Electron Flux and Precipitation During ICME Case Studies

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Interplanetary Coronal Mass Ejections

Comparison of trapped and precipitating electron fluxes during two ICMEs with rotating magnetic clouds.

Evaluated ICMEs occurred on Dec 31, 2015 and June 27, 2013. Both events had a preceding sheath region and intense magnetic storms during the ejecta impact.

- 2015 event: south to north (SN) B_z rotation in ejecta.
- 2013 event: opposite (north to south, NS) ejecta B_z rotation.

Solar wind data for these events are from Wind spacecraft, Dst data from WDC Kyoto, and AL index from OMNI. The magnetopause and plasmapause positions are calculated from the Shue et al. (1998) and O'Brien and Moldwin (2003) models respectively.

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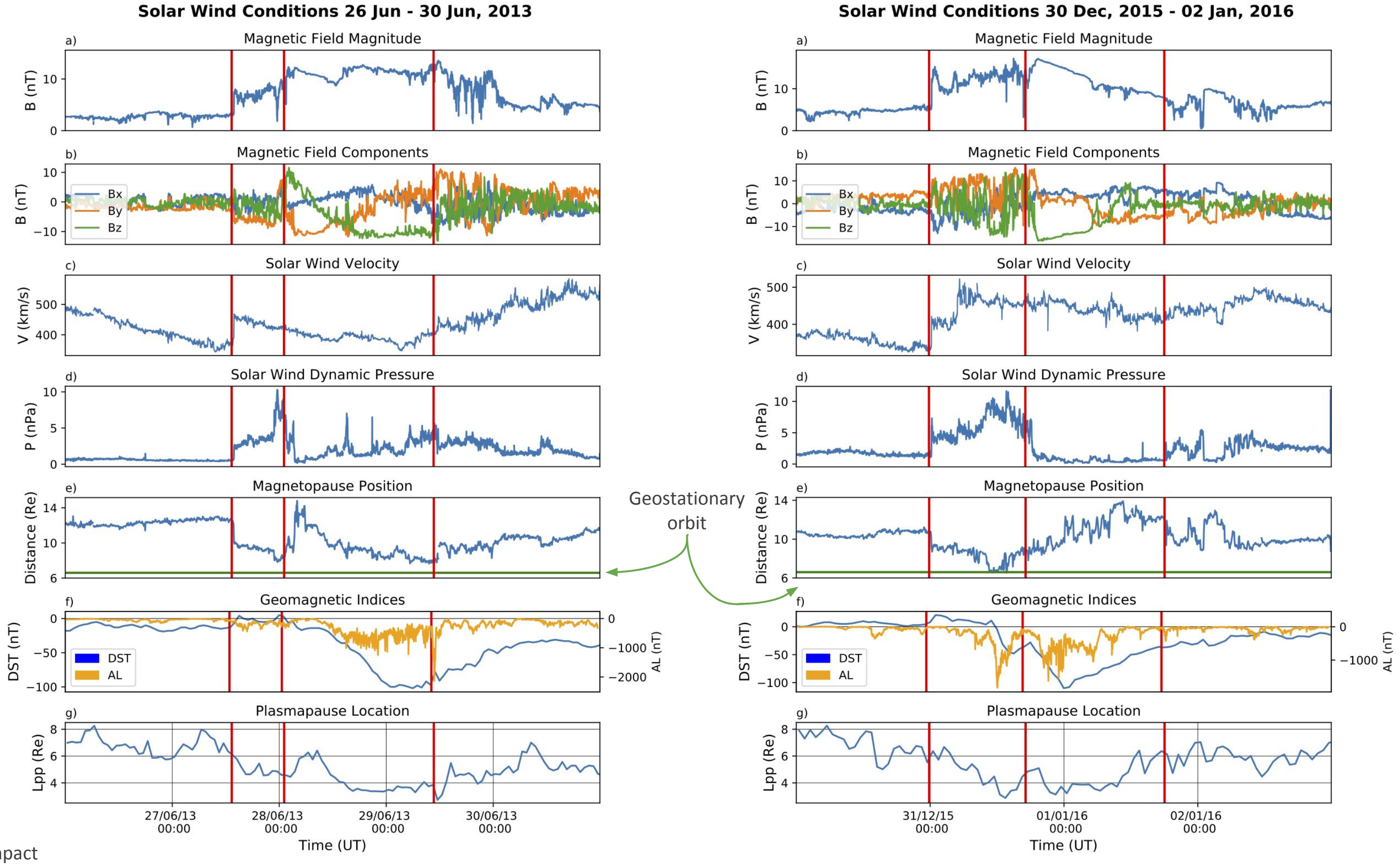

First red line: Shock impact

Second red line: Ejecta leading edge

Third red line: Ejecta trailing edge

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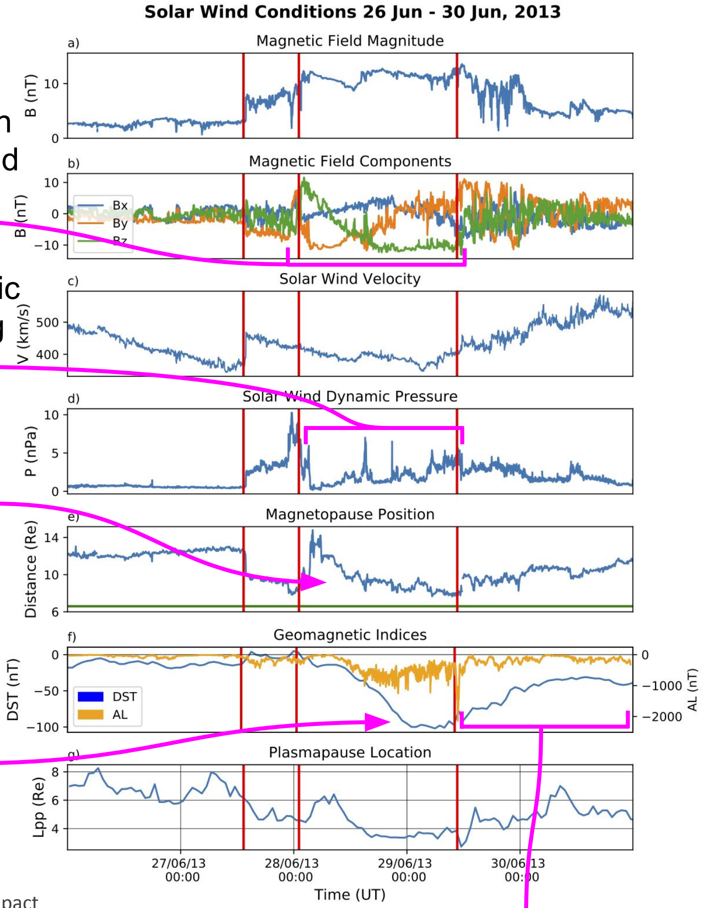


North to south magnetic cloud rotation

Elevated dynamic pressure during ejecta

Progressive magnetopause compression

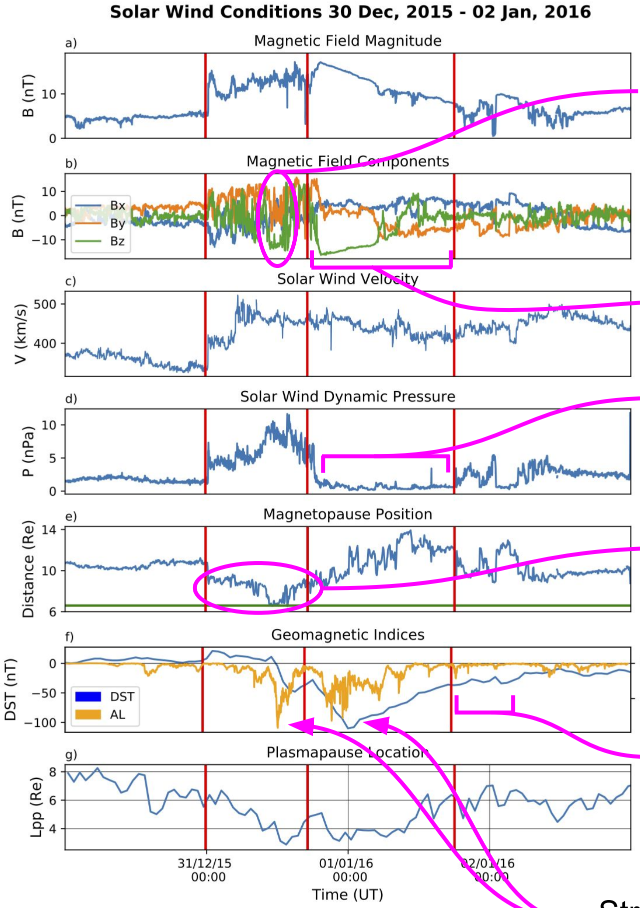
Strong geomagnetic activity

Slow recovery after end of ejecta

First red line: Shock impact

Second red line: Ejecta leading edge

Third red line: Ejecta trailing edge



Extended southward field during sheath region

South to north magnetic cloud rotation

Weak dynamic pressure during ejecta

Extremely compressed magnetopause

Rapid recovery after end of ejecta

Strong geomagnetic activity

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Wave Activity

Chorus, plasmaspheric hiss, ULF Pc5, and EMIC wave activity were investigated during the two events.

Chorus and hiss waves were measured by the Van Allen Probes. ULF and EMIC wave activity were measured by GOES-13 and GOES-15.

Equatorial electron cyclotron frequencies ($f_{ce,eq}$) were calculated based on the Tsyganenko and Sitnov geomagnetic field model (TS04D). Lower band chorus waves are typically between 0.1 $f_{ce,eq}$ and 0.5 $f_{ce,eq}$ and upper-band chorus waves are between 0.5 $f_{ce,eq}$ and 1.0 $f_{ce,eq}$

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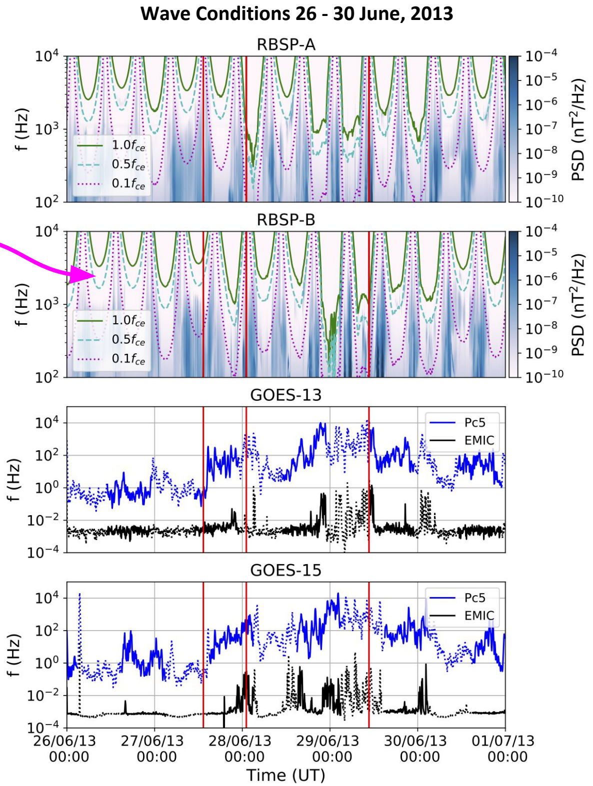
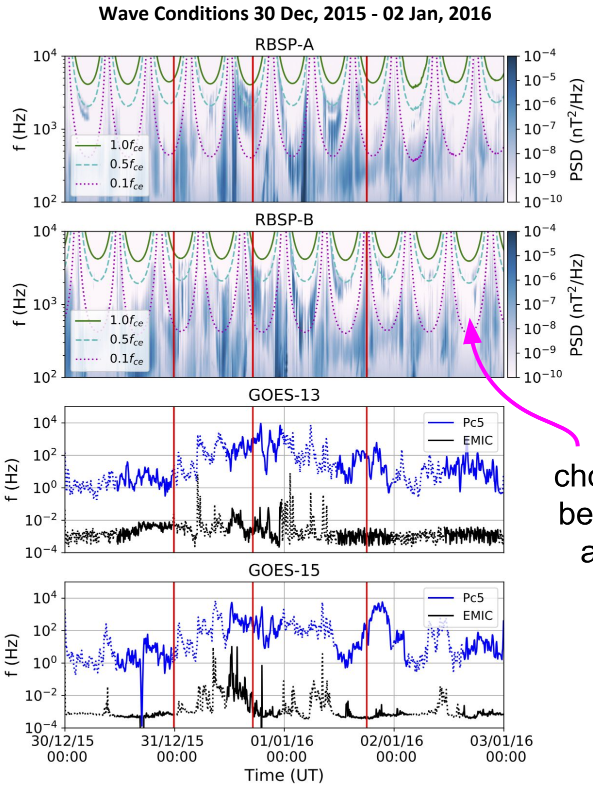
Upper-band chorus waves are between the green and blue lines





Lower-band chorus waves are between the pink and blue lines

First red line: Shock impact

Second red line: Ejecta leading edge

Third red line: Ejecta trailing edge

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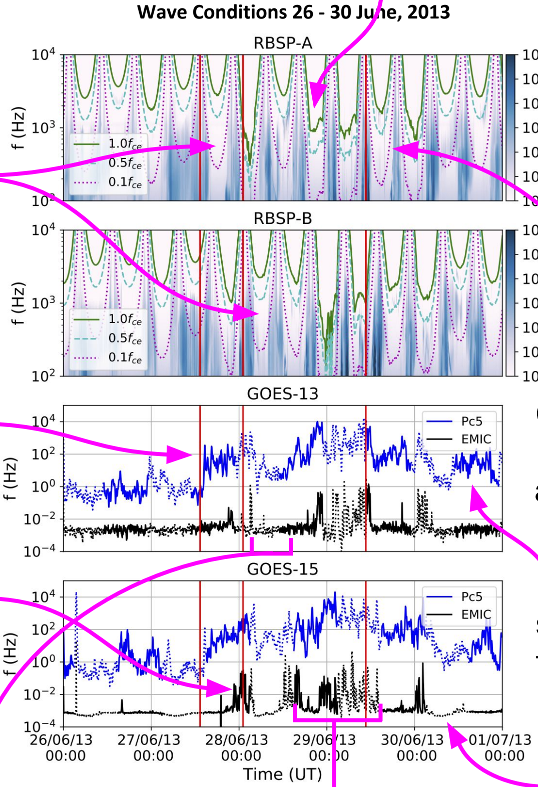
Initially low wave activity in both events

Chorus activity remains low in southward ejecta

Very low chorus and hiss activity in sheath and northward ejecta

Enhanced ULF activity during sheath region

Enhanced EMIC activity upon ejecta impact



Chorus activity remains low after the ejecta

ULF activity stays high after the ejecta ends

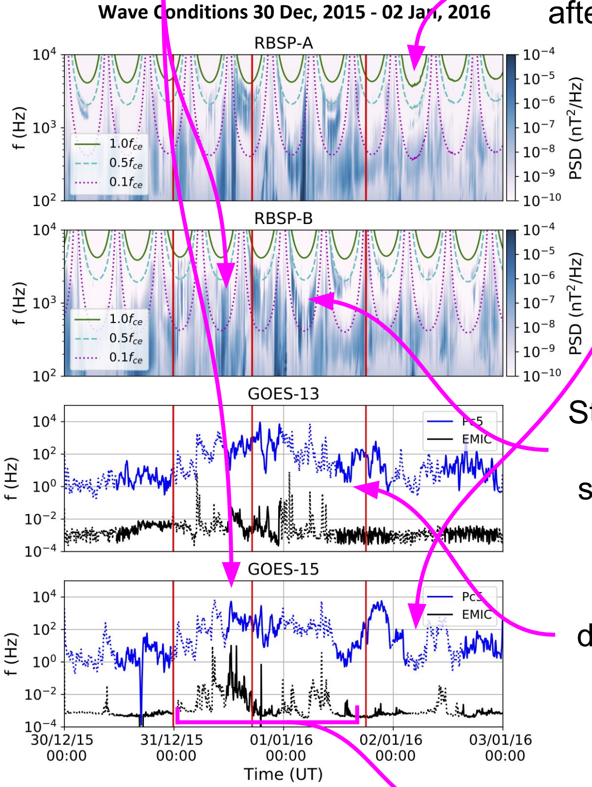
Weak ULF and EMIC activity during northward ejecta

Strongest ULF and EMIC activity during southward ejecta

EMIC activity rapidly decreases after end of ejecta

Enhanced wave activity during southward period of sheath

Wave activity rapidly decreases after end of ICME



Strong lower-band chorus during southward ejecta

Weaker ULF during northward ejecta

Elevated ULF and EMIC waves throughout sheath and ejecta

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Flux data

- Precipitating fluxes are calculated from POES data: energies of >30 keV, >100 keV, and >300 keV.
- Trapped electron fluxes measured by Van Allen probes: energies of 32 keV (representative of source population), 346 keV (seed population), 1079 keV (core population), and 3.4 MeV (ultrarelativistic population).
- Precipitating fluxes evaluated from geomagnetic latitudes 55° to 69°. Trapped fluxes evaluated from L-shell 3.0 to 8.0, which corresponds to same geomagnetic latitudes when using the magnetic dipole model.

Precipitating electron flux

Flux data from 90° MEPED telescope

$$\log_{10}(J_{precip}) = \frac{1}{2}(\log_{10}(J_0) + \log_{10}(J_{90}))$$

Flux data from 0° MEPED telescope

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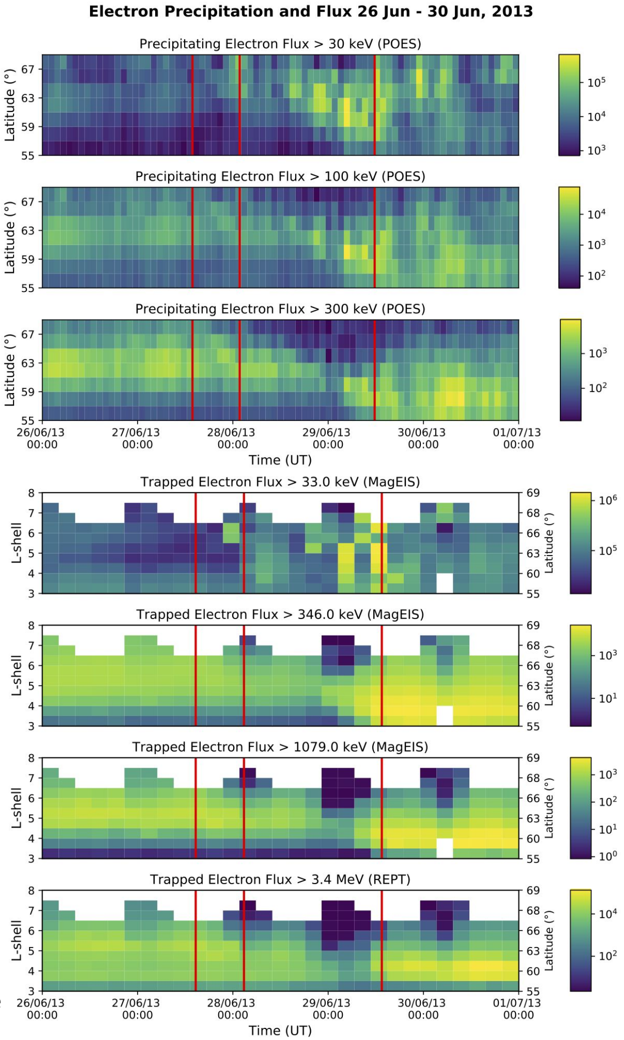
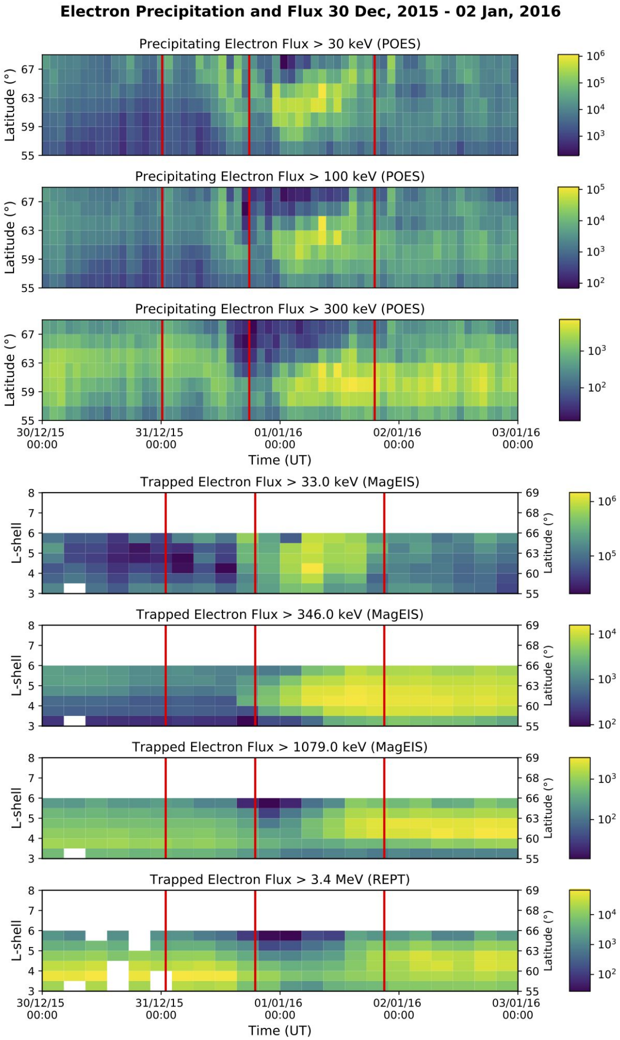
North to south magnetic field rotation in ejecta





South to north magnetic field rotation in ejecta

First red line: Shock impact
Second red line: Ejecta leading edge
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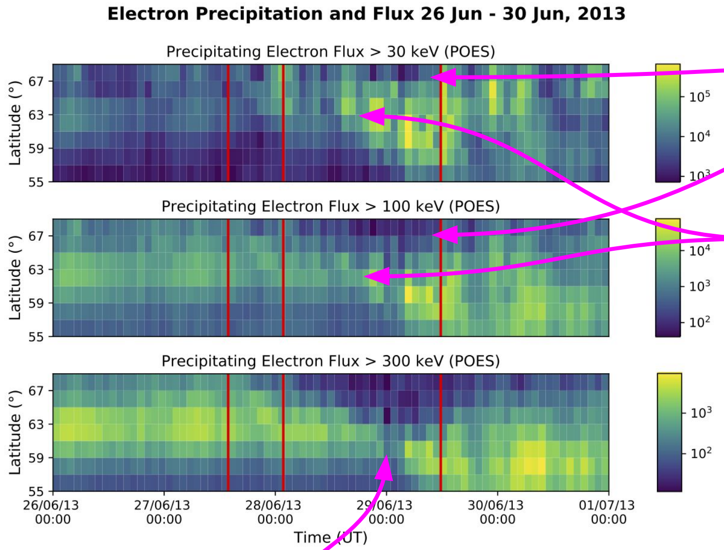
Precipitating Flux Similarities

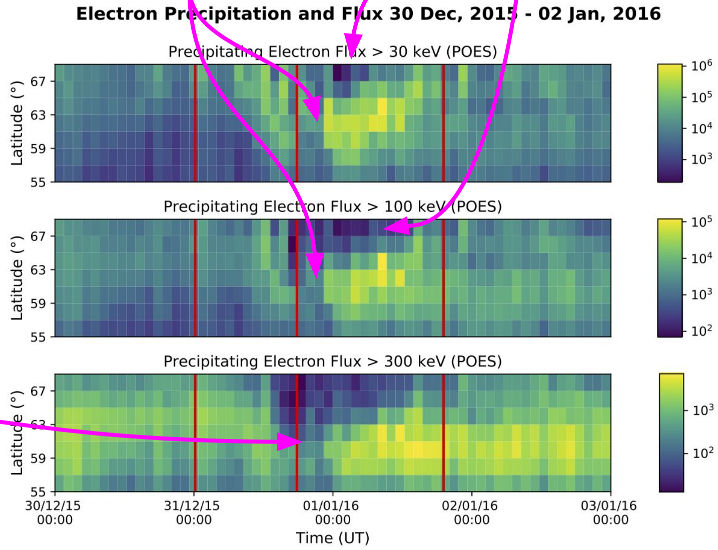
NS Event



Depleted high-latitude precipitation during southward field

Enhanced mid-latitude 30 keV and 100 keV precipitation during southward field

SN Event



300 keV precipitation strongly suppressed during southward magnetic field

First red line: Shock impact
Second red line: Ejecta leading edge
Third red line: Ejecta trailing edge

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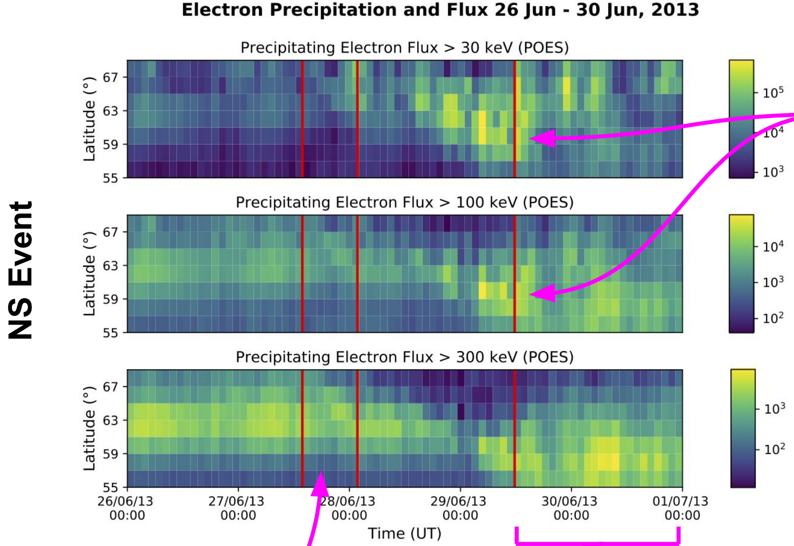
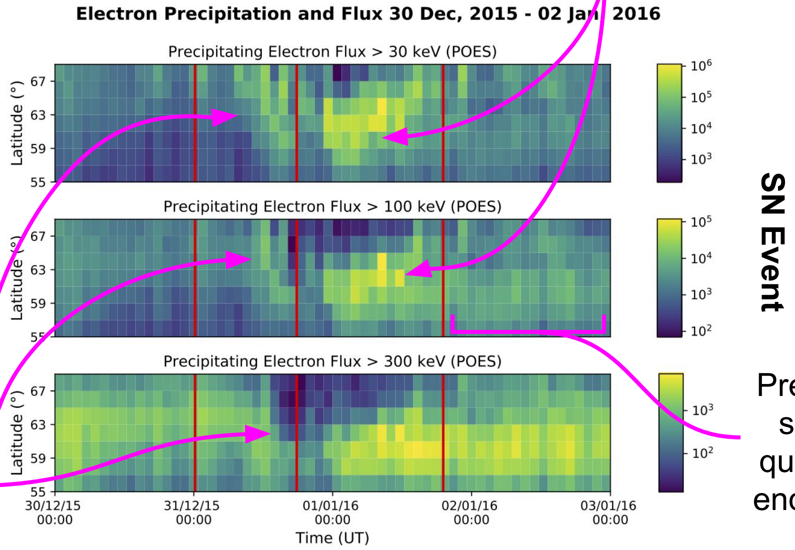
Precipitating Flux Differences



Region of enhancement moves to lower latitudes over time

Region of enhancement moves to higher latitudes over time



Constant precipitation during sheath region in all energy channels

Precipitation continues to fluctuate after end of ejecta

Precipitation changes during southward excursion in sheath

Precipitation stabilises quickly after end of ejecta

First red line: Shock impact
Second red line: Ejecta leading edge
Third red line: Ejecta trailing edge

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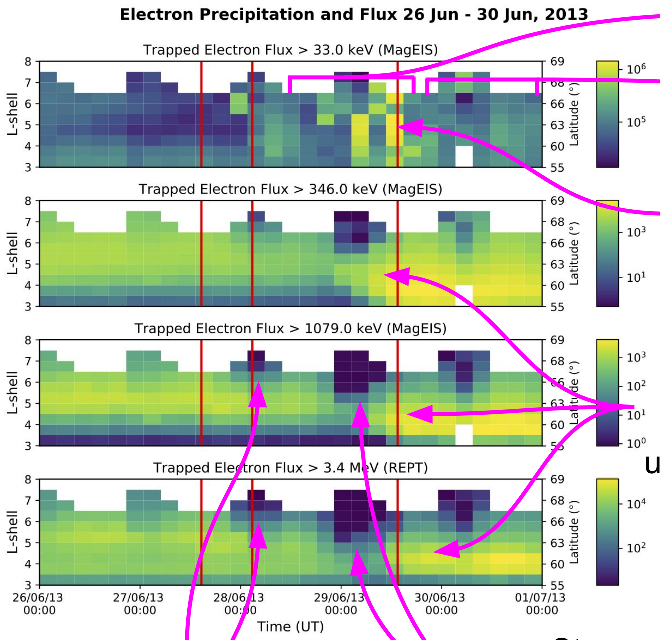
Trapped Flux Similarities

Source fluxes strongly enhanced during ejecta

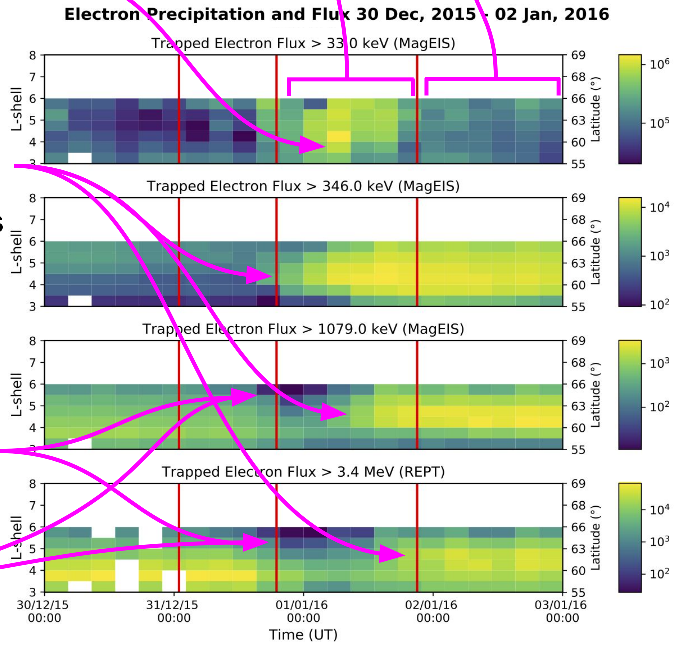
Source fluxes return to near pre-event levels after ejecta

Peak source flux at time of southernmost magnetic cloud

NS Event



Progressive enhancement of seed, core, and ultrarelativistic fluxes



SN Event

Strong seed, core, and ultrarelativistic flux depletions during southward ejecta

High L-shell core and ultrarelativistic flux depletions upon ejecta impact

First red line: Shock impact
Second red line: Ejecta leading edge
Third red line: Ejecta trailing edge

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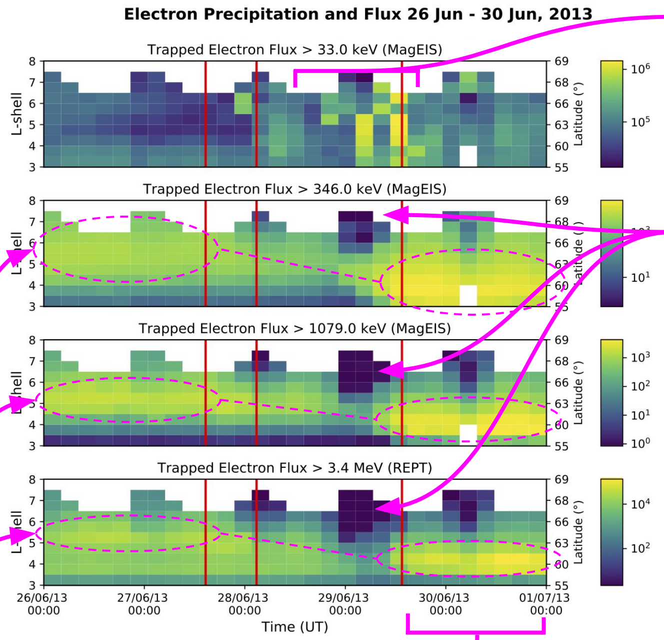
Trapped Flux Differences



NS Event

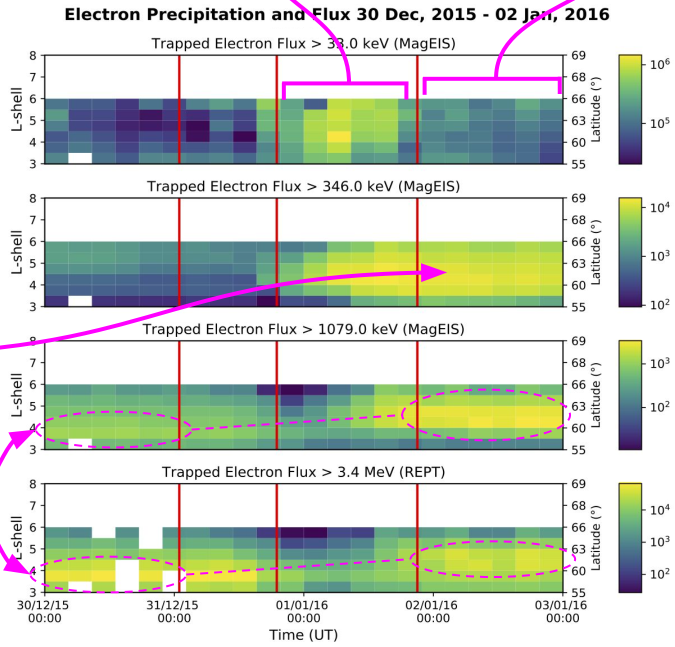
Sporadic source flux enhancement

High L-shell seed depletions during southward ejecta

Seed fluxes strongly enhanced after ejecta from initially low levels

Coherent source flux enhancement

Stable fluxes after end of ejecta



SN Event

Peak fluxes shift from mid L-shells (pre-event) to low L-shells (post-event)

Fluxes vary after end of ejecta

Peak fluxes shift from low L-shells (pre-event) to mid L-shells (post-event)

First red line: Shock impact
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Discussion: Source flux

Trapped source electron fluxes were strongly enhanced (~ order of magnitude) during the ejecta of both events, then quickly weakened after the ejectas ended.

Greatest source flux enhancement occurred during the portion of the ejecta with the southward magnetic field.

The enhancement was smooth and began in the mid-sheath region of the SN event. The NS event had sporadic and strongly fluctuating source flux enhancement during the ejecta.

Rapid source flux depletion indicates that acceleration to higher energies occurred, causing enhancements in seed, core, and ultrarelativistic populations.

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Discussion: Seed flux

Seed fluxes enhanced strongly during both ejecta, with enhancements beginning soon after the time of southernmost magnetic fields in both events.

Seed fluxes were depleted at high L-shells in the southern phase of the NS event. This was not observed in the SN event, possibly due to lower RBSP apogee.

Seed fluxes remained enhanced after both ejecta, suggesting slow decay times due to plasmaspheric hiss and/or continuing acceleration to 100's keV energies

The location of peak seed flux after the events differed: L-shell of 3.5 - 4.0 in NS event compared to L-shell 4.0 - 4.5 in the SN event.

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Discussion: Core and ultrarelativistic fluxes

The core and ultrarelativistic populations were initially high in both events, depleted during the ejecta, and then enhanced again. These enhancements persisted after the end of the ejecta. Core fluxes were enhanced first, followed by the ultrarelativistic flux enhancement soon after, indicating acceleration of source / seed electrons to MeV energies.

SN event: enhancements were likely due to acceleration by whistler mode chorus waves since there was high chorus activity. The enhancements began in the mid-ejecta, allowing for slower acceleration by chorus waves.

NS event: enhancements were likely due to rapid energisation by ULF waves due to high ULF activity, weak chorus activity, and strongly compressed plasmapause. This enhancement began near the end of the ejecta.

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Discussion: Core and ultrarelativistic fluxes

Strong high L-shell depletions occurred in the southward phase of both ejecta. The seed population was also depleted here in the NS event, along with a high L-shell depletion at the sheath / ejecta boundary. Magnetopause shadowing and the Dst effect likely caused these depletions, as the magnetopause was strongly compressed with strong geomagnetic storms at these times.

Location of peak fluxes changed after each event:

- NS event: peak flux moved to lower L-shell ($5.0 < L < 5.5$ to $3.5 < L < 4.5$)
- SN event: peak flux moved to higher L-shell ($3.5 < L < 4.5$ to $4.5 < L < 5.5$)

Fluxes varied more after the NS event, consistent with ongoing chorus activity.

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Discussion: Precipitating >30 keV & >100 keV fluxes

Precipitating 30 keV and 100 keV flux follows pattern of source flux: low fluxes before and after the ejecta with strong enhancement during the ejecta.

Timing and location of the 30 keV and 100 keV precipitation enhancement during the ejecta follows the source flux enhancement. Enhanced 30 keV and 100 keV precipitation reaches lowest latitude at time of most intense trapped source flux.

Source electrons induce lower band chorus waves that precipitate low energy electrons from the belts, and also provide population to be precipitated.

In the NS event, there is low chorus activity and distant plasmasphere, so high precipitation is likely due to plasmaspheric hiss. Precipitation likely caused by high chorus activity in the SN event.

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Discussion: Precipitating >300 keV flux

300 keV precipitation follows the trapped seed, core, and ultrarelativistic populations: initially high, depletes during the southward potion of the ejecta, then enhances again after the end of the southward ejecta.

Location of enhanced 300 keV precipitation corresponds to the location of peak high-energy trapped flux. Lower precipitation occurred at times / locations of depleted high-energy trapped fluxes.

This indicates that high energy trapped populations experienced constant losses via precipitation. Losses due to enhanced precipitation would have been outweighed by the gains in trapped radiation belt populations during the ICMEs.

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Summary

- We examined trapped and precipitating electron fluxes during two ICMEs with rotating magnetic cloud from POES and RBSP data.
- Notable similarities were observed in the two events, e.g. strong source flux enhancements in each ejecta that rapidly depleted after the end of the ejecta.
- We also observed significant differences, such as the different shifting of the location of the peak trapped core and ultrarelativistic electron fluxes.
- This indicates that there are different mechanisms acting on the electron populations, which may be related to the opposite magnetic cloud orientations during each event.

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Further Information

This presentation is based on the results of:

George, H., Kilpua, E., Osmane, A., Asikainen, T., Kalliokoski, M. M. H., Rodger, C. J., Dubyagin, S., and Palmroth, M.: Outer Van Allen belt trapped and precipitating electron flux responses to two interplanetary magnetic clouds of opposite polarity, Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2020-18, in review, 2020.

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