The cause of the mid-latitude ionospheric plasma flow during storm recovery phase observed by the SuperDARN Hokkaido East Radar compared to AMPERE and TIEGCM data

Kohei Omori[1], Nozomu Nishitani[1], Tomoaki Hori[1], Gang Lu[2], Brian Anderson[3], Sarah Vines[3]

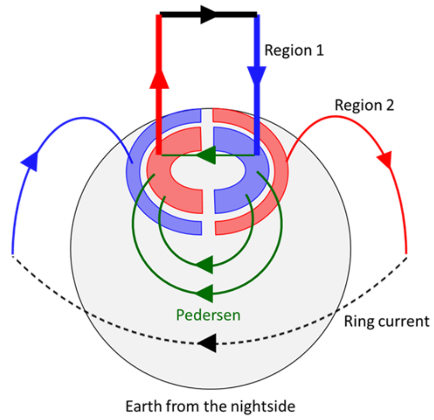
[1] ISEE, Nagoya University

[2] National Center for Atmospheric Research

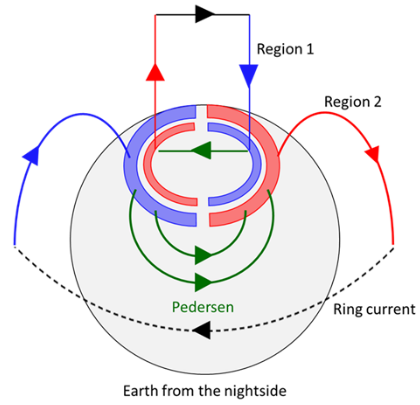
[3] The Johns Hopkins University, Applied Physics Laboratory

Mid-latitude ionospheric electric field during a Geomagnetic Storm

- Due to magnetospheric-ionospheric coupling
  - **Penetration of convection electric field**
    - Occurs when the shielding is broken by a sudden increase in the convection electric field.
  - **Overshielding**
    - Occurs when the shielding electric field becomes dominant over the convection electric field.

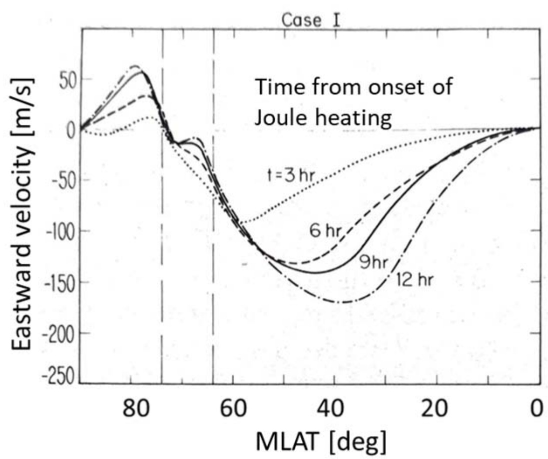


Penetration of convection electric field



Overshielding

- Due to ionospheric-thermospheric coupling
  - **Disturbance Dynamo**
    - Dynamo action due the neutral wind caused by Joule heating in the polar regions.
    - Generates westward flow in the mid-latitude ionosphere on the night side [Blanc and Richmond, 1980].



Latitudinal distribution of zonal drift velocity in the nightside ionosphere [Blanc and Richmond, 1980]

The westward plasma flow velocity due to Disturbance Dynamo gradually increases over a ~12 hours from the onset of the storm.

Motivation and Purpose

- Several previous studies using SuperDARN radar have mentioned the effects of Disturbance Dynamo.

Zou and Nishitani (2014)	Joshi et al. (2015)
• Reported that **the westward ionospheric plasma drift velocity increases around 46° MLAT** on the night side several hours **after substorm** onset by Superposed Epoch Analysis using the HOK data. • Concluded that those drifts were caused by the Disturbance Dynamo.	• Studied ion-neutral particle interactions during a geomagnetic storm using North American SuperDARN radars and NATION Fabry-Perot interferometers. • Showed that **the velocities of neutral winds and ion drift coincide** during **the recovery phase of magnetic storms**.

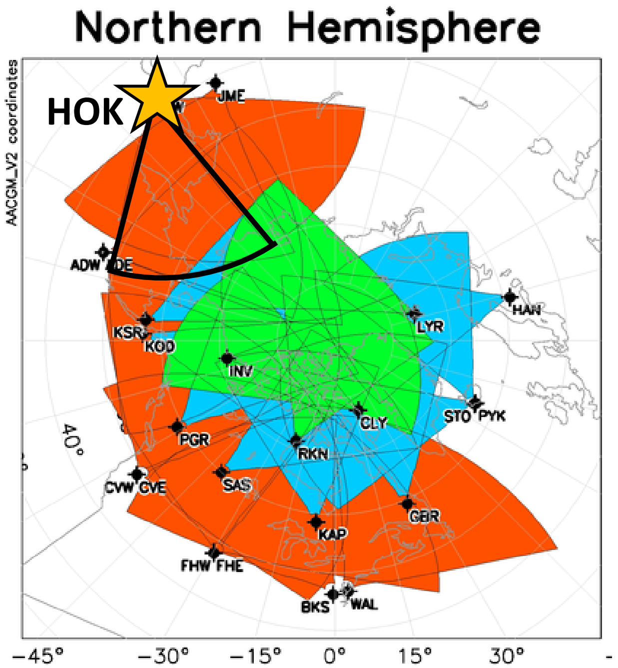
- They did not consider the effects of **electric fields of magnetospheric origins**, such as convection electric field penetration and Overshielding.

■ Purpose

- To study magnetospheric and thermospheric effects on ionospheric plasma flow during the storm recovery phase observed by SuperDARN Hokkaido East radar, using **AMPERE** and **TIEGCM** data.

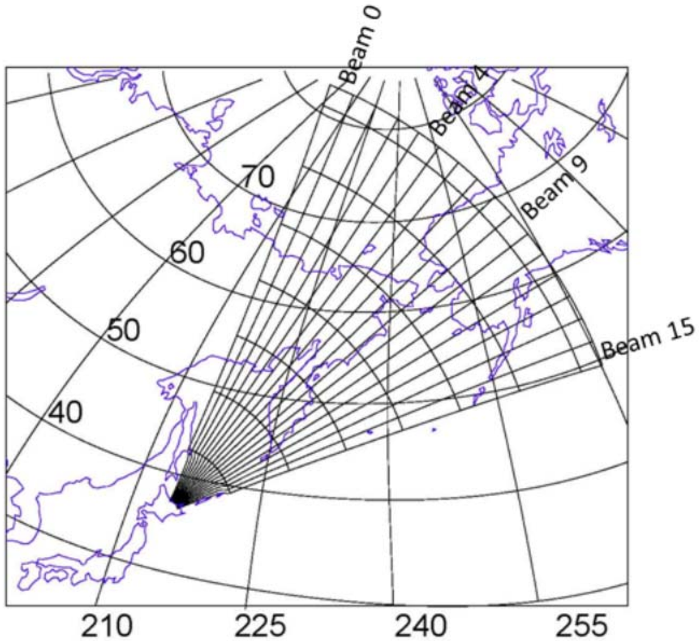
Instrumentation and model

■ SuperDARN (Super Dual Auroral Radar Network)
- A global network of ground-based HF radars.
- Observing the line-of-sight velocity of ionospheric plasma.



http://vt.superdarn.org/tiki/assets/pages/fov/all/allfovs_20191027.png

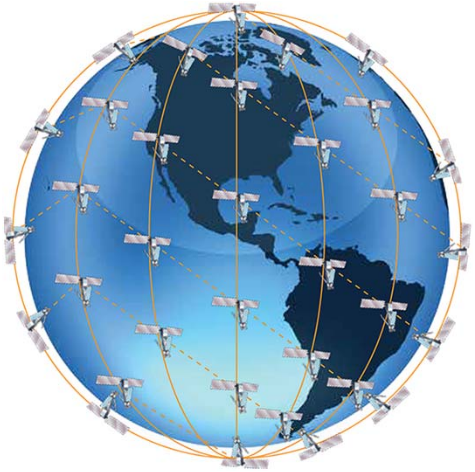
■ Hokkaido East Radar (HOK)
- It is located at the lowest geomagnetic latitude (37.3° N) among all the SuperDARN radars.
- It covers the mid-latitudes (40-60° MLAT).



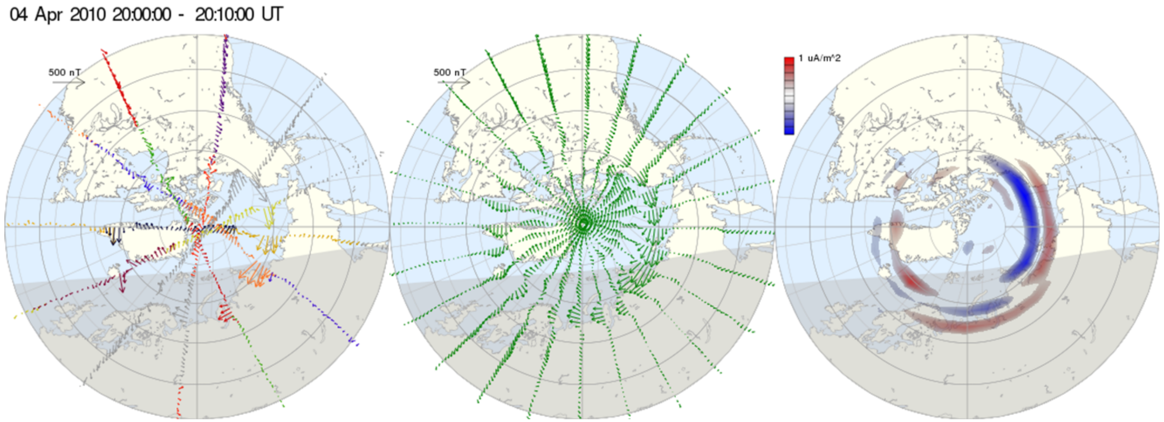
Zou master thesis (2012)

Instrumentation and model

- Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE)
  - AMPERE is a magnetic field observation system to study the electrodynamic properties of the global magnetosphere-ionosphere coupling [Anderson et al. 2000].
  - Provides near-real-time magnetic field measurements using the Iridium satellite network.
  - Field-Aligned Currents are derived from magnetic signatures.



Iridium satellite network
https://www.polaris-as.dk/iridium-maritime/



The horizontal plane vectors

spherical harmonic fit to the magnetic perturbations

radial current

Red: upward current

Blue: downward current

http://ampere.jhuapl.edu/

Instrumentation and model

■ Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM)

- TIEGCM, developed at the National Center for Atmospheric Research (NCAR) High-Altitude Observatory(HAO), is a global 3-D numerical model that simulates the coupled thermosphere/ionosphere system from ~97 to ~600 km altitude [Qian et al., 2013].

- Data used in this study
  - ➢ Ion drift velocity due to
    - ExB & wind
    - ExB only
    - Wind only
  - ➢ neutral wind velocity

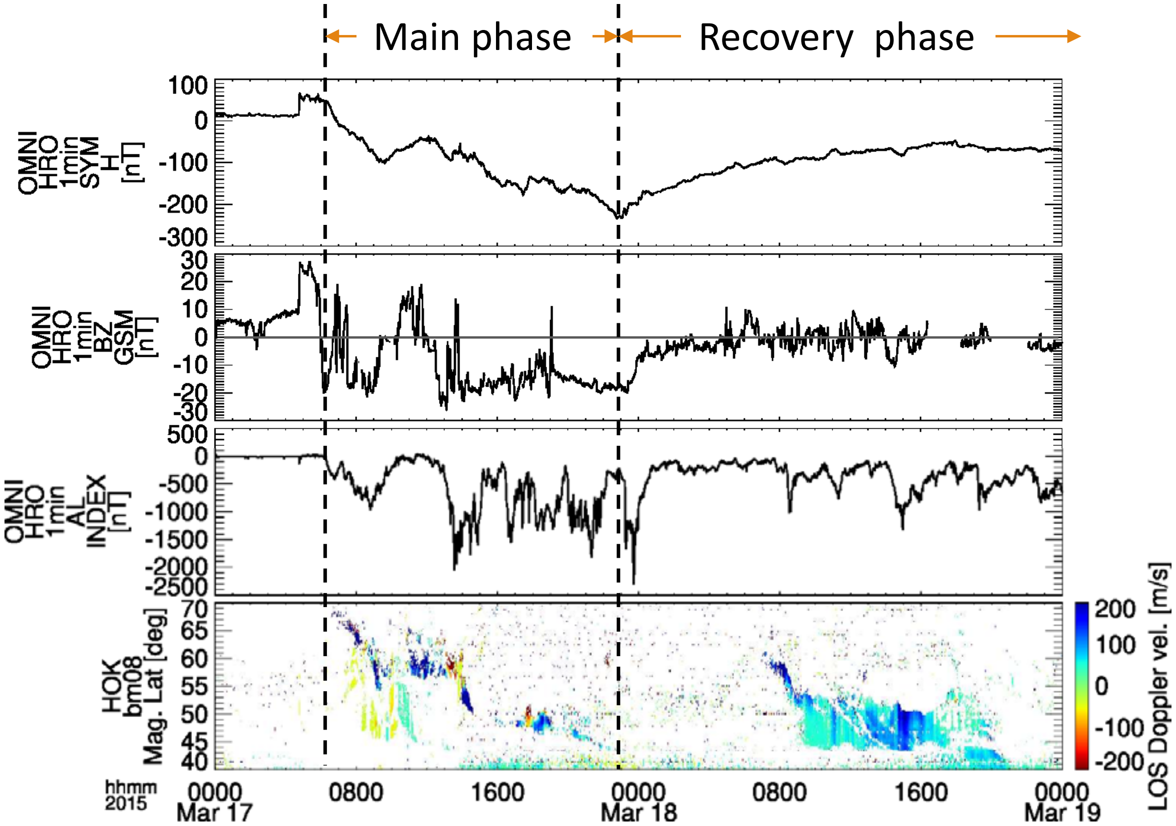
- Altitude: ~350 km

TIEGCM 2.1

Dang, T., Zhang, B., Lei, J., Wang, W., Burns, A., Liu, H., Pham, K., and Sorathia, K. A.: Azimuthal averaging–reconstruction filtering techniques for finite-difference general circulation models in spherical geometry, Geosci. Model Dev., 14, 859–873, https://doi.org/10.5194/gmd-14-859-2021, 2021.

Storm event

- Geomagnetic storm in March 2015



March 17-18, 2015

Main phase: 0618~2246 UT on the 17th

Recovery phase: 2246 UT on the 17th~

- Echoes were observed from 0900~1800 UT (1800~0300 LT)
- Similar to Disturbance Dynamo trend.

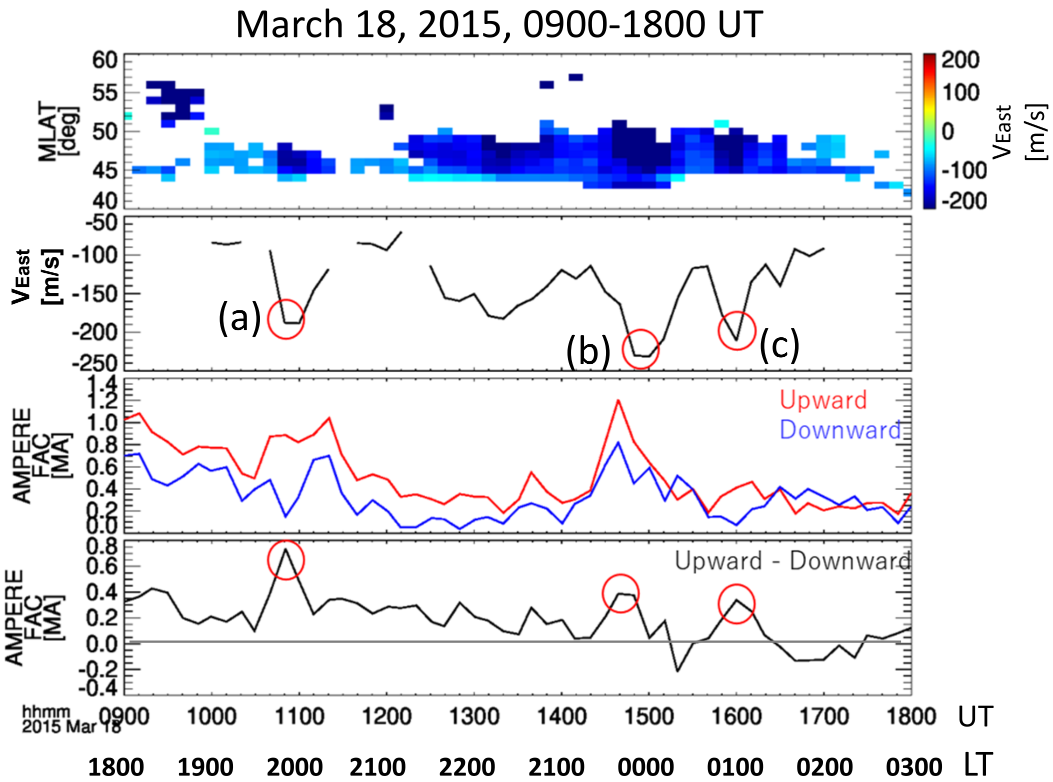
Result & Discussion (Comparison with AMPERE)

HOK
Zonal Plasma Flow

HOK
Zonal Plasma Flow at 46° MLAT

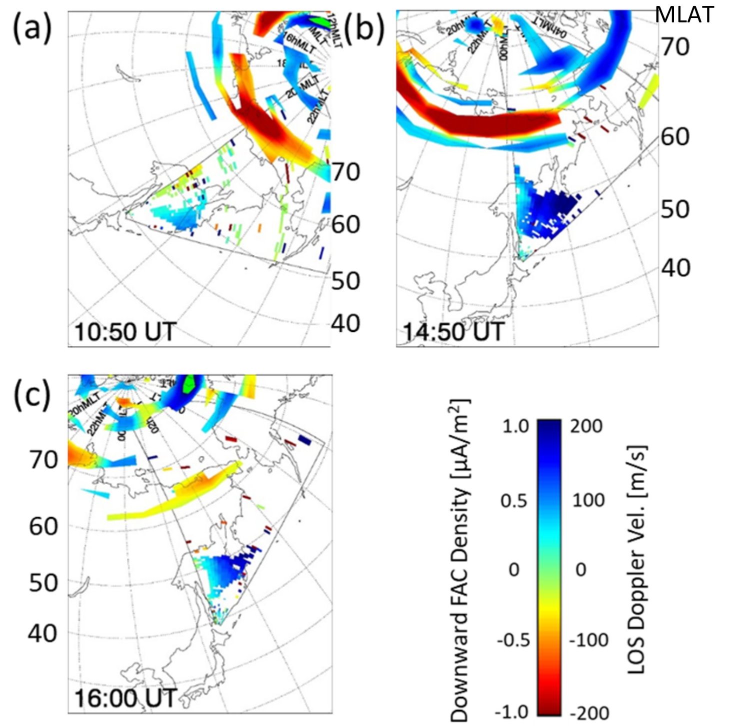
AMPERE
Upward & Downward FAC

AMPERE
Difference between
Upward and Downward FAC



*AMPERE line plots are at geographic latitude 143.75° GLAT.

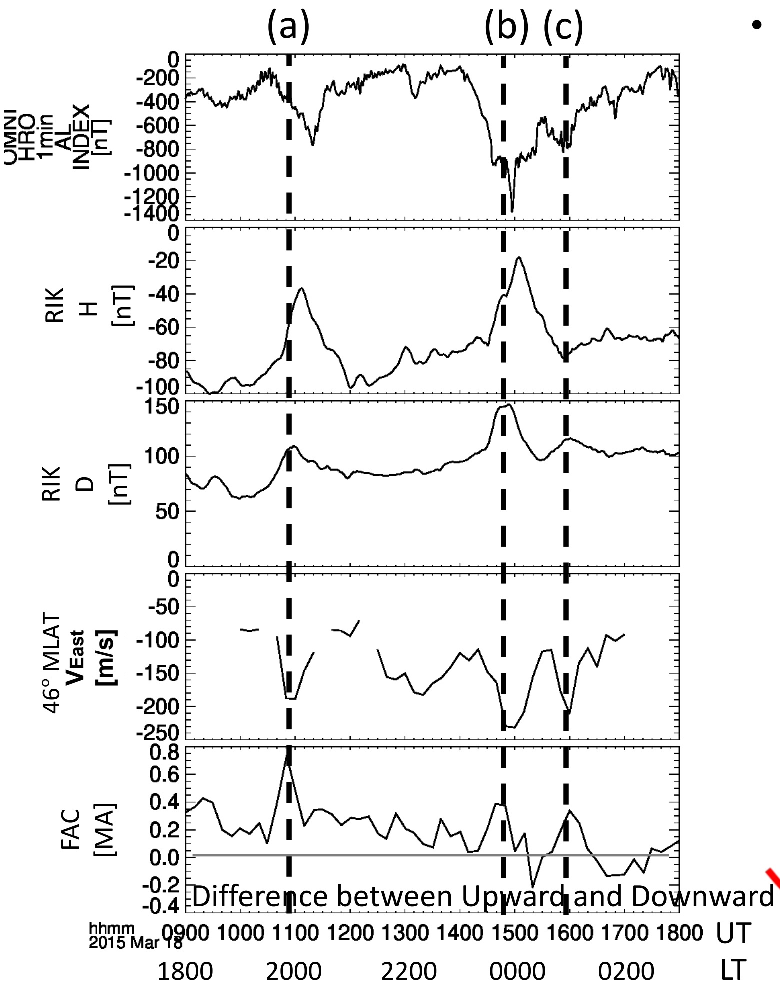
- Peak of westward plasma flow velocity corresponds to peak of difference between upward FAC and downward FAC intensities.



(a),(b)
Upward **Region-1** FAC > Downward **Region-2** FAC

(c)
Upward **Region-2** FAC > Downward **Region-1** FAC

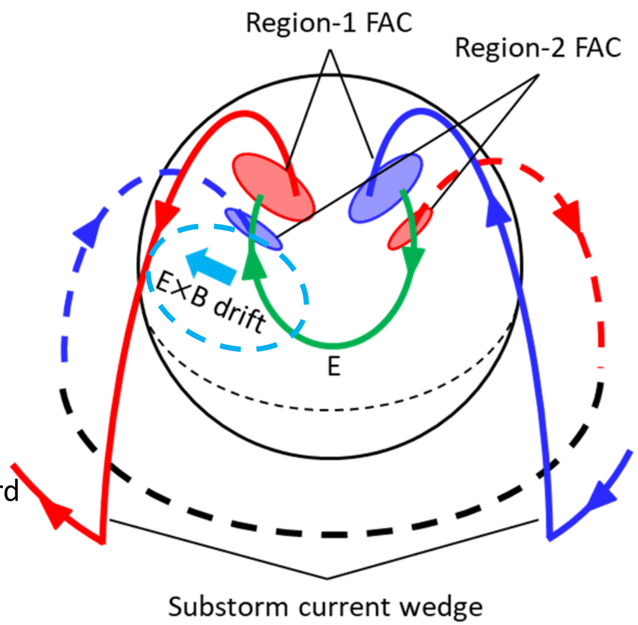
Result & Discussion (Comparison with AMPERE)



- (a) 1050 UT, (b) 1450 UT
  - ➢ **Expansion phase** of the substorm.

Upward FAC increased by current wedge

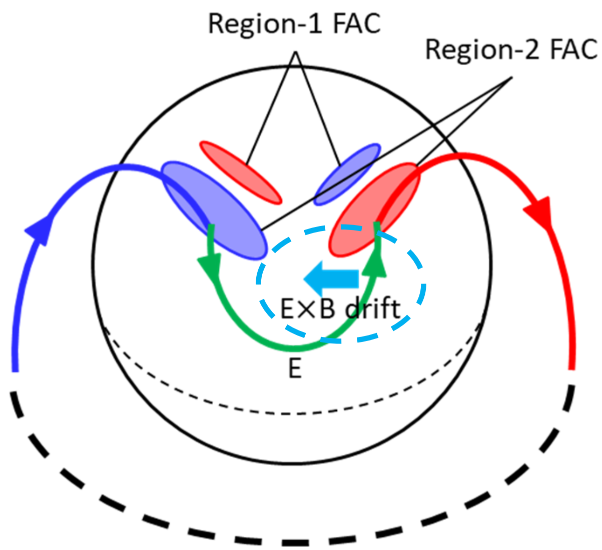
✓ Plasma flow is accelerated by the **Penetration electric field**



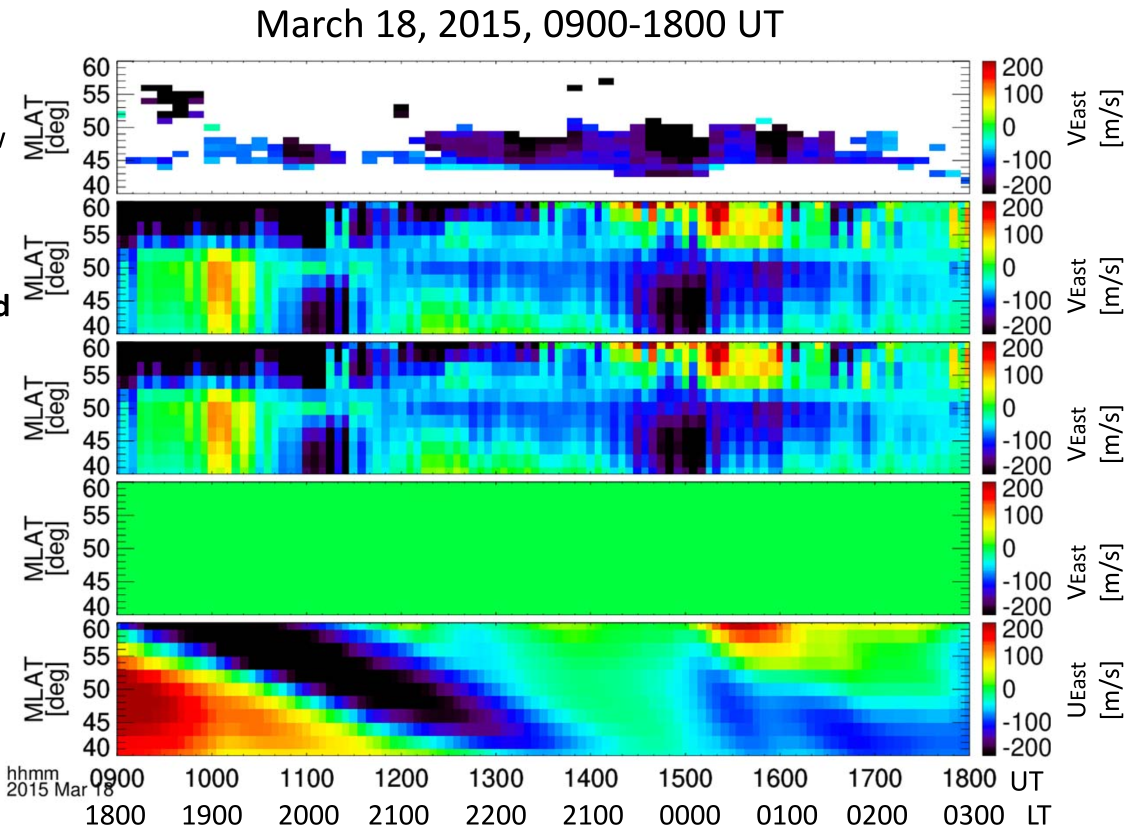
- (c) 1600 UT
  - ➢ **Recovery phase** of the substorm.

Overshielding occurs during the substorm recovery phase due to convection reduction [Hashimoto et al. 2017]

✓ Plasma flow is accelerated by the **Overshielding electric field**



Result & Discussion (Comparison with TIEGCM)



*TIEGCM data are at geographic latitude 143.75° GLAT.

- Observations of HOK and simulations of "zonal ion drift due to ExB & Wind" are consistent with each other.

- **"Zonal ion drift due to wind (neutral-plasma collision at 350 km altitude)"** is almost 0 m/s.

✓ Westward plasma flow observed at HOK is almost due to **ExB drift**.

Possible causes

- Polarization electric field by Disturbance Dynamo
- Penetration of convection electric field
- SAPS

Summary & conclusion

- We compared ionospheric plasma flows observed at HOK during the recovery phase of the geomagnetic storm in March 2015 with **AMPERE** and **TIEGCM** data.
  - The increase in the westward plasma flow velocity and the increase in the difference between the upward and downward FAC intensities are in good agreement.
    - when **Region 1** upward FAC is predominant
      polar electric field penetration effect associated with substorm expansion is dominant.
    - when **Region 2** upward FAC is predominant
      Overshielding effect associated with the substorm recovery phase is dominant.
  - Comparison with the TIEGCM showed that **the F-region neutral winds had little effect (in terms of neutral-plasma collision)** on this event.
  - ✓ In studying the effects of Disturbance Dynamo after geomagnetic storms, it is important to consider the effects of magnetospheric-originated electric fields, and comparisons with AMPERE and TIEGCM are an effective way.

Future work

- Study the quantitative relationship between FAC and mid-latitude electric fields.
- Study the magnitude of Disturbance Dynamo's effect on mid-latitude ionospheric electric fields.
- Study the effects of SAPS (relative location to the ionospheric trough region could provide more clues).

Reference

- Blanc, M., & Richmond, A. D. (1980), "The ionospheric disturbance dynamo", Journal of Geophysical Research, Vol. 85, No. A4, Pages 1669-1686, https://doi.org/10.1029/JA085iA04p01669
- Dang, T., Zhang, B., Lei, J., Wang, W., Burns, A., Liu, H., Pham, K., and Sorathia, K. A.: Azimuthal averaging–reconstruction filtering techniques for finite-difference general circulation models in spherical geometry, Geosci. Model Dev., 14, 859–873, https://doi.org/10.5194/gmd-14-859-2021, 2021.
- Hashimoto, K. K., Kikuchi, T., Tomizawa, I., & Nagatsuma, T. (2017), “Substorm overshielding electric field at low latitude on the nightside as observed by the HF Doppler sounder and magnetometers”, Journal of Geophysical Research: Space Physics, Vol.122, Pages 10851–10863, https://doi.org/10.1002/2017JA024329
- Joshi, P.P., J.B.H. Baker, J. M. Ruohoniemi, J. J. Makela,D. J. Fisher, B. J. Harding, N. A. Frissell, and E. G. Thomas (2015), “Observations of storm time midlatitude ion-neutral coupling using SuperDARNradars and NATION Fabry-Perotinterferometers”, Journal of Geophysical Research, Vol. 85, No. A4, Pages 1669-1686, https://doi.org/10.1002/2015JA021475
- Zou, Y., & Nishitani, N. (2014), "Study of mid-latitude ionospheric convection during quiet and disturbed periods using the SuperDARN Hokkaido radar", Advances in Space Research, Vol. 54, Pages 473–480, https://doi.org/10.1016/j.asr.2014.01.011