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Comprehensive Observations of Multi-scale Polar Ionosphere Structuring Processes During Oct. 13, 2016 Geomagnetic Storm

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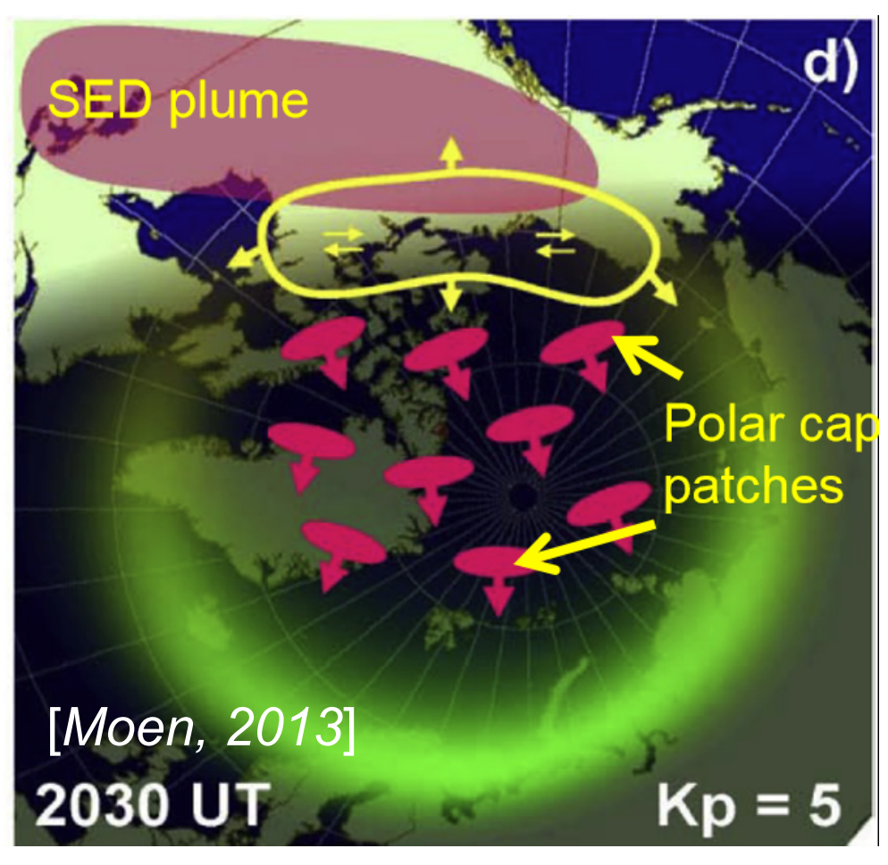
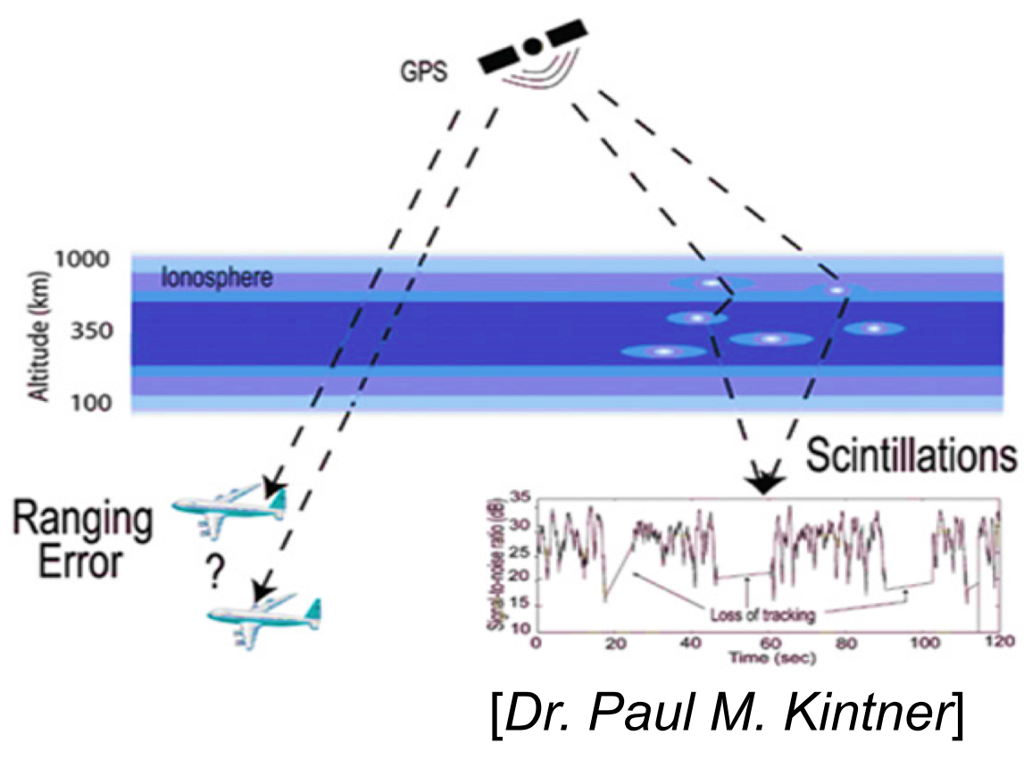
Introduction

- **Storm-enhanced density (SED):** A ridge of electron density enhancement occurs at mid-latitude and subauroral region at noon and postnoon MLTs.
- **Polar cap patches:** 100s km islands of **high-density** plasma in the polar cap ionosphere.
- Main cause for disruptions of satellite navigation and communication signals in polar cap regions.



[*Moen, 2013*]



[*Dr. Paul M. Kintner*]

Purpose & Method

- This study investigates the dynamic transport and multi-scale structuring process of ionosphere concentrated plasma into the high-latitude polar cap in the Northern Hemisphere during the Oct. 13, 2016 Geomagnetic Storm.
- We've used observational data from GPS TEC, SuperDARN, RISR-C and Sondrestrom incoherent scatter radars, AMPERE and DMSP satellites during this geomagnetic storm event.

① Dayside Storm-Enhanced Density (SED) Formation

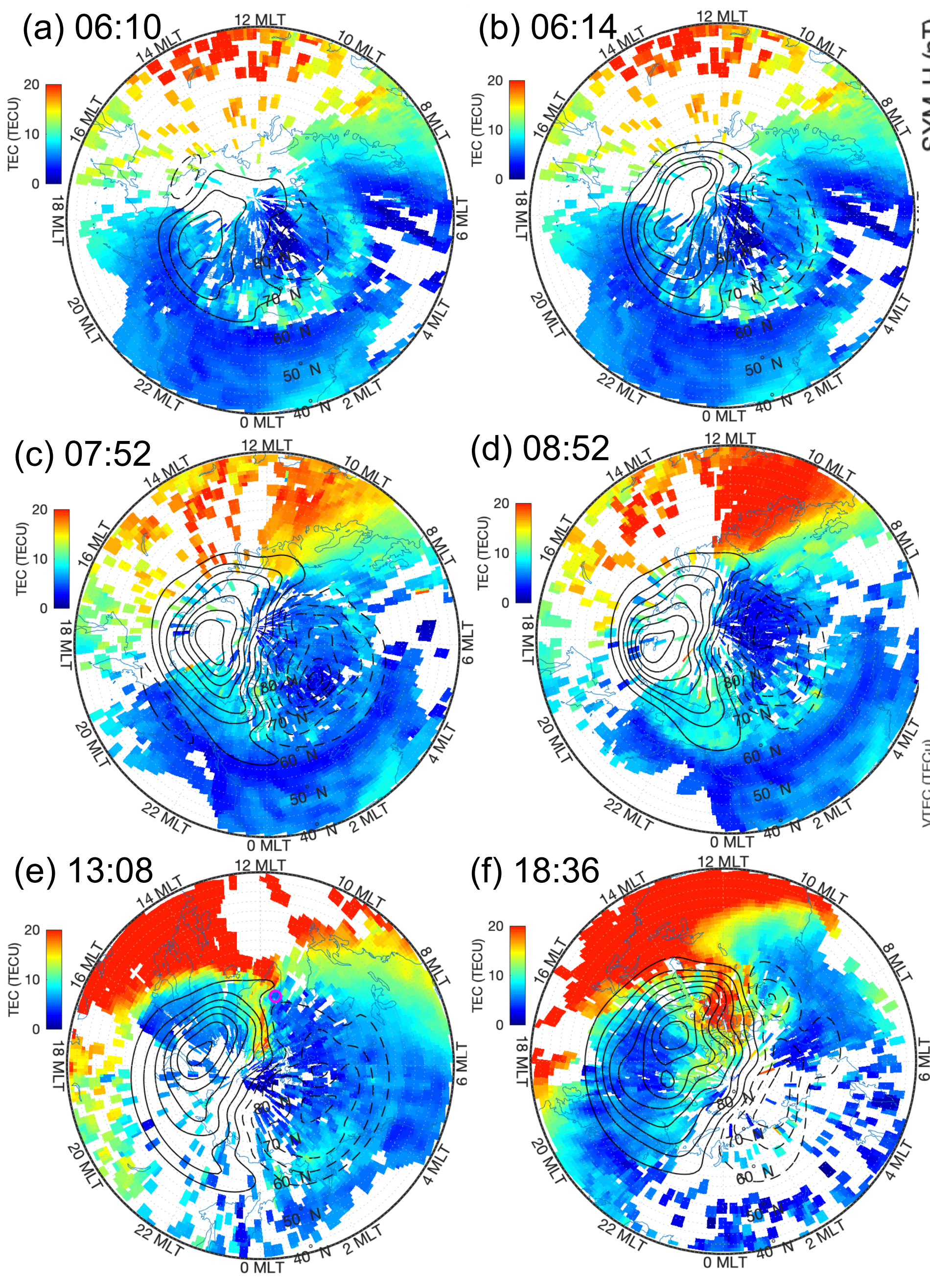


Figure 1. GPS TEC maps from the Madrigal database with high-latitude ionosphere convection pattern from SuperDARN and estimate cusp locations overlaid at (a) 06:10 UT, (b) 06:14 UT, (c) 07:52 UT, (d) 08:52 UT and (e) 13:08 UT and (f) 18:36 UT.

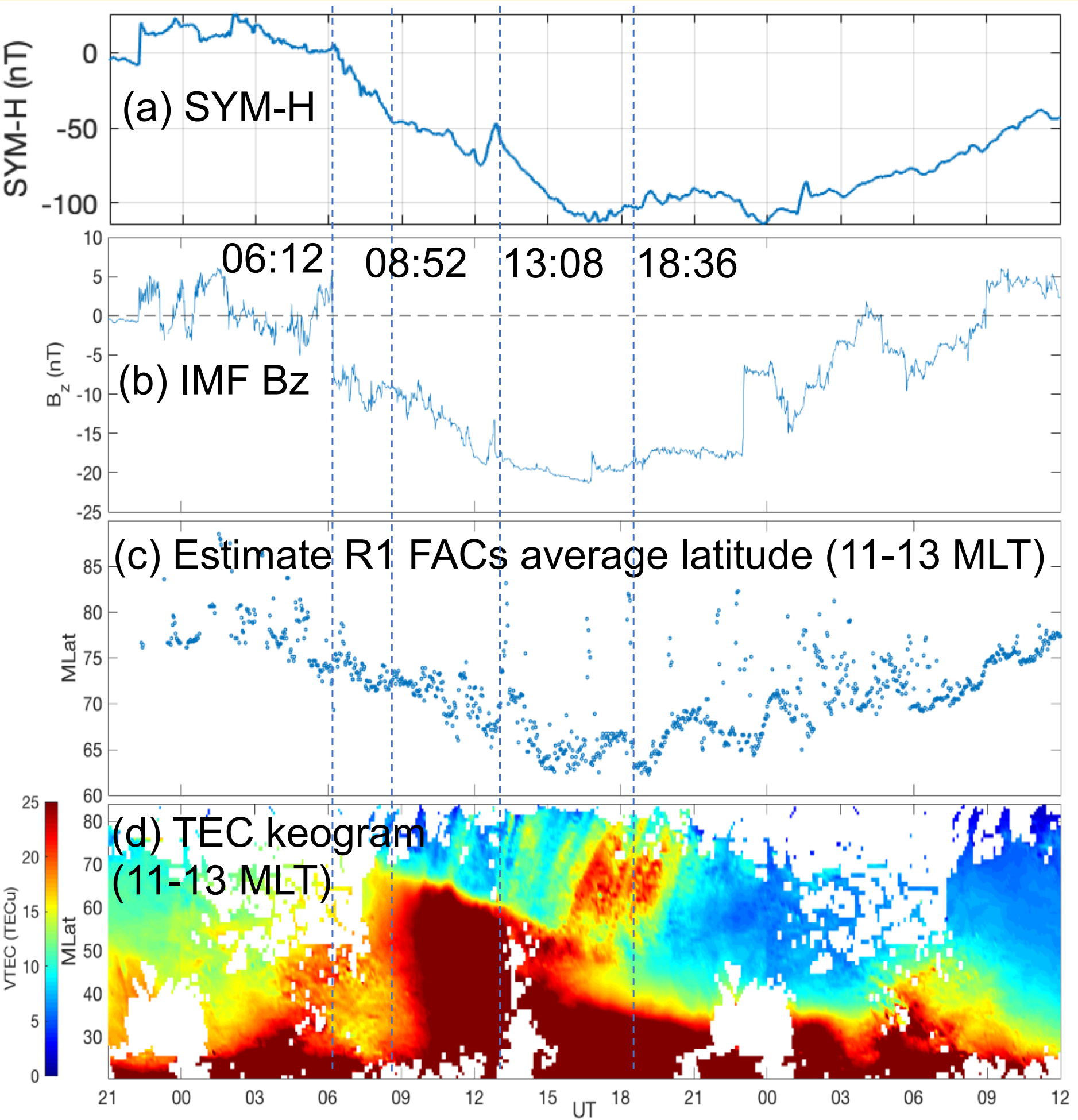


Figure 2. SYM-H, IMF Bz, R1 FACs Lat and TEC keograms near noon.

- The convection pattern has expanded significantly at 06:14 UT after the sudden southward IMF Bz turning at 06:12 UT.
- Significant plasma density enhancement on dayside mid-latitude from 07:52 UT to 08:52 UT as positive phase of an ionosphere storm.
- The poleward transport of the plasma has been intermittent and several polar cap patches are formed at ~13:06 UT.
- Continuous transport of dense plasma has formed a TOI like structure at 18:36 UT.
- Overall density is lower on the next day at 06:10 UT as negative phase of the ionosphere storm.

④ Structures Within the SED plume in the Polar Cap

- While the TEC map shows a large-scale SED plume entering the polar cap, DMSP and RISR-C measurements indicate that lots of smaller-scale density structures and therefore strong density gradients are present within the large-scale plume.
- Simultaneous DMSP crossings from different directions have seen distinct density variations.
- RISR-C also shows low electron temperatures within the density enhancement, similar to characteristics of the SED.

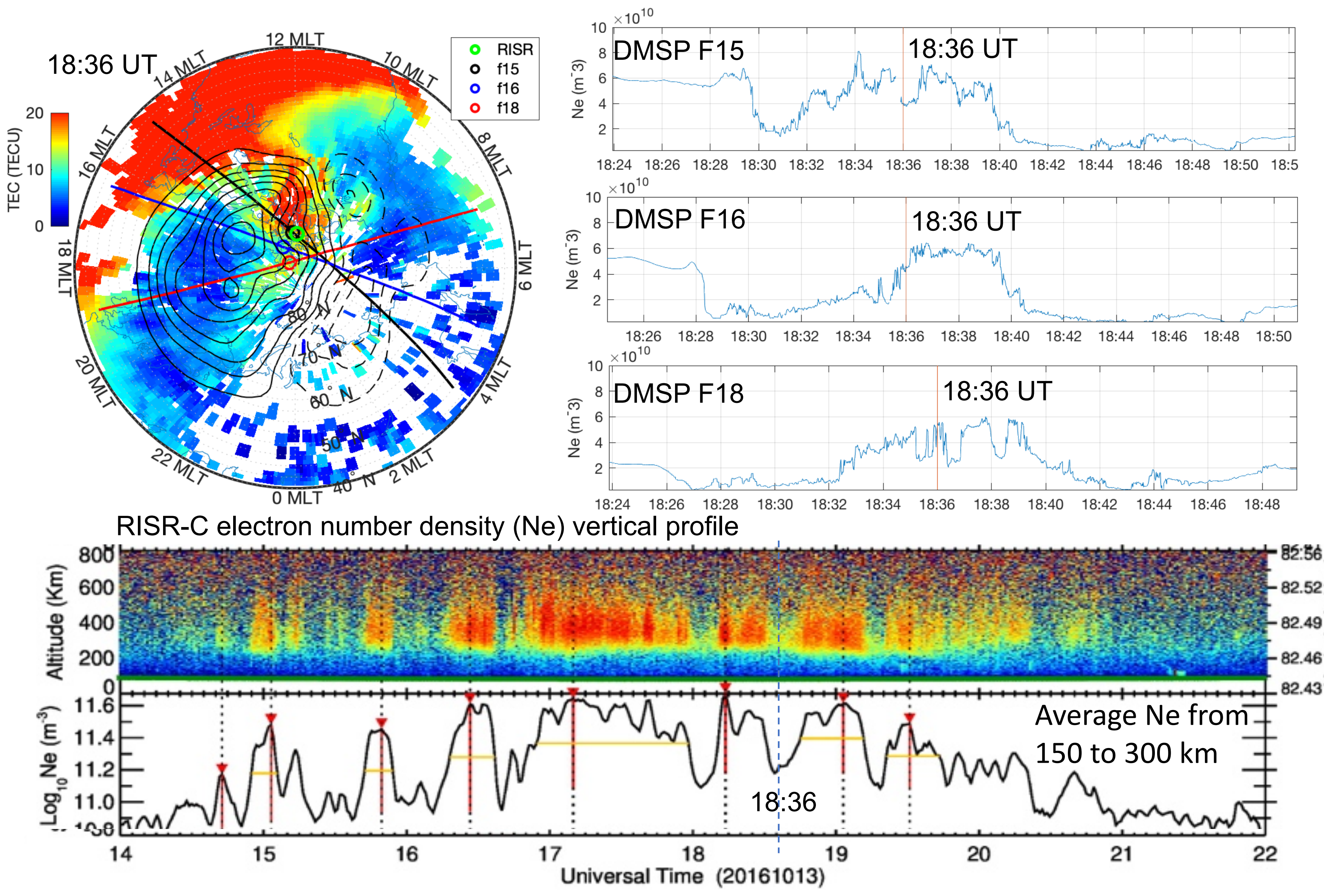


Figure . (Left) GPS TEC maps and SuperDARN convection patterns with the trajectories of three DMSP satellites overlaid at 18:36 UT, Oct. 13, 2016. (Right) DMSP satellites F15, F16 and F18 in situ measurements of plasma number density. (Bottom) RISR-C electron density vertical profiles.

② Segmentation of Polar Cap Patch

- At 13:00 UT when the dayside cusp is near the magnetic noon, the poleward convection flow near magnetic noon directly transports the high-density plasma from the source region into the polar cap.
- At 13:08 UT (4b), a convection flow kink appears near the magnetic noon as the convection inflow region shifts towards the dawn side.
- As a result, plasma with lower density are transported to the polar cap, as seen at 13:12 UT.
- The group of high-density plasma moving poleward into the polar cap is cut off from its source region and becomes a polar cap patch.
- The **Sondrestrom ISR**, marked by the magenta circle, is located near the dayside convection inflow region around 11 MLT.

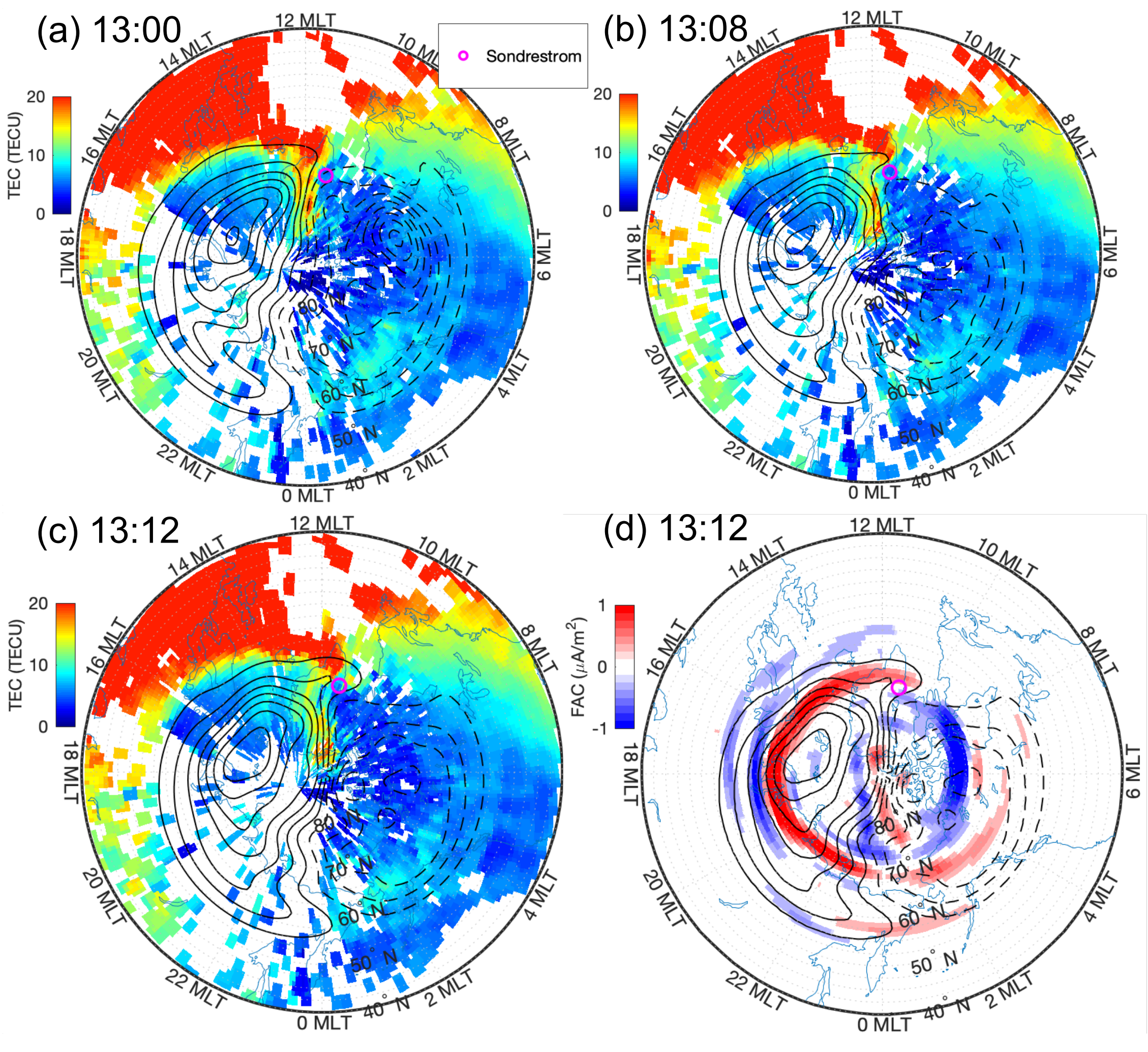


Figure 3. GPS TEC, AMPERE FACs maps and SuperDARN convection patterns at 13:00 UT (a), 13:08 UT (b) and 13:12 UT (c, d) on Oct. 13, 2016.

③ ISR Observation: Signatures of Reconnection

- From 12:35 UT to 12:50 UT, a sudden northward excursion of the IMF Bz (black curve) and negative excursion of the IMF By (blue curve) occurs.
- As the radar corotates into the dayside convection inflow region, the background flow direction changes gradually from eastward (blue) to northward (green).
- At ~12:55 UT, following the sudden IMF shifts, an initial E-region electron temperature increase can be seen near 72 Mlat.
- At ~13:00 UT, a channel of northeastward flow burst exceeding 2 km/s appears.
- At ~13:04 UT, significant F-region ion temperature increase and density depletion are observed simultaneously, due to enhanced frictional heating within the flow channel and thus increased recombination rate.
- This series of observations matches well with the signatures of magnetic reconnection in the ionosphere (Carlson, 2012).
- The flow channel resulting from dayside reconnection changes the flow direction, transports lower density plasma and further reduced plasma density near the cusp region.

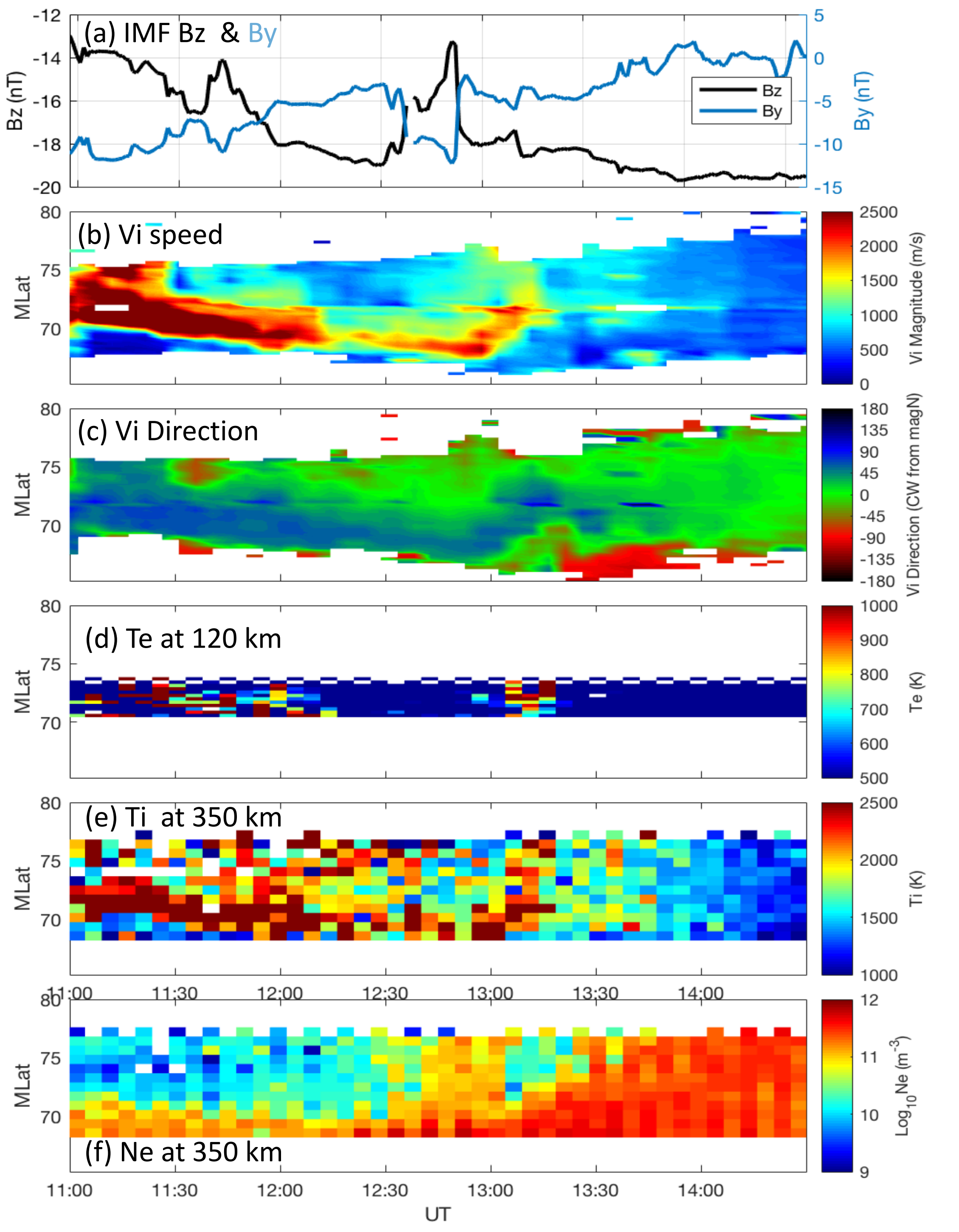


Figure 4. Sondrestrom ISR observations of iononspheric plasma convection velocity speed (b) and direction (c), electron temperature at 120 km altitude (d), ion temperature (e) and electron density (f) at 350 km altitude from 11 UT to 14:30 UT on Oct. 13, 2016. (a) The solar wind IMF By and Bz components.

- Flow direction change and enhanced frictional heating associated with the dayside reconnection is the segmentation mechanism for this polar cap patch.

CONCLUSIONS

1. During geomagnetic storms, extended period of southward solar wind IMF leads to expansion of high-latitude convection pattern and plasma density enhancement at mid-latitude and subauroral regions, e.g., SED.
2. High density plasma moving poleward into the polar cap is segmented into patches due to a sudden convection direction change near the inflow region, which is a result from strong flow channels associated with dayside reconnection.
3. Steady positive IMF By shifts the dayside cusp and the convection inflow region towards postnoon direction, which leads to continuous transport of dense plasma into the polar cap and the formation of SED plume.
4. Simultaneous DMSP satellite crossings from different angles show very distinct density structures. Density variations at a scale length of ~100s km with strong density gradients are present within the large-scale SED plume.

References:

- Moen, J., Gulbrandsen, N., Lorentzen, D. A., & Carlson, H. C. (2007). On the MLT distribution of F region polar cap patches at night. Geophysical Research Letters, 34, L14113. https://doi.org/10.1029/2007GL029632
- Carlson, H. C. (2012). Sharpening our thinking about polar cap ionospheric patch morphology, research, and mitigation techniques. Radio Science, 47, RS0L21. https://doi.org/10.1029/2011RS004946
- Kintner (2008) http://www.doncio.navy.mil/chips/ArticleDetails.aspx?ID=2782