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Sawtooth events and O+ in the plasma sheet and boundary layer: CME- and SIR-driven events

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Background and Motivation

- Sawtooth events are quasiperiodic injections of energetic particles over a large range of MLT at geosynchronous orbit
- Brambles et al. (2011) suggested that heavy ion outflow was needed to produce sawtooth events in simulations
- Transit time from ionosphere to tail is consistent with a heavy ion outflow feedback for driving subsequent sawtooth injections
- Need for heavy ion feedback may depend on whether coronal mass ejection (CME) or streaming interaction region (SIR) drives event (Brambles et al., 2013)

Tail O+ Source and Implications for Sawtooth Driving

Nightside auroral zone (Tung et al., 2001; Sauvaud et al., 2004):
- Direct access to plasma sheet
- Expected source for heavy ion feedback

Cusp (Seki et al., 2000):
- Requires convection to reach mid-tail plasma sheet
- Directly driven by solar wind, so not a candidate for a feedback mechanism

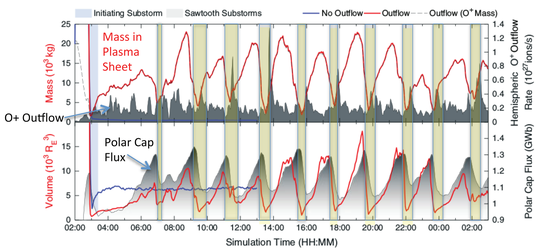

Figure 1: Evolution of plasma sheet and polar cap parameters during a simulation of an idealized sawtooth event. From Ouellette et al. (2013).

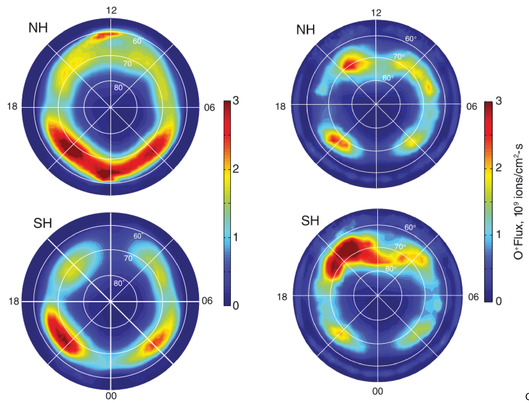

Figure 2: Average ionospheric outflow during simulations of CME-driven (left) and SIR-driven (right) sawtooth events. Outflow in the CME-driven event is primarily from the nightside, whereas outflow in the SIR-driven event is primarily from the dayside. From Brambles et al. (2013).

References

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Case Studies: CME-Driven Event (1 October 2001) and SIR-Driven Event (24 October 2002)

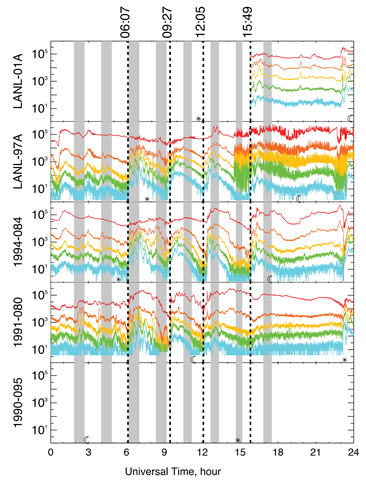

Figure 3: LANL geosynchronous energetic particle data from 1 October 2001. Four sawtooth injections identified by Cai and Clauer (2009) are marked with vertical dashed lines.

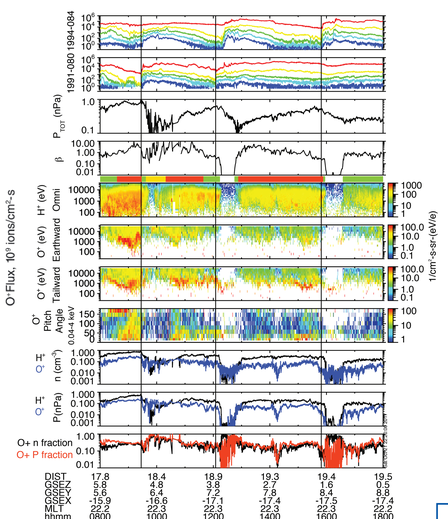

Figure 4: Cluster data from the magnetotail during the 1 October 2001 sawtooth event. The second through fourth injection times are marked. The energy-dispersed O+ seen before the second injection is consistent with a nightside ionospheric source (Sauvaud et al., 2004). The cold O+ beams seen before the third and fourth injections are consistent with a cusp source (Seki et al., 2000). The O+/H+ density and pressure ratios are flat or even decreasing before each injection.

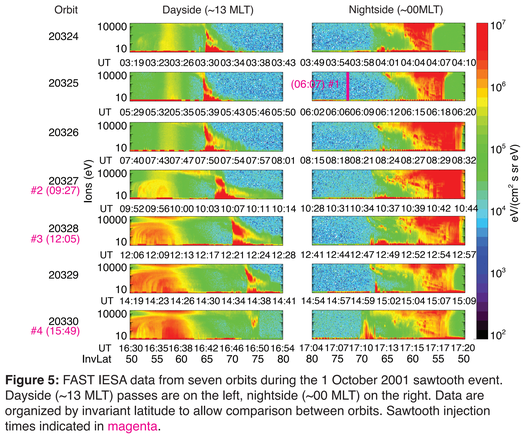

Figure 5: FAST IESA data from seven orbits during the 1 October 2001 sawtooth event. Dayside (~13 MLT) passes are on the left, nightside (~00 MLT) on the right. Data are organized by invariant latitude to allow comparison between orbits. Sawtooth injection times indicated in magenta.

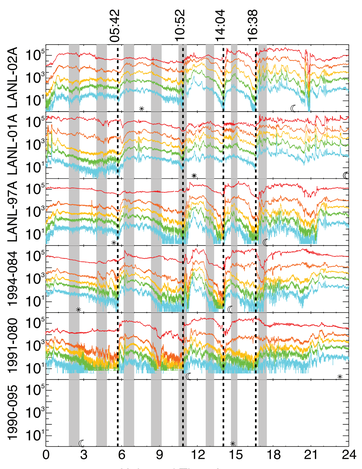

Figure 6: LANL geosynchronous energetic particle data from 24 October 2004. Four sawtooth injections are marked. Four other injections identified by Huang et al. (2004) do not meet the Cai and Clauer (2009) criteria for sawtooth injections and are not marked.

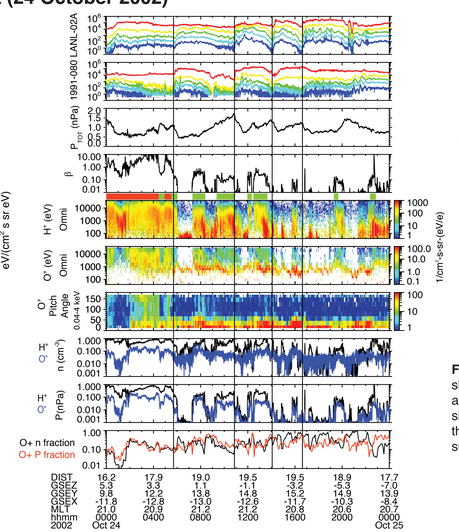

Figure 7: Cluster data from the magnetotail during the 24 October 2002 sawtooth event. The four sawtooth injection times are marked. The cold O+ beam seen from about 0540 onward is consistent with a cusp source (Seki et al., 2000). The O+/H+ density and pressure ratios are flat before the first sawtooth injection, decreasing before the second, and increasing before the third and fourth.

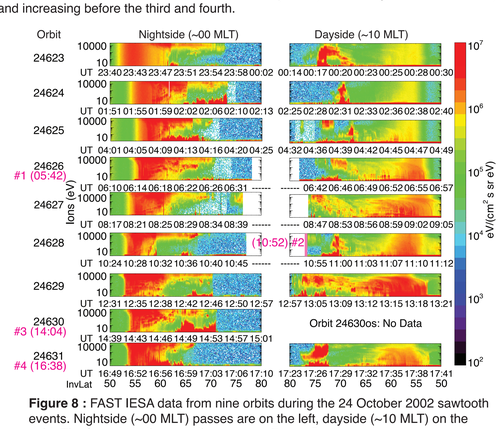

Figure 8 : FAST IESA data from nine orbits during the 24 October 2002 sawtooth events. Nightside (~00 MLT) passes are on the left, dayside (~10 MLT) on the right. The format is otherwise the same as Figure 5.

Summary

- Although simulations have suggested that feedback of heavy ions flowing out of the nightside auroral region produce sawtooth events, in situ data show that most of the O+ near the near-Earth neutral line is of cusp origin.
- Heavy ions may still play a role in producing sawtooth events, but the heavy ion feedback mechanism via reconnection, proposed by Brambles et al. (2011), is not consistent with the observations.

Statistical Studies

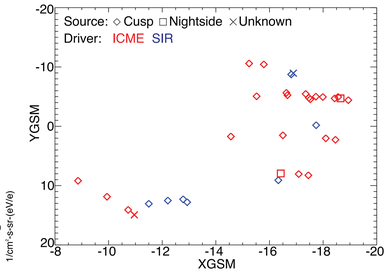

Figure 9: Locations of Cluster at times of injections when Cluster plasma sheet or lobe data are available. In only 2 of 33 cases does the O+ originate in the nightside auroral region, and one of those is the first injection of the sequence. In 29 cases, the O+ originates in the cusp.

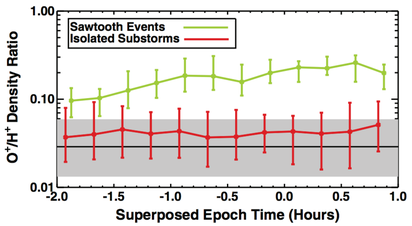

Figure 10: Superposed epoch analysis shows that the O+/H+ density ratio before and during sawtooth events (green) is significantly higher than average, whereas there is no significant difference for isolated substorms (red). From Liao et al. (2014).

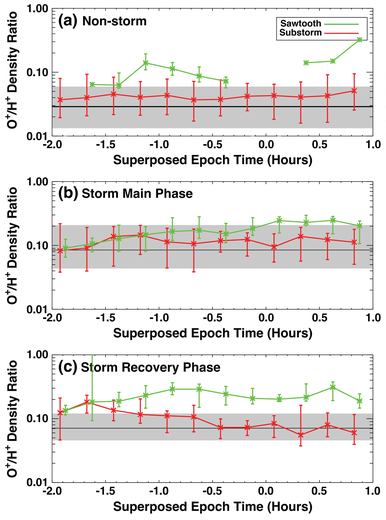

Figure 11: However, much of that difference is due to sawtooth events mostly occurring during geomagnetic storms, when the O+/H+ density ratio is expected to be higher. From Liao et al. (2014).

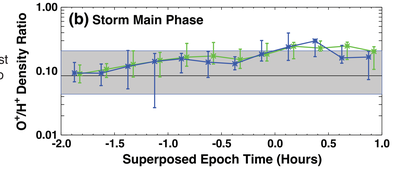

Figure 12: There is also no significant difference between the density ratio observed around the first injection of the sawtooth event (blue) and the ratio observed around subsequent injections (green). From Liao et al. (2014).