Meso-Scale Polar Cap Flows and their Impact on Polar Cap Patch Propagation

Amelia Lee[1], Toshi Nishimura[1], Katherine Davidson[1], Waqar Younas[1], Nozomu Nishitani[2], Kazuo Shiokawa[2]
[1]Center for Space Physics, Boston University, [2]Nagoya University, Nagoya, Japan

INTRODUCTION

- Meso-scale flow (50-500 km) enhancements observed within two cell convection pattern in the polar cap [Lyons+ 2016].
- Polar cap patches are meso-scale regions of enhanced density in the F-region ionosphere, generally understood to be driven by 2-cell convection pattern in an anti-sunward IMF [Crowley 1996]
- Recent studies suggest meso-scale flow channels impact polar cap patch propagation and evolution [Nishimura+ 2014, Lyons+ 2016].
- **Few studies on meso-scale flow channels in the polar cap, and few studies done at high resolution**

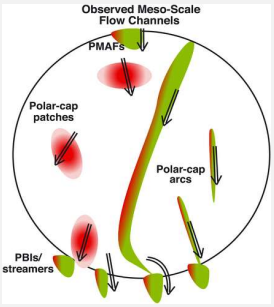

Figure 1. Structures observed to be modified by meso-scale flow channels [Lyons+ 2016].

Objectives:

- Qualitatively characterize the lifetime, structure, and evolution of meso-scale flow channels in the polar cap
- Understand how meso-scale flow channels might drive polar cap patch propagation and evolution
- Examine how polar cap patches and meso-scale flow channels might impact GPS positioning error

DATA & METHODOLOGY

- OMTI All Sky Imagers (ASI) at Eureka (EUR) and Resolute Bay (RSB) to survey for days with polar cap patch activity
- SuperDARN to obtain high-resolution velocity vector maps of days with good radar coverage and good optical data
- Analyzed 6 case studies with conditions ranging from quiet to moderate geomagnetic storms

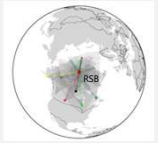

Figure 2. SuperDARN radar stations coverage that overlap with RSB OMTI ASI's coverage.

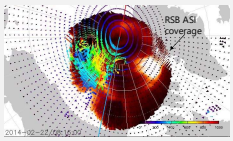

Figure 3. Resolute Bay OMTI ASI coverage.

- Spherical Elementary Current Systems (SECS) method is used to obtain high-resolution velocity flow maps
- SECS can resolve meso-scale flow channels within the larger flow patterns

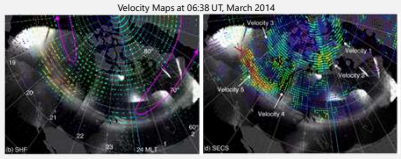

Figure 4. Examples of vectors maps obtained by SHF (b) and SECS (d) from Nishimura+ 2024.

CASE STUDY 1: QUIET CONDITIONS

2014/01/26 06:45-07:26 UT, Resolute Bay

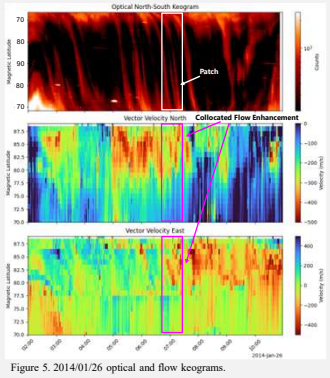

Figure 5. 2014/01/26 optical and flow keograms.

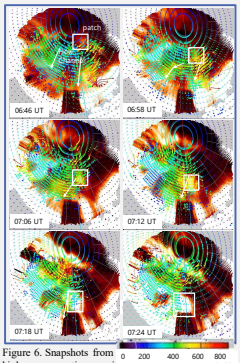

Figure 6. Snapshots from high-res convection movie.

- Patch propagation and velocity enhancements occur between 06:45 and 07:25 UT, and between 77-88° magnetic latitude
- Flow channel [FC] lasts ~32 minutes, ~ 500-1000 km 06:45-07:25 UT
- FC reaches ~500 m/s around 06:58 UT
- FC leaves RSB coverage, patch stays at edge of RSB coverage

CASE STUDY 2: WEAK CONDITIONS

2023/02/21 04:00-04:22 UT, Eureka

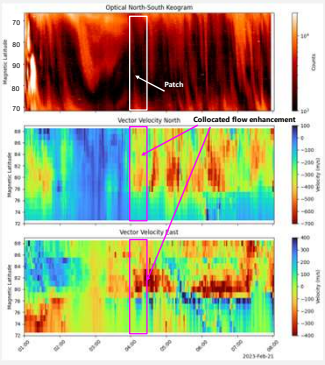

Figure 7. 2023/02/21 optical and flow keograms.

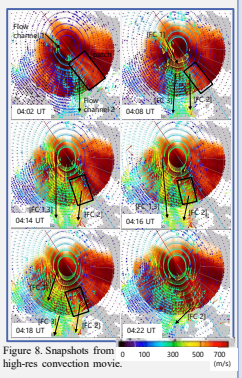

Figure 8. Snapshots from high-res convection movie.

- Patch propagation and velocity enhancements occur between 04:02 and 04:22 UT and 76-87.5° magnetic latitude
- Flow channel [FC] 2 lasts ~16 minutes, FC 1 ~14 minutes, 300-500 km
- Patch leaves EUR coverage with FC 2
- Flow channels appear not to exceed ~700 m/s

CASE STUDY 3: MODERATE CONDITIONS

2014/02/22 07:50-08:22 UT, Resolute Bay

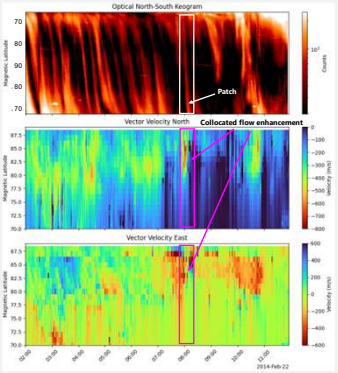

Figure 9. 2014/02/22 optical and flow keograms.

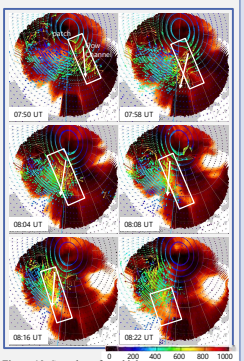

Figure 10. Snapshots from high-res convection movie.

- Patch propagation and velocity enhancements occur between 07:50 and 08:22 and 77-88° magnetic latitude
- Flow channel [FC] lasts ~25 minutes
- FC width narrows and widens between 500 and 1000 km
- FC reaches a velocity of 900 m/s around 07:58 UT

GPS POSITIONING ERRORS

We examine the impact of polar cap patches and meso-scale flow enhancements on GPS positioning errors.

2014/11/16:

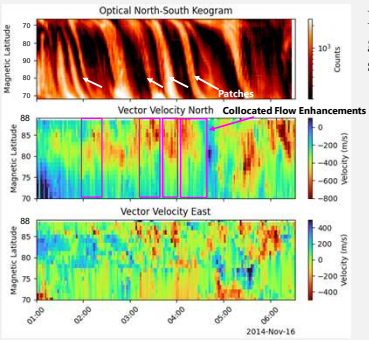

Figure 11. 2014/11/16 optical and flow keograms.

Moderate geomagnetic storm

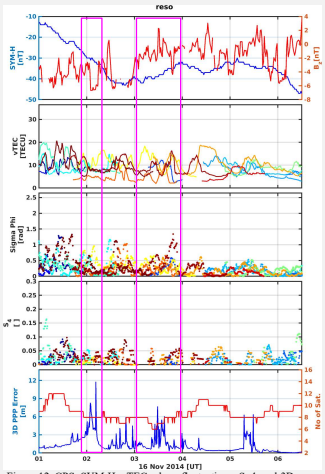

Figure 12. GPS, SYM-H, vTEC, phase fluctuations, S_4, and 3D positioning error at Resolute Bay.

- Series of patches and flow enhancements 01:50-02:20 UT and 03:00-04:00 UT
- Positioning errors 01:50-02:20 UT and 03:00-04:00 UT correspond to series of patches and flow enhancements

CONCLUSIONS

- Meso-scale flow channels follow **repeated patterns of growing, changing direction, and dissipating on a 15–25 minute timescale**, but experience a lot of variation on a 2–5 minute timescale
- **Patch propagation occurs on the same 15-25 minute scale of meso-scale flows**, but do not experience variation on the 2-5 minute timescale.
- Flows that appear within the larger patterns evolve on shorter timescales than the large-scale patterns
- Patches take longer to traverse polar cap than meso-scale flow channels change, so **several flow channels may impact one patch**
- Keograms show **flow enhancements and patch propagation are correlated in time and magnetic latitude**
- Patches and flow enhancements correspond to a TEC enhancement and thus GPS positioning errors and phase fluctuations

ACKNOWLEDGEMENTS & REFERENCES

AL would like to thank the OMTI ASI team for use of the data and the SuperDARN team for use of the data.

1. Crowley 1996
2. Lyons et al., 2016
3. Nishimura et al., 2014
4. Nishimura et al., 2024

amelia.a.lee21@gmail.com or ameliale@umich.edu