
- The average expansion speed is 2.2° per minute, independent of AL





- Agrees with Substorm Current Wedge expansion speeds previously published.

MHD simulations



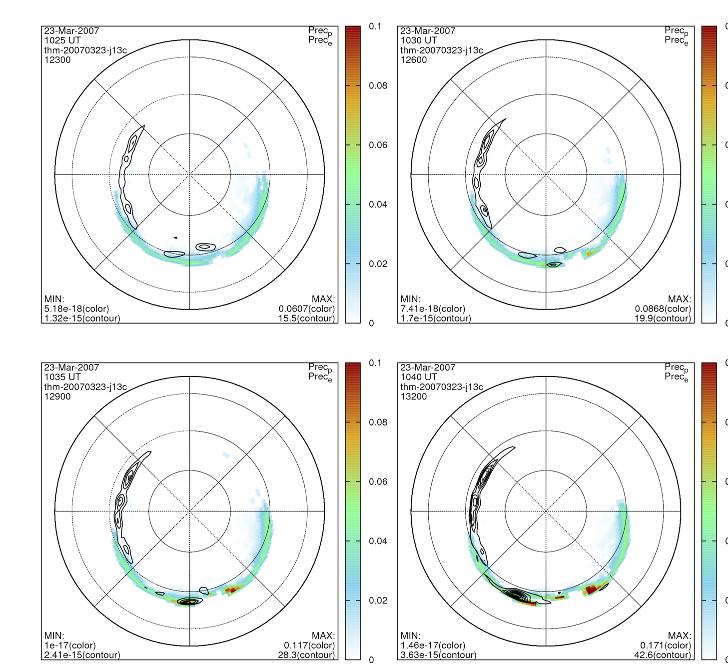


Figure: (Above) Proton precipitation (color) and discrete electron precipitation (contours). (Left) Mapped proton precipitation and B_Z in the Central Plasma Sheet.

- OpenGGCM Simulation of proton precipitation due to fieldline curvature shows the split corresponds to the SCW.

Conclusion

- Global simulations of proton precipitation due to fieldline curvature predict splitting of proton precipitation due to formation of SCW.
- Azimuthal splitting of proton aurora is common phenomena ($\sim$ 50% of events)
- Azimuthal splitting is more common in strong substorms
- Expansion speed consistent with SCW expansion speed

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