The Thermal Plasma Sensor (TPS) for the Geospace Dynamics Constellation

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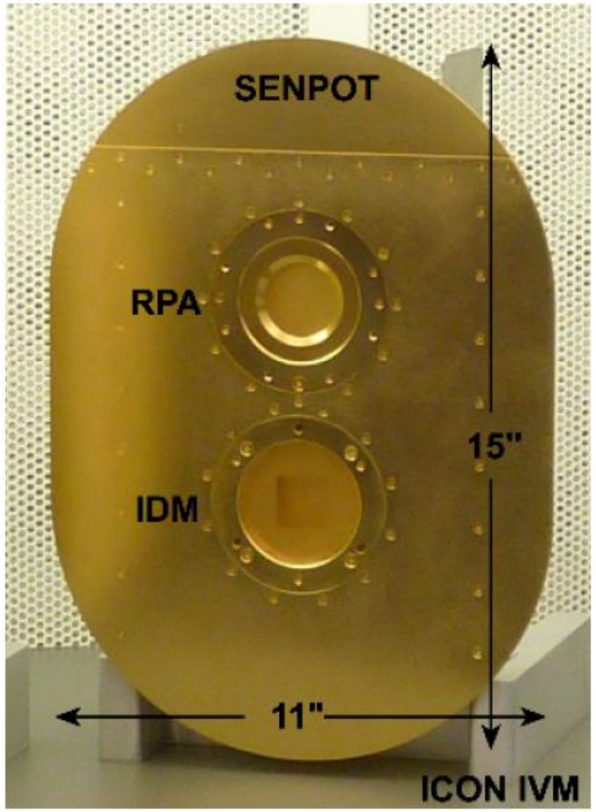
Thermal Plasma Sensor for GDC

To address science questions related to ion-neutral coupling, we need the physical plasma quantities measured by TPS: 3-D ion velocity, T_i, N_i, and composition.

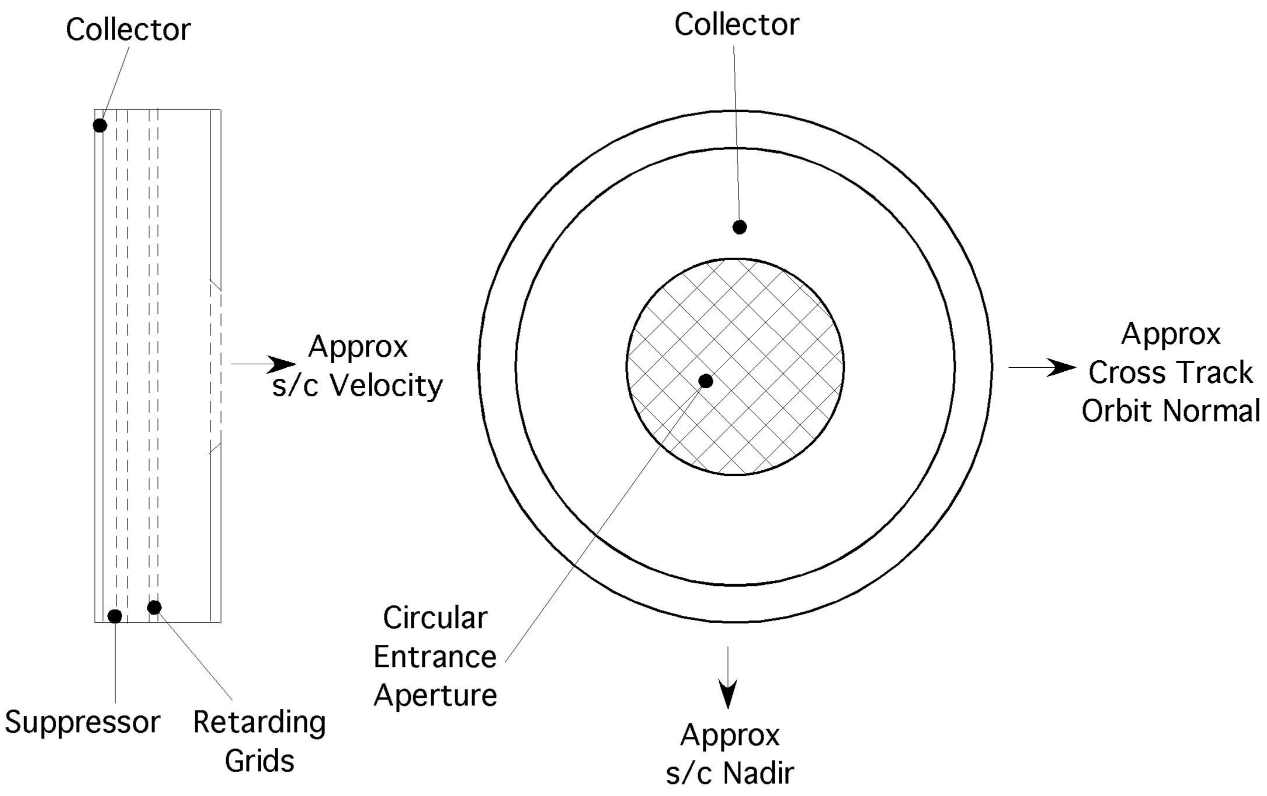
- **Two planar, gridded ion detectors:**
  - **Retarding Potential Analyzer (RPA)**:
    - Measures ram ion flux (current) as a function of retarding voltage
    - I-V curve produced 1/sec
    - Curve analyzed to infer ram ion velocity, temperature, composition and density
  - **Ion Drift Meter (IDM)**:
    - Measures ram ion flux on segmented (four sectors) collector
    - Ion arrival angle proportional to ratio of currents on adjacent collector halves
    - Current collected 16/sec
    - Ion drift in two directions perpendicular to ram direction produced at 1 Hz



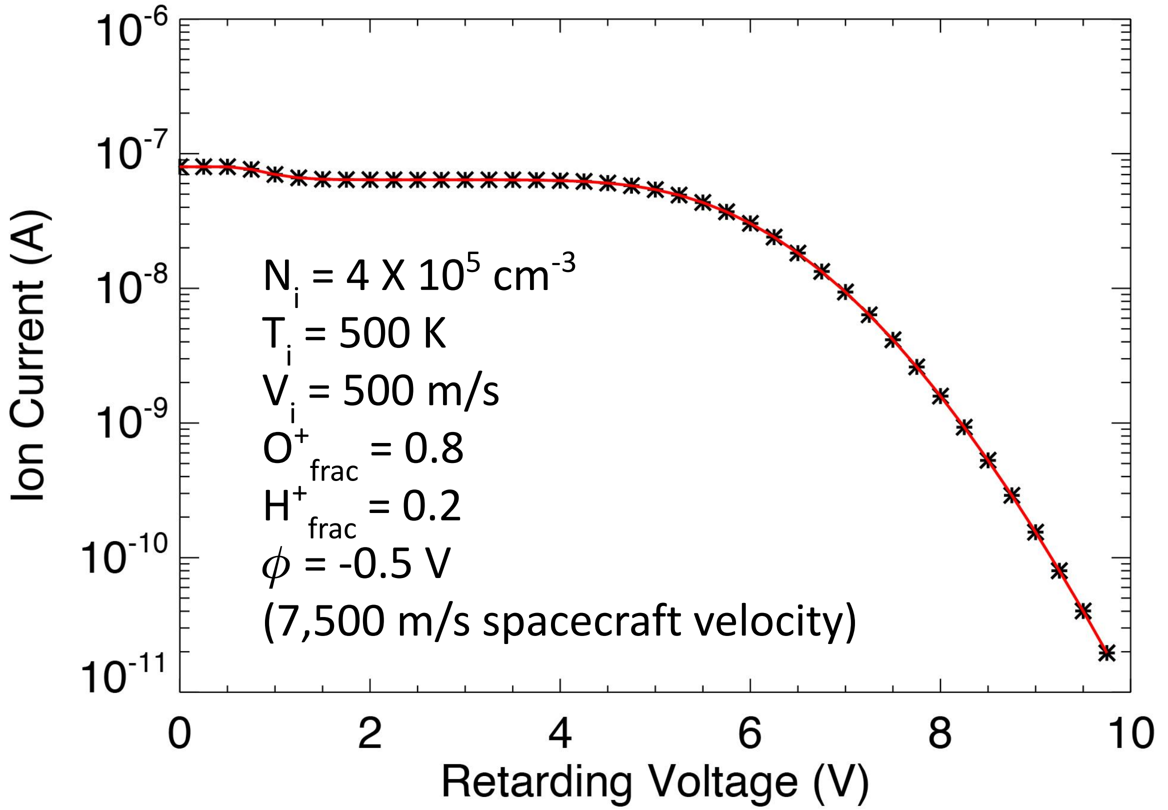
- **Plus:**
  - **SenPot (Sensor Potential)**

Retarding Potential Analyzer (RPA)

Measures ram ion flux (current on the collector) as a function of voltage on the retarding grid.



A current- voltage curve is thus produced that is a function of the retarding voltage and the collected ion current.



Retarding Potential Analyzer (RPA)

Ambient thermal ions are assumed to be characterized by a Maxwellian velocity distribution flowing supersonically along the sensor axis toward the sensor with velocity V_r

If the retarding grid plane is at potential ϕ with respect to the plasma, then only ions with energy greater than $q\phi$ or velocity $V_\phi = \left(\frac{2q\phi}{m}\right)^{1/2}$ will reach the collector. The flux is then given by (Whipple, 1959):

$$F(\phi) = \frac{N}{2}\sum_i V_r C_i \left[1 + erf(\beta_i f_i) + \frac{1}{\sqrt{\pi}\,\beta_i V_r} exp(-\beta_i^2 f_i^2)\right] \quad (1)$$

$$\phi = (R_v + \psi_s)$$

$$f_i = V_r - \left({}^{2q\phi}/_{m_i}\right)^{1/2}$$

$$\beta_i = \left({}^{m_i}/_{2kT}\right)^{1/2}$$

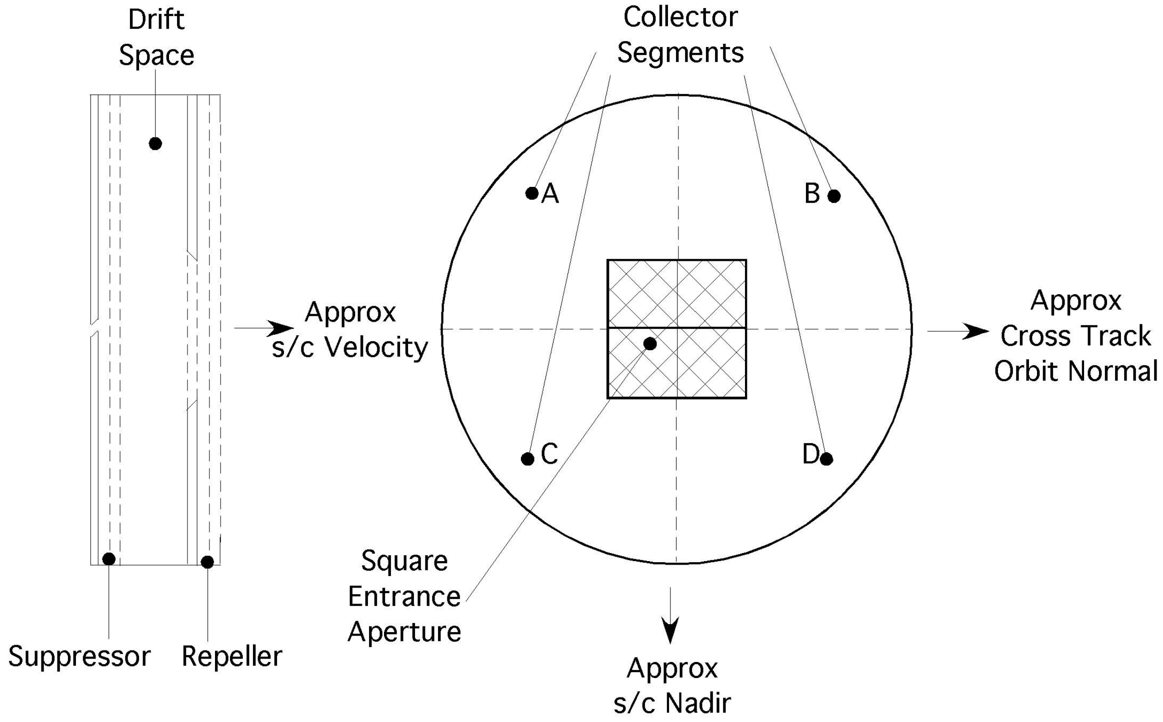
$$V_r = -(\vec{V}_d + \vec{V}_s).\hat{n}$$

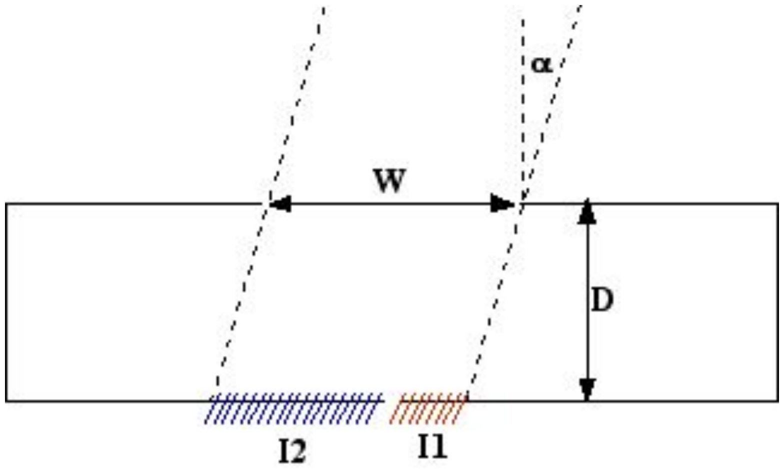
ψ_s = sensor ground with respect to the plasma
$\vec{V}_s$ = spacecraft velocity
R_v = retarding grid potential
m_i and T = ion mass and temperature
C_i = fractional contribution of ions with mass m_i to the total
$\hat{n}$ = the unit vector in the look direction of the sensor.

- Sum is taken over all constituent masses that are present.

The Levenberg–Marquardt method (an adaptation of Newton's method of least-squares minimization) is used to perform a non-linear least squares fit to equation (1) to retrieve the ram velocity, ion temperature, total ion density, and the constituent ion mass fractions.

Ion Drift Meter (IDM)





Ion beam passes though square aperture and planar grounded grids, impinges on a collector with four segments with axes parallel to the aperture edges.

$$\left(\vec{V}_d + \vec{V}_s\right) \cdot \hat{t} = \left[V_r^2 - {}^{2q\phi}/_{m_i}\right]^{\frac{1}{2}} \tan\alpha \quad (2)$$

- $\hat{t}$ is the unit vector along the selected transverse direction and V_r and ψ_s are extracted from the RPA processing.
- Ion arrival angle α, is simply proportional to the ratio of currents to adjacent collector halves.
- Transverse ion drift ($\vec{V}_d$) is related to the arrival angle through (2).

Science Investigations

Three primary science investigations proposed supporting the GDC mission objectives:

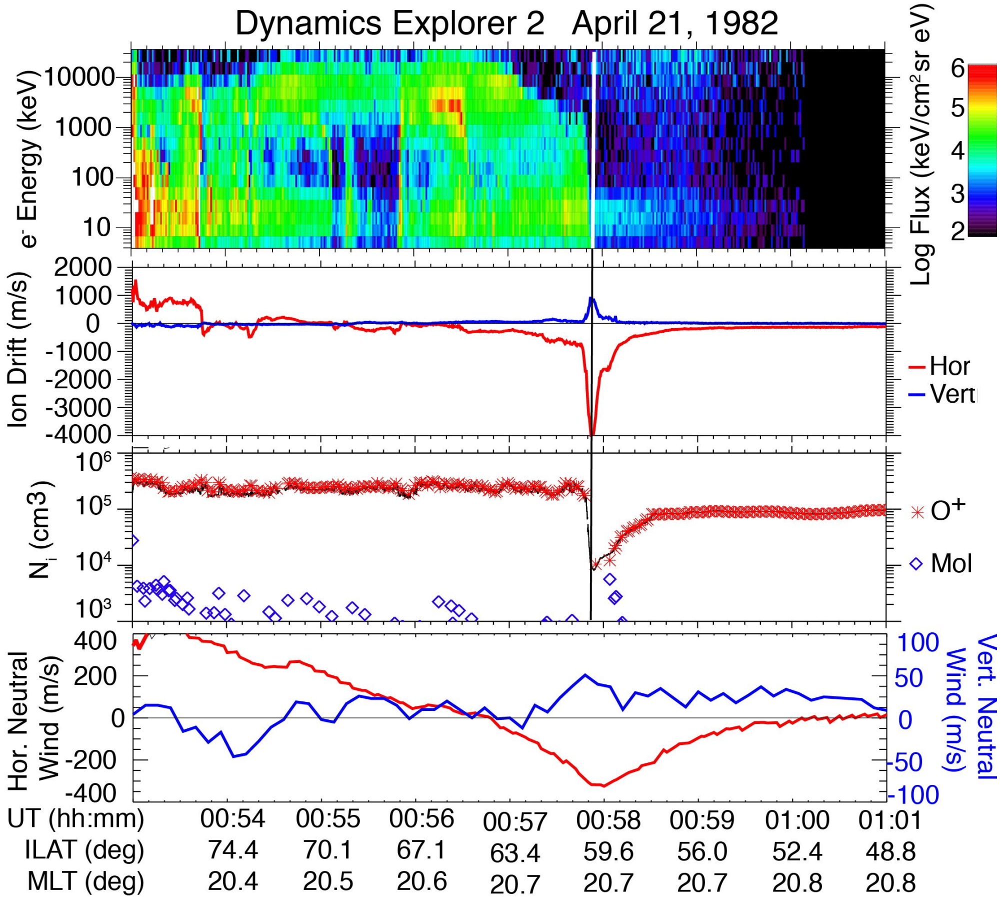
GDC Objective 1.1 Determine how high-latitude plasma convection and auroral precipitation drive thermospheric neutral winds. ***SQ 1. How does the ion-neutral velocity difference depend on the local plasma drift, neutral wind, and plasma density?***

GDC Objective 1.2 Determine how localized, coherent plasma density features arise and evolve. ***SQ 2: How are plasma structures at sub-auroral latitudes and in the polar cap related to the convective motion of the plasma with respect to the Sun?***

GDC Objective 2.1 Determine the relative importance of penetration electric fields and disturbance winds in driving plasma density variations at middle and low latitudes during geomagnetic storms. ***SQ 3: How does the local plasma density at sub auroral latitudes depend the plasma drifts perpendicular and parallel to the magnetic field as a function of location and storm time epoch?***

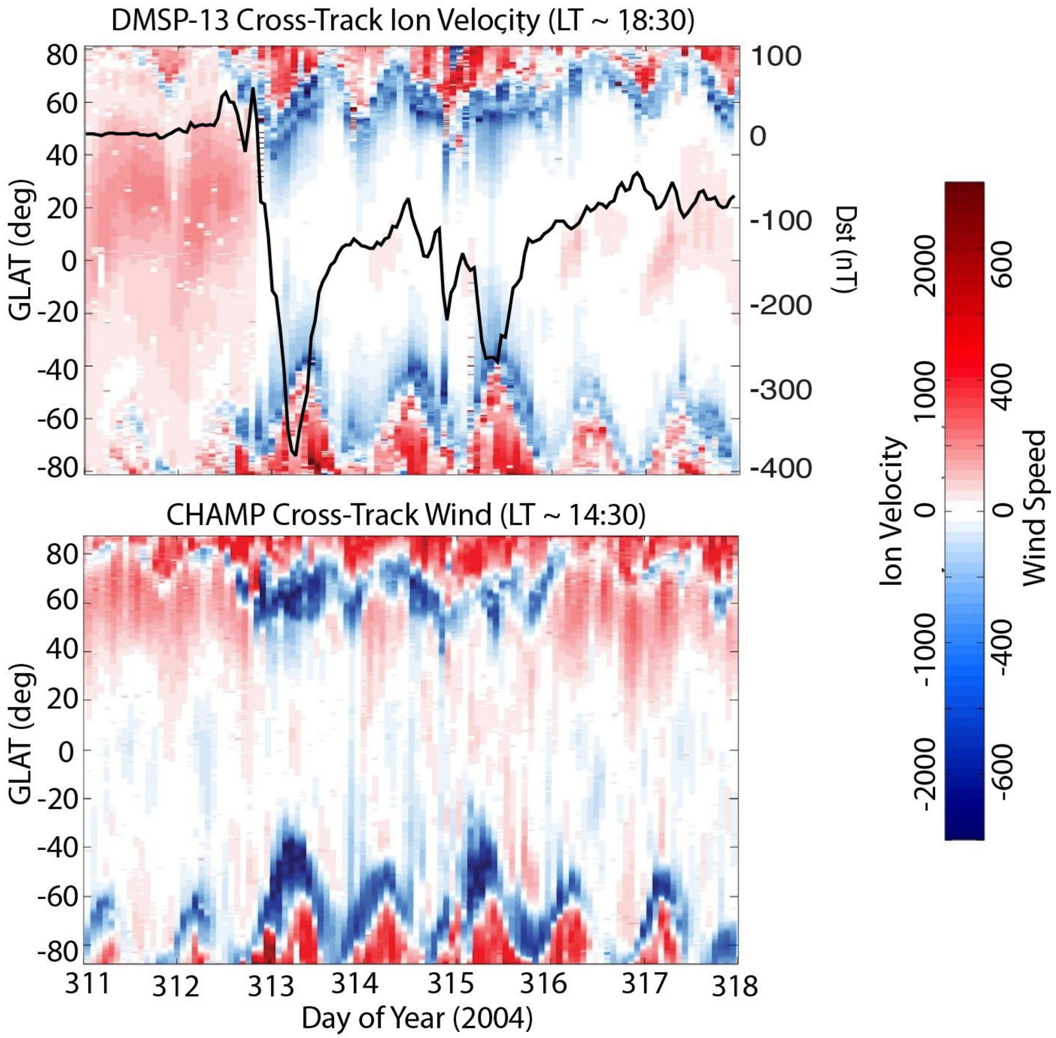
These investigations focus on the impact of plasma motions (measured by TPS) on the ionosphere and thermosphere.

SQ 1. Investigate the relationships between the ion-neutral velocity difference and the local plasma drift, neutral wind and plasma density.



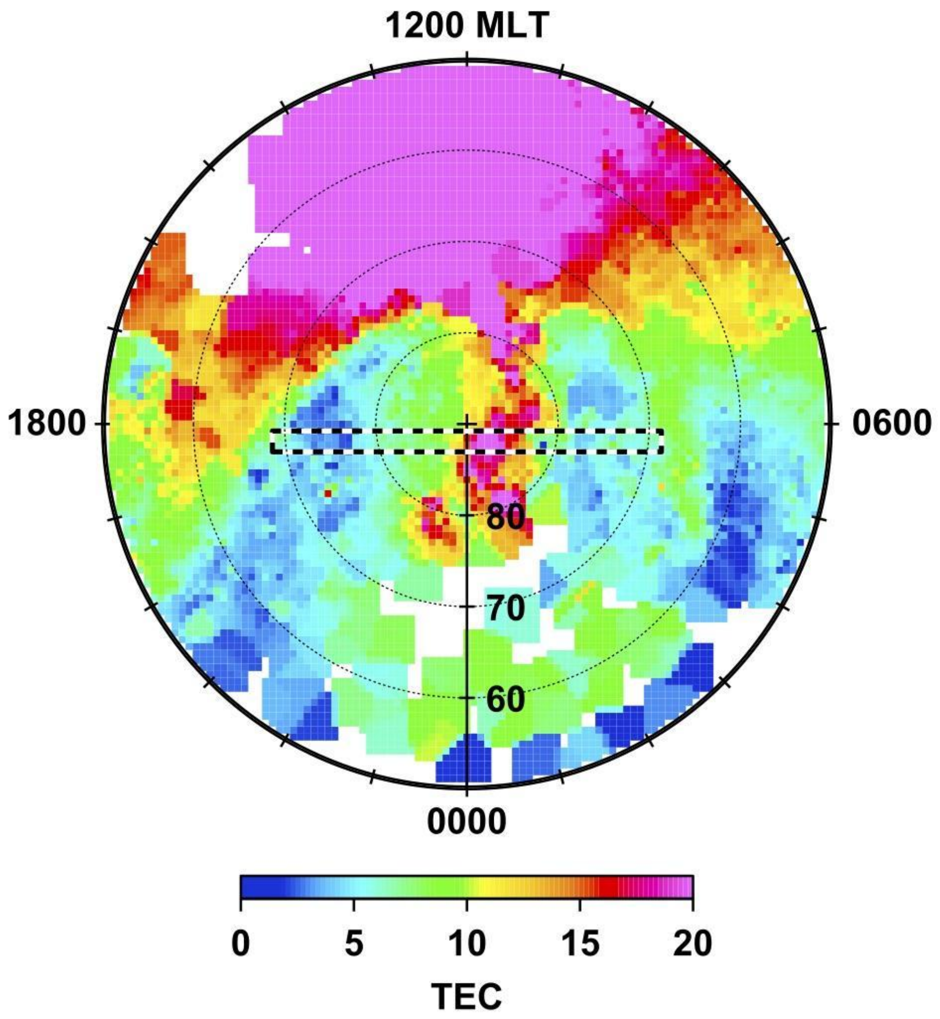
SAID event from the DE-2 spacecraft.

- Precipitating electron energy flux, horizontal and vertical ion drift, ion density and composition, bottom panel, horizontal and vertical neutral winds.

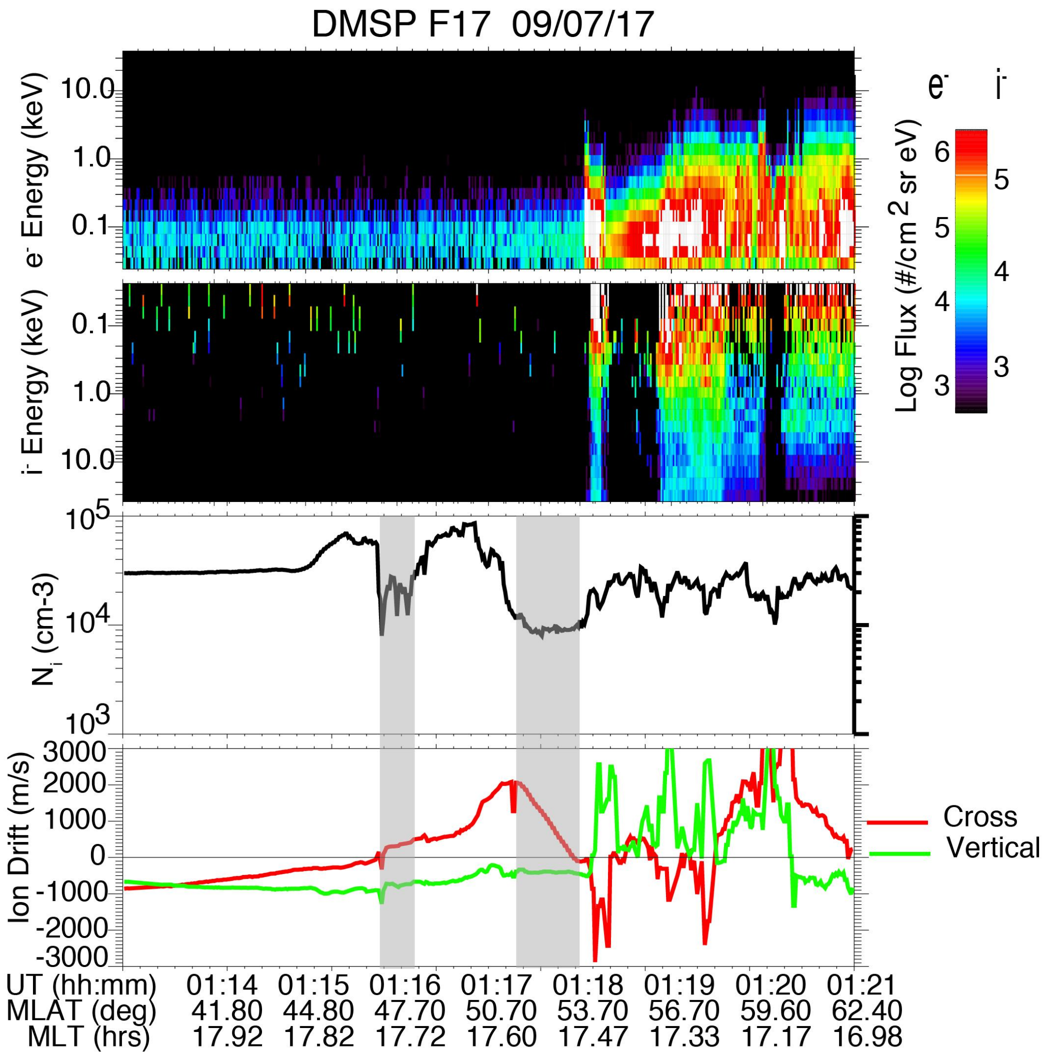


Latitudinal profiles of zonal ion drift and neutral wind from DMSP F13 and CHAMP

SQ 2: How are plasma structures at sub-auroral latitudes and in the polar cap related to the convective motion of the plasma with respect to the Sun?



GPS TEC map in MLT (noon the top) and MLAT (50° - 90°) showing a tongue of ionization (TOI) and its development into polar cap patches. [David et al., 2016]

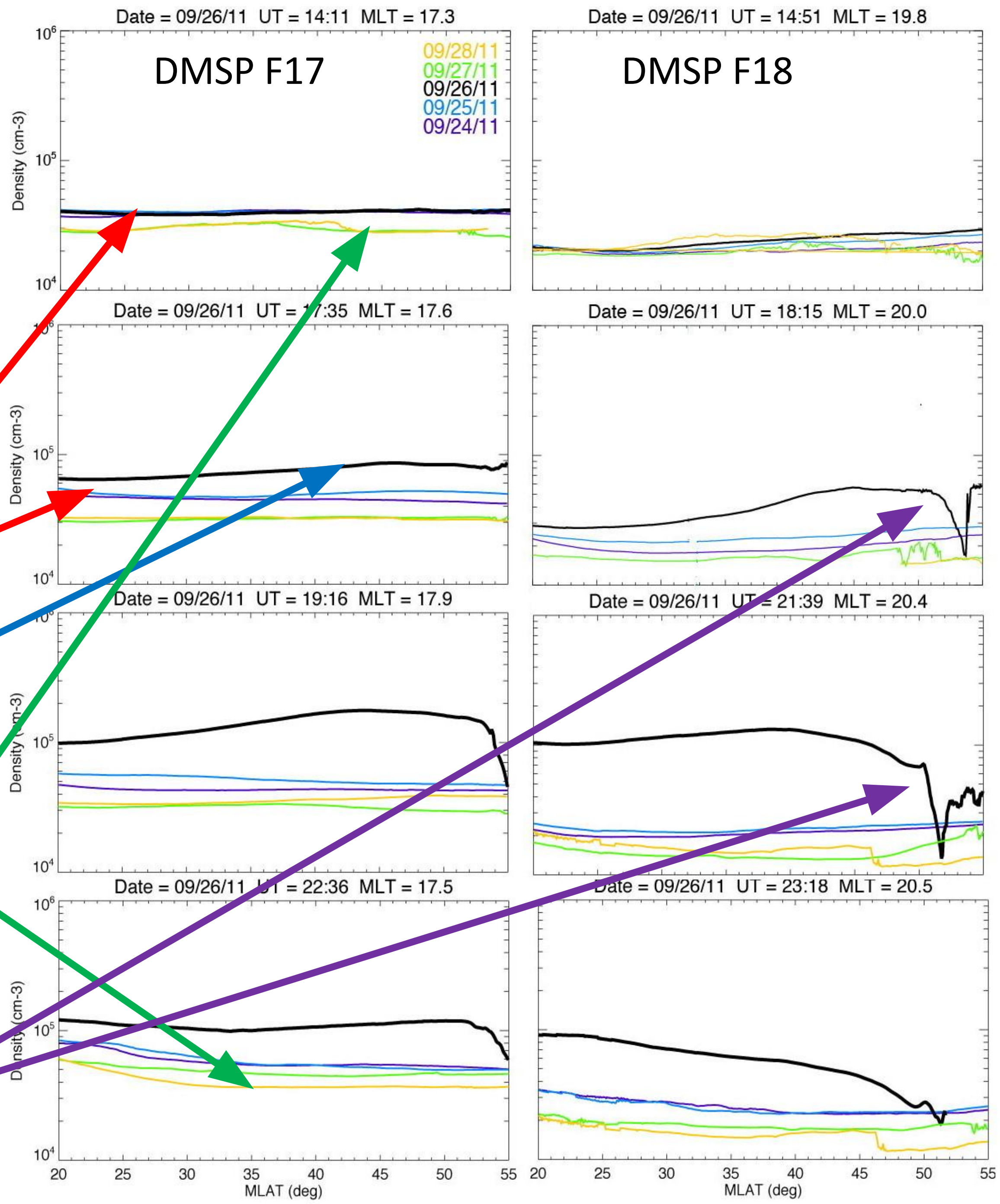


DMSP F17 measurements of the mid-latitude ionosphere trough (MIT). From top to bottom: electron energy flux, ion energy flux, ion density, horizontal and vertical ion drifts. (Adapted from Aa et al., 2017)

SQ 3. Examine the dependence of the local plasma density at sub auroral latitudes on the plasma drifts perpendicular and parallel to the magnetic field as a function of location and storm time epoch.

September 26, 2011

- Shock in the solar wind speed and storm sudden commencement at ~12:20 UT
- Dst reached a minimum value of about -114 near 23:00 UT.
- Quiet time prior to storm – nearly identical density profiles
- Density increase/positive ionospheric storm phase first observed ~5 hours after storm onset near 17:35 UT
- Positive phase continued until about 9:00 UT on Sep 27 and then negative phase began – lasted 2 days
- Deep midlatitude trough formed during positive phase and moved equatorward. Filled in at onset of negative phase



Ion density measurements from selected passes from F17 (dusk) and F18 (post dusk). Each plot shows the data for two days before and after the storm versus MLAT at similar UTs. (UT and GLON are locked for DMSP so spacecraft in similar GLON sectors at similar UTs.)