University of Saskatchewan

The Fast Borealis Ionosphere: New observations and insights from mapping the polar ionosphere every four seconds

Dan Billett, Remington Rohel, Carley Martin, Kathryn McWilliams, Karl Laundal

SuperDARN Canada

Photo: Ashton Reimer

Upgrading SUPERDARN CANADA

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Research Article | Open Access

Borealis: An Advanced Digital Hardware and Software Design for SuperDARN Radar Systems

K. A. McWilliams ✉, M. Detwiller, K. Kotyk, K. Krieger, R. Rohel, D. D. Billett, D. Huyghebaert, P. Ponomarenko

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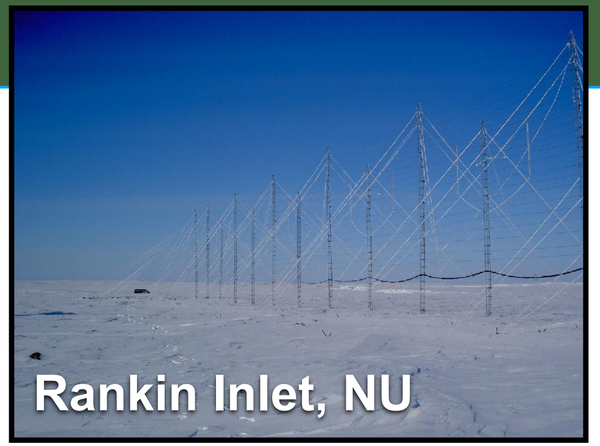
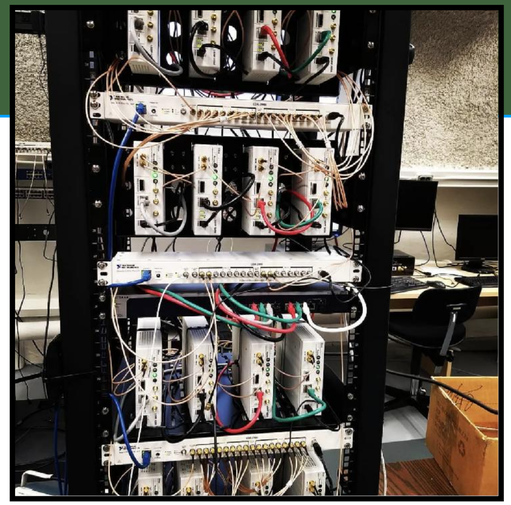
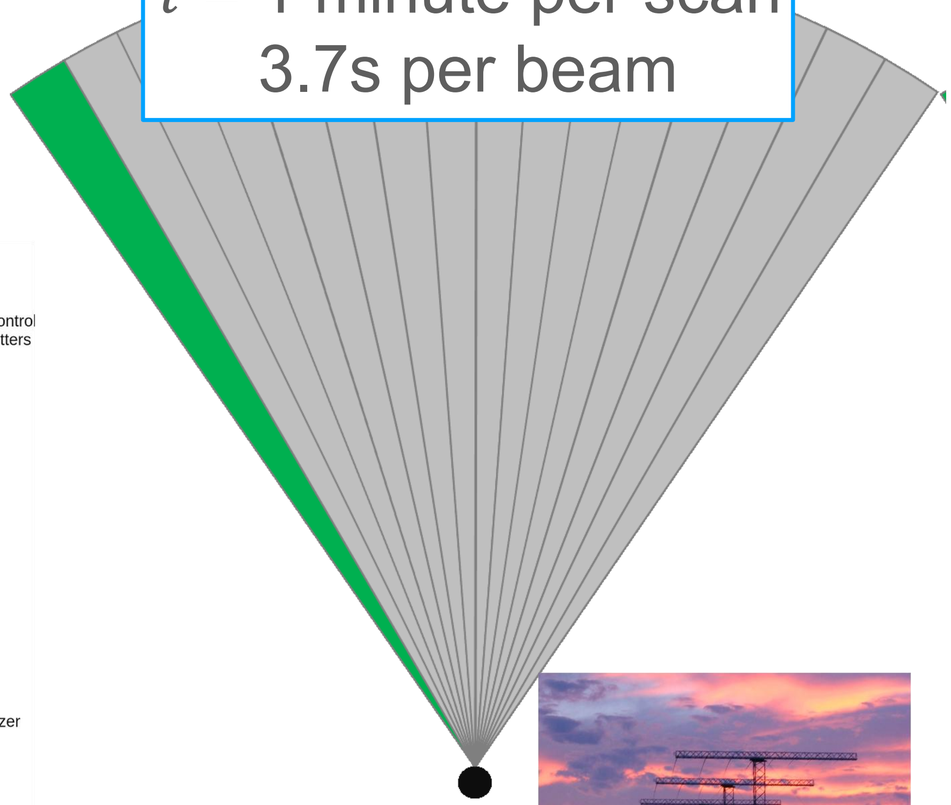




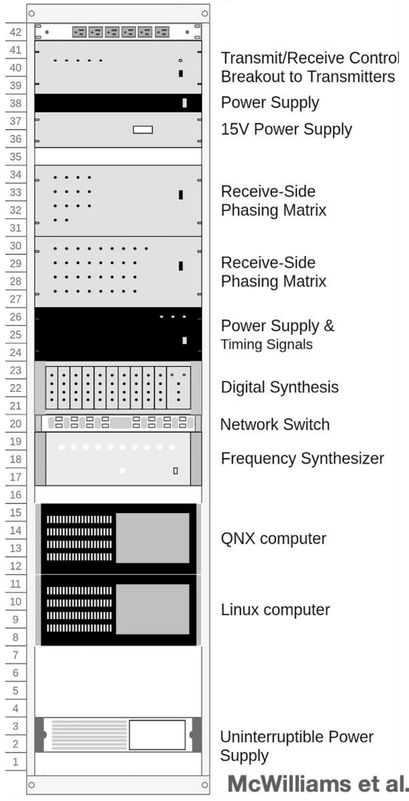
Borealis upgrades - transmission changes

Traditional “Narrow beam”

τ = 1 minute per scan
3.7s per beam



ROS and GC214 (42U)



McWilliams et al., 2022

SUPERDARN CANADA

Borealis upgrades - transmission changes

Traditional “Narrow beam”

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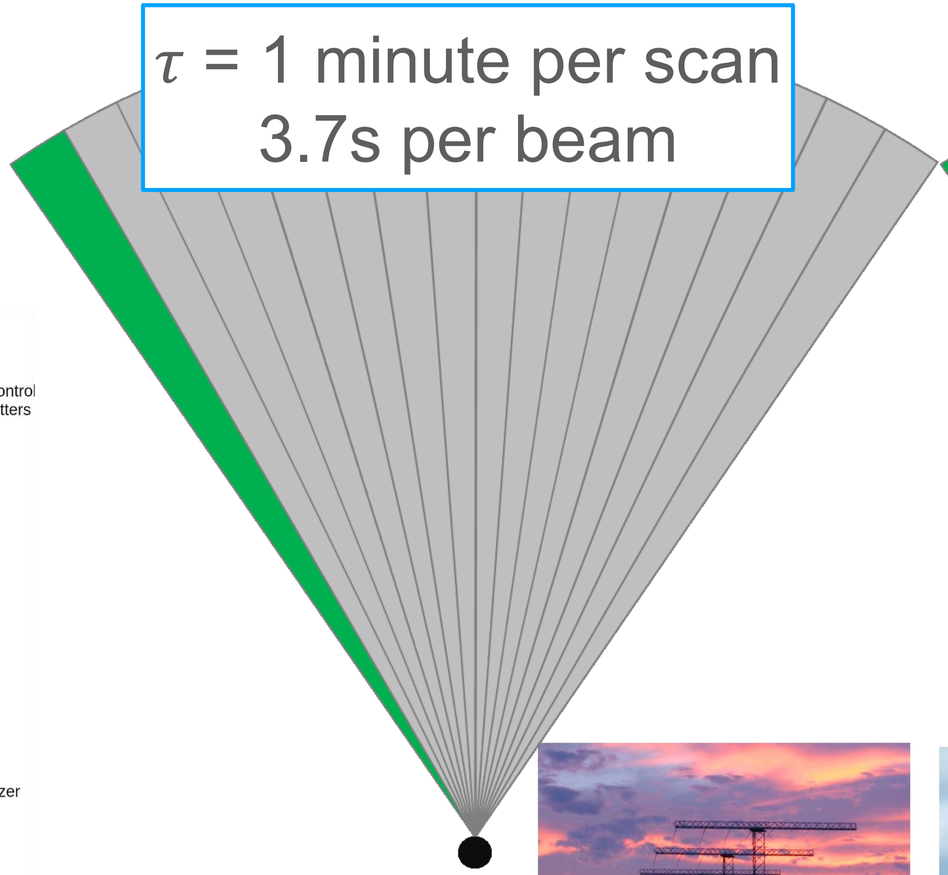
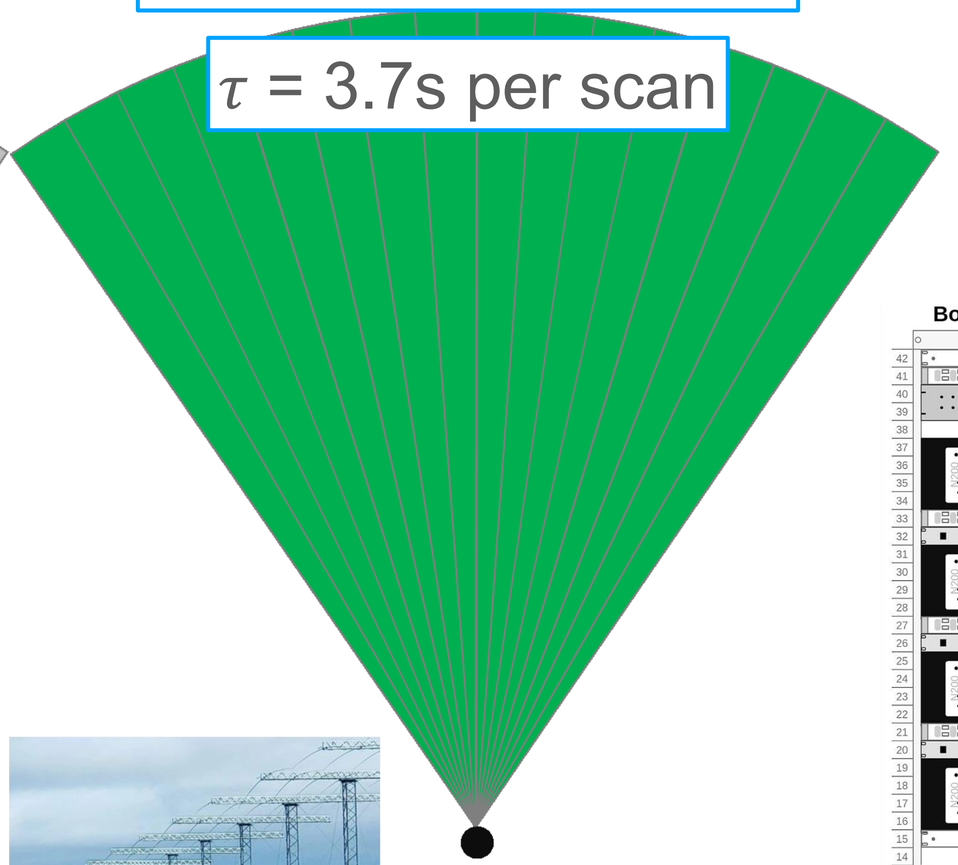
Borealis “Wide beam”

τ = 3.7s per scan





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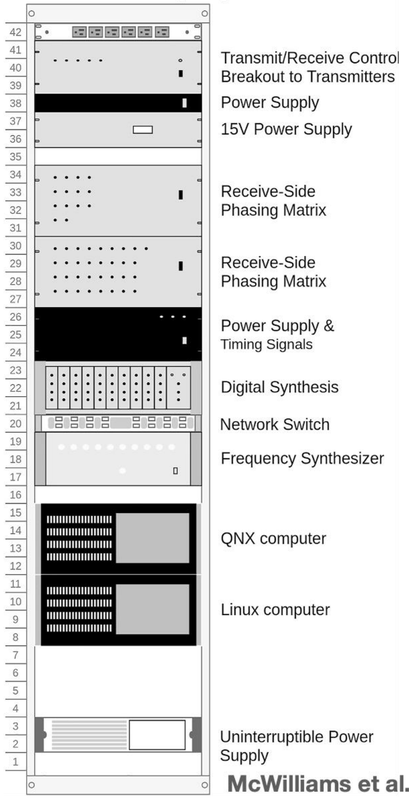
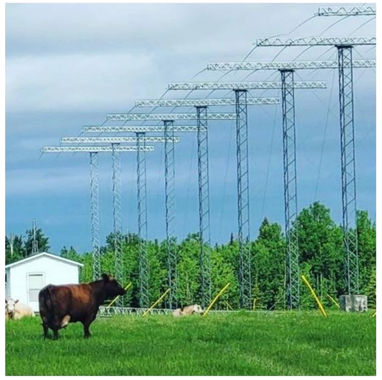
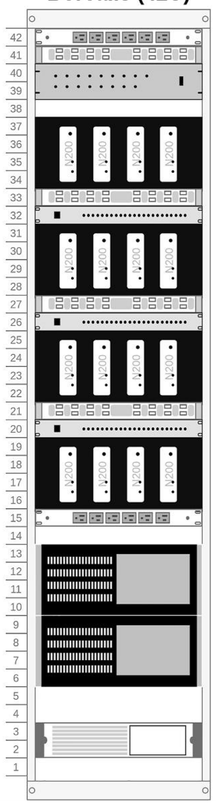


McWilliams et al., 2022

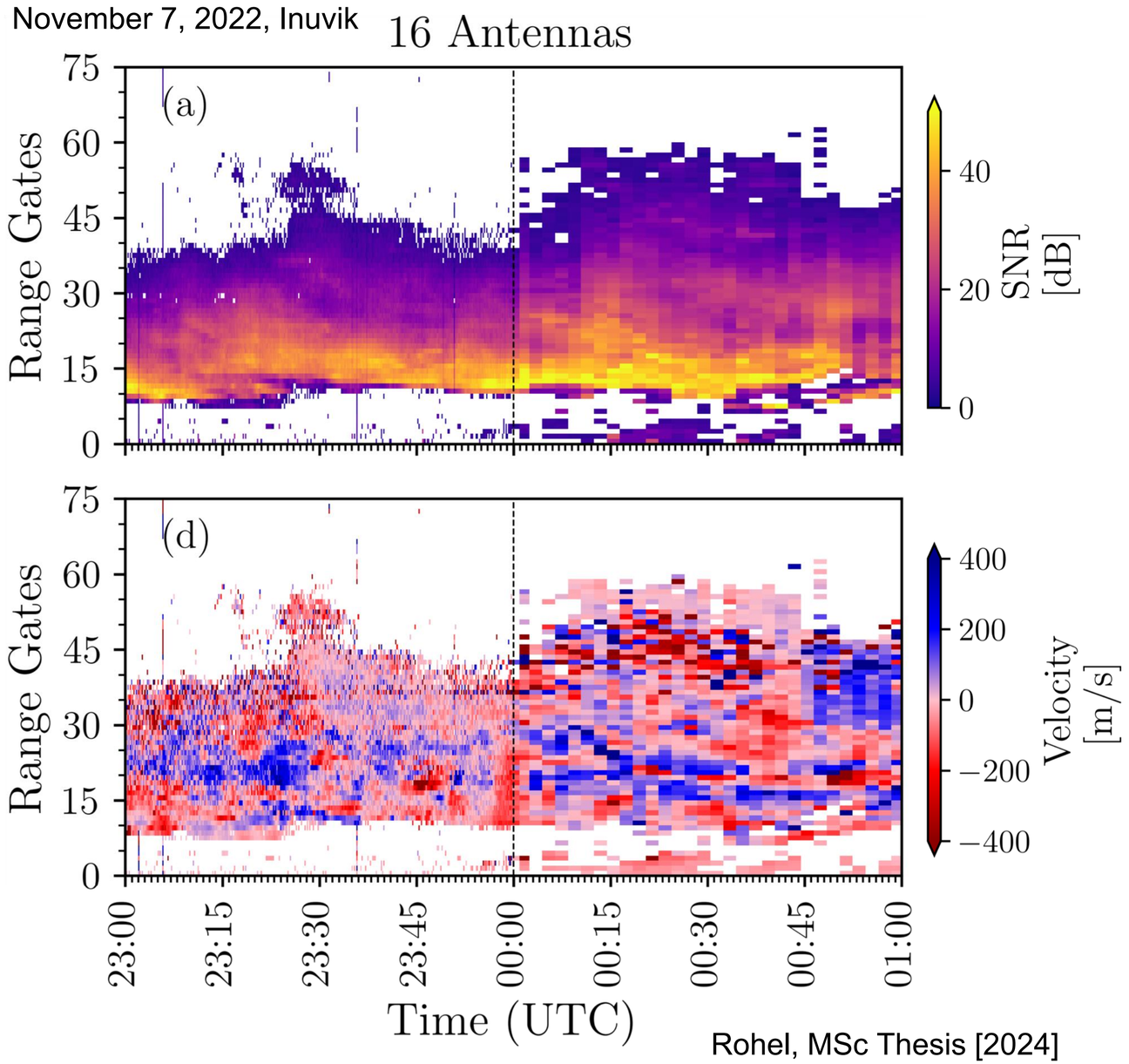


SUPERDARN CANADA

Borealis (42U)



Borealis upgrades - “Wide beam” transmission



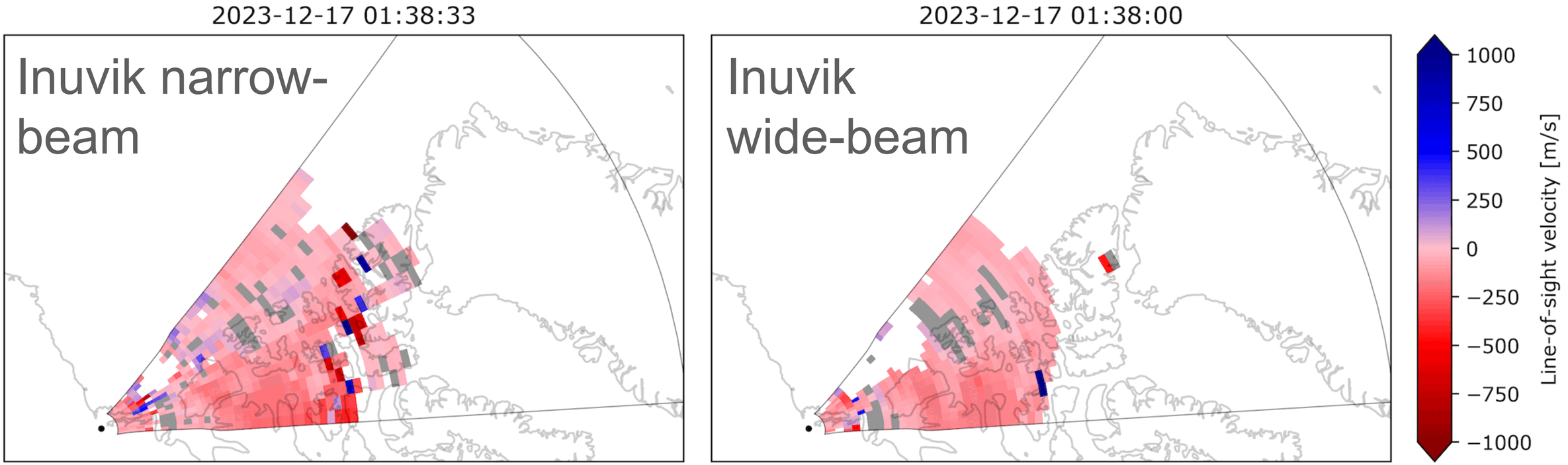
Rohel, MSc Thesis [2024]

Effective x16 temporal resolution improvement

1min → 3.7s

~9dB drop in SNR results in ~10% less total echoes

Borealis upgrades - “Wide beam” transmission



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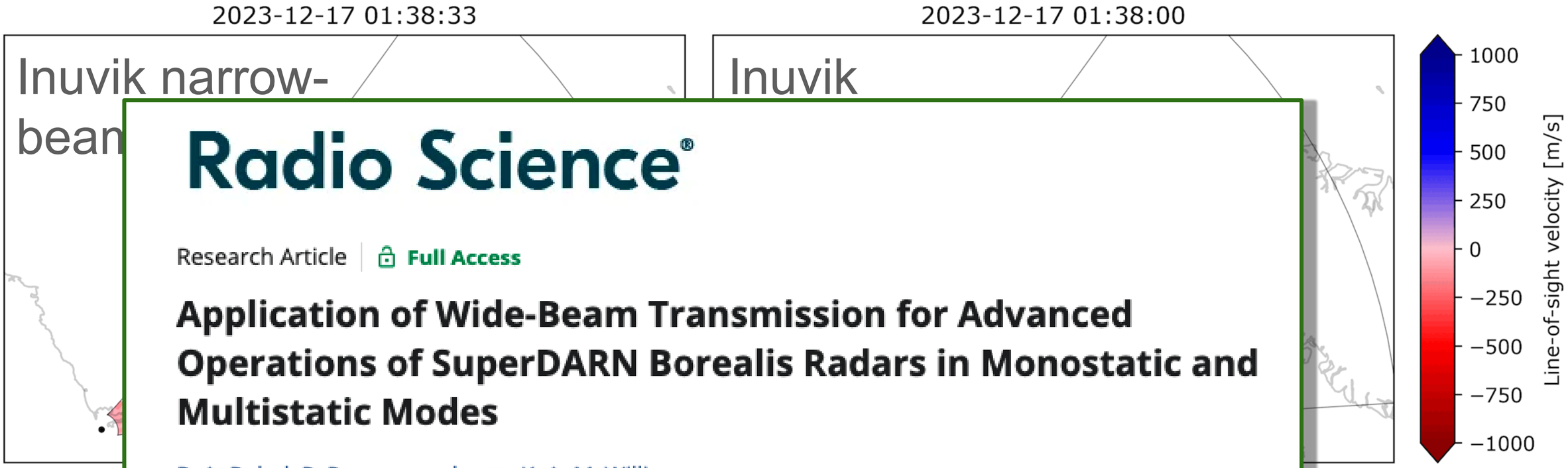

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Application of Wide-Beam Transmission for Advanced Operations of SuperDARN Borealis Radars in Monostatic and Multistatic Modes

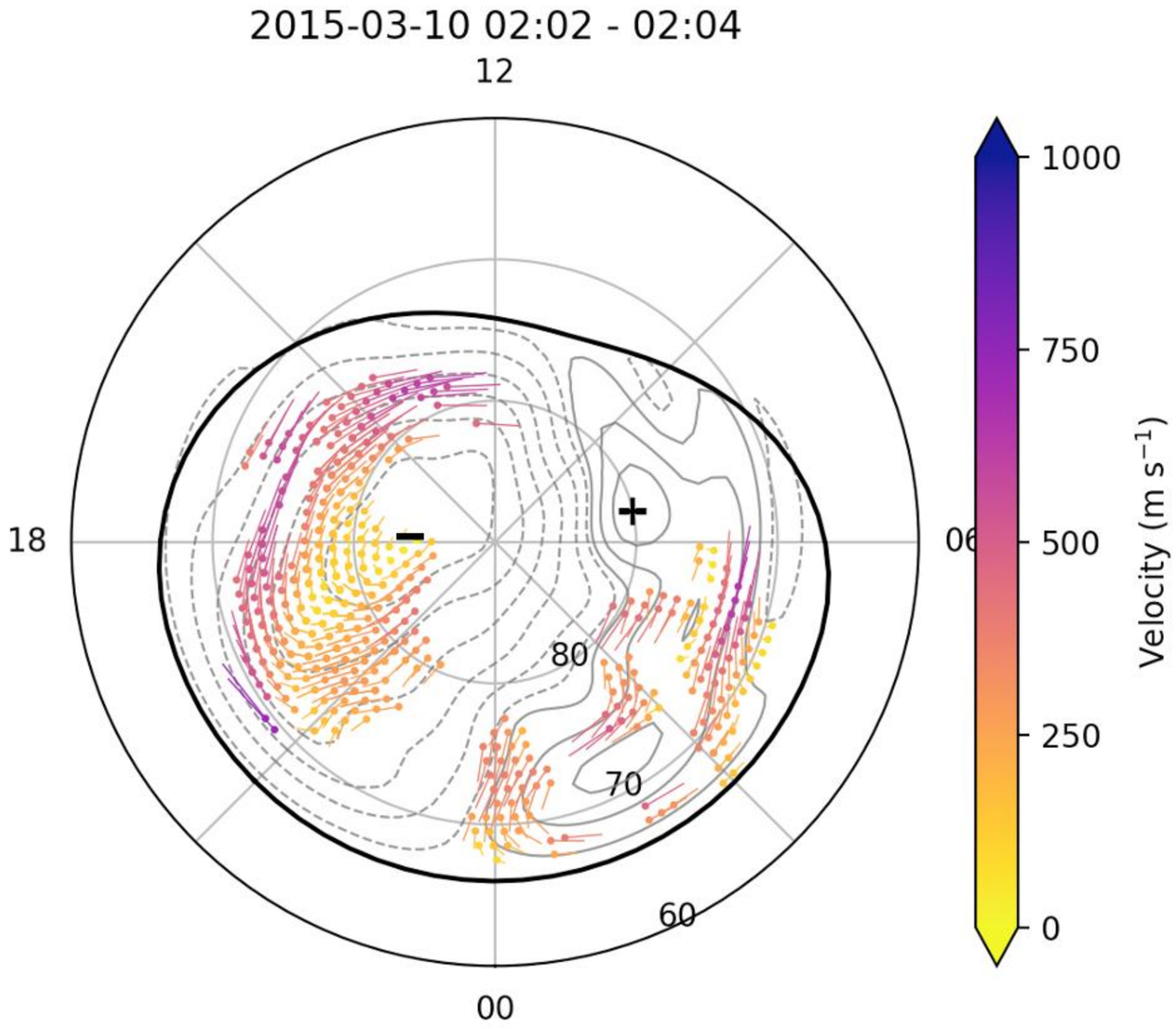
R. A. Rohel, P. Ponomarenko, K. A. McWilliams

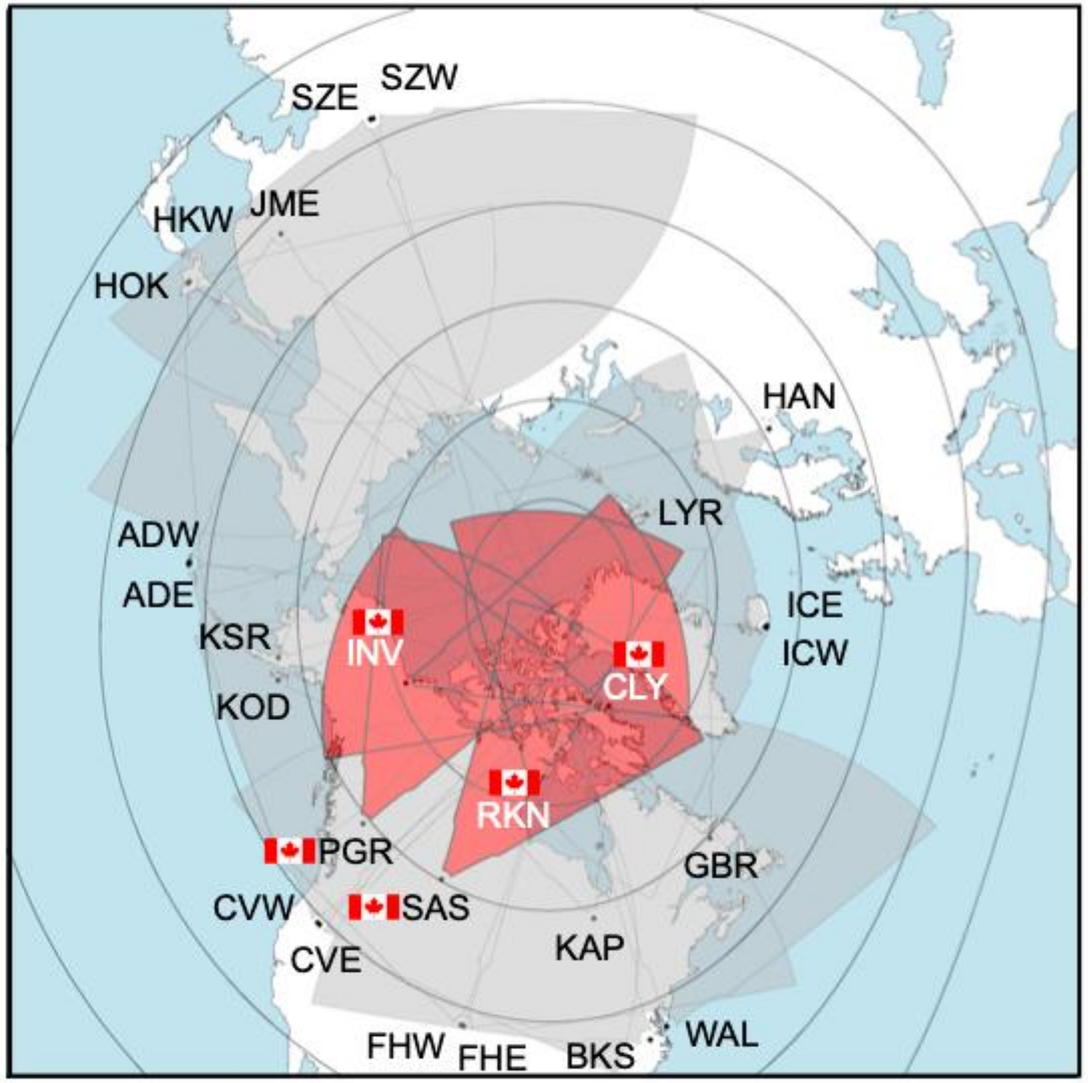
First published: 17 May 2024 | https://doi.org/10.1029/2023RS007900

Improvement

1min → 3.7s

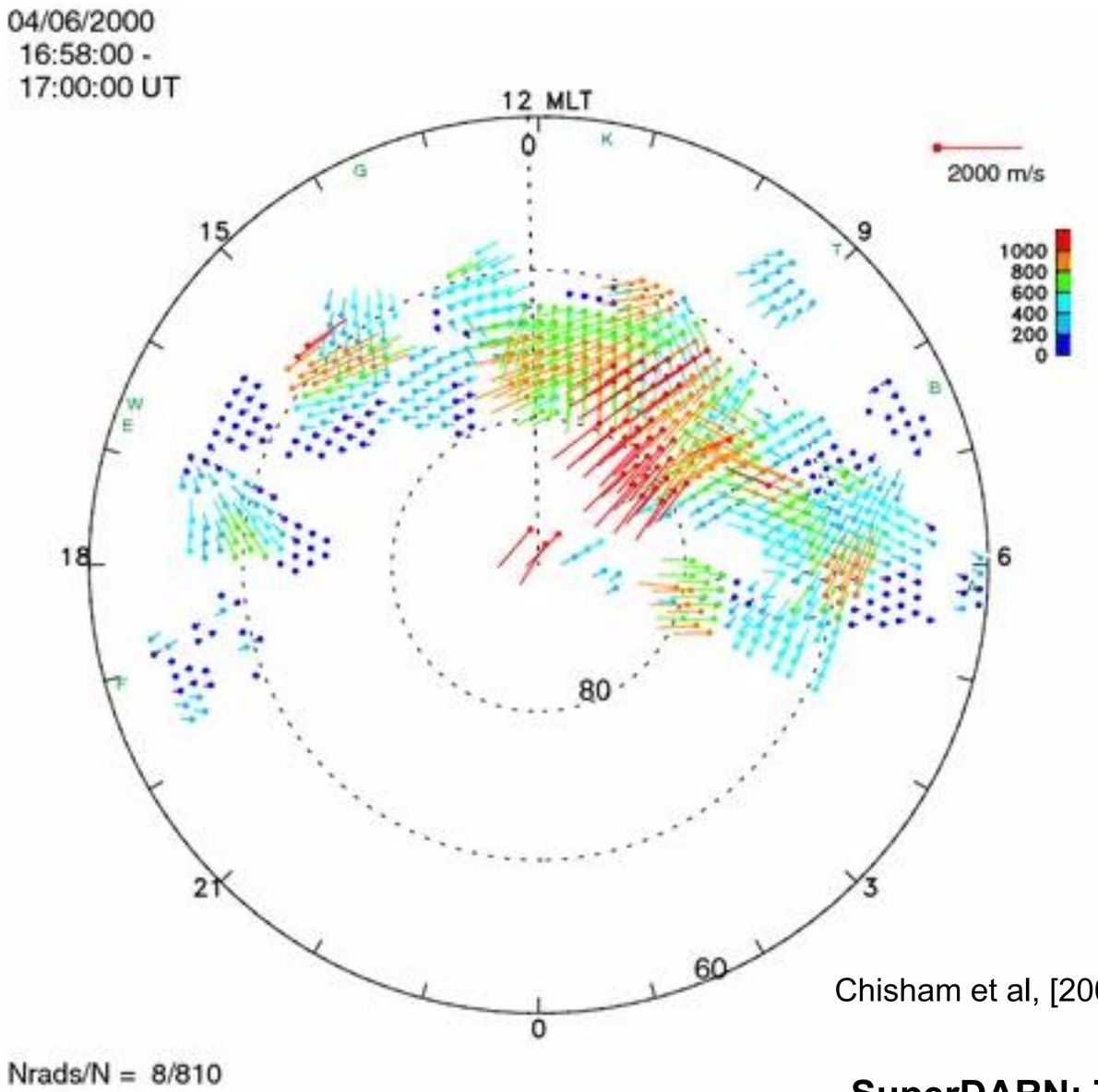
High-res SuperDARN Convection Patterns?





Making a convection map: the standard way

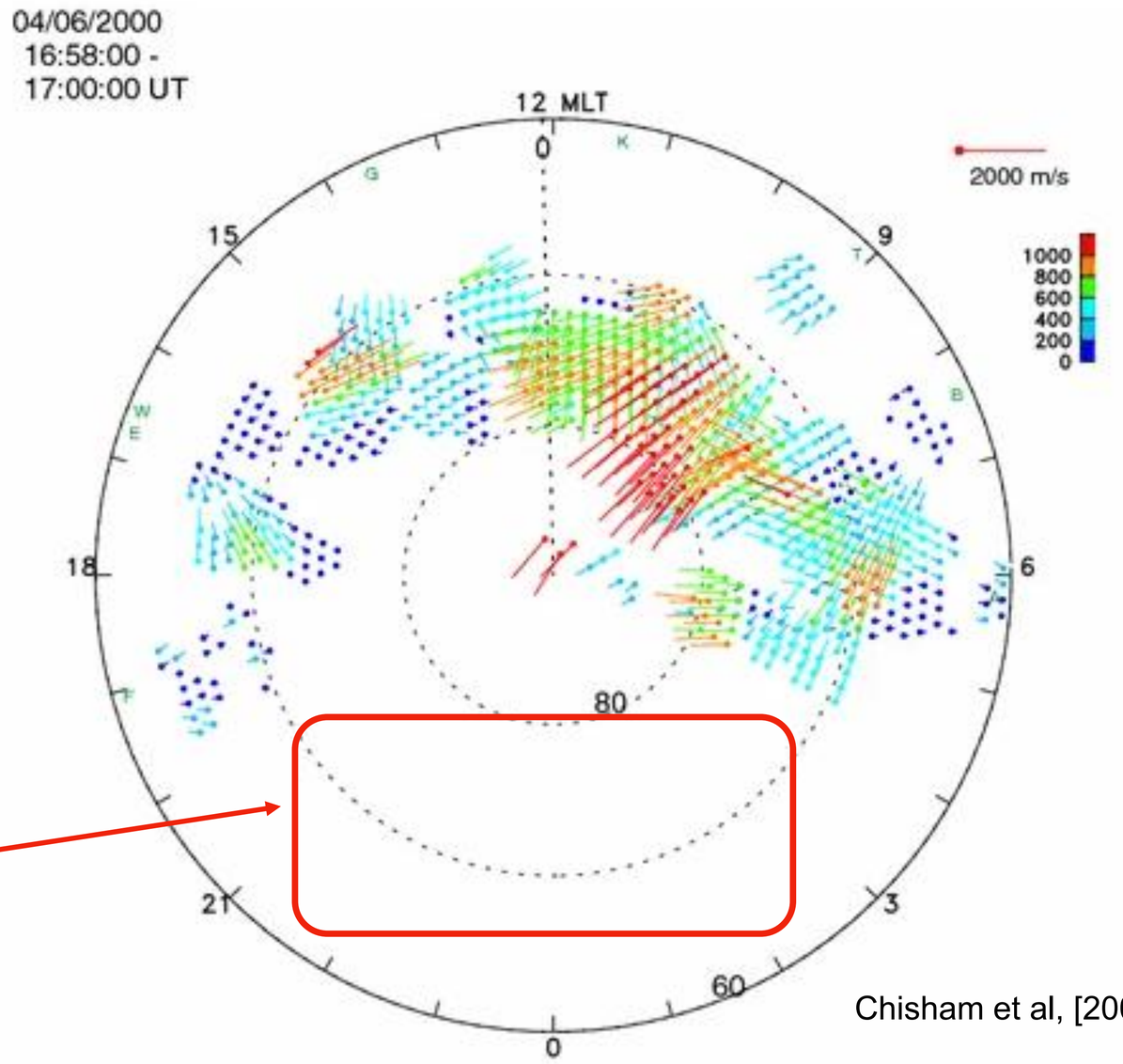
- Collect LOS velocity measurements from all radars
  - Nominally **every two minutes**
- Grid data into equal area bins



Chisham et al, [2007]

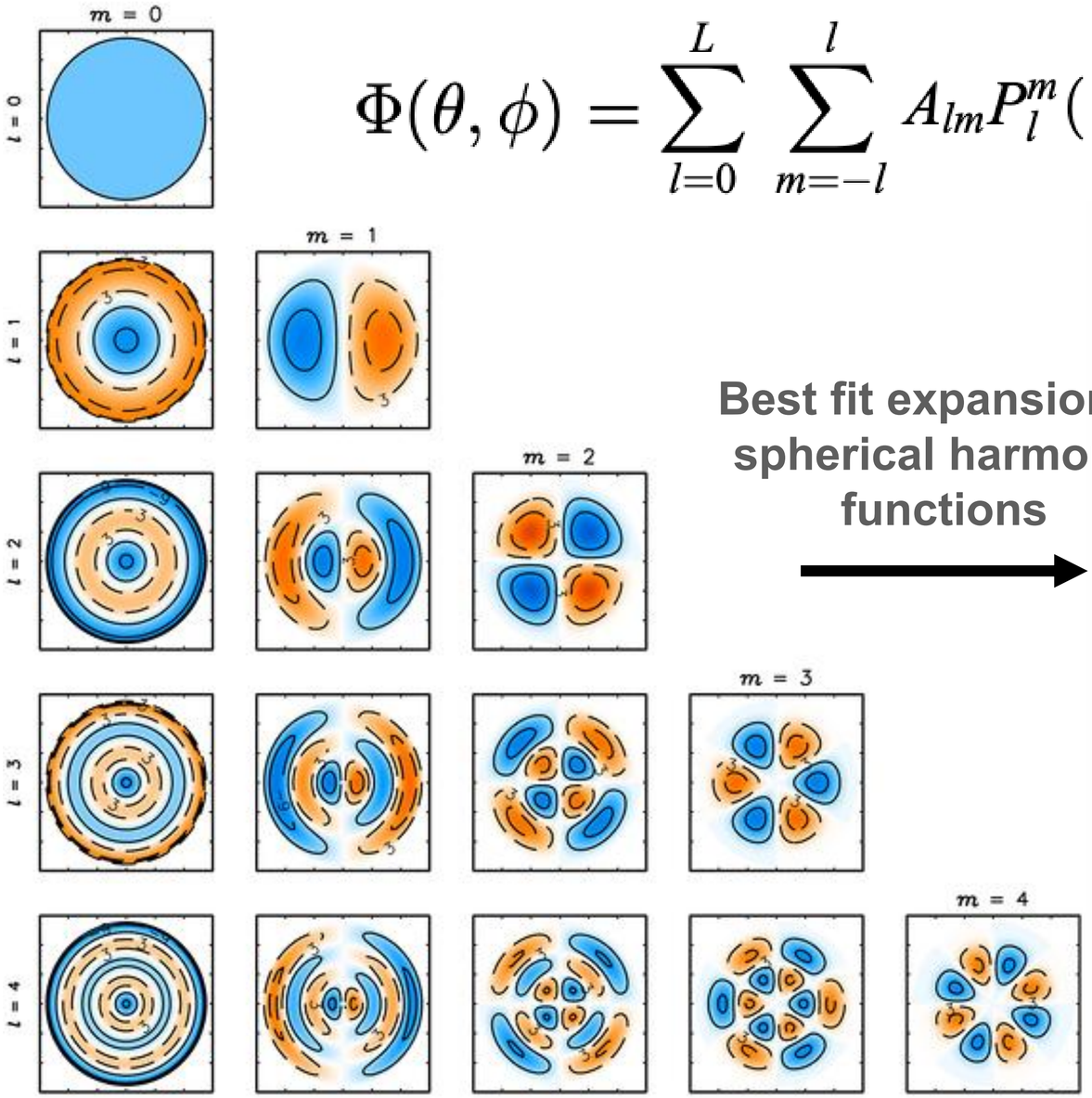
Making a convection map: the standard way

- Collect LOS velocity measurements from all radars
  - Nominally **every two minutes**
- Grid data into equal area bins
- (Optional) Fill gaps with “data” from statistical model



Chisham et al, [2007]

The SuperDARN Ionospheric Convection

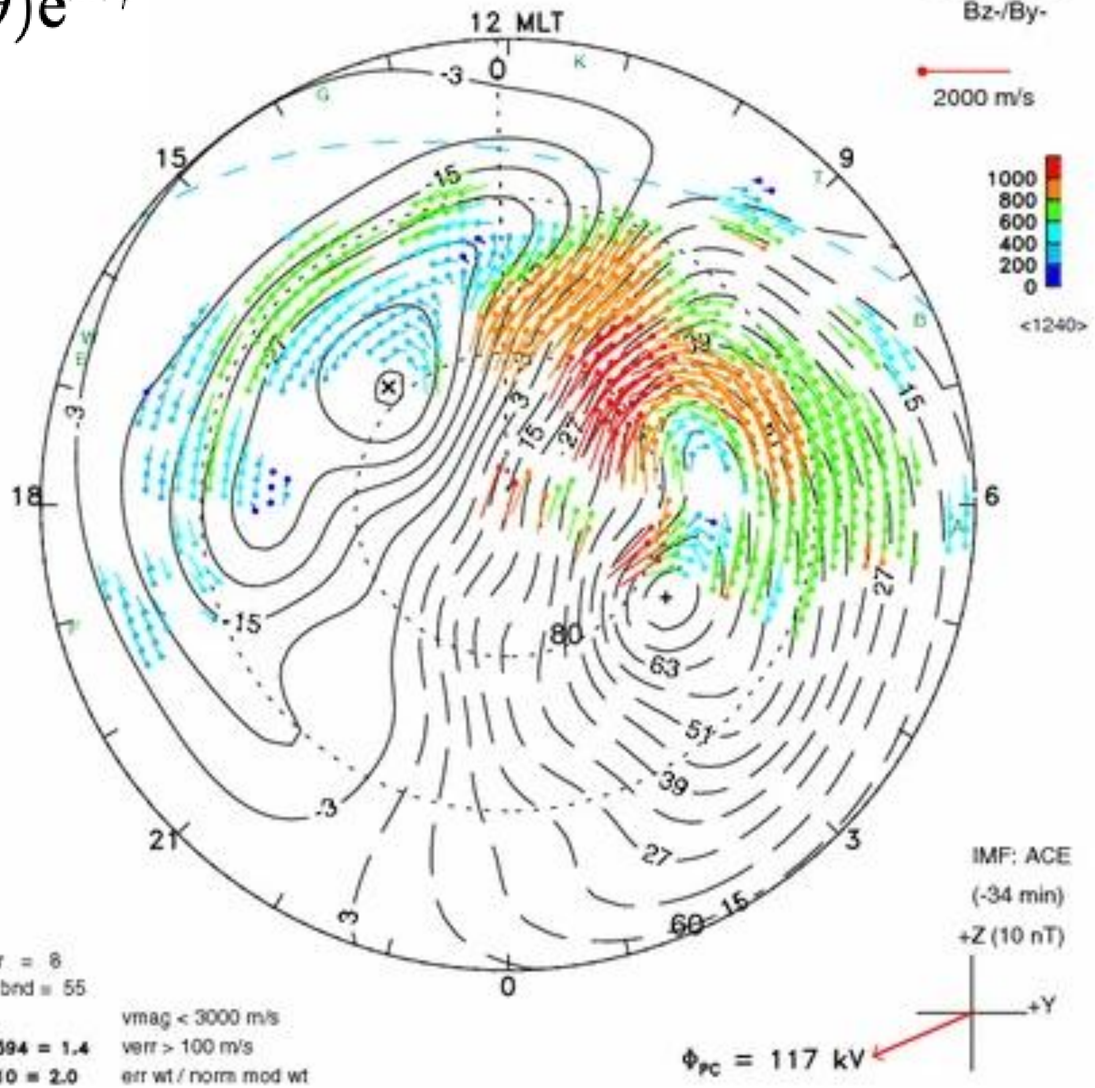


$$\Phi(\theta,\phi) = \sum_{l=0}^{L} \sum_{m=-l}^{l} A_{lm} P_l^m(\cos\theta) e^{im\phi}$$

Grocott et al., 2012

Best fit expansion of spherical harmonic functions

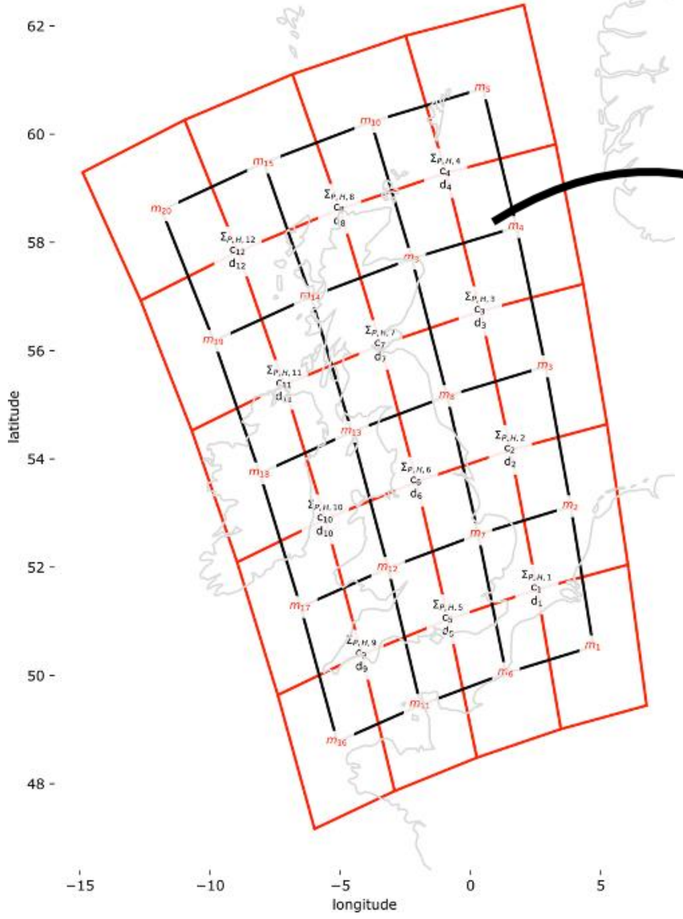
Chisham et al., 2007

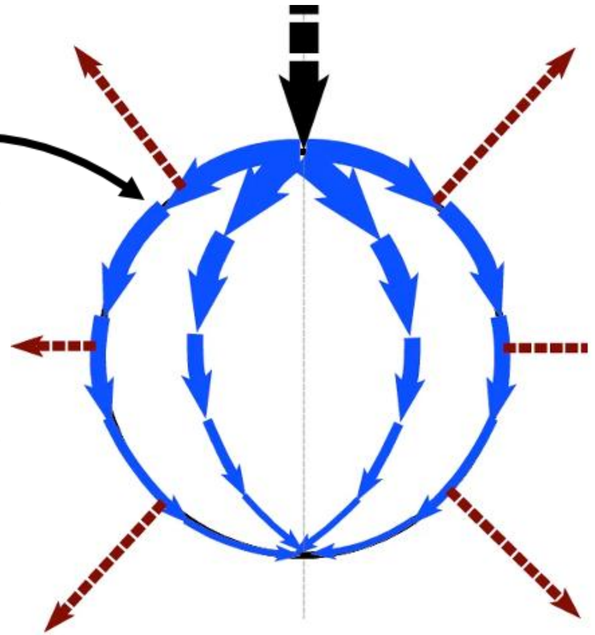


Local mapping of polar electrodynamics

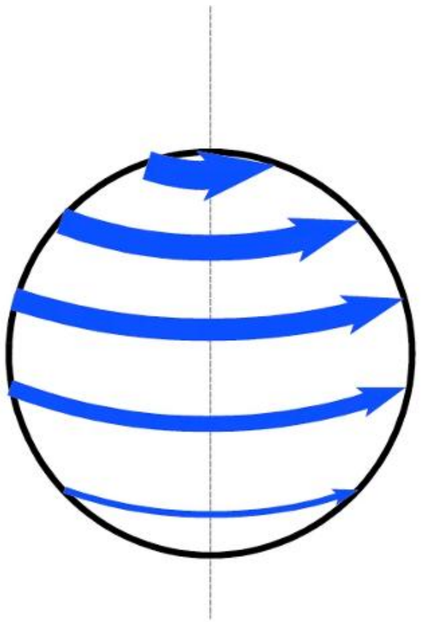
Electric field is directly represented through the sum of divergence-free and curl-free components **(spherical elementary current systems method)**

Laundal et al, 2022





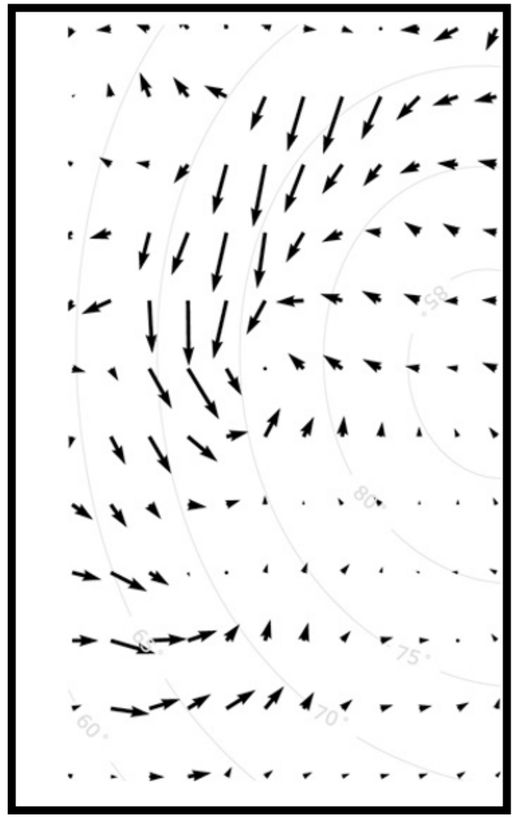
Curl-free elementary system
(with associated FACs)



Divergence-free elementary system

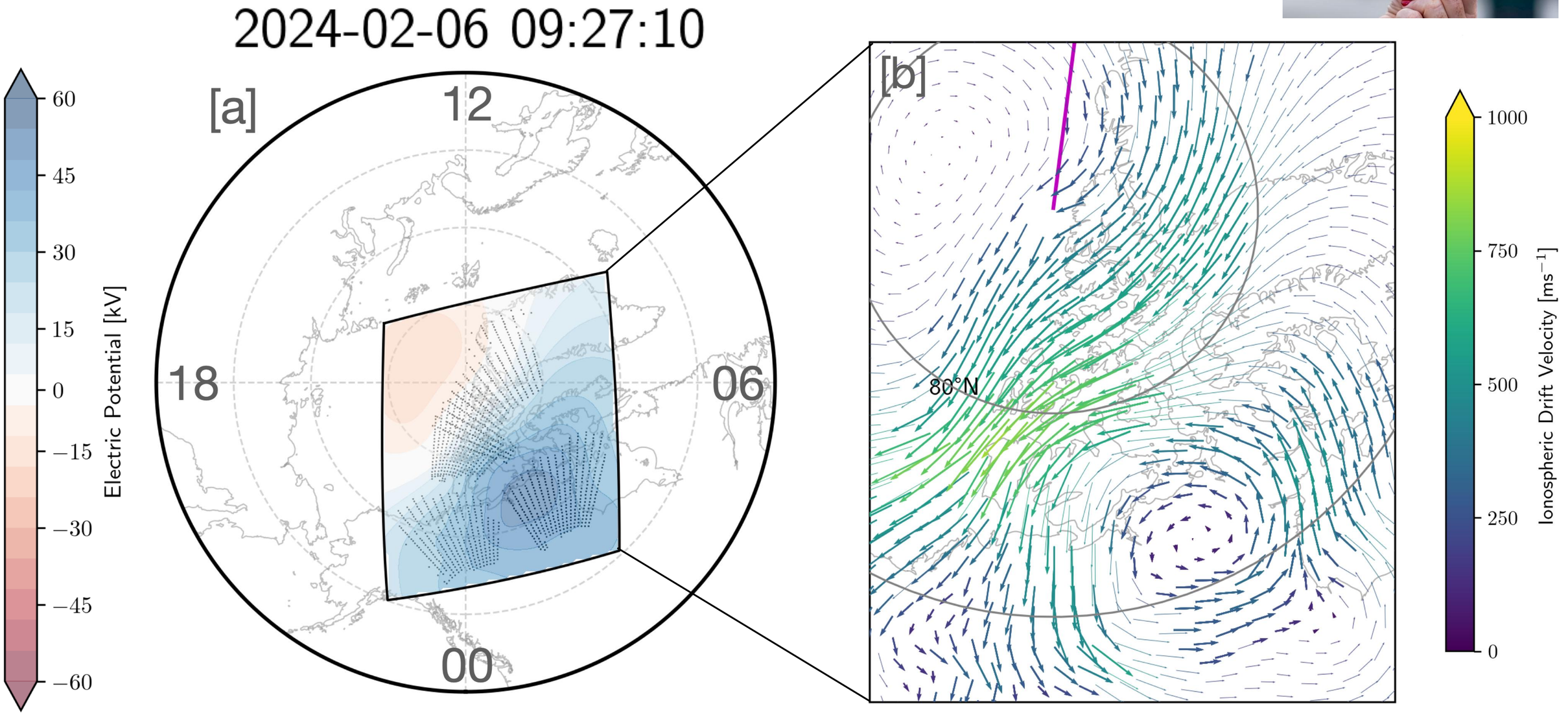
Vanhamäki & Juusola, 2019

Horizontal currents



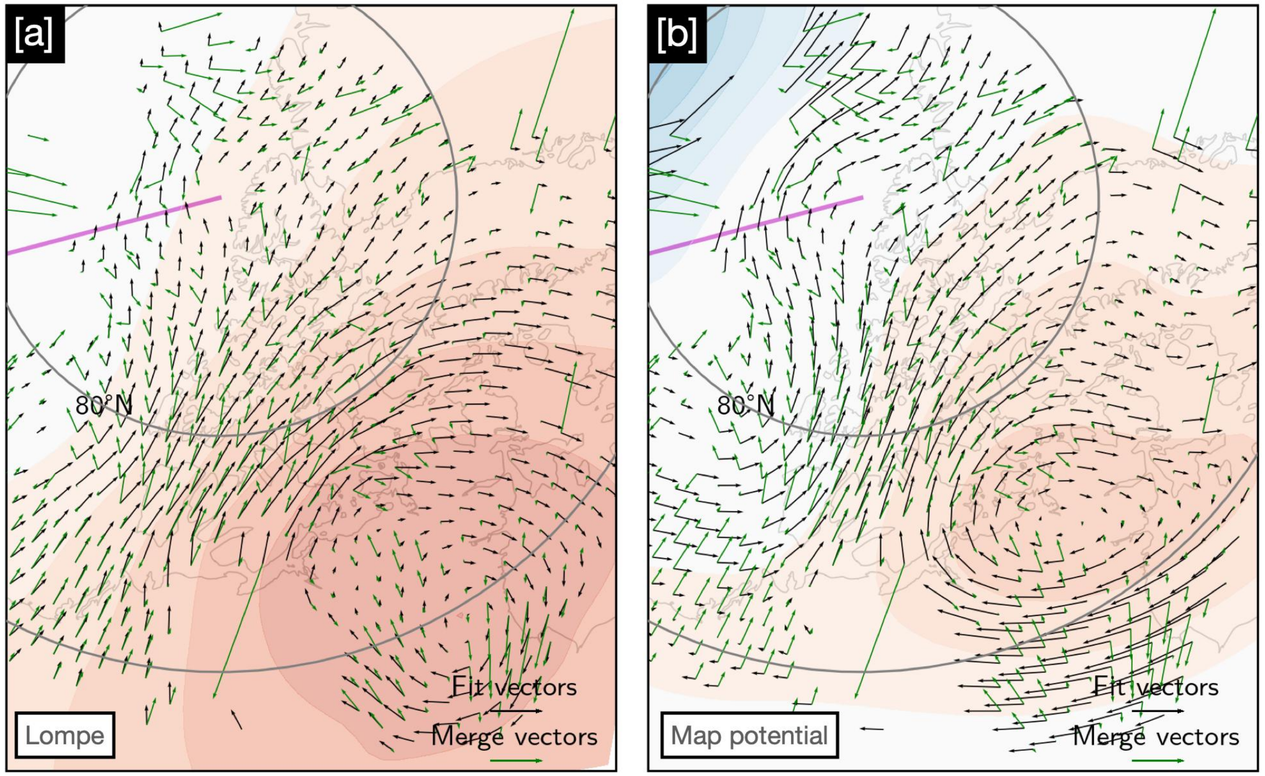
Laundal et al, 2022

Lompe applied to SuperDARN

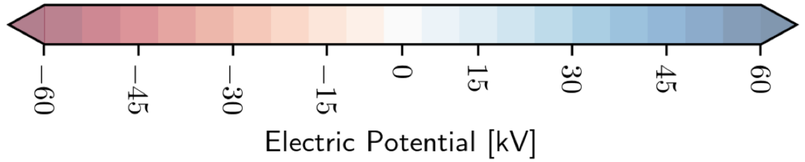


Lompe vs Map Potential

Merge vectors = combined velocity from direct LOS/fitacf measurements



Fit vectors = Lompe or Map Potential solution



2024-01-16 02:18:43

500 [m/s]

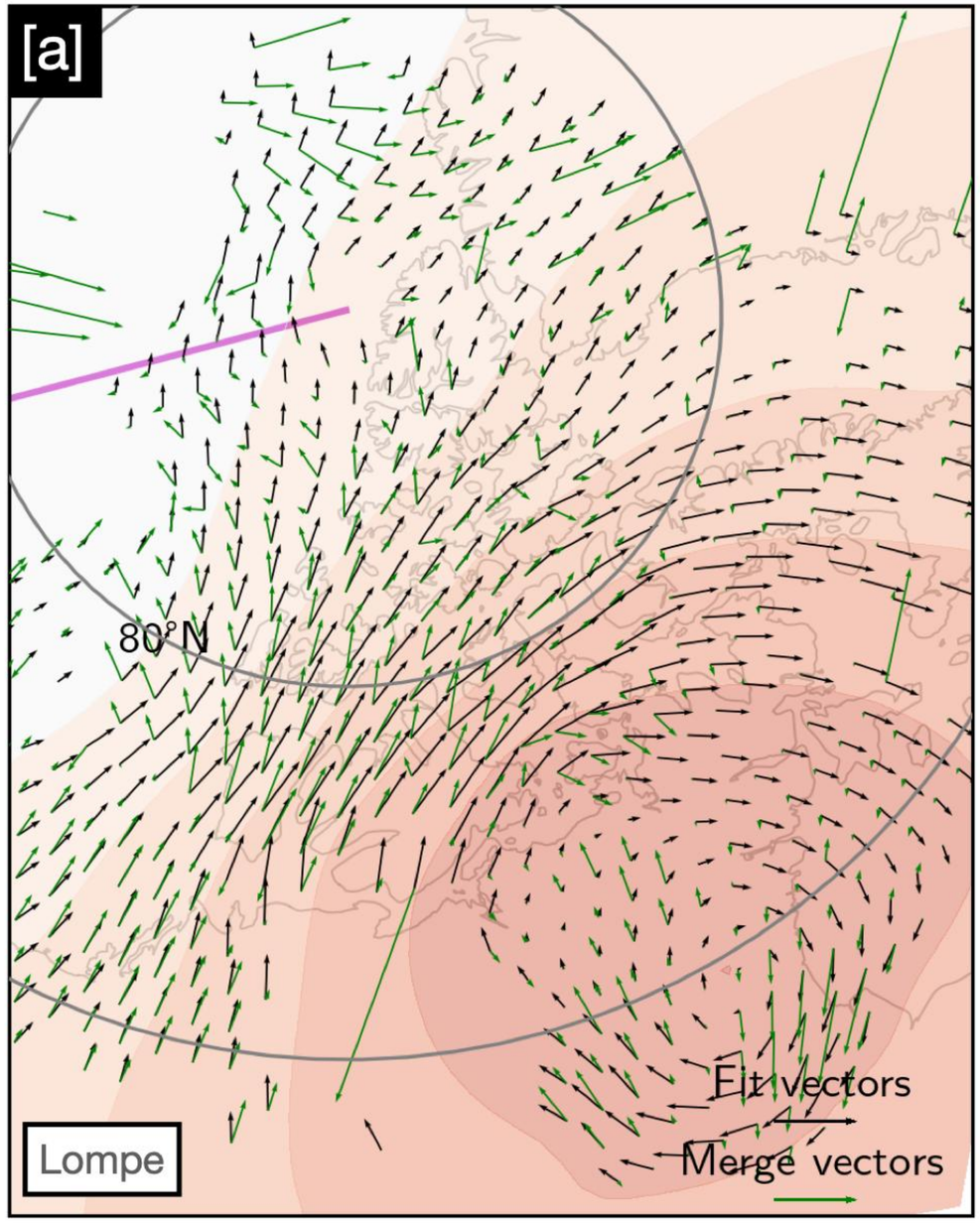
Lompe vs Map Potential

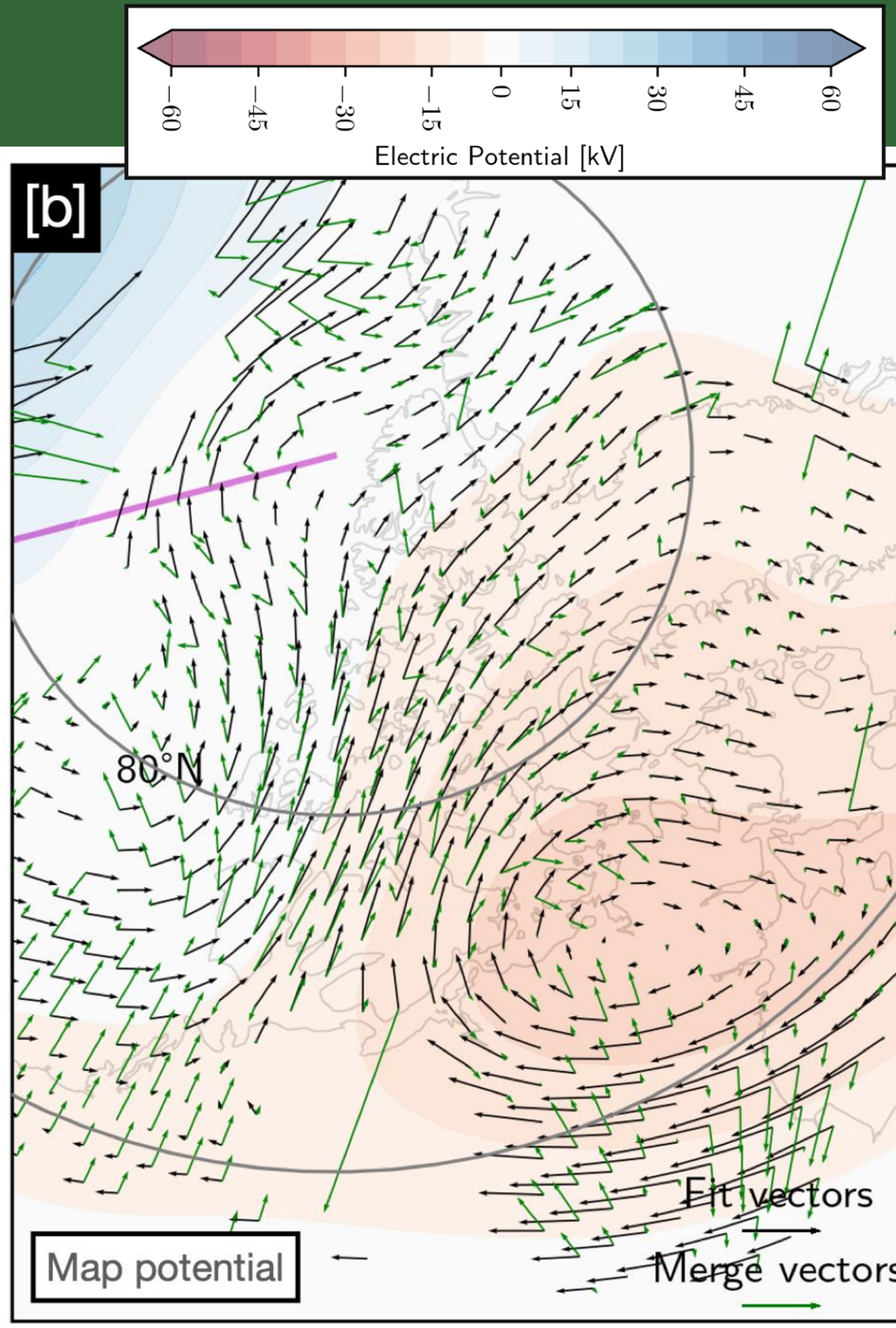
Merge vectors: combined velocity from direct LOS/fitacf measurements

Fit vectors: Lompe **or** Map Potential solution

2024-01-16 02:18:43

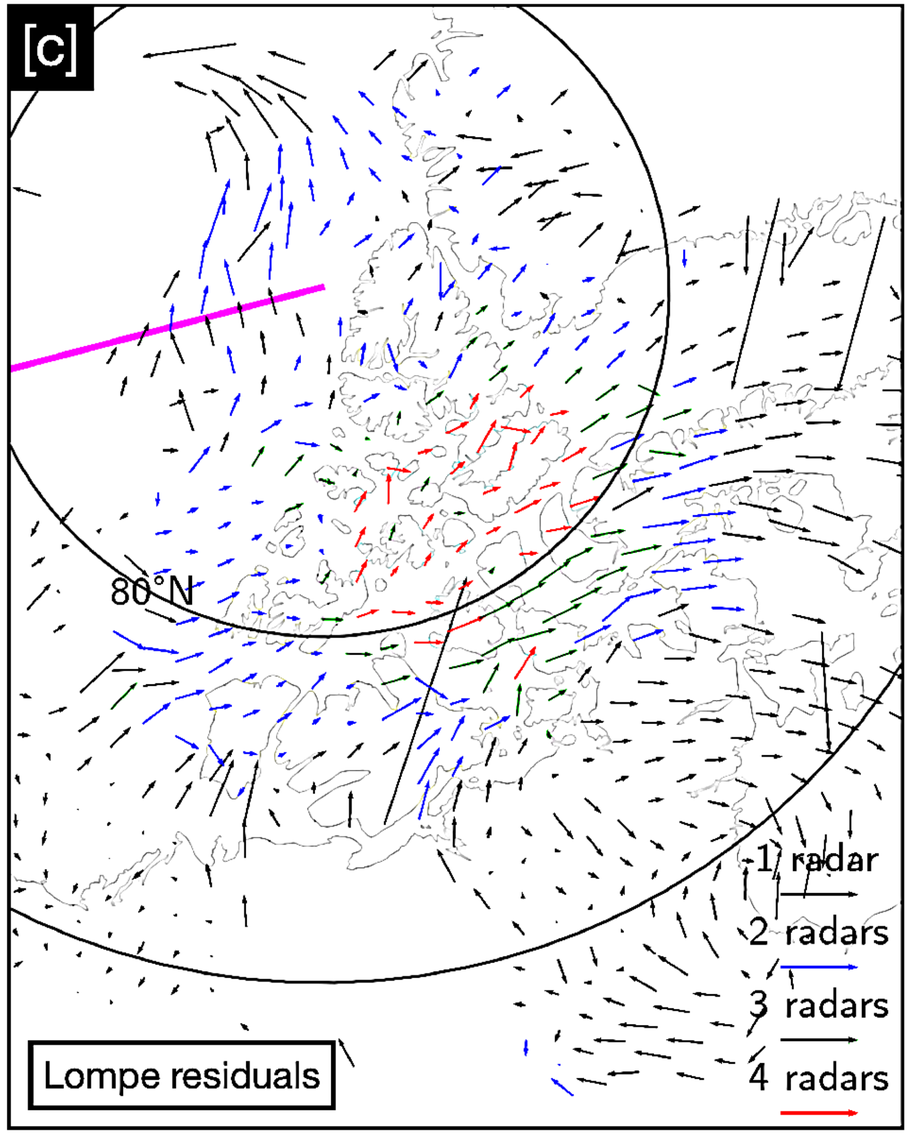
500 [m/s]

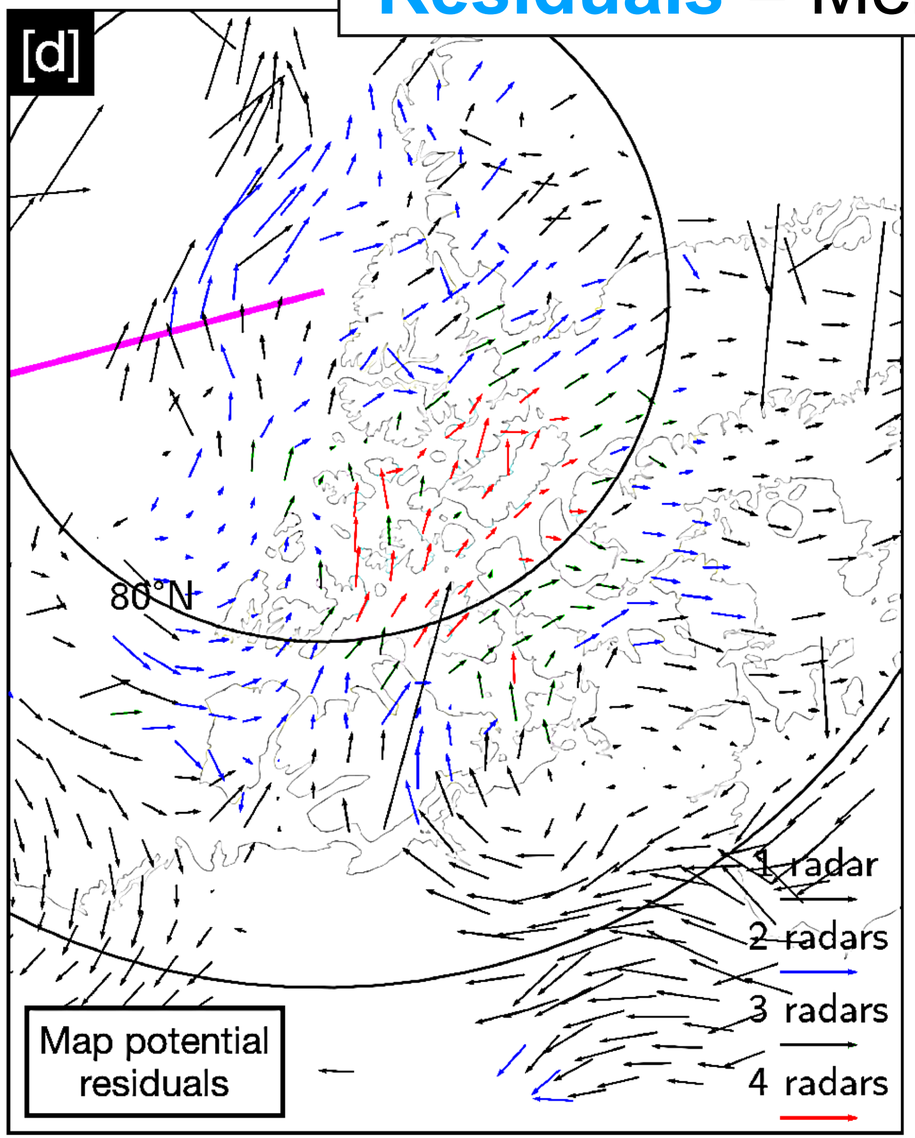




Lompe vs Map Potential

Residuals = Merge - Fit



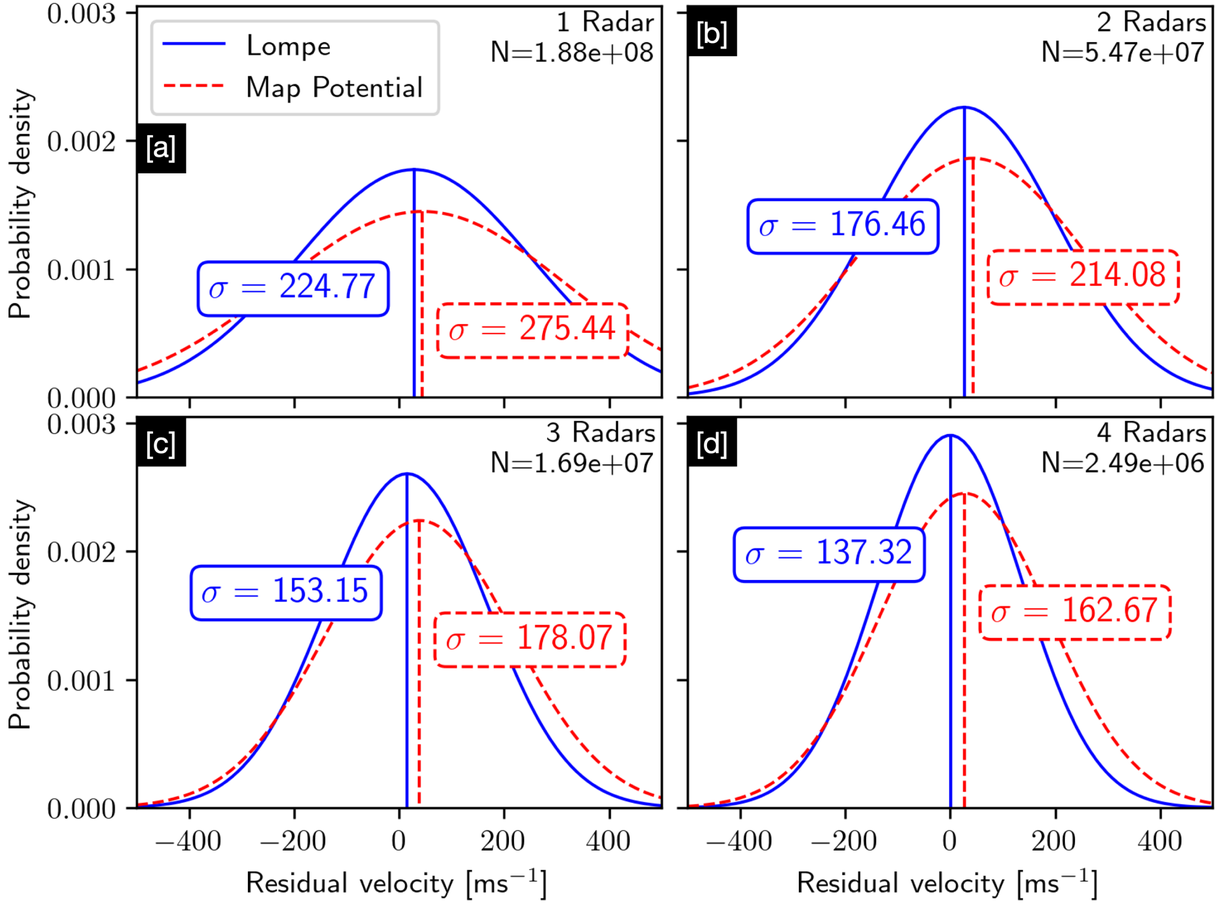


2024-01-16 02:18:43

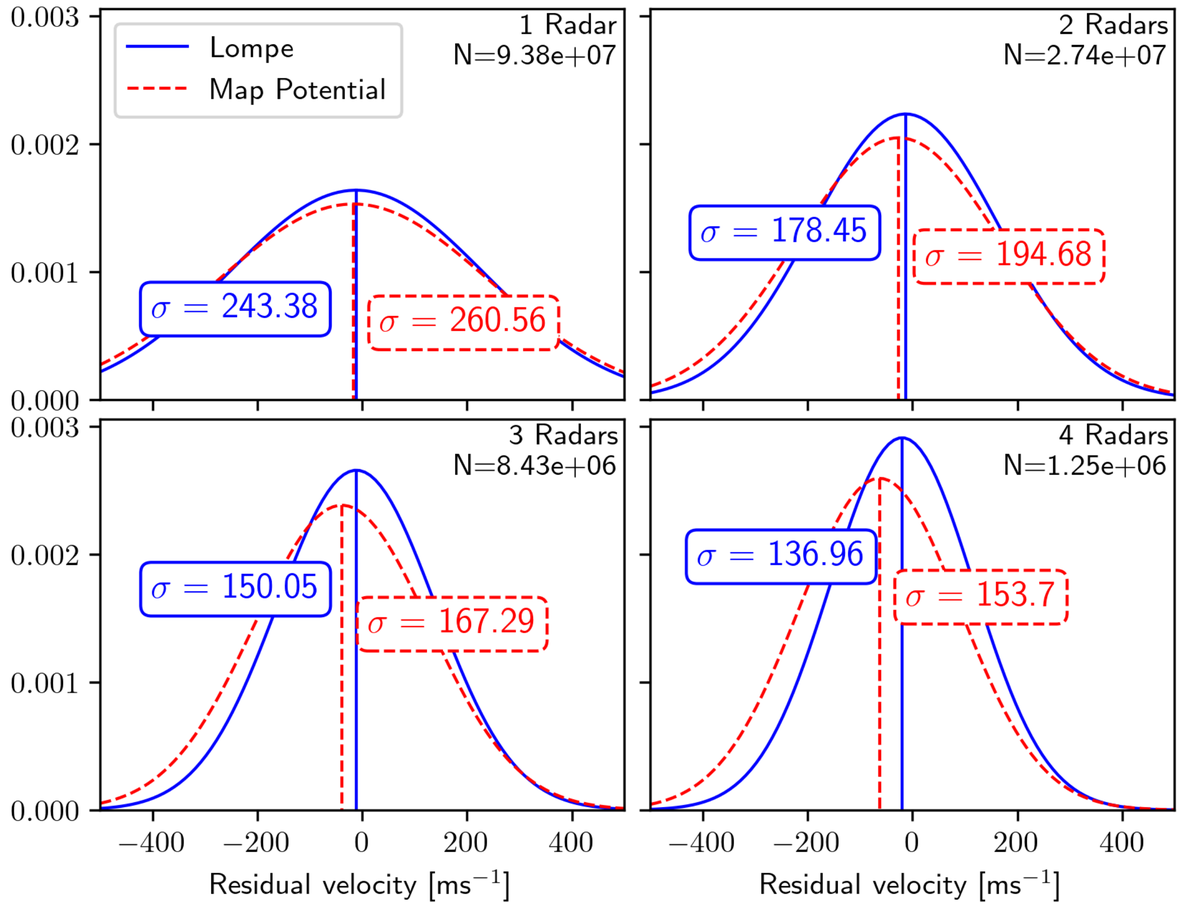
500 [m/s]

Lompe vs Map Potential - Jan/Feb 2024 wide-beam runs

Zonal residuals



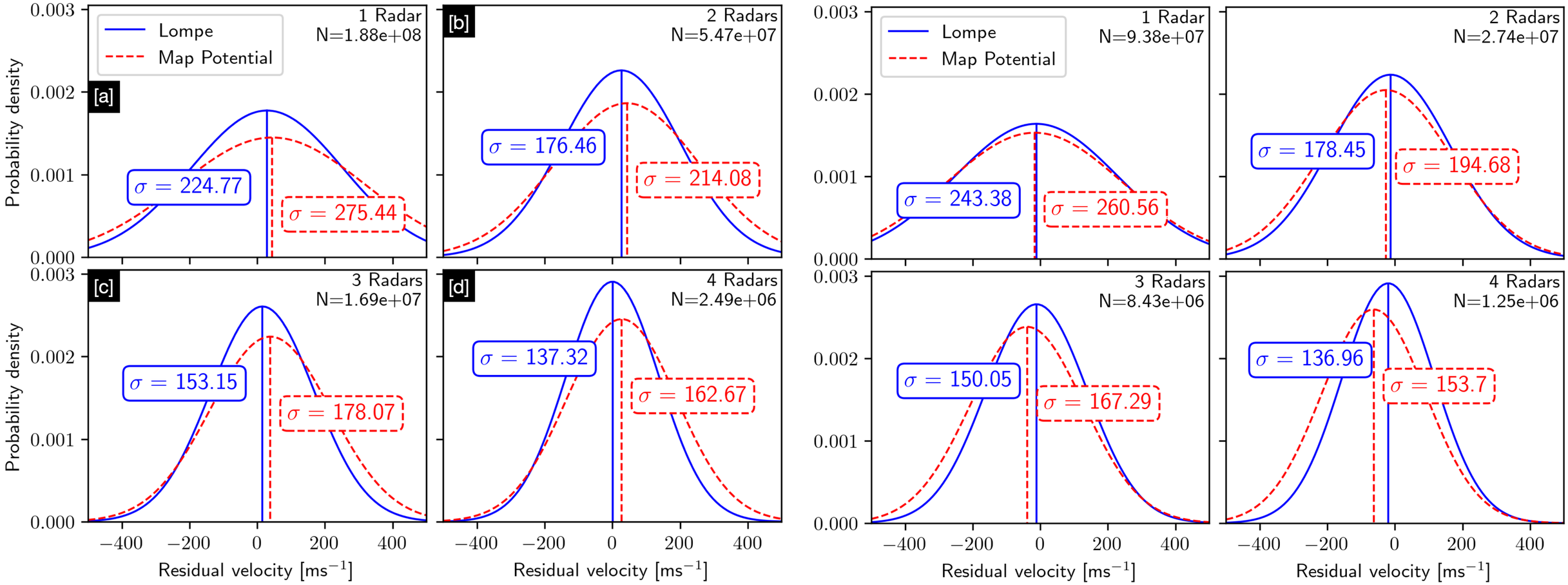
Meridional residuals



Lompe vs Map Potential - Jan/Feb 2024 wide-beam runs

Zonal residuals

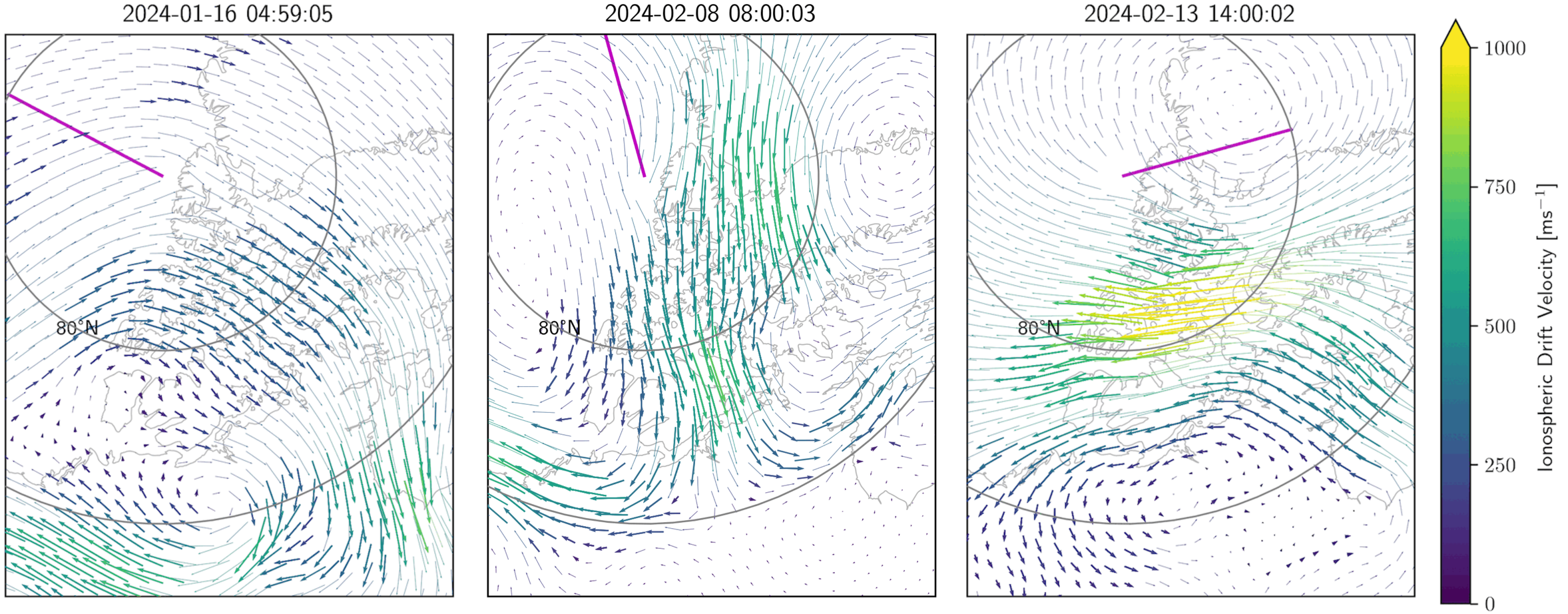
Meridional residuals



Lompe residual σ is systematically smaller, median closer to zero

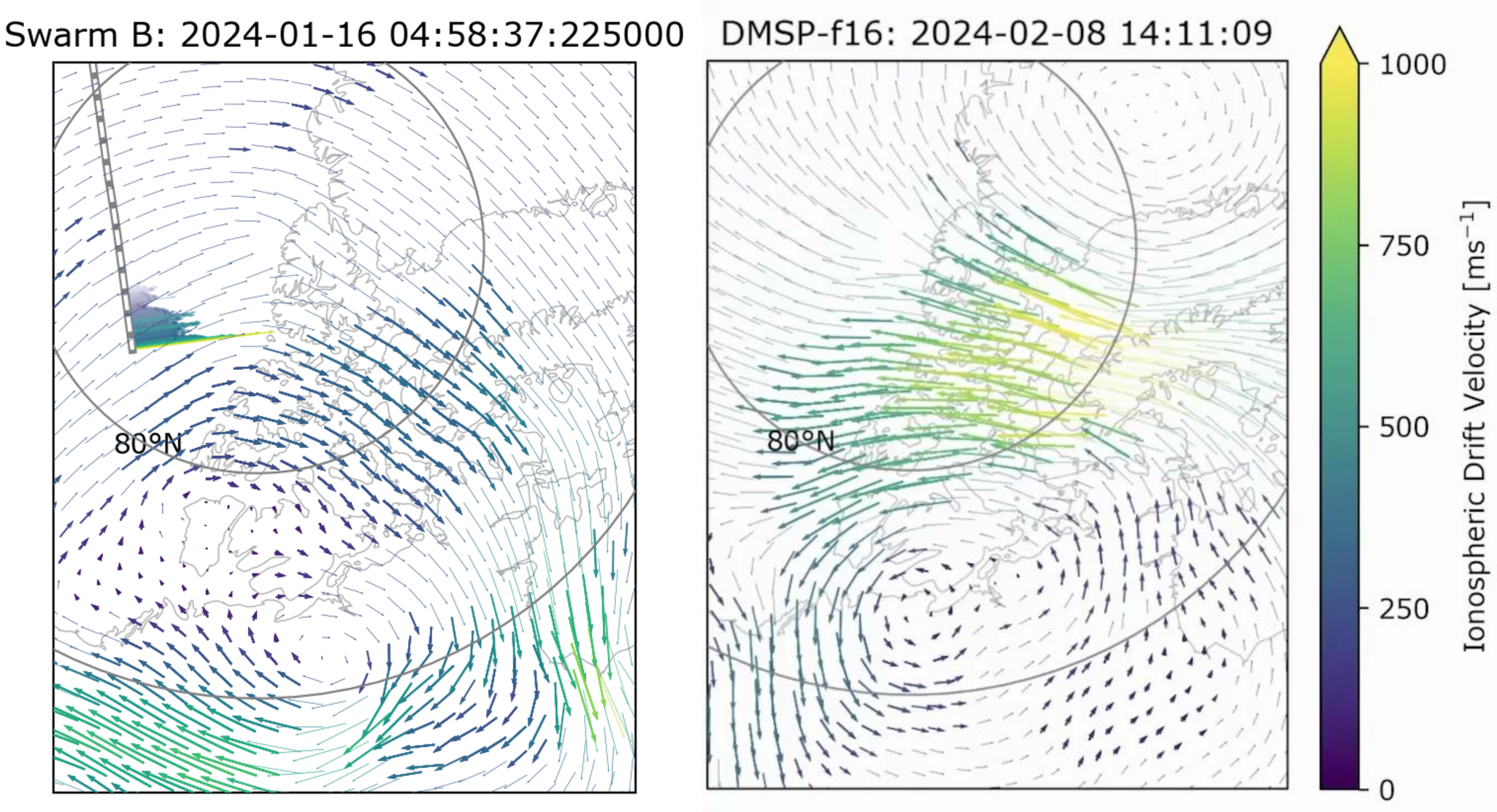
The Fast Borealis Ionosphere:

Polar cap ionospheric drift patterns every 3.7s



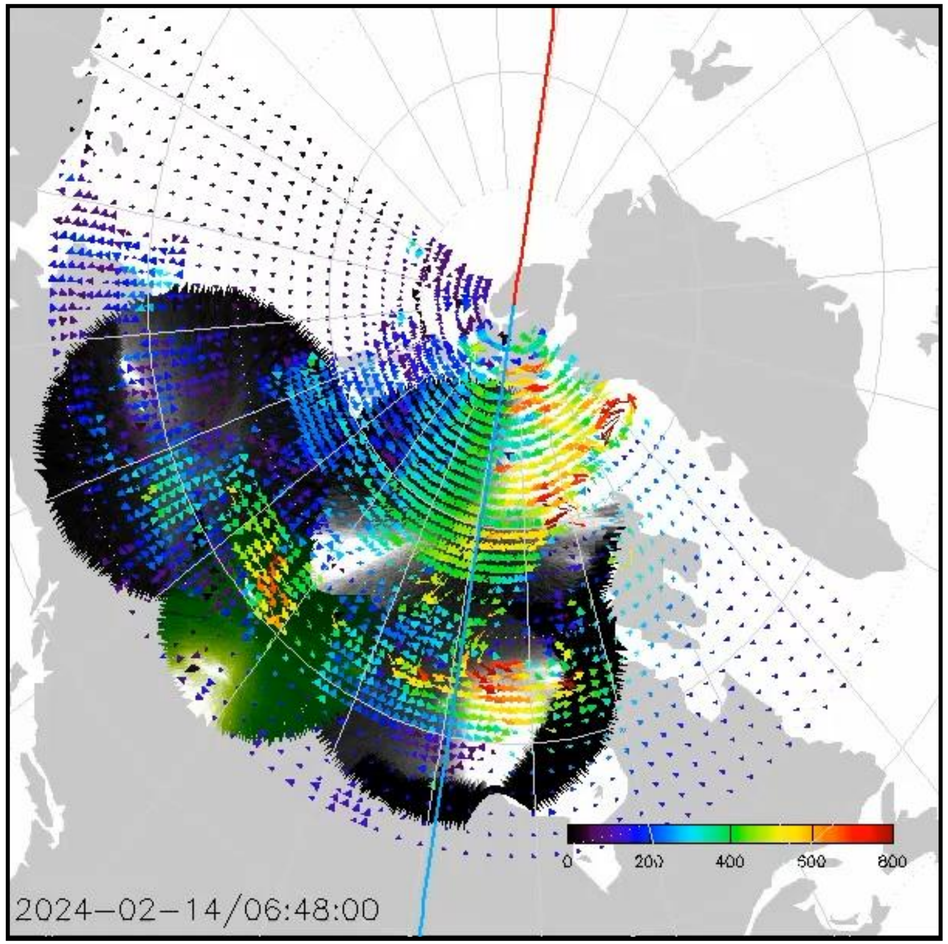
The Fast Borealis Ionosphere:

The **temporal resolution** of a satellite,
the **large coverage** of a ground-based network



Collaborations + Conjunctions

Fast Borealis Ionosphere + all-sky cameras



Credit: Toshi Nishimura @ Boston

Collaborations + Conjunctions

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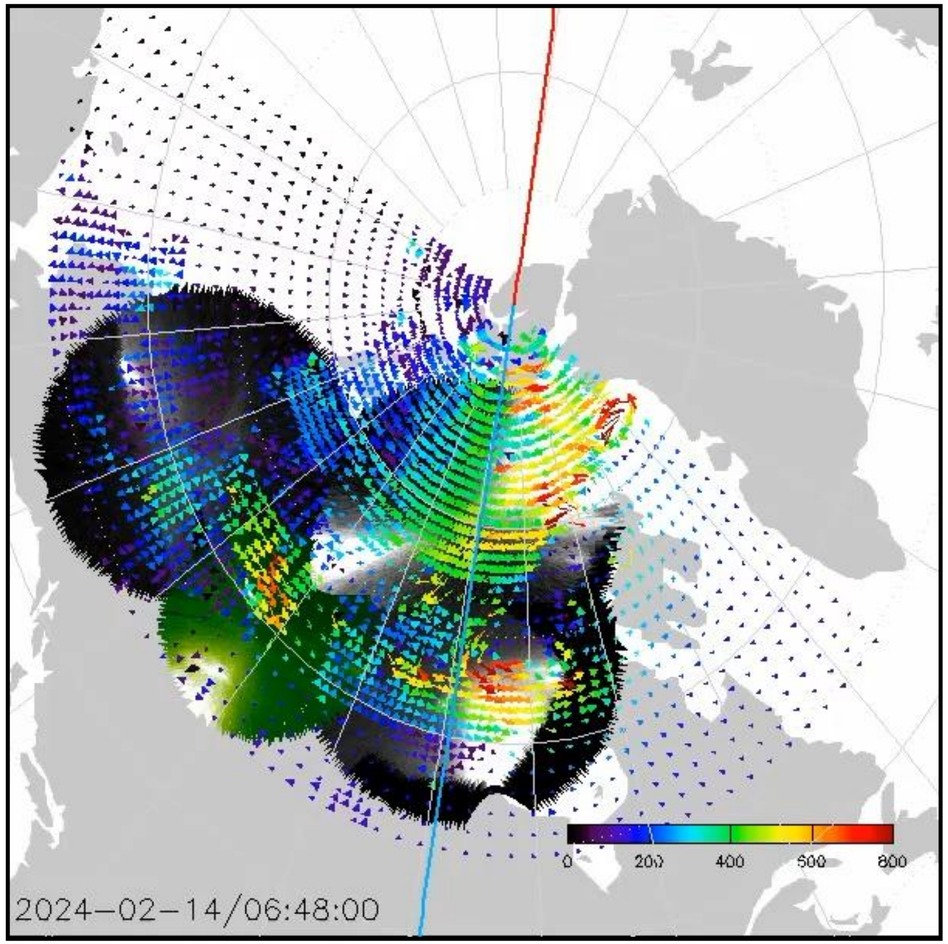

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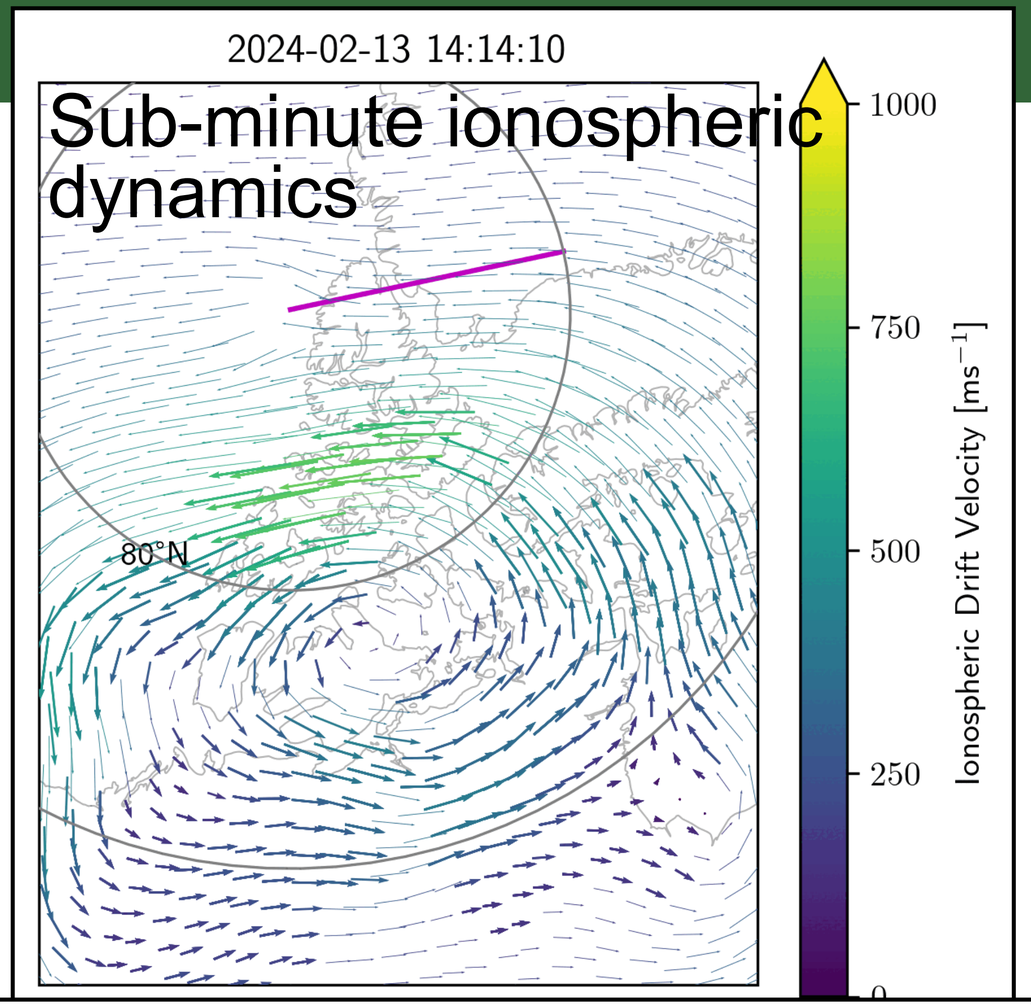
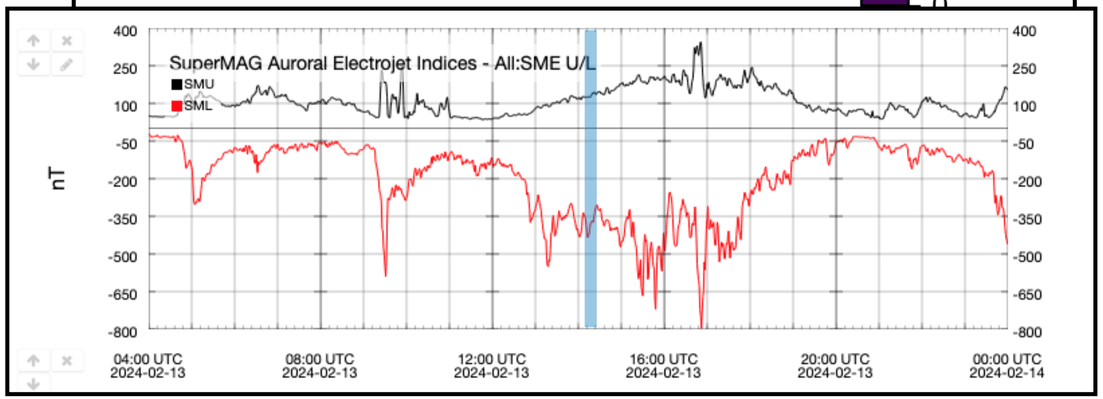


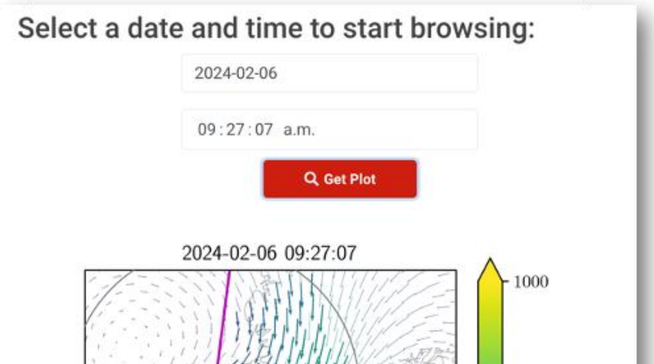


The Fast Borealis Ionosphere

daniel.billett@usask.ca

- Data freely available online once generated

Quick-browse plots available at superdarn.ca/fbi



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daniel.billett@usask.ca

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- ~53 days worth, including 2024 solar eclipse

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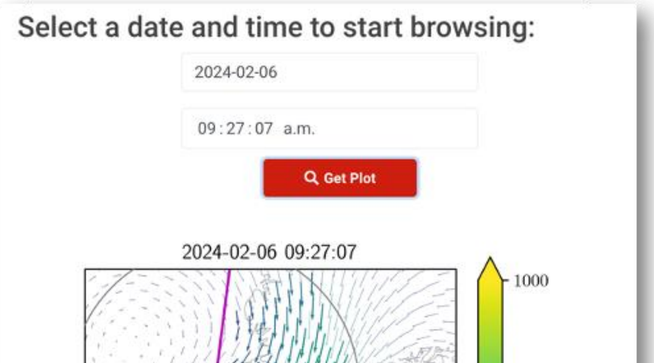

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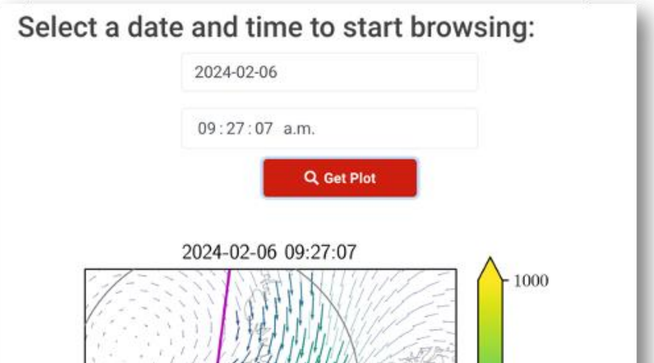

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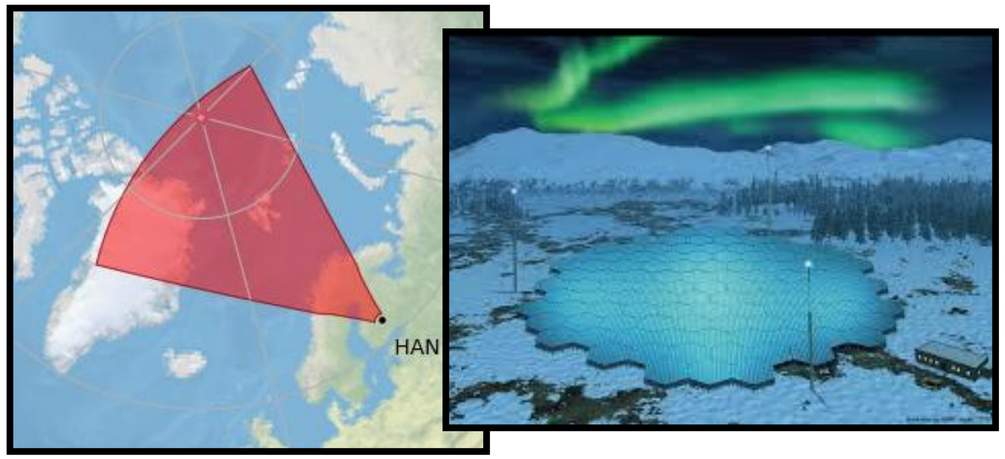

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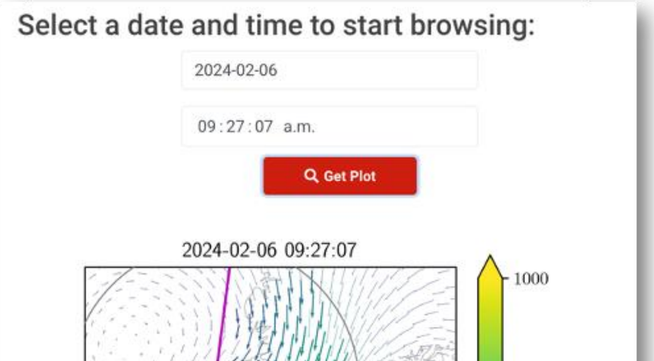

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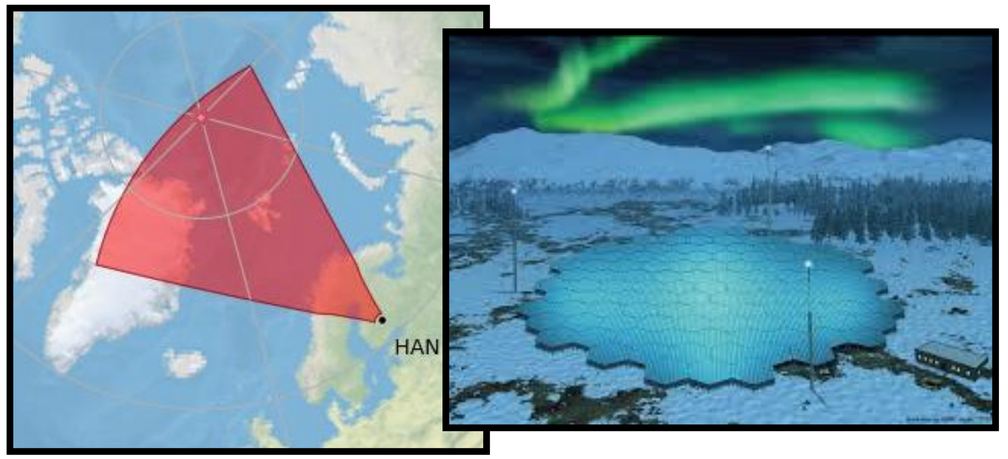
- 2025: Borealis at Hankasalmi to overlap with EISCAT_3D
- Working towards **24/7/365** operations



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