Coordinated Radar, Optical and Satellite Analysis of Plasma Sheet-Subauroral Ionospheric Coupling via Meso-Scale Flow Channels

Lawrence Lyons
UNIVERSITY OF CALIFORNIA LOS ANGELES

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Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTB1
Arlington, Virginia 22203
Air Force Materiel Command
**ABSTRACT**

The subauroral ionosphere is a critical region with structure and dynamics controlled by coupling processes with the magnetosphere. While the subauroral ionosphere is often described as slowly-varying structures in the magnetosphere-ionosphere coupling, dynamical processes influenced by auroral/plasma sheet transients are suggested to largely contribute to currents and flow speeds in the subauroral ionosphere much more rapidly. The goal of this investigation is to quantitatively determine how plasma sheet flow channels affect subauroral density and flow dynamics for extending our understanding of the subauroral ionosphere beyond the current quasi-steady picture and towards a much more dynamic coupling with the magnetosphere via meso-scale flow channels at auroral-to-subauroral latitudes. During the year-2 investigation, we investigated the relation between subauroral flow structures and subauroral discrete arc using SuperDARN, DMSP and all-sky imagers. We found that subauroral ion drifts can be visualized by the subauroral arc, and that substorm injections control the timing and location of subauroral ion drifts.
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The subauroral ionosphere is a critical region with structure and dynamics controlled by coupling processes with the magnetosphere. While the subauroral ionosphere is often described as slowly-varying structures in the magnetosphere-ionosphere coupling, dynamical processes influenced by auroral/plasma sheet transients are suggested to largely contribute to currents and flow speeds in the subauroral ionosphere much more rapidly. The goal of this investigation is to quantitatively determine how plasma sheet flow channels affect subauroral density and flow dynamics for extending our understanding of the subauroral ionosphere beyond the current quasi-steady picture and towards a much more dynamic coupling with the magnetosphere via meso-scale flow channels at auroral-to-subauroral latitudes. Our key outcomes of this research are summarized below.

**Influence of Auroral Streamers on Rapid Evolution of Ionospheric SAPS Flows**

Subauroral polarization streams (SAPS) often show large, rapid enhancements above their slowly varying component. We present simultaneous observations from ground-based all-sky imagers and flows from the Super Dual Auroral Radar Network radars to investigate the relationship between auroral phenomena and flow enhancement. We first identified auroral streamers approaching the equatorward boundary of the auroral oval to examine how often the subauroral flow increased. We also performed the reverse query starting with subauroral flow enhancements and then evaluated the auroral conditions. In the forward study, 98% of the streamers approaching the equatorward boundary were associated with SAPS flow enhancements reaching ~700 m/s and typically hundreds of m/s above background speeds. The reverse study reveals that flow enhancements associated with streamers (60%) and enhanced large-scale convection (37%) contribute to SAPS flow enhancements. The strong correlation of auroral streamers with rapid evolution (approximately minutes) of SAPS flows suggests that transient fast earthward plasma sheet flows can often lead to westward SAPS flow enhancements in the subauroral region and that such enhancements are far more common than only during substorms because of the much more frequent occurrences of streamers under various geomagnetic conditions. We also found a strong correlation between flow duration and streamer duration and a weak correlation between SAPS flow velocity and streamer intensity. This result suggests that intense flow bursts in the plasma sheet (which correlate with intense streamers) are associated with intense SAPS ionospheric flows perhaps by enhancing the ring current pressure and localized pressure gradients when they are able to penetrate close enough to Earth.

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**On the Origin of STEVE: Particle Precipitation or Ionospheric Skyglow?**

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One of the recent developments in ionospheric research was the introduction of a subauroral spectacle called STEVE (Strong Thermal Emission Velocity Enhancement). Although STEVE has been documented by amateur night sky watchers for decades, it is an exciting new upper atmospheric phenomenon for the scientific community. Observed first by amateur auroral photographers, STEVE appeared as a narrow luminous structure across the night sky. Currently, only one scientific study has focused on STEVE, revealing that it corresponds to a narrow (tens of kilometers in north-south extent) and long (thousands of kilometers in east-west direction) structure located in the subauroral region. An important and fundamental question that arises from this study is the origin of STEVE; more specifically, does STEVE correspond to a new ionospheric phenomenon or is it due to particle precipitation? In this letter, we analyze a STEVE event on 28 March 2008 observed by Time History of Events and Macroscale Interactions during Substorms (THEMIS) ground-based All-Sky Imagers and a Polar Orbiting Environmental Satellite (POES). The POES-17 satellite crossed STEVE at the center of the All-Sky Imager field-of-view, allowing us to collect particle data simultaneously. These concurrent measurements show that STEVE might not be associated with particle precipitation (electrons or ions). Therefore, this event suggests that STEVE's skyglow (which we defined to be unrelated to aurora or airglow) could be generated in the ionosphere.


**Evolution of the current system during solar wind pressure pulses based on South Pole all-sky imager and conjugate magnetometer observations**

We investigated evolution of ionospheric currents during sudden commencements using an all-sky imager at the South Pole station and the ground magnetometer network in the conjugate northern hemisphere. Preliminary (PI) and main (MI) impulse currents showed two-cell patterns propagating antisunward, particularly during a southward interplanetary magnetic field (IMF). Although this overall pattern is consistent with the Araki (1994) model, we found several interesting features. The PI and MI currents in some events were highly asymmetric with respect to the noon-midnight meridian; the post-noon sector did not show any notable PI signal, but only had an MI starting earlier than the pre-noon MI. Not only equivalent currents but also aurora and equatorial magnetometer data supported the much weaker PI response. We suggest that interplanetary shocks impacting away from the subsolar point caused the asymmetric current pattern. Additionally, even when PI currents form in both pre- and post-noon sectors, they can initiate and disappear at different timings. The PI currents did not immediately disappear but coexisted with the MI currents for the first few minutes of the MI. During a southward IMF, the MI currents formed equatorward of a preexisting DP-2, indicating that the MI currents are a separate structure from a preexisting DP-2. In contrast, the MI currents under a northward IMF were essentially an intensification of a preexisting DP-2. The magnetometer and imager combination has been shown to be a powerful means for tracing evolution of ionospheric currents, and we showed various types of ionospheric responses under different upstream conditions. The results have been published in *Earth, Planets and Space*.


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The 17 March 2013 storm: Synergy of observations related to electric field modes and their ionospheric and magnetospheric Effects

The main phase of the 17 March 2013 storm had excellent coverage from ground-based instruments and from low- and high-altitude spacecraft, allowing for evaluation of the relations between major storm time phenomena that are often considered separately. The shock impact with its concurrent southward interplanetary magnetic field (IMF) immediately drove dramatic poleward expansion of the poleward boundary of the auroral oval (implying strong nightside reconnection), strong auroral activity, and strong penetrating midlatitude convection and ionospheric currents. This was followed by periods of southward IMF driving of electric fields that were at first relatively smooth as often employed in storm modeling but then became extremely bursty and structured associated with equatorward extending auroral streamers. The auroral oval did not expand much further poleward during these two latter periods, suggesting a lower overall nightside reconnection rate than that during the first period and approximate balance with dayside reconnection. Characteristics of these three modes of driving were reflected in horizontal and field-aligned currents. Equatorward expansion of the auroral oval occurred predominantly during the structured convection mode, when electric fields became extremely bursty. The period of this third mode also approximately corresponded to the time of largest equatorward motion of the ionospheric trough, of apparent transport of high total electron content (TEC) features into the auroral oval from the polar cap, and of largest earthward injection of ions and electrons into the ring current. The enhanced responses of the aurora, currents, TEC, and the ring current indicate a common driving of all these storm time features during the bursty convection mode period.


SAPS/SAID revisited: A causal relation to the substorm current wedge

We present multispacecraft observations of enhanced flow/electric field channels in the inner magnetosphere and conjugate subauroral ionosphere, i.e., subauroral polarization streams (SAPS) near dusk and subauroral ion drifts (SAID) near midnight. The channels collocate with ring current (RC) injections lagging the onset of substorms by a few to ~20 min, i.e., significantly shorter than the gradient-curvature drift time of tens of keV ions. The time lag is of the order of the propagation time of reconnection-injected hot plasma jets to the premidnight plasmasphere and the substorm current wedge (SCW) to dusk. The observations confirm and expand on the previous results on the SAID features that negate the paradigm of voltage and current generators. Fast-time duskside SAPS/RC injections appear intimately related to a two-loop circuit of the substorm current wedge (SCW2L). We suggest that the poleward electric field inherent in the SCW2L circuit, which demands closure of the Region 1 and Region 2 sense field-aligned currents via meridional currents, is the ultimate cause of fast RC injections and SAPS on the duskside.

Transient solar wind-magnetosphere-ionosphere interaction associated with foreshock and magnetosheath transients and localized magnetopause reconnection

This chapter reviews recent findings of multi-scale structures and dynamics in the high-latitude ionosphere, particularly on meso-scale (10s-100s km) processes, as well as their roles in cross-regional interaction processes. Localized and transient structures often occur at the cusp, polar cap, and auroral oval, and their magnitudes can be comparable or larger than those of large-scale background. However, their properties and coupling are not well understood, and specification of their structures and variabilities are critical for numerical modeling. The meso-scale covers a myriad processes and phenomena, including poleward-moving auroral forms (PMAFs), polar cap patches, auroral arcs, poleward boundary intensifications (PBI), streamers, substorm, surges, diffuse aurora, and related flow channels, field-aligned currents (FACs) and precipitation/conductance. Small-scale features also play important roles in the creation and behavior in multi-scale dynamics. While those structures are localized, they have net effects on large-scale dynamics, and can influence surrounding regions by propagating over long distances. An approach to quantify meso-scale precipitation contributions using the THEMIS all-sky imagers is presented, and we show that meso-scale precipitation has a substantial (25-50%) contribution, indicating critical importance of multi-scale processes for understanding Geospace processes. The current state and necessity of specification for advancing understanding of multi-scale coupling processes are discussed.


Throat aurora: The ionospheric signature of magnetosheath particles penetrating into the magnetosphere

Throat aurora is suggested to be generated during magnetospheric cold plasma flowing into the magnetopause reconnection site and to be the ionospheric signature of the newly opened flux from reconnection. By examining simultaneous low-altitude satellites and ground observations, we confirm that the throat auroras are associated with low-energy electron and ion precipitation of magnetosheath type and thus provide the first evidence that they occur along open magnetic field lines. Additionally, the observations have important possible implications: (1) solar wind particles can penetrate deep into the magnetosphere and may make significant contributions to the low-energy plasmas often observed in the dayside outer magnetosphere and (2) localized shapes of the magnetopause and the ionospheric open-closed field line boundary may be substantially changed, during generation of the throat aurora. The results have been published in Journal of Geophysical Research and this paper became the cover figure in JGR February 2016 issue.


The plasmapause formation seen from meridian perspective by KAGUYA

Observations by the extreme ultraviolet (EUV) imager on board the IMAGE spacecraft revealed that the formation of a sharp plasmapause occurs in the postmidnight sector soon (<1 h) after the
convection enhancement. These results cannot be explained simply by the conventional theory of
the plasmapause formation that the plasmapause coincides with the last closed equipotential of
the convection electric field superposed on the Earth's corotation electric field. However, due to
the limitation that the EUV imager provides information on only the azimuthal distribution of the
plasmapause, the formation mechanism still remains an open issue. Now global images of the
plasmasphere from meridian perspective become available, thanks to the telescope of extreme
ultraviolet (TEX) instrument on board the KAGUYA spacecraft. Here we studied
the plasmapause formation mechanism by analyzing the sequential TEX images of an erosion event
during the geomagnetic disturbance ($K_p = 5$) on 1–2 May 2008. The temporal evolution of the
plasmapause locations at postmidnight observed by TEX agreed with those predicted by the
dynamic simulations based on the interchange mechanism. Furthermore, the $He^+$ column density
in the nightside plasmasphere decreased by ~30% only at the low latitudes ($<20^\circ$) during the
enhanced convection period. This suggests that the plasmapause formation occurs first near the
equatorial region during a geomagnetic disturbance, and it agrees with the plasmapause
formation mechanism based on the interchange instability. Although we cannot conclude
exclusively for the interchange mechanism, this is the first study to present the plasmapause
formation viewed from the meridian perspective.

Murakami, G., K. Yoshioka, A. Yamazaki, Y. Nishimura, I. Yoshikawa, M. Fujimoto, The
plasmapause formation seen from meridian perspective by KAGUYA, J. Geophys. Res., 121,