CEDAR Grand Challenge Summary: Storms and Substorms without Borders (SSWB)

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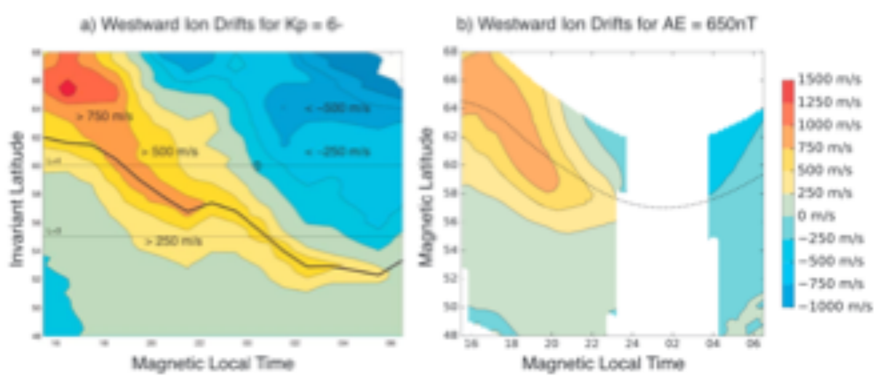
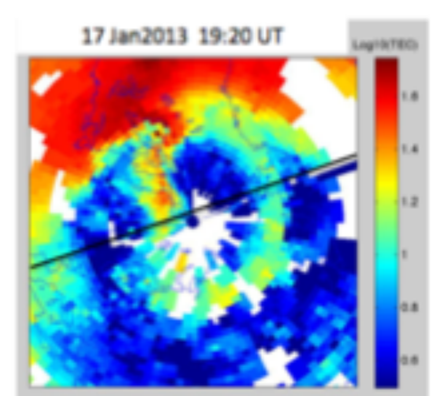
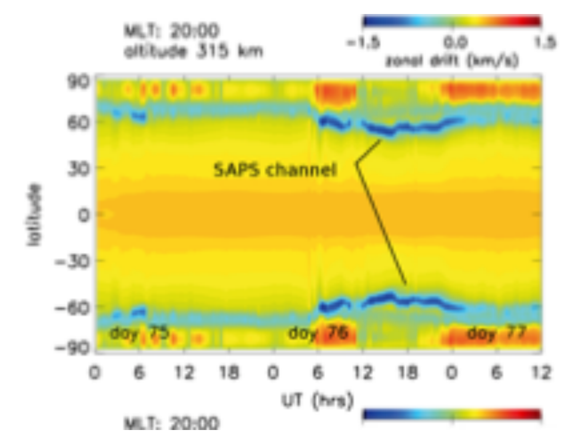
CEDAR + GEM communities







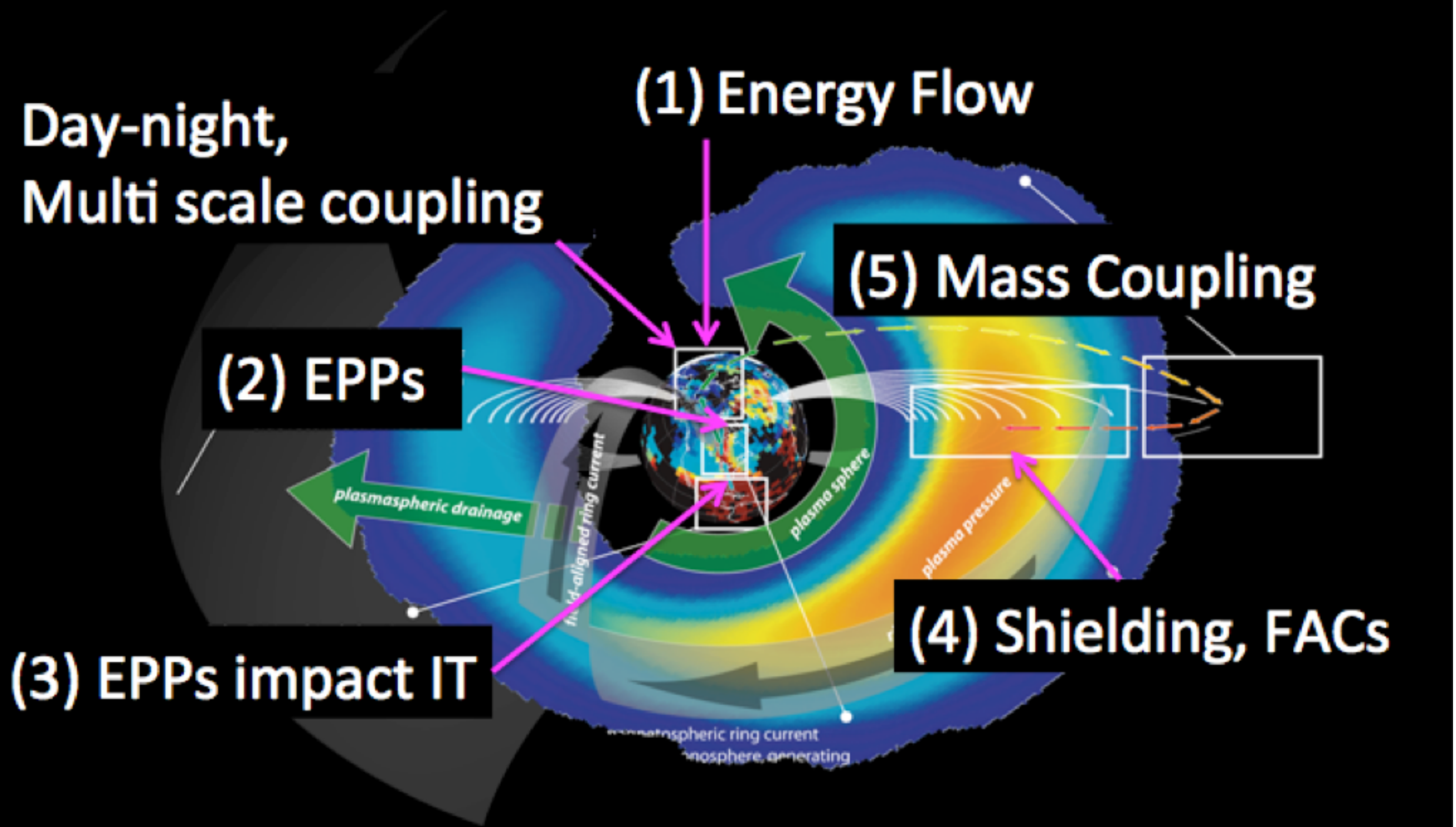
History:

- CEDAR/GEM session in 2013
- CEDAR 2014: “Storm/substorm-time subauroral Geospace"
- GC sessions at CEDAR 2015, 2016, 2017
- Fall AGU sessions on subauroral topics: 2015, 2016, 2017

System scale coupling is an inherently all-community set of studies
CEDAR and GEM are both essential

CEDAR Santa Fe June 29, 2018

Geospace System Science during Storms/Substorms



Subauroral Electrodynamic Coupling and Sub Auroral Polarization Stream (SAPS)

Storm time FACs
Iijima and Potemra, 1978

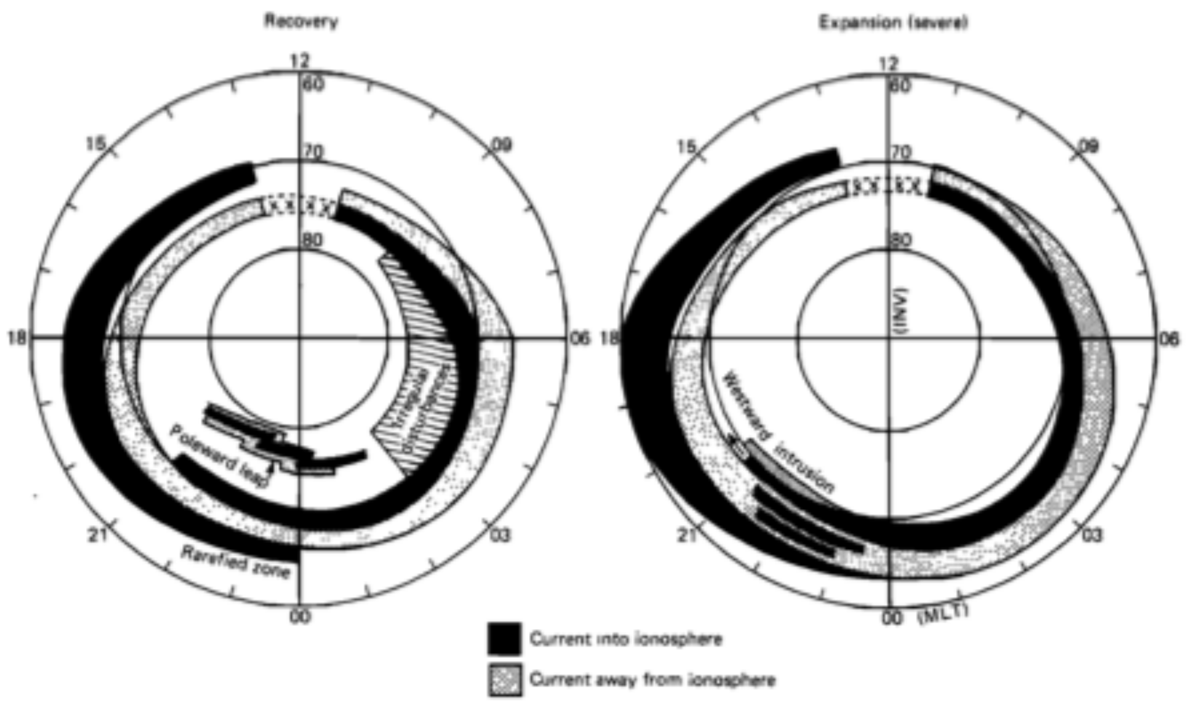
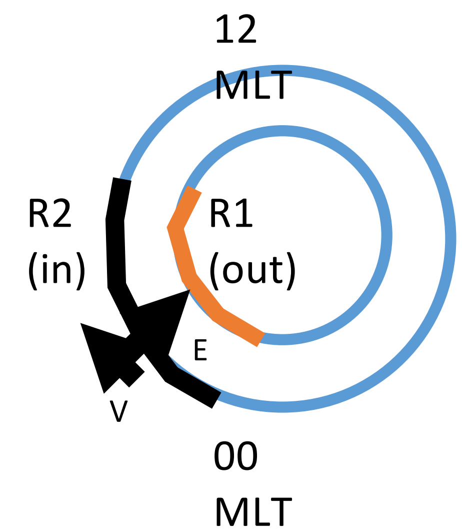


Fig. 15. Schematic diagram illustrating substorm-associated changes superimposed upon the basic distribution of field-aligned currents.

Electric fields in the ionosphere
(Ohm's Law)

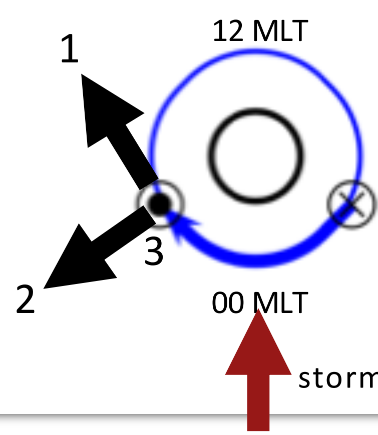


Conventional Wisdom:

<u>SAPS Mechanism</u>

Current closure through low conductance ionosphere = potential created = poleward E field in dusk sector

Region 2: $\nabla \cdot \mathbf{J} = 0$ $\quad j_{\|} = \nabla p \times \nabla V$

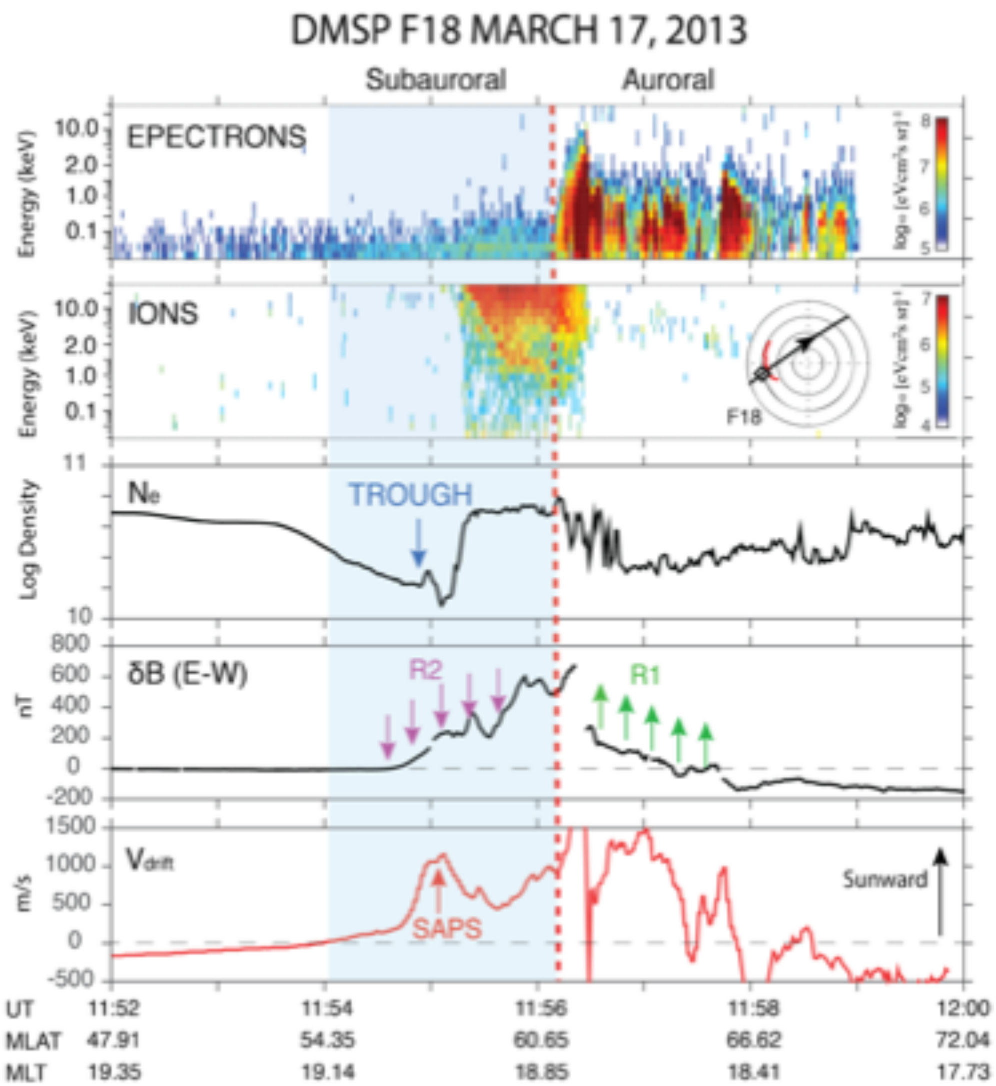


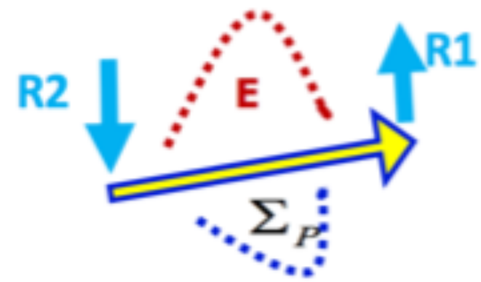
1: Azimuthal pressure gradient
2: Radial flux tube volume gradient
3: 1 x 2 = parallel current closure

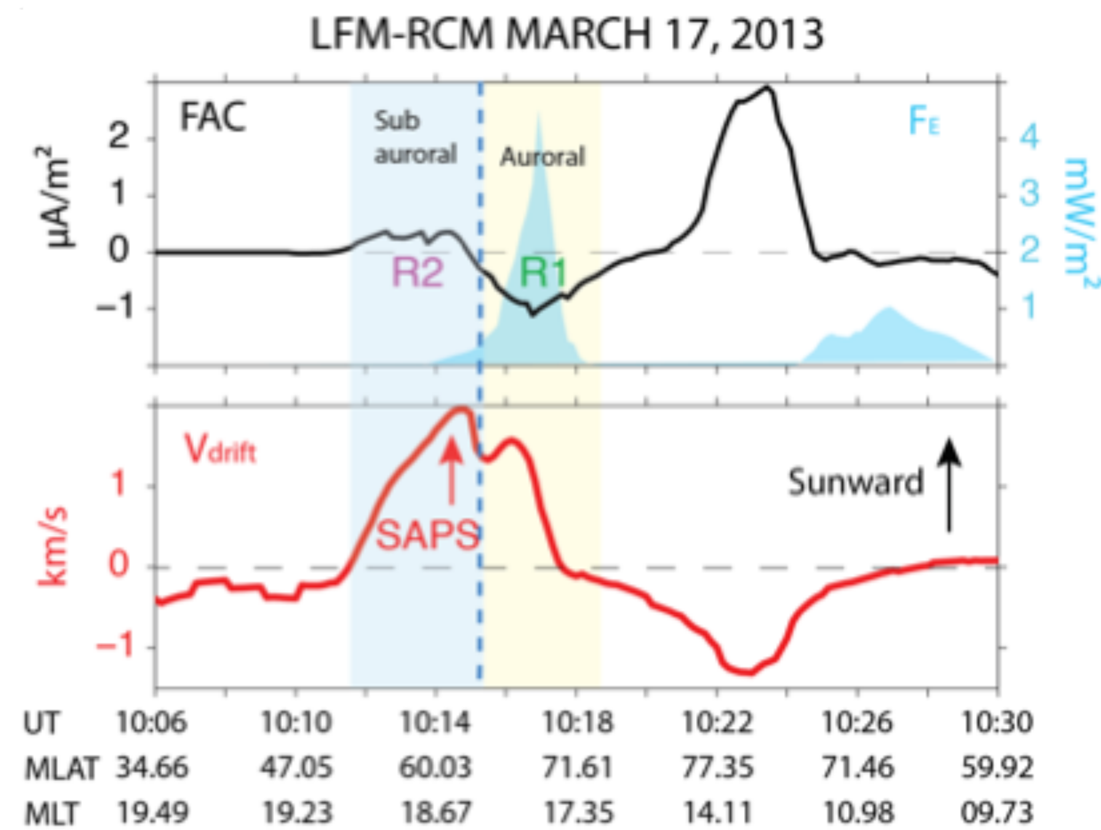
Vasyliunas, 1970; 2009

Foster and Burke 2002
Anderson 1991

Sub Auroral Polarization Stream (SAPS)
Sub Auroral Ion Drift (SAID)







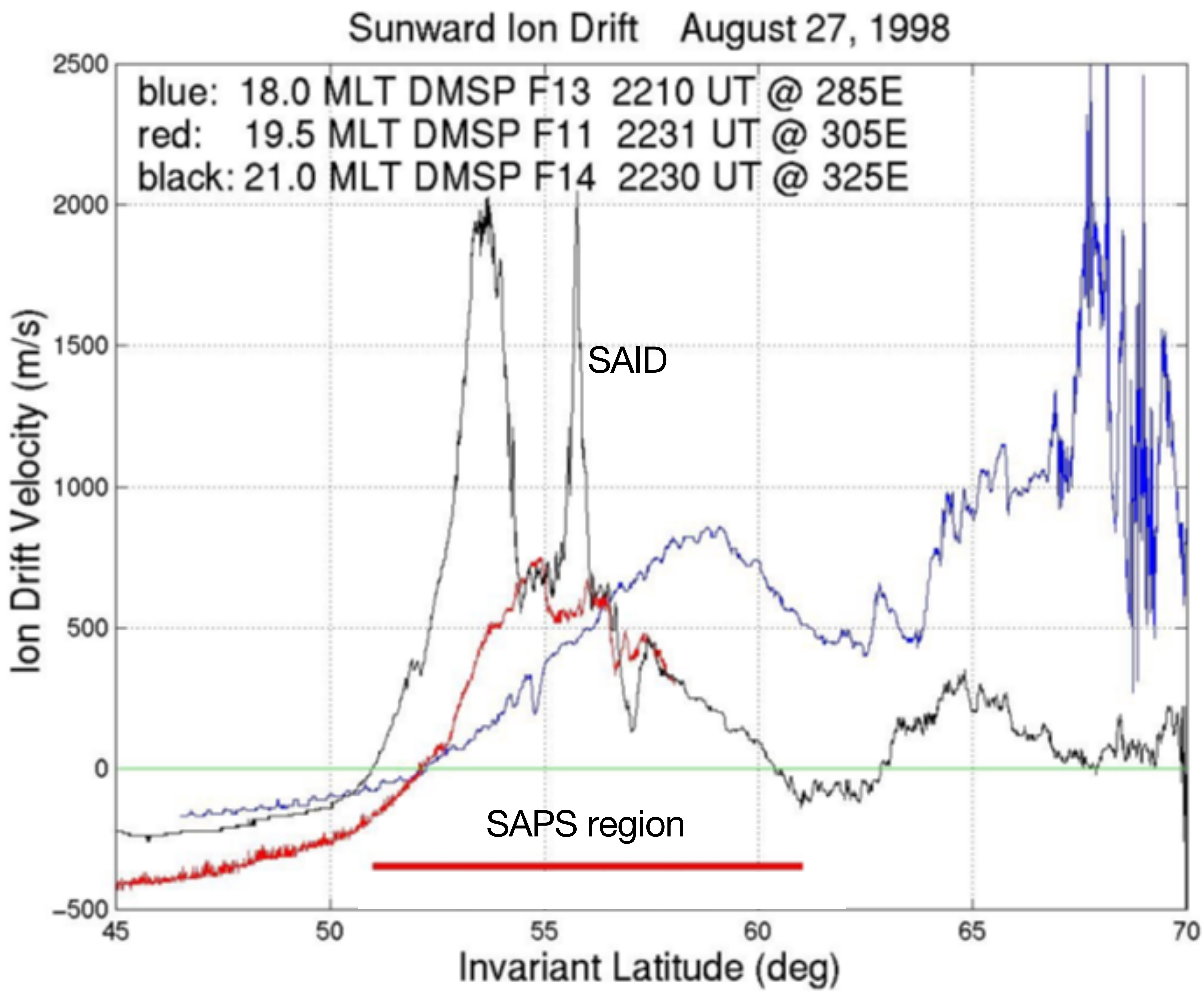
but…

Predictions: SAPS and SAID

1. **tag the partial RC buildup,**
2. **are bracketed by R1 & R2 FACs,**
3. **maximize @ minΣ_P(n_e)**

1. **Predicted timescales are too slow to explain the fast appearance of premidnight SAID and duskside SAPS**
2. **SAID are not bracketed by R1 & R2 FACs. Rather, $j_{\parallel}^{\downarrow}$ peaks @ the poleward edge or $j_{\parallel}^{\downarrow} \propto E_{\Lambda}$**
3. **E-field peaks on the wall of the density trough, not in the density minimum. Often there is no trough at all!**

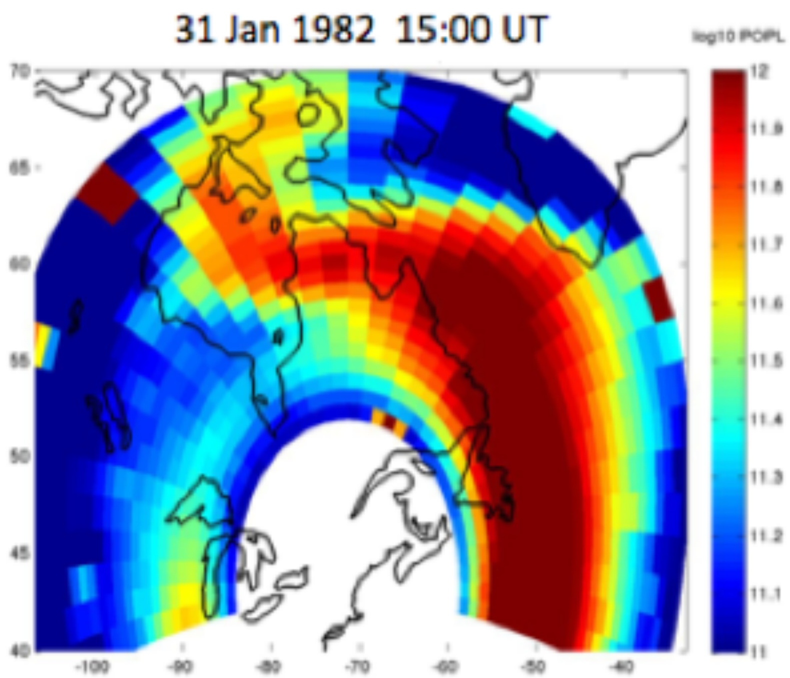
Sub Auroral Polarization Stream (SAPS)
Sub Auroral Ion Drift (SAID)

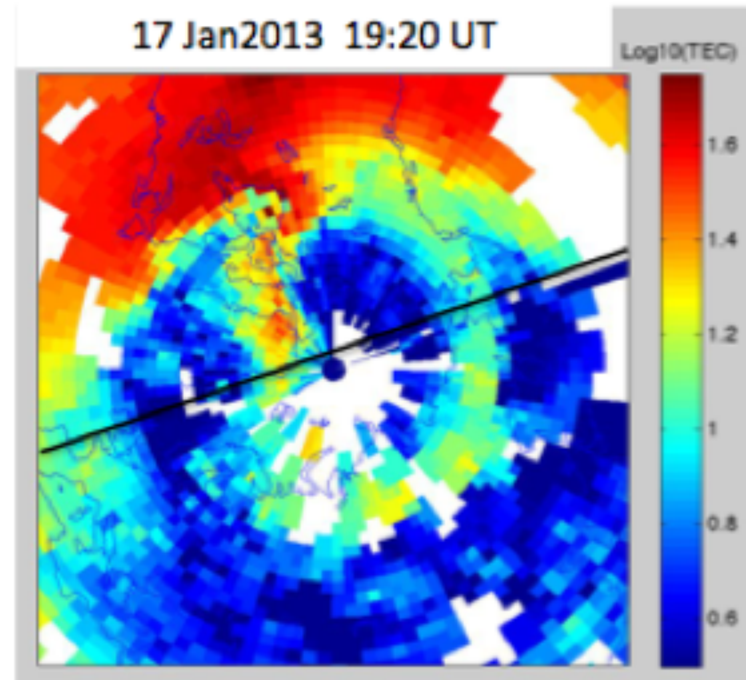


Subauroral Ionospheric Structure: Storm Enhanced Density

A

Radar Scan snapshot

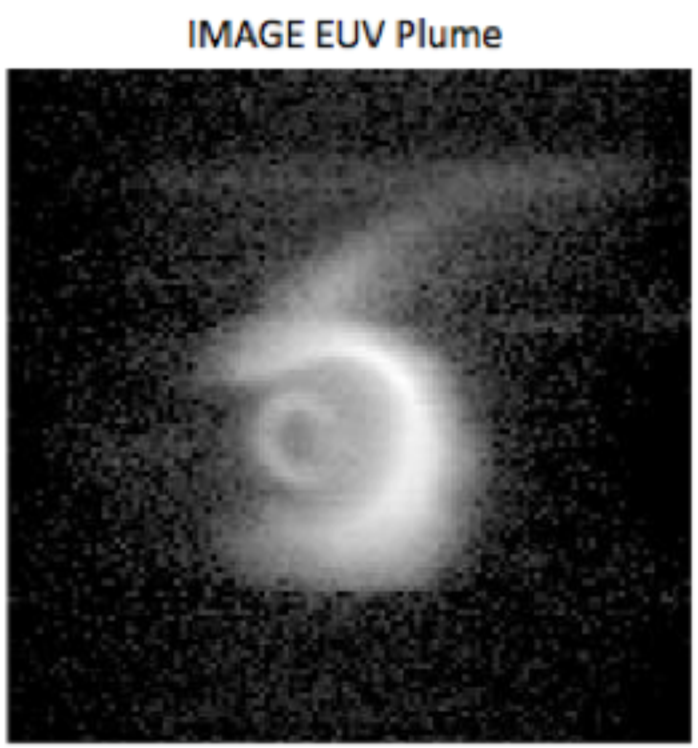




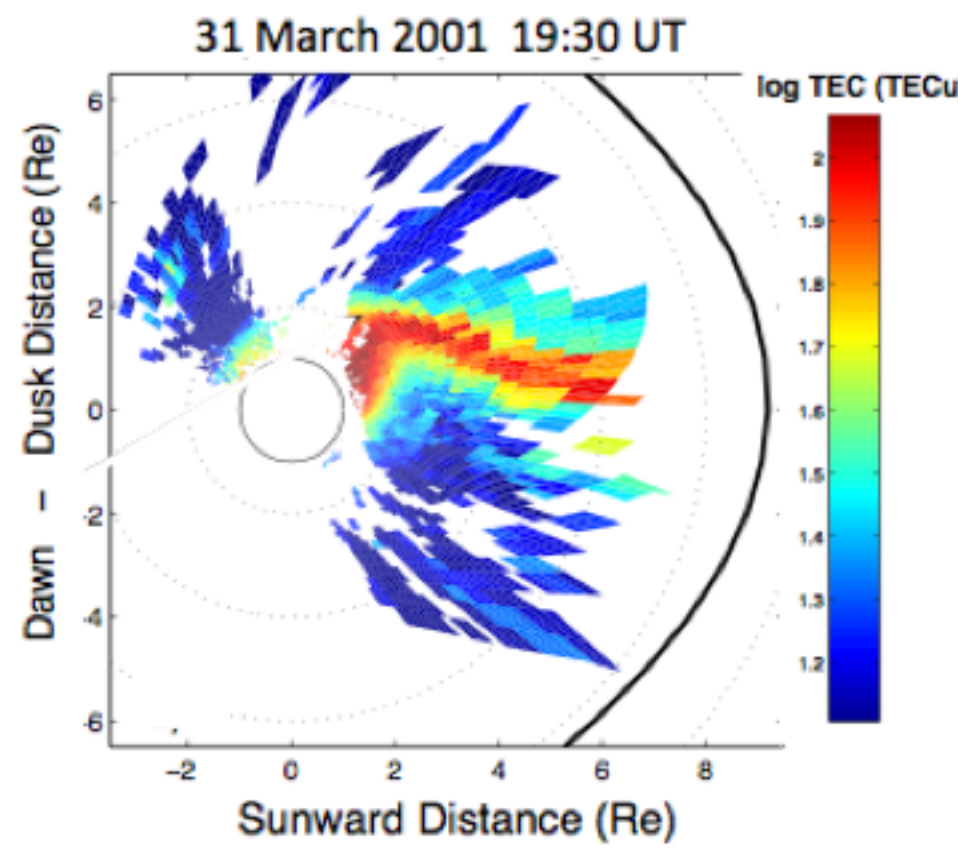
B

TEC TOI snapshot

C



12 April 2001 03:49 UT

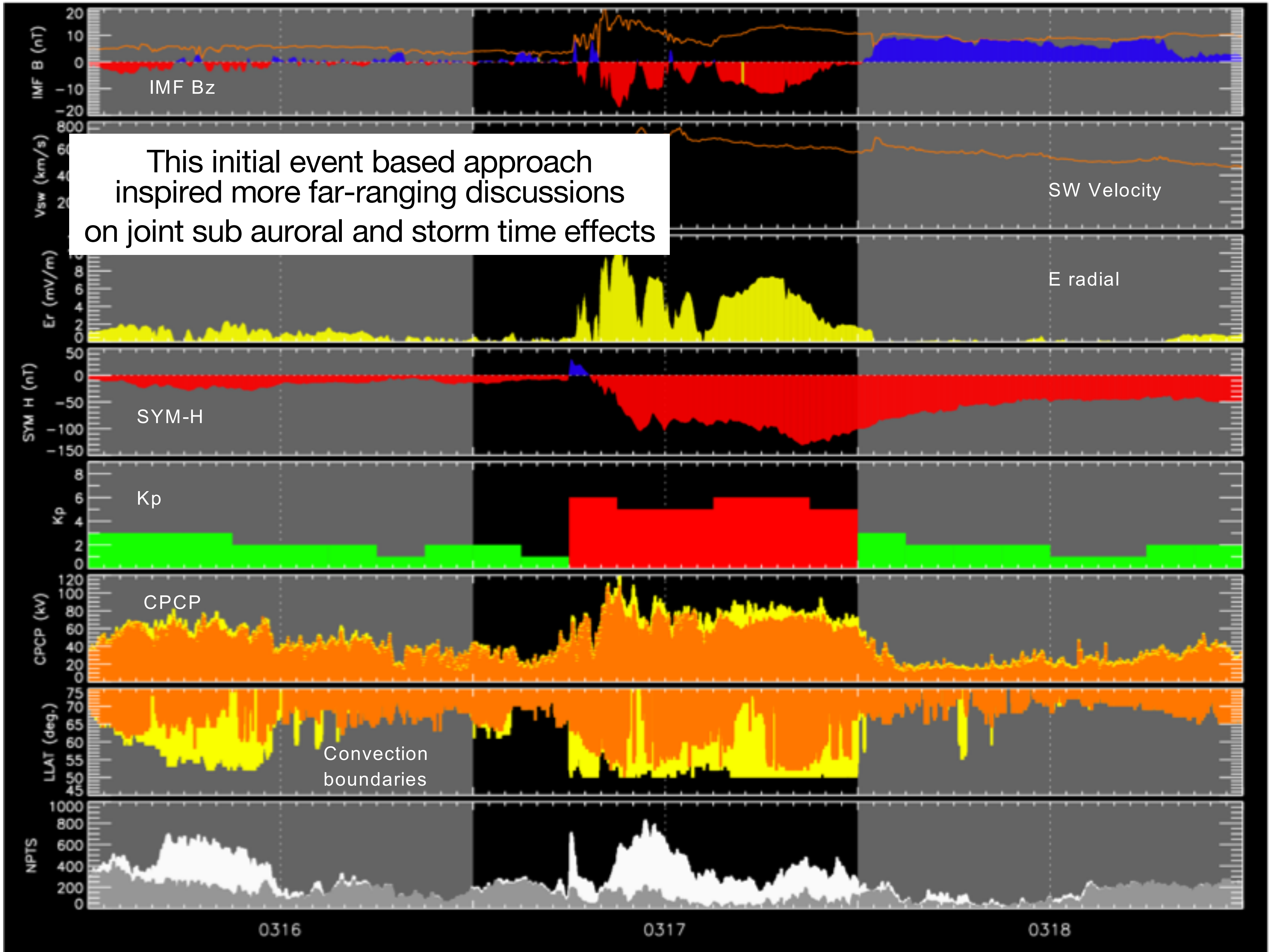


D

SSWB: Emerging Science Questions

- **What is the nature and significance *for the whole M-I-T system* of the disturbance electric fields, including SAPS?**
- **What is the role of thermosphere-ionosphere coupling during extreme forcing - e.g. significant SAPS features and neutral wind disturbances?**
- **How well can we account for (i.e, explain and predict) observed re-distribution of ionospheric Storm Enhanced Density; SED?**
- **What are the key mechanisms (and how many are there) behind the appearance of sub auroral fast flows and enhanced potential structures?**
- **Is SAPS a storm time phenomenon only, or does it occur at other times?**
- **How is SAPS coupled to other processes at other geospace locations such as high latitude?**
- **What are the key distinguishing features between SAPS and SAID flows? Are we in fact using the same term to describe phenomena with different physical drivers?**

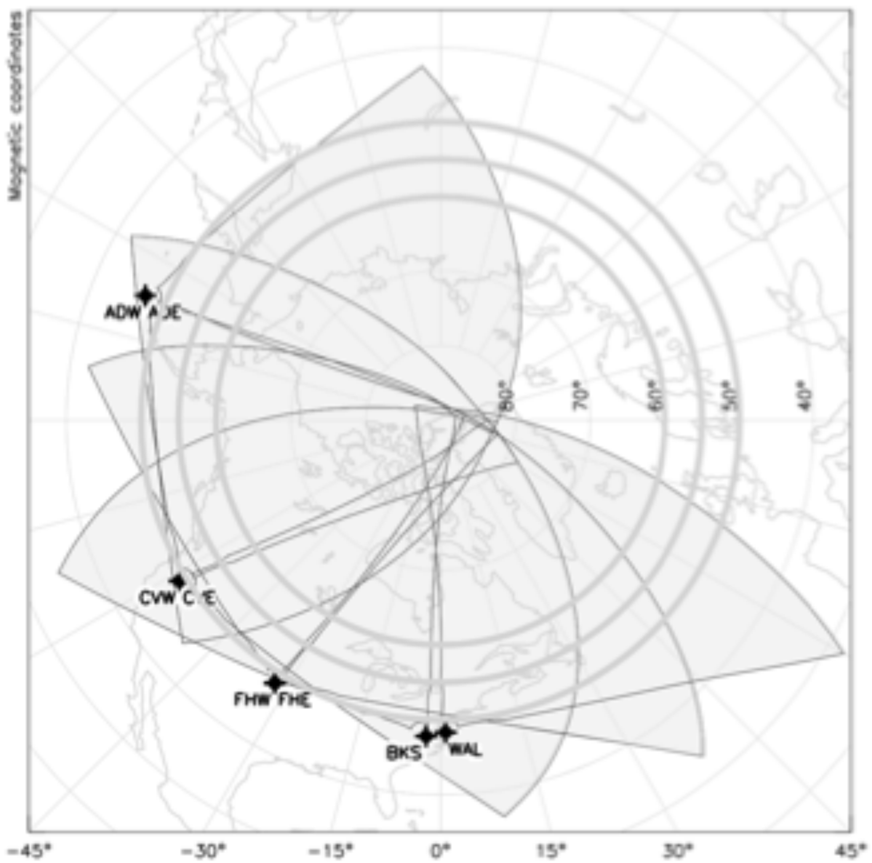
GC Focused Study Event: March 16 - 18, 2013
GEM/CEDAR: Understand Thermosphere-Magnetosphere-Ionosphere Coupling

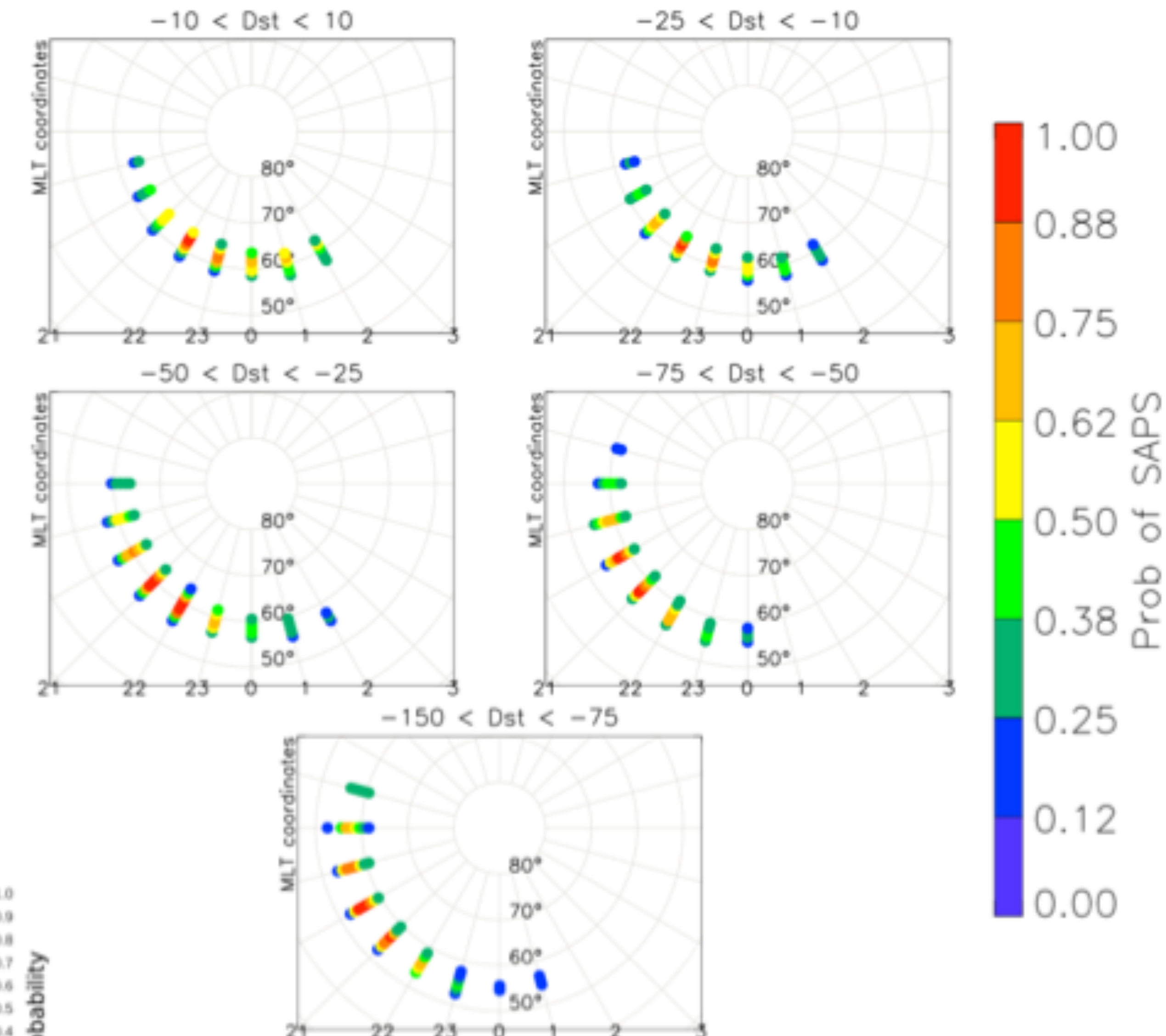


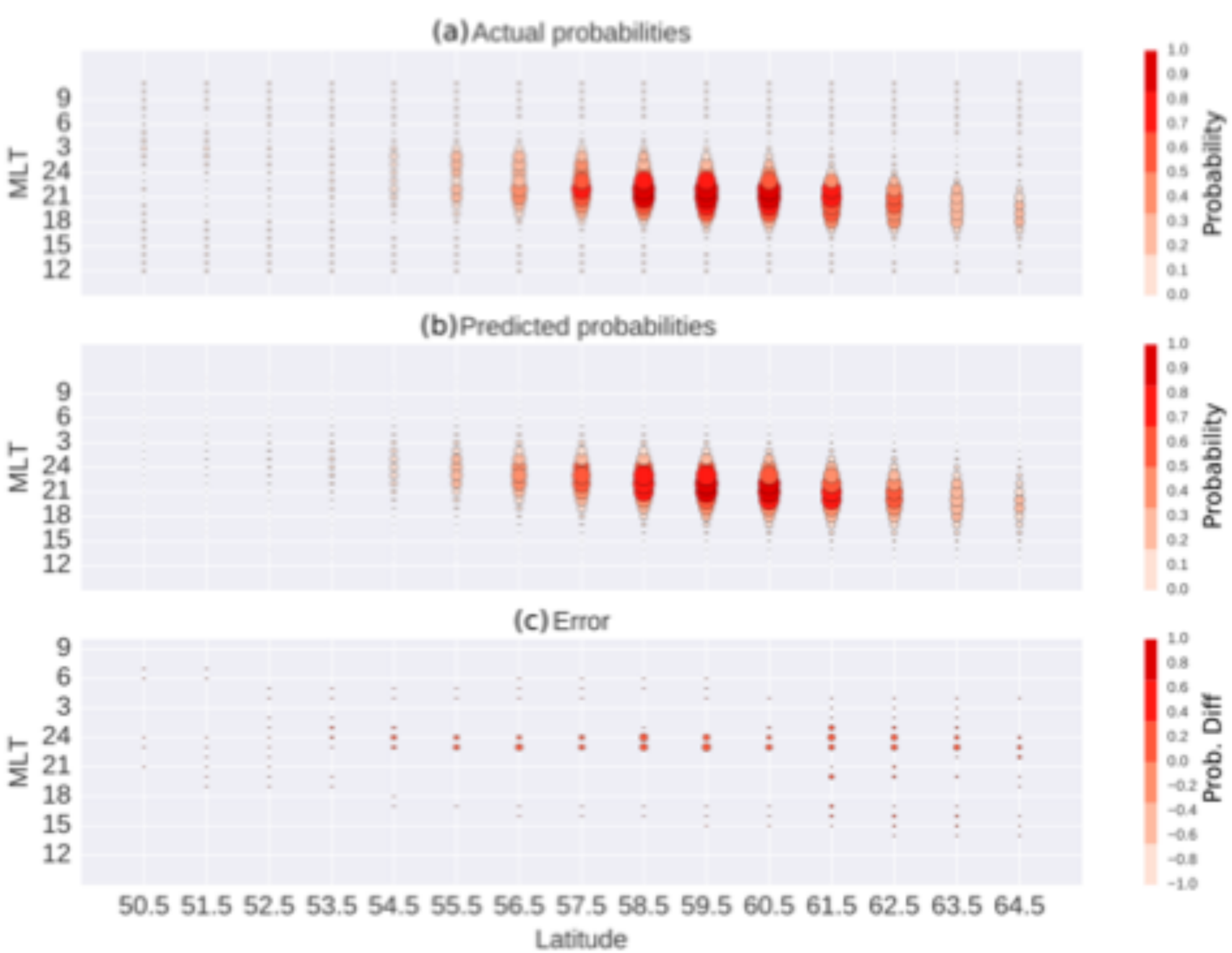
This initial event based approach inspired more far-ranging discussions on joint sub auroral and storm time effects

Selected Results: Observational Features

New Empirical Models of SAPS from SuperDARN



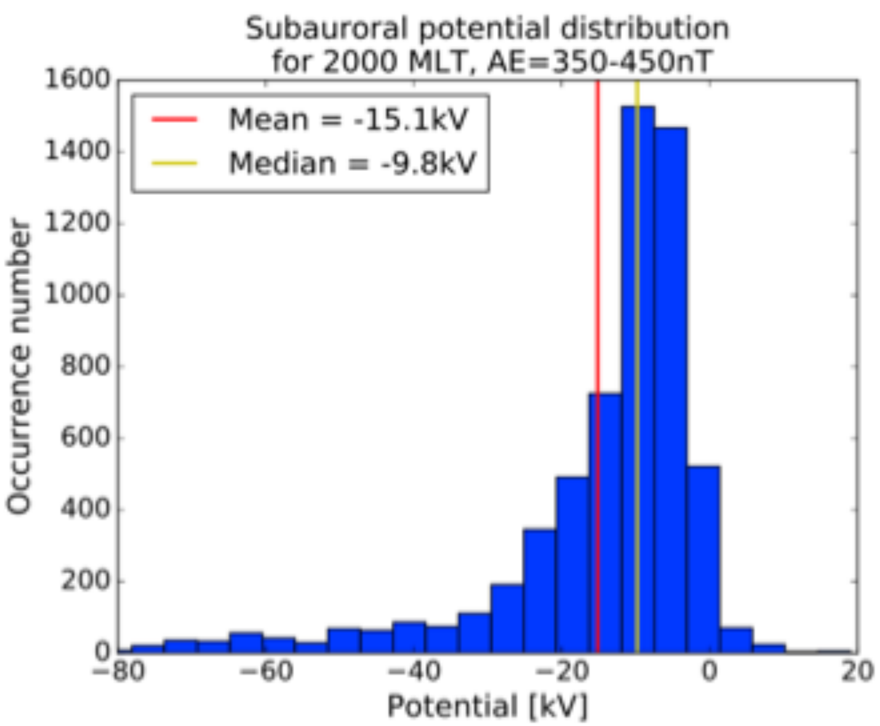


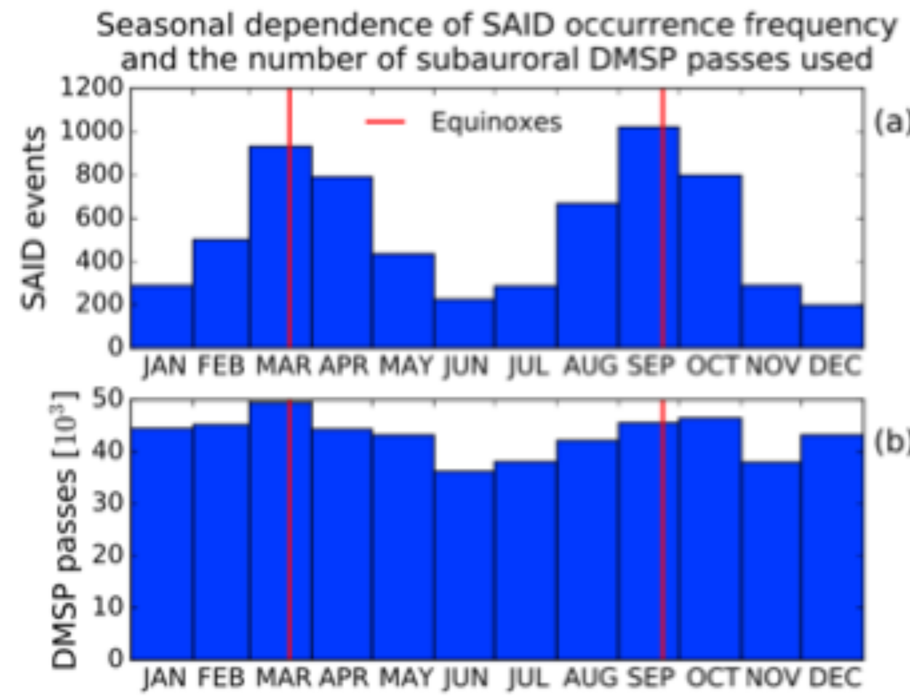


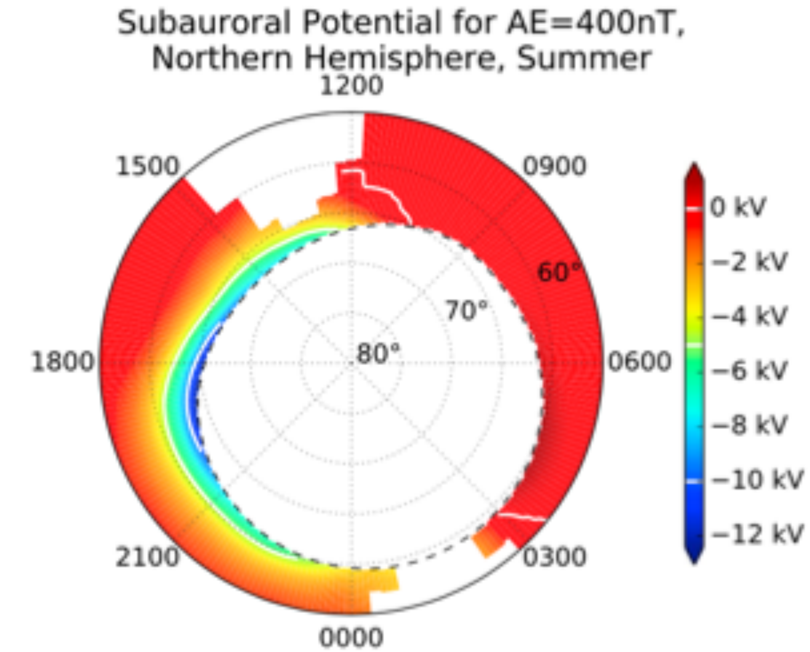
- During relatively **quiet** conditions (–10 nT < Dst ≤10 nT) SAPS tend to occur 15% of the time but are localized to the midnight sector > 60 MLAT.
- During **moderate storm** conditions (–75 nT < Dst ≤ –50 nT) SAPS occur 87% of the time centered at 20 MLT and below 60 MLAT
- Some nonlinearity at strong driving levels (thermosphere-ionosphere coupling)
- Empirical model now available

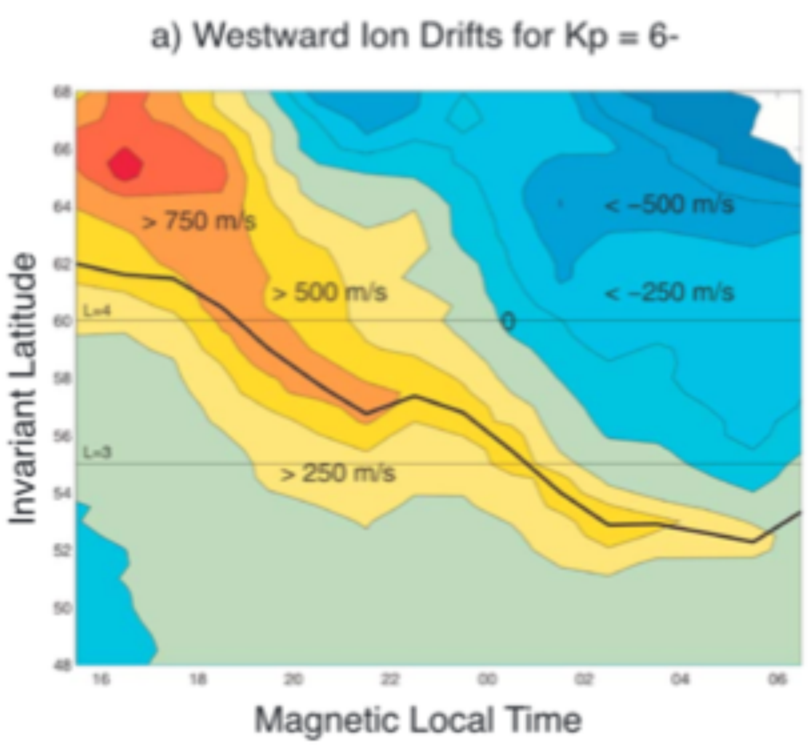
Kunduri et al JGR 2017

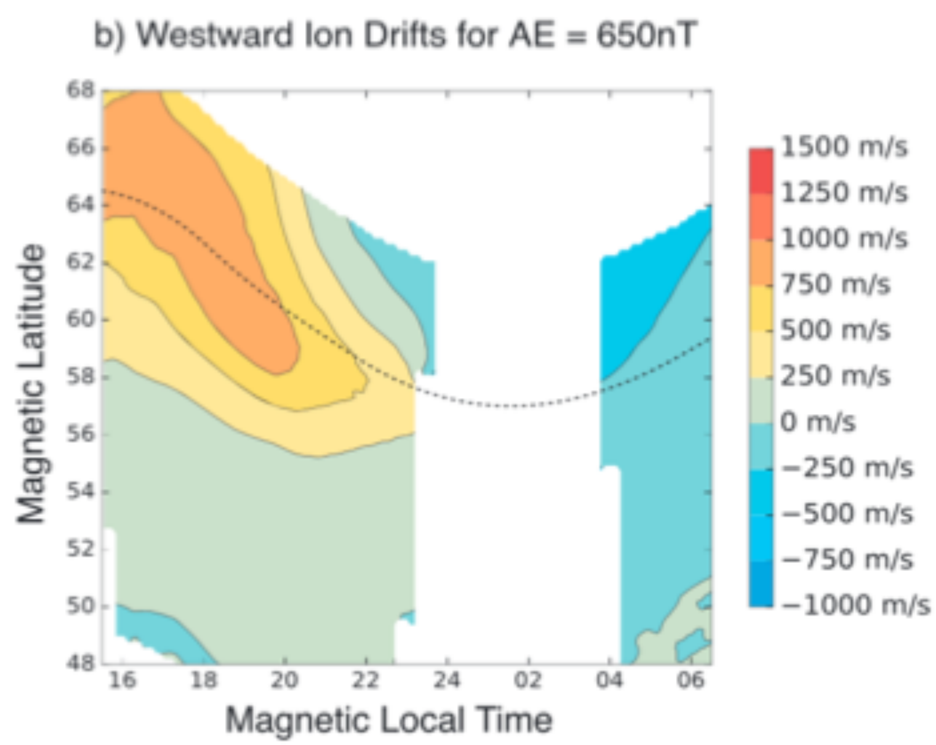
New Empirical Models of SAPS / SAID from DMSP, AE











- SAID vs SAPS?
- Sub auroral stormtime potential extends all the way from noon to midnight
- Median SAPS field is statistically conjugate between hemispheres (not conductivity dependent: current driven paradigm?)
- Linear dependence on activity (not nonlinear?)
- Empirical model is available

Landry and Anderson JGR 2017

Vertical Upwelling, Westward Wind Effects Associated with Stormtime SAPS (Thermosphere PLUS Magnetosphere - Ionosphere)

Zhang et al JGR 2016

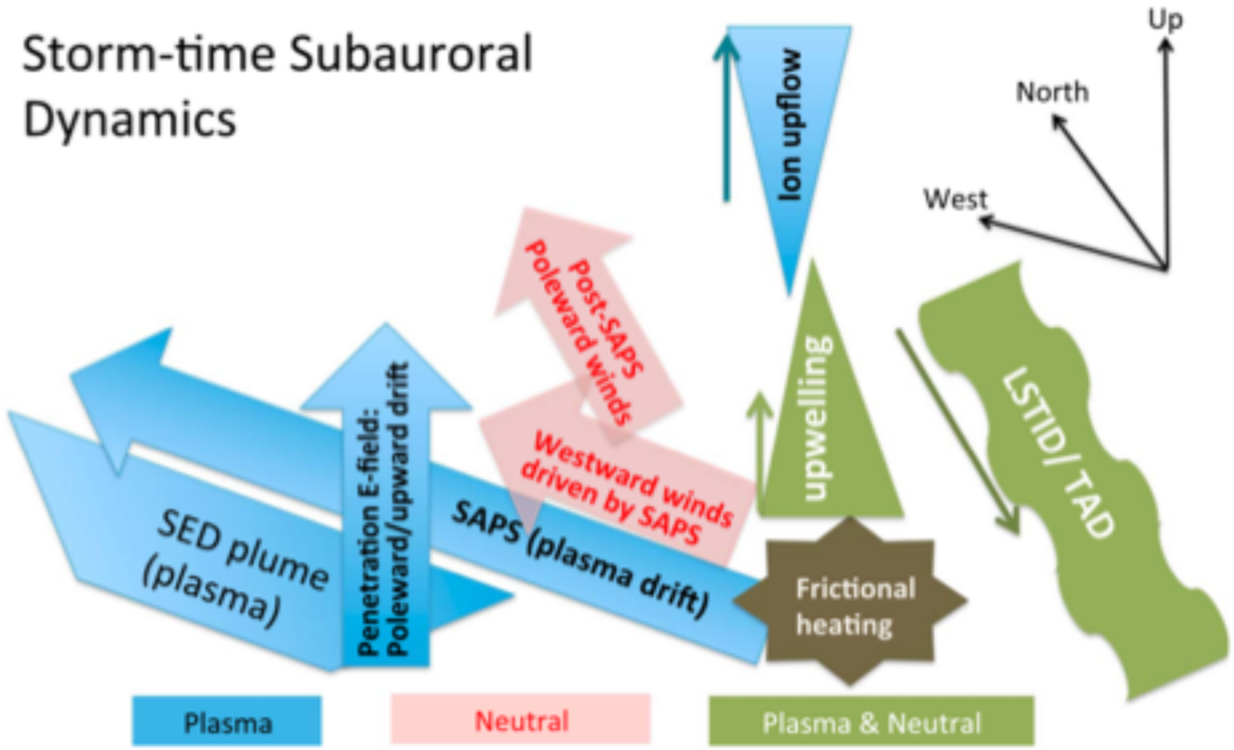
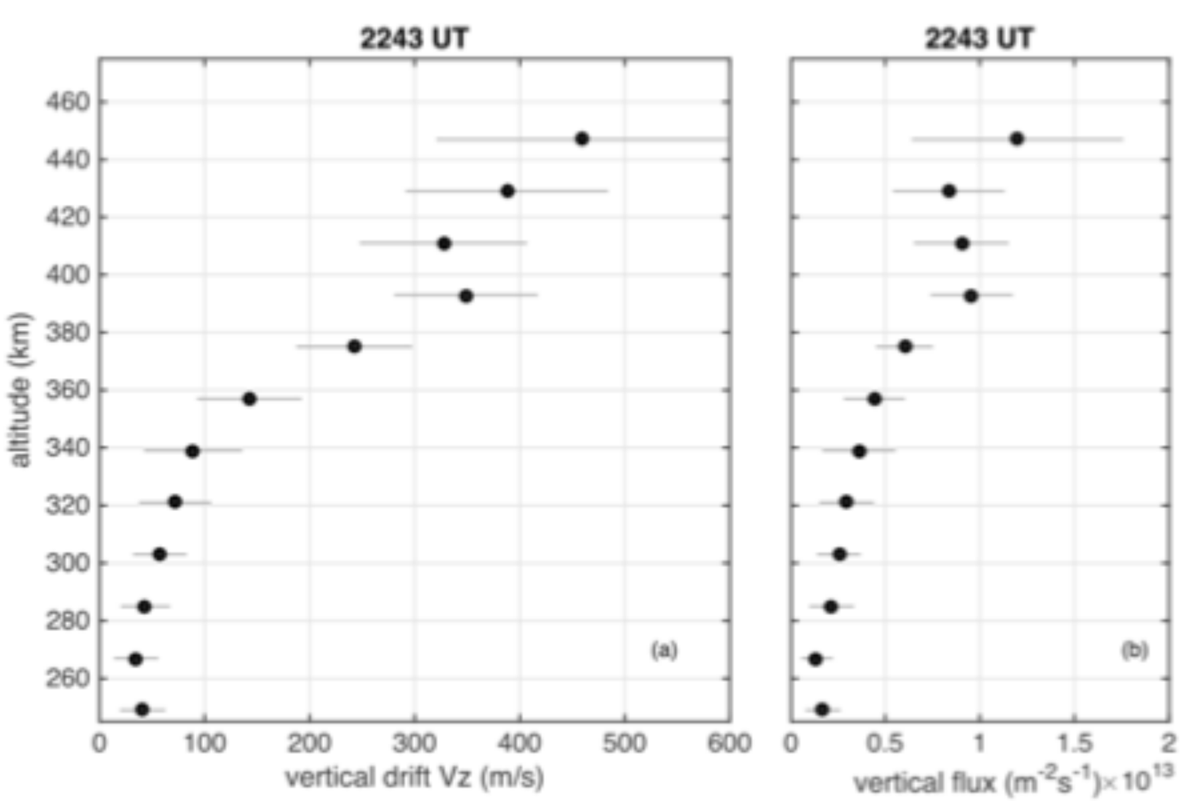
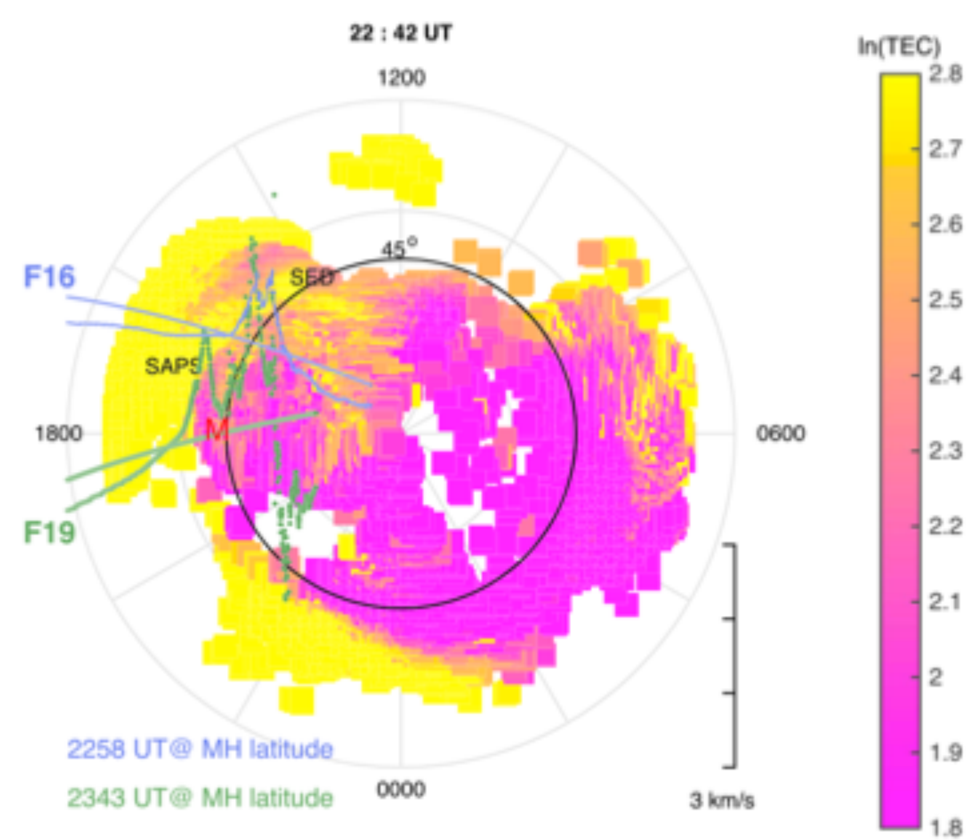


Figure 17. Schematic summary representation of primary storm time subauroral ionosphere and thermosphere dynamics observed during the 17–18 March 2015 St. Patrick's Day great geomagnetic storm.

- Strong Ion-Neutral Coupling effects
- Westward winds driven by strong SAPS flows
- Large vertical flux within SAPS channels (frictional heating)
- Requires coupled whole atmosphere models to correctly interpret qualitatively and/or quantitatively (future)





Magnetosphere-Ionosphere Connections: Van Allen Probes, SuperDARN

Geophysical Research Letters

RESEARCH LETTER
10.1029/2018GL077969

Key Points:
- There is a high correlation between the times of energetic electron injections and the times of

Energetic Electron Injections Deep Into the Inner Magnetosphere: A Result of the Subauroral Polarization Stream (SAPS) Potential Drop

Solène Lejosne[1], B. S. R. Kunduri[2], F. S. Mozer[1], and D. L. Turner[3]

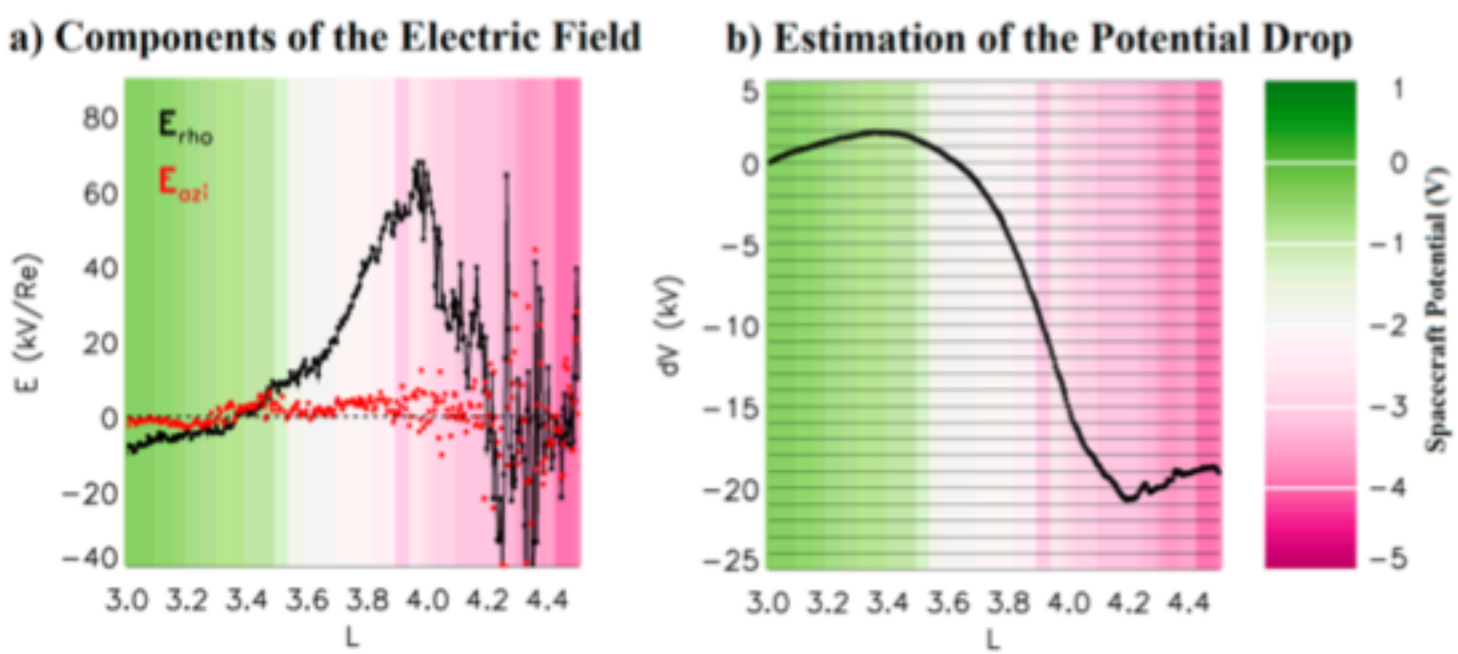


Figure 2. A SAPS measured by Van Allen Probes B during an outbound pass on 1 March 2013. The background color represents the spacecraft potential. The transition from 0 V at L = 3 to −4 V at L = 4.4 indicates a plasmapause crossing. (a) The maximum electric field was observed at 15:10 UT when the spacecraft was close to L = 4 and 22 MLT. (b) The potential drop across the SAPS channel is the difference between the potentials at L = 3.5 and L = 4.1. It is of −22.5 kV over 0.6 Re.

- Energetic electron injections (10s to 100+ keV) in the inner magnetosphere are highly correlated with SAPS structures associated with ring current sector potential drops
- SAPS also encountered in-situ in the magnetosphere
- Implications for coupled models: precipitation driven conductivity enhancement at sub auroral latitudes?

Variability: Connections between SAPS Intensifications and Auroral Streamers

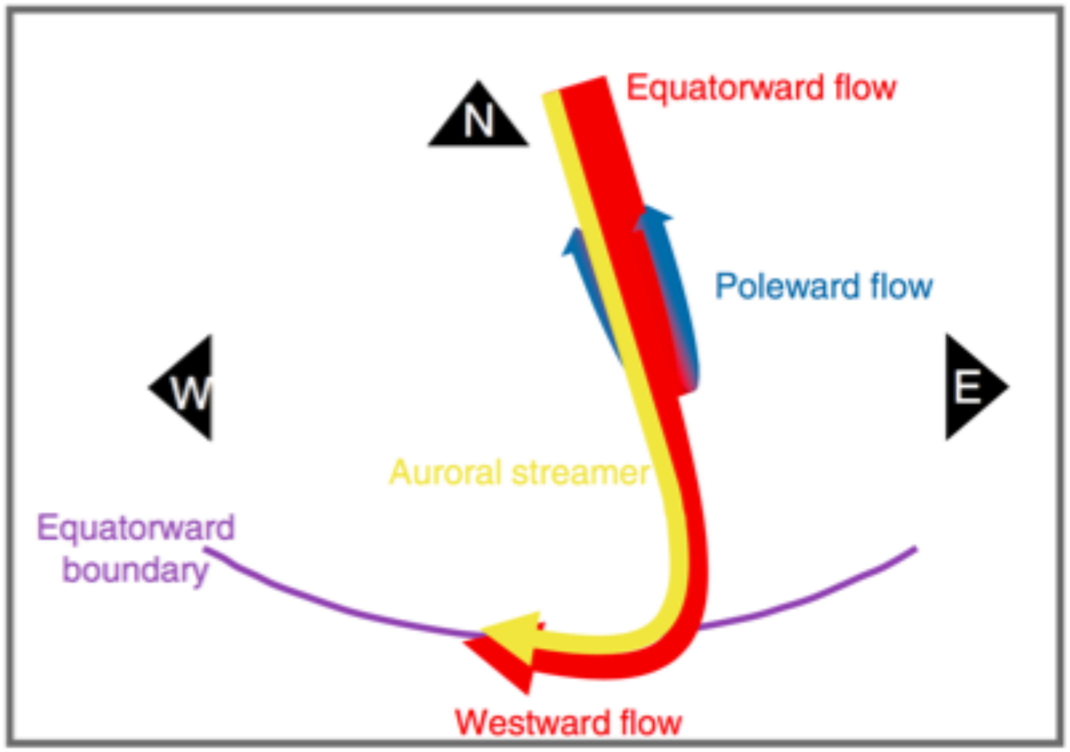
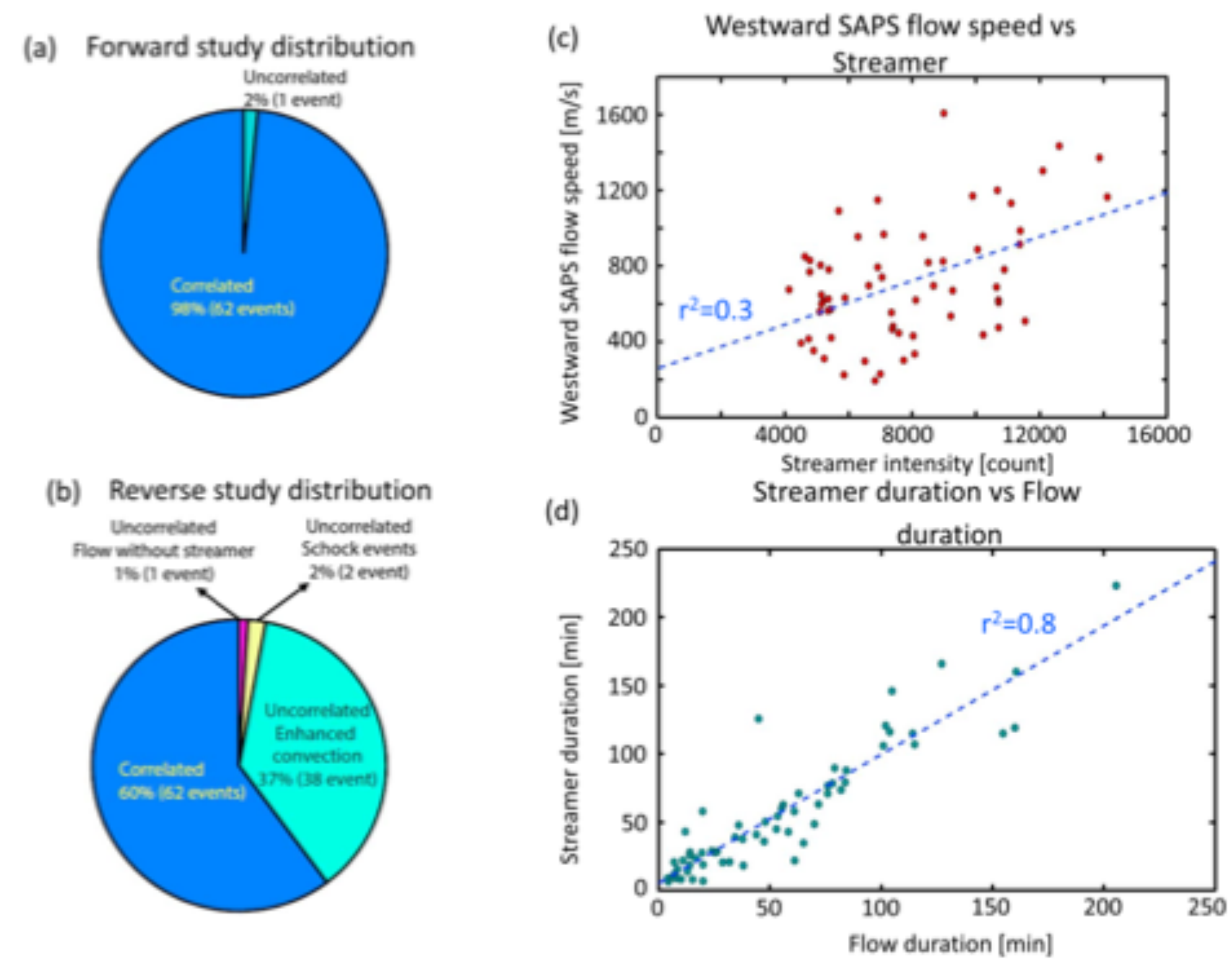
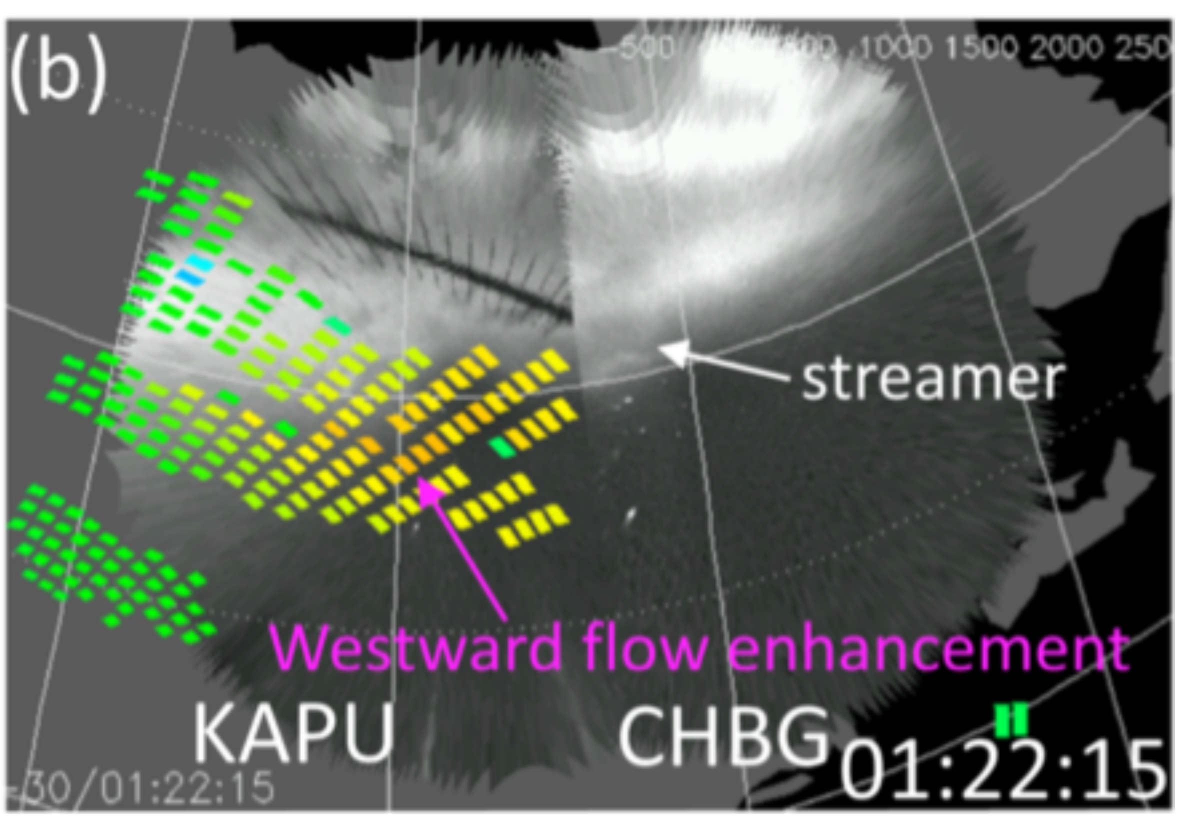


Figure 9. Schematic illustration of the association between auroral streamers and flow enhancements in the auroral and subauroral ionosphere.





- Auroral streamers associated with substorm flow bursts in plasma sheet; dynamic in nature
- Streamers exiting the nightside high latitude convection pattern are associated with intensifications in westward SAPS flow speed
- Streamer duration seen also to have impacts on flow duration of SAPS

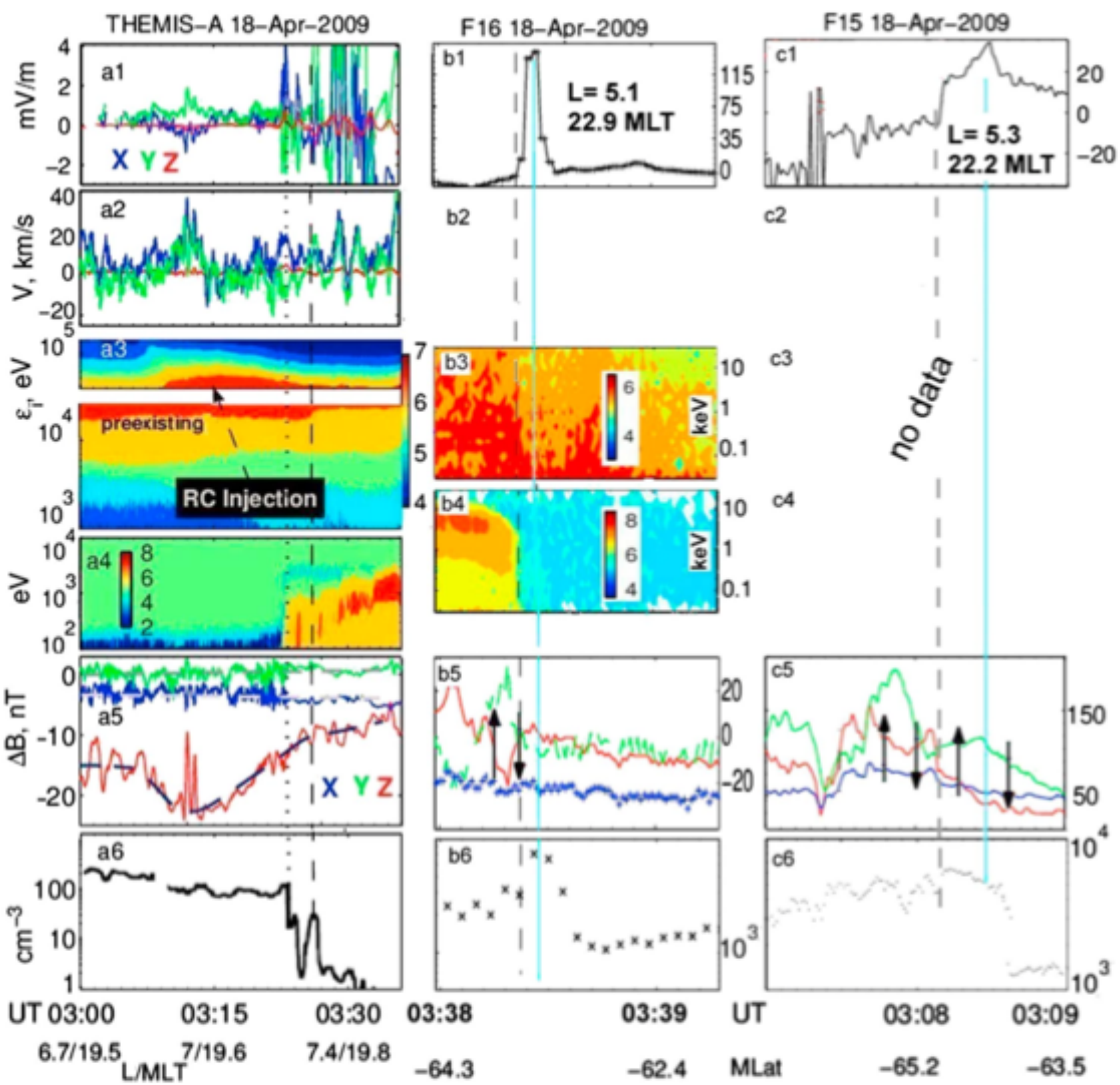
Gallardo-Lacourt et al JGR 2017

RESEARCH ARTICLE
10.1002/2017JA024263

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

Key Points:
- SAPS/RC injections on the duskside appear in much shorter time than predicted by the ion

Evgeny Mishin[1], Yukitoshi Nishimura[2,3], and John Foster[4]



- Observed SAPS/SAPSWS features disagree with the classic paradigm of voltage and current generators
- SAPS and tens of keV ring current injections on the duskside appear after the substorm onset much faster than the ion gradient-curvature drift time in the plasmasphere
- Time lag is of the order of the propagation times of reconnection-injected hot plasma jets to the premidnight plasmasphere and the substorm current wedge (SCW) to dusk

Selected Model Results from SSWB's "SAPS Focus Study"

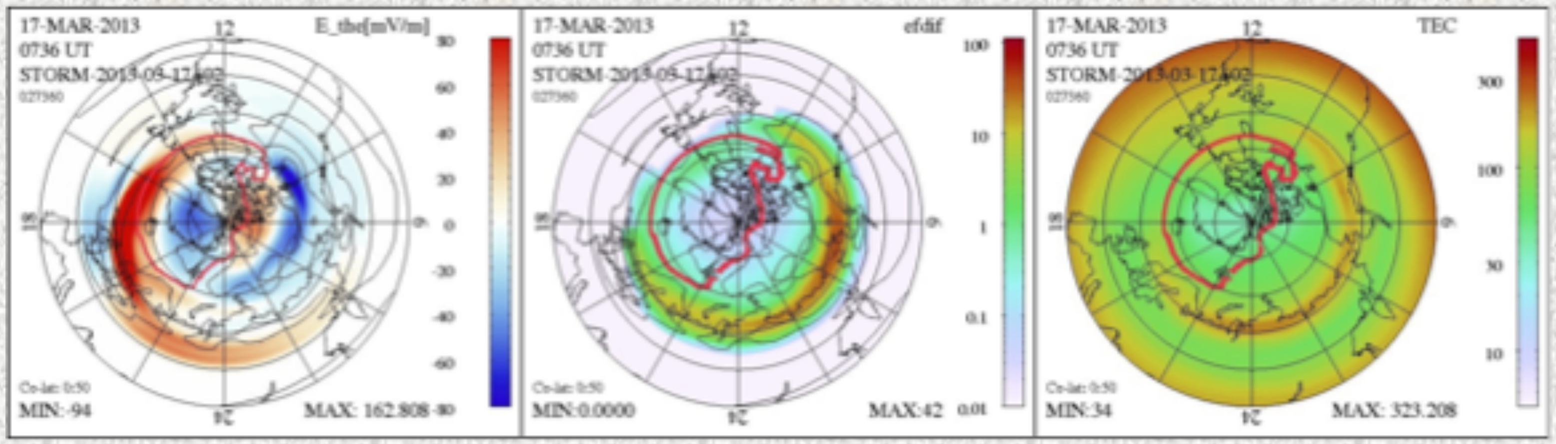
Features:

- Brought together both GEM & CEDAR modelers
- Coupled models were used, since SAPS requires whole M-I-T system approach
- Resulting capabilities advance global model representations, not just for SAPS

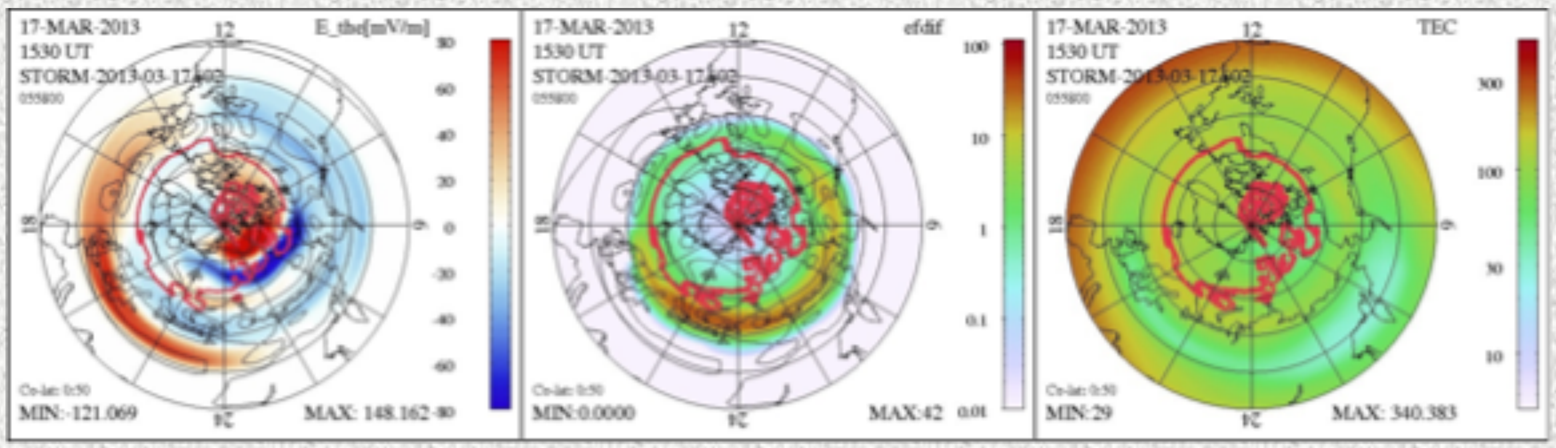
OpenGGCM-RCM-CTIM Reproduces SAPS: 2013-3-17

0736 UT

N-S E field | diffuse e- precipitation | TEC

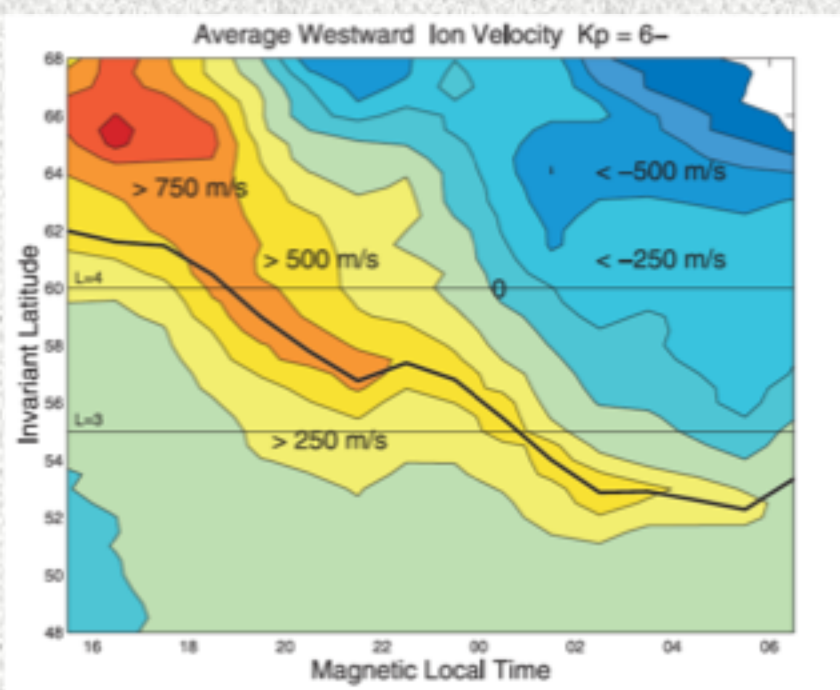


1530 UT

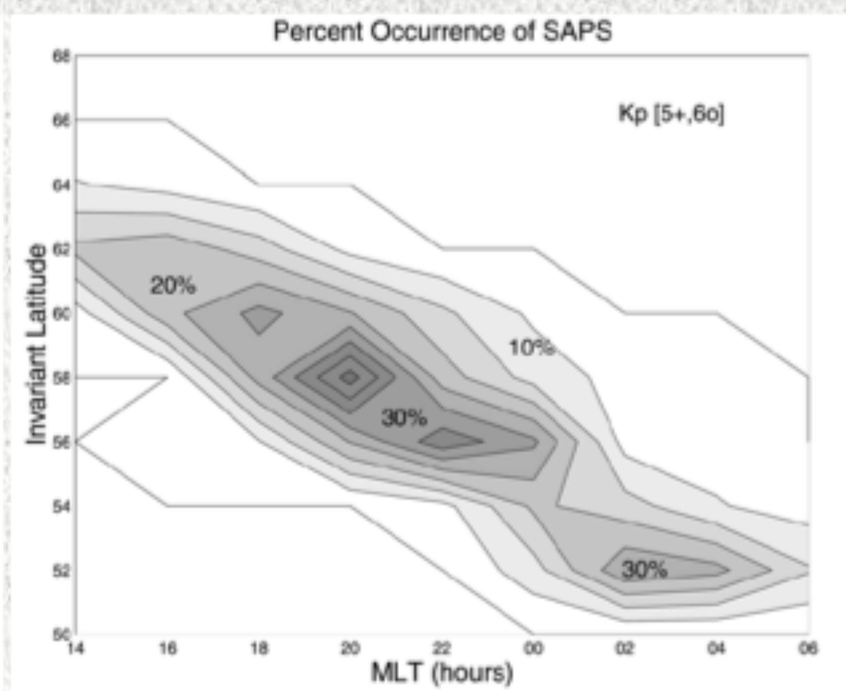


- 2 Southward IMF Bz turnings.
- SAPS sunward flow (northward E-field) enhanced equatorward edge of e- precipitation in dusk-midnight MLT.
- SAPS reduces TEC due to recombination.
- Trough extends eastward due to horizontal advection.

Obs. [Foster & Vo, 2002]



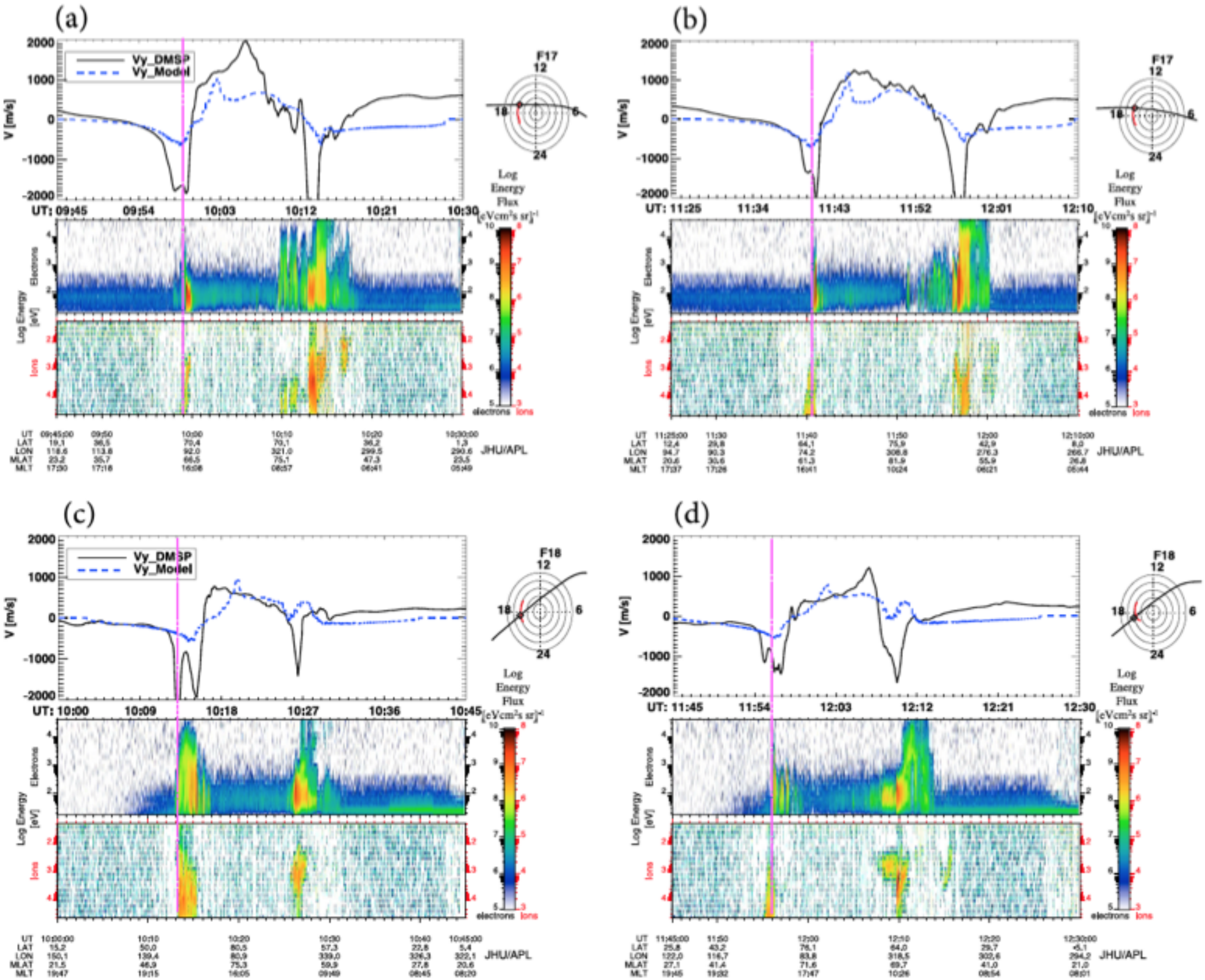
Model



- MLT-latitude dependence compares well with results from statistical studies (Foster & Vo, 2002).
- SAPS moves equatorward as MLT varies from dusk to dawn.

[Raeder et al., 2016, UNH,Rice,CU]

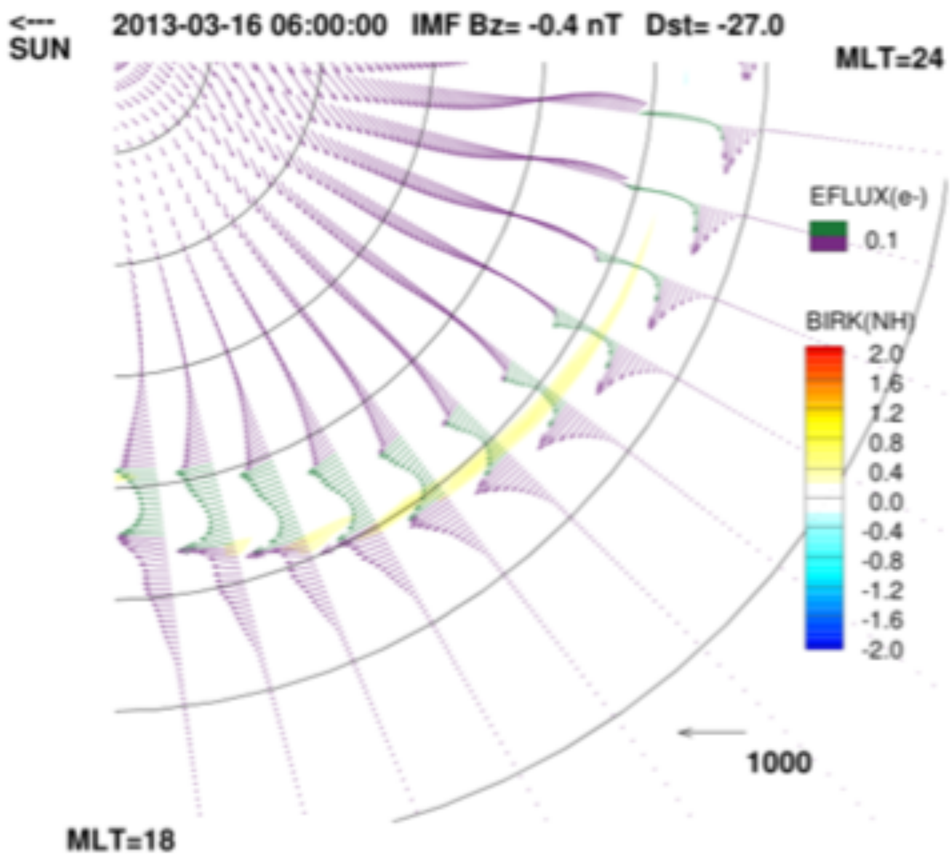
SWMF(MHD)-->RAM Reproduces SAPS: 2013-3-17

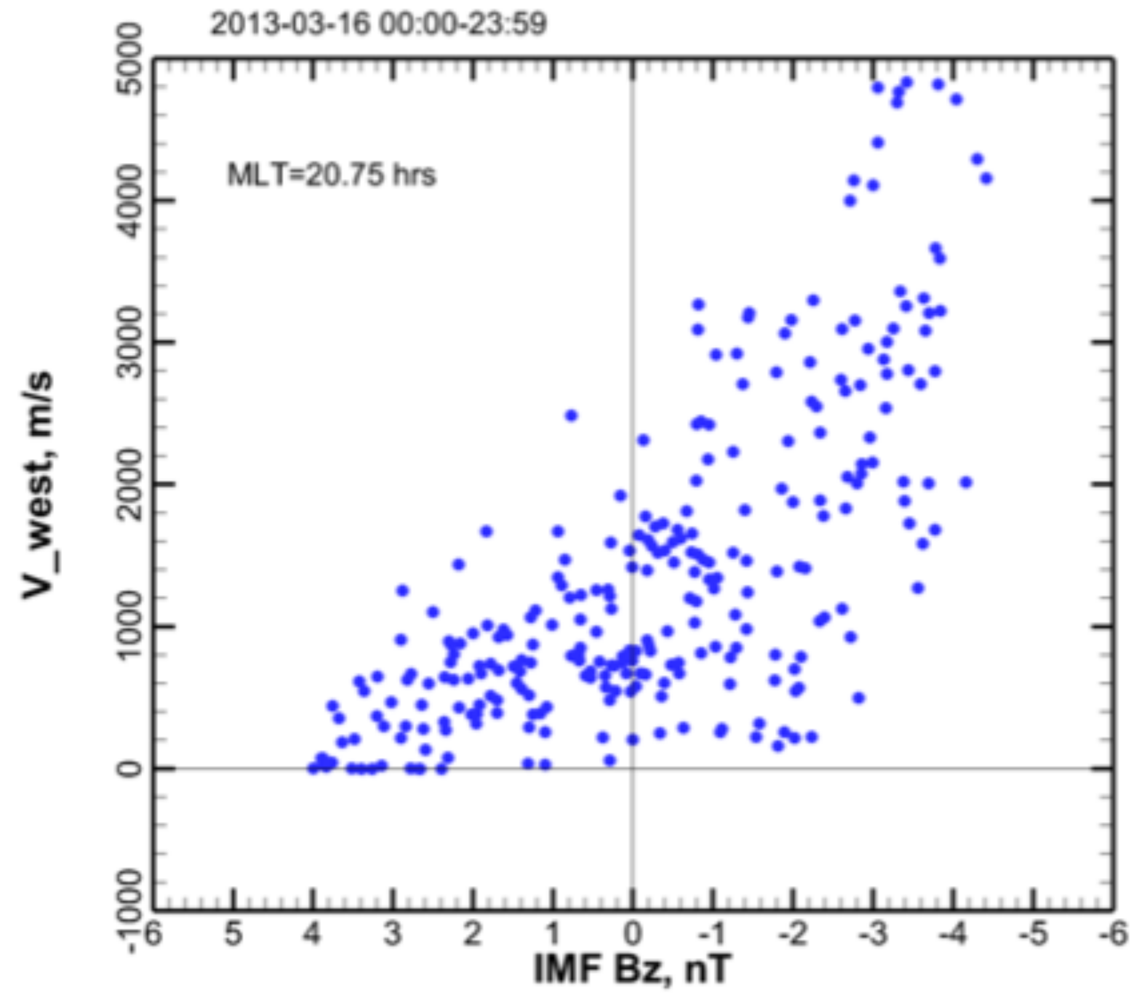


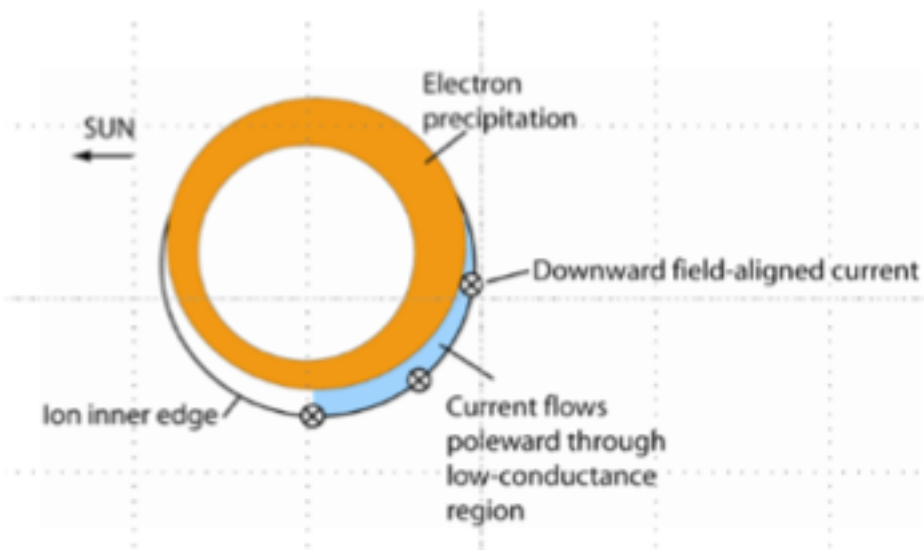
- enhanced sunward flow equator edge of e- precipitation
- dusk MLT sector along the 4 DMSP orbits for the same event.
- Blue dash curves: model
- Black lines: DMSP obs.

[Yu et al., 2015, LANL, Michigan]

RCM Reproduces SAPS During Non-Storm Intervals: 2013-03-16



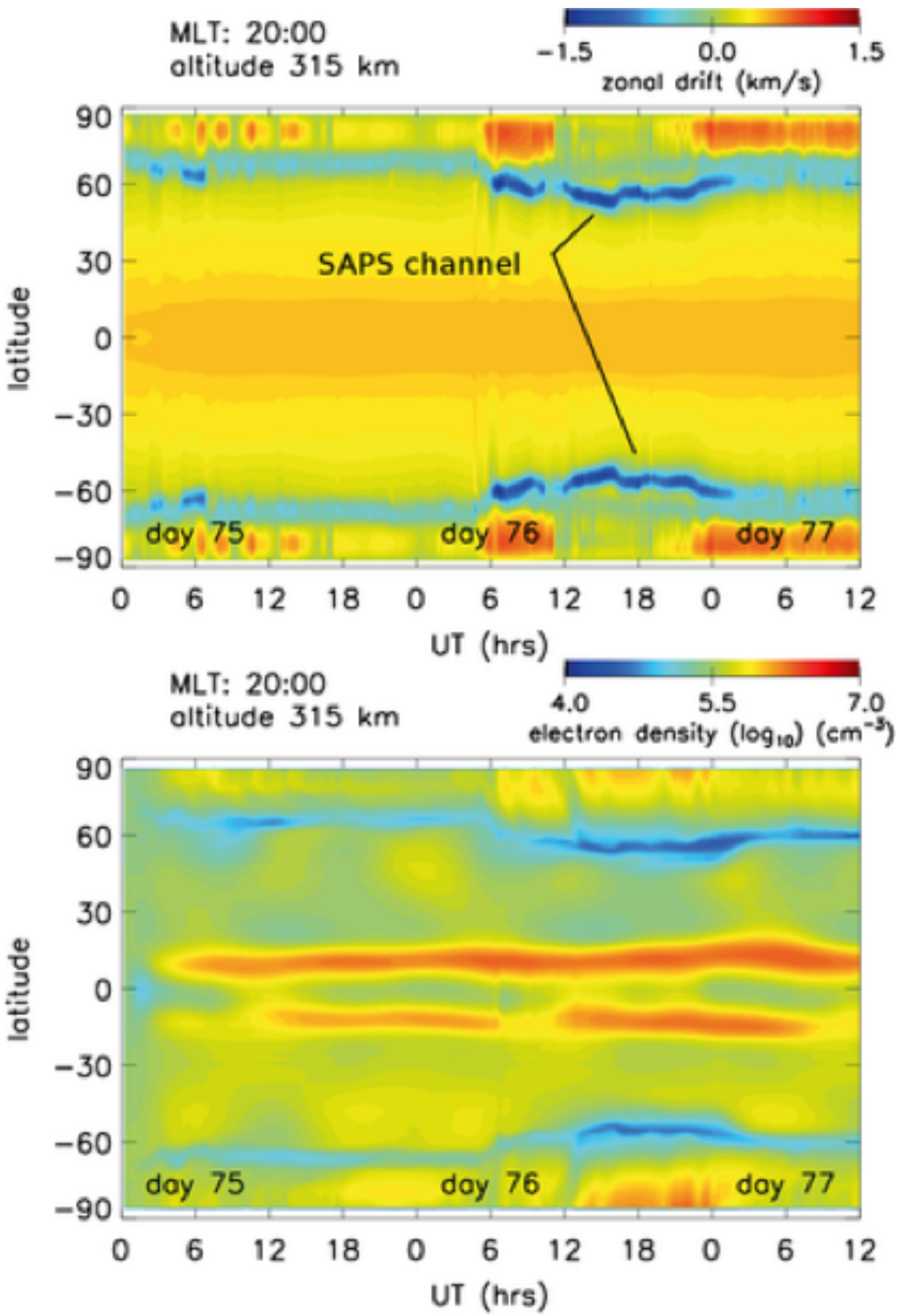




- SAPS is not limited to storm time.
- SAPS in RCM is driven by southward IMF Bz turnings (more southward Bz is, stronger sunward flow is).
- Southward IMF Bz turnings trigger transient changes in the separation between the equatorward boundary of magnetospheric electrons (producing aurora and enhanced conductivity) and the ring current ions (producing field-aligned currents).
- The low-conductivity “gap” between the two boundaries is where Pedersen current closes the field-aligned current, resulting in a band of strong poleward electric field.

[Sazykin et al., 2018. Rice]

SAMI3-RCM: SAPS deepens trough: 2015-3-17

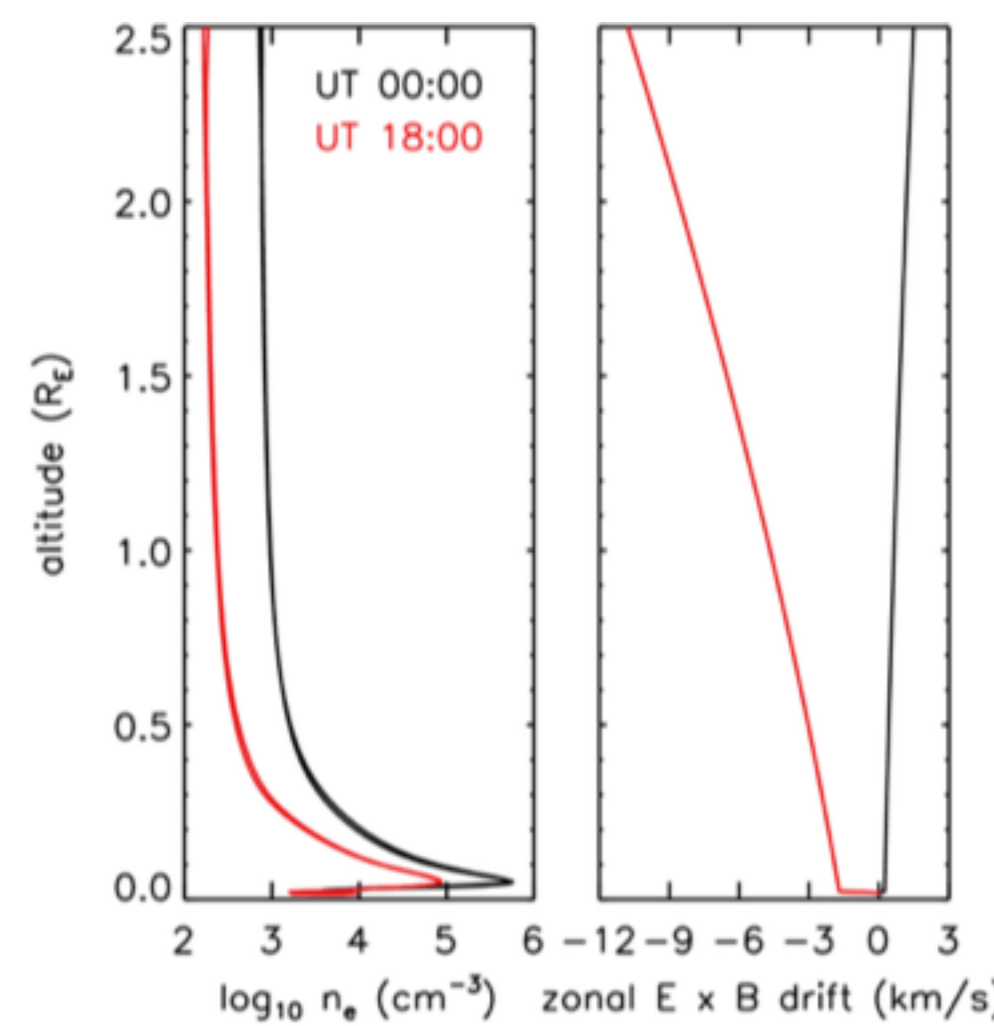


In the SAPS region, significant electron density depletions are expected on theoretical grounds due to

- enhanced rate of recombination in the non-sunlit ionosphere
- horizontal transport pattern (supply of low-density plasma into SAPS)

This has been confirmed with IS radar and low-altitude satellite measurements.

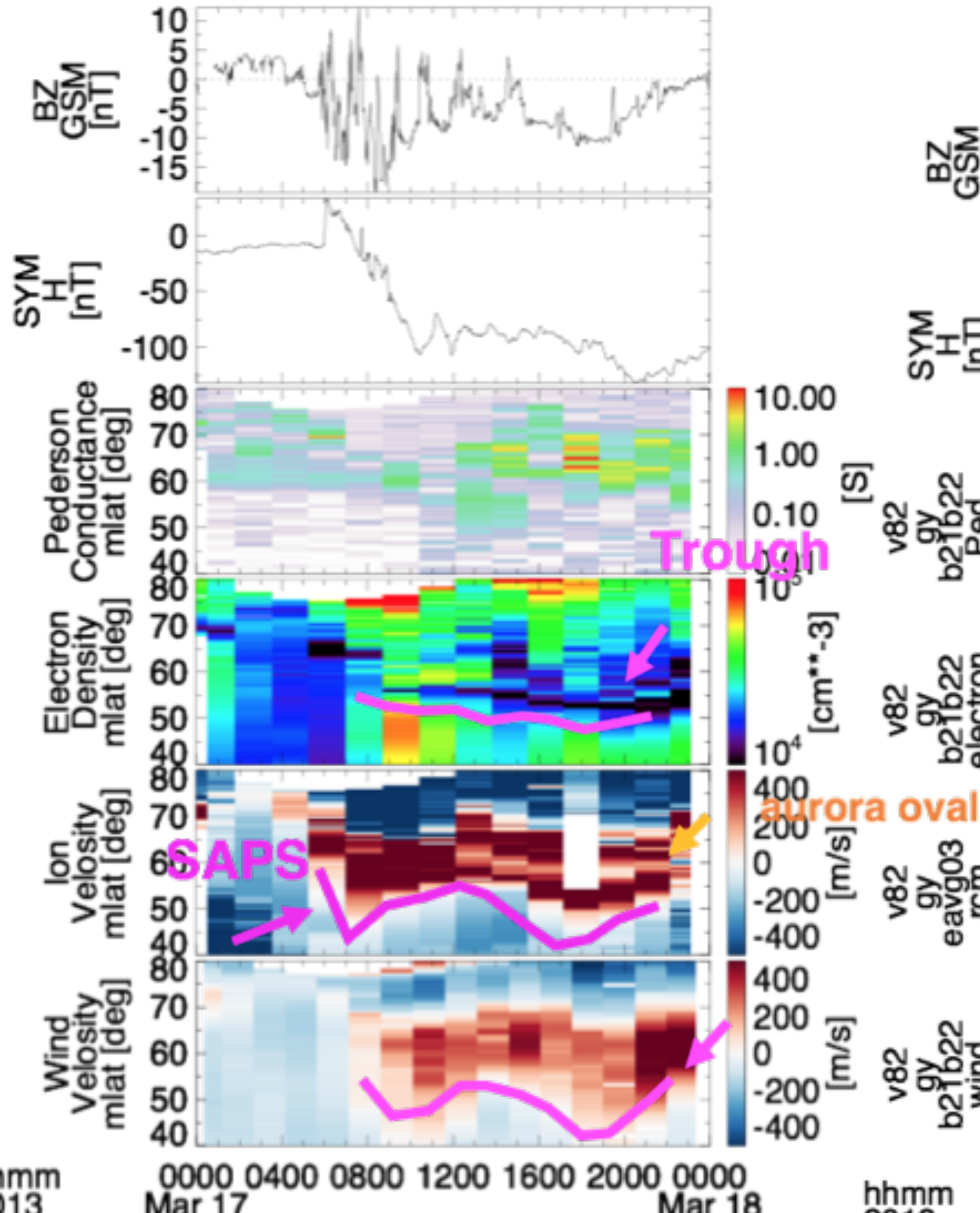
Simulations with the SAMI3-RCM coupled ionosphere-magnetosphere model confirm this picture.



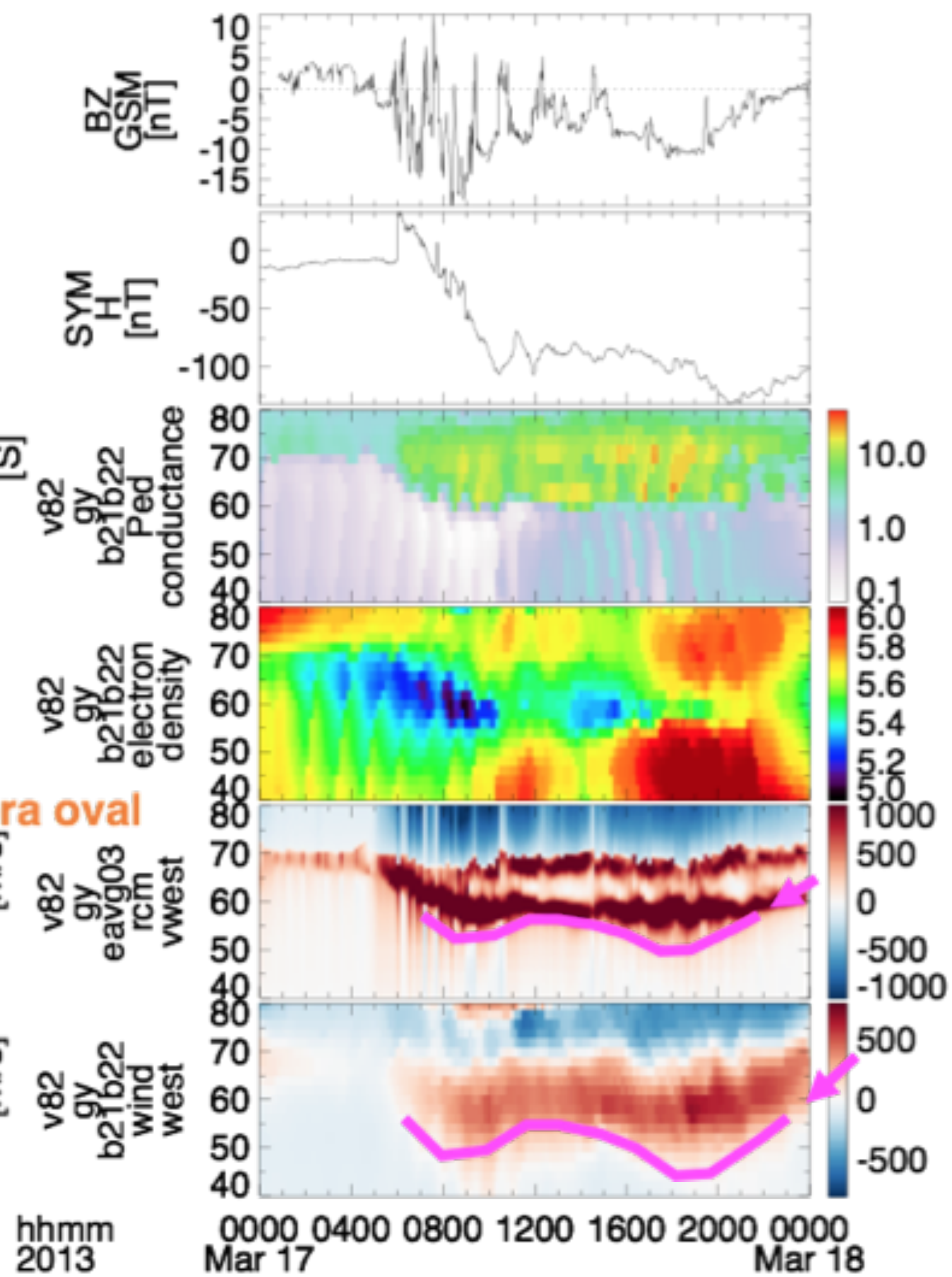
[Huba et al., JGR, 2017, NRL, Rice]

SAPS Plasma & Neutral Flow Interaction:
Coupled CTIP-RCM Model: 2013-3-17

Observations:
DMSP-18: MLT=19



Model



- SAPS westward plasma flow (DMSP) and neutral westward flow (GOCE) reproduced by the coupled model.
- The force term analysis shows SAPS plasmas accelerate neutrals via ion drag even in the trough where the density is low.
- after IMF Bz turns northward, the enhanced neutrals accelerate plasmas (flywheel effect).

[Banafsheh et al., 2018, UCLA, CU, BU]

SSWB CEDAR Grand Challenge Accomplishments

- New empirical models
- Quiet time SAPS: identified in data, reproduced in RCM
- New concepts of SAPS driving mechanisms
- Importance of thermosphere: system perspective required
- Sustained modeling efforts: increasingly coupled, requiring whole system approaches
- Brought CEDAR and GEM together (modelers, observationalists)

Future directions:

- Summary/review/directions article on SSWB sub auroral research
- Excellent potential for continuing joint CEDAR-GEM research: problems require both communities
- Multi-scale model implications
  - How to resolve fine scale structure and preserve global energy inputs and configurations?
  - What scales are in fact important - e.g. SAPS vs SAID?
- Connections to STEVE phenomenon (within subauroral region; relation to drivers?)
- Critical tests of driving theories
  - How many are there and when does each occur?
  - Dependence on background conditions, space/time scales?