Subauroral ion drift: observations and model

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Abstract

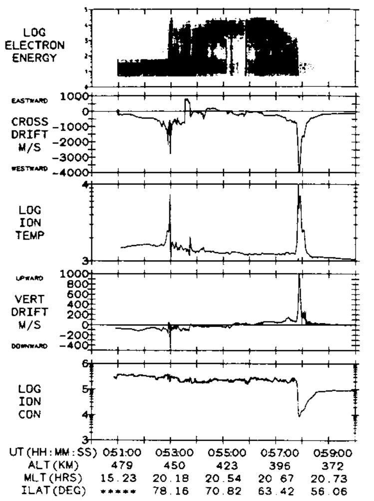
We propose a physical mechanism that explains how "polarization jets" (PJ) or "subauroral ion drifts" (SAID) are formed in the course of a substorm and how they evolve. A PJ/SAID is a narrow, latitudinally aligned, region of strong westward winds (> 1 km/s) in the subauroral ionosphere. We consider them to be the ionospheric signature of an inward moving injected plasma front. The flow shear that exists across this interface when it arrives in the vicinity of the plasmapause is responsible for the generation of intense electric fields in the premidnight sector, where PJ/SAID are observed. Quantitative simulation of this mechanism accounts for PJ/SAID width and peak drift velocity. The mechanism explains why PJ/SAID are observed poleward of or in the vicinity of the plasmapause. The inward traveling time of the injected plasma agrees with the delay between substorm onset and the apparition of PJ/SAID; the evolution of the ionospheric signature is consistent with observations as well.

Recently, we have observed "abnormal SAID", corresponding to eastward flow. We argue that the same mechanism can be invoked, but this requires a peculiar configuration of the storm-time magnetosphere.

Substorms and SAID

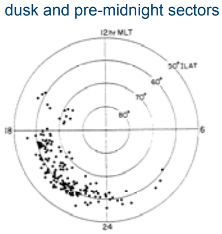
A magnetospheric substorm is a reconfiguration of the tail due to a near-Earth X-type line, characterized by "bursty bulk flow", both Earth- and tailward.

A subauroral ion drift layer is a narrow layer observed during a substorm at subauroral latitude, characterized by a sharp ionospheric ion drift peak:



from Anderson et al. [1991]

- less than 1 ILAT across
- westward drift
- peak drift > 1 km/s
- mainly in the dusk and pre-midnight sectors



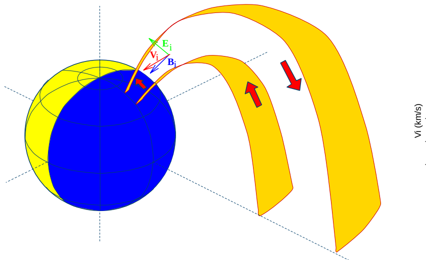
from Spiro et al. [1979]

- temperature peak due to ion-neutral collisions
- fast recombination of NO^+ formed during collisions
- reduced ionospheric charged particle density
- reduced conductivity
- conjugate events in N- and S-hemisphere
- sometimes double or multiple SAID events

Ion drifts are observed soon after substorm onset. After about half an hour (begin of recovery) these drifts develop into the narrow and intense peaks typical of SAID.

Proposed scenario

During a substorm, hot plasmasheet plasma is injected into the nightside inner magnetosphere. We view the SAID as the ionospheric projection of the injected plasma front: Since the magnetic field lines are (roughly speaking) equipotentials, the magnetospheric electric field is geometrically boosted by the mapping into the ionosphere



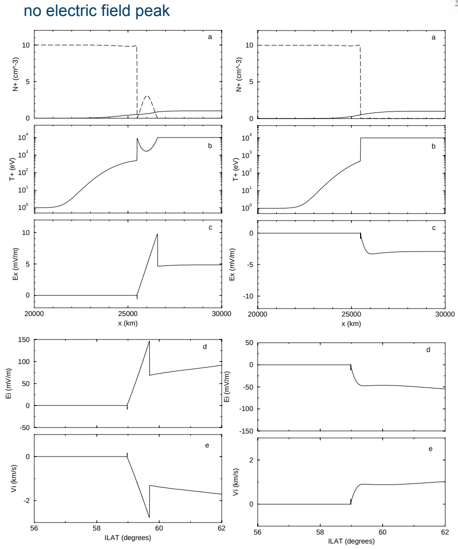
The plasma front is a type of shock. Its inward speed is about the Alfven speed $V_n = B_n/\sqrt{(\mu_0 \rho)}$; it slows down at plasmapause since the density goes up there:
- Speed in the plasmatrough: 10 km/s
- Speed at the plasmapause: 0.5 km/s

Strong electric fields are found at the interface:
- thermo-electric field/finite gyroradius effects
- magnitude and sense of the flow shear affect field strength, especially in the pre-midnight case (see De Keyser et al. [1997], De Keyser and Roth [1997])

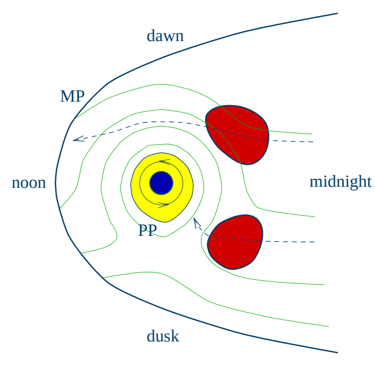
The characteristic lifetime of such an interface is estimated to be 100 - 1000 s. There is a dynamic equilibrium: in a frame co-moving with the plasma front, plasma is moving toward the interface on either side (source), while plasma precipitates in the ionosphere (loss). Cancellation of both effects corresponds to the hypothesis of a tangential discontinuity (TD) structure. We use a TD model [Roth et al., 1996] to compute the electric structure of the interface.

Left: pre-midnight, L = 4, flow shear 10 km/s:
correct width, drift speed peak, and dissipated power

Right: post-midnight, L = 4, flow shear -6 km/s:
no electric field peak

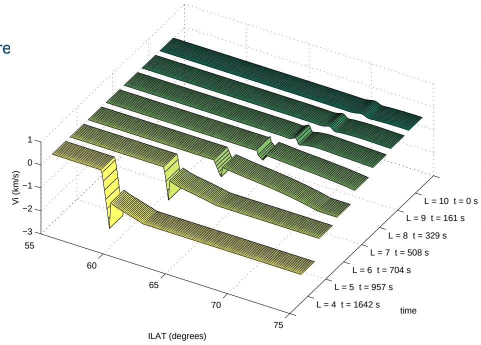


Magnetospheric configuration



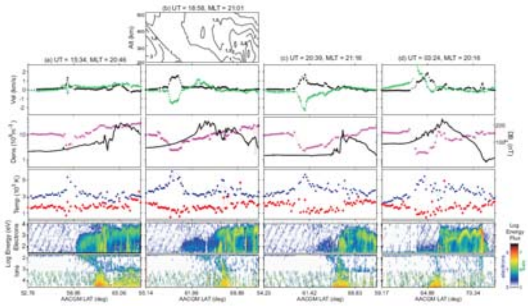
Evolution during substorm

Evolution of the ionospheric signature during a substorm: correct timing and morphology changes



Eastward SAID

Recently we have discovered a new type of subauroral drift, characterized by eastward drifts: "abnormal SAID" [Voiculescu and Roth, 2008] in data from the DMSP spacecraft. Below we give an example of an event observed on successive passes.



Conclusions

Our model explains why SAID most often are situated near the plasmapause. At the same time, the model accounts for the minor drift velocities seen during substorm expansion and the dynamic evolution of these structures into SAID near the beginning of the substorm expansion phase. We find a qualitative and quantitative agreement with observed ionospheric ion drift velocity profiles, and hence observed dissipated power in the ionosphere. The model offers an explanation of the preferred pre-midnight occurrence of SAID. The model is consistent with observations of hot plasma inside the inner magnetosphere (particle flux dropouts) in conjunction with SAID recordings in the ionosphere, and with the observation of energetic electron precipitation down to the SAID location. The model also accomodates for the possibility for double/multiple and even reverse SAID (e.g., at the back end of the injected plasma entity).

References

J. F. Lemaire, M. Roth, and J. De Keyser. *High altitude electrostatic fields driving subauroral ion drifts*. In R. L. Xu and A. T. Y. Lui, eds., Magnetospheric Research with Advanced Techniques, pages 61-64. Elsevier Science Publishers B.V., 1998.

J. De Keyser, M. Roth, and J. Lemaire. *The magnetospheric driver of subauroral ion drifts*. Geophys. Res. Lett., 25:1625-1628, 1998.

J. De Keyser. *Formation and evolution of subauroral ion drifts in the course of a substorm*. J. Geophys. Res., 104(6):12,339-12,350, 1999.

J. De Keyser. *Storm-time energetic particle penetration into the inner magnetosphere as the electromotive force in the subauroral ion drift current circuit*. In S. Ohtani, ed., Magnetospheric Current Systems, Geophysical Monograph Series 118, pages 261-265. AGU, 2000.

M. Voiculescu and M. Roth, *Eastward sub-auroral ion drifts or ASAID*, Ann. Geophys., 26, 1955–1963, 2008

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