Regional ionospheric disturbances during magnetic storms

John Foster
Regional Ionospheric Disturbances

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Regional Disturbances
Meso-Scale (1000s km)

- **Storm Enhanced Density** (SED): Plumes of enhanced plasma stretching poleward from the mid-latitude ionosphere in the afternoon sector. Related to SAPS electric field.
- **Mid-latitude TEC enhancement** inside the PBL. Source population for SED plumes.
- **Equatorial – low-lat plasma redistribution**. Deep TEC depletions over SAA. Enhanced, spread equatorial anomaly peaks.
Storm Enhanced Density

Ionospheric signature of the plasmasphere erosion plumes imaged from space.

Serves as tracer of disturbance electric fields [ExB motion]

Links mid to polar ionosphere and plasmasphere to magnetotail with enhanced fluxes of heavy ions during disturbed conditions

Responsible for SPW effects at mid, auroral, and polar latitudes

Workshop Hypothesis:
Predictable tracer of Ring Current Expansion (?)
[Poleward Edge of SED = SAPS = Ring Current Tracer]

Inner Edge of SAPS – motion related to Penetration E Field
Space Weather Storm Front Observations at 300 km Altitude

Storm Enhanced Density (SED)

Mid-Latitude Ionosphere

> 50 TECu
Schematic Relationship

Millstone Hill IS Radar

DMSP
Effect: SED

Cause:
Electric Field

Source: ???

DMSP IDM

log Density (cm$^{-3}$)

log10 Density [10.25,12.25] (m$^{-3}$) SED February 6, 1986 17:45 UT

DMSP F-13 RPA May 30, 2003 01:35 UT

DMSP IDM

electro\n\nprecipitation

RC Ions

SAPS
GPS samples the ionosphere and plasmasphere to ~20,000 km. Dual-frequency Faraday Rotation Observations give TEC (Total Electron Content)

TEC is a measure of integrated density in a 1 m² column

1 TEC unit = $10^{16}$ electrons m⁻²
Visualizing the Ionospheric Storm Front: GPS TEC

GPS TEC Map from 20-Nov-2003 15:00:00 to 20-Nov-2003 15:10:00

MIT Haystack Observatory
Global Phenomenon:

SED Plume is carried through the Cusp and forms the Polar Tongue of Ionization

GPS TEC Map

Merged SuperDARN/DMSP Convection
Common projection: maglat/MLT @ 350 km alt

[Foster et al., JGR 2005]
Millstone Hill Azimuth Scan  April 12, 2001 UT  Westward Ion Velocity

Parameters Tabulated for 1400 Radar Scans:
- Latitude of SAPS Peak
- Magnitude of Peak
- Width of SAPS Channel
- Date
- UT and MLT
- Kp

SAPS Peak
Polarization Stream
2-Cell Convection

SAPS Peak
Plasmasphere
Gradient
Trough
Auroral Precipitation
Statistical Boundaries @ 80 W Longitude for Kp ~ 6

(1) Foster & Vo [2002]
(2) Vo & Foster [2001]
(3) Colerico [2005]
(4) Foster [1993]

Geodetic Latitude vs. Local Time (hr)

- (1) SAPS
- (2) Gradient
- (3) SED (GPS TEC)
- (4) SED (Radar)
**Sub-Auroral Polarization Stream**

A Strong Electric Field forms in the Low-Conductivity Region between the Inner Edge of the Plasmasheet Precipitation and the Plasmapause.

**DMSP F15**  
6 April 2000  
21 MLT

- **F15**
- **Trough**
- **Plasmapause**
- **Plasmasheet**
- **SAPS**
- **2-Cell Convection**
Disturbed Ring Current drives Magnetic Field-Aligned Currents into the Sub-Auroral Ionosphere

Equatorward Motion of SAPS indicates Penetration of Ring Current to Lower Latitudes And Enhancement of Penetration E Field

(Slide courtesy D. Mitchell)
Equatorward Expansion of Poleward Wall @ 280 E Longitude

February 8, 1986
Millstone ISR
[Foster, 1993]
Low-Altitude Datasets Align Closely
Equatorward Expansion of Poleward Wall @ 280 E Longitude

Geodetic Latitude

Universal Time (hr) April 11, 2001

Noon

18 LT

MHR
Conclusion: We can use the steep Density / TEC gradient at the poleward edge of the SED to locate the equatorward extent of the strong SAPS channel.

Conclusion: The SAPS, SED, and TEC-gradient boundaries appear to behave in a regular (predictable) fashion as functions of disturbance level and MLT.

Mid-Latitude TEC Enhancement or Where Does the SED Come From?
Prompt Dayside Enhancement of TEC (19-21 UT)
Mid-Latitude TEC Enhancement at Base of SED Plume
TEC Enhancement at Base or Erosion Plume Corotates over US East Coast
Low-Latitude Ionosphere & Plasmasphere: Effects of Sub-Auroral Disturbance Electric Fields

- **Undershielded eastward electric field:**
  Strong uplift at equator redistributes plasma to higher latitudes

- **Mid-Latitude TEC: Spread EA & Bulge:**
  Downwelling & poleward/sunward plasma transport increase TEC at low & mid latitudes

- **SED/TEC plumes & plasma tails:**
  SAPS overlaps outer plasmasphere (PBL) carrying thermal plasma sunward
Bubbles

TEC hole

[References: Greenspan et al. (March 1989 storm); Basu et al. (July 2000 storm)]
Effects of Penetration Electric Fields

DMSP

Thermospheric Density Enhanced

Key West

Guiana

30°

Steep Trough Gradients Move Equatorward

GPS Samples

Ionosphere/Plasmasphere TEC
Redistribution of Low Latitude Ionosphere

TEC (TECu)

0 20 40 60 80 100 120 140 160 180 200

16 18 20 22 24 26 28

UT July 15/16, 2000

Florida

Chile

Brazil
Another Example - Similar Structure
Redistribution of Low Latitude Ionosphere

21 UT

May 29/30, 2003
Watch for formation of Bulge at 19:30 UT
(6 hours later – Bulge remains at 285 E longitude)
Space-Based View of May 2003 Event

May 29, 2003
(Day 149), 23:06 UT

IMAGE/FUV SI-13
135.6 OI emissions
10 minute integration
SSL, UC Berkeley
View from 21:00 LT
October 30, 2003  Plasma Redistribution

Similar Structure
Growth of TEC at Mid Latitudes

Oct 30/31, 2003 UT hour

vertical TEC (TECu)

21 UT

Arizona [-110,28]

Florida [-80,28]

Brazil [-45,0]
Merged Foster-Vo SAPS model with Millstone 2-cell convection
(SAPS is associated only with the DUSK convection cell)