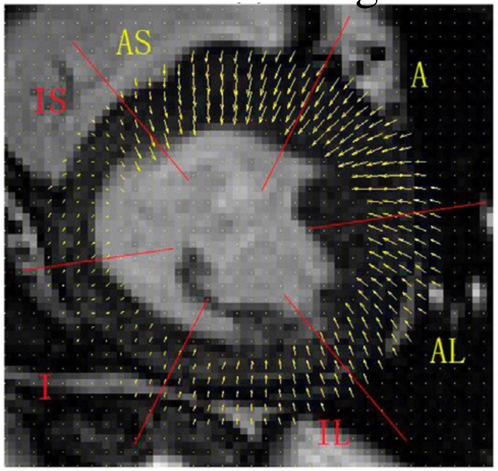
Optical flow technique: from the aurora to the solar wind

B. Gallardo-Lacourt, L. V. Goodwin, L. Kepko, E. Spanswick, E. Donovan, and C. DeForrest

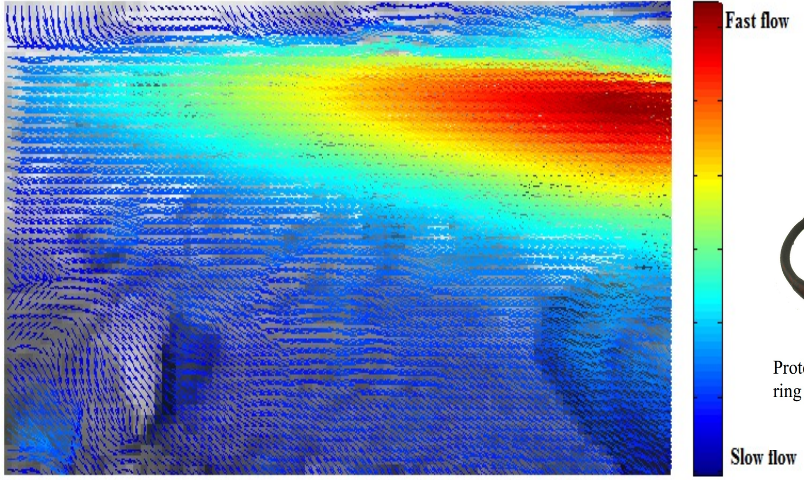
Myocardium Motion MRI image



Gao et al., 2016

Patagonian Glacier Motion

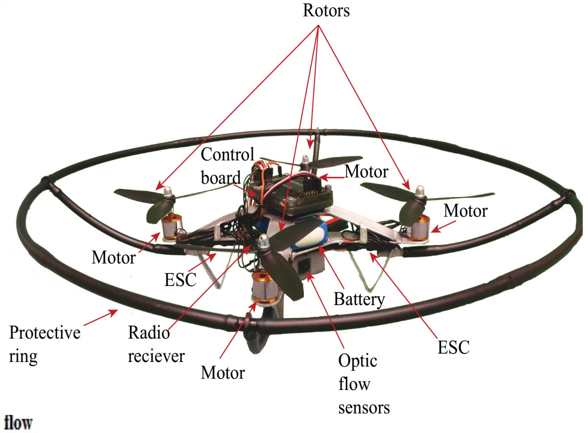
Fast flow



Slow flow

Lannutti et al., 2016

Quadcopter with optical flow sensors



Hurd et al., 2013

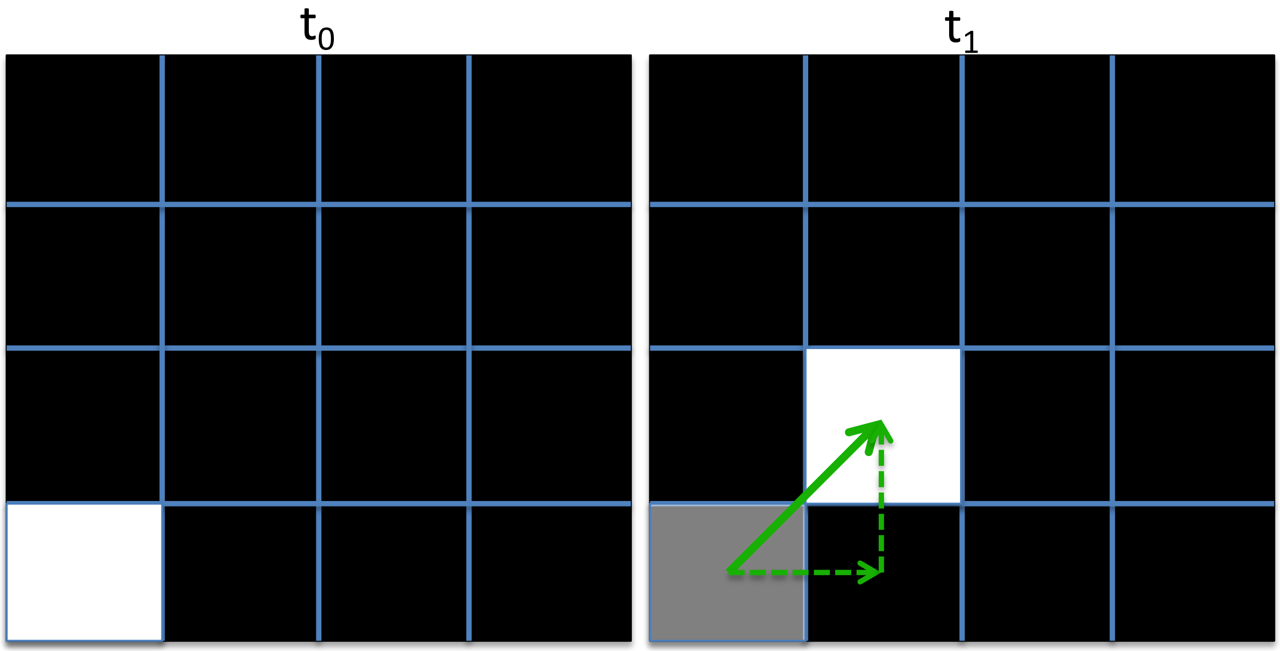
Optical flow Methods

- feature-based method
- Gradient-based method

  e.g., Horn and Schunk, Srinvasan, Lucas and Kanade, and Fennema and Thompson.

Optical Flow (OF) Technique

- Optical flow used here (also called gradient or differential method) is the representation of the apparent two-dimensional motion of an “object”
- We calculate the motion between two image frames

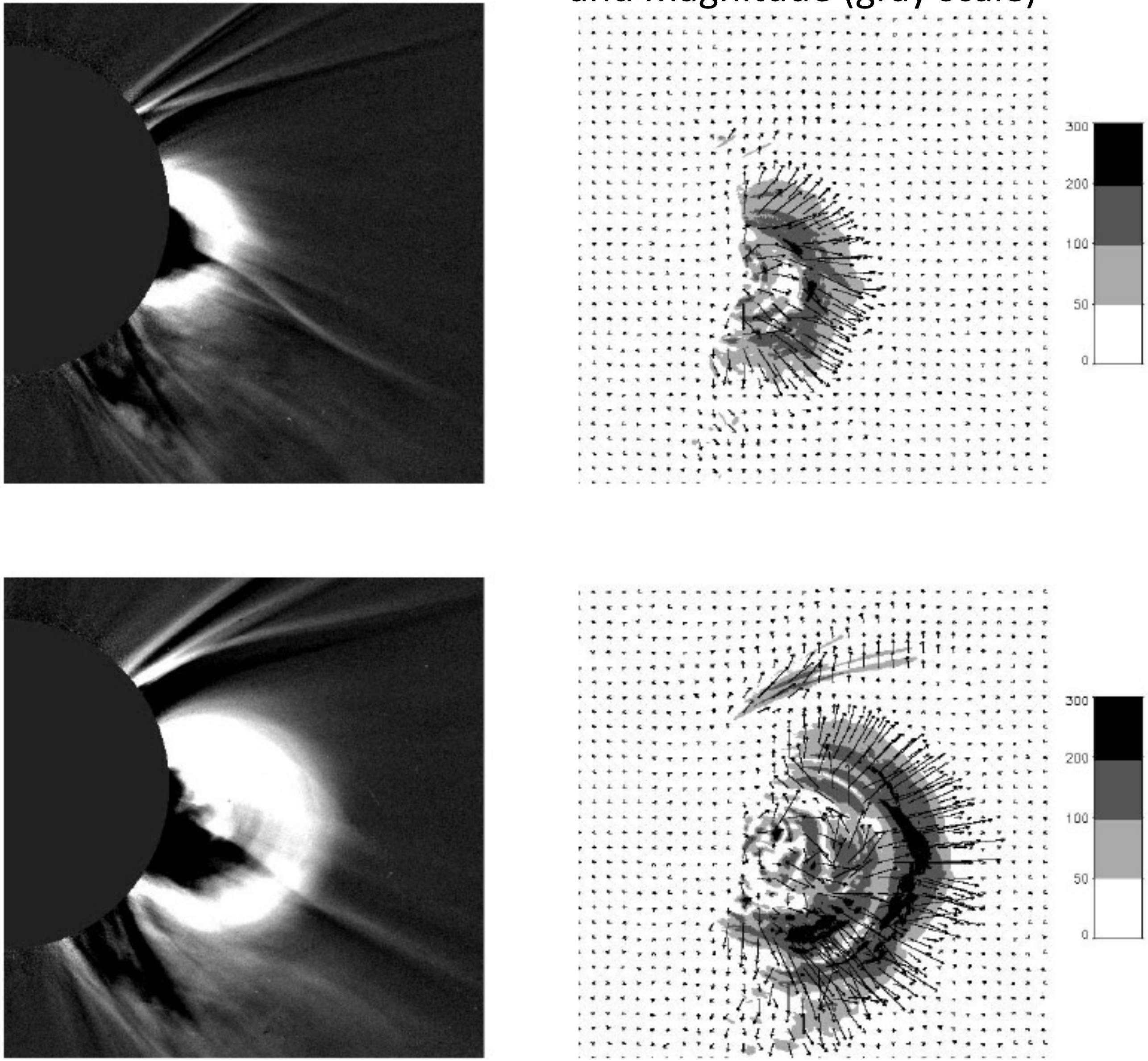


Constrains to consider

Luminosity consider constant (no changes) – Robust estimator

Issues with no well-defined structure’s boundaries

OF technique applications on CMEs



LASCO CME observation

Optical flow vectors (arrows) and magnitude (gray scale)

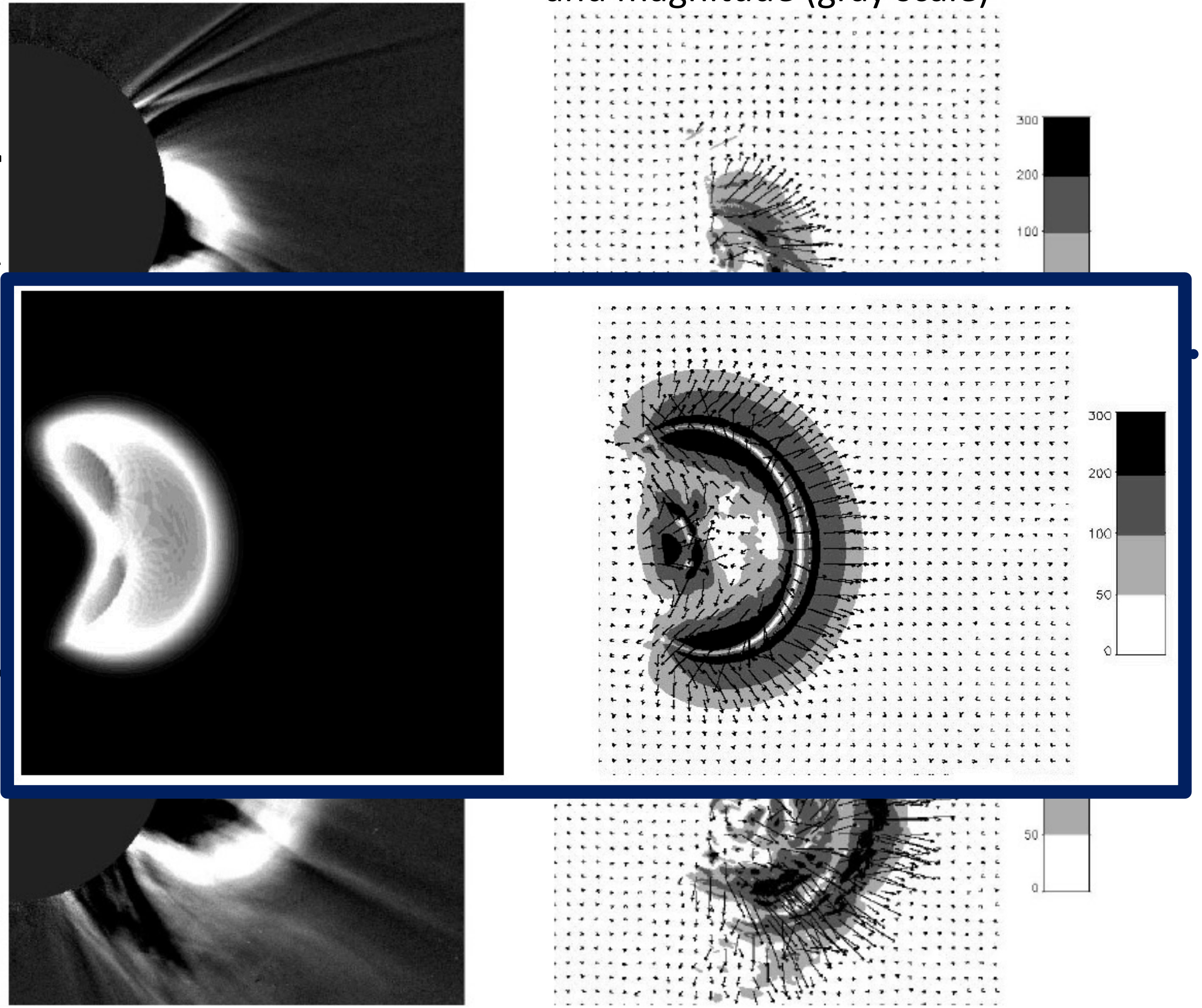
[Colaninno and Vourlidas, 2006]

- Colaninno and Vourlidas (2006) Calculated the motion of a CME observed by LASCO using the optical flow method

OF technique applications on CMEs

LASCO CME observation

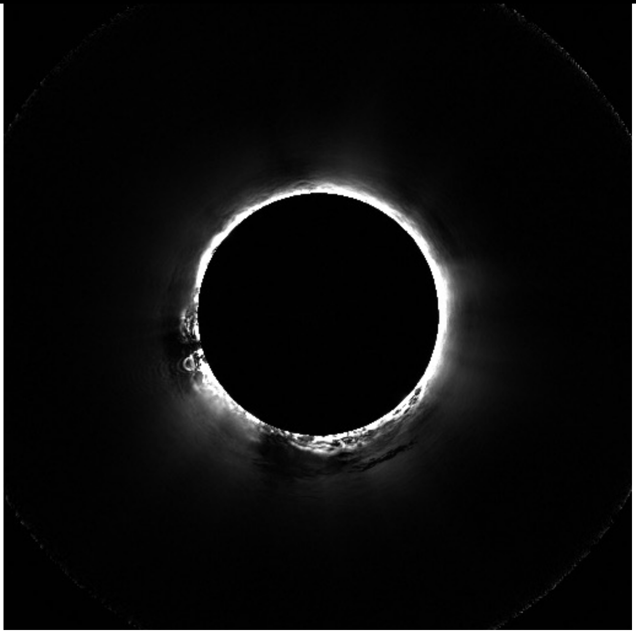
Optical flow vectors (arrows) and magnitude (gray scale)



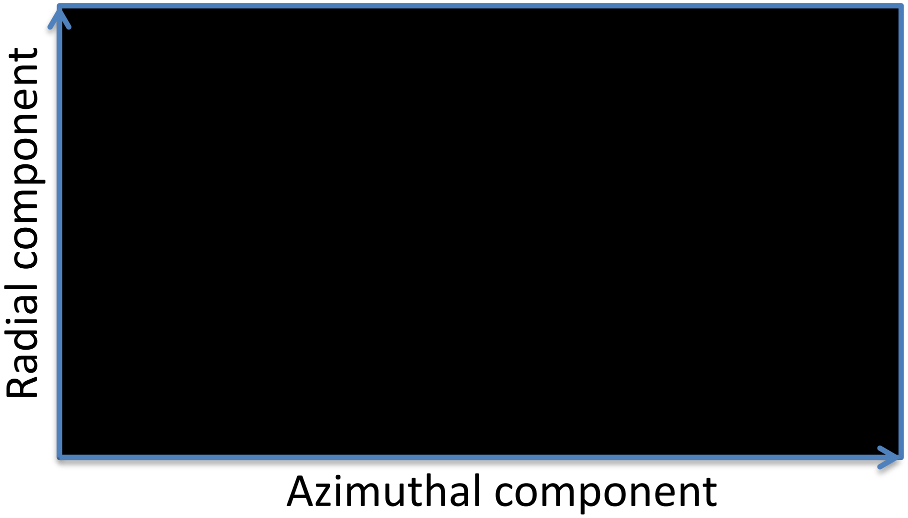
[Colaninno and Vourlidas, 2006]

- Colaninno and Vourlidas (2006) Calculated the motion of a CME observed by LASCO using the optical flow method
- This methodology was validated by using a synthetic CME

OF technique applications to STEREO data



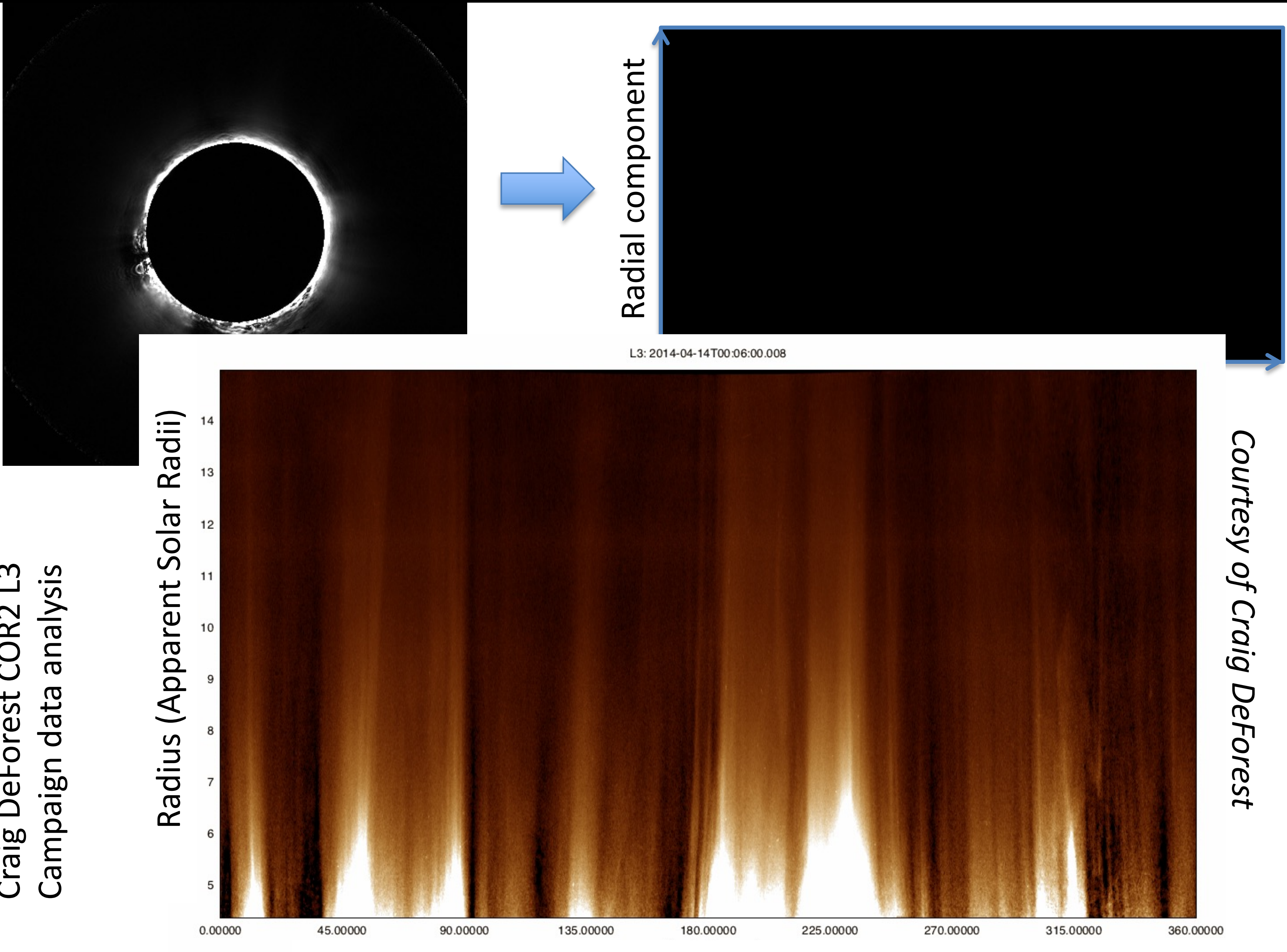
COR1 Attempt



OF technique applications to STEREO

COR1 Attempt

Radial component

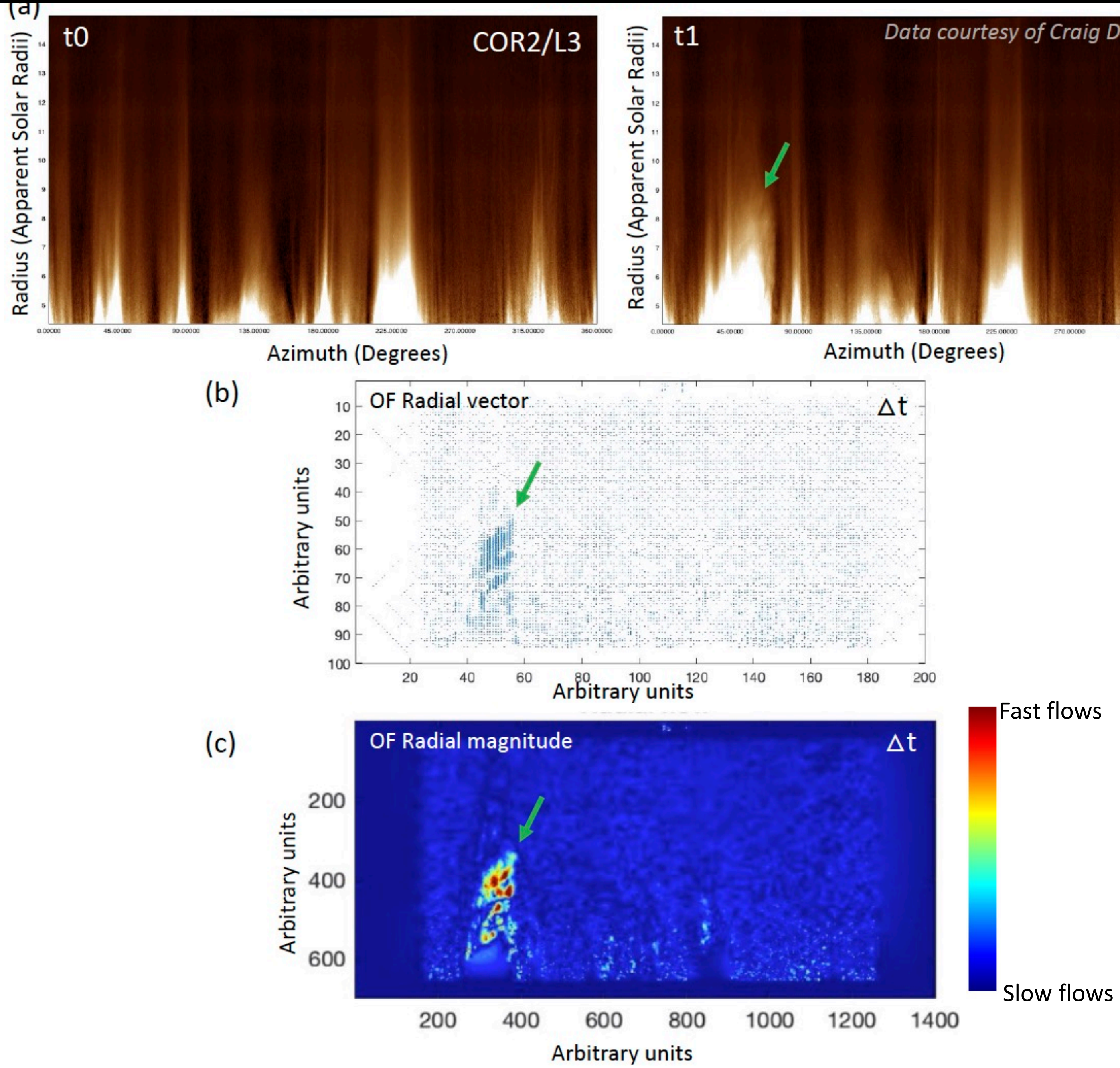


Azimuth (Degrees)

Craig DeForest COR2 L3
Campaign data analysis

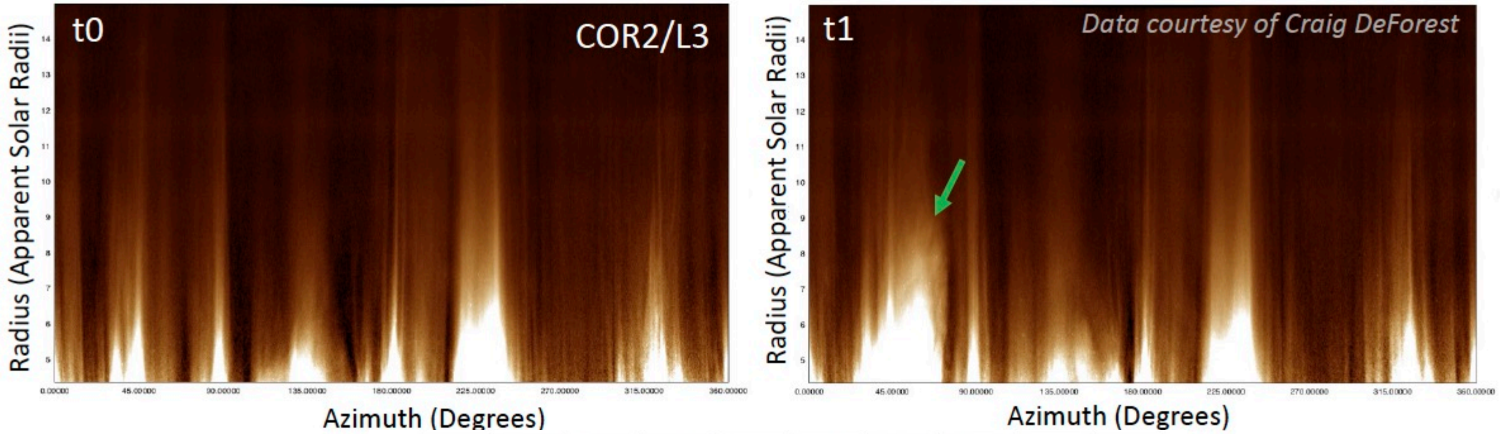
Courtesy of Craig DeForest

OF technique applications to STEREO – **Radial component**

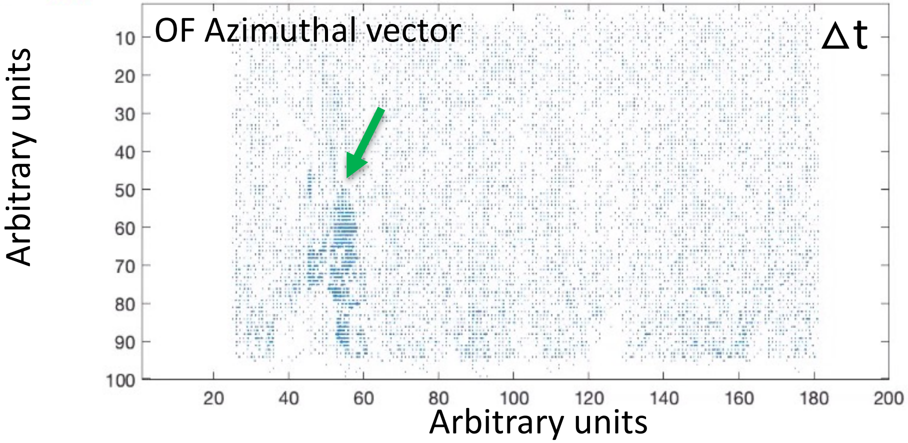


OF technique applications to STEREO – **Azimuthal component**

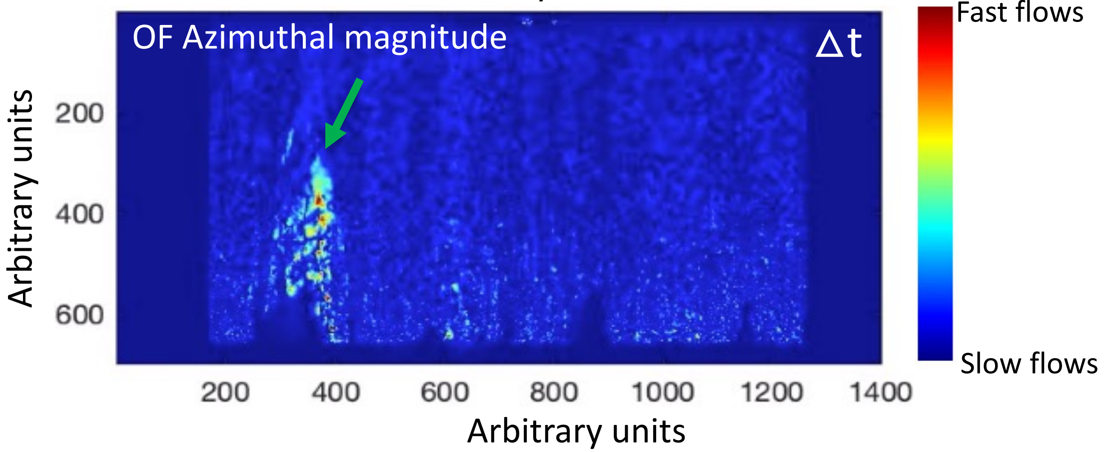
(a)



(b)

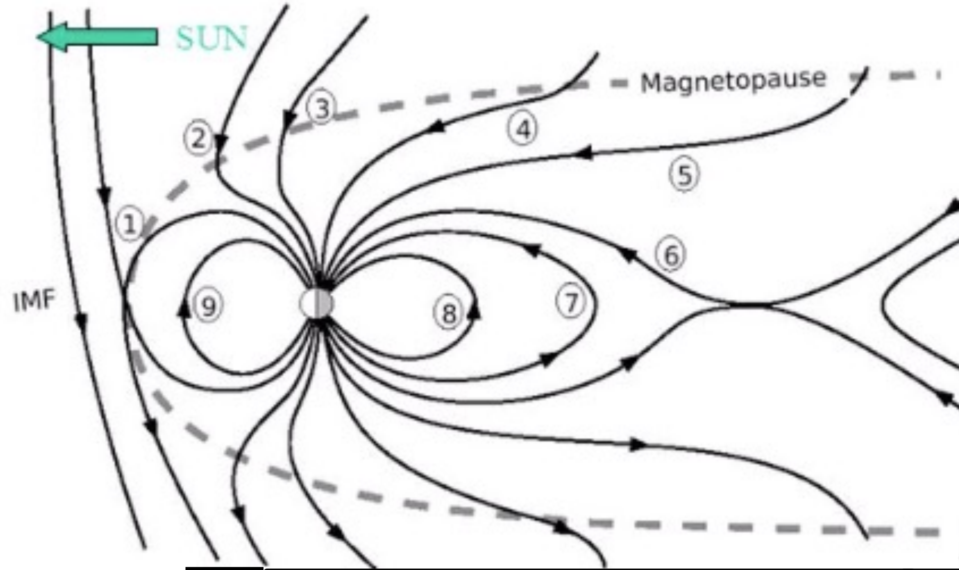


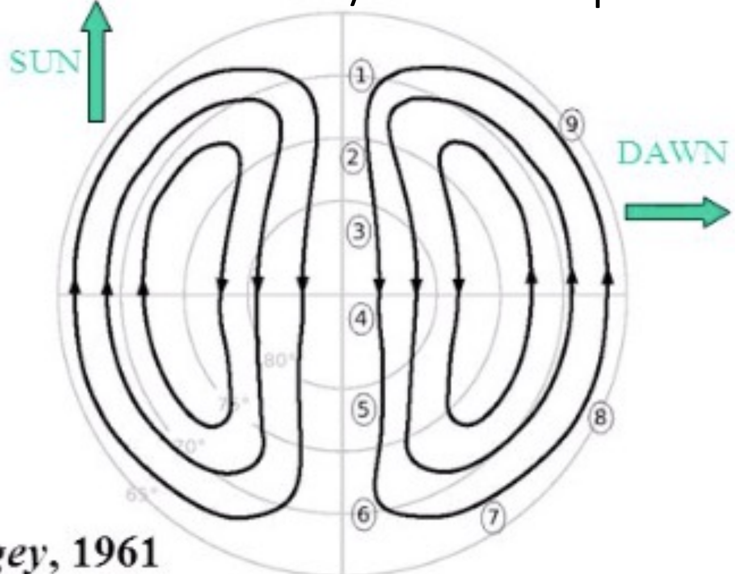
(c)



Plasma motion in the near-Earth space environment

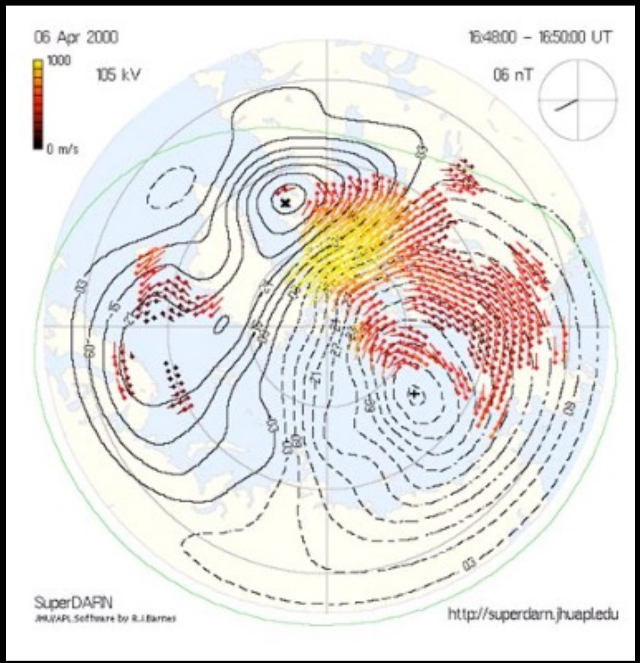
This work is motivated by Magnetosphere-ionosphere plasma convection/convection patterns

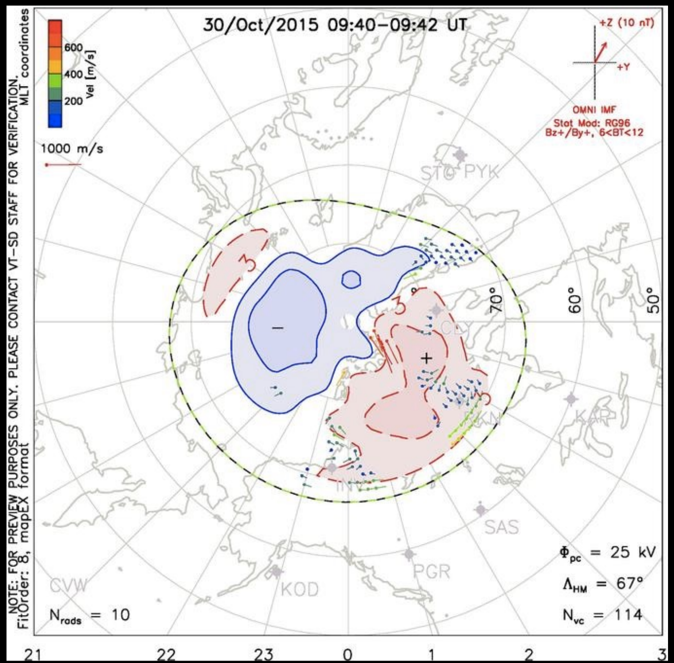




Dungey, 1961

Expectations

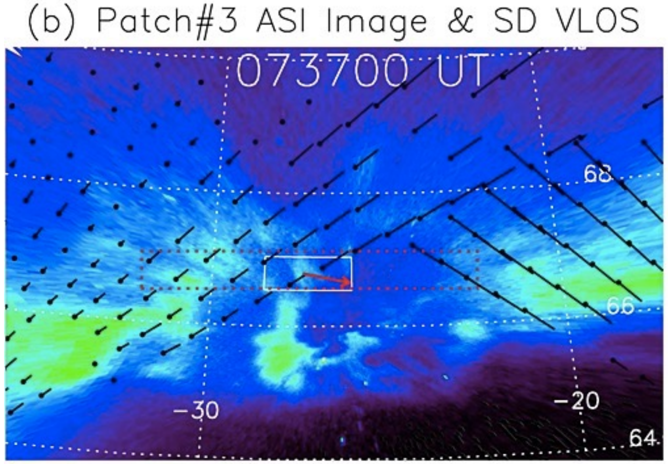


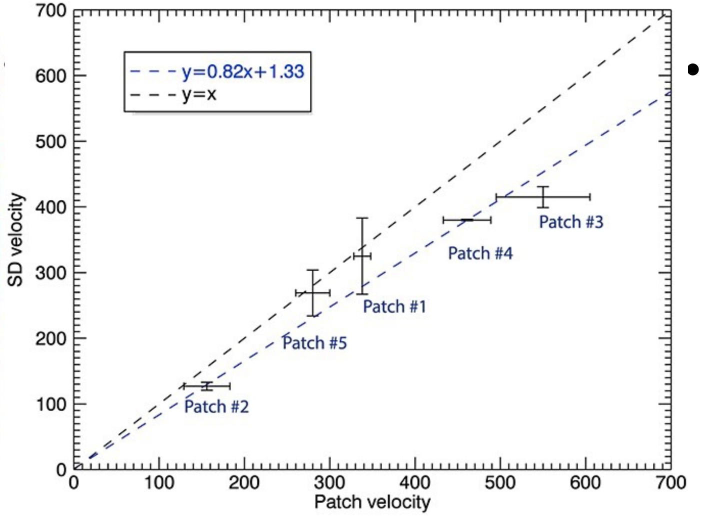


Reality

The motion of auroral structures

[Yang et al., 2015]

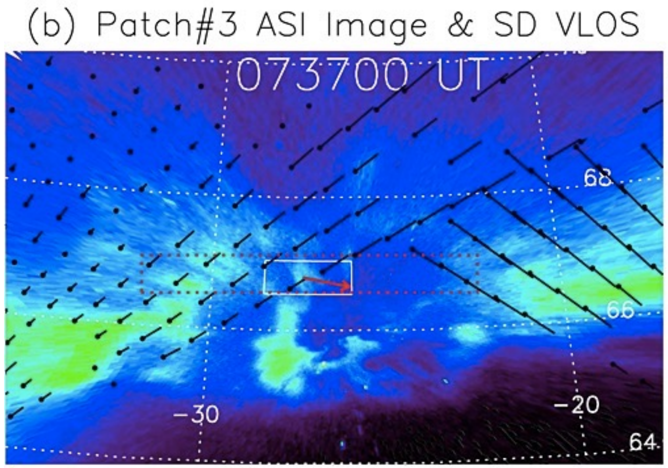


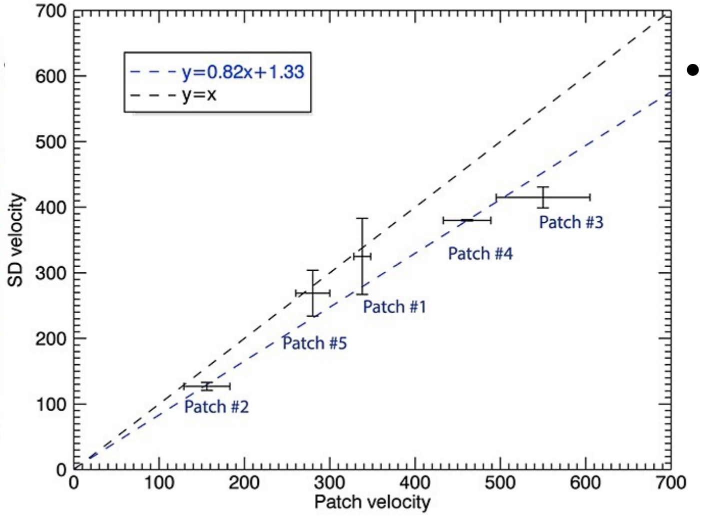


- In the aurora, some of the structures move with convection

The motion of auroral structures

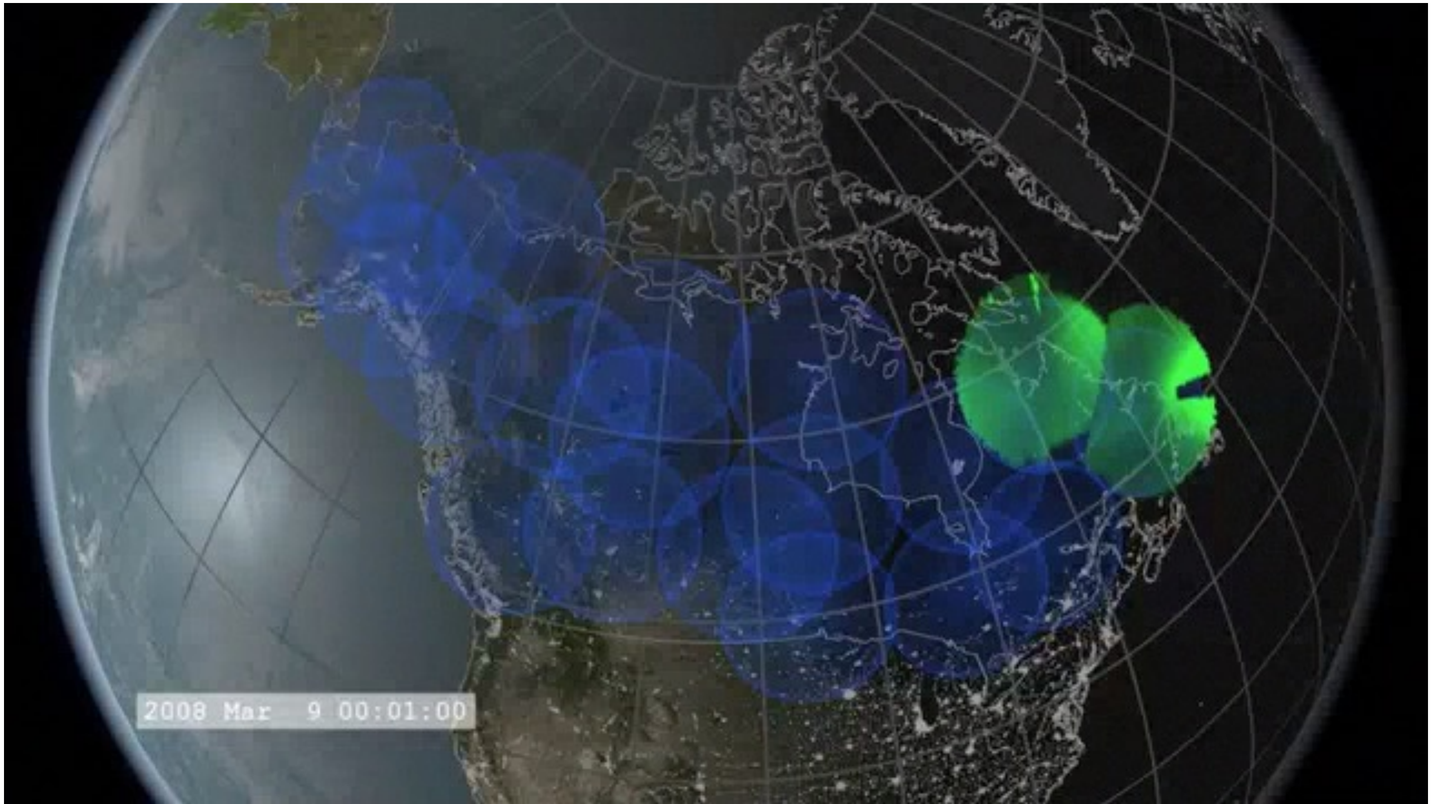
[Yang et al., 2015]





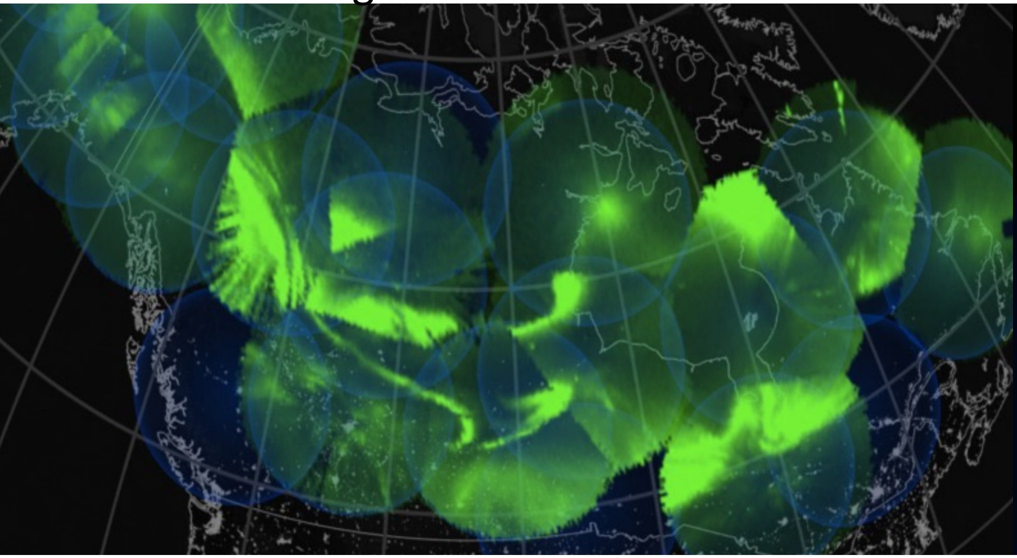
- In the aurora, some of the structures move with convection

White-light **THEMIS** all-sky Imagers(ASI)

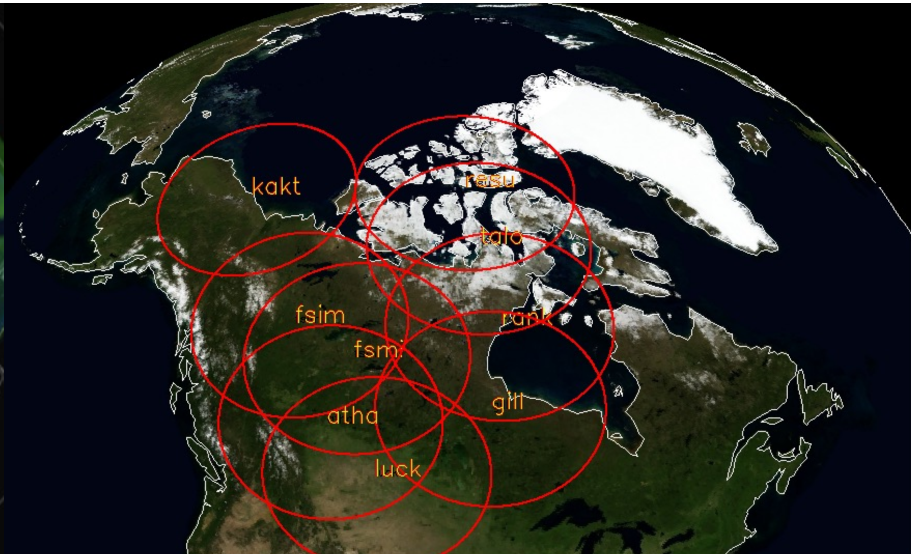


Available auroral optical data

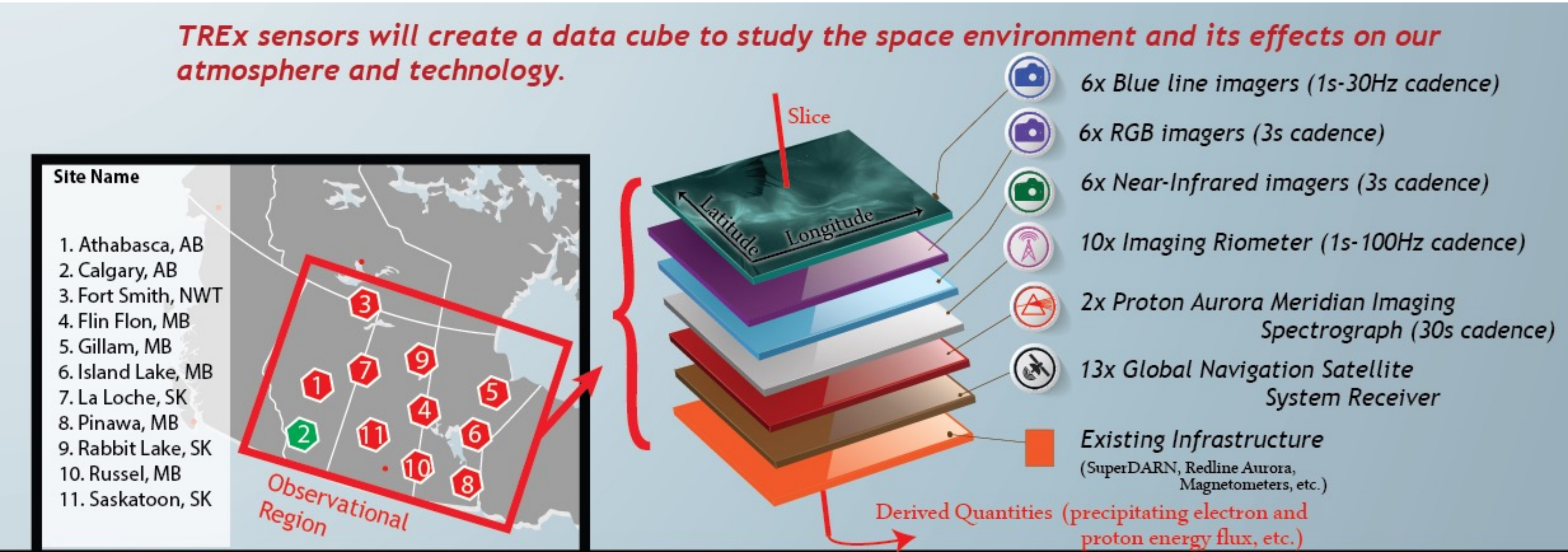
White light – THEMIS ASI



Redline – REGO ASI



Near Infrared and RGB – TREx



TREx sensors will create a data cube to study the space environment and its effects on our atmosphere and technology.

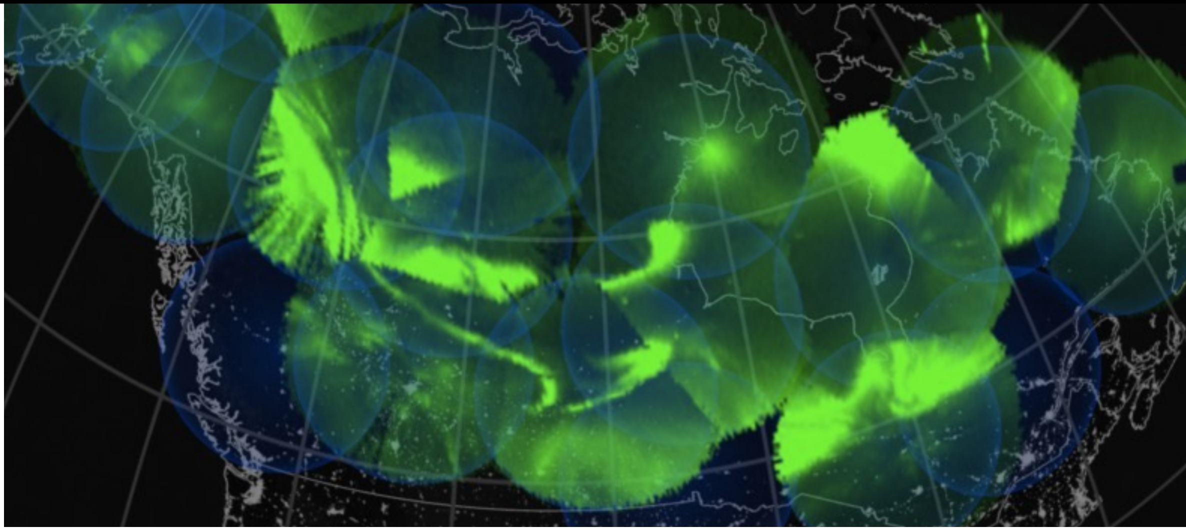
Site Name

1. Athabasca, AB
2. Calgary, AB
3. Fort Smith, NWT
4. Flin Flon, MB
5. Gillam, MB
6. Island Lake, MB
7. La Loche, SK
8. Pinawa, MB
9. Rabbit Lake, SK
10. Russel, MB
11. Saskatoon, SK

- 6x Blue line imagers (1s-30Hz cadence)
- 6x RGB imagers (3s cadence)
- 6x Near-Infrared imagers (3s cadence)
- 10x Imaging Riometer (1s-100Hz cadence)
- 2x Proton Aurora Meridian Imaging Spectrograph (30s cadence)
- 13x Global Navigation Satellite System Receiver
- Existing Infrastructure (SuperDARN, Redline Aurora, Magnetometers, etc.)

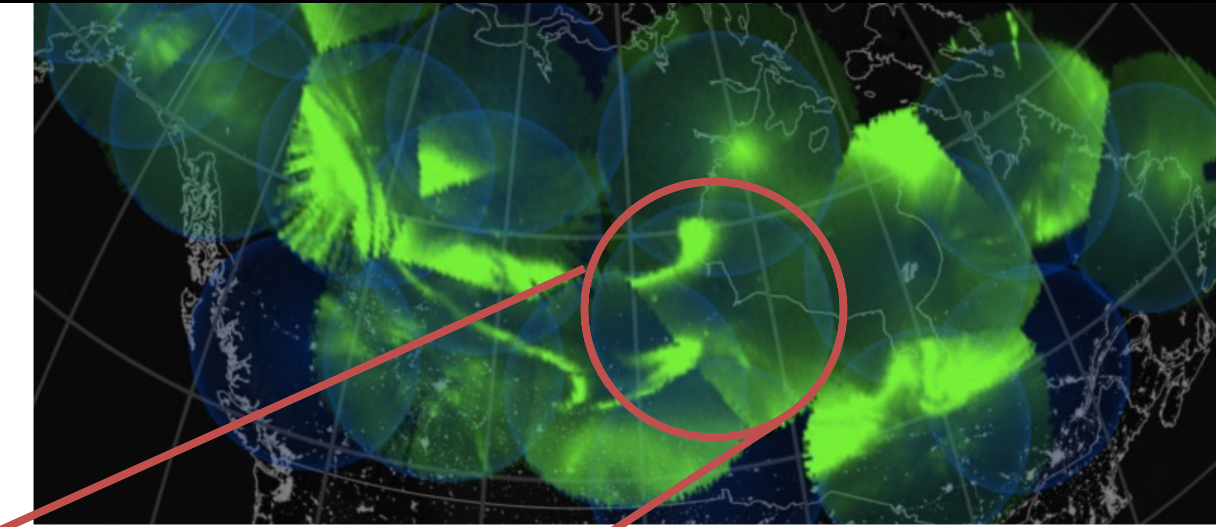
Derived Quantities (precipitating electron and proton energy flux, etc.)

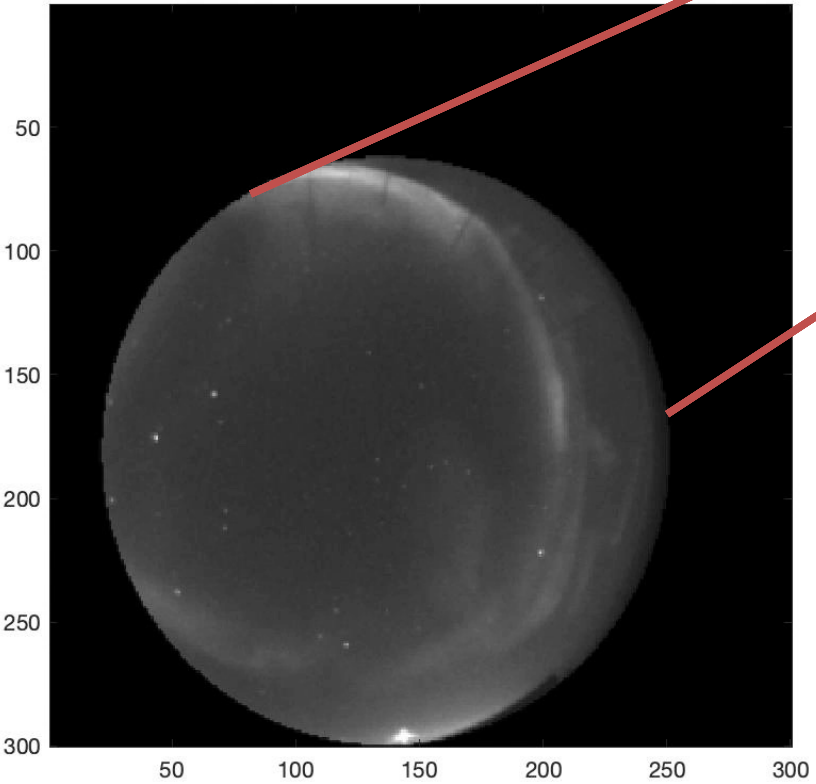
OF technique—applications to the aurora

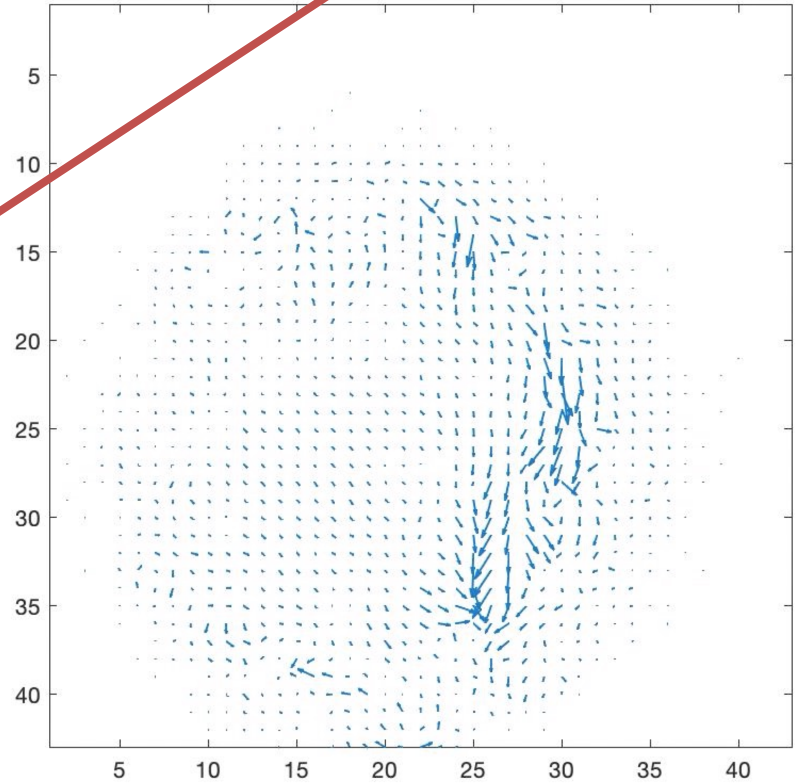


OF technique—applications to the aurora

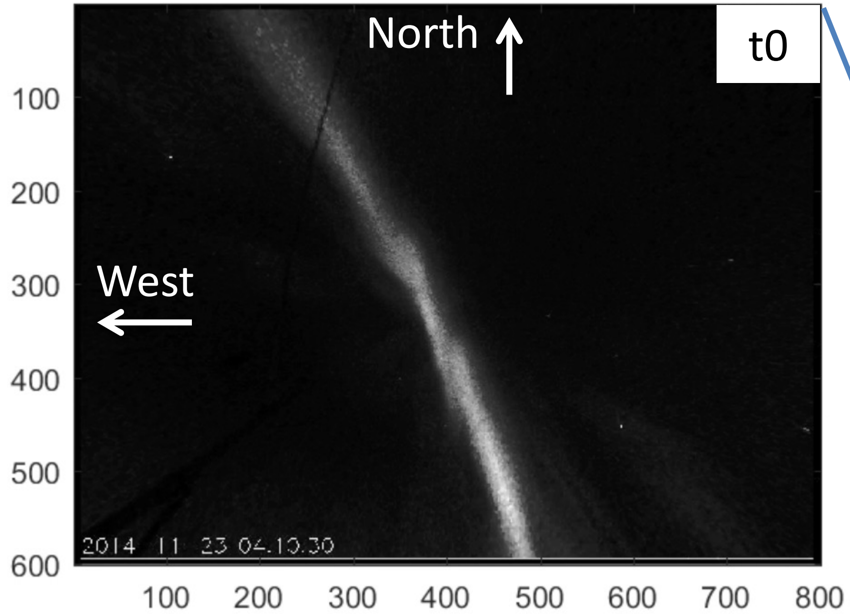
- Applying this technique, we easily identified auroral arcs' motion
- We reduced noise by re-binning pixels in the original image
- We identified faint structures, that could otherwise be missed

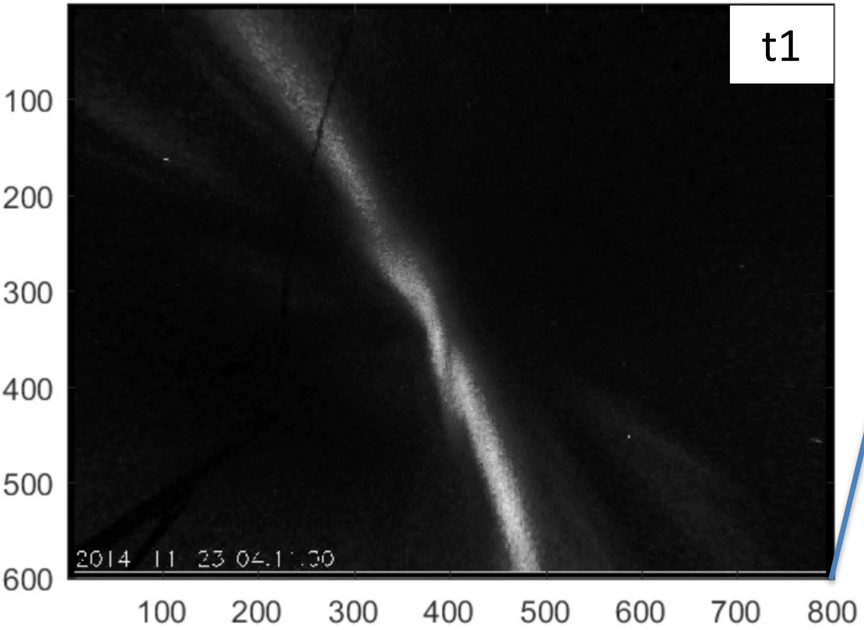




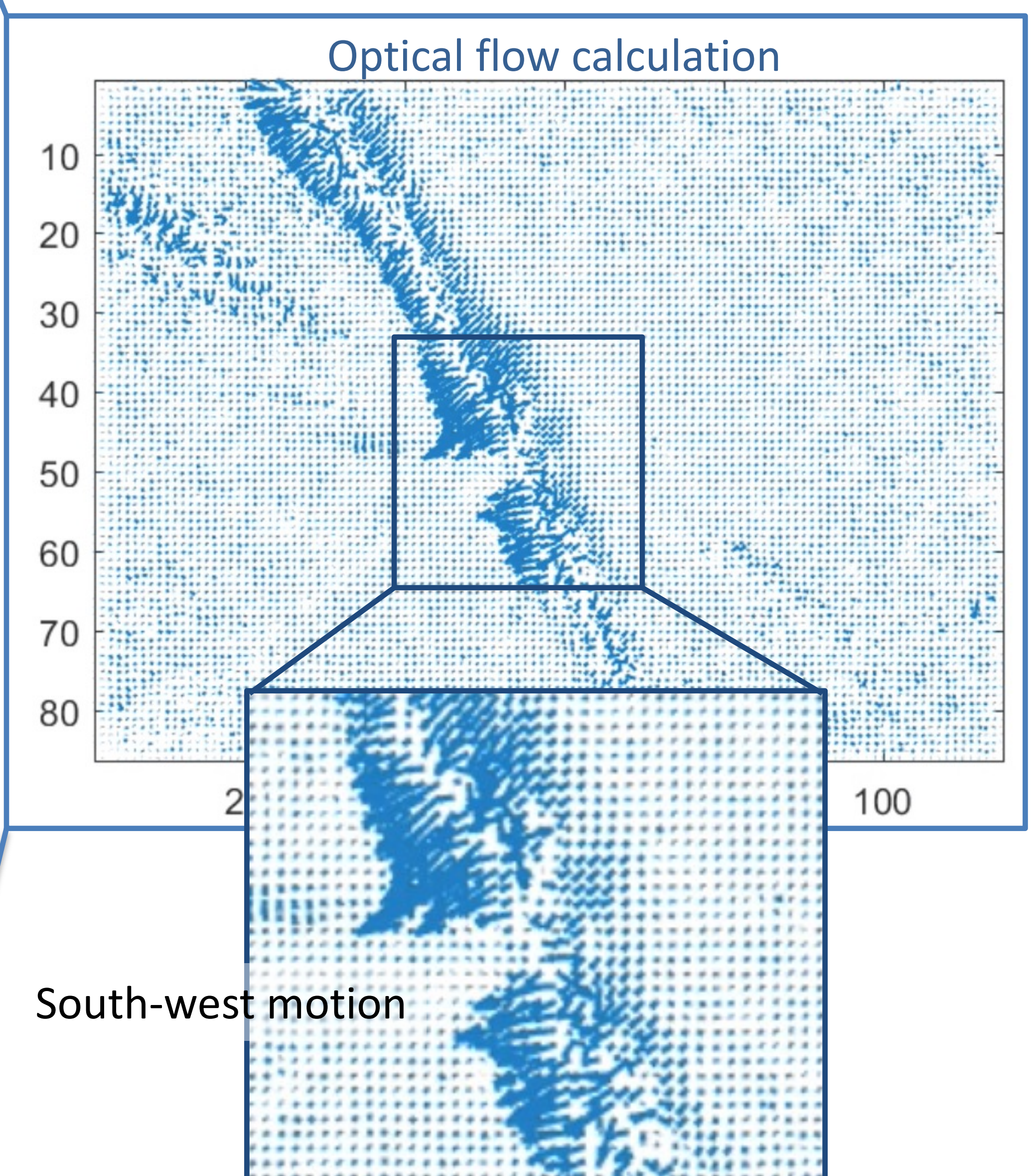


OF technique applications to the aurora



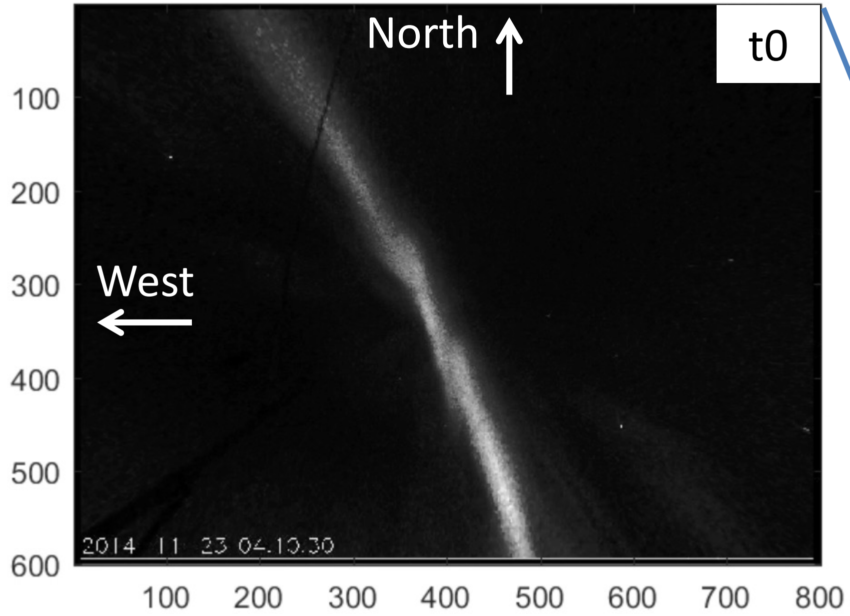


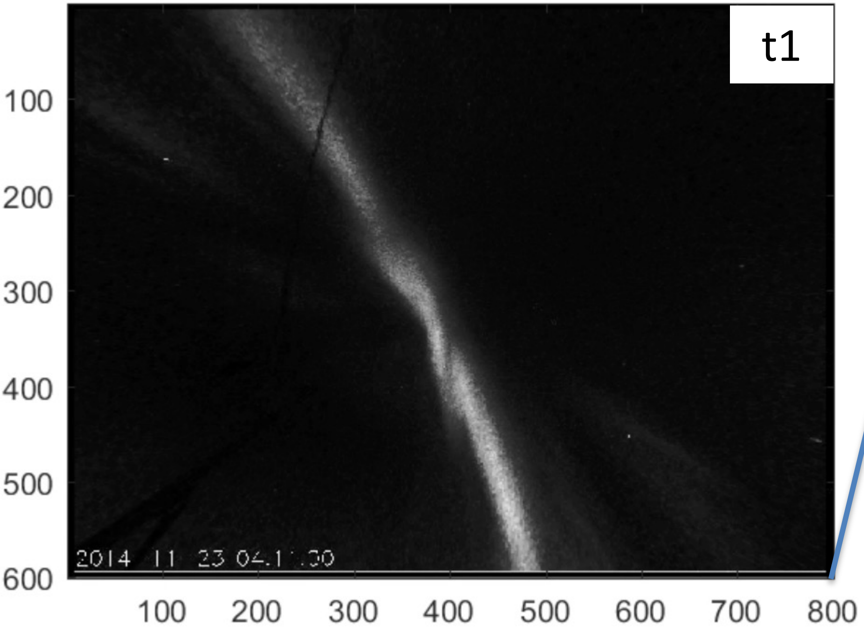
- Easily identified the south-west motion of this auroral arc



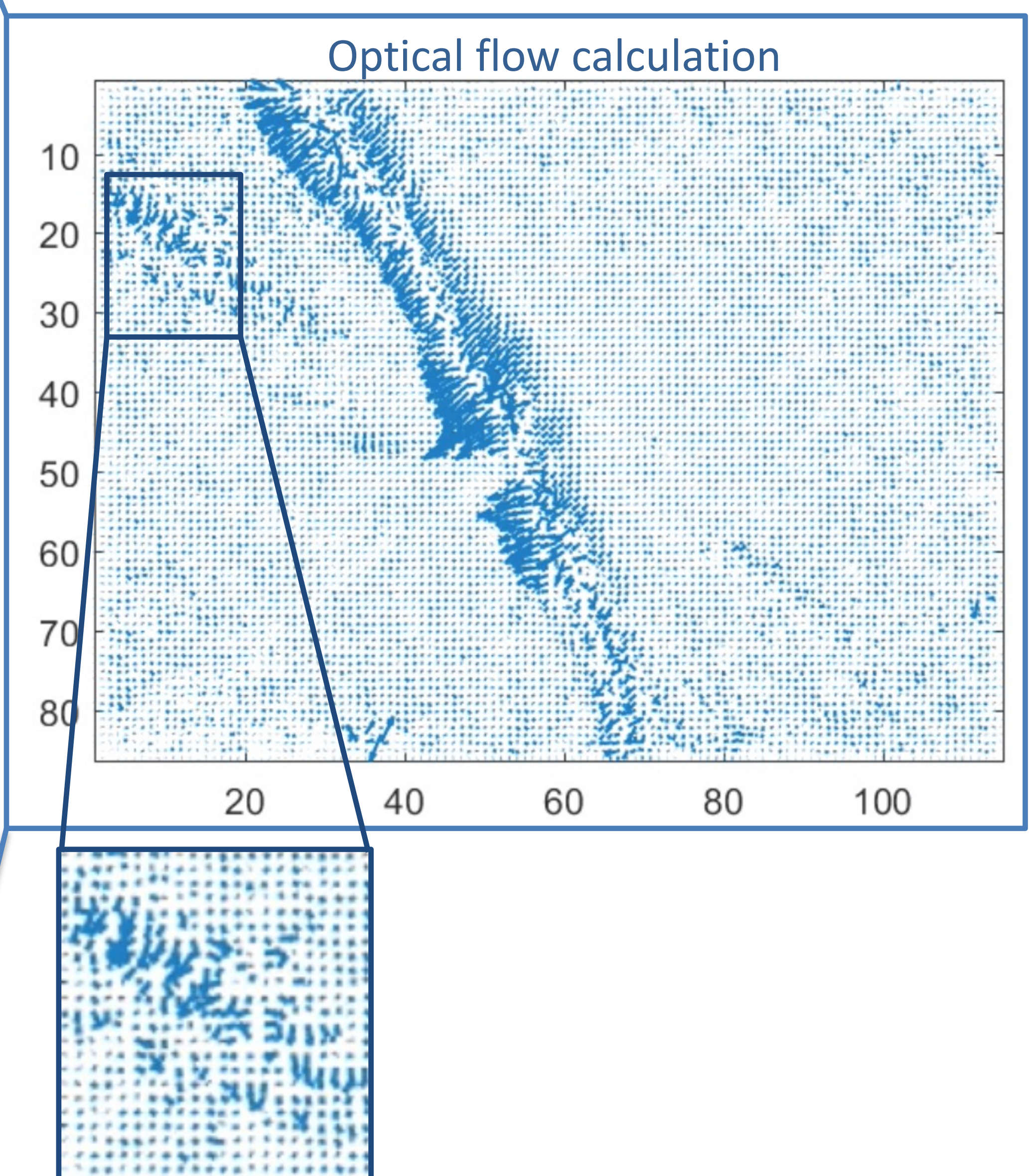
South-west motion

OF technique applications to the aurora

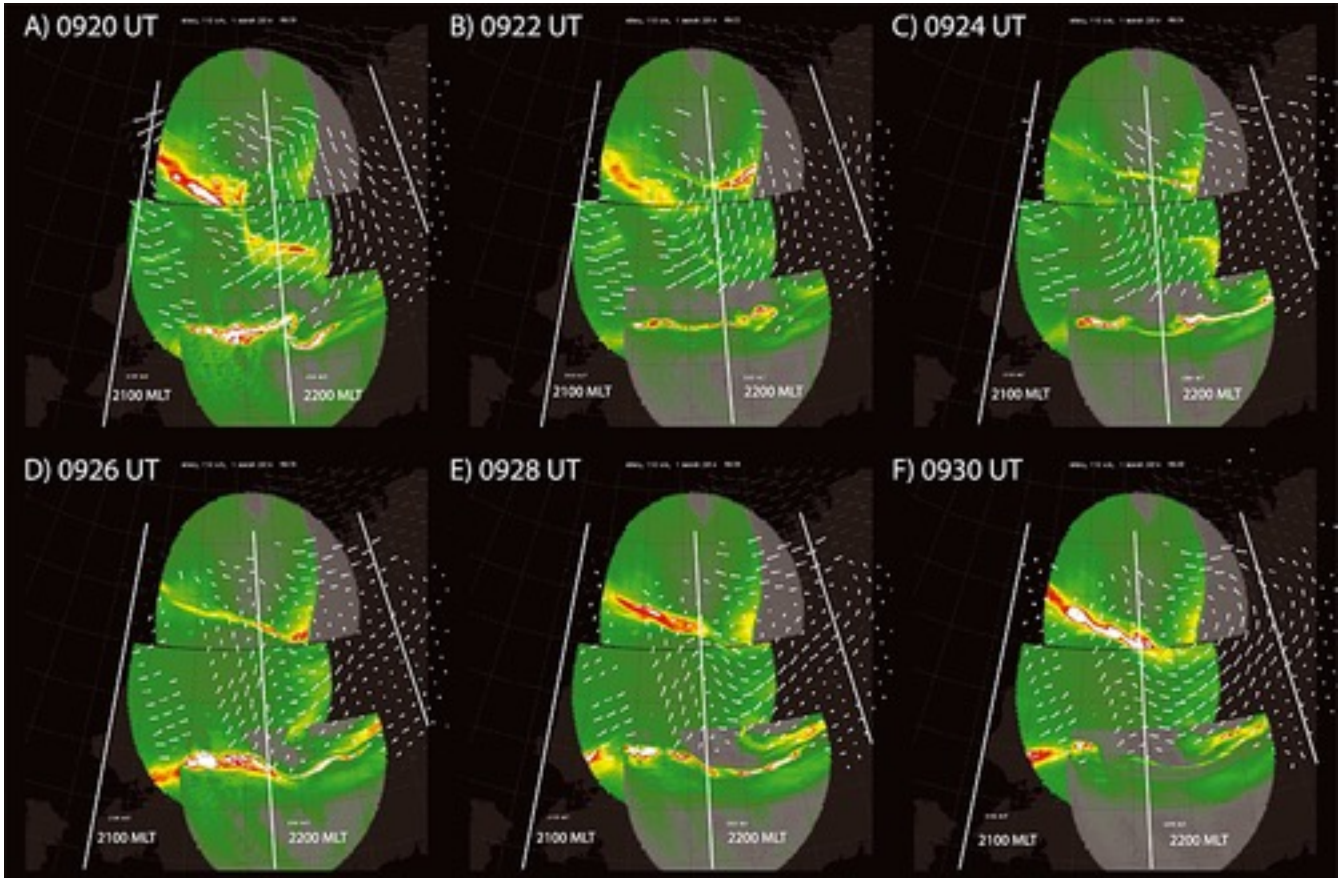




- We are also able to identify faint structures


Optical flow calculation

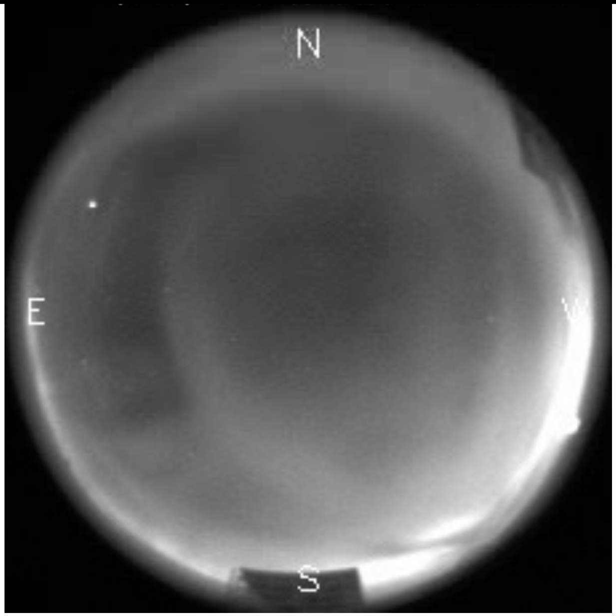
OF technique—uses of SuperDARN for validation (preliminary)

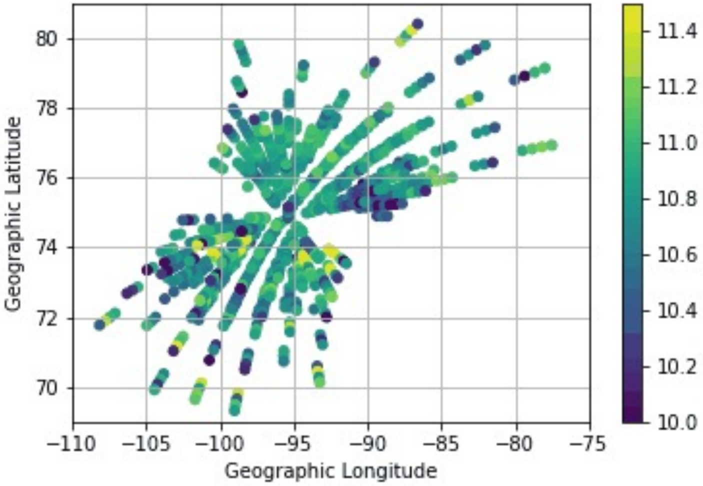


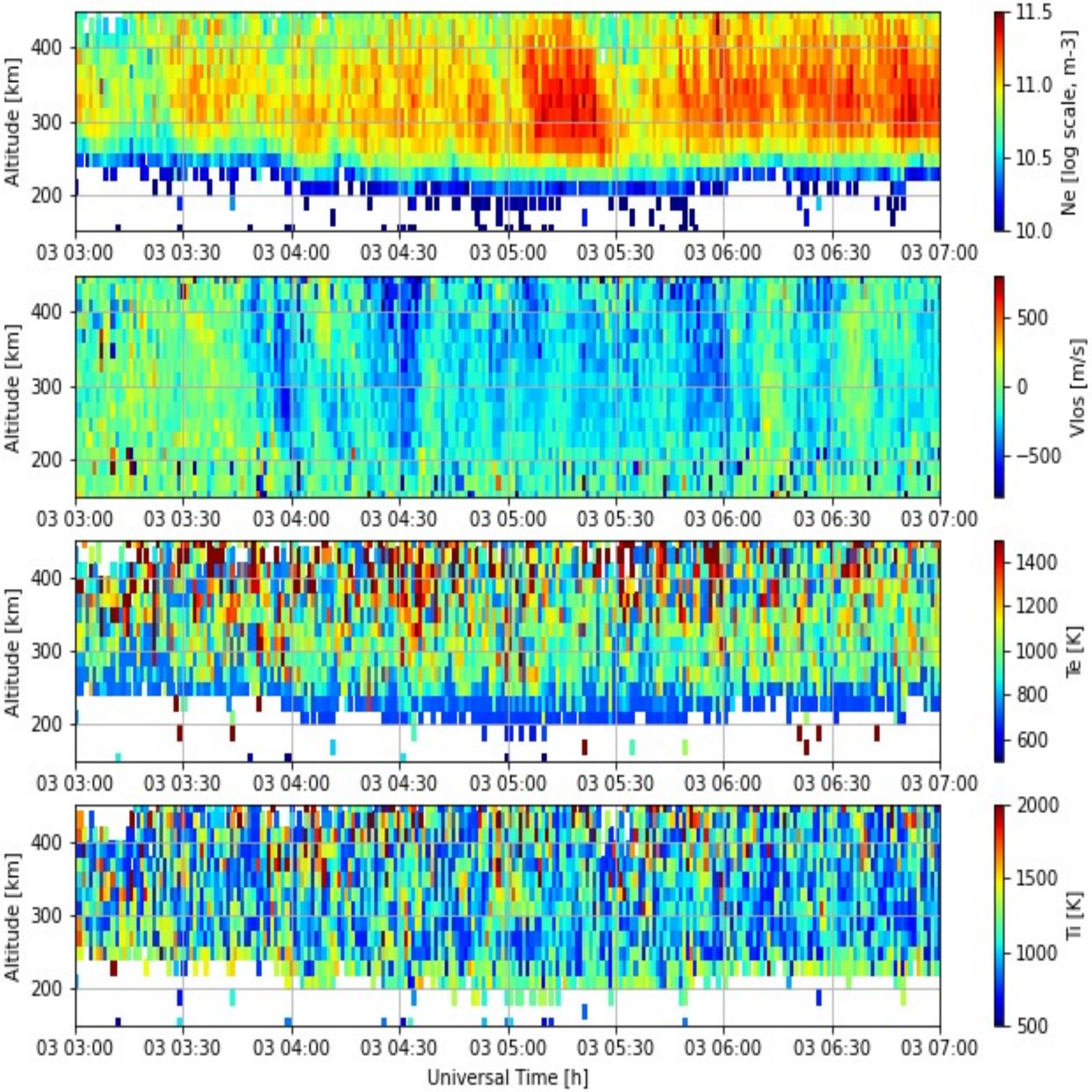
[Bristow et al., 2016]

- Line-of-sight (LOS) velocity observations obtained by SuperDARN radars are projections of the ionospheric plasma velocity along radar beam directions [e.g., *Greenwald et al.*, 1995; *Chisham et al.*, 2007]
- In the aurora, some of the structures move with convection (e.g., patchy pulsating aurora and omega bands). SuperDARN measurements can help us validate the OF flow technique

OF technique—uses of ISR for validation (preliminary)







- Incoherent Scatter Radars (ISR) overlap with auroral imagers
- These radars provide electron density, line-of-sight flow velocity, electron and ion temperature

Conclusions and Future work

- Optical flow technique is a good approach to analyze structures' motion
  - Tracking of auroral arcs or streamers
  - Tracking in STEREO COR2-L3 data

- Our future work includes:
  - Aurora: Direct comparison with coherent and incoherent scatter radar data(ongoing)
  - Compare results with other techniques for validation/complement

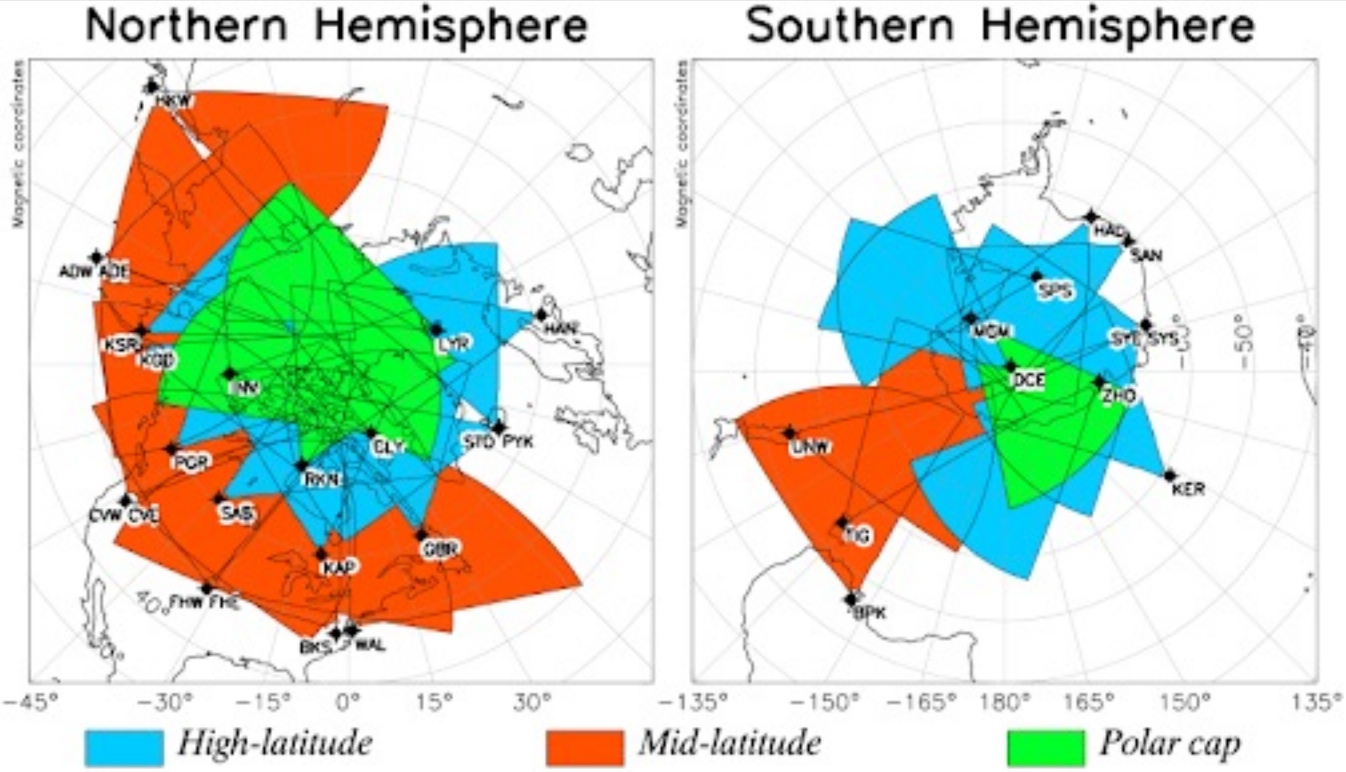
Relevance to PUNCH

PUNCH science objectives: (1) to understand how coronal structures become the ambient solar wind; and (2) to understand the dynamic evolution of transient structures in the young solar wind. The PUNCH team tracks CME and CIR evolution, and characterizes cross-scale shock dynamics

OF tracking could not only help PUNCH's science objectives but also help us validate the approach

Backup slides

SuperDARN radars



SuperDARN radars

High frequency coherent scatter radars that measures signals scattered from magnetic field-aligned plasma irregularities in the ionospheric E and F region

- Line-of-sight (LOS) velocity observations obtained by SuperDARN radars are projections of the ionospheric plasma velocity along radar beam directions [e.g., *Greenwald et al.*, 1995; *Chisham et al.*, 2007]
- The radars scan over azimuth sectors of 16 to 20 beams separated by about 3.25°, typically observing along a single direction for an integration period of 3 s to 6 s. Temporal resolution of a full scan: 1-2 minutes
- *LOS observations from a single site are insufficient to make this determination since the projections do not provide any information on the velocity components perpendicular to the lines of sight*

SuperDARN radars - Velocity vectors

1. Old method: Spherical harmonic Fit (SHF)

- The SuperDARN measurements are used to determine a solution for the distribution of electrostatic potential, Φ, expressed as a series expansion in spherical harmonics
- In addition, data from a statistical model constrains the solution in regions of no data coverage [*Ruohoniemi and Baker*, 1998]
- In this approach, the plasma velocities are considered divergence free
- The level of detail that can be represented depends on the order of the fit
- This imposes a limit on the minimum size of features that will be represented in the results
- Often the LOS observations exhibit more detail than can be represented in the SHF patterns, producing great discrepancies

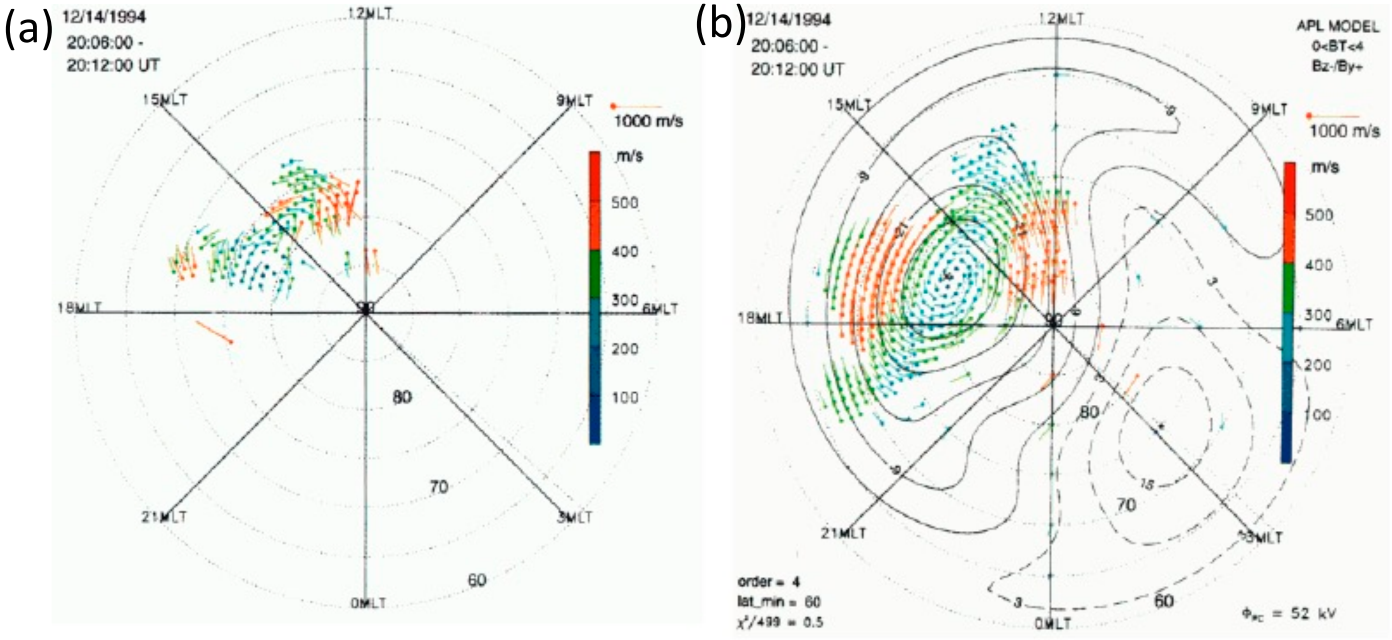


Figure: Velocity vectors obtained for (a) overlapping radar echoes and (b) SHF technique

[Ruohoniemi et al., 1998]

SuperDARN radars - Velocity vectors

2. New method: Local Divergence-Free Fitting (LDFF)

[Bristow et al., 2016]

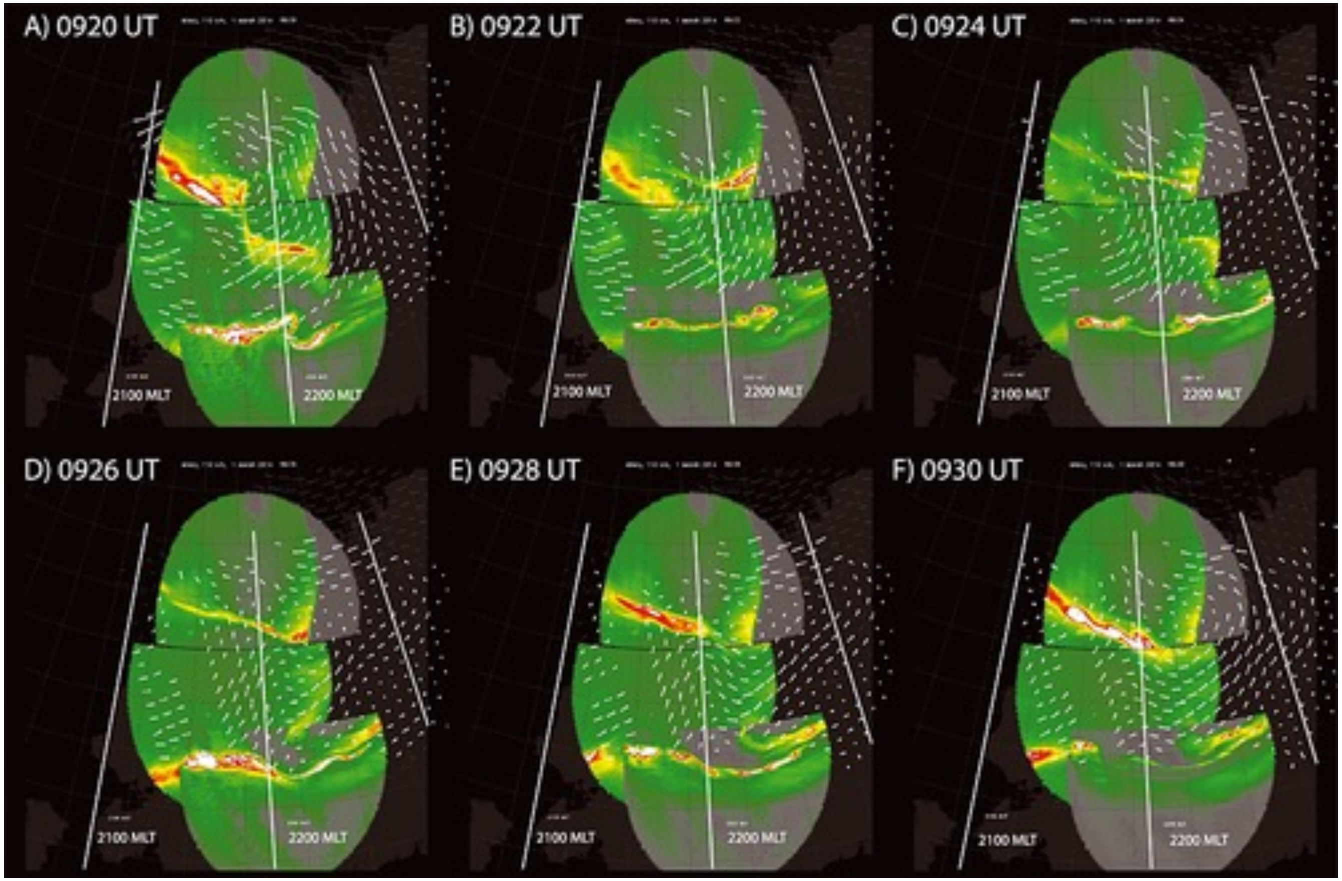
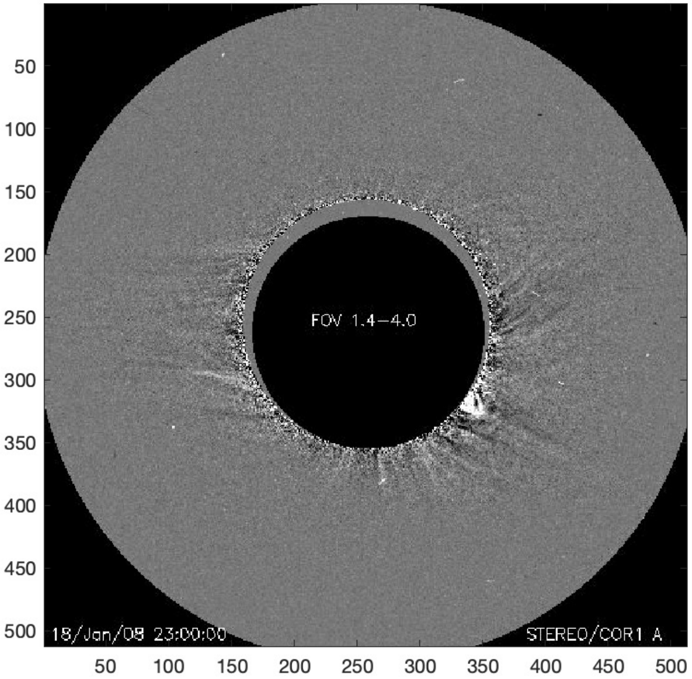


Figure: Sequence of all-sky imager composites with convection velocities superposed. Imagers the three Alaska Poker Flat, Toolik Lake, Kaktovik, are shown. Frames are separated 2 min, starting with UT

- The Local Divergence-Free Fitting (LDFF) technique can be used to produce convection maps with a spatial resolution determined by the resolution of the observations rather than an arbitrary fit order
- It is limited by the resolution of the observations and the observed noise level
- The LDFF technique allows us to identify and analyze the motion of small and mesoscale (100s km) structures


FOV 1.4–4.0
18/Jan/08 23:00:00
STEREO/COR1 A
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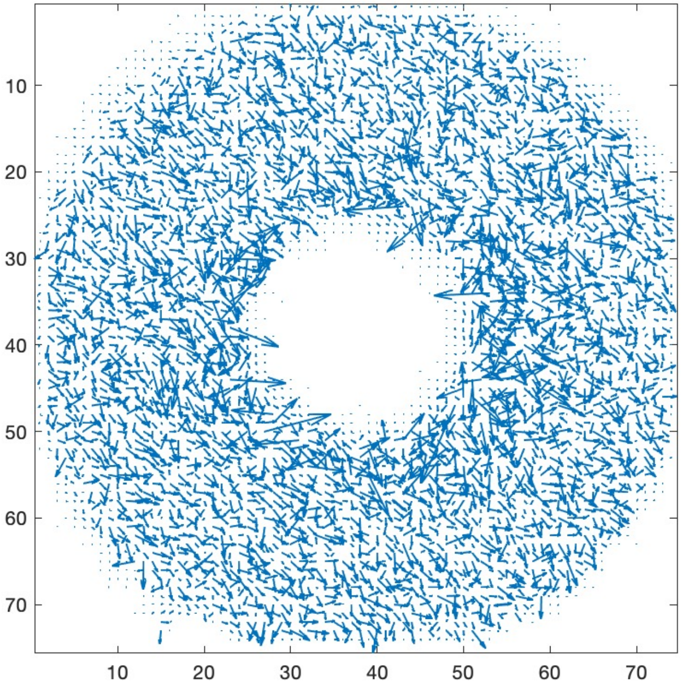
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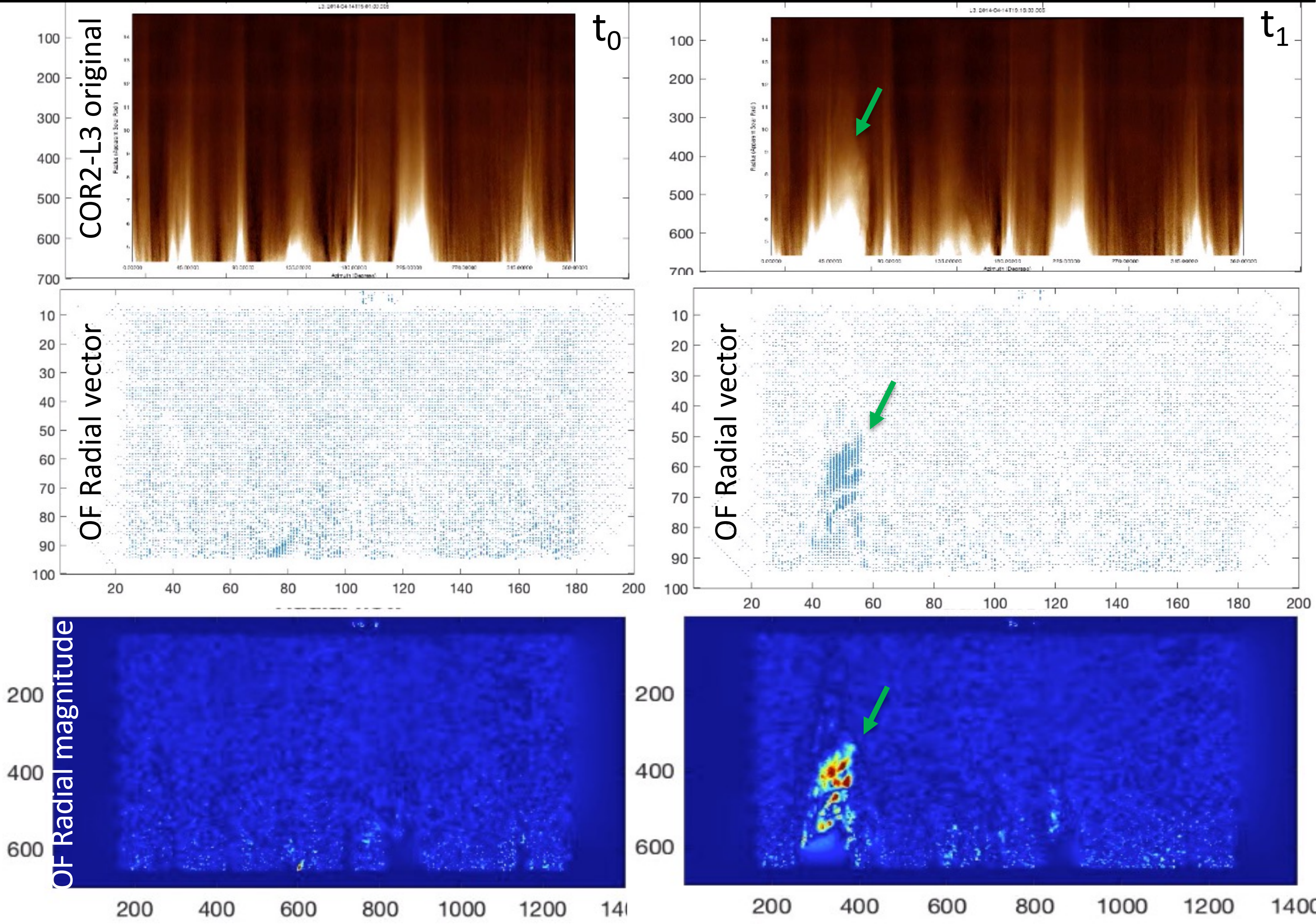
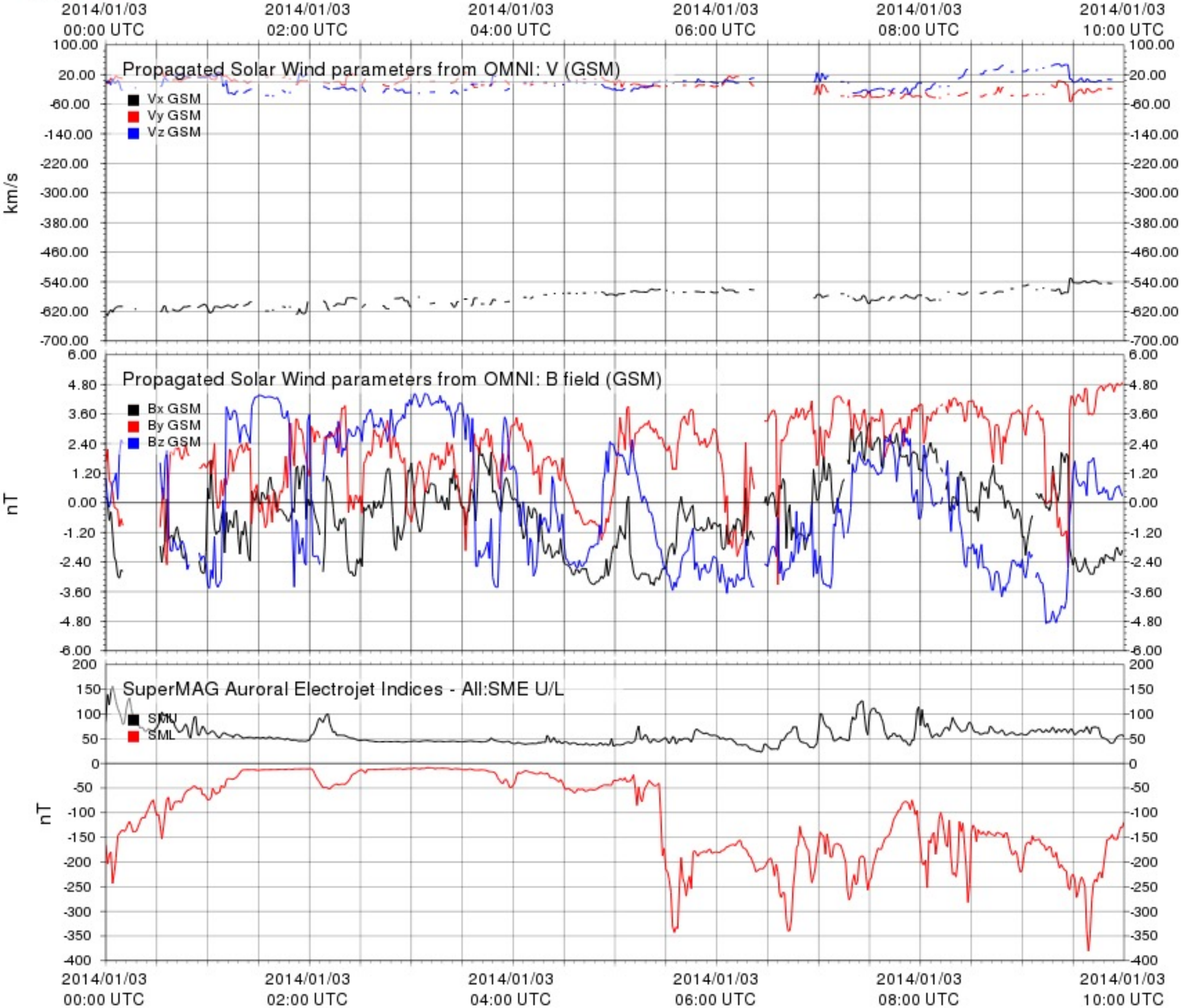
OF technique applications to STEREO – **Radial component**



SuperMAG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Propagated Solar Wind parameters from OMNI: V (GSM)
Vx GSM
Vy GSM
Vz GSM
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-60.00
-140.00
-220.00
-300.00
-380.00
-460.00
-540.00
-620.00
-700.00
Propagated Solar Wind parameters from OMNI: B field (GSM)
Bx GSM
By GSM
Bz GSM
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4.80
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0.00
-1.20
-2.40
-3.60
-4.80
-6.00
SuperMAG Auroral Electrojet Indices - All:SME U/L
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