Midlatitude Ionospheric Features in the Plasmasphere Boundary Layer: The View From Millstone Hill

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SuperDARN 2011 Workshop
June 2, 2011

Thanks to J. C. Foster, A. J. Coster, NSF, NASA, MIT Haystack REU students, SD Collaborators, and the ASG
Outline

• The Plasmasphere Boundary Layer from Millstone Hill
• PBL Feature 1: SAPS Morphologies and Conductivity
• PBL Feature 2: Embedded Irregularities

Opportunities for SD-MHO Collaboration will be highlighted throughout..
... Curiously, the plasmapause region has not been described as a boundary layer, in spite of being observed at locations where the cool (∼1 eV) dense (∼400 el/cc) plasmasphere overlaps with, or is otherwise in close proximity to, the hot (∼100 eV–100 keV) tenuous (∼1 el/cc) plasmas of the plasmatrough or the plasmasheet and ring current ... “
The PBL Is A Region of Dynamic, Meso/Microscale, System Level Response

System Level Responses Require System Level Observations and Science
Millstone Hill UHF Incoherent Scatter Radar

46 m steerable MISA (68 m zenith not shown)

Zenith measurements since 1960
Fully wide-field since 1978

2.5 MW peak TX
440 MHz

Incoherent Scatter Spectrum

Massachusetts Institute of Technology
SuperDARN 2011 Workshop  Mid-Lat View from Millstone Hill  June 2, 2011
Kp = 6 event  
F10.7 = 233  
DsT -100 nT

Millstone Hill UHF Radar  
Azimuth Scan (4 deg El)  
Log Electron Density m^-3 [10, 12.5]  
1980-10-11 03:47:27 UTC

ISR Field of View  
Complements Mid-latitude SuperDARN (Wallops, Blackstone, Ft. Hays, etc.)

Plasmasphere Boundary Layer
Kp = 6 event
F10.7 = 233
DsT -100 nT

Millstone Hill UHF Radar
Azimuth Scan (4 deg El)
Line-of-sight Ion Velocity [0,800] m/s
1980-10-11 03:47:27 UTC

 ISR Field of View
Complements Mid-latitude SuperDARN (Wallops, Blackstone, Ft. Hays, etc.)

Millstone Hill
Incoherent Scatter Radar:
Wide-Field Access To The Full Plasma State

42.6 N, 288.5 E
54 MLAT
L ~ 2 to 4
Storm Enhanced Density (SED): ISR Picture

Millstone Hill IS Radar
Eastern North America
Magnetic meridian N scans
30 minute cadence

Foster, 1993
Storm Enhanced Density (SED): GPS Picture

SED Plumes extend through mid-latitudes
Conjugate features are detected

Foster et al, 2002

Foster and Rideout, 2007
Plasma Redistribution TEC/Plasmasphere Plume	
March 31, 2001

Magnetosphere-Ionosphere Coupling

Direct Observation of Velocity and Flux by Millstone Hill ISR

Ground-Based GPS Maps TEC Plume

[Foster et al., GRL 2002]

GPS TEC [10,150] TECu 19:30 UT March 31, 2001

Log Sunward Ion Flux [13.15] (m$^{-2}$ s$^{-1}$)

GPS TEC > 50 TECu

> 120 GPS sites

GEOSPACE

Electric field near Region 2 footprint
Flux up to 1E15 m$^2$ s$^{-1}$
Sub-Auroral Polarization Stream (SAPS)

Westward (sunward) subauroral velocity near footprint of region 2 / ring current

2-5 deg wide

Embedded small and highly variable structures (SAID)

Overlaps edge of storm enhanced density (SED)

Dusk sector transport of material to noontime cusp

Foster and Vo, 2002
Sunward ion flux driven by SAPS

Foster et al, 2007

Sunward ion flux caused by SAPS/SED overlap

Foster et al, 2007
Connections to Polar Processes

20 Nov 2003
1820 UTC

SED connects through cusp
Some material contributes to cusp ion upwelling
Some material goes over polar cap (Tongue of ionization)

Foster et al, 2005
Connections to Polar Processes

20 Nov 2003

SED material is uplifted as it travels from mid to high latitudes

Participates in ion upwelling

Mass-loads plasma sheet with heavy, cold O+ ions

Foster et al, 2005
The Evolving Mesoscale Picture

(P. Brandt, JHU/APL)

MHO and SuperDARN work together in the ‘big picture’ view

1. Solar EUV and Joule heating drives storm enhanced plasma densities at low latitudes

2. The magnetospheric ring current connects to the ionosphere generating electric fields that funnel the low-latitude plasma towards higher latitudes.

3. Massive amounts of ionospheric plasma is supplied to the cusp, where it flows out into the magnetosphere

4. Heavy ionospheric plasma reaches the plasma sheet, where it affects reconnection rates impacting substorm activity

5. Ionospheric plasma is energized by storm convection and substorm, enhancing plasma pressure, which drives the ring current system that connects through the ionosphere

6. Storm-time electric fields lead to transport and loss of plasmaspheric ions through magnetopause affects dayside reconnection rates
Mid-Latitude Flows: SAPS Statistical Study

Individual events

Westward ion velocity, m/s

Localization of SAPS

GPS TEC < 50 TECu

Kp = 2 and greater

10,000+ scan database

Kp = 2 and greater

10,000+ scan database
SAPS Flux: Inverse Density/Velocity Relation

Erickson et al JGR 2011
SAPS Flux: Inverse Density/Velocity Relation

How do these features compare with SuperDARN statistics?
System Regulation: Westward Flux Invariance

Millstone Hill SAPS Westward Flux 1979-2001

Log Ion Flux, m$^{-2}$ s$^{-1}$

15.0
14.5
14.0
13.5
13.0

14.6 -0.07 MLT R=0.98

Erickson et al
JGR 2011
What are characteristics of ionospheric conductivity in region 2 area and how do they regulate SAPS?

Pedersen Conductivity

\[ \sigma_P = \frac{n_{ei} L}{B} \left[ \frac{\omega_{ci} \nu}{(\nu^2 + \omega_{ci}^2)} - \frac{\omega_{ce} \nu}{(\nu^2 + \omega_{ce}^2)} \right] \]

depends on:
- ionospheric electron density
- neutral density
- ion-neutral collision frequency
- magnetic field strength

Red: measured by ISR
Green: modeled

Ideal radar (points up B)
Millstone Hill radar (scans across B)
Field-Aligned Integrated Conductance

Most scans cover 250 - 500 km F layer conductance

Ion Velocity [0, 800] m/s

\[
\sigma_P = \frac{n_{e0}}{B} \left[ \frac{\omega_{ci} v}{(v^2 + \omega_{ci}^2)} - \frac{\omega_{ce} v}{(v^2 + \omega_{ce}^2)} \right]
\]
**SAPS Integrated Conductivity Results**

**Integrated Pedersen Conductivity Inside and Outside SAPS**

- Each graph shows the integrated Pedersen conductivity curves at the midpoint and three degrees equator-ward.

- Integrated Pedersen conductivity at SAPS midpoint is 2x lower.

- SAPS electron density peaks at higher altitudes: collisions with neutrals decrease, causing lower conductivity.

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**How do SuperDARN SAPS convection patterns compare in subauroral regions?**

Conductance effects on SAPS features in CRCM - do they match MHO, SD data? (see also trough effects) e.g. Zheng et al, 2008

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**Summer**

**Winter**

**Equinox**
UHF Coherent Scatter as Electric Field Monitor

VHF; Nielsen and Schlegel, 1985

Foster and Erickson, 2000
Subauroral Electric Field Dynamic Variations

Significant spatial, temporal structure within SAPS stream and specifically SAID size structures

Likely modulated by conductivity microscale variations

UHF megawatt class large aperture allows sub-second, km scale resolution

Relation to HF scattering irregularities? k-space, w-space studies...

Erickson et al, 2002
Persistent low velocity SD echoes

Very frequent (e.g. Feb 2006: 19 out of 27 observation days)

Long duration (7+ hours per night)

Low Doppler shift (30-90 m/s)

Very small spectral width

Low activity (Kp 0-2)

Sub-auroral region (54-60 inv lat)

Cause?
The Experiment: 22-23 Feb 2006 (SD + ISR)

Wallop SuperDARN: Individual Beam RTIs

MHO: 34 az, (18/28/48 el) + zenith focused on 55-60 inv @ 300 km
SuperDARN Wallops HF Backscatter + MHO Gradients 2200 – 0500 UTC  2006-02-22

2200 – 2340: Ground refracted scatter
2340 – 0140: GDI or trough wall or zonal gradient (seen before). TGI not active yet.

0140 onwards: TGI conditions present as Te gradient changes sign. Scatter weakens at higher beams as density decreases. TX frequency adjusted at 0410 UT – enhances scatter (refraction change)
Summary

- PBL filled with interesting M-I coupling, subauroral physics
- Millstone Hill covers eastern North America plasma parameters
- Excellent opportunities for MHO-SuperDARN collaborations

Collaborations encouraged!

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Dramatic, Longitude-Specific TEC Increases

(A. J. Mannucci  Oct 2003 storm)
Storm Enhanced Density (SED): GPS Picture

Yizengaw et al, 2008

SED Plumes can be found in other longitudes (easier with IMAGE EUV help: plasmaspheric plumes)