Enhanced operation of SuperDARN radars with the Borealis radar system

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Outline

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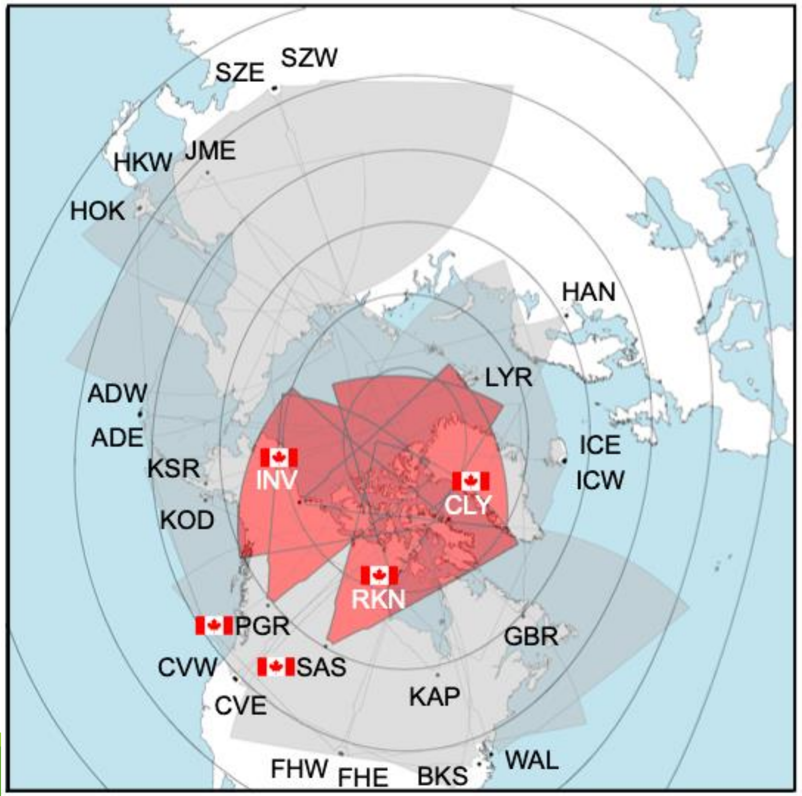
Image courtesy of Theodore Kolkman

Super Dual Auroral Radar Network

40+ radars worldwide

5 managed by Usask

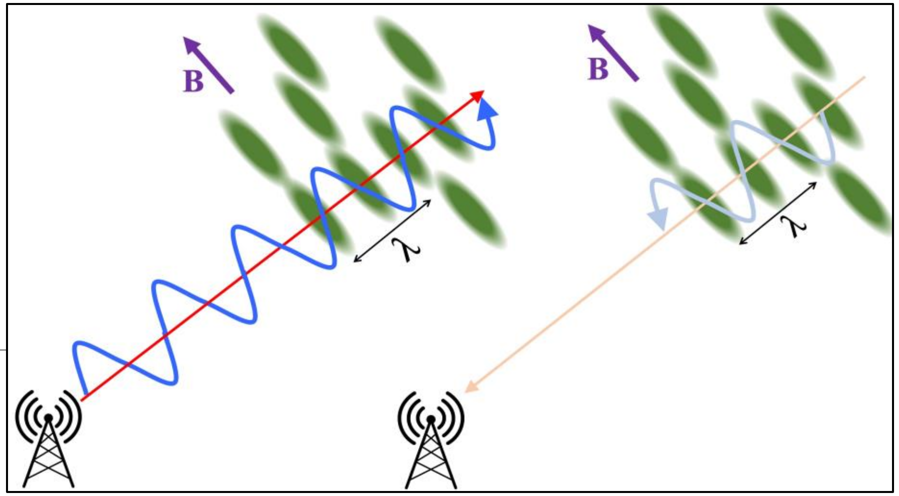


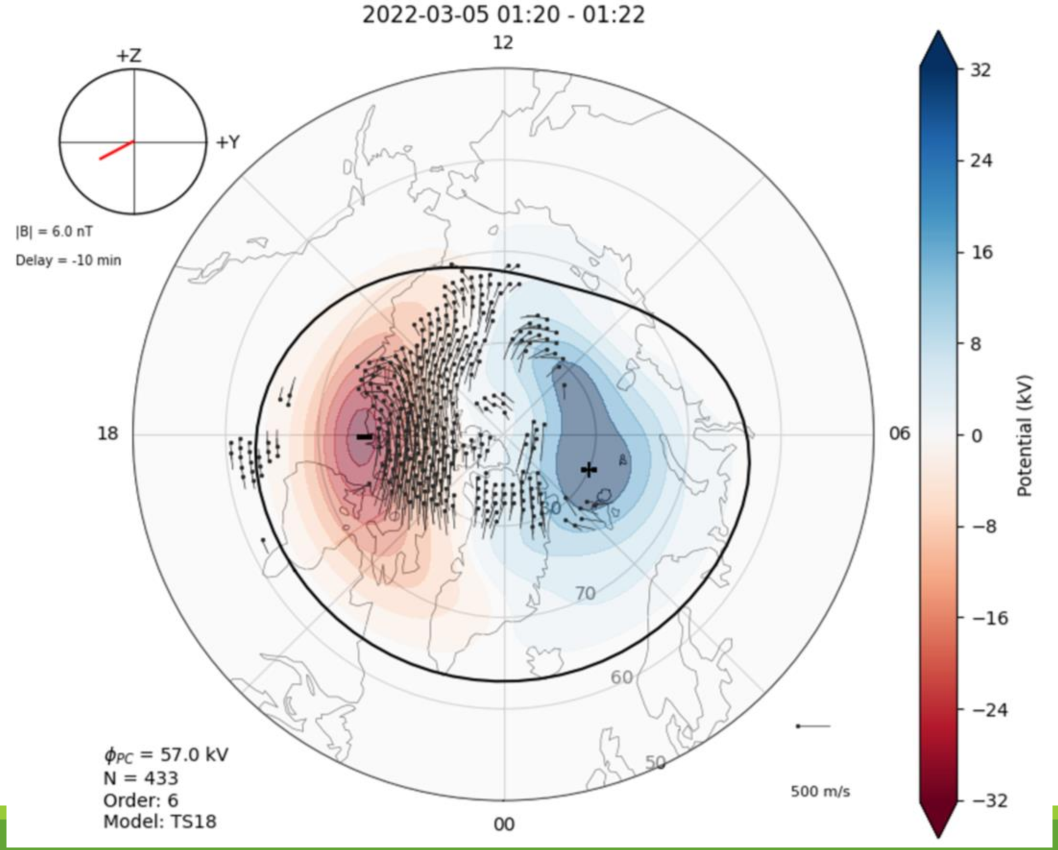
From superdarn.ca

Prince George radar. From SuperDARN Canada

Operating Principles

- Transmits short HF (10-18 MHz) pulses
- Pulses "echo" from ionospheric irregularities
- Doppler shifts measured along line-of-sight
- Process repeated in new direction
- Velocity measurements from multiple radars combined to map plasma convection





Top: from superdarn.ca
Bottom: from Dr. Daniel Billett

Problem Formulation

Consecutive directional scanning:

- sampling rate limited by number of beams (1 minute)
- different directions sampled at different times
- Doppler measurements co-linear along a beam – fixed direction for a radar

New "Borealis" system developed at Usask:

- allows separate beamforming for transmit (TX) and receive (RX) beams
- signals from antennas saved independently, allowing postprocessing

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

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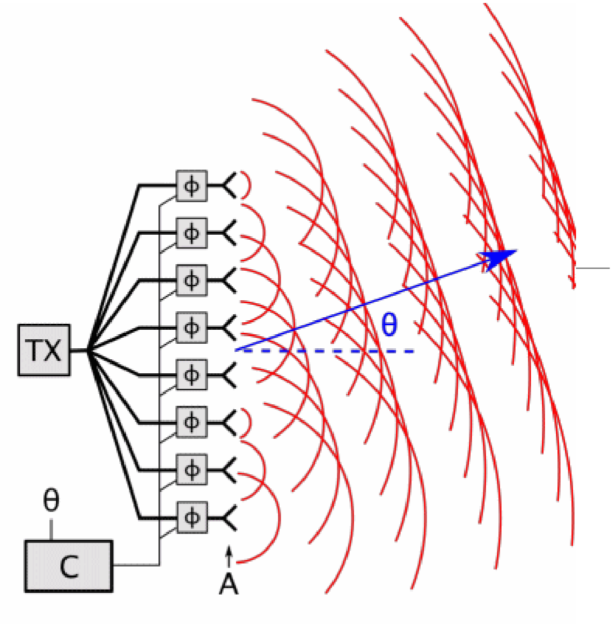
Research Objectives

1. To develop the operational capability to transmit a beam that illuminates a SuperDARN radar FOV to overcome the limitations of directional scanning.
2. To develop the operational capability to transmit with one SuperDARN radar and receive with another while transmitting a wide beam, and geolocate any received signals.

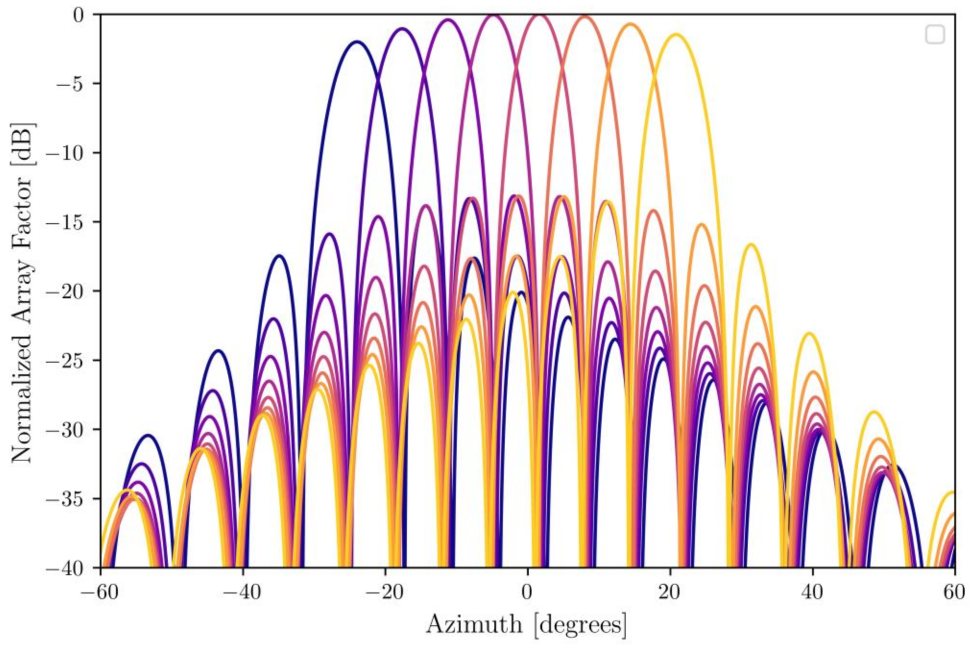
Phased Array Beamforming

Superposition of waves emitted by each antenna in the far-field

Antenna phases chosen for constructive interference in specific direction(s)



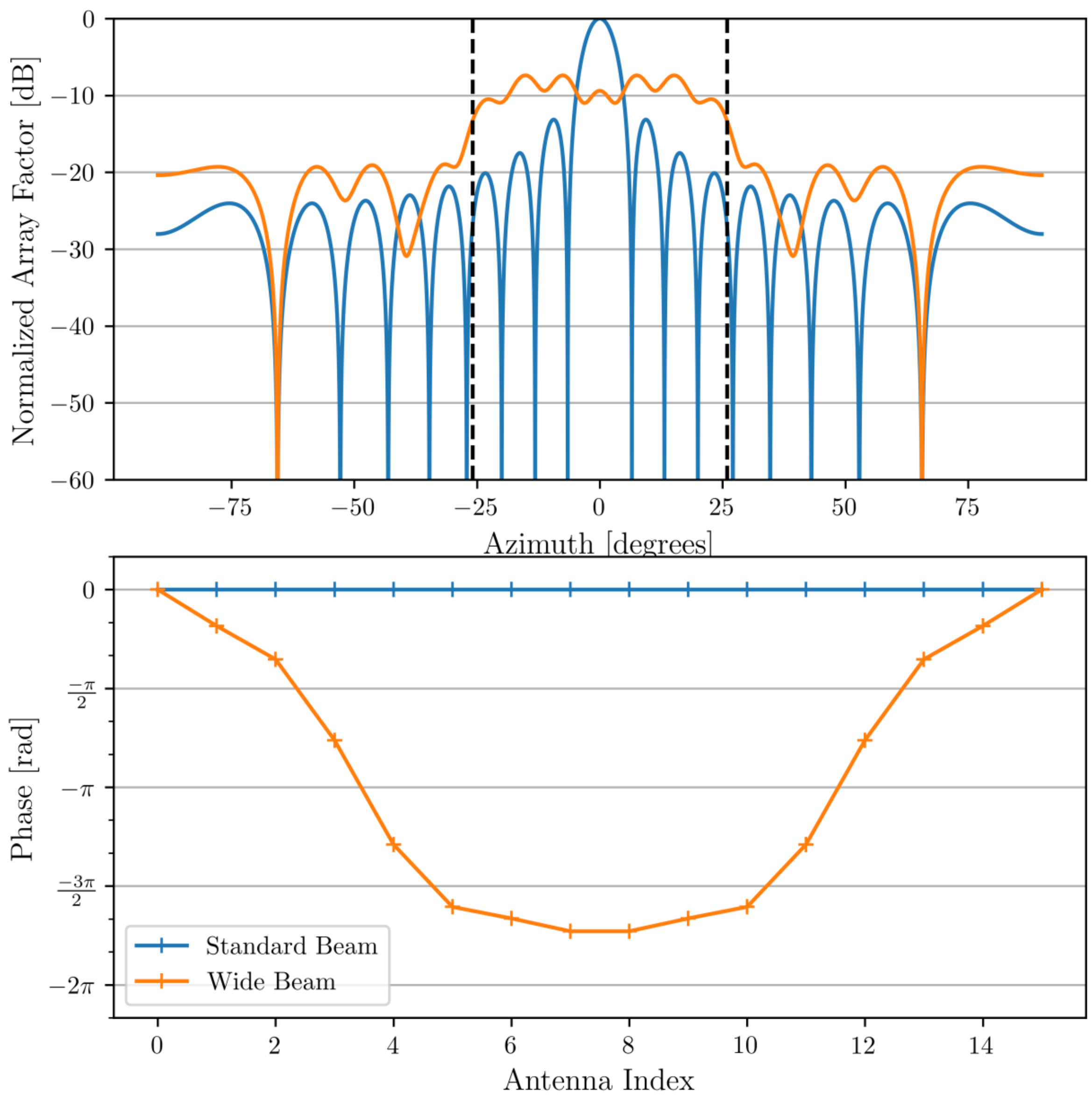
From superdarn.ca



Beam Optimization

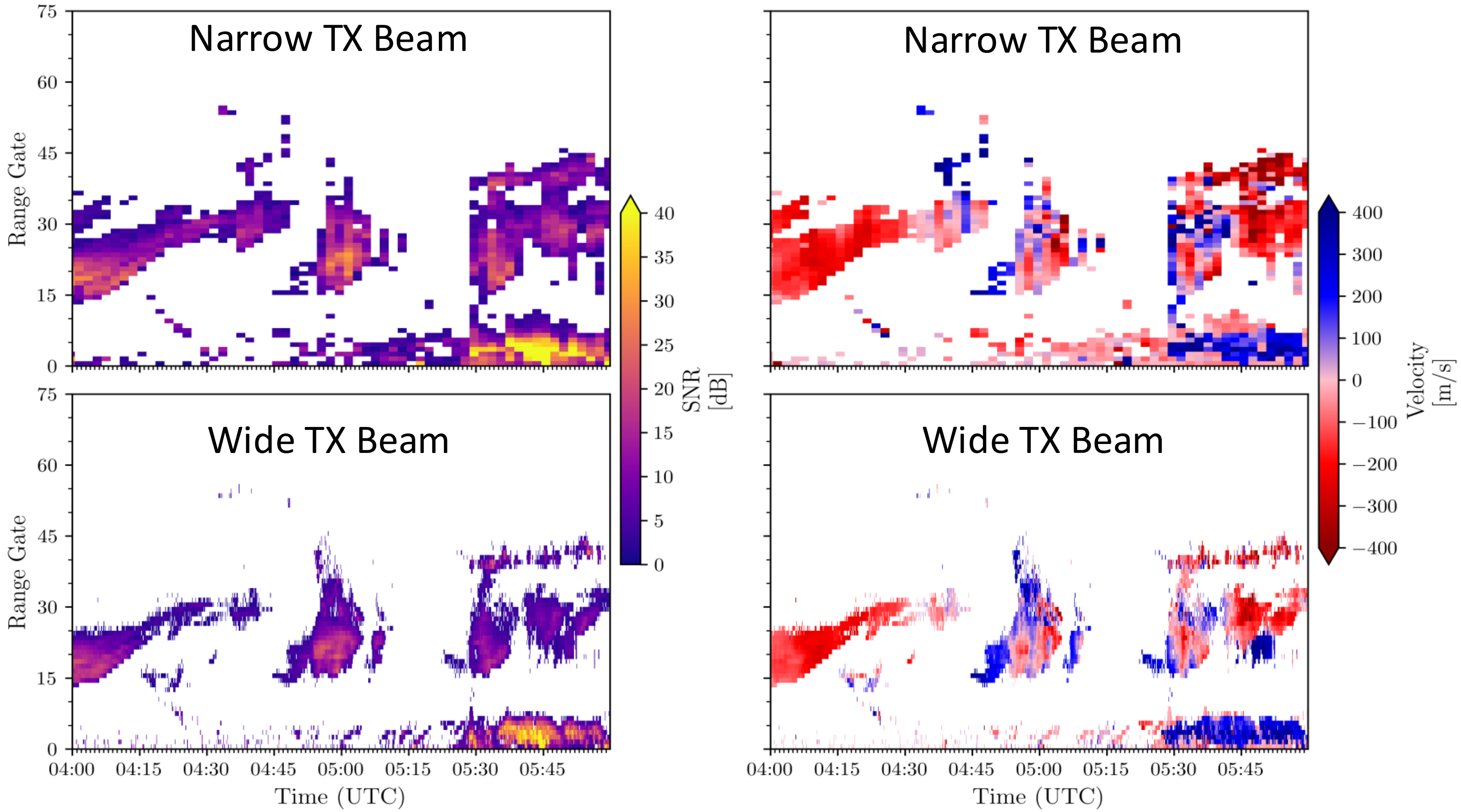
Beam objectives:

- as uniform as possible between dashed lines
- as little power as possible outside dashed lines



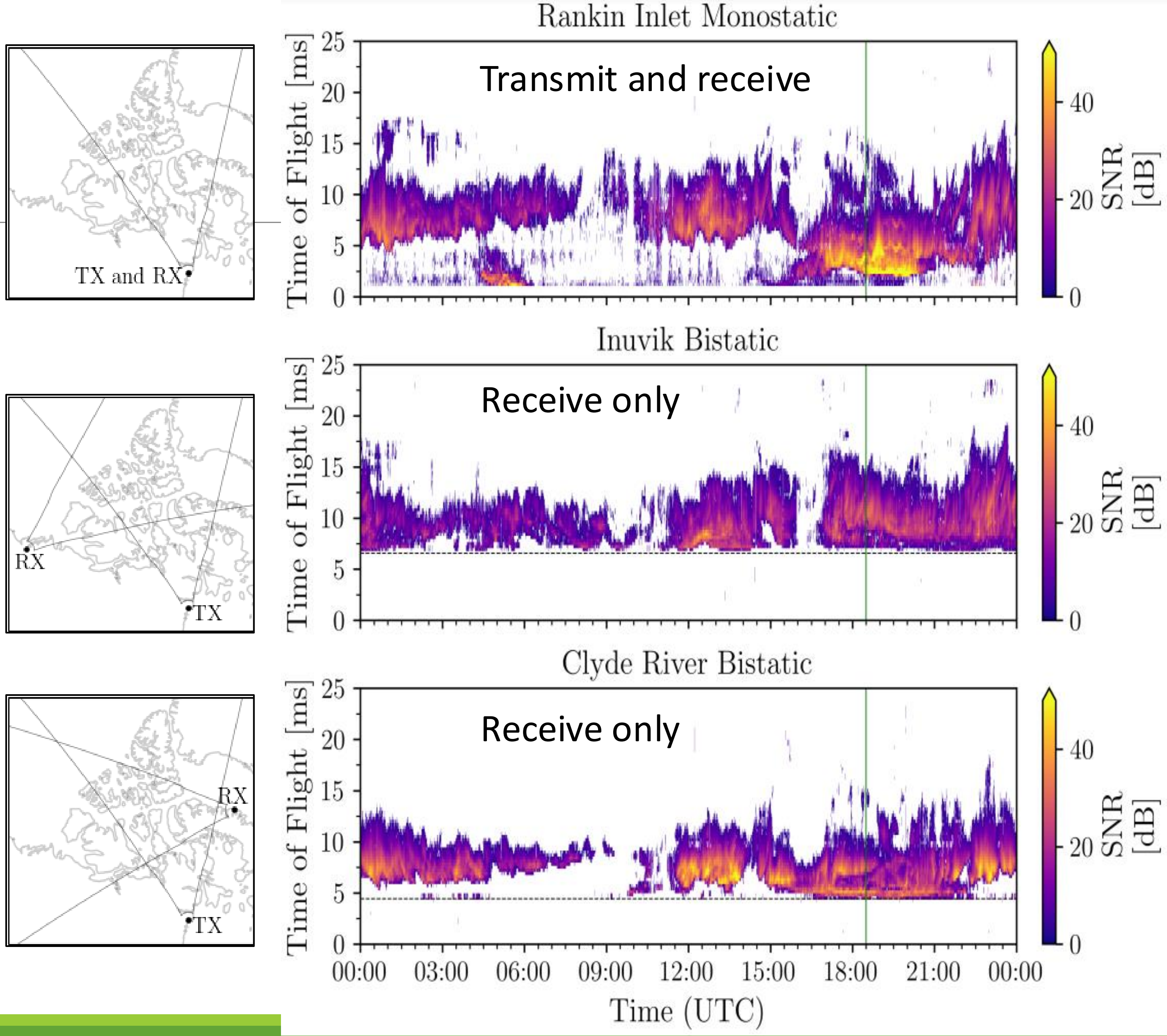
Wide Beam Results

- General structure is the same
- Lower SNR with wide beam – some low-SNR data lost
- 16-fold increase in temporal resolution



Multistatic Operation

- Implementation requires synchronization of radar sites
- No scatter expected at close range due to propagation delay
- Breaks some standard SuperDARN assumptions
    - Doppler shift along line-of-sight
    - ray retraces outbound path after scattering



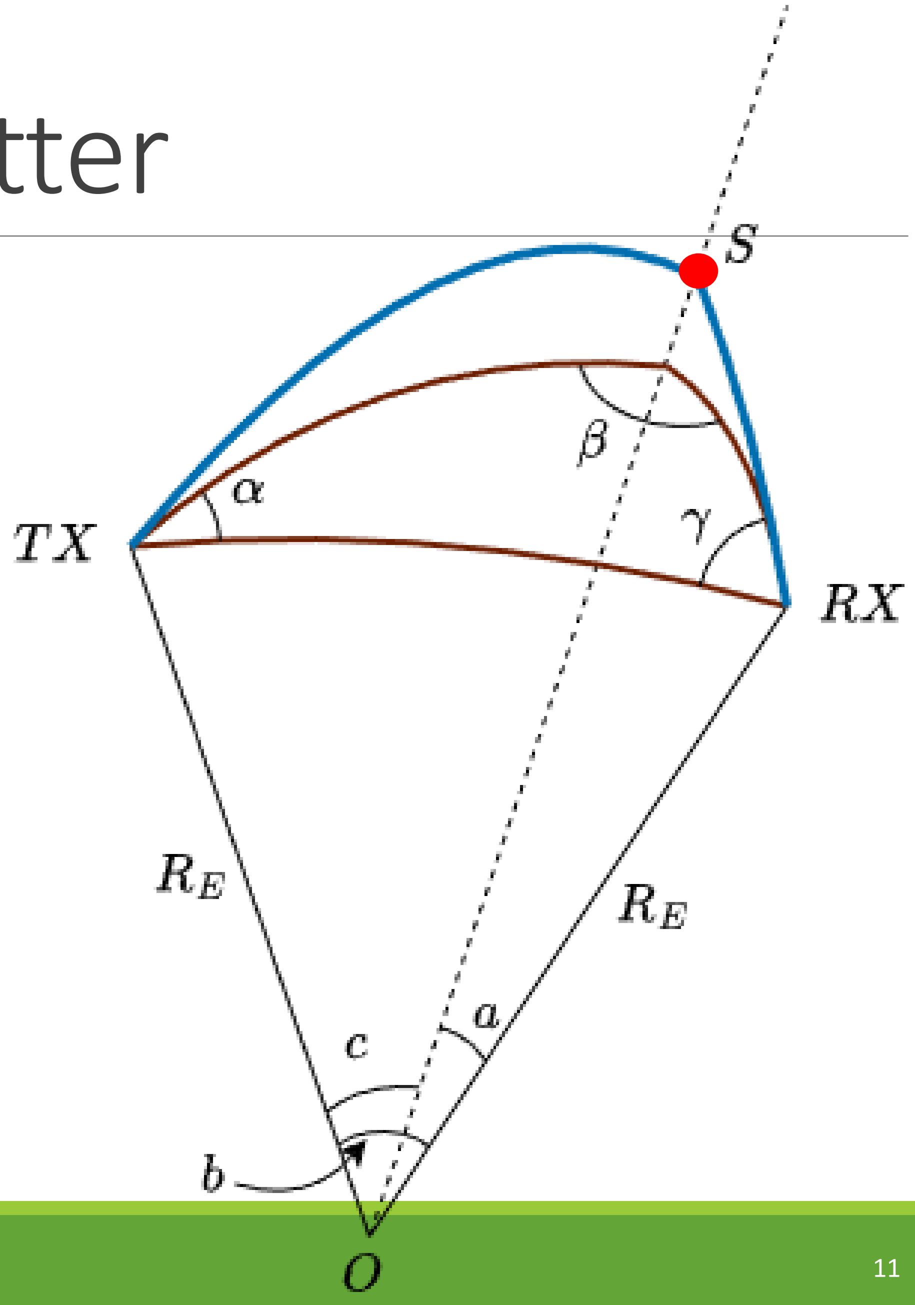
Locating Multistatic Scatter

Uses standard assumptions of ionospheric composition:

- vertical magnetic field
- spherically uniform ionosphere

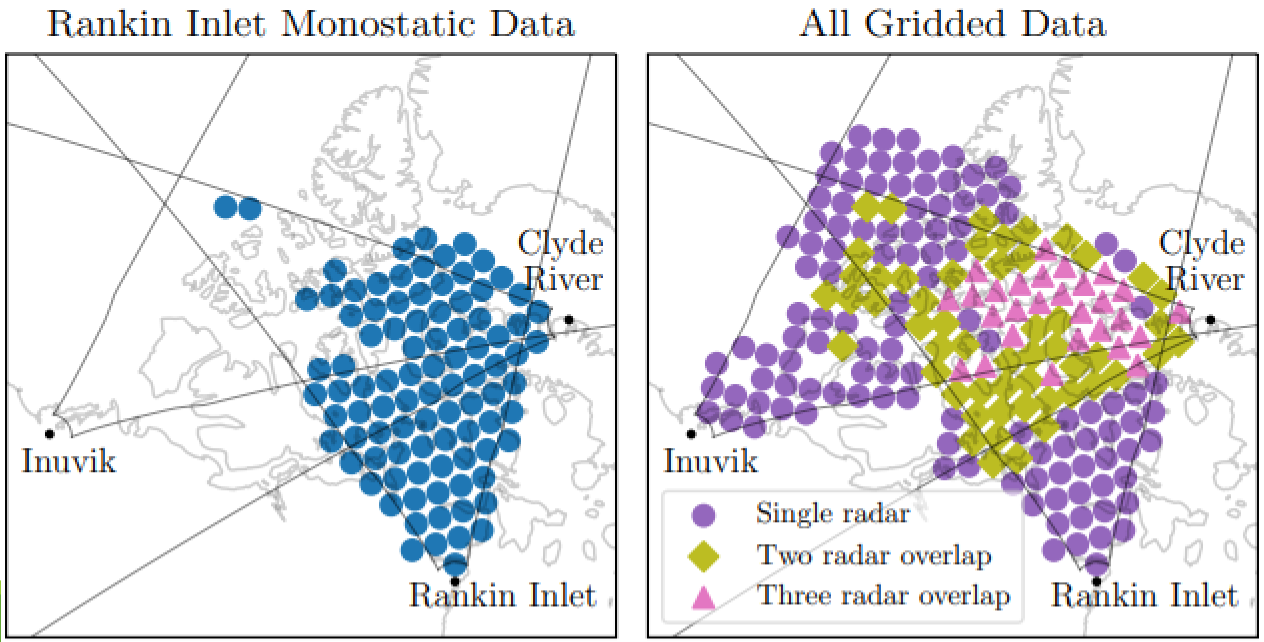
Sufficient information to find scattering point:

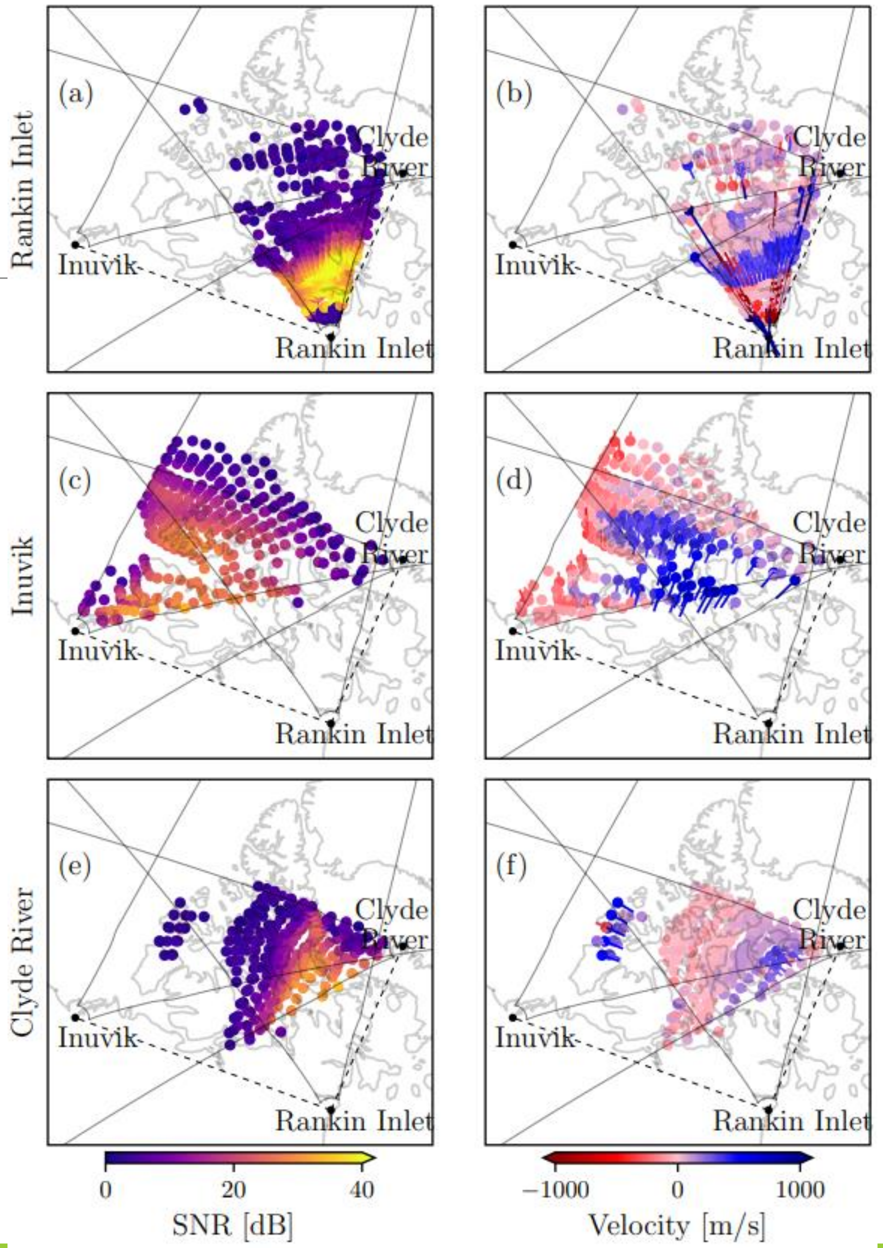
- azimuth and elevation angles of arrival at RX
- time of flight (group range) of wave
- site locations



Multistatic Results

- Doppler shifts in novel directions
- Lots of overlapping vector component measurements





Summary

Wide beam operation:

- sixteen-fold increase in temporal resolution achieved
- side lobes and artifacts present but mitigated through RX beam adjustments

Multistatic operation:

- derived geolocation equations
- additional velocity vectors measured
- extended spatial coverage

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

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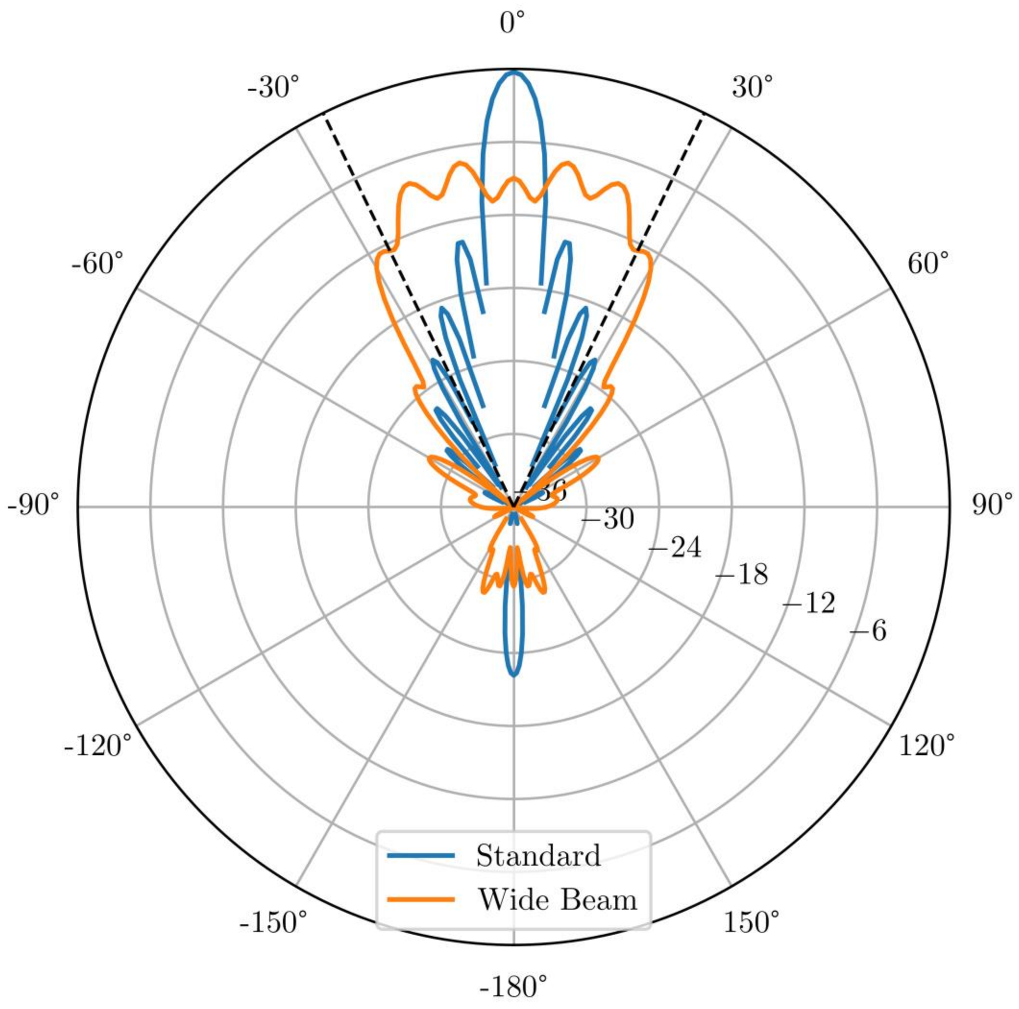
Canada

Side lobes and Artifact

All antennas have side lobes

- mitigated by using same beam pattern for receiver (RX) and transmitter (TX)

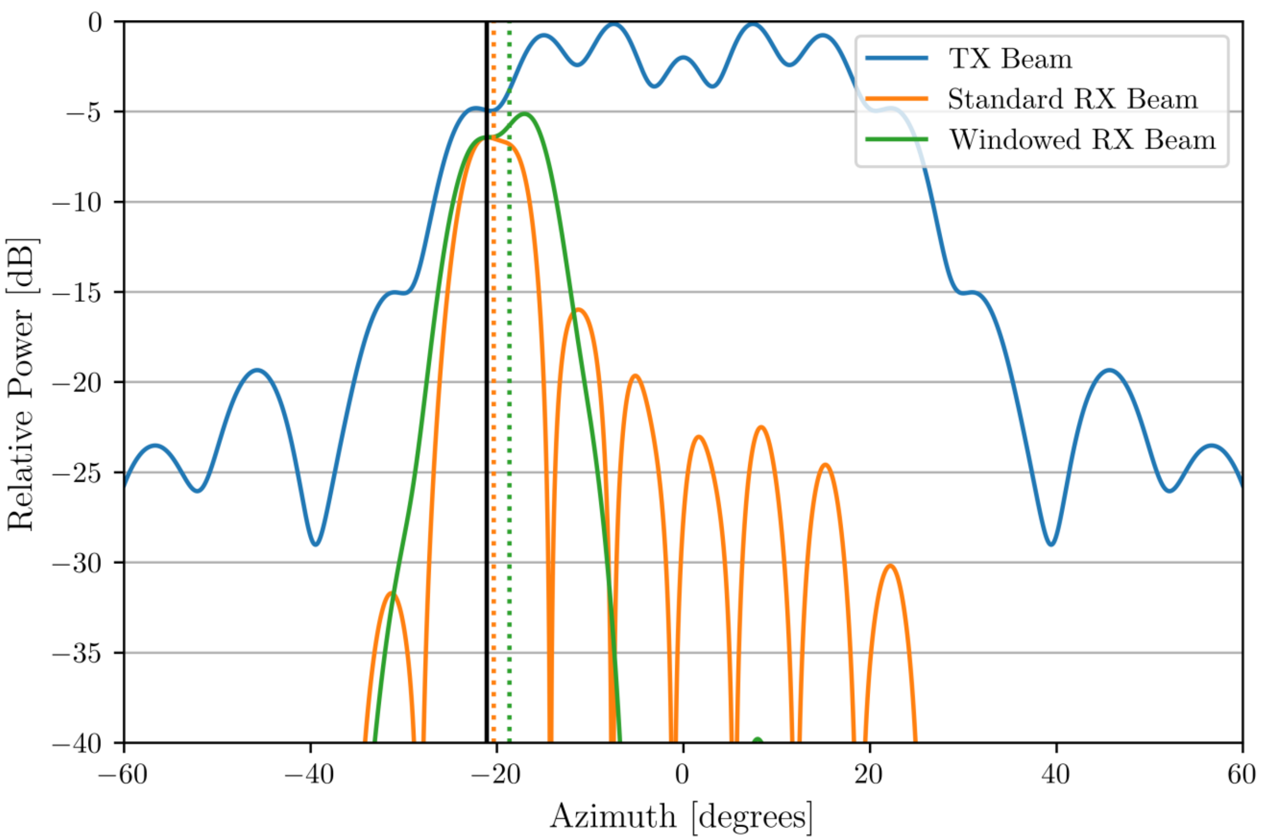
TX with wide beam
+ RX with standard beam
= more leakage from side lobes

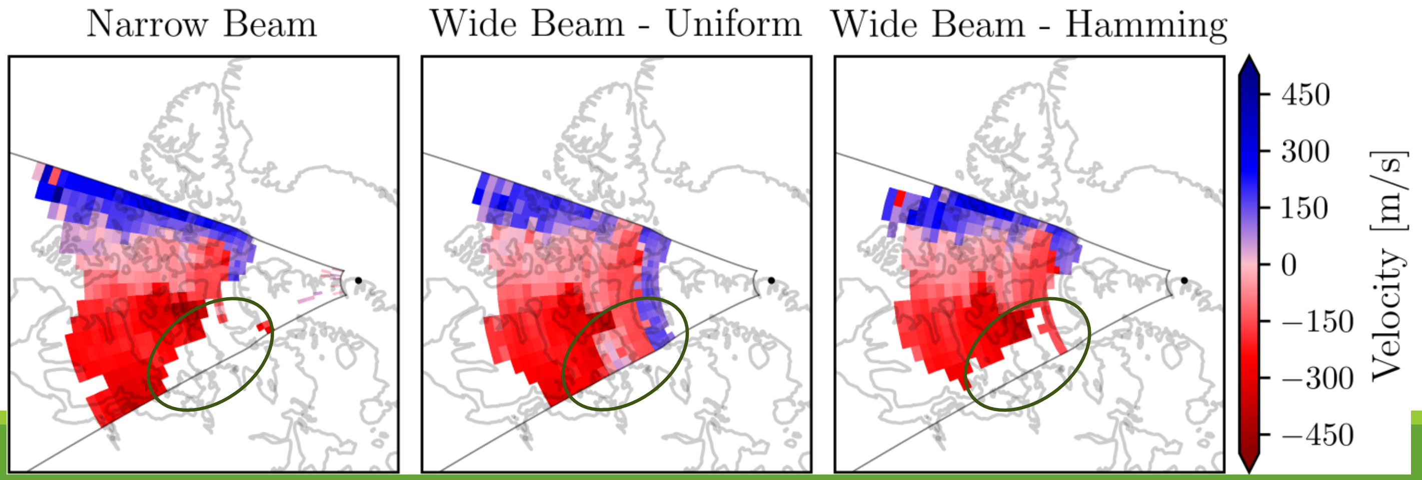


Beam Corrections

Two corrections taken:

1. Apply window function to reduce RX beam side lobes
   - from –13 dB to –30 dB
2. Direct RX beam to offset TX beam non-uniformity





Geolocation

Cosine law for virtual height

$$h_v = \sqrt{\frac{R^2}{4} + R_E^2 + RR_E \sin\varepsilon} - R_E$$

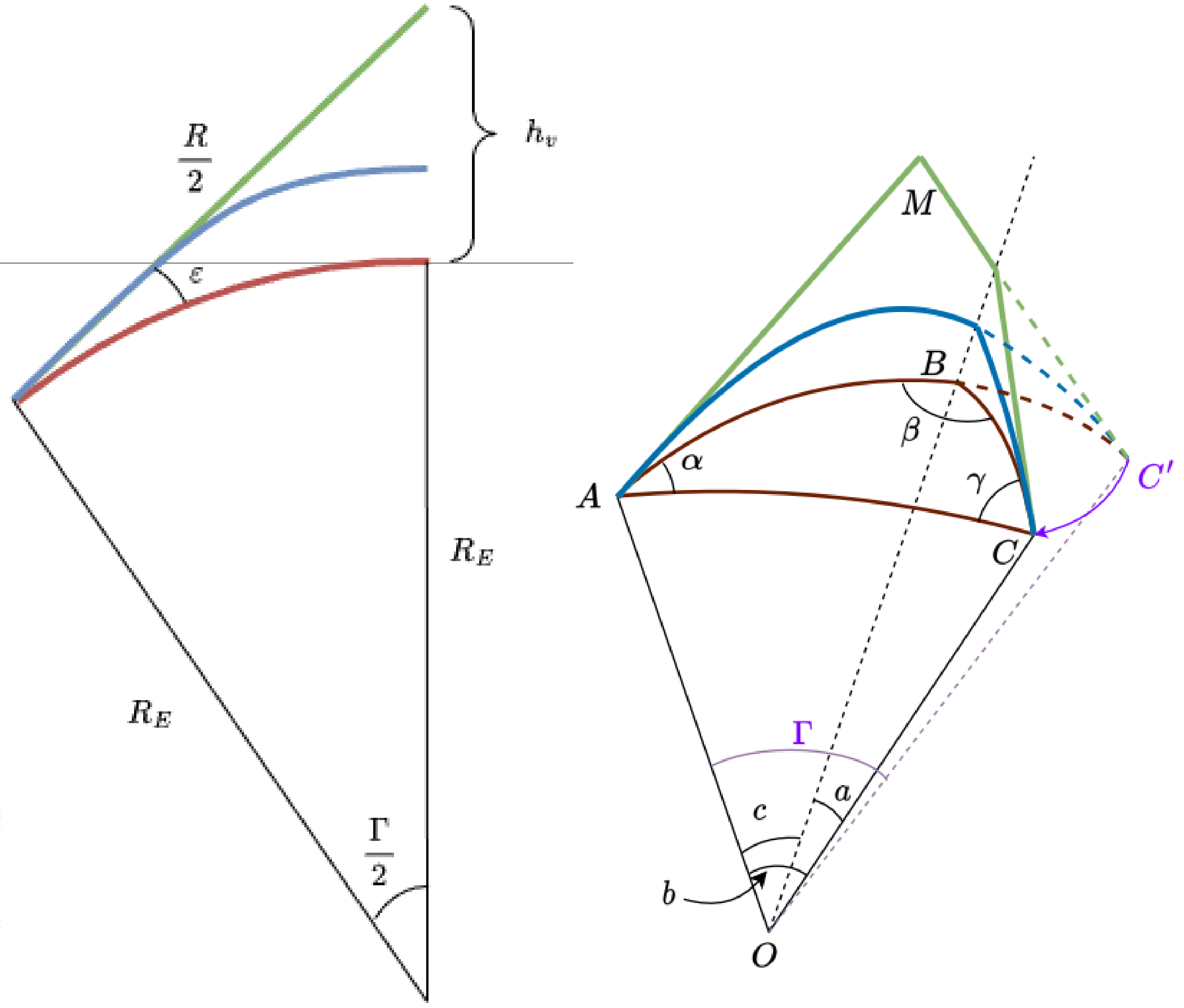
Sine law for geocentral angle

$$\Gamma = 2\arcsin\left(\frac{R}{2}\frac{\cos\varepsilon}{R_E + h_v}\right)$$

Spherical cosine law for c

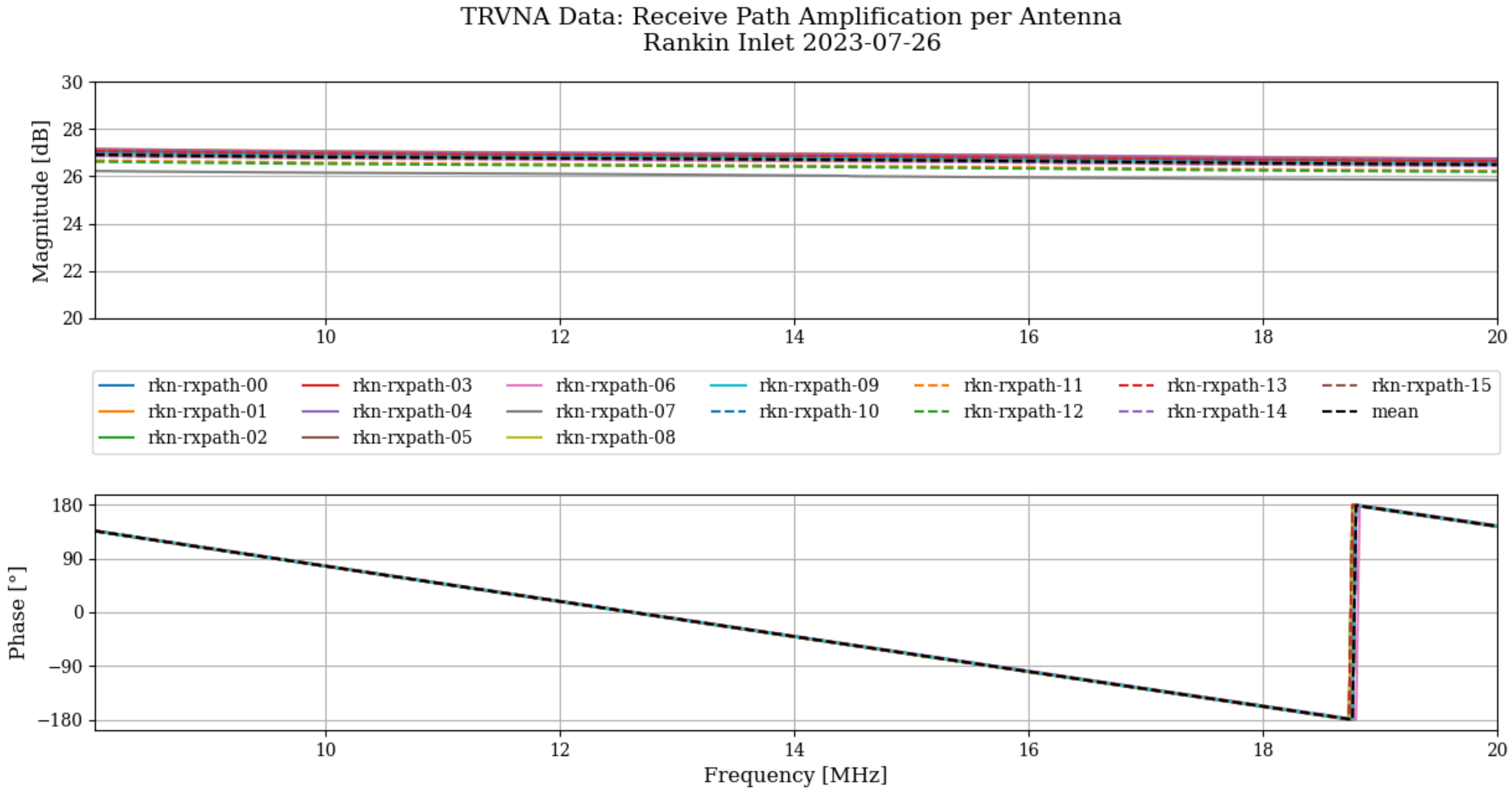
$$\cos(c) = \cos(a)\cos(b) + \sin(a)\sin(b)\cos(\gamma)$$

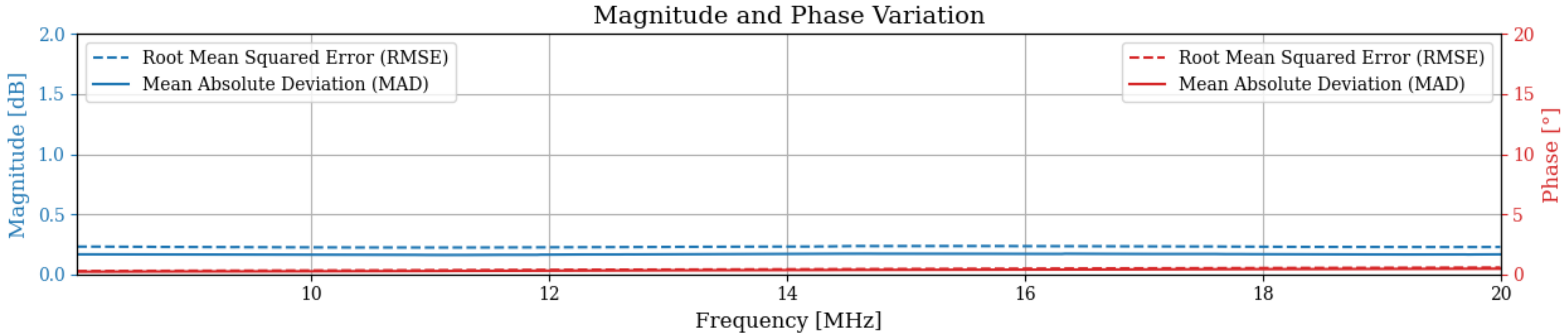
$$c = \arctan\left[\frac{1 - \cos(b)\cos(\Gamma) - \sin(b)\sin(\Gamma)\cos(\gamma)}{\cos(b)\sin(\Gamma) - \sin(b)\cos(\Gamma)\cos(\gamma)}\right]$$



Calibration

Most recent Rankin Inlet RX path data





Calibration

Most recent Rankin Inlet VSWR data