

Advanced imaging of ionospheric plasma structures with high temporal resolution by Borealis SuperDARN radar systems

Remington Rohel, Pasha Ponomarenko*,
Kathryn McWilliams,

University of Saskatchewan

Outline

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- SuperDARN pros, cons, and way forward

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- Summary and future work

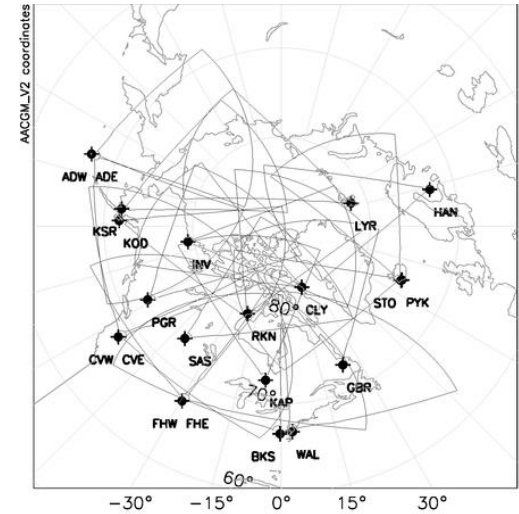
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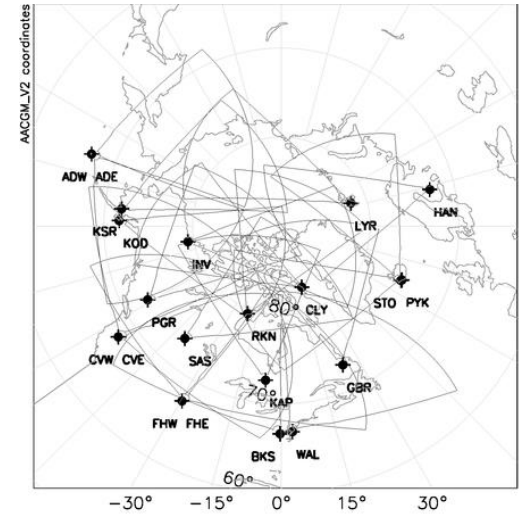
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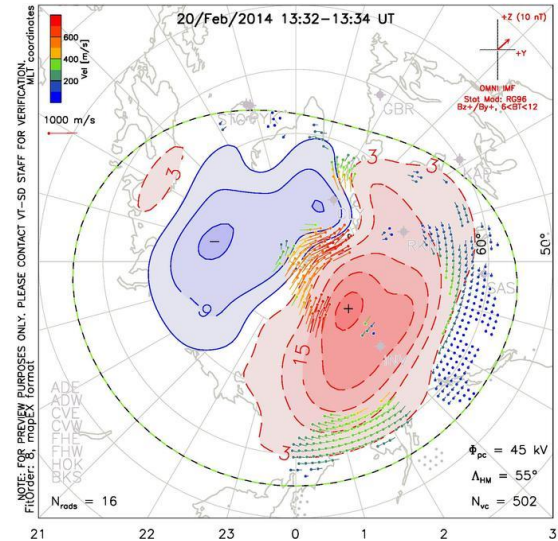
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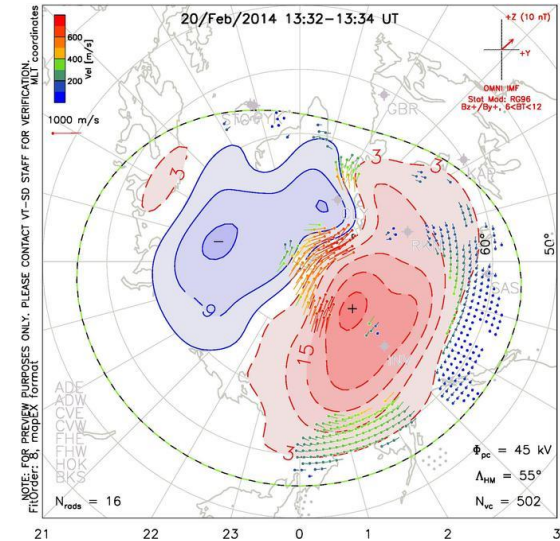
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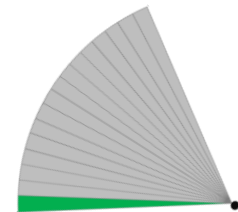
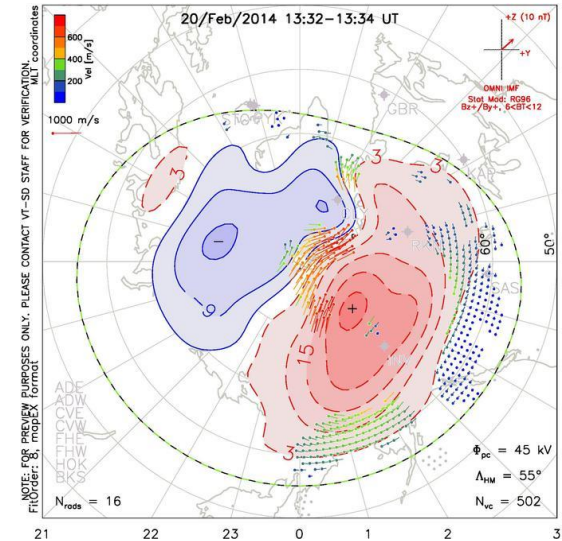
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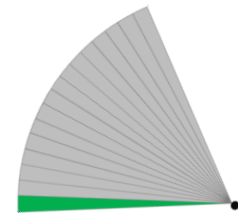
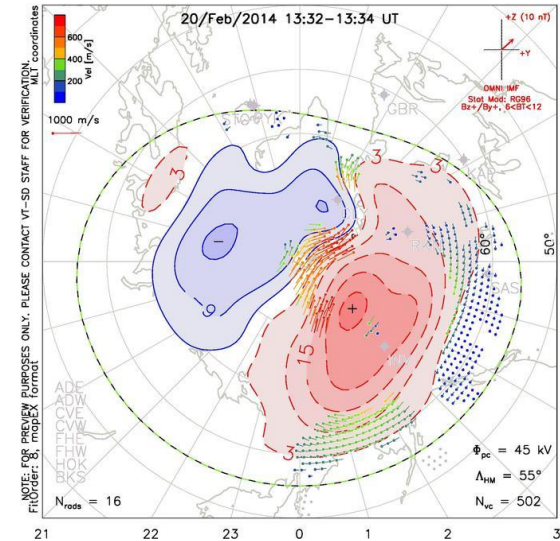
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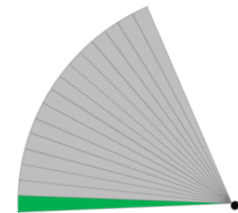
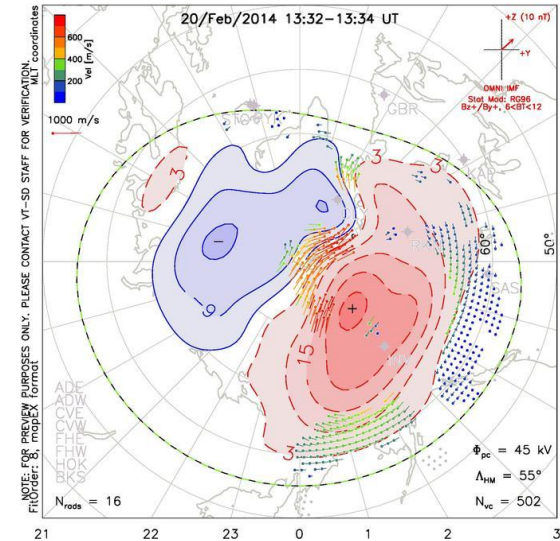
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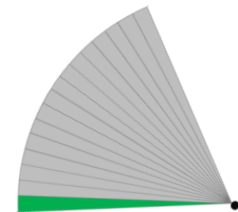
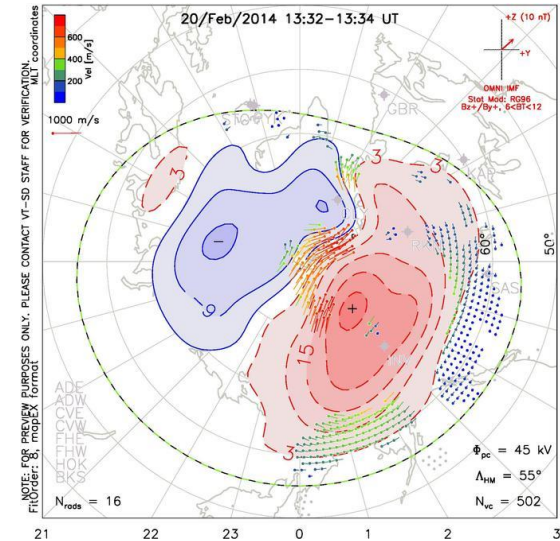
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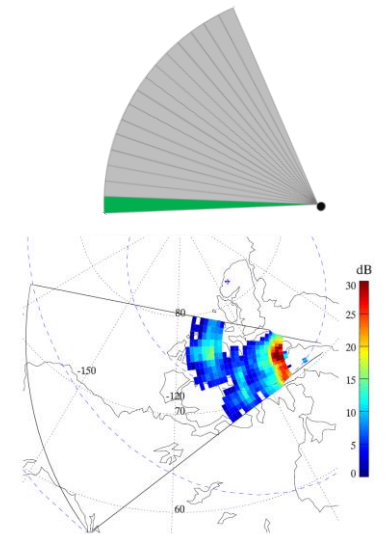
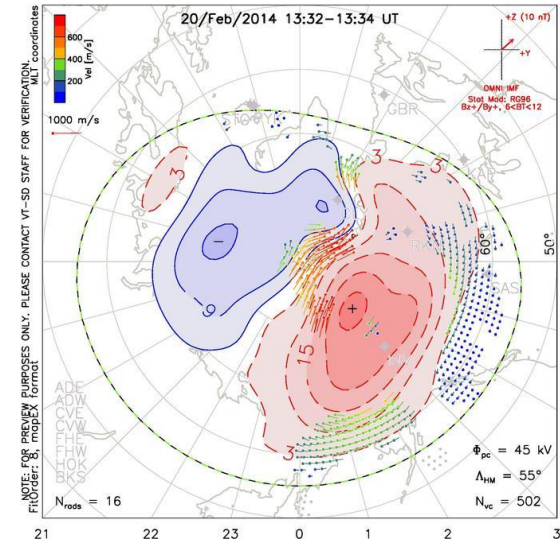
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 - **spatial coverage is restricted** by current propagation conditions



Way forward

<https://doi.org/10.1029/2022RS007591>

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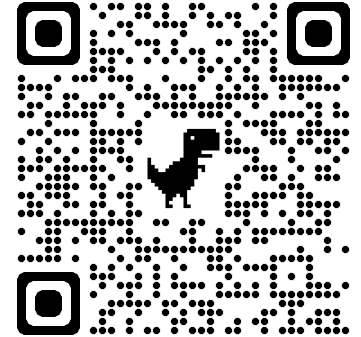
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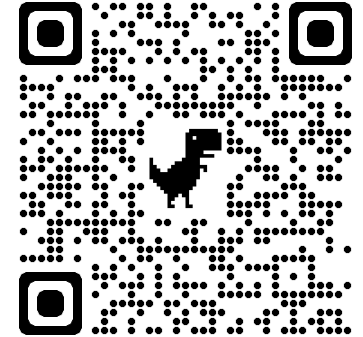
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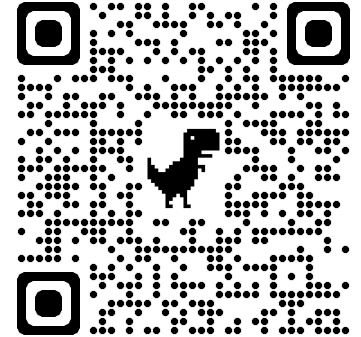
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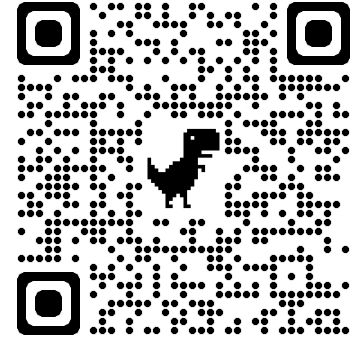
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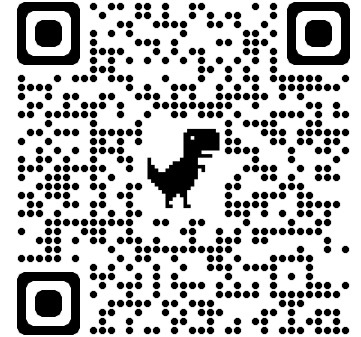
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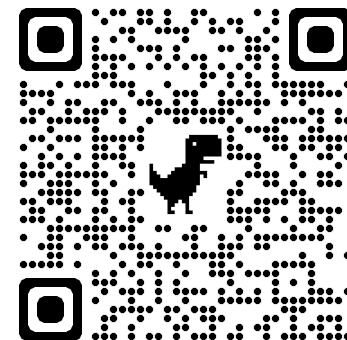
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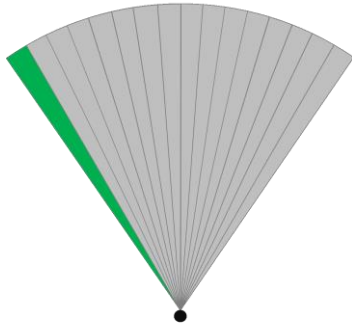
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 - Improving field-of-view sampling with **wide-beam transmission** using non-linear antenna array phasing
 - Improving spatial coverage and velocity determination with **multistatic reception** by radars with overlapping fields of view



Wide-beam transmission

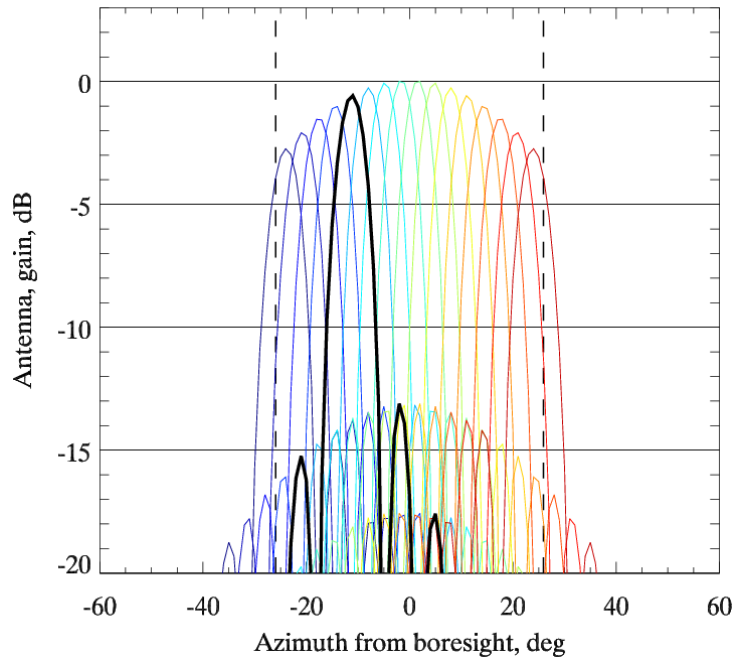
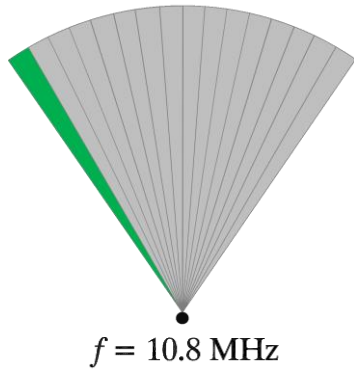
Wide-beam transmission

Conventional



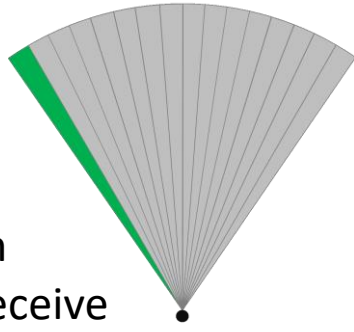
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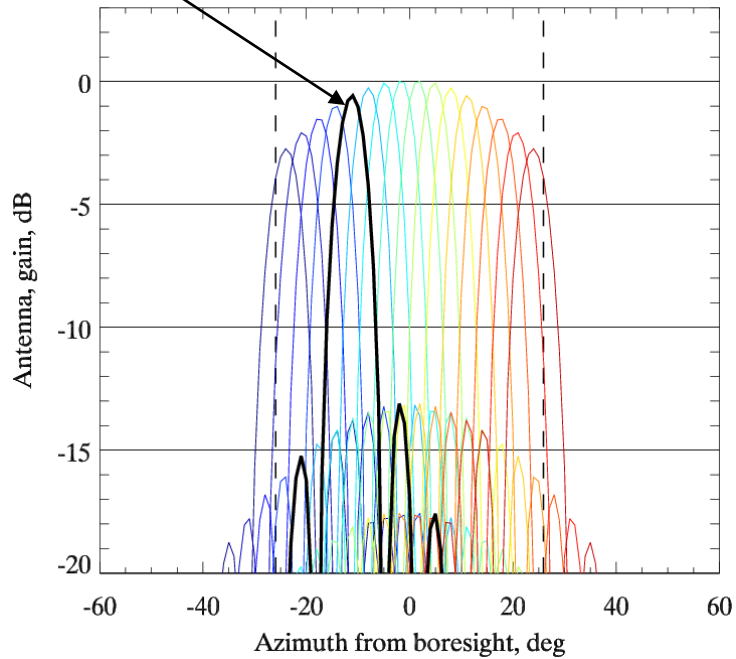


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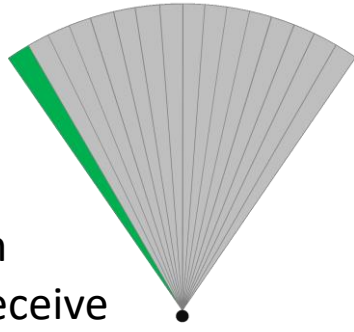


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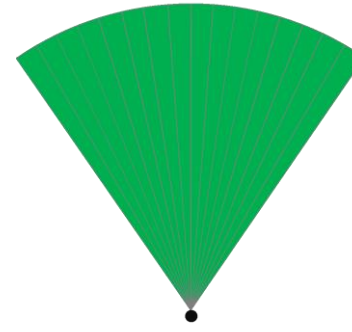


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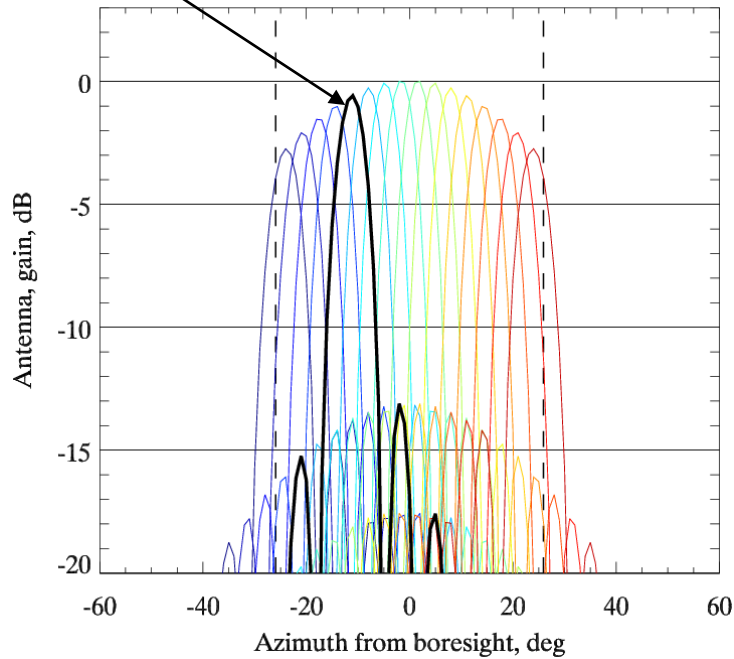


New



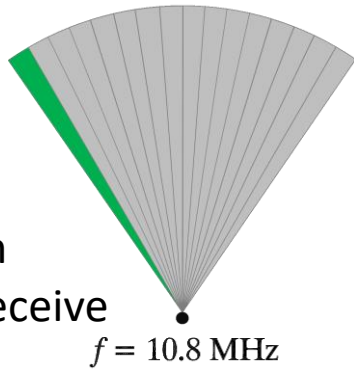
Narrow-beam
Transmit & Receive

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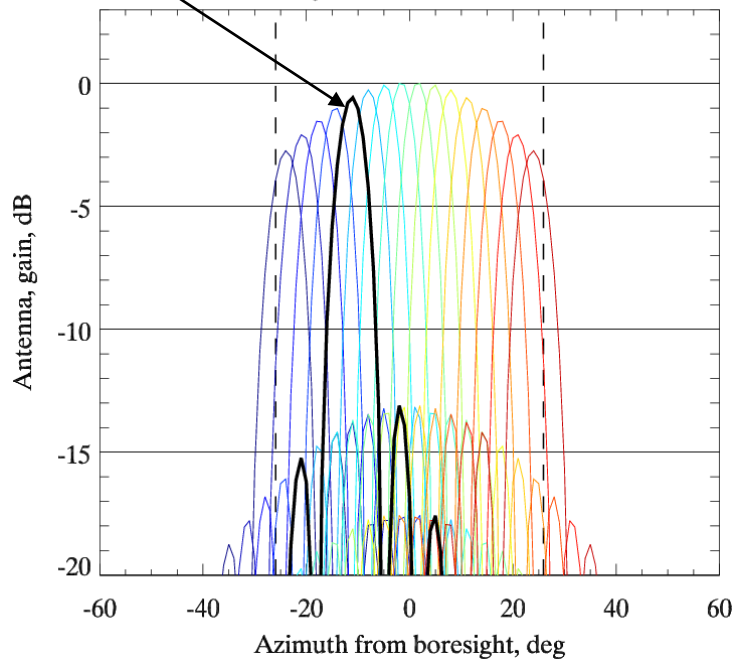


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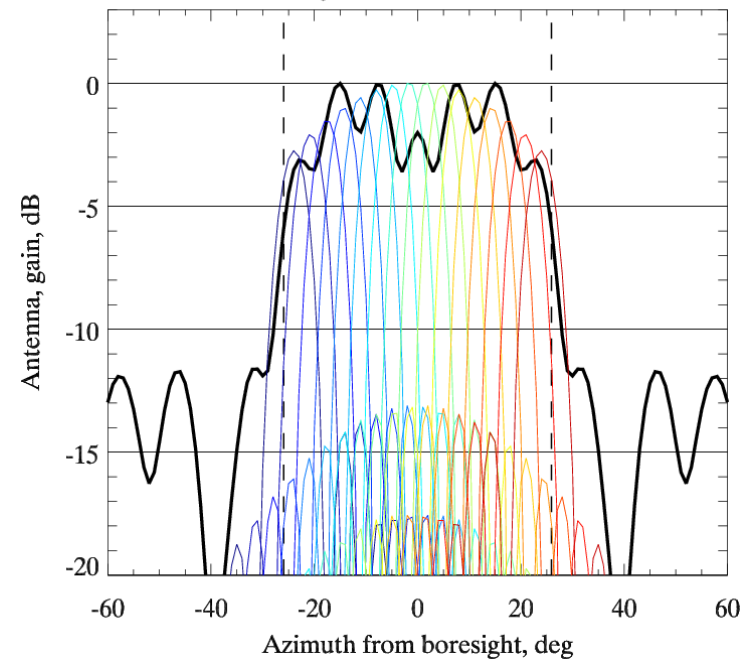
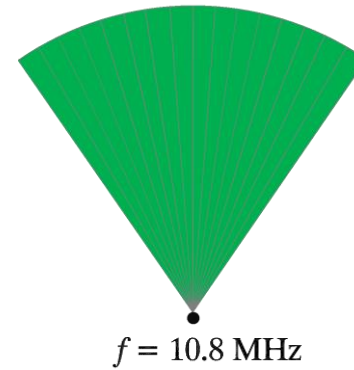
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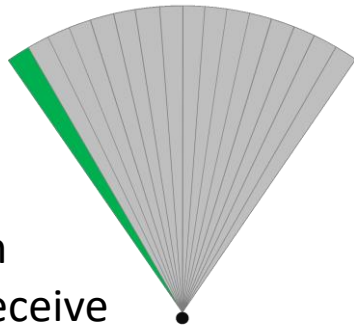


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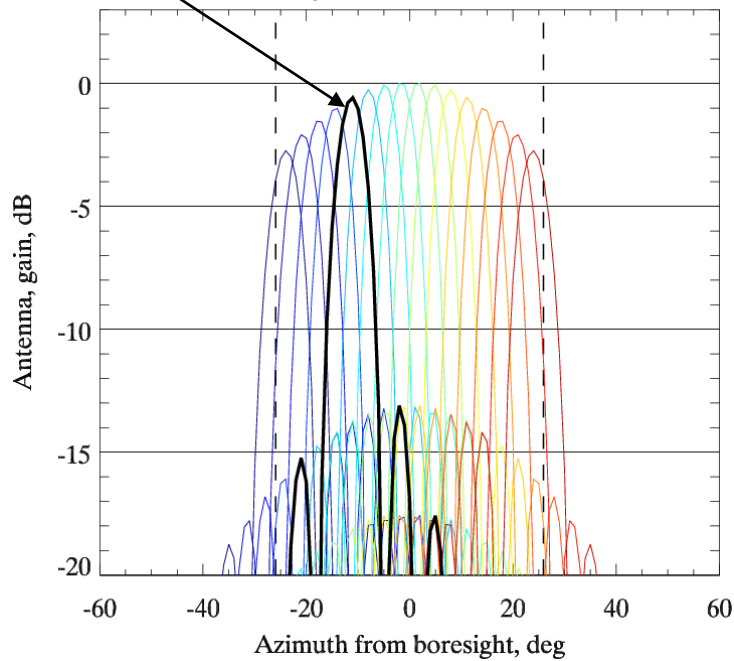
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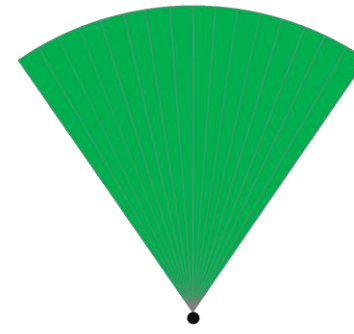


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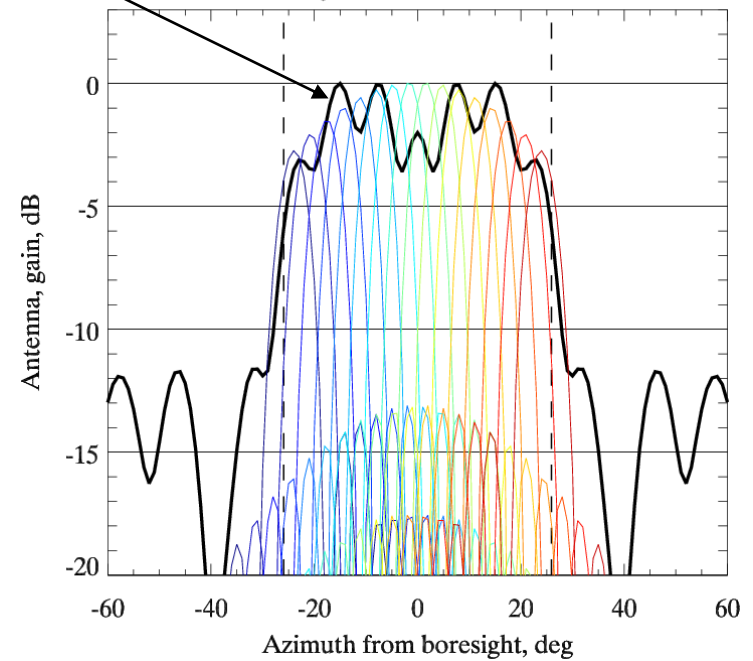


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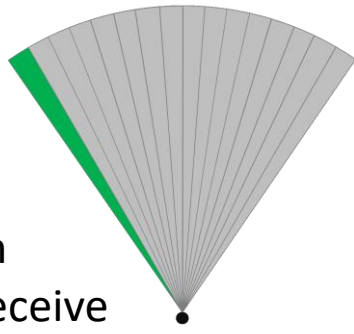
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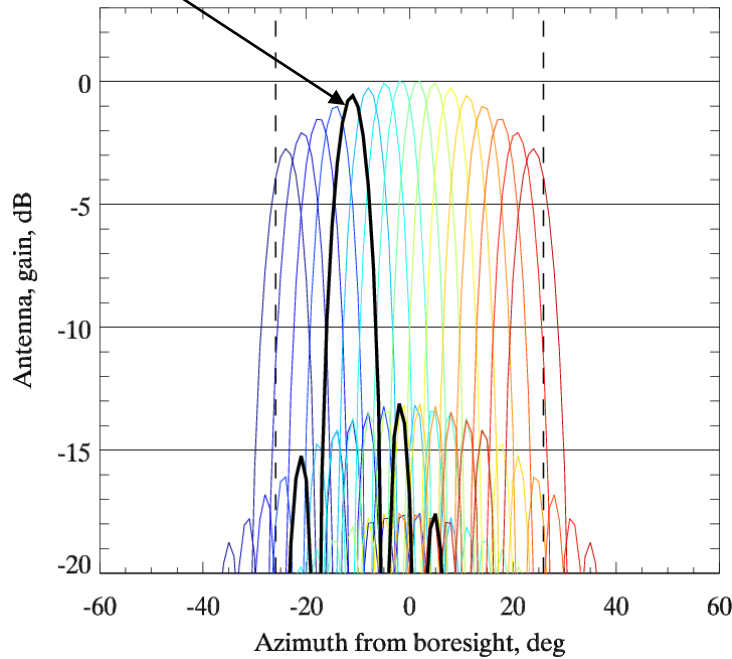
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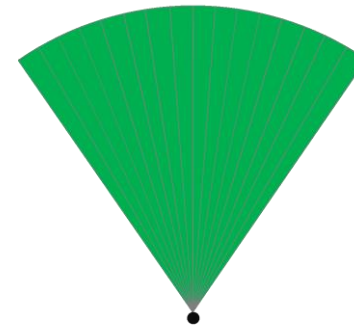


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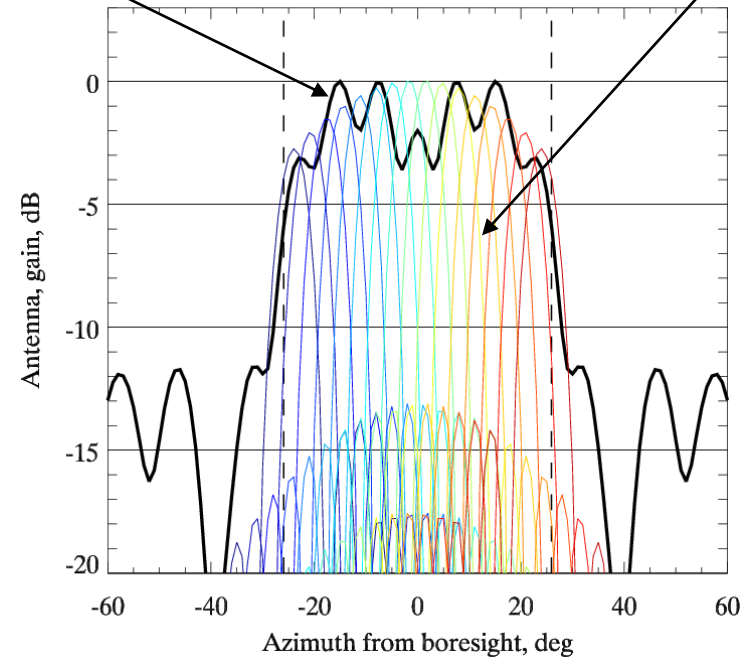
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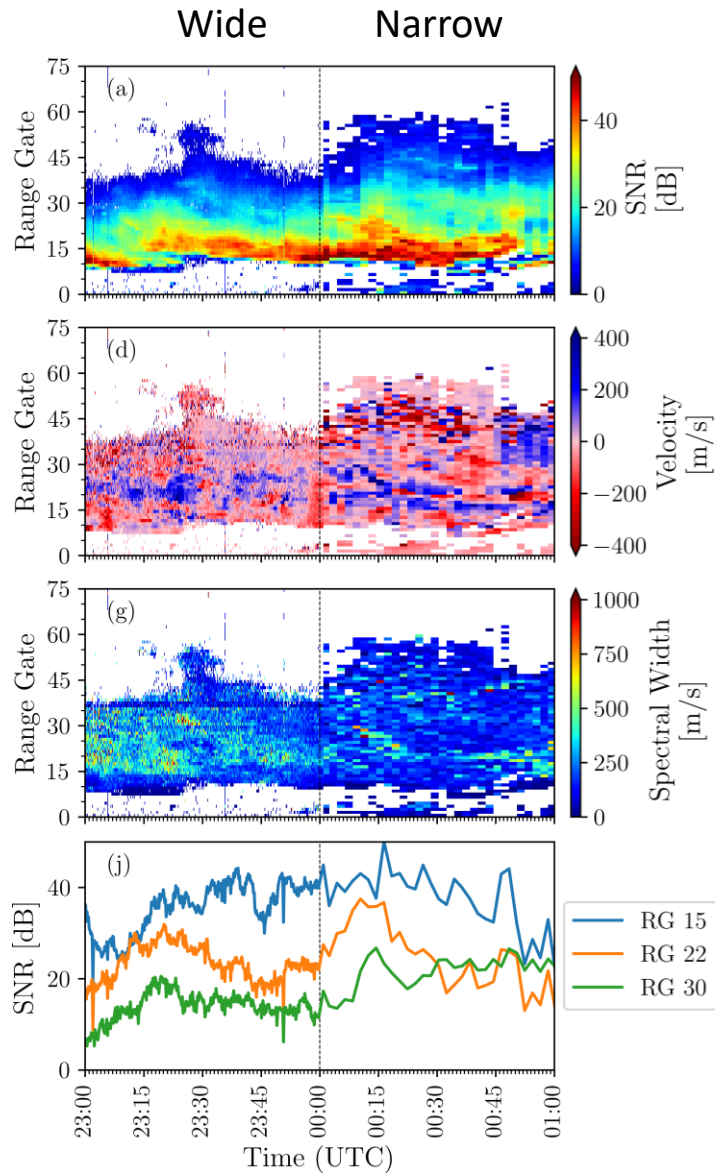
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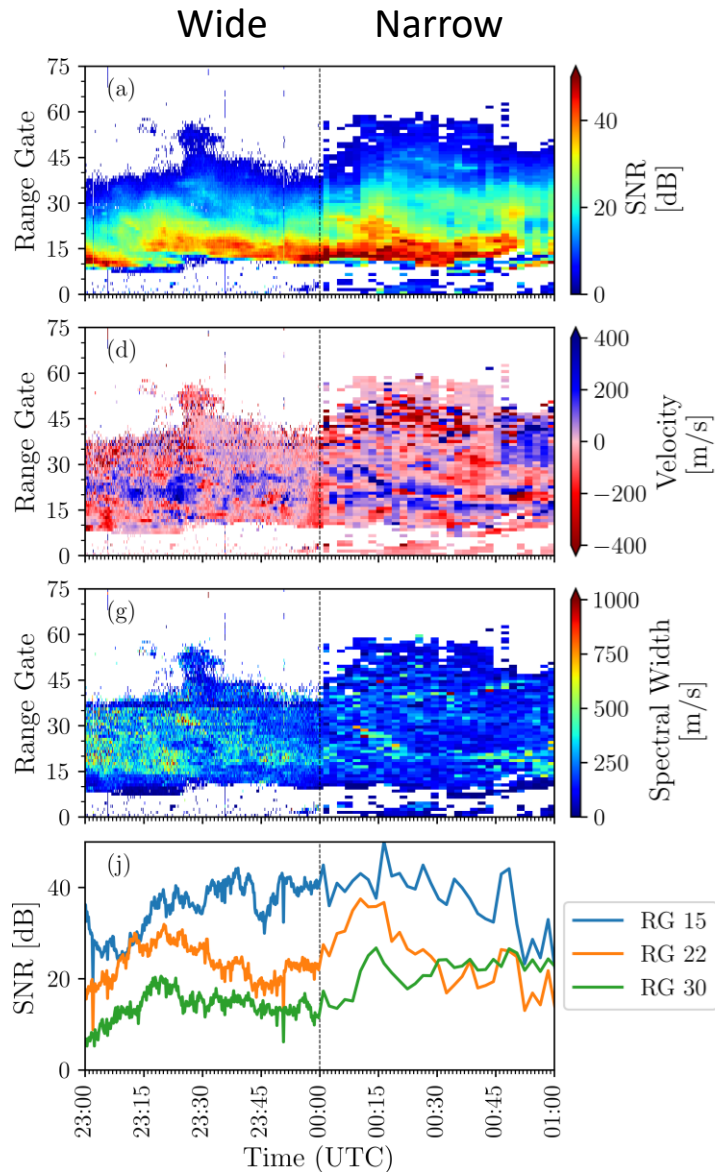


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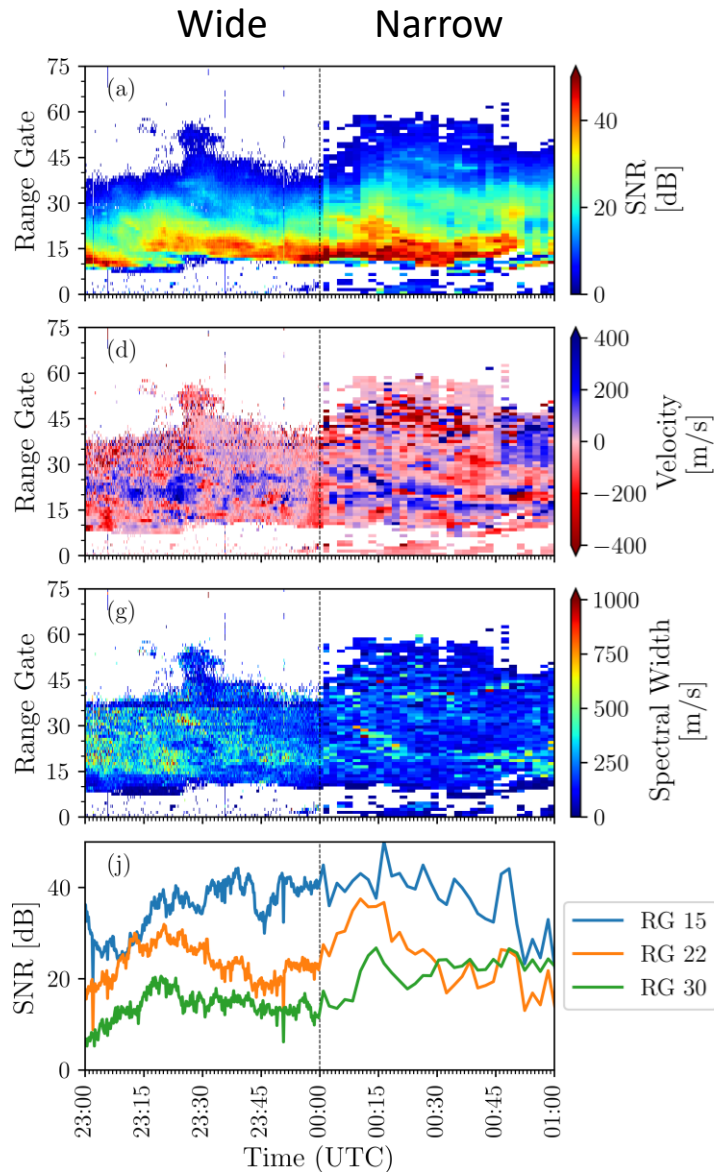


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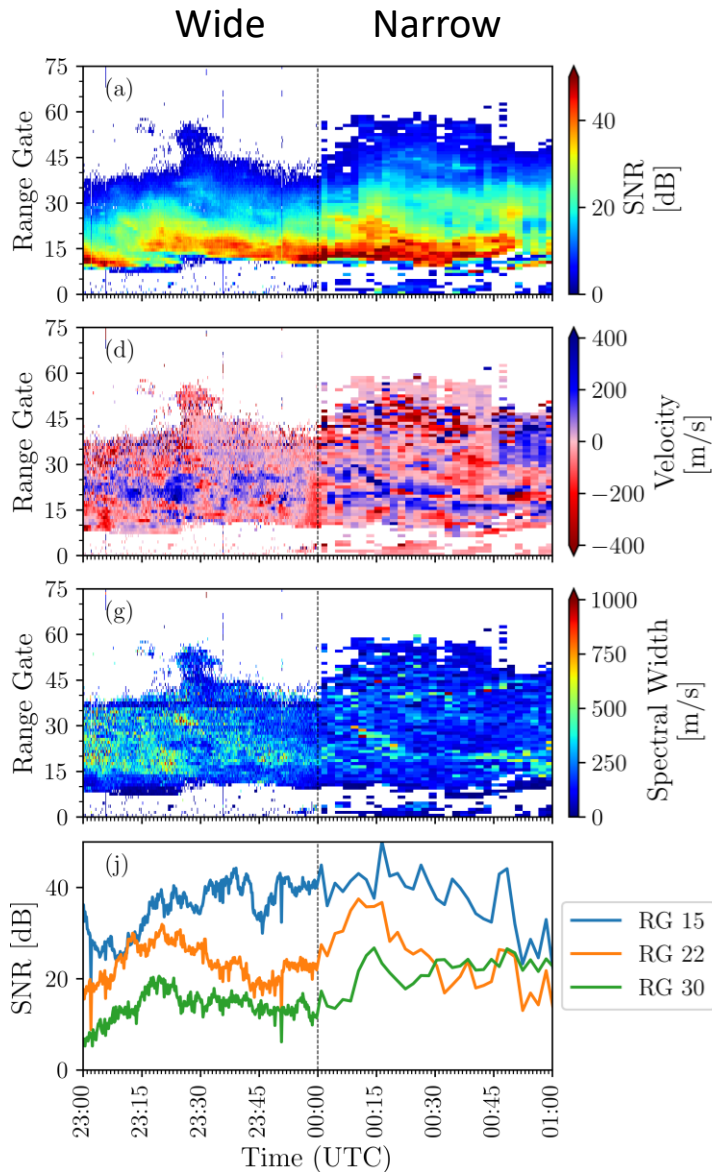
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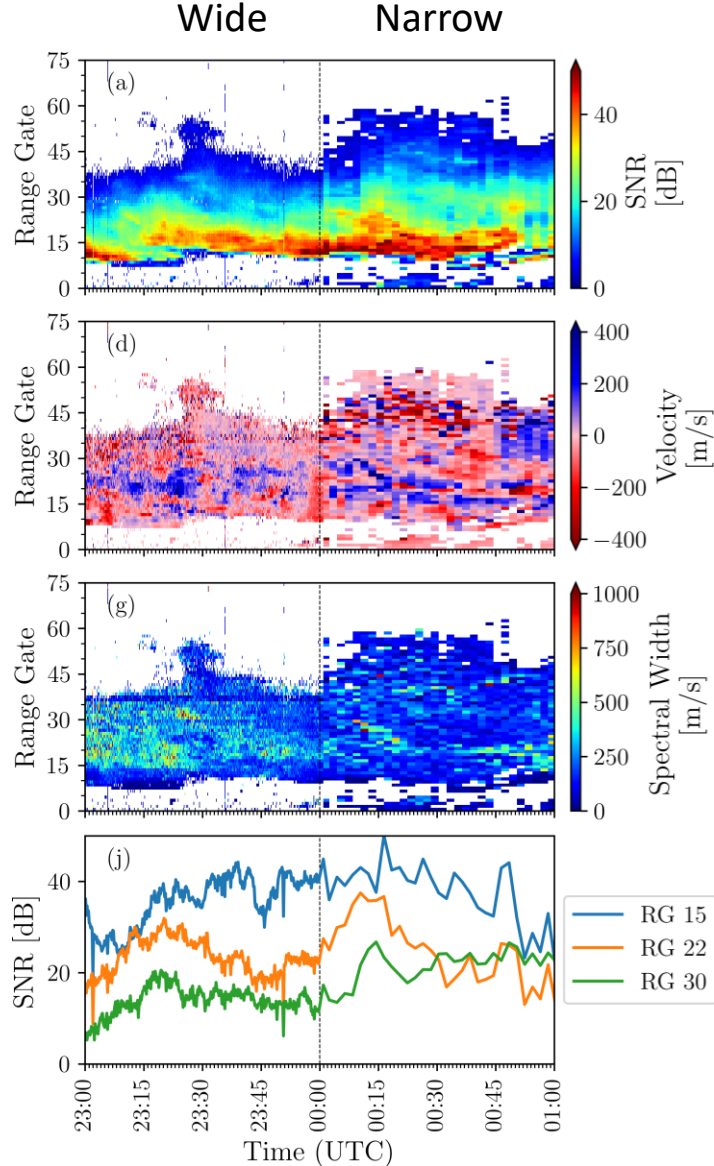
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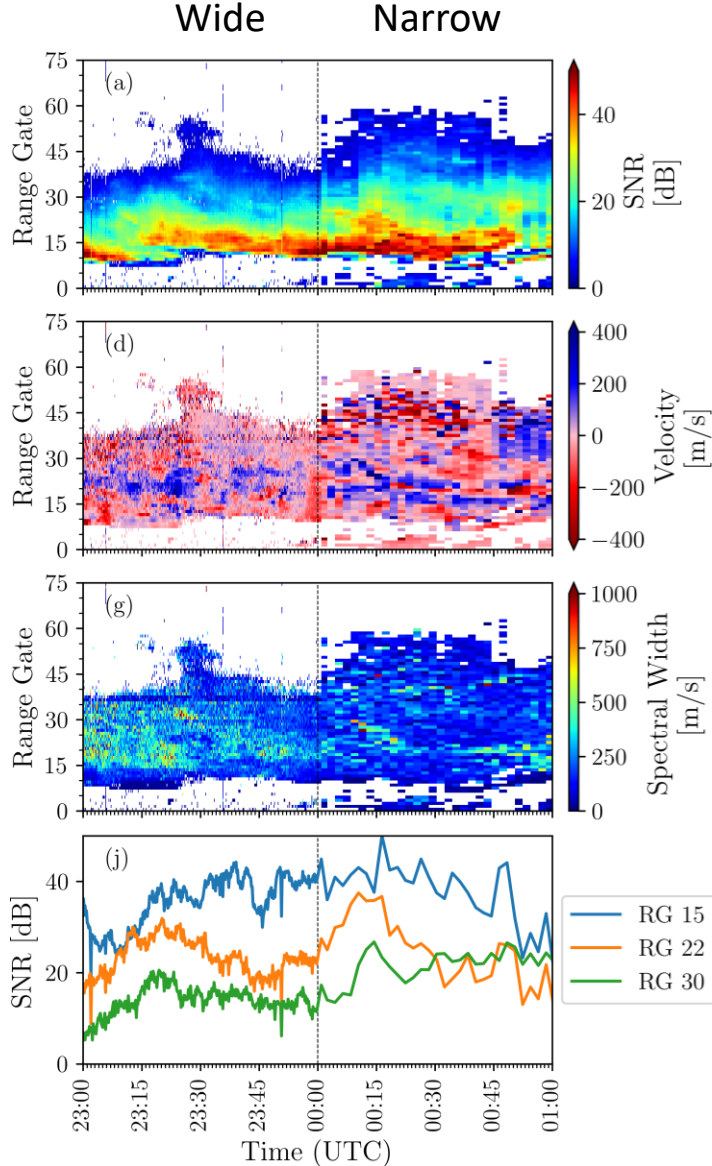
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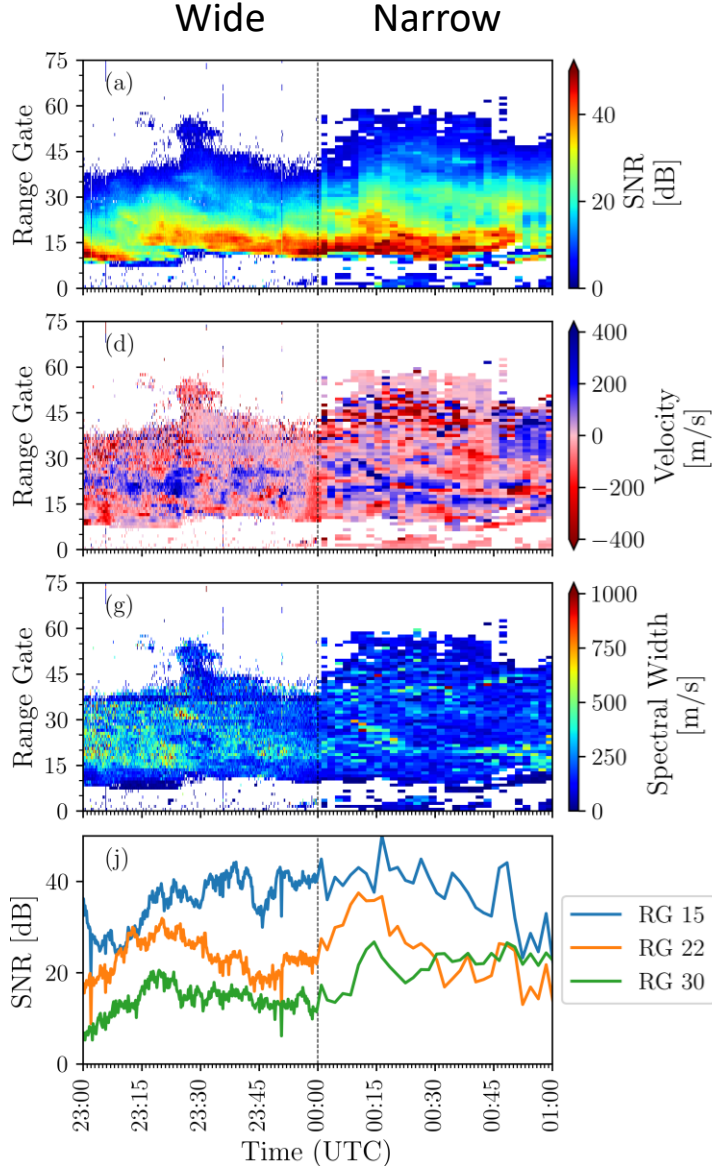
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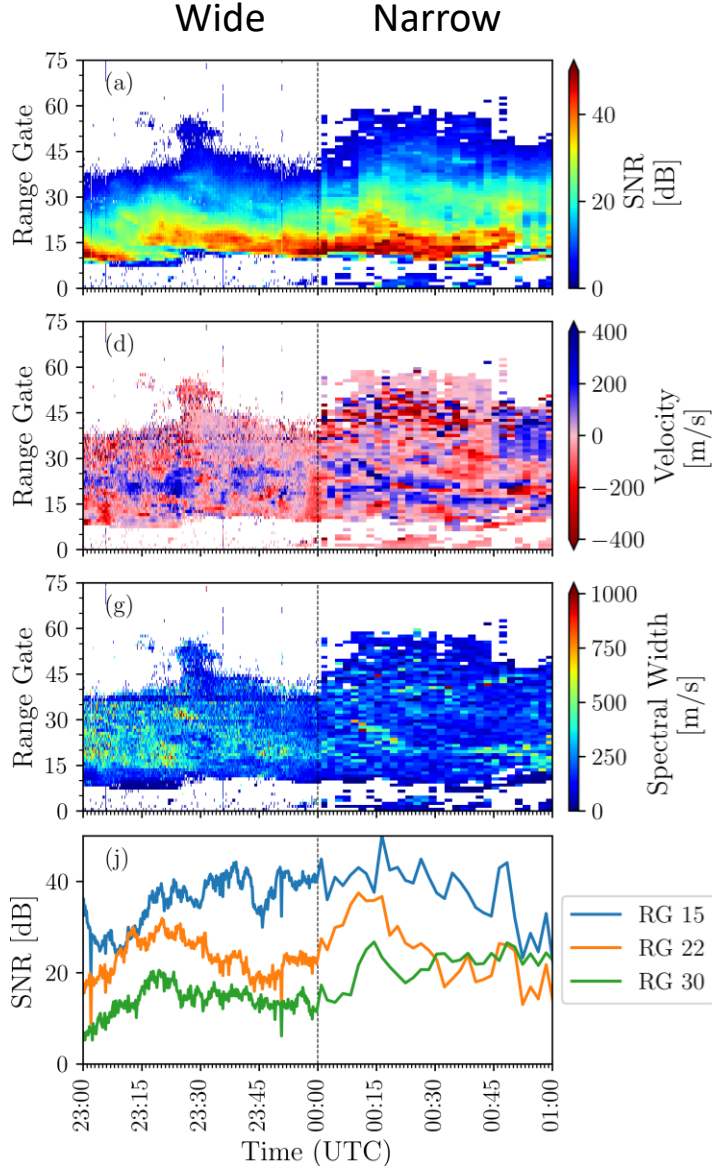
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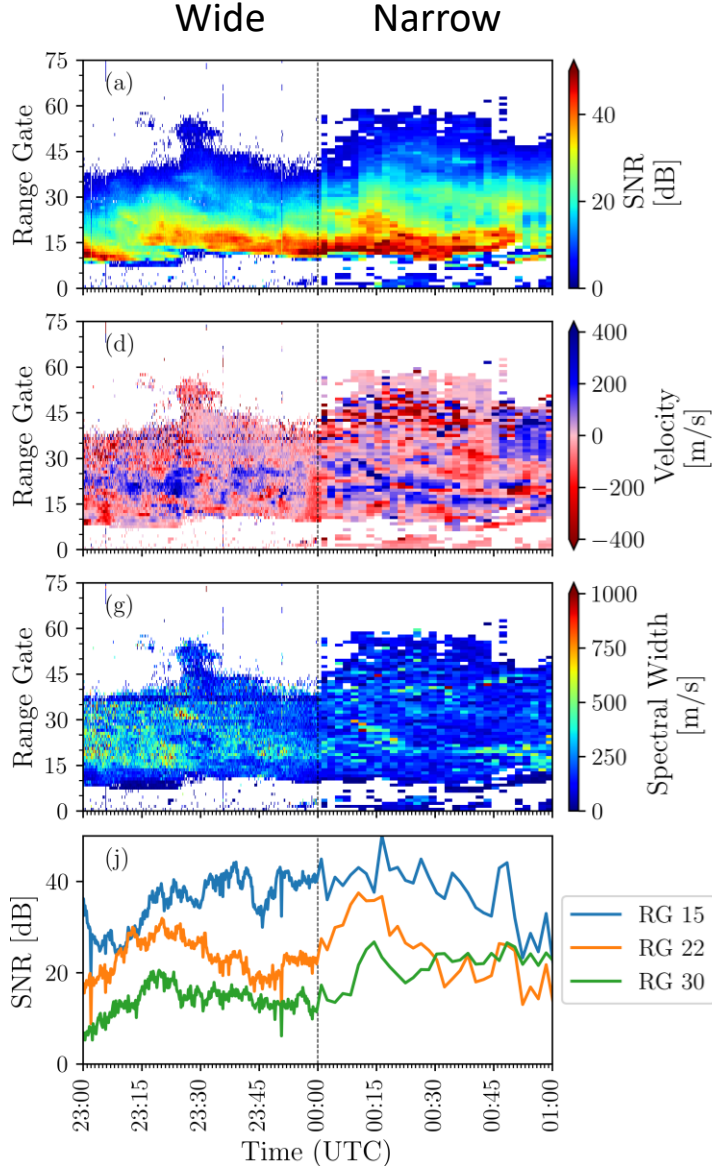
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 - fixed by adjusted receive antenna phase progression

Test example and side effects



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 - non-critical (normal dynamic range 30-40 dB)
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- **16-fold increase in data volume** if using the same integration time

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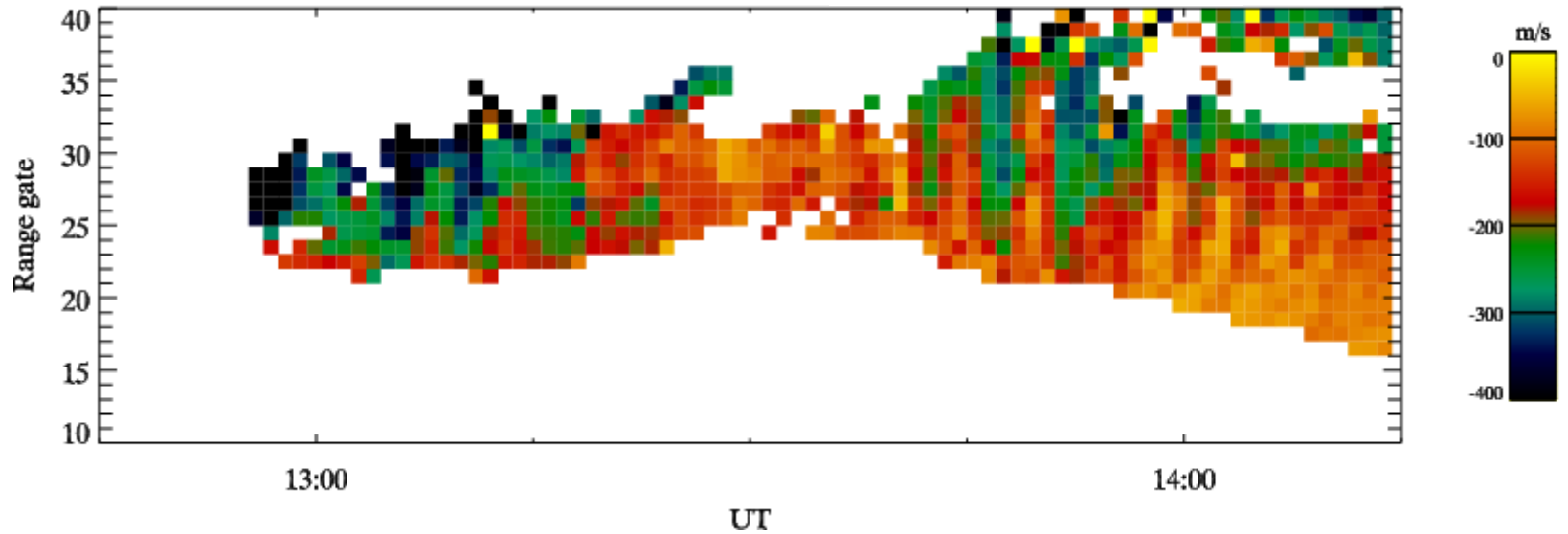


- **SNR decrease (≈ 10 dB)**
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- **Side-lobe contamination (-13 dB)**
 - Hamming window for received signal power (side lobes ≤ -40 dB)
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 - non-critical (extra storage)

Example: Pc5 ULF wave

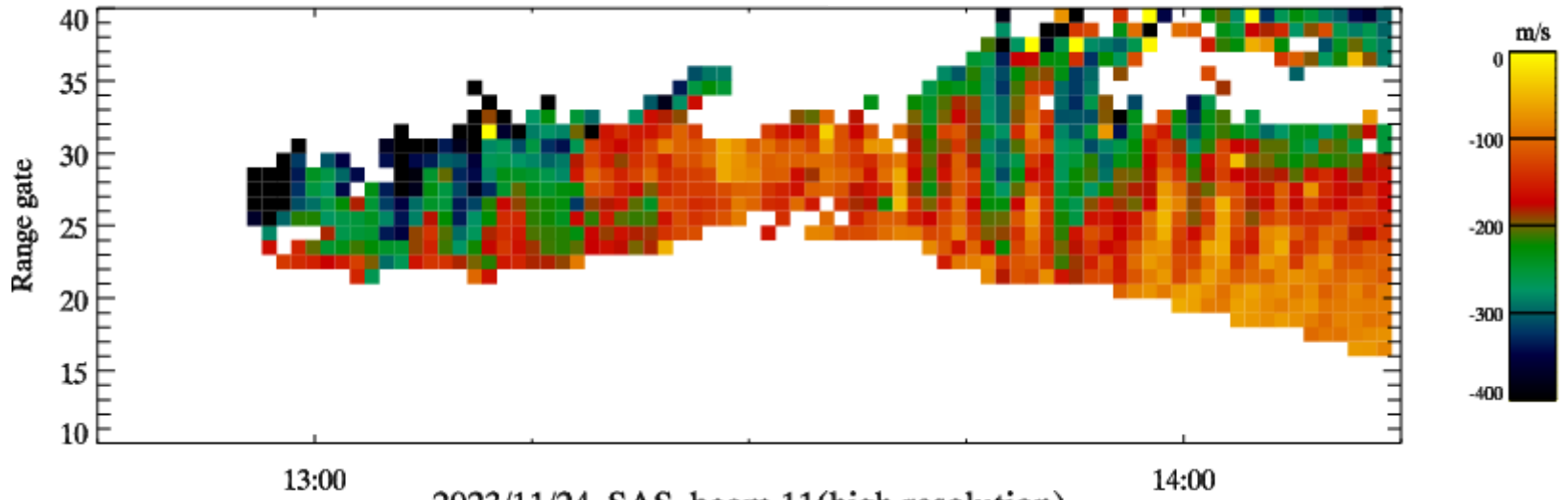
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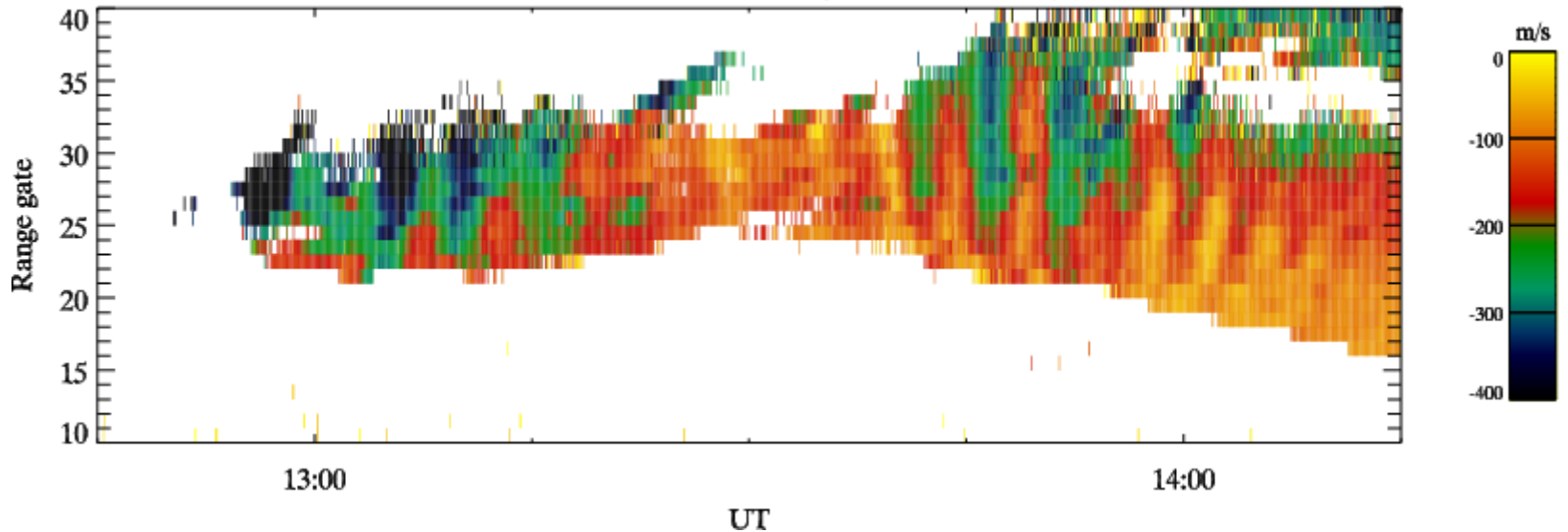


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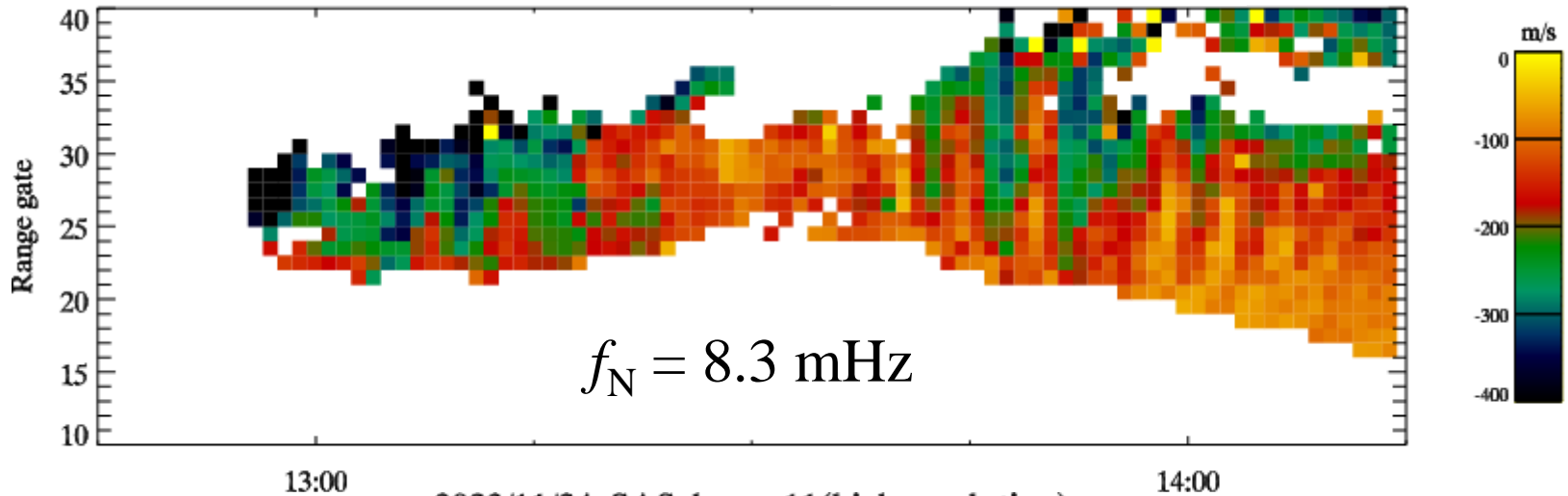


2023/11/24, SAS, beam 11 (high resolution)

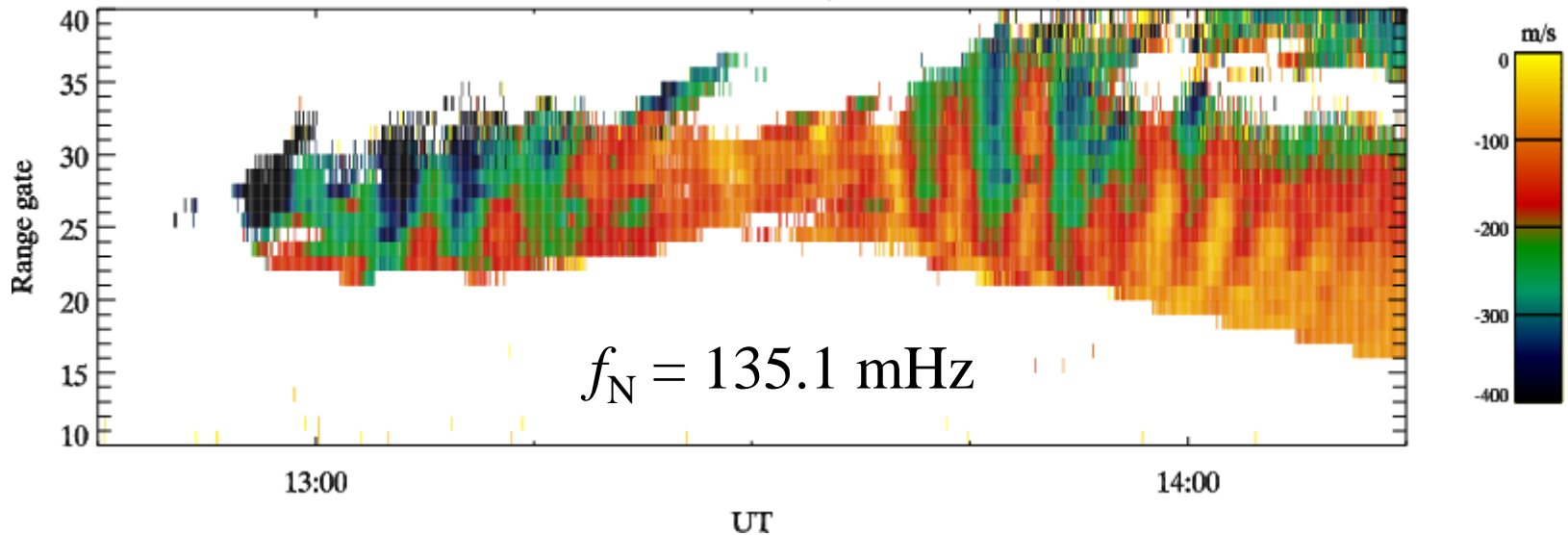


Example: Pc5 ULF wave

2023/11/24, SAS, beam 11 (emulated conventional)

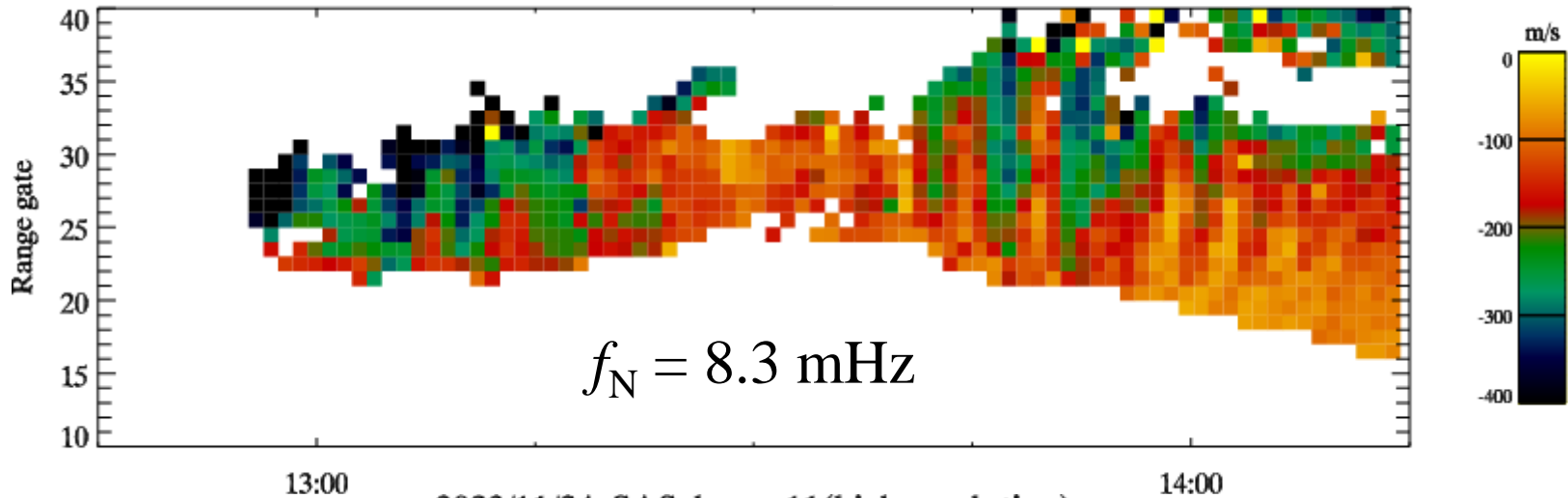


2023/11/24, SAS, beam 11 (high resolution)

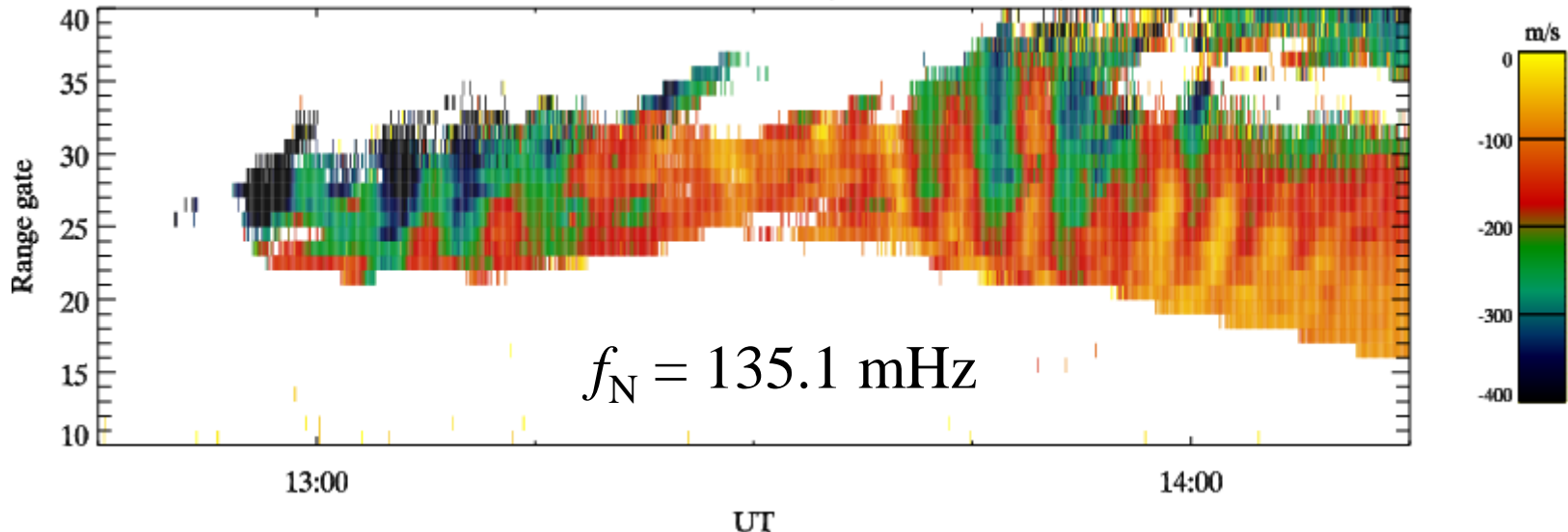


Example: Pc5 ULF wave

2023/11/24, SAS, beam 11 (emulated conventional)



2023/11/24, SAS, beam 11 (high resolution)



For more exciting examples see Dan Billett's presentation on Thursday!

Bistatic *vs* monostatic scatter


Bistatic *vs* monostatic scatter



Monostatic
(transmit & receive)

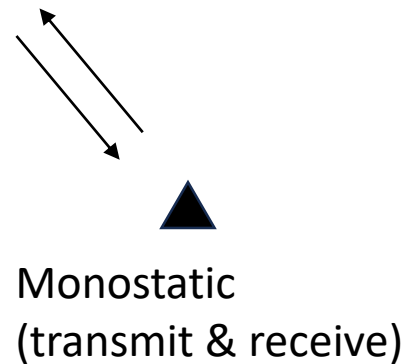
Bistatic *vs* monostatic scatter

 Irregularity

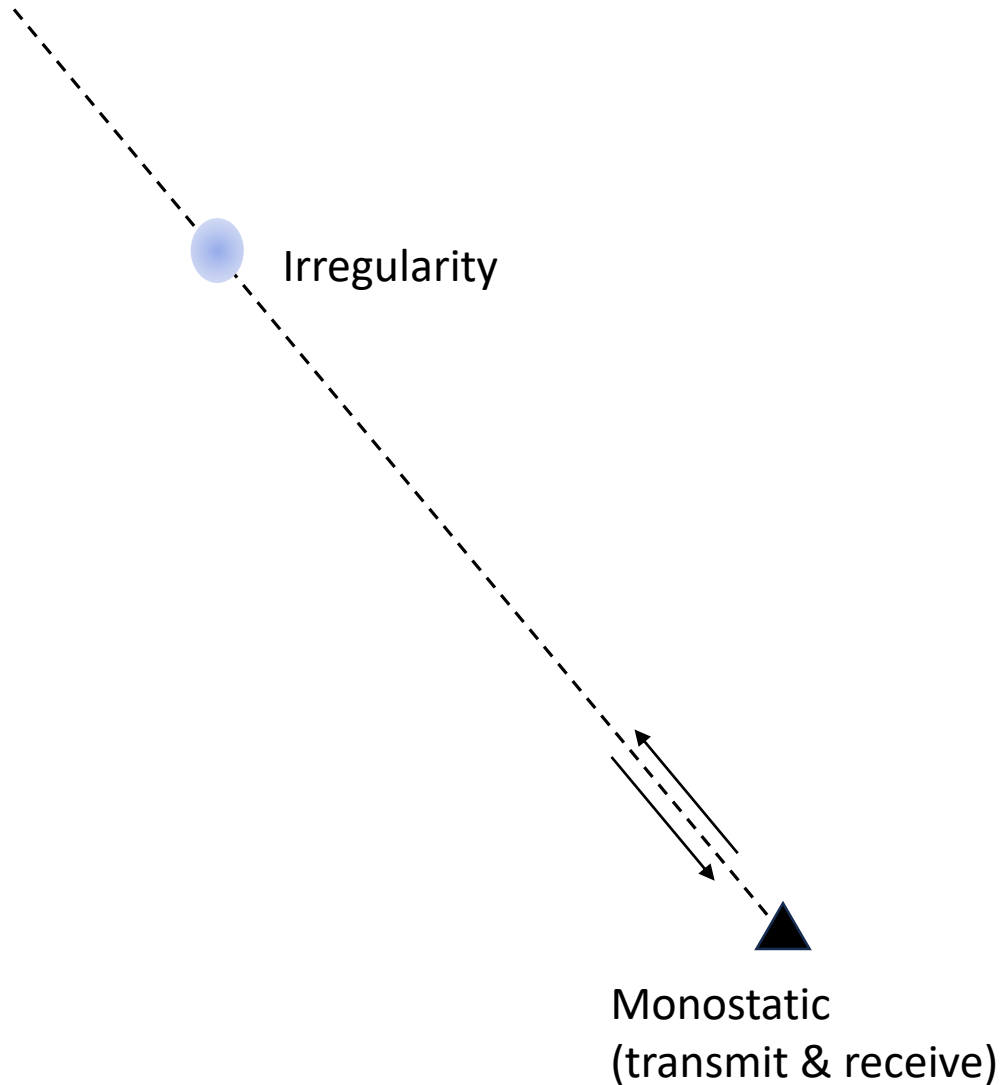

Monostatic
(transmit & receive)

Bistatic *vs* monostatic scatter

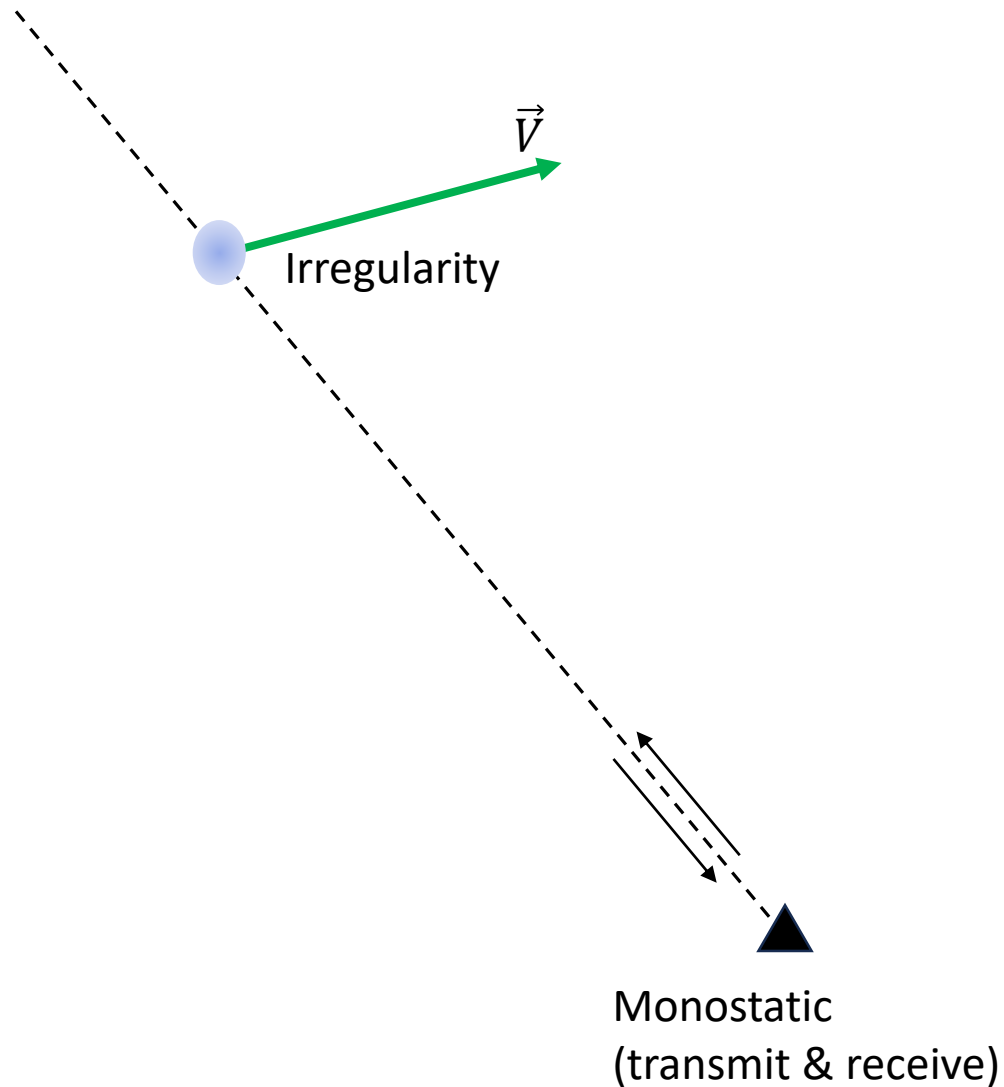
 Irregularity



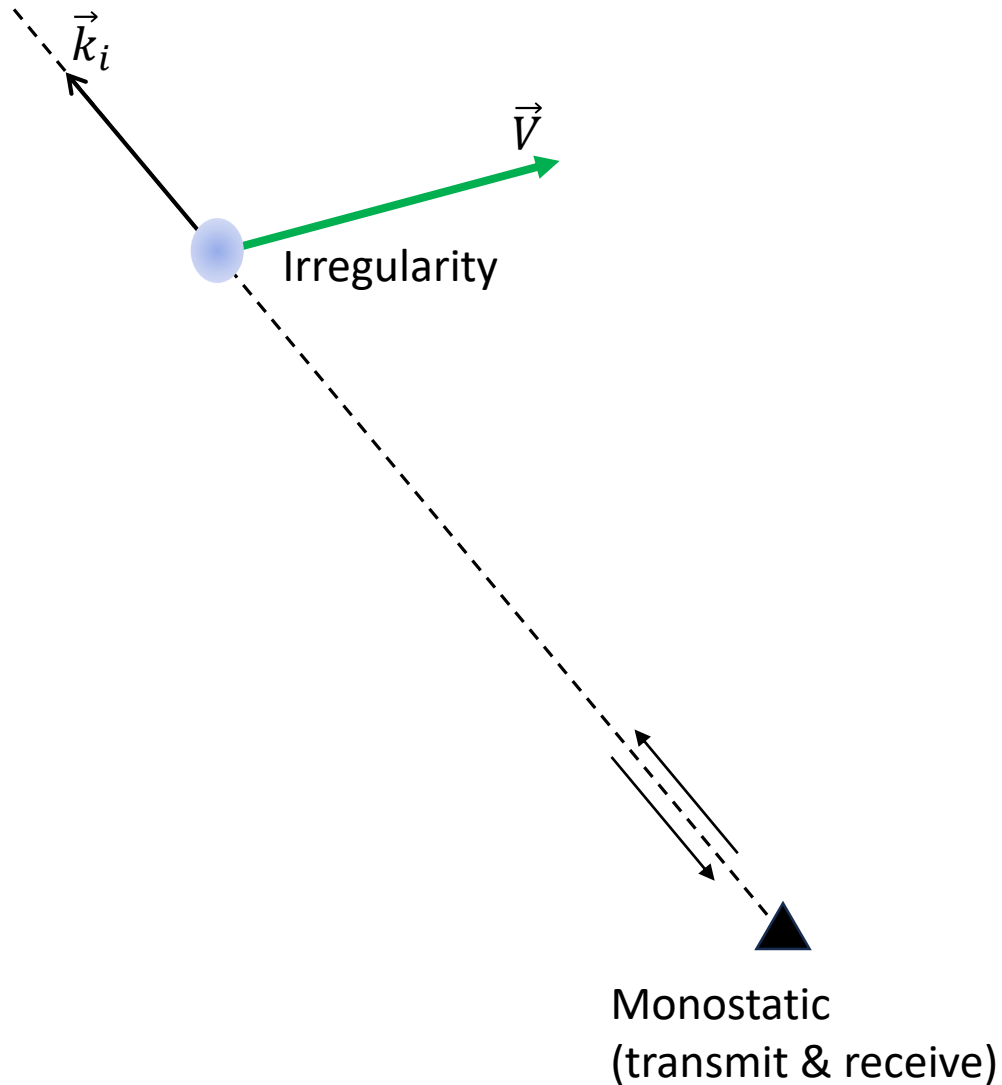
Bistatic vs monostatic scatter



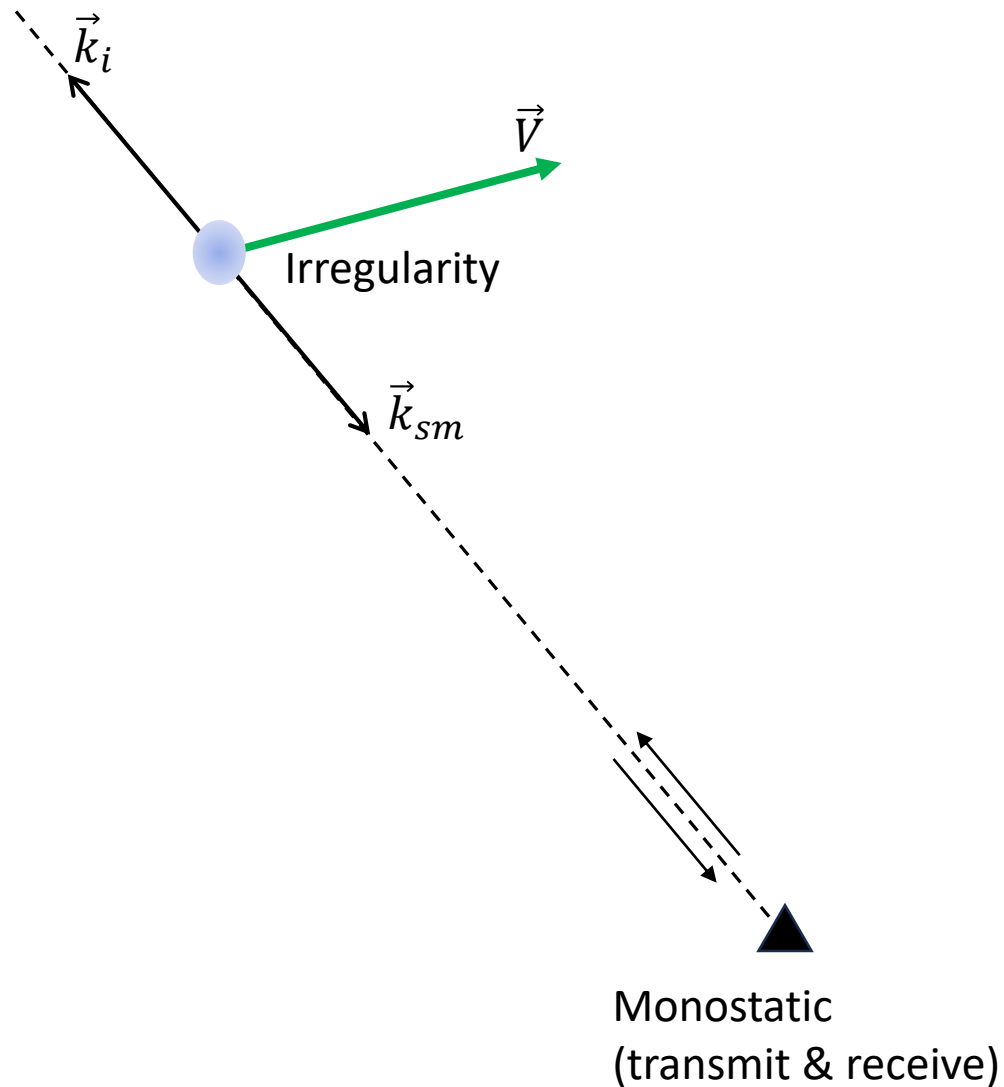
Bistatic vs monostatic scatter



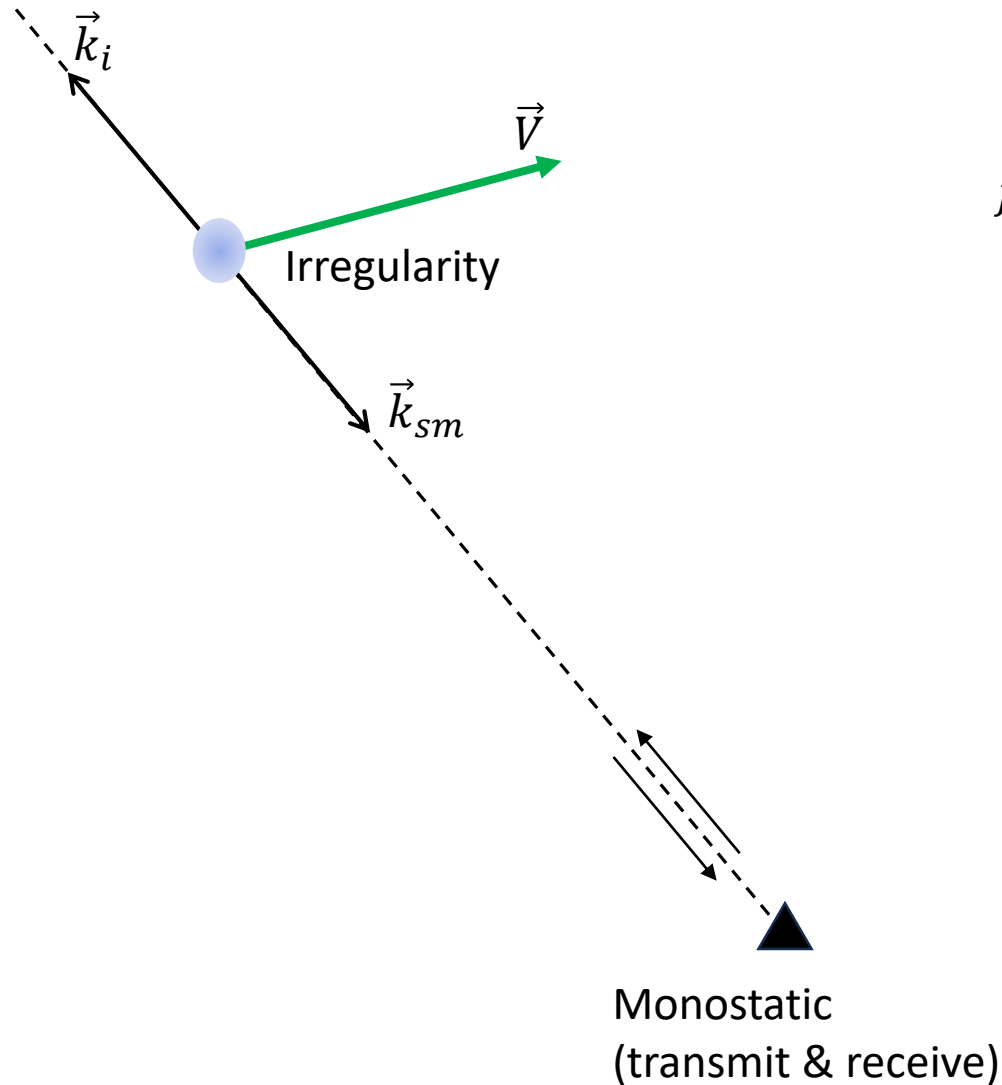
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Bistatic vs monostatic scatter

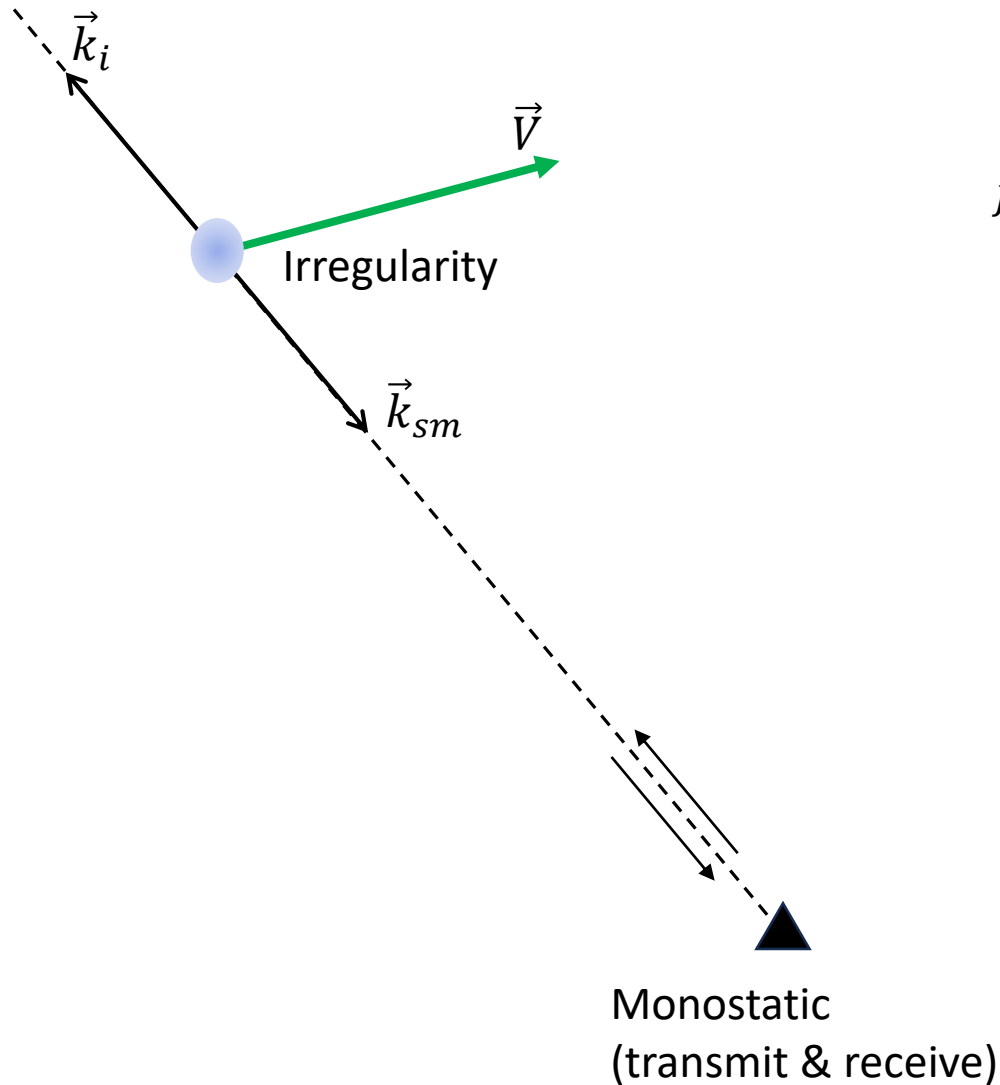


Bistatic vs monostatic scatter



$$f_D = \frac{1}{2\pi} \vec{K} \cdot \vec{V}$$

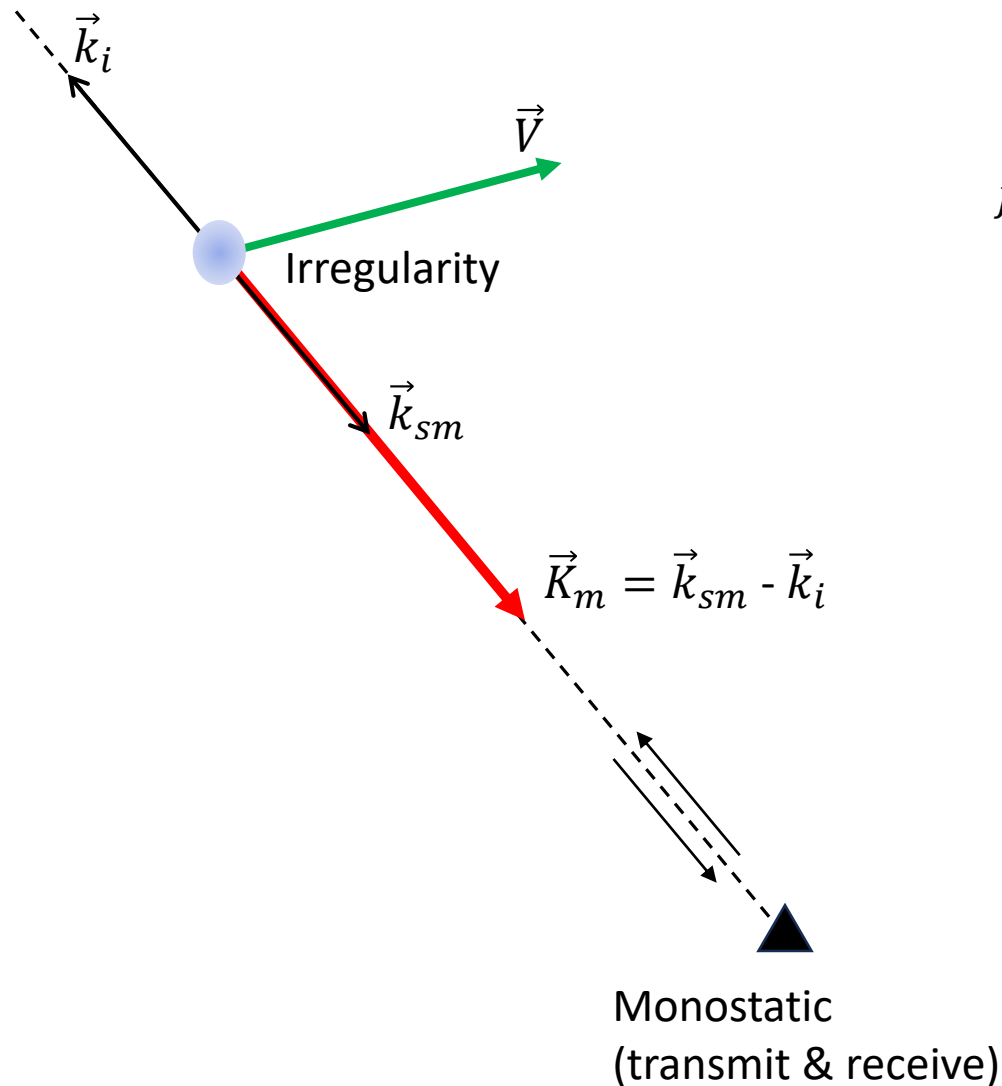
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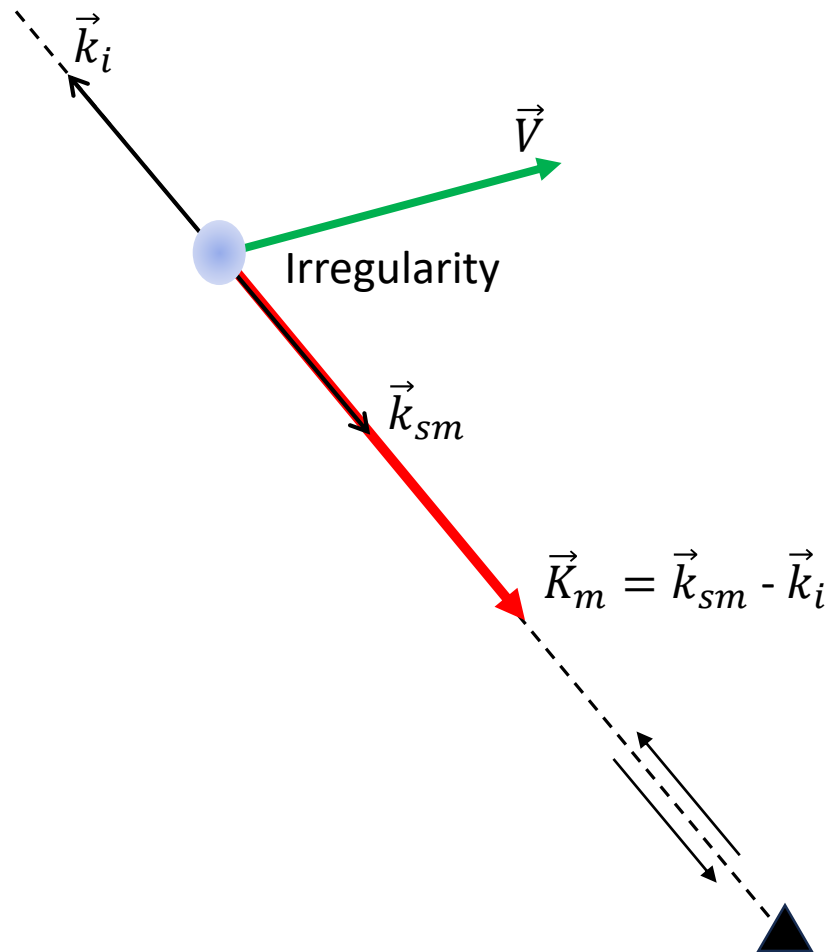
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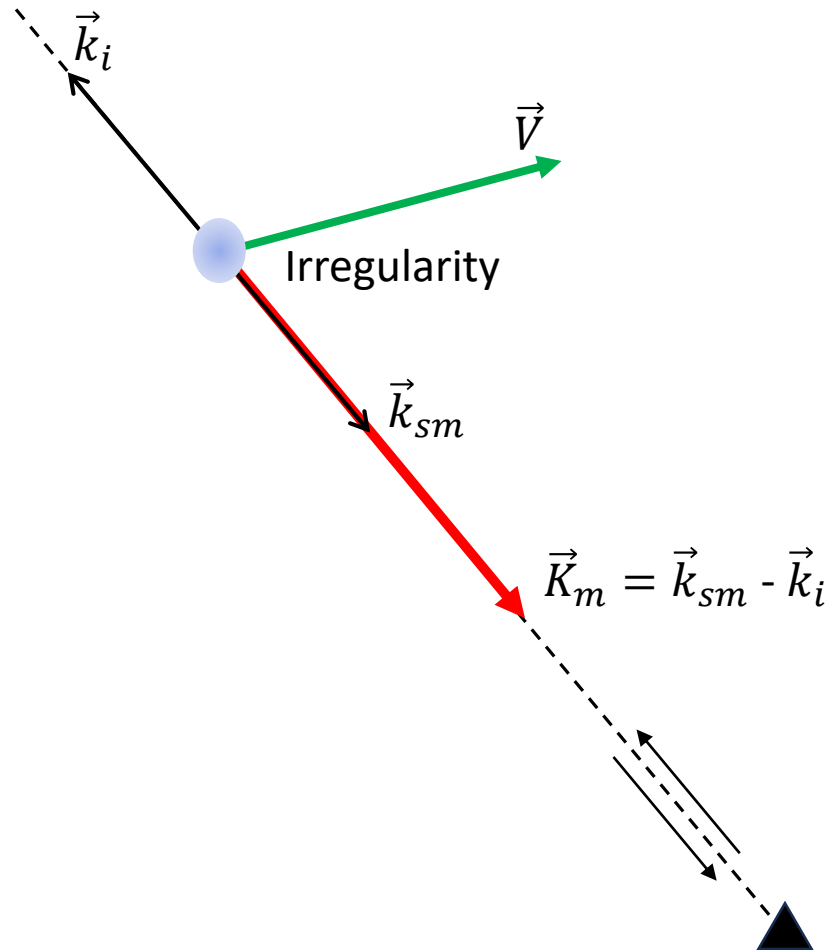
$$f_D = \frac{1}{2\pi} \vec{K} \cdot \vec{V}$$

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$$|\vec{K}_m| = 2k$$

Monostatic
(transmit & receive)

Bistatic vs monostatic scatter



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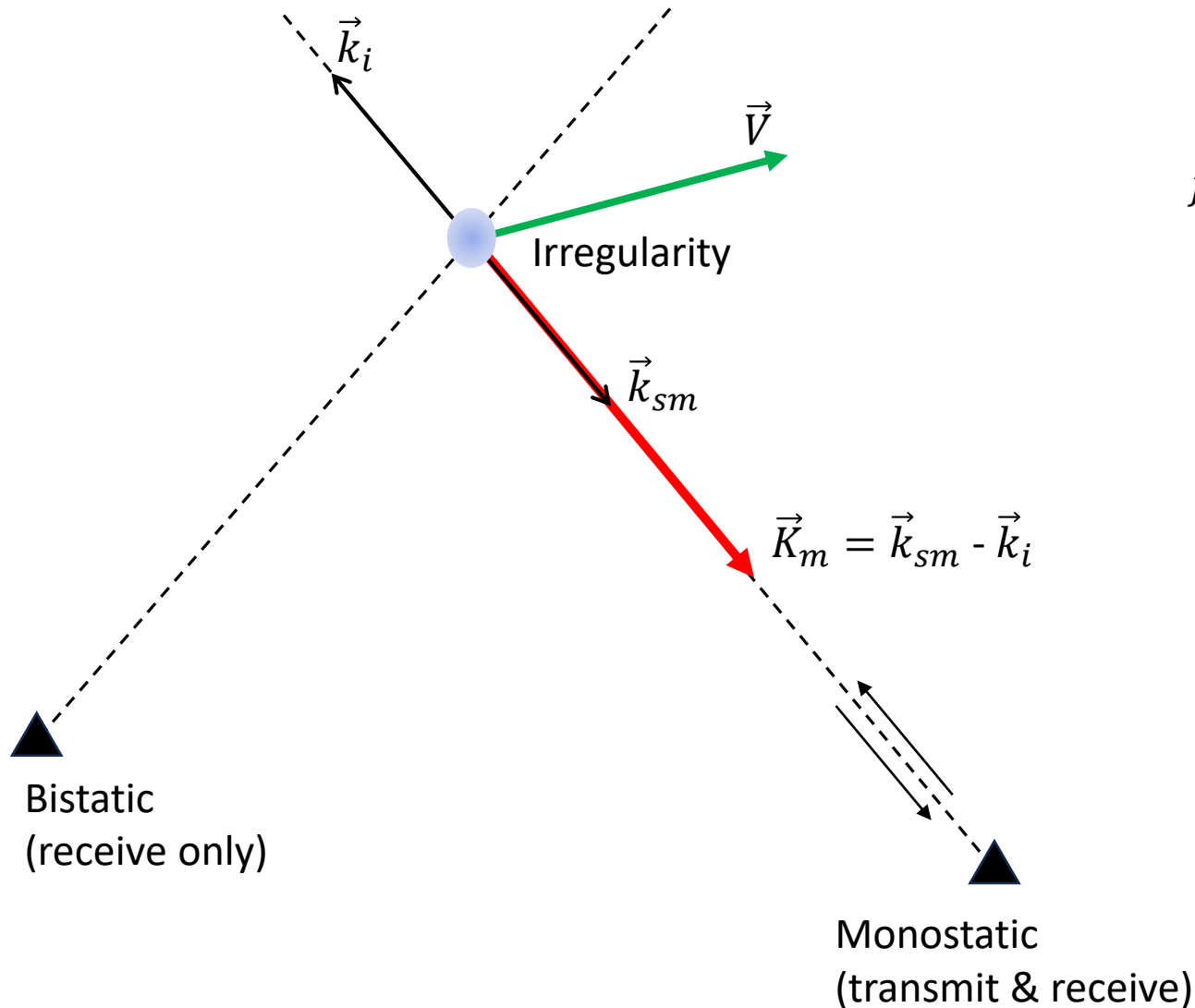
$$\vec{K} = \vec{k}_s - \vec{k}_i$$

$$|\vec{K}_m| = 2k$$

▲
Bistatic
(receive only)

▲
Monostatic
(transmit & receive)

Bistatic vs monostatic scatter

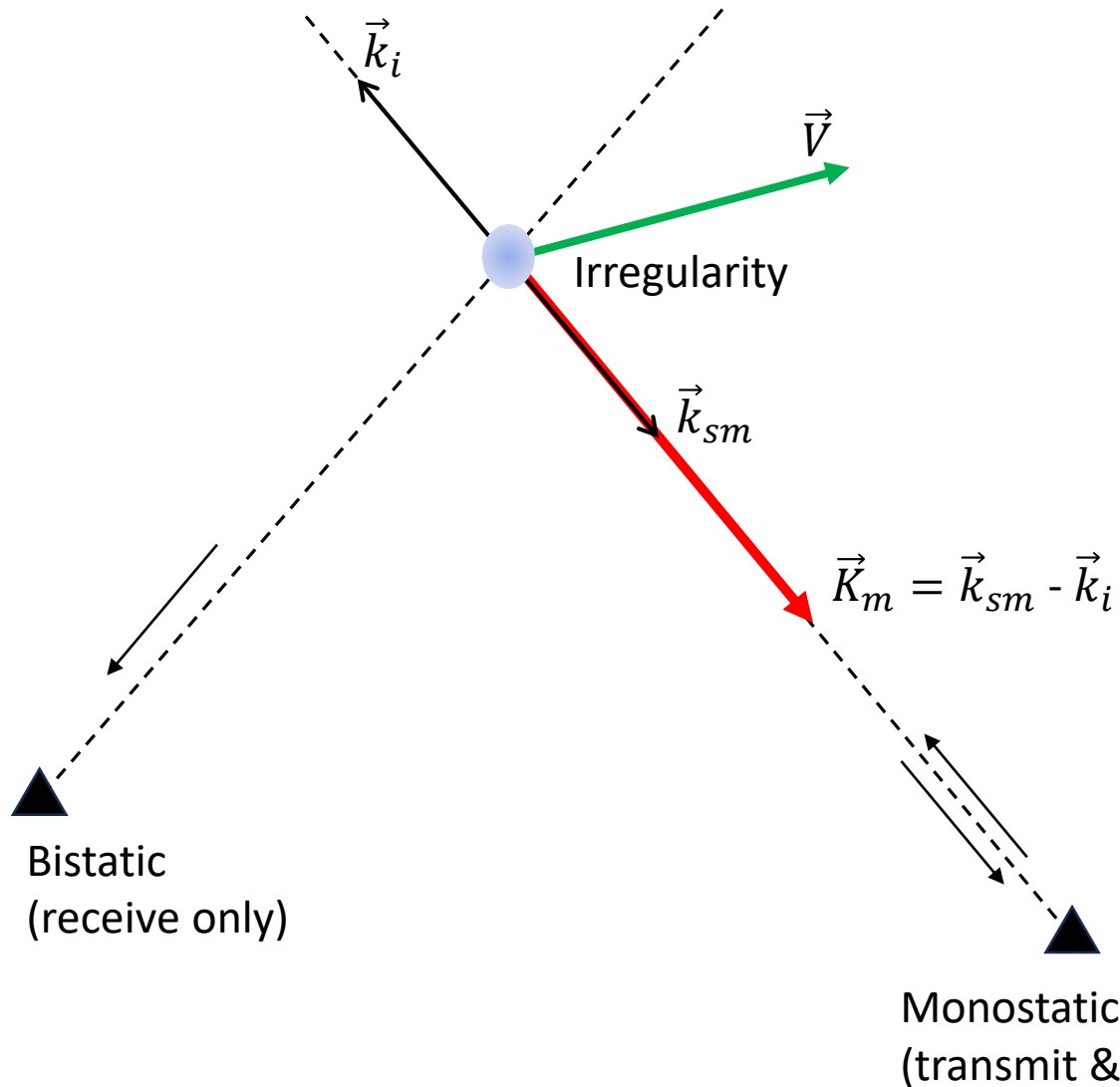


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Bistatic vs monostatic scatter

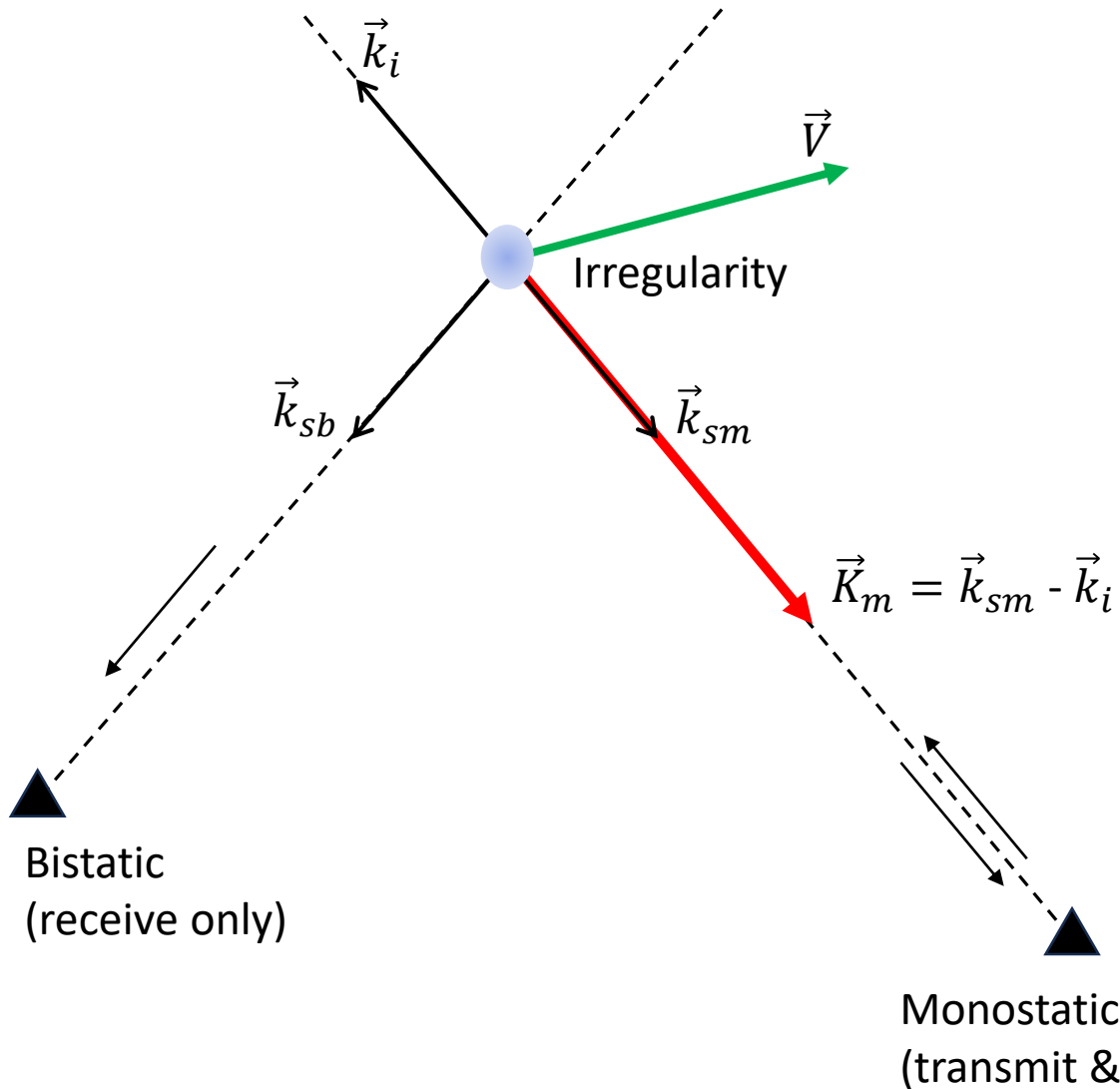


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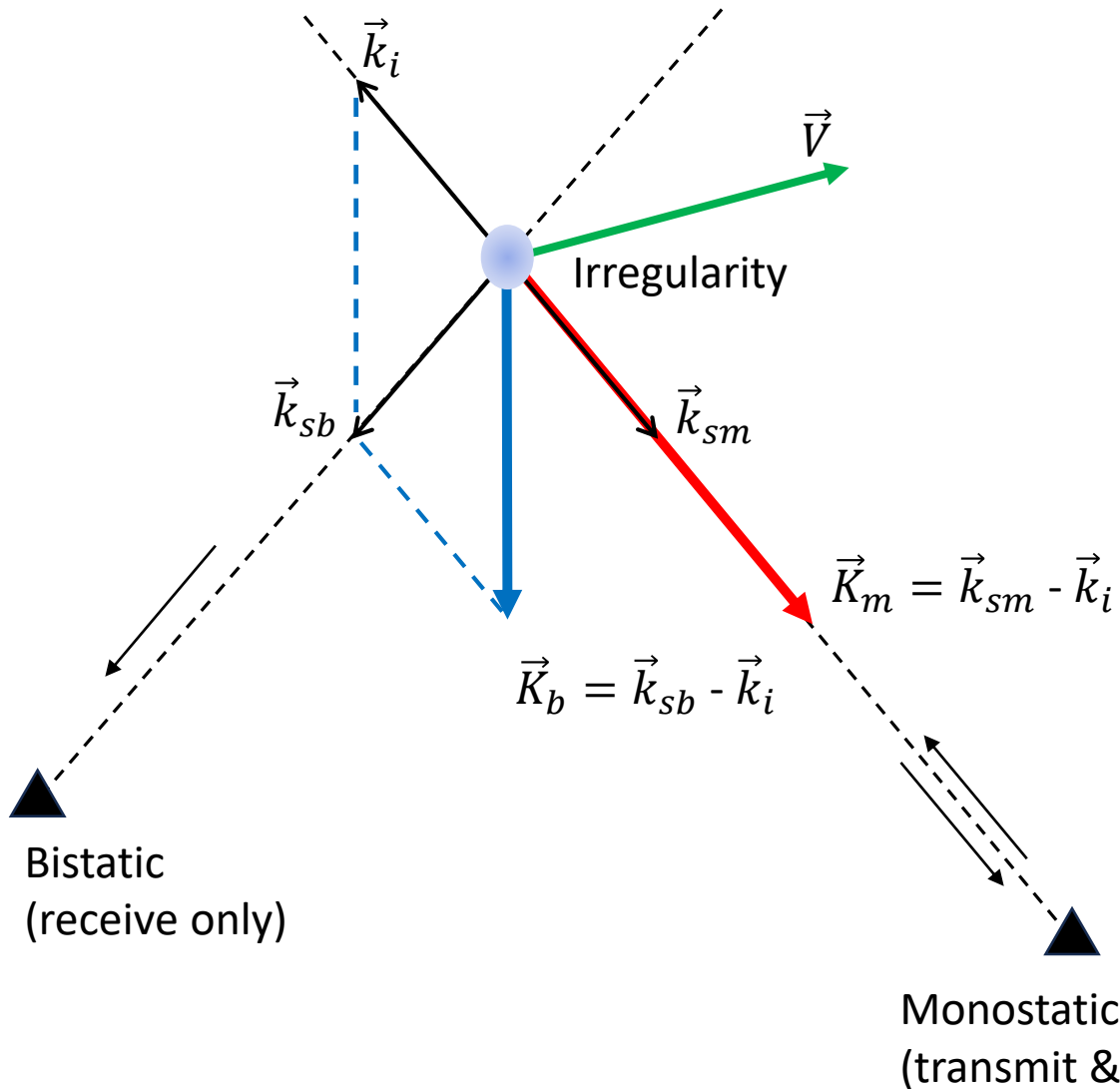


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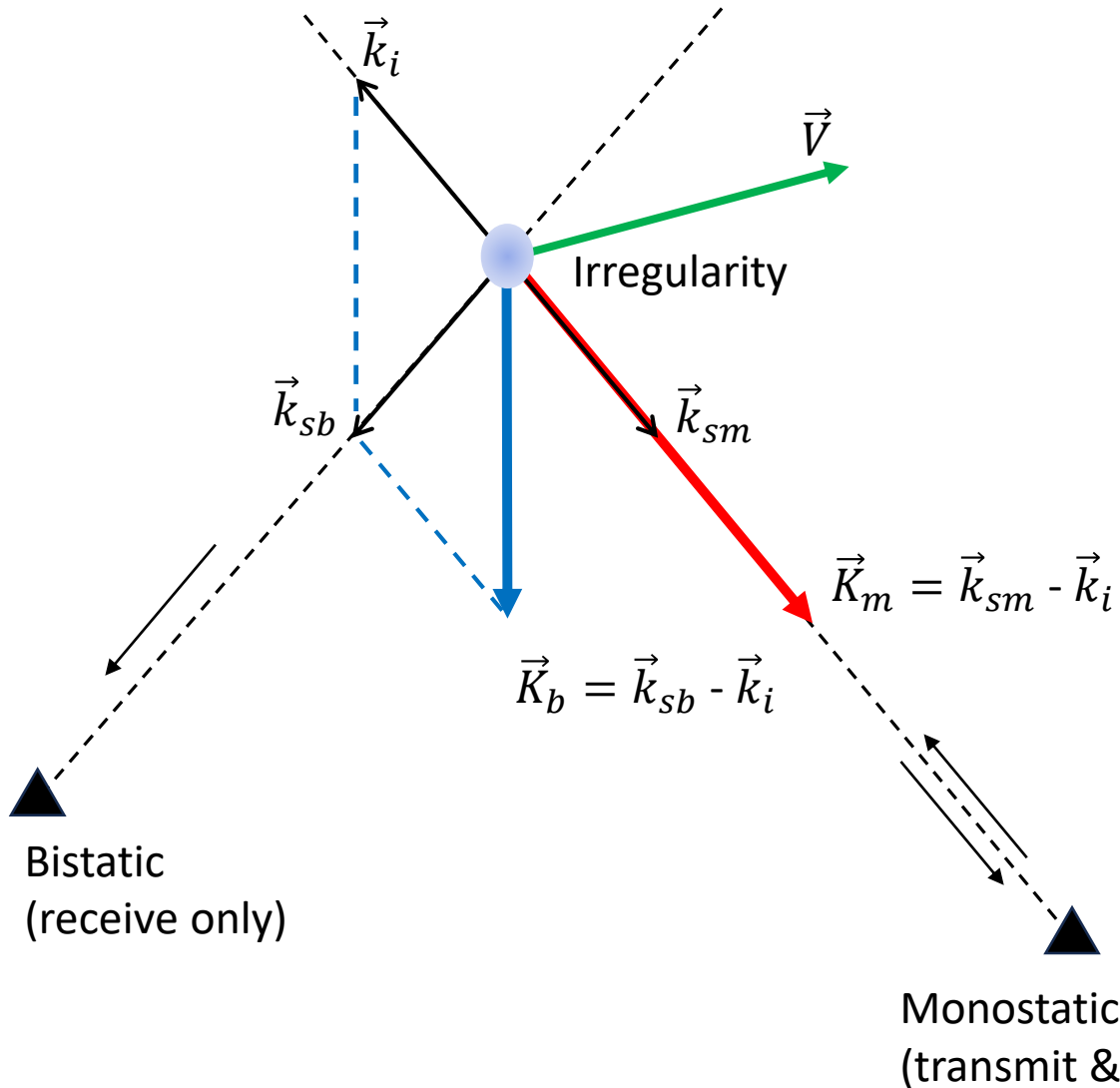


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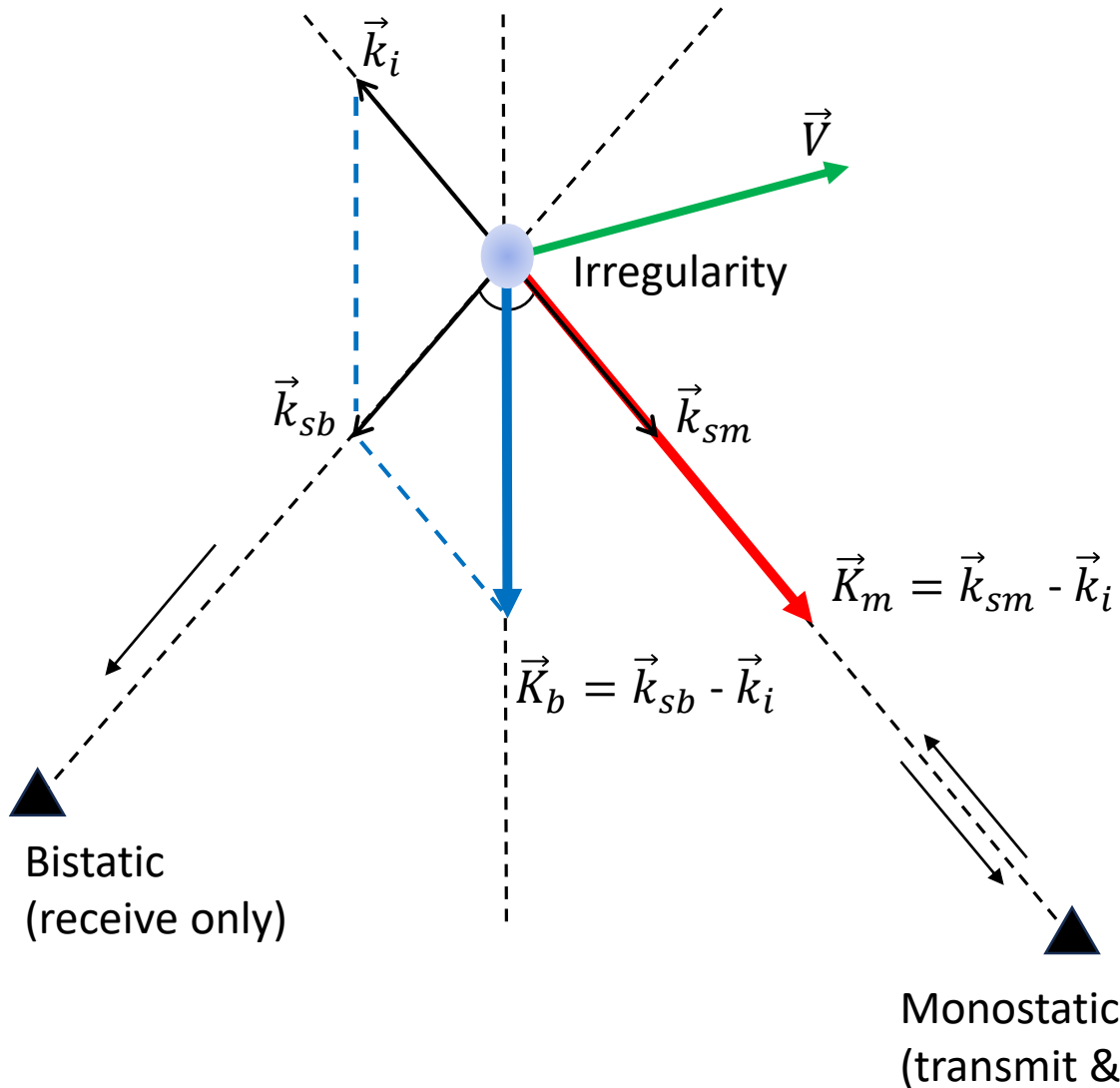
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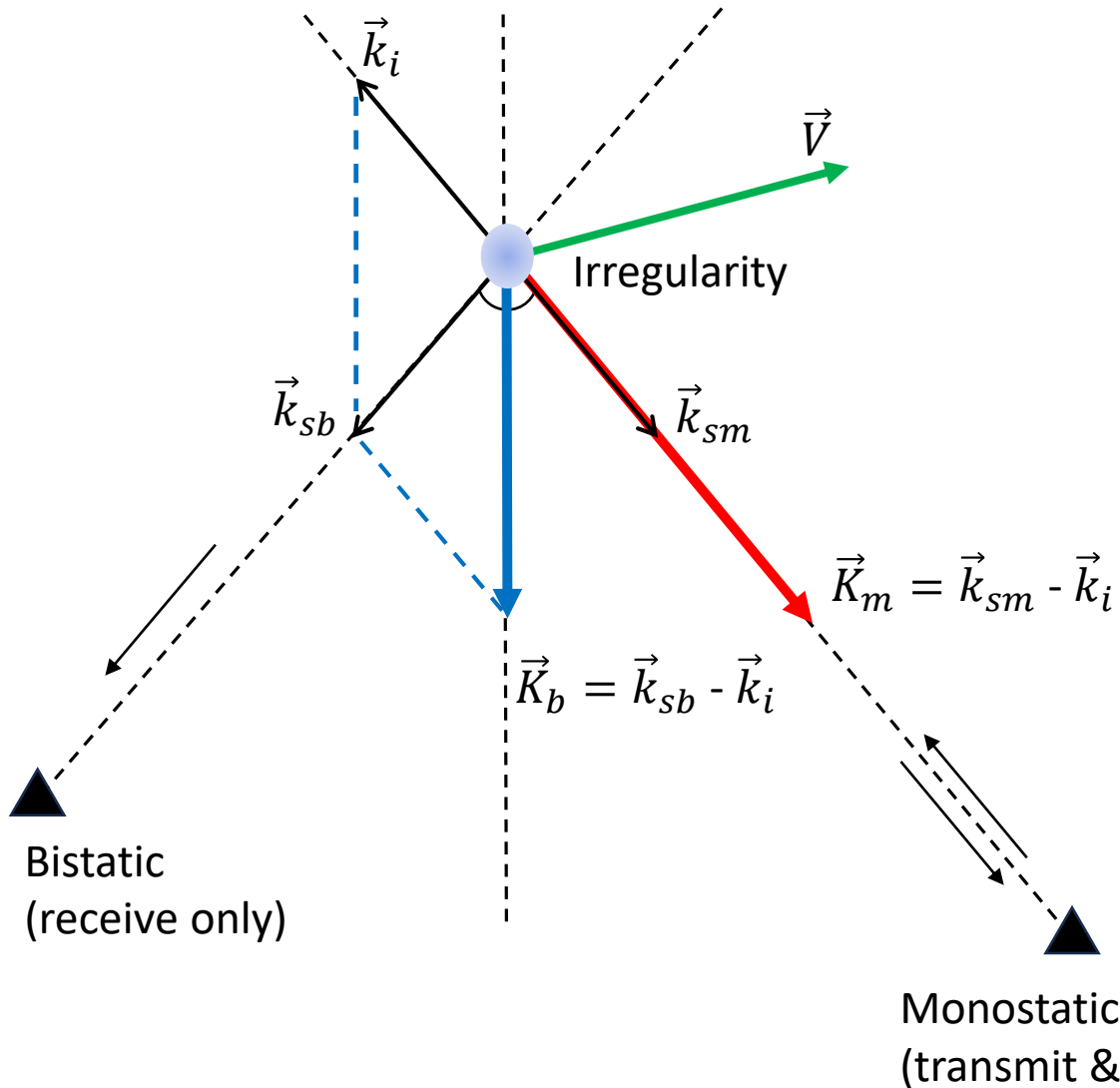
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Bistatic sounding provides **additional velocity vector component!**

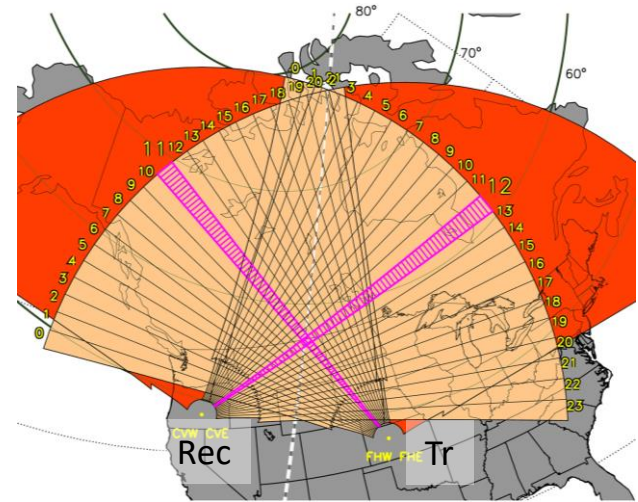
Multistatic operations

Multistatic operations

- Previous work:

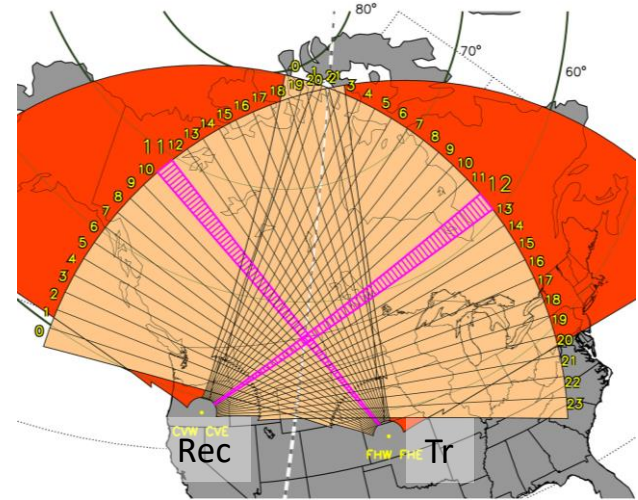
Multistatic operations

- Previous work:
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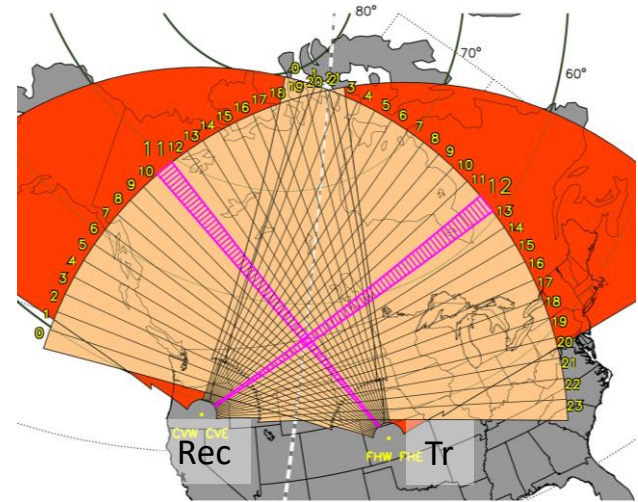
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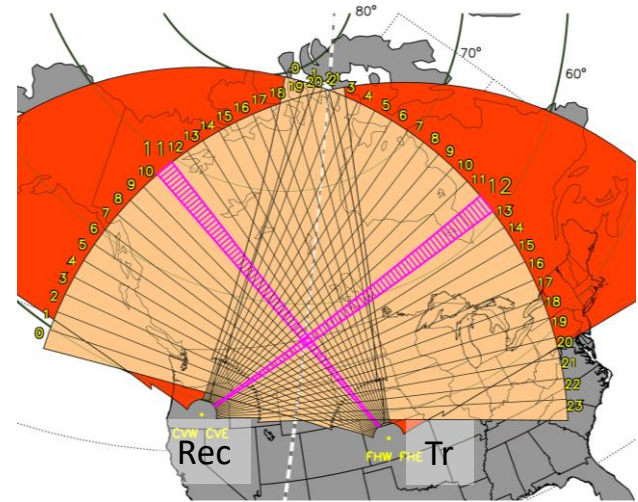
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- Widebeam transmission:



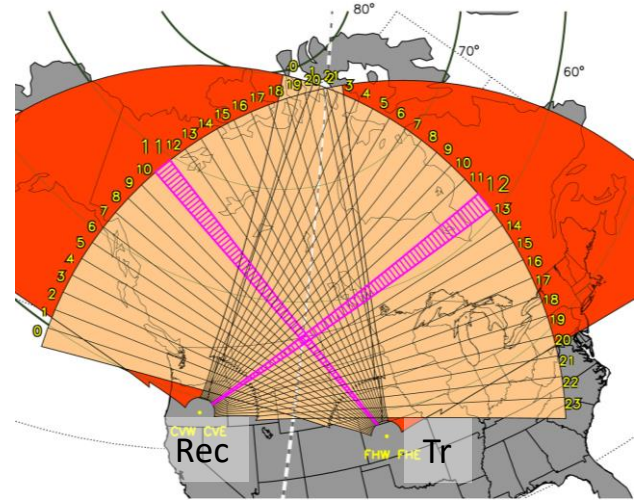
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 - Allows **simultaneous multi-beam reception**

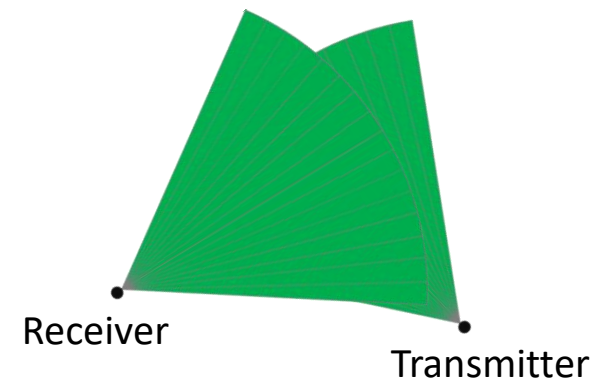


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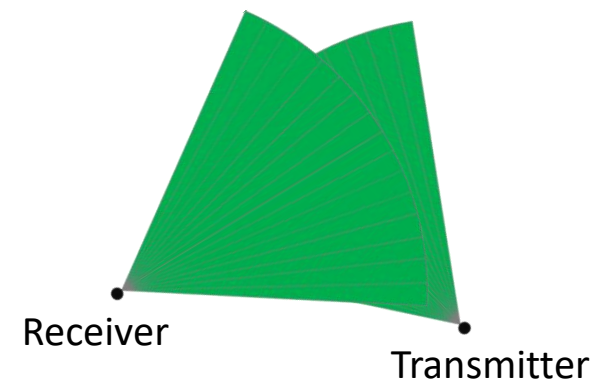
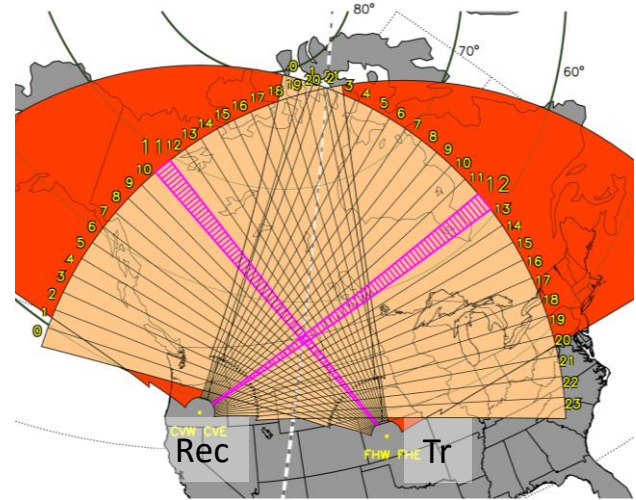


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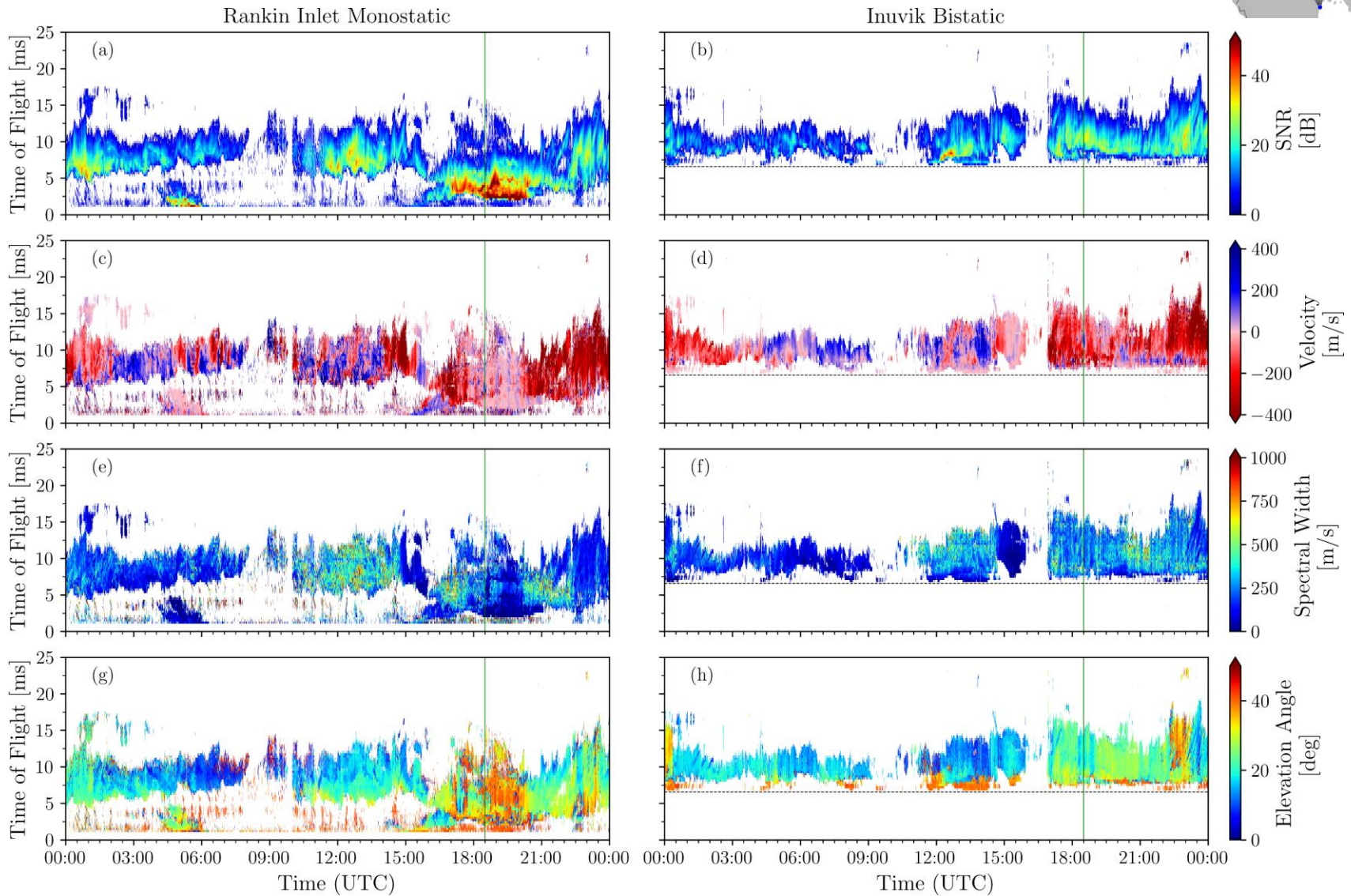
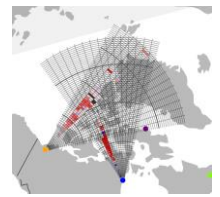
Multistatic operations

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 - sampling a field-of-view in **1.5-2 hr**
- Widebeam transmission:
 - Allows **simultaneous multi-beam reception**
 - sampling whole field of view in **3.7 s**



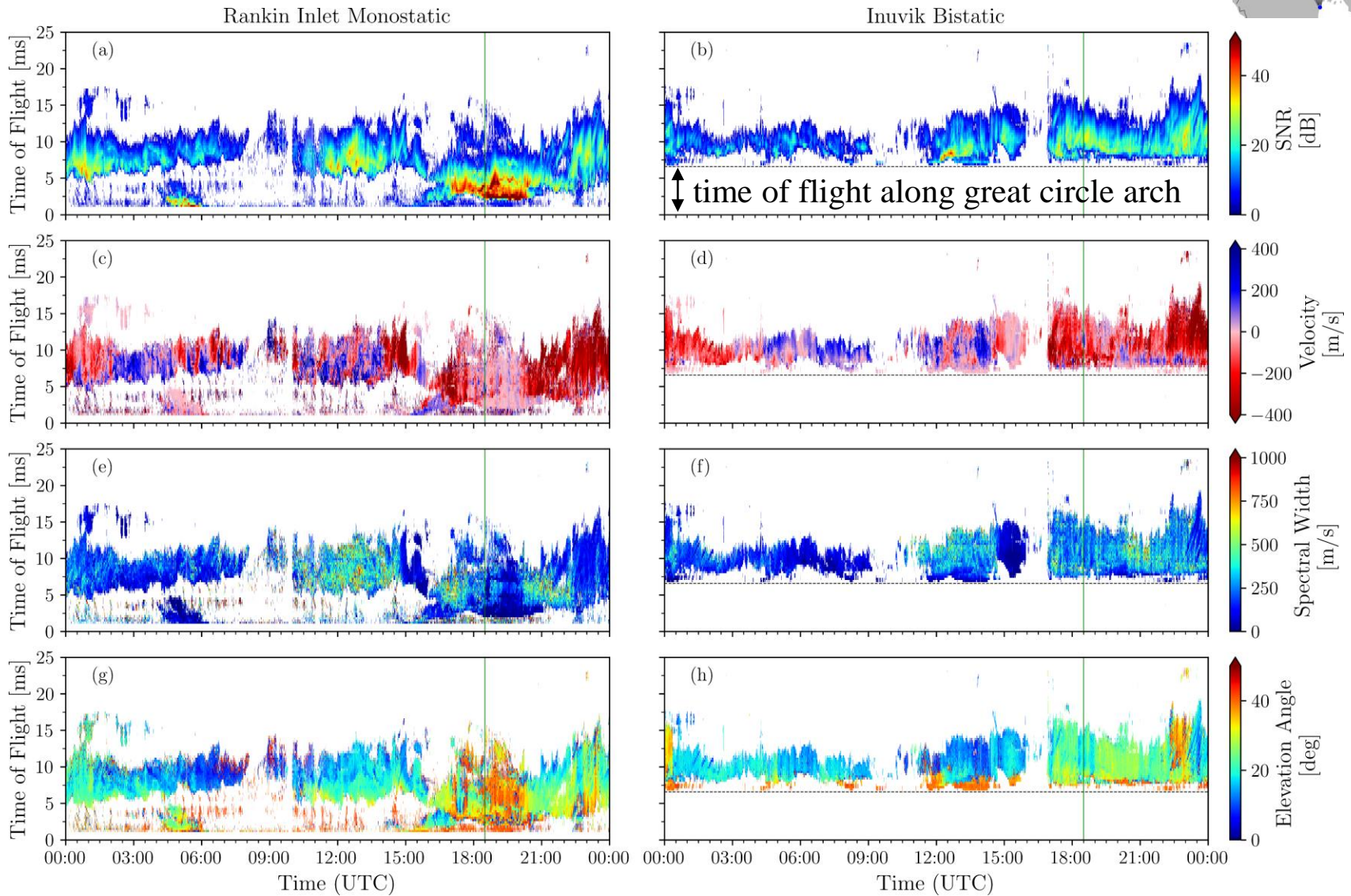
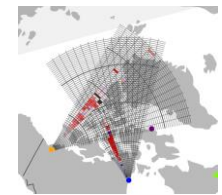
Multistatic test

10 January 2023, beam 7



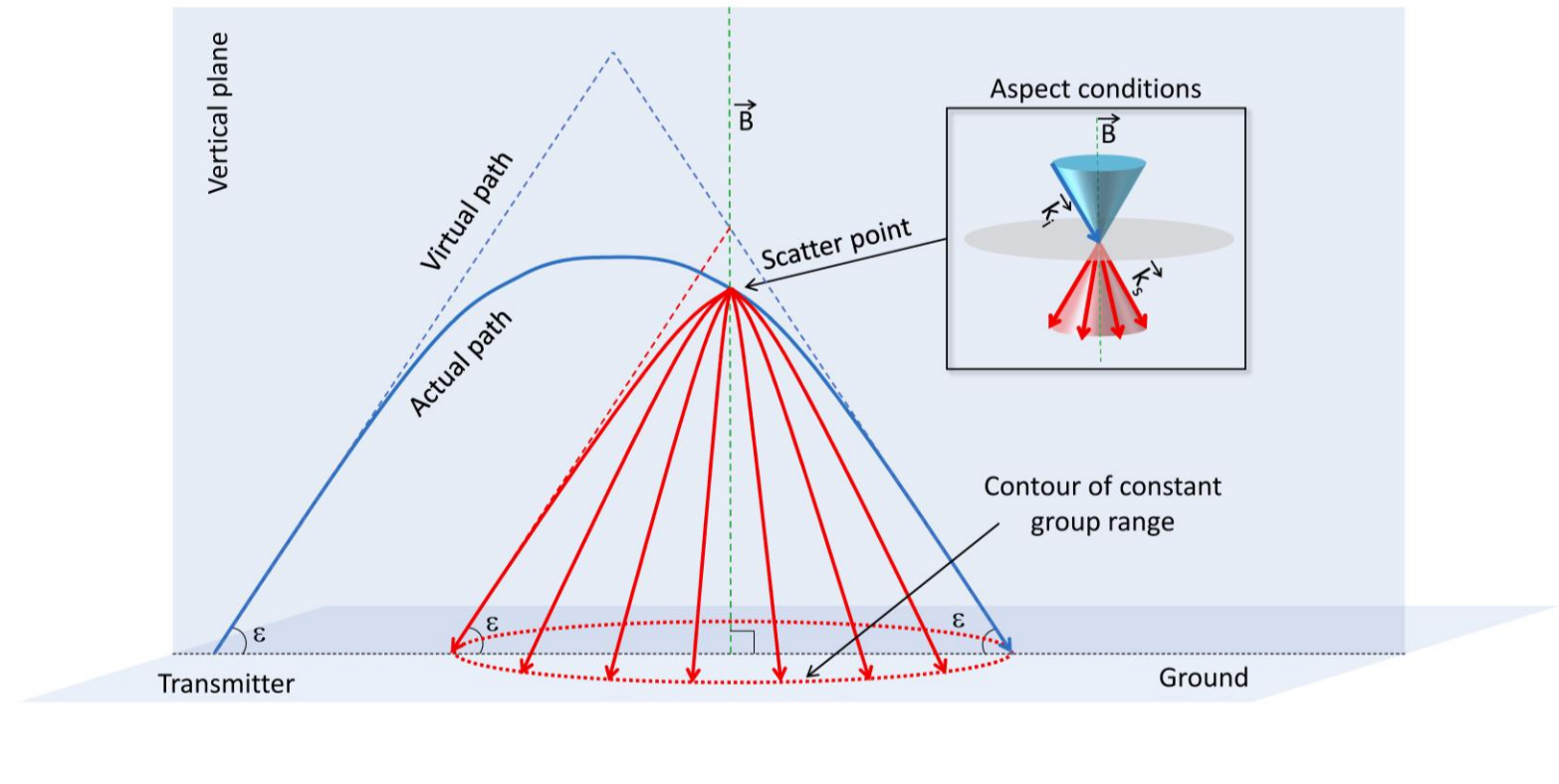
Multistatic test

10 January 2023, beam 7

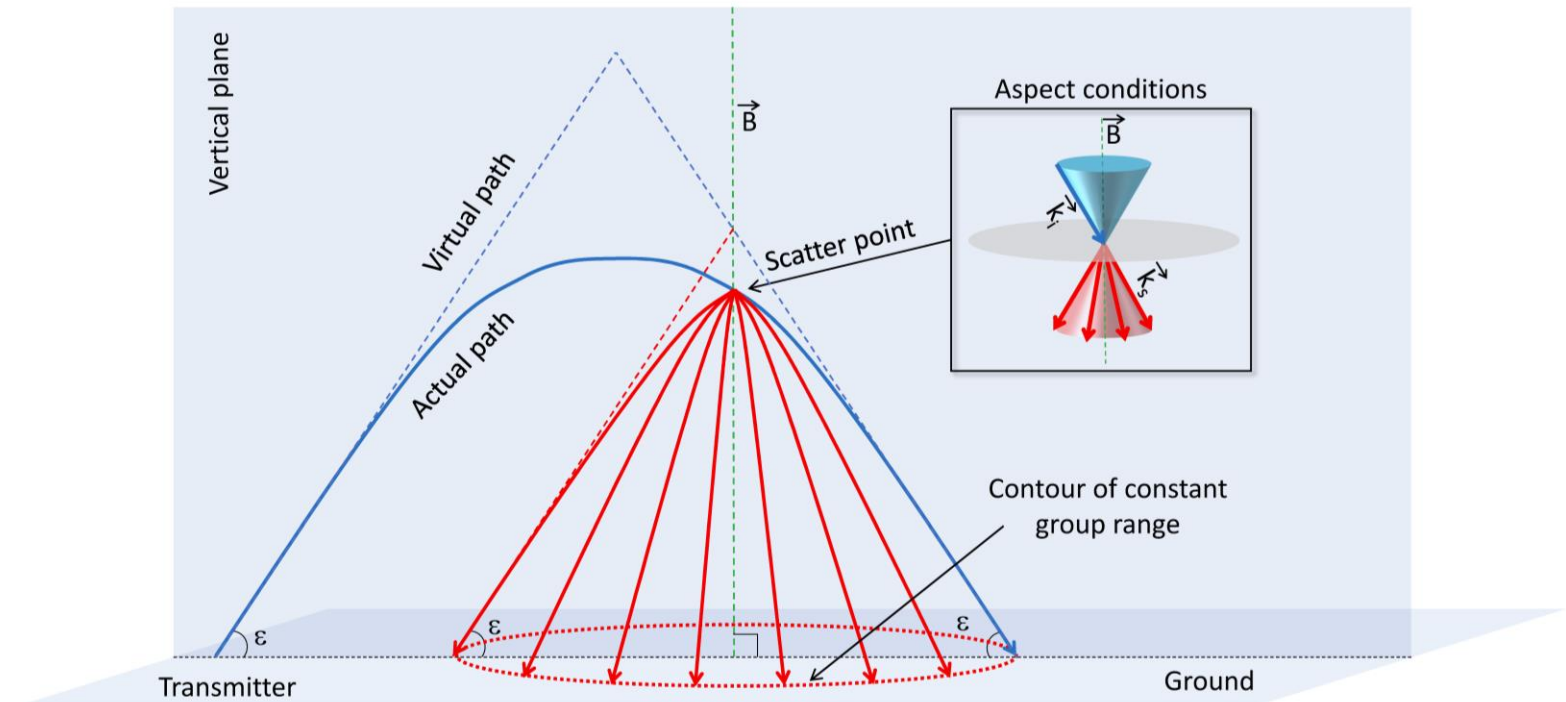


Multistatic geolocation: theory

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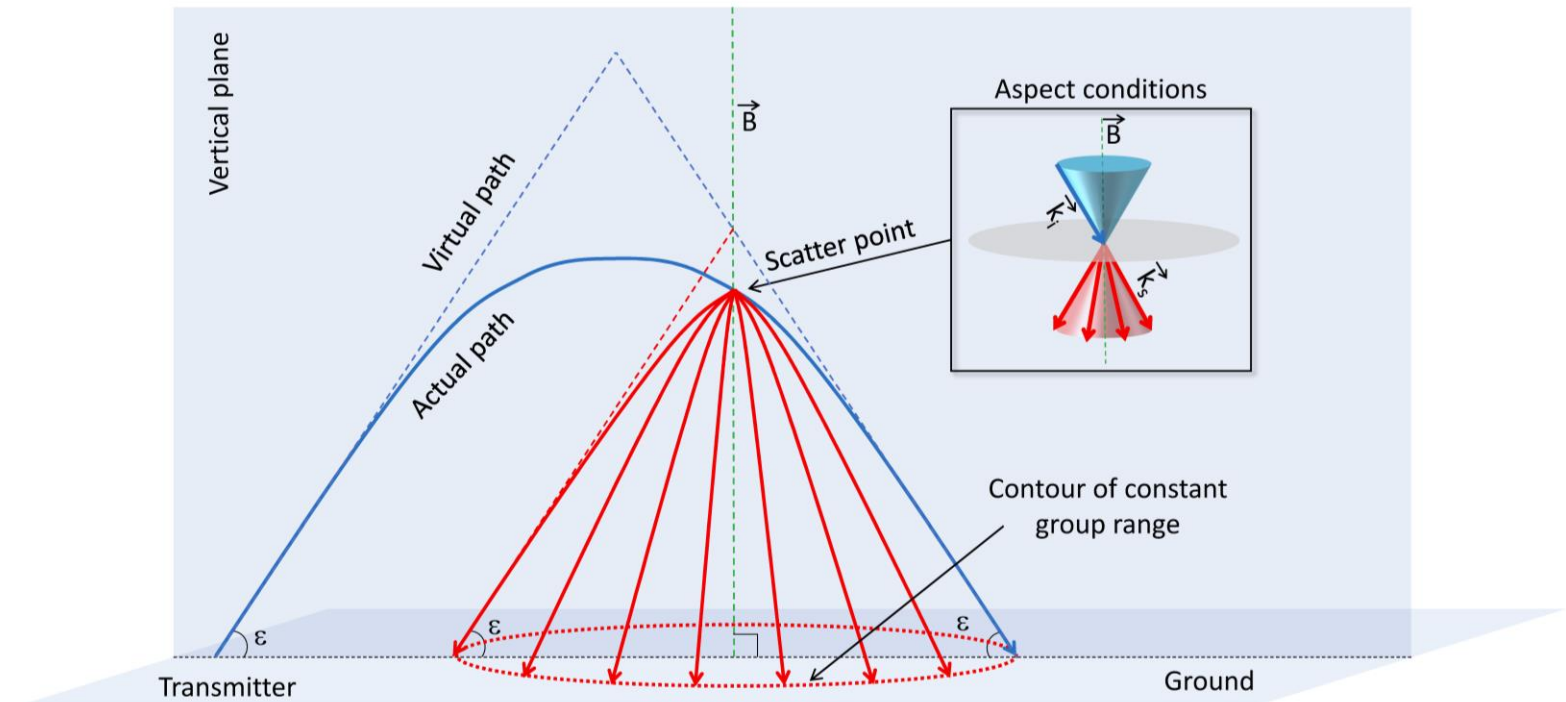


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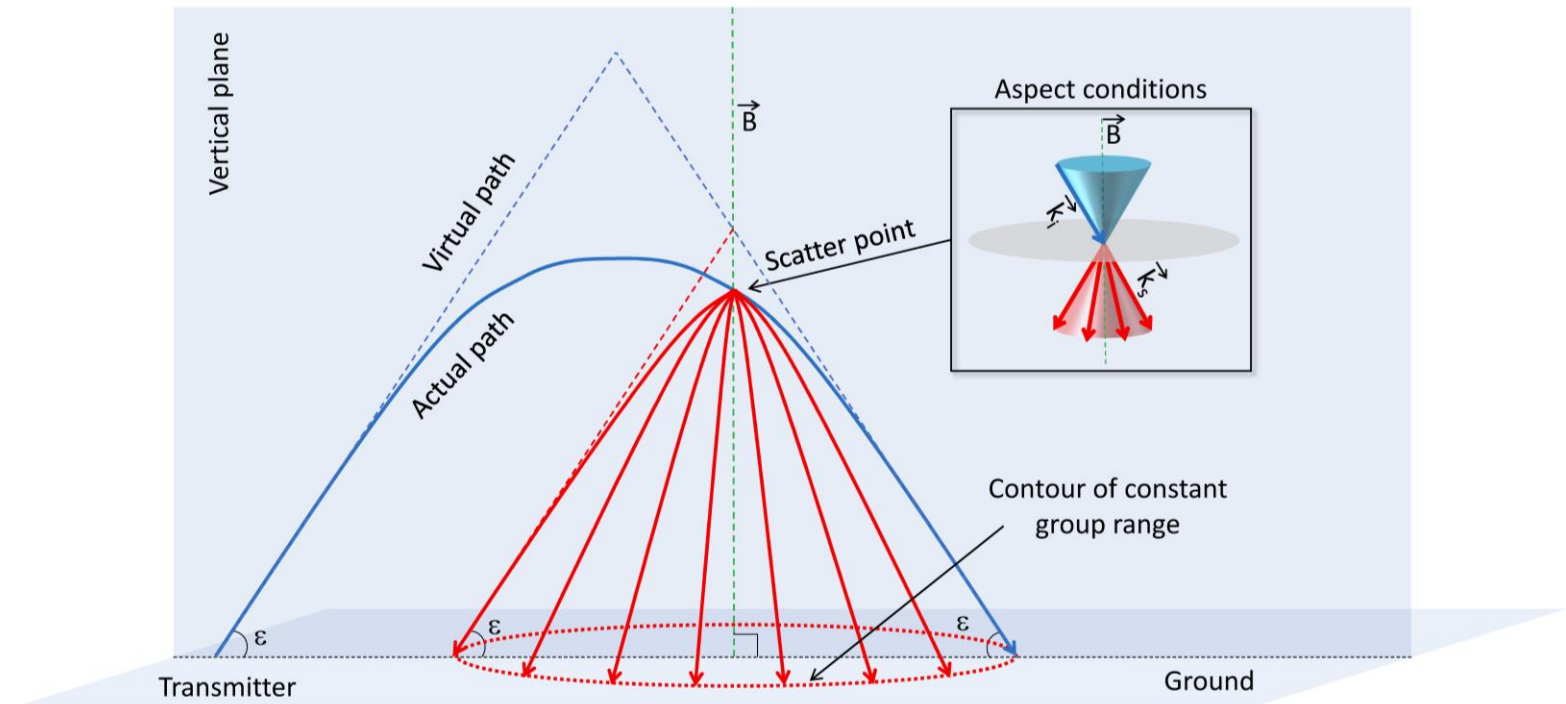
- Assumptions:

Multistatic geolocation: theory



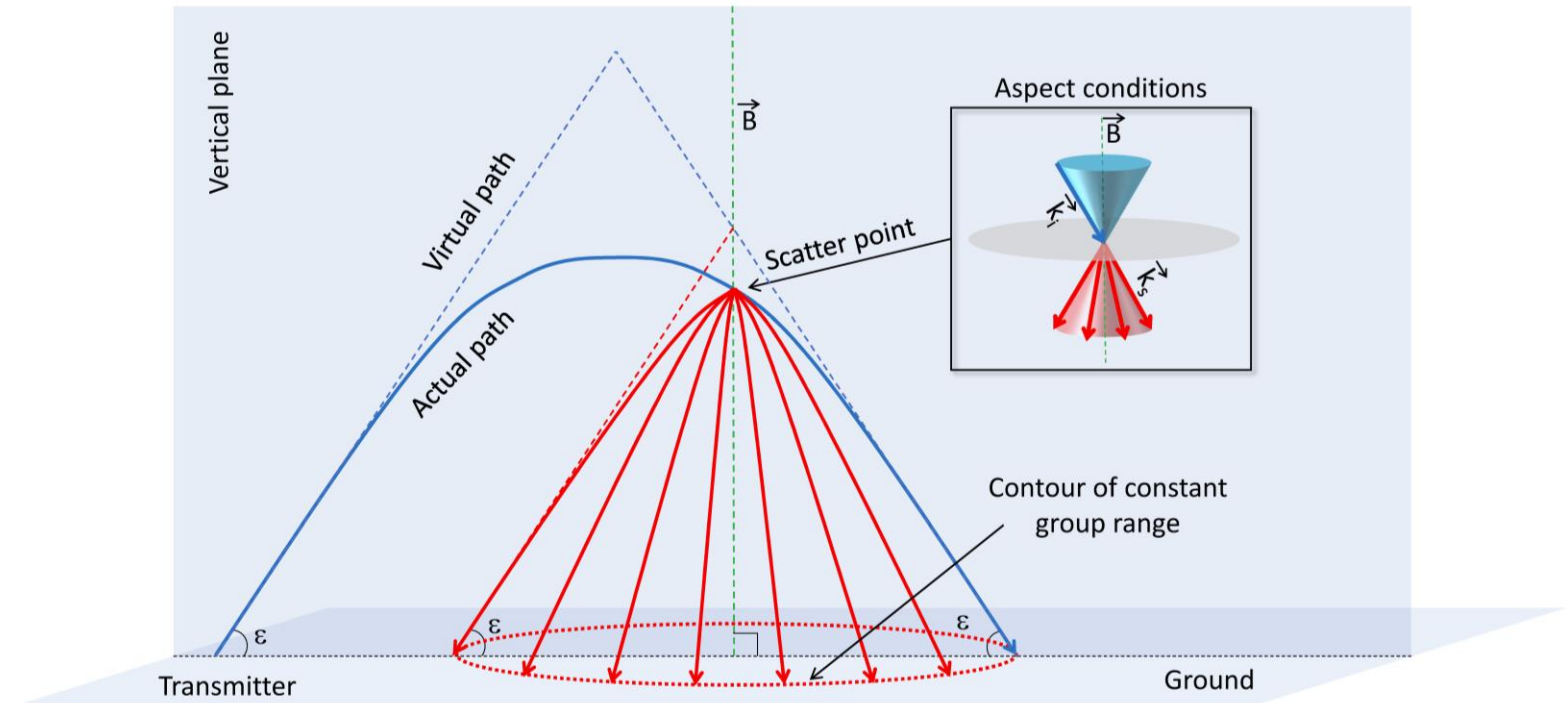
- Assumptions:
 - Spherically stratified ionosphere

Multistatic geolocation: theory



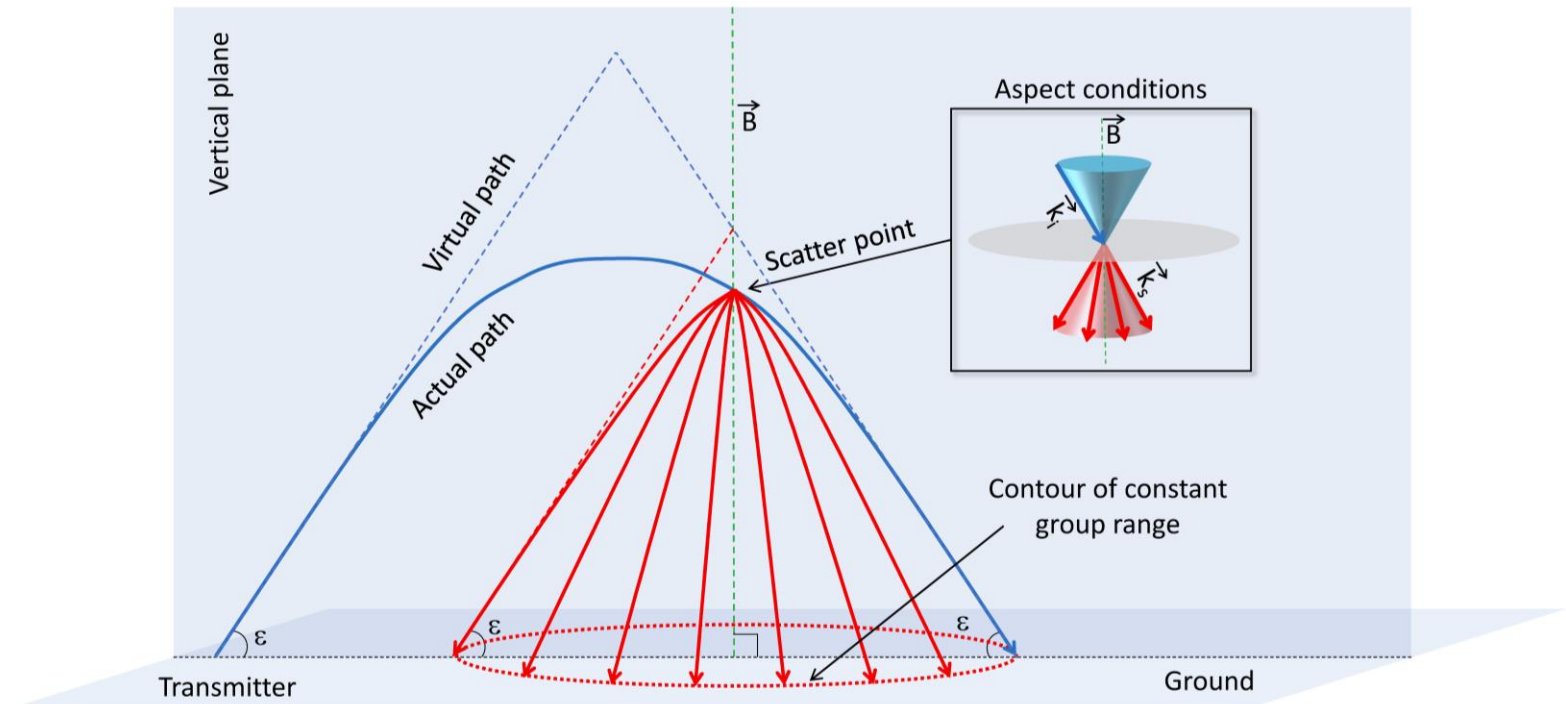
- Assumptions:
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 - Vertical magnetic field (suitable for high latitudes)

Multistatic geolocation: theory



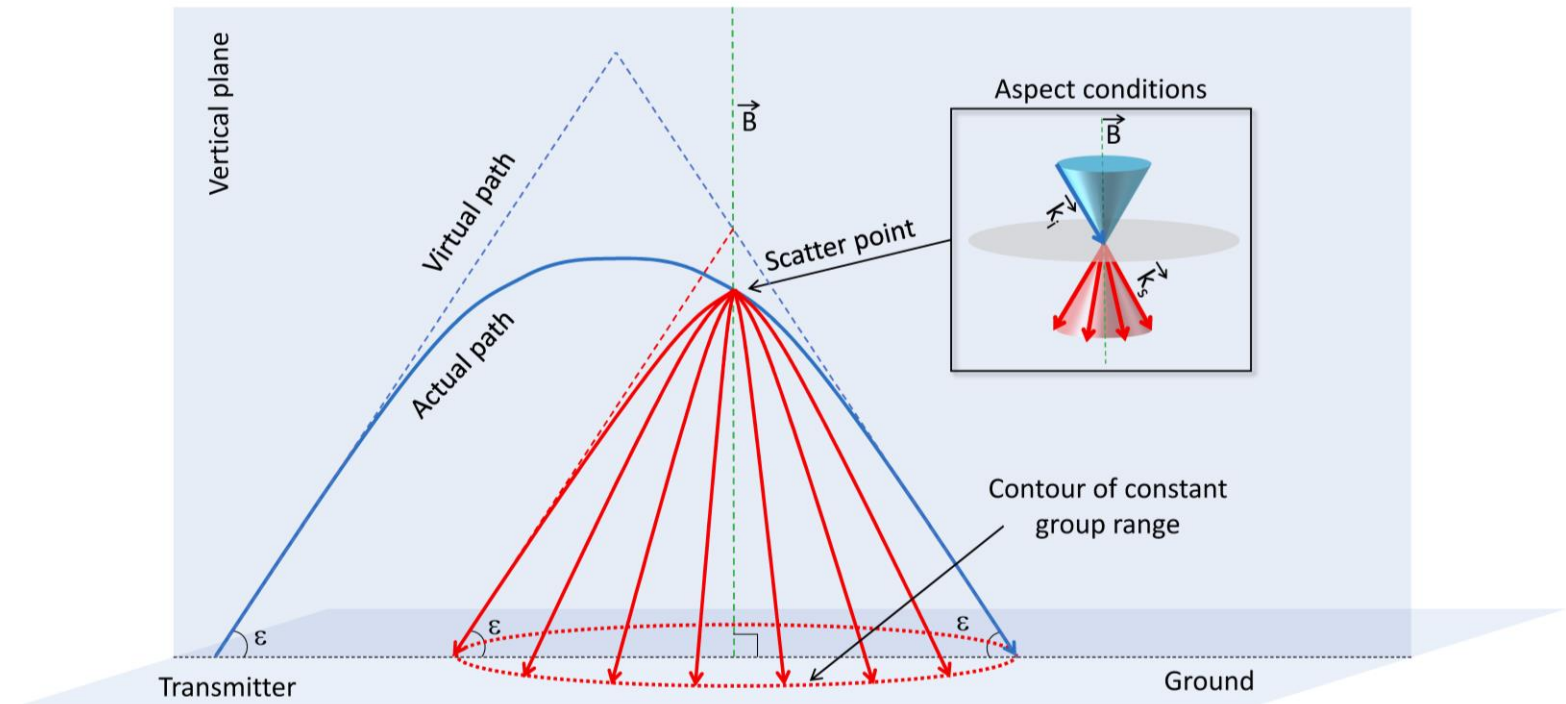
- Assumptions:
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 - Scattering occurs into the cone of equal aspect angle with respect to the magnetic field (specular aspect conditions)

Multistatic geolocation: theory



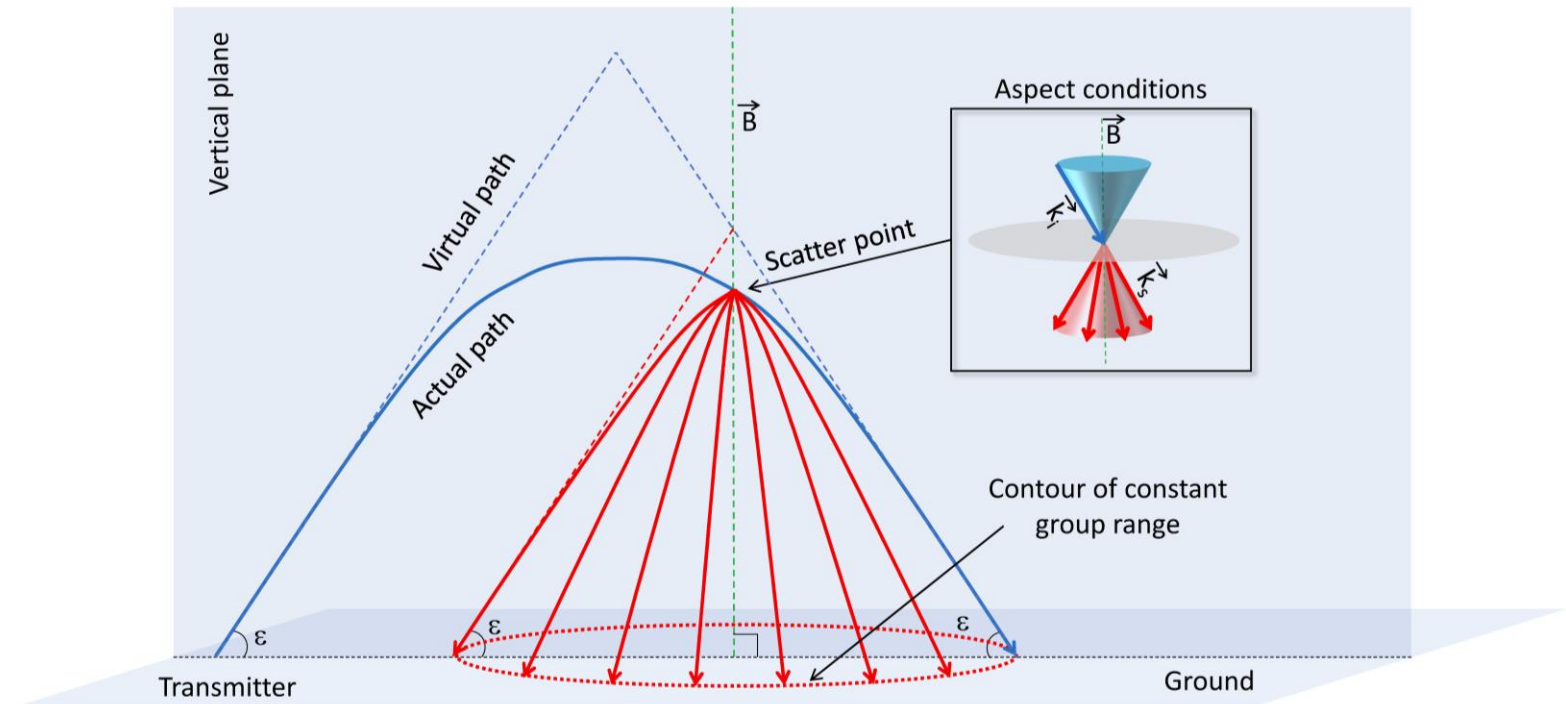
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Multistatic geolocation: theory



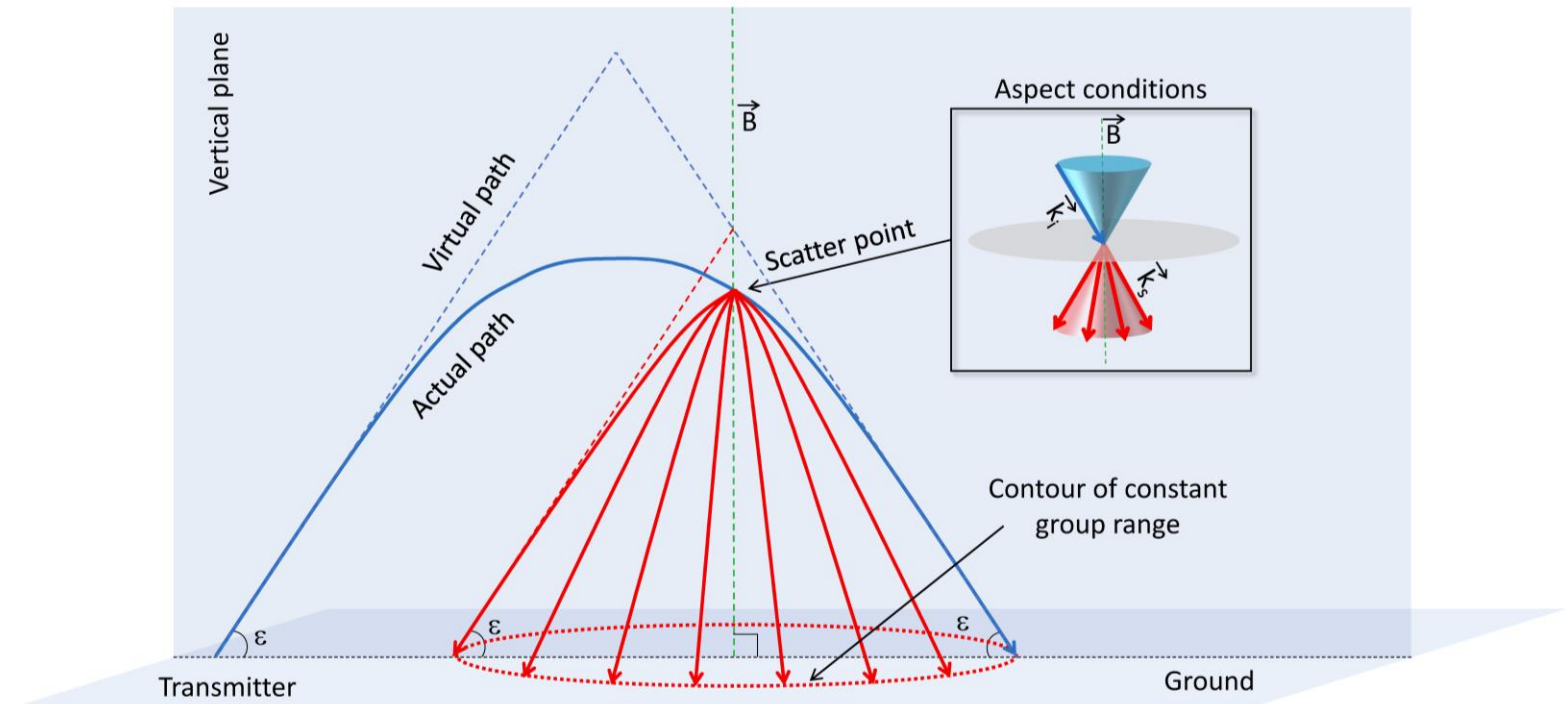
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Multistatic geolocation: theory



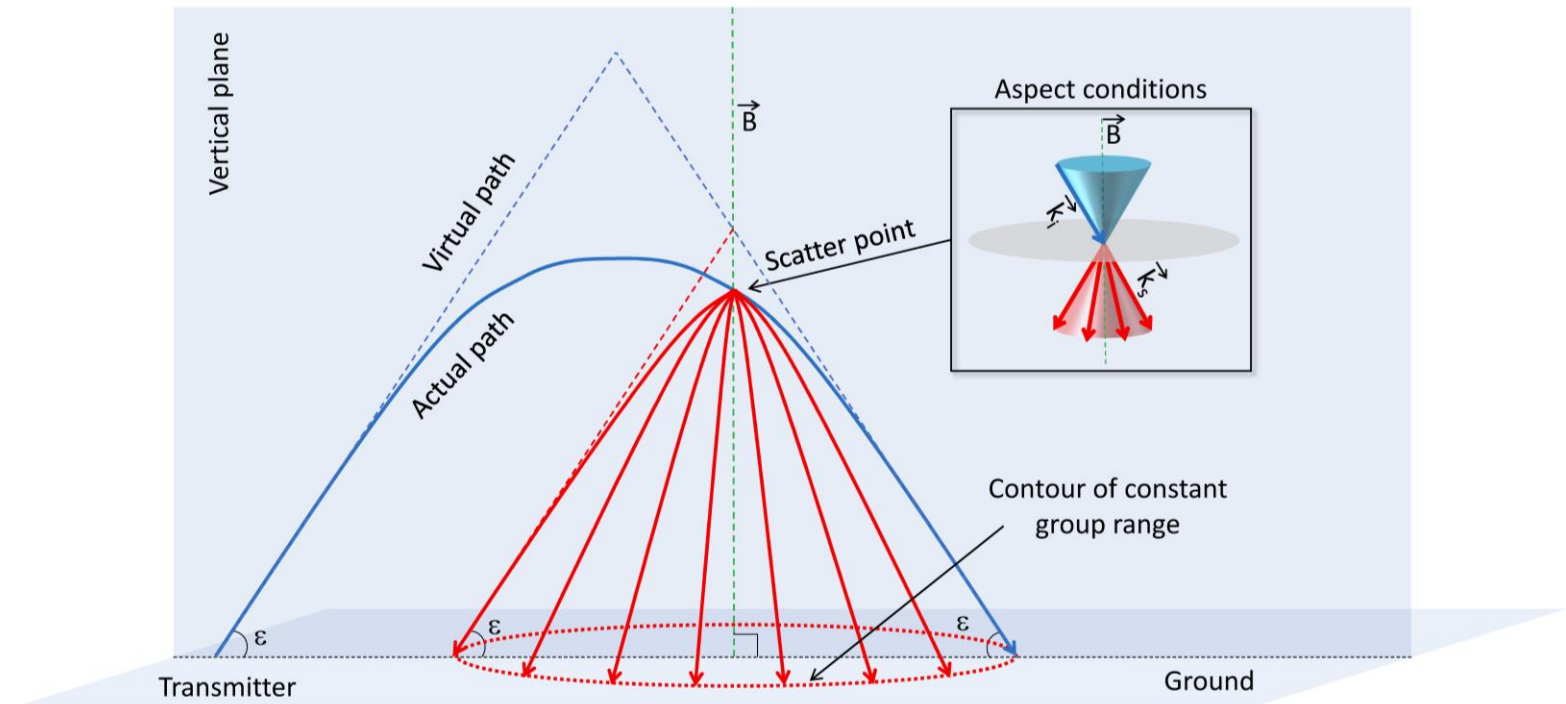
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Multistatic geolocation: theory

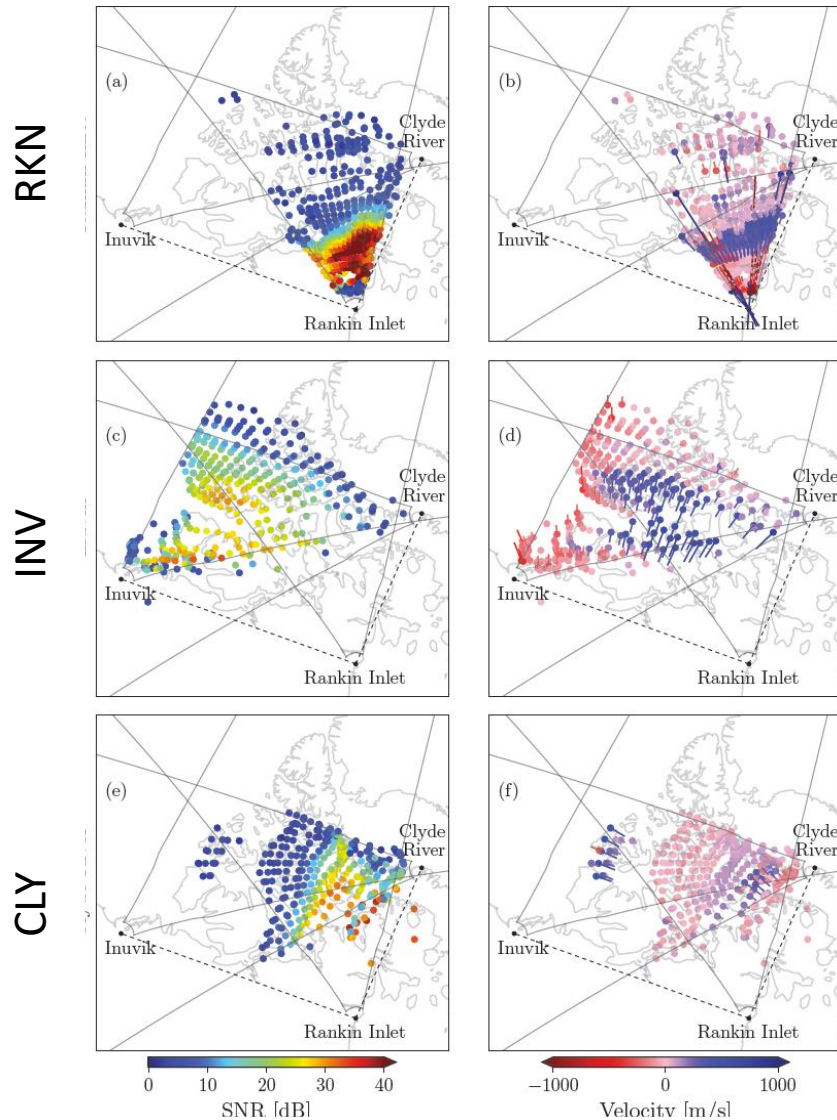


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 - Beam direction
 - Great-circle distance and direction to the transmit site

Multistatic geolocation: implementation

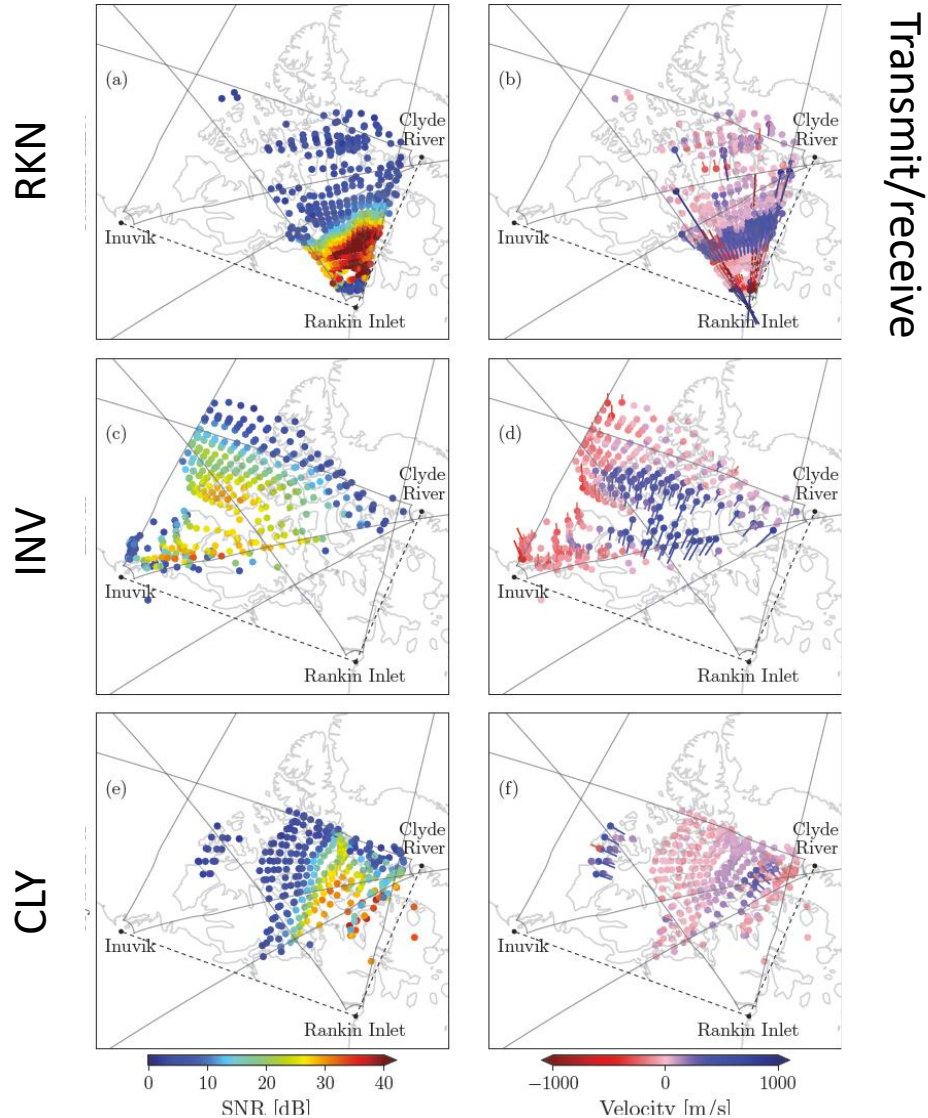
Multistatic geolocation: implementation

10 January 2023, 18:30 UT (single scan)



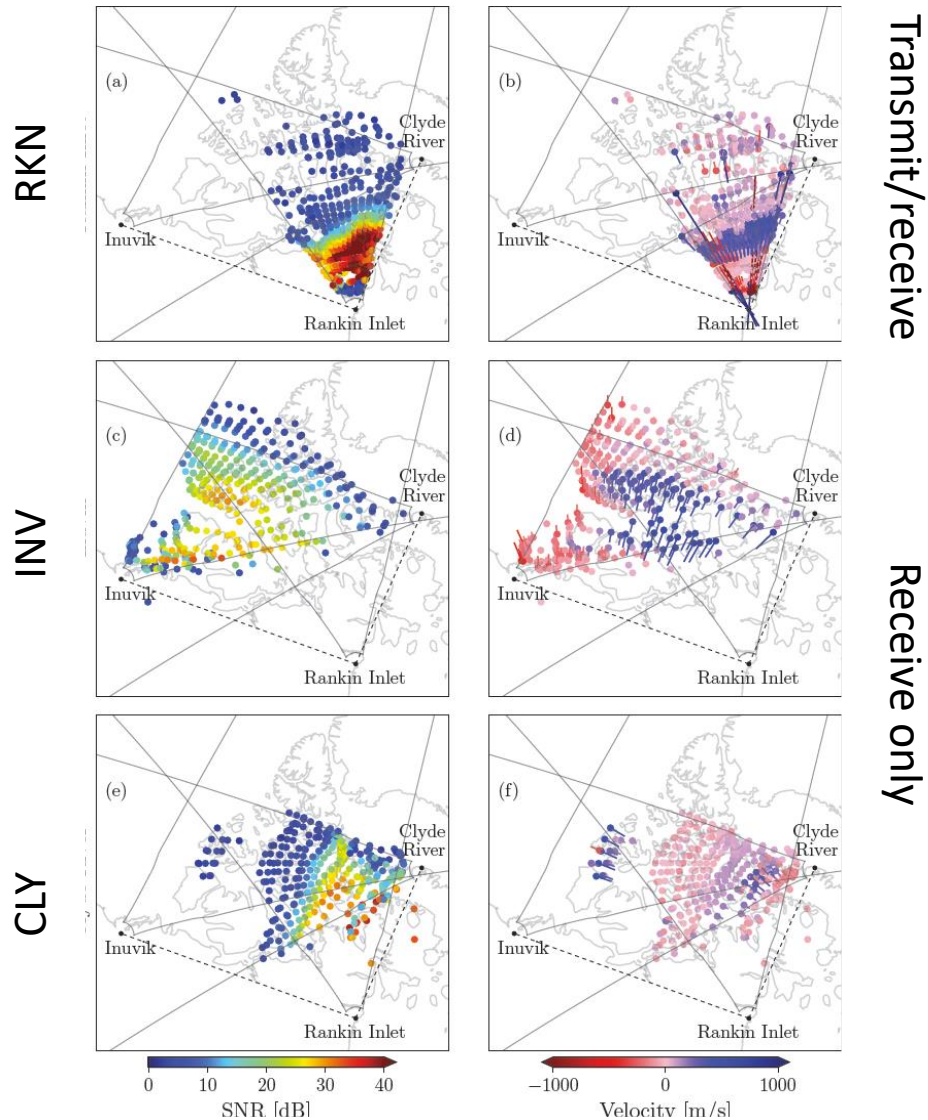
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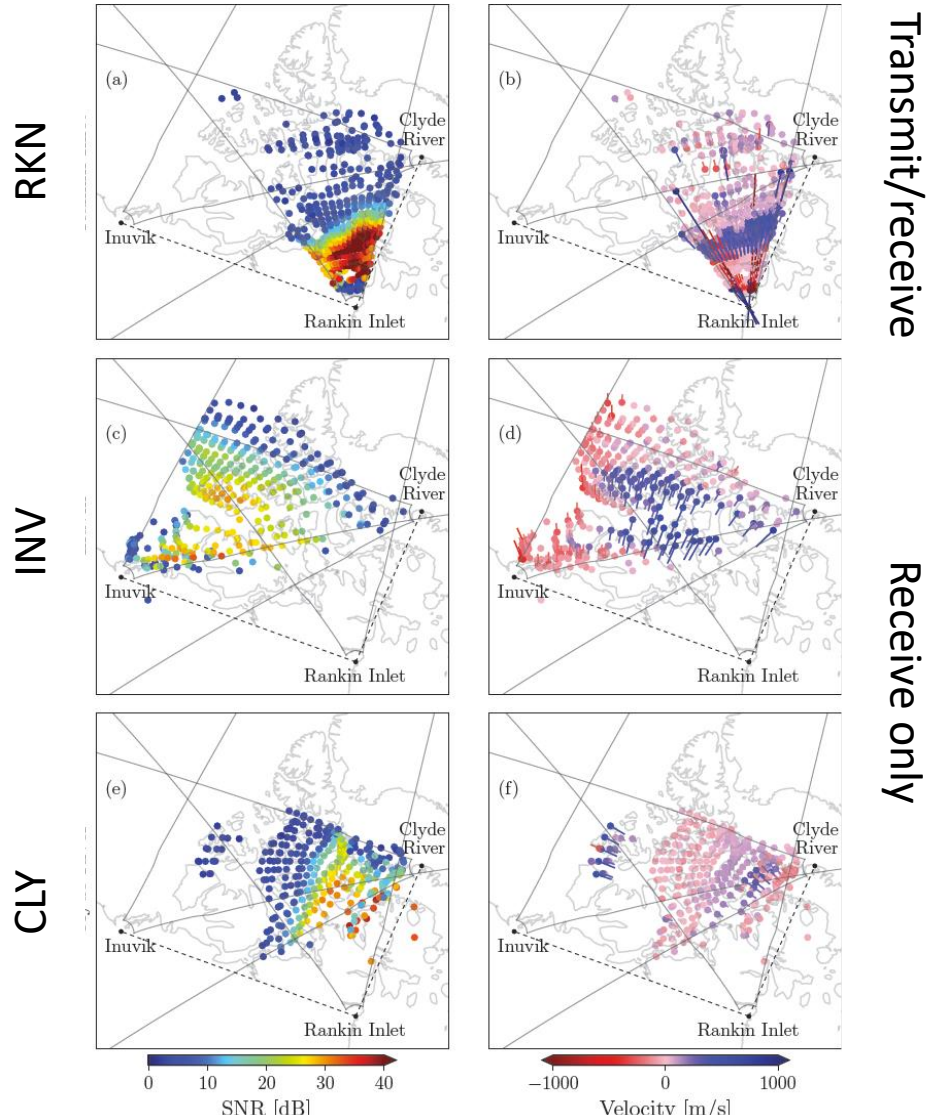
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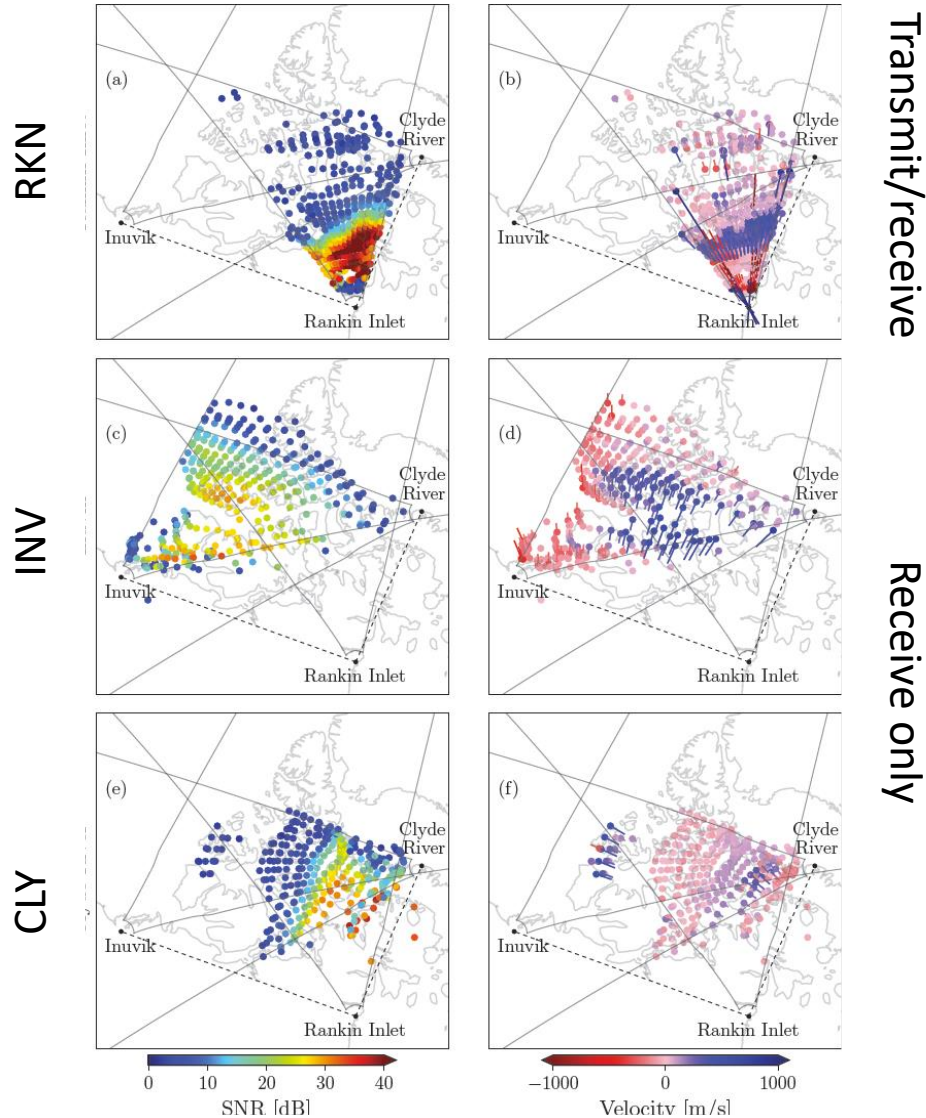
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Equal grid coverage



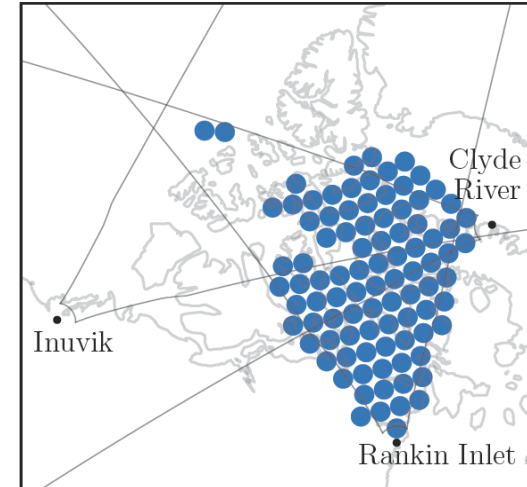
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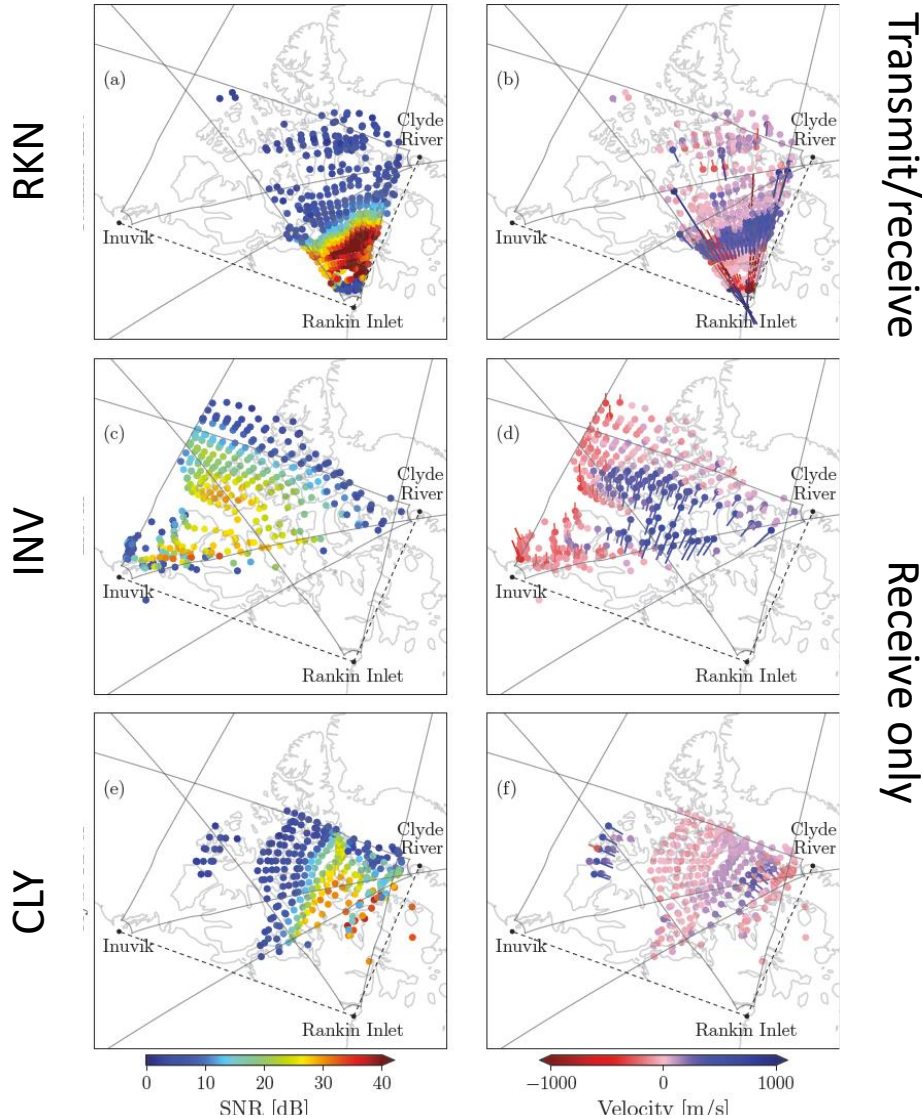
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Rankin Inlet Monostatic Data



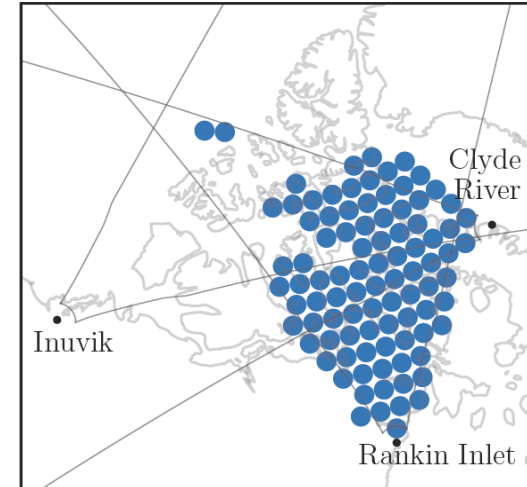
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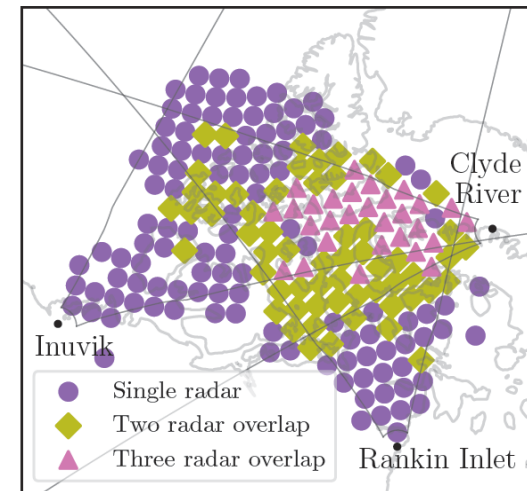


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All Gridded Data



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Radio Science manuscript came back from the reviewers for minor revision.