Assessing Polarimetric SAR Interferometry coherence region parameters over a permafrost landscape

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DLR

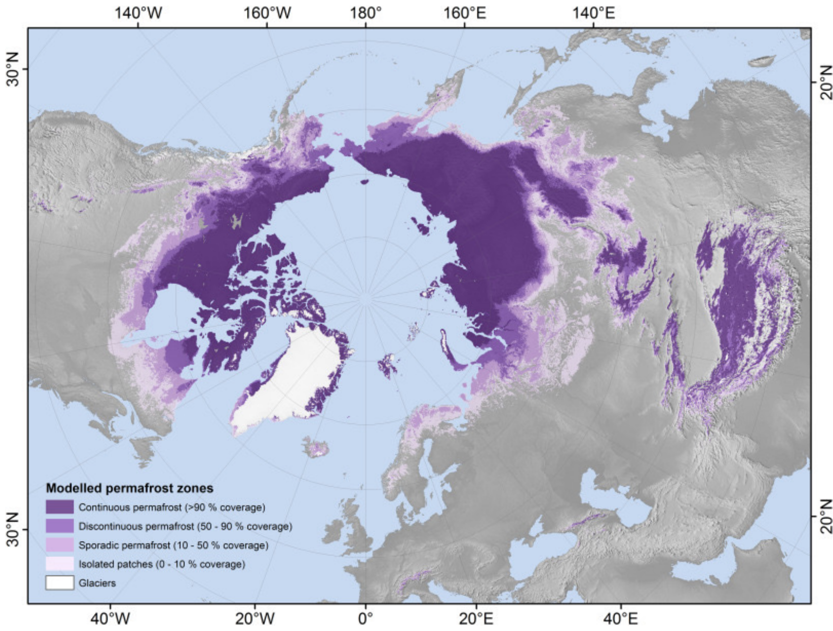
Motivation and goals

- permafrost = soil that remains < 0 °C for at least 2 consecutive years

permafrost degradation
(active layer thickness increase)

local scale:
landslides, mass wasting
hydrology
damage to settlements, infrastructures

global scale:
carbon cycle



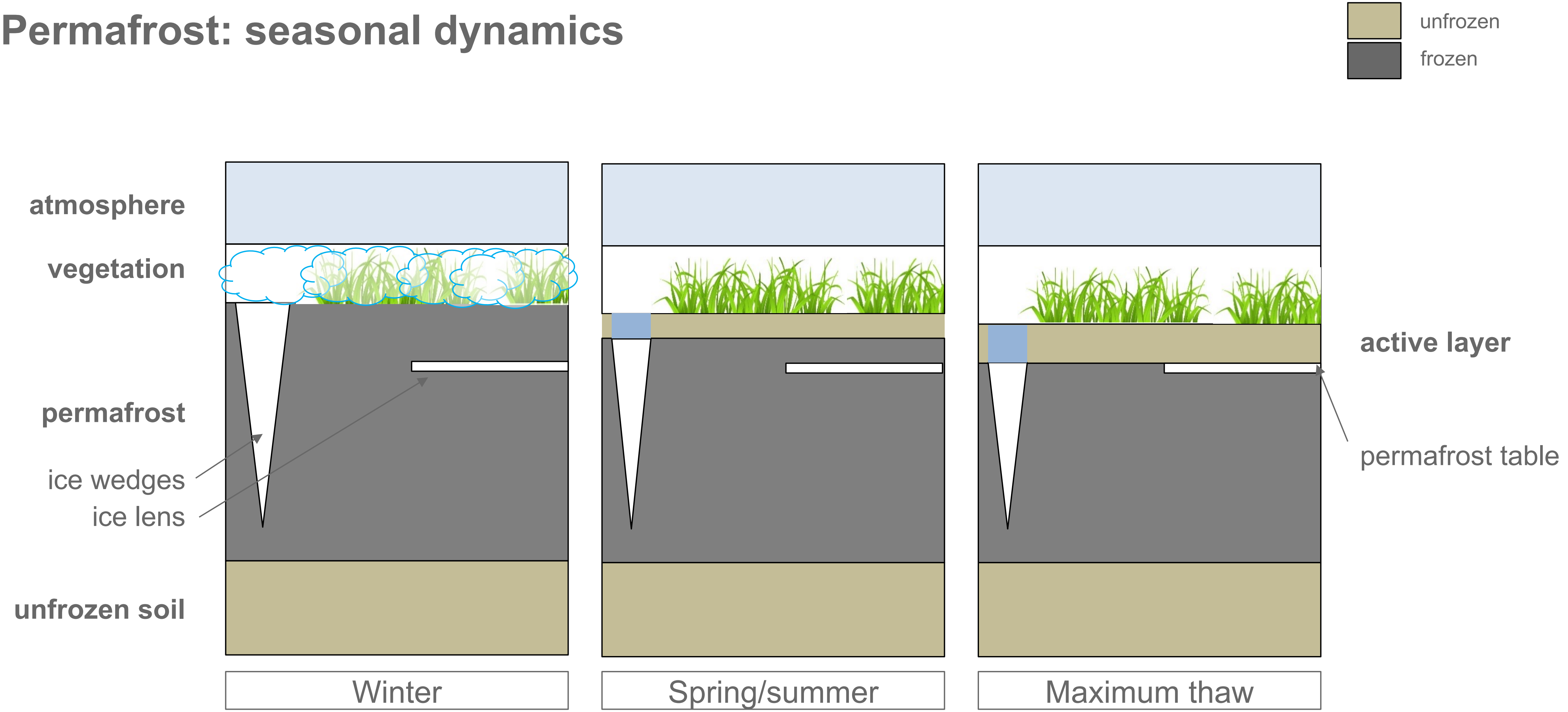
Obu et al., “Northern Hemisphere permafrost map based on TTOP modelling for 2000–2016 at 1 km2 scale”, Earth-Science Reviews,2019

- first Pol-InSAR analysis over Siksik Creek, in the continuous permafrost region of the Canadian Arctic

- examine the influence of
  - season
  - vegetation type

  on the PolInSAR coherence regions

Permafrost: seasonal dynamics



Sedge image by Freepik

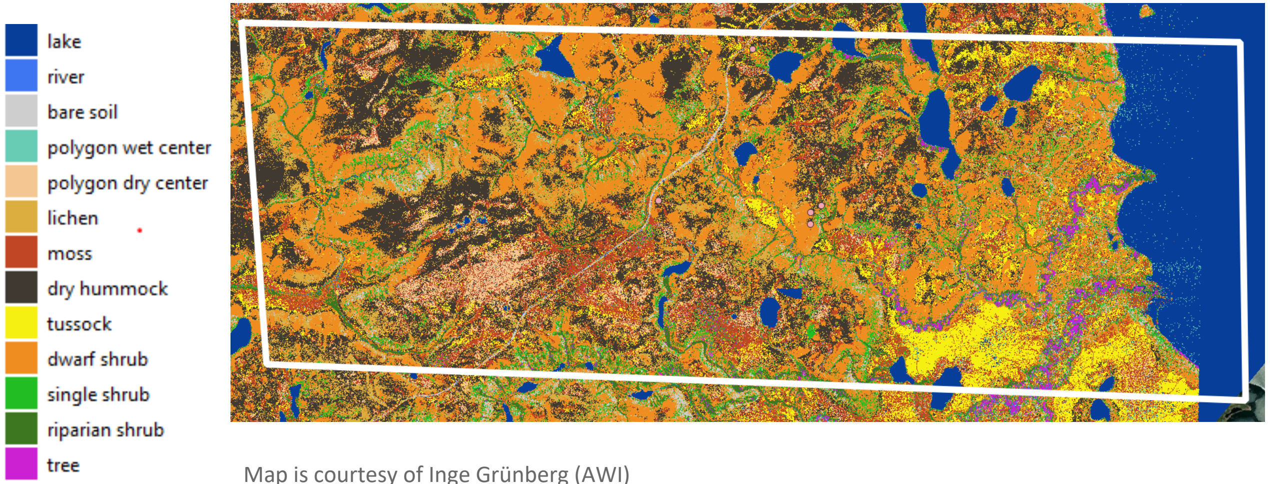
Dataset: PermASAR campaign and Siksik Creek Testsite

- 2 missions: summer 2018 and winter 2019
- 9 test sites in Canada
- F-SAR operations:
  - X,C,L-band
  - Fully polarimetric
  - Several baselines

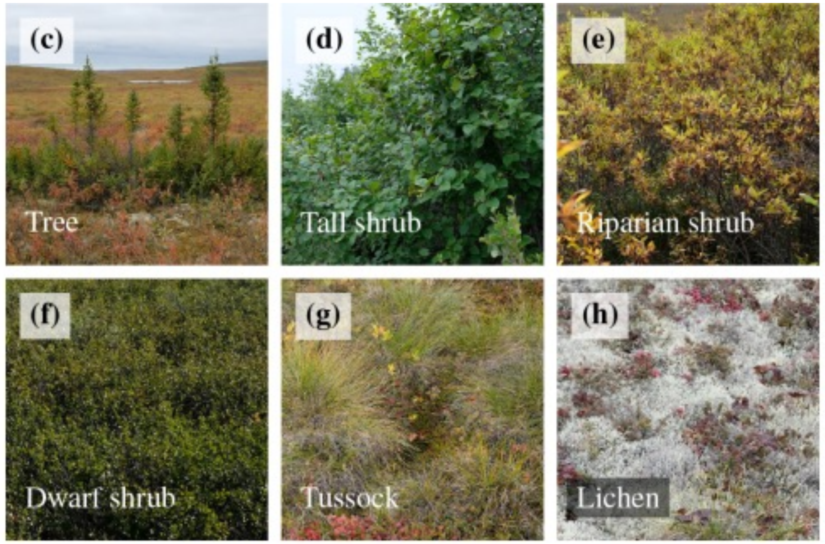
Investigate interaction radar signals ↔ permafrost soils

- Ground measurements (land cover, DTM..)

Focus on **Siksik Creek** testsite



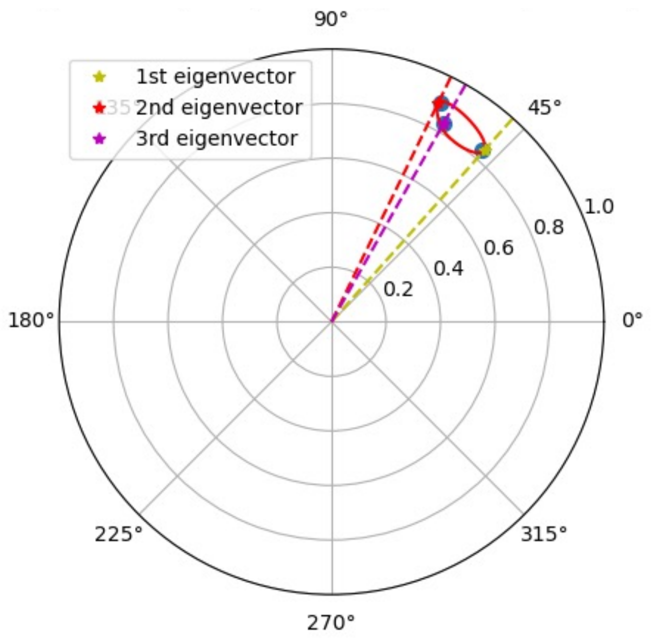
Map is courtesy of Inge Grünberg (AWI)



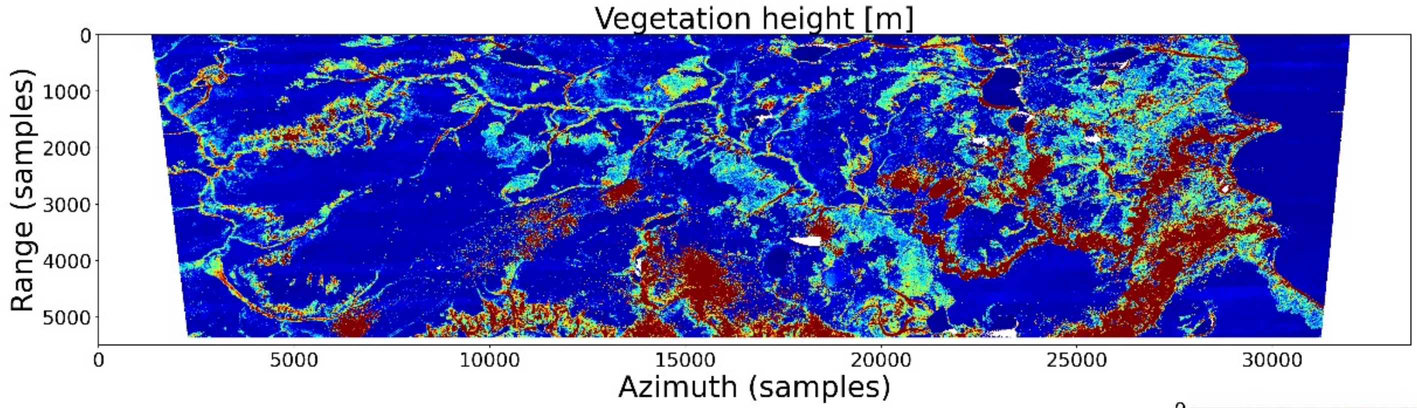
Grünberg et al., "Linking tundra vegetation, snow, soil temperature, and permafrost", Biogeosciences, 2020.

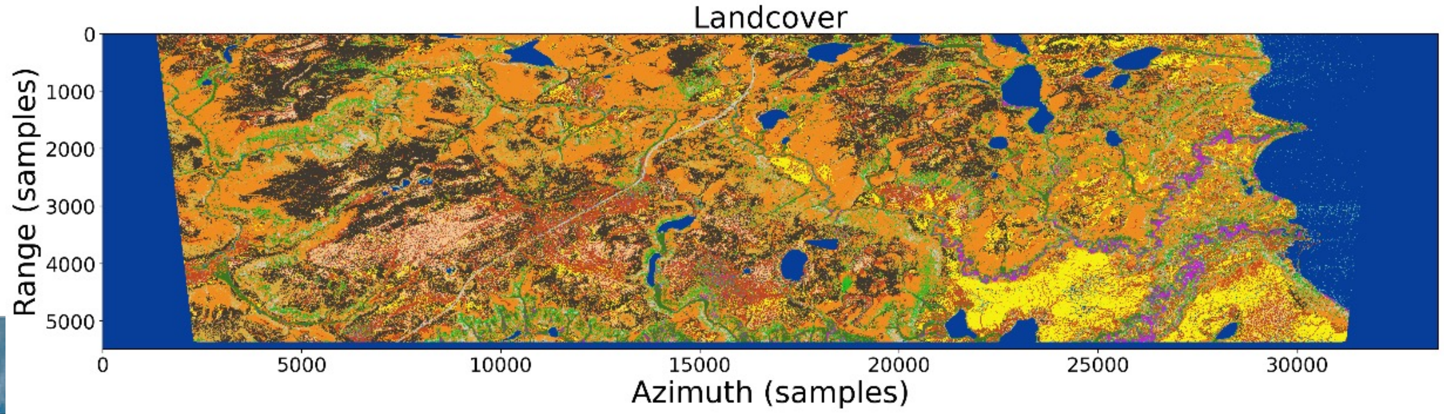
Workflow

- PolInSAR observation space
- Polar decomposition: derive max. phase extent ↔ extent of phase center heights with polarisation
- Transfer to max phase center height extent: $h = \frac{\Delta\Phi}{\kappa_z}$
- Compare with Lidar heights and landcover map



Lange et al., “Airborne Laser Scanning (ALS) Point Clouds of Trail Valley Creek, NWT, Canada (2018)”, 2021

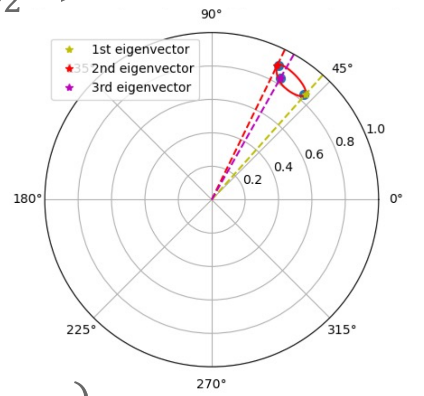




Coherence region extent determination

- Image 1: scattering matrix $[S_1] = \begin{bmatrix} S^1_{HH} & S^1_{HV} \\ S^1_{VH} & S^1_{VV} \end{bmatrix} \rightarrow$ scattering vector $k_1 = \frac{1}{\sqrt{2}}[S^1_{HH} + S^1_{VV}, S^1_{HH} - S^1_{VV}, 2S^1_{HV}]$
- Image 2: scattering matrix $[S_2] = \begin{bmatrix} S^2_{HH} & S^2_{HV} \\ S^2_{VH} & S^2_{VV} \end{bmatrix} \rightarrow$ scattering vector $k_2 = \frac{1}{\sqrt{2}}[S^2_{HH} + S^2_{VV}, S^2_{HH} - S^2_{VV}, 2S^2_{HV}]$

- PolInSAR matrices: coherency matrices $T_1 = < k_1 k_1^{*T} >$ and $T_2 = < k_2 k_2^{*T} >$ and $\Omega_{12} = < k_1 k_2^{*T} >$
- Pre-whitening and normalization: $\Pi = T_M^{-1/2} \Omega_{12} T_M^{-1/2}$ with $T_M = \frac{1}{2}(T_{11} + T_{22})$.



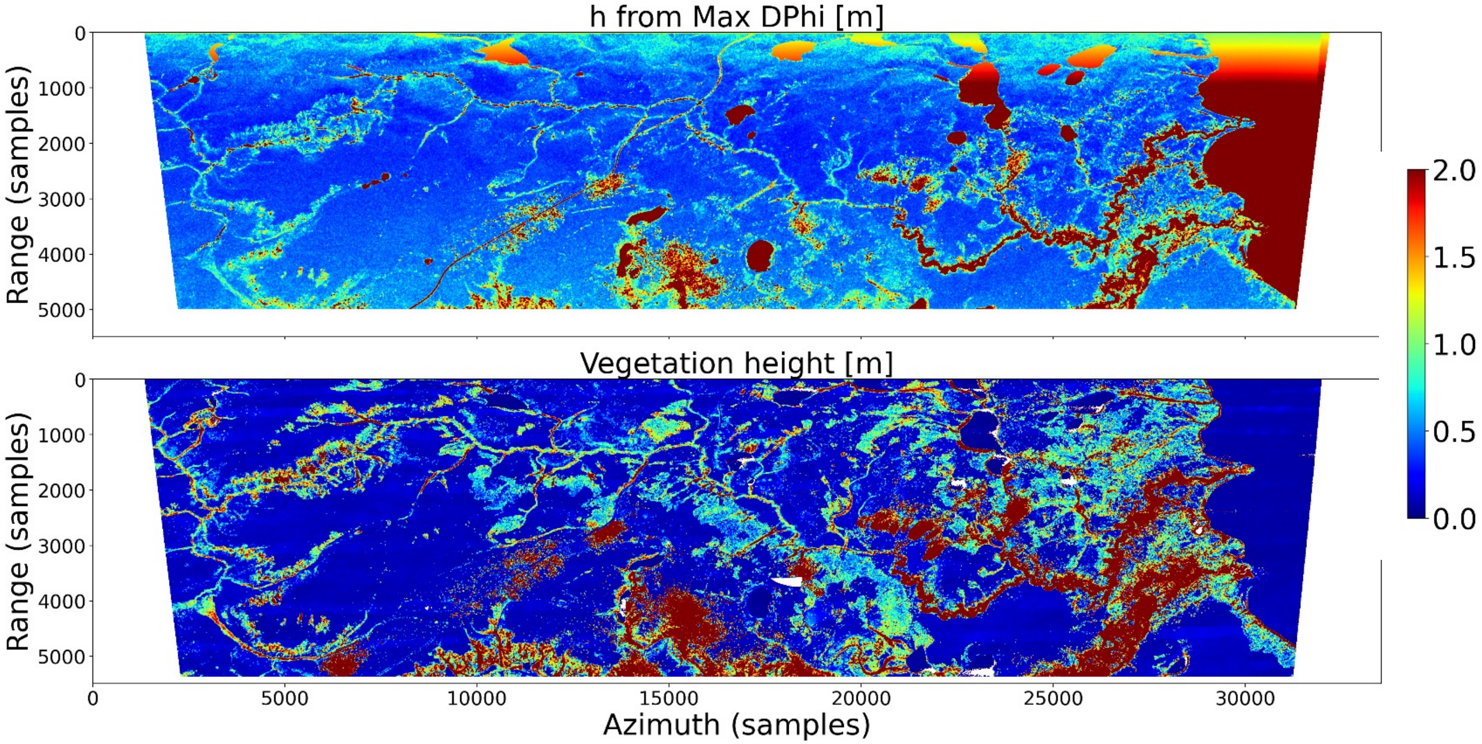
- Polar decomposition: $\Pi = U\,P$ where
  - $P = \left(\Pi^{*T}\Pi\right)^{1/2}$ positive semi-definitive hermitian matrix
  - $U = \Pi P^{-1}$ unitary matrix

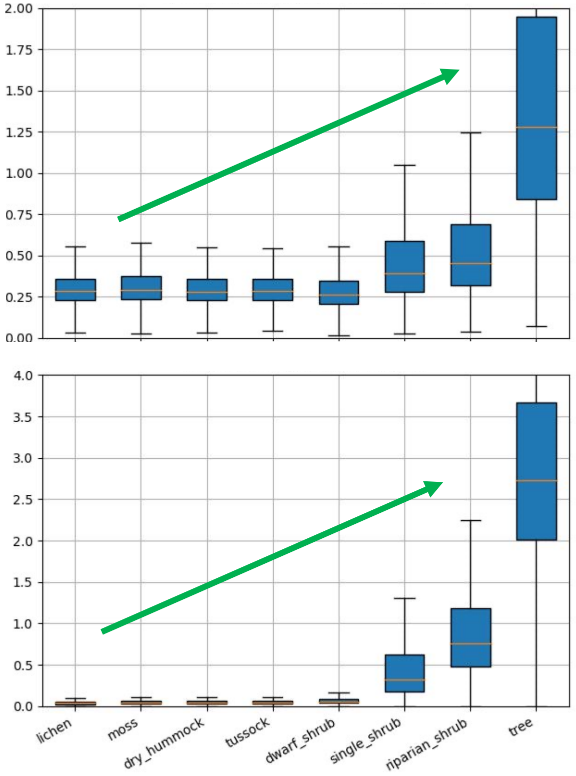
    $\rightarrow$ **phases can be be maximized/minimized by the eigenvectors of U: $\gamma(\phi_{min}), \gamma(\phi_{max})$**

Summer L-band

B=100m

Summer case



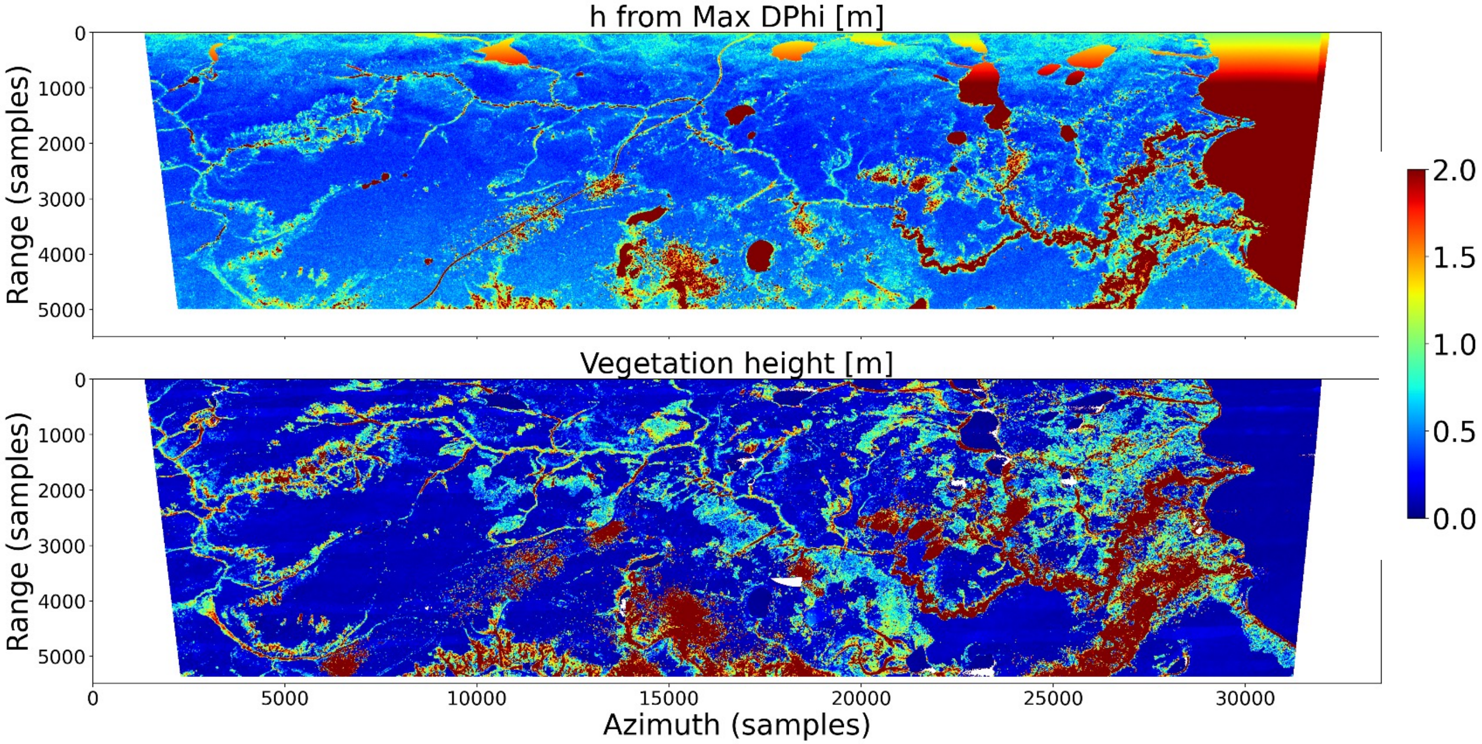


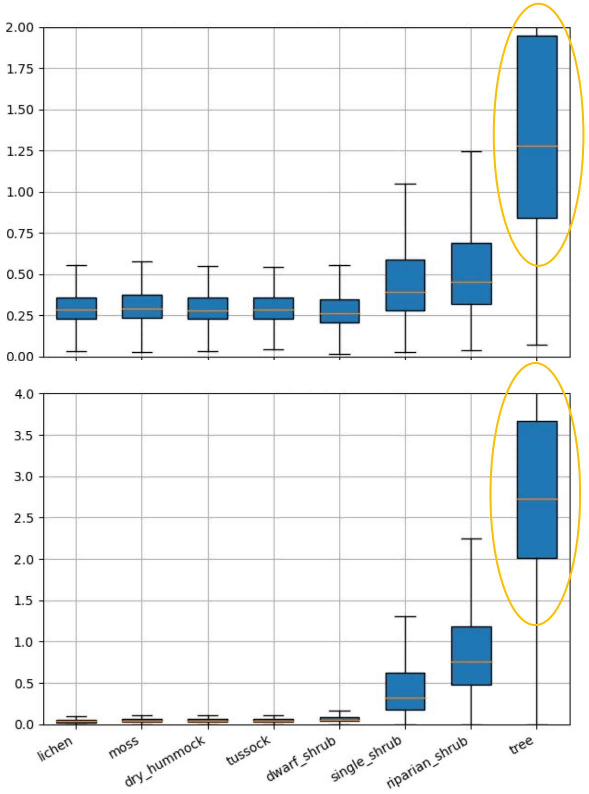
- Relative changes between landcover types are correct

Summer L-band

B=100m

Summer case



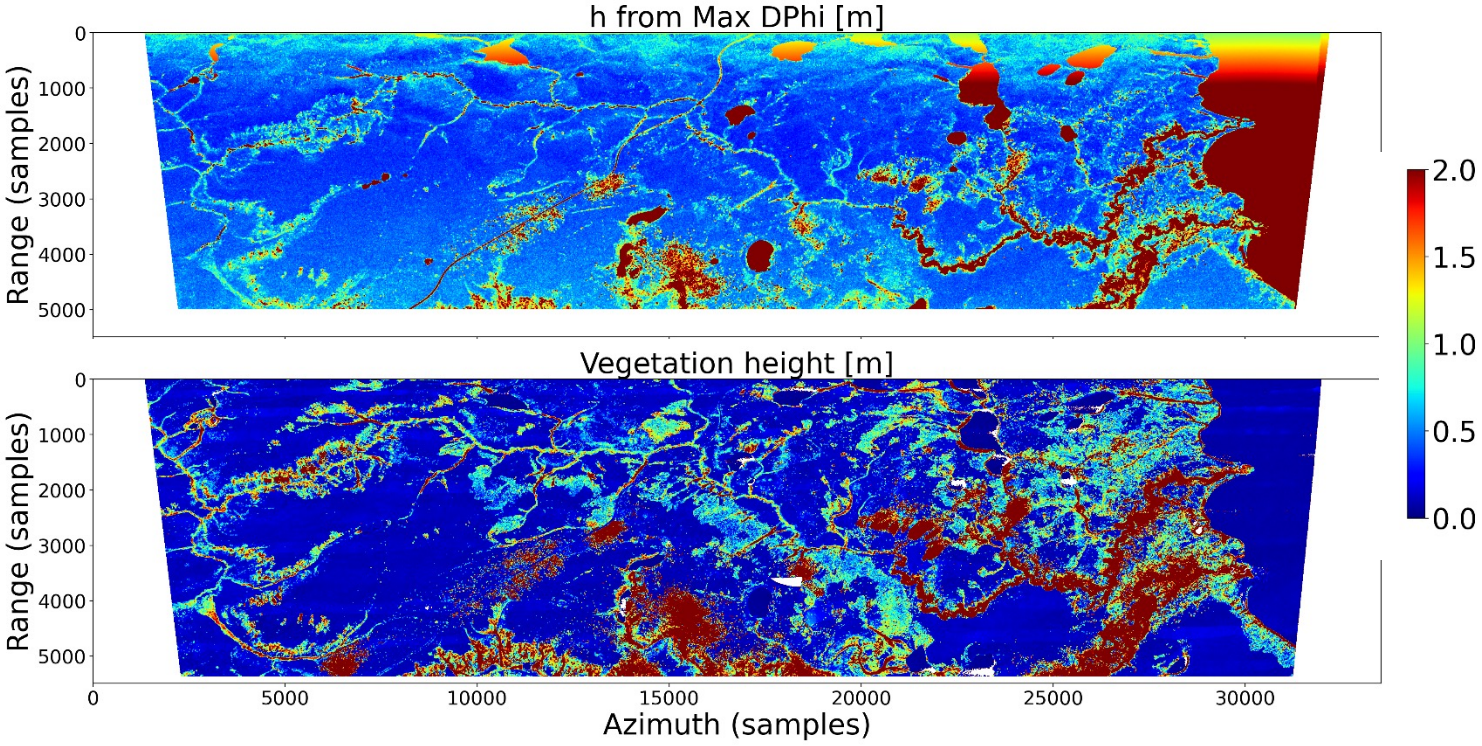


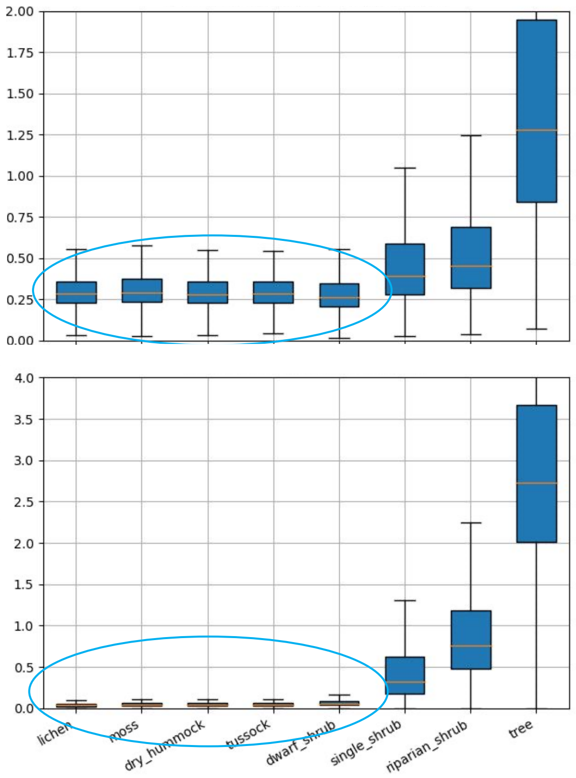
- Relative changes between landcover types are correct
- Underestimation of tree height

Summer L-band

B=100m

Summer case



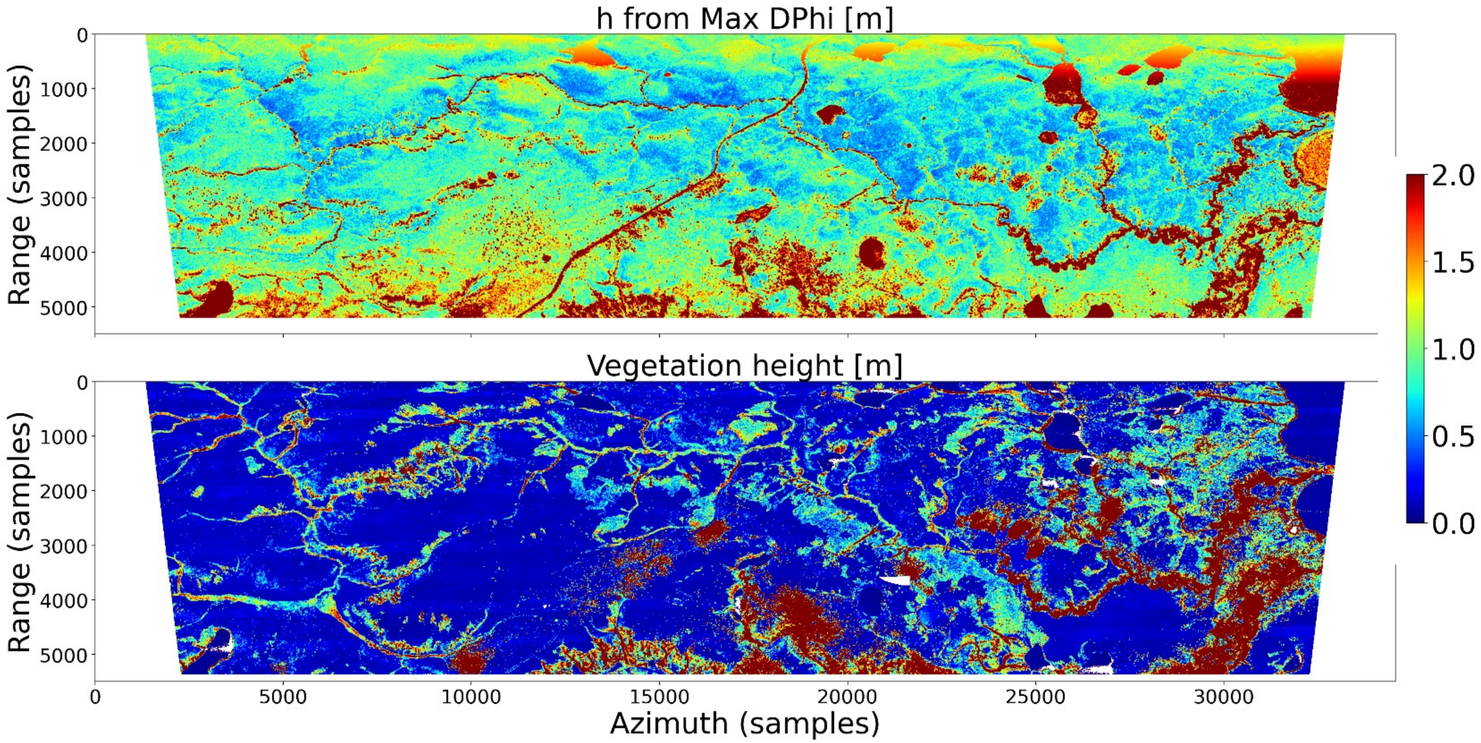


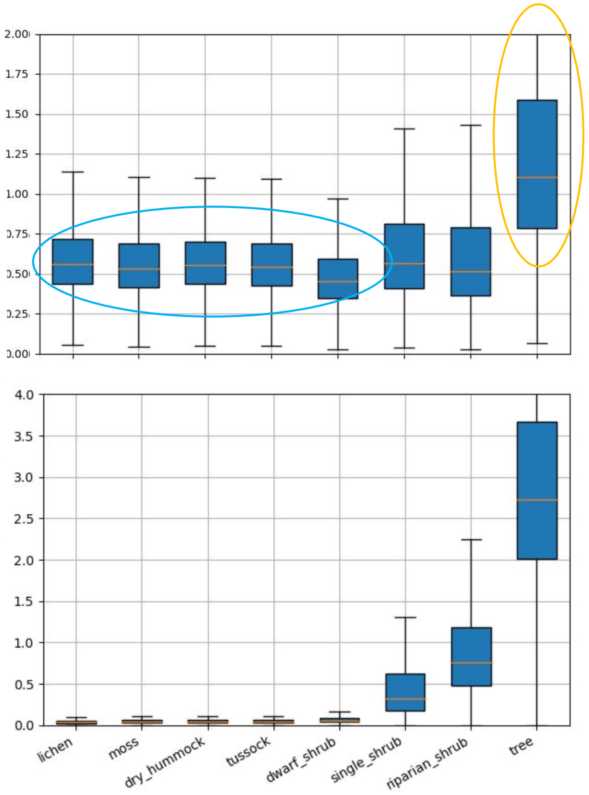
- Relative changes between landcover types are correct
- Underestimation of tree height
- Overestimation at small vegetation:
  - Underestimation of reference map
  - Noise level?

Winter L-band

B=100m

Winter case



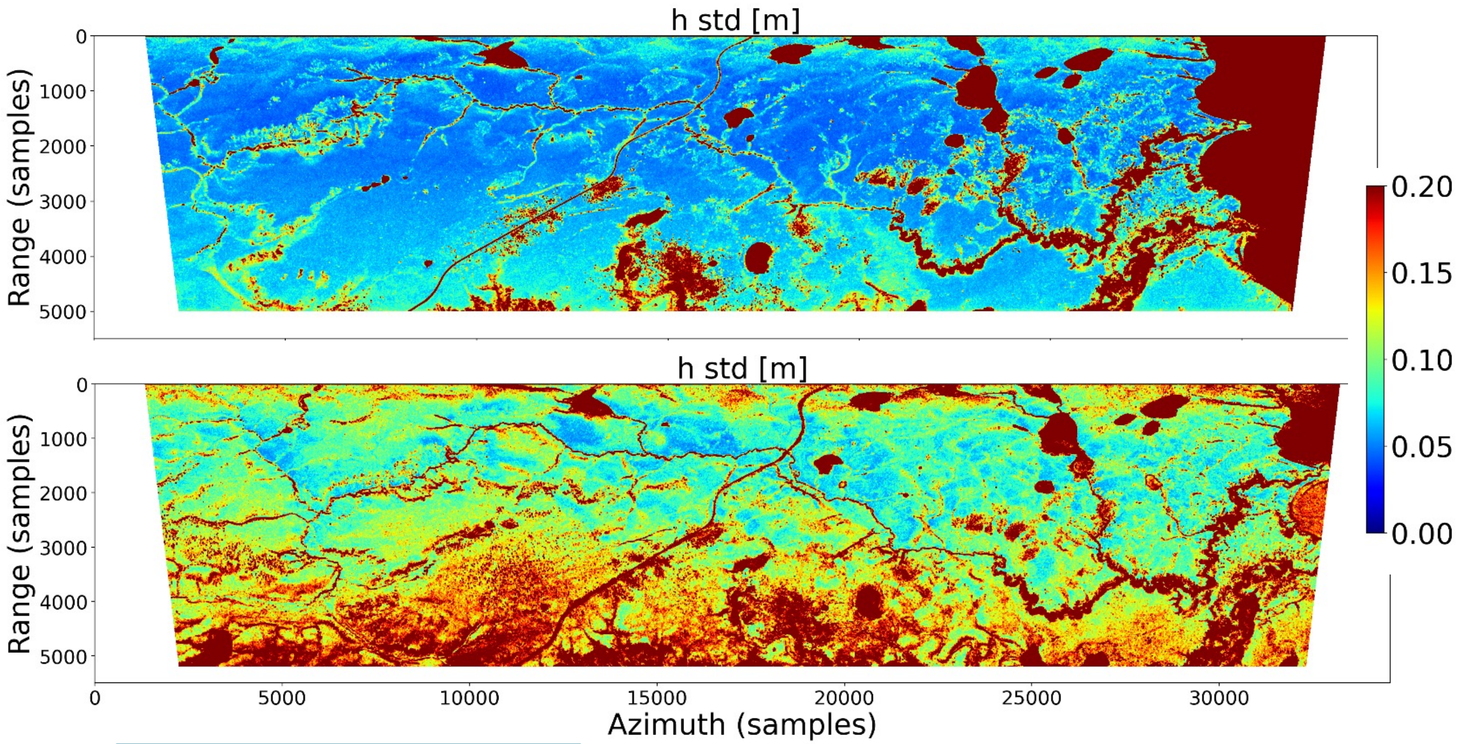


- Height extent of trees decreases
- Height extent of small vegetation increases

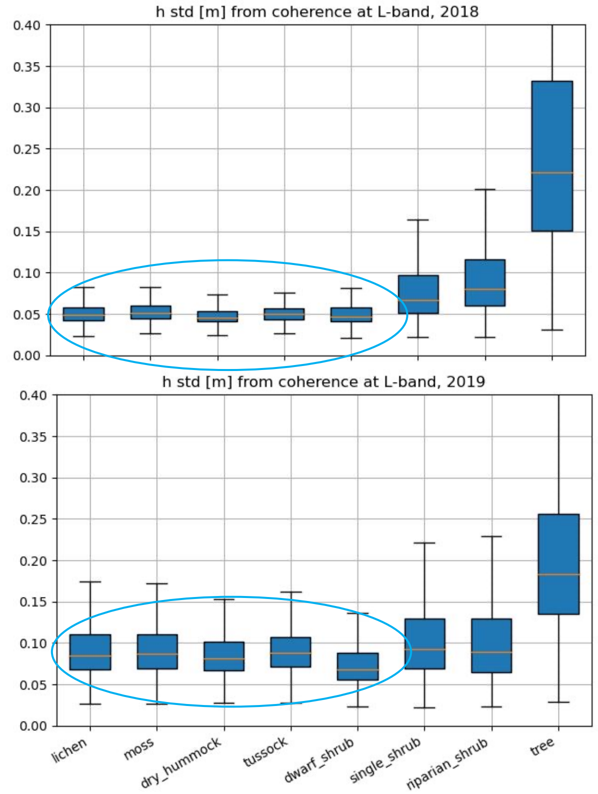
→ interpretation: volume decorrelation due to penetration in the ground

Error estimation: phase standard deviation

Summer L-band



Winter L-band



Phase standard deviation from CR centre:

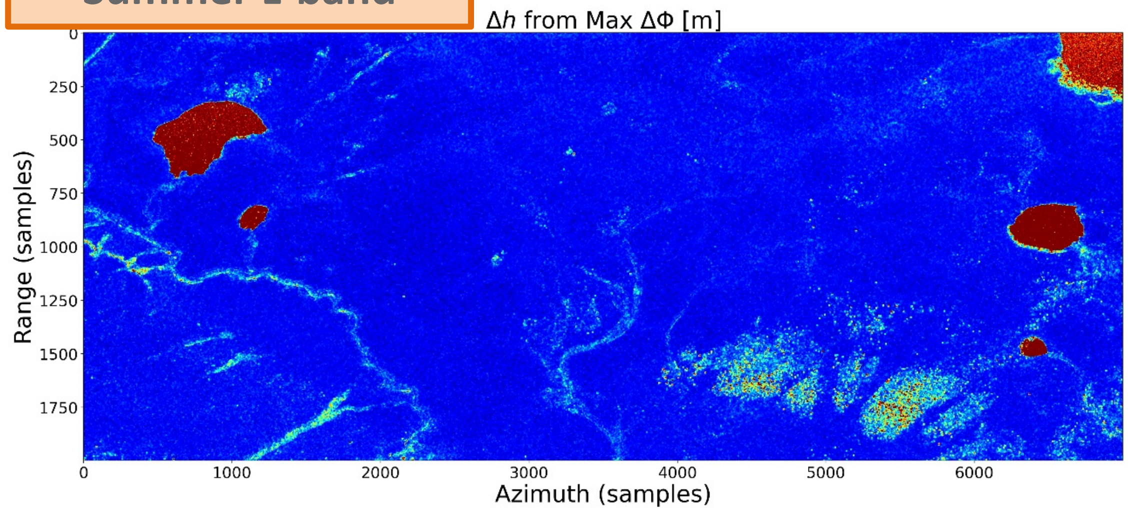
$$\sigma_\phi \approx \frac{1}{\sqrt{2L}} \frac{\sqrt{1-\gamma^2}}{\gamma}$$

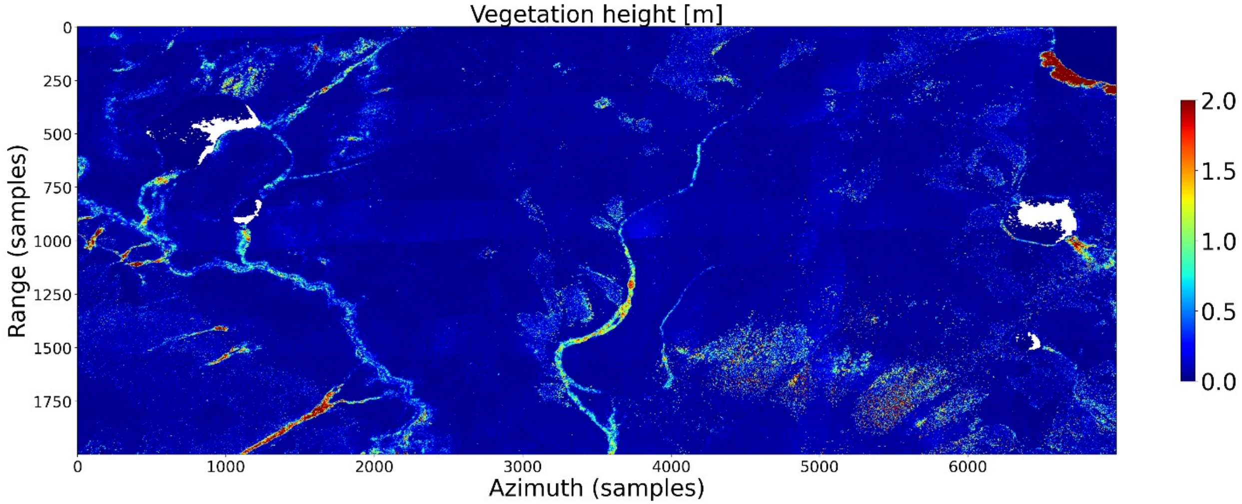
$$\rightarrow \sigma_h \approx \frac{\sigma_\phi}{\kappa_z}$$

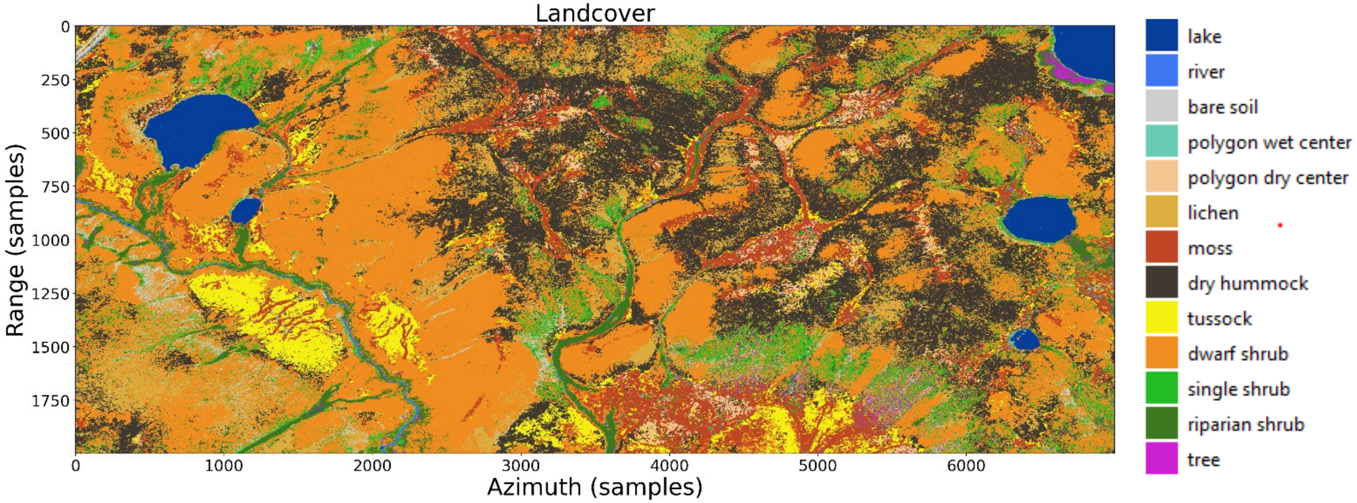
→ interpretation: volume decorrelation due to penetration into the ground

Focus on a small area (zoom!)

Summer L-band

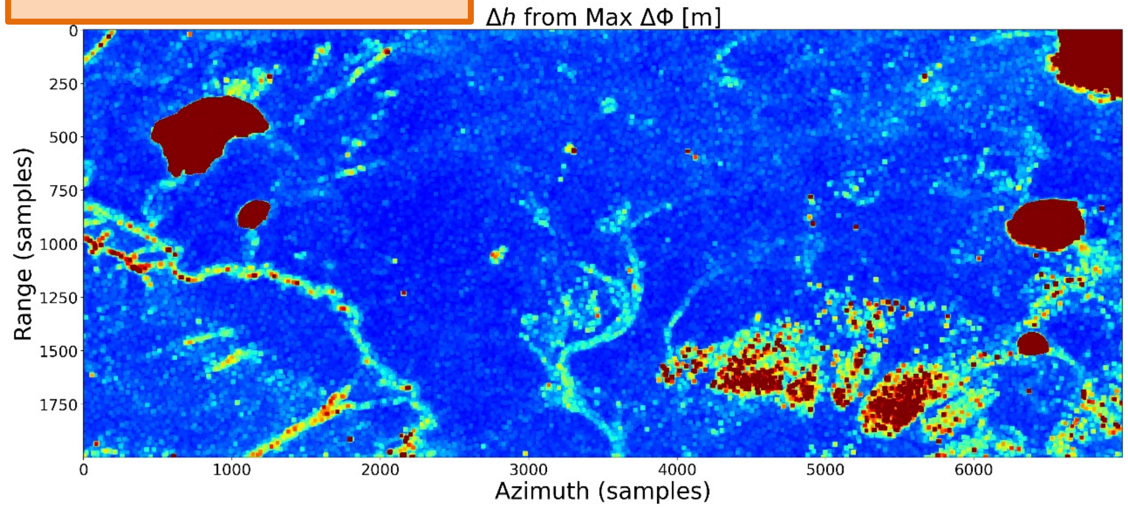


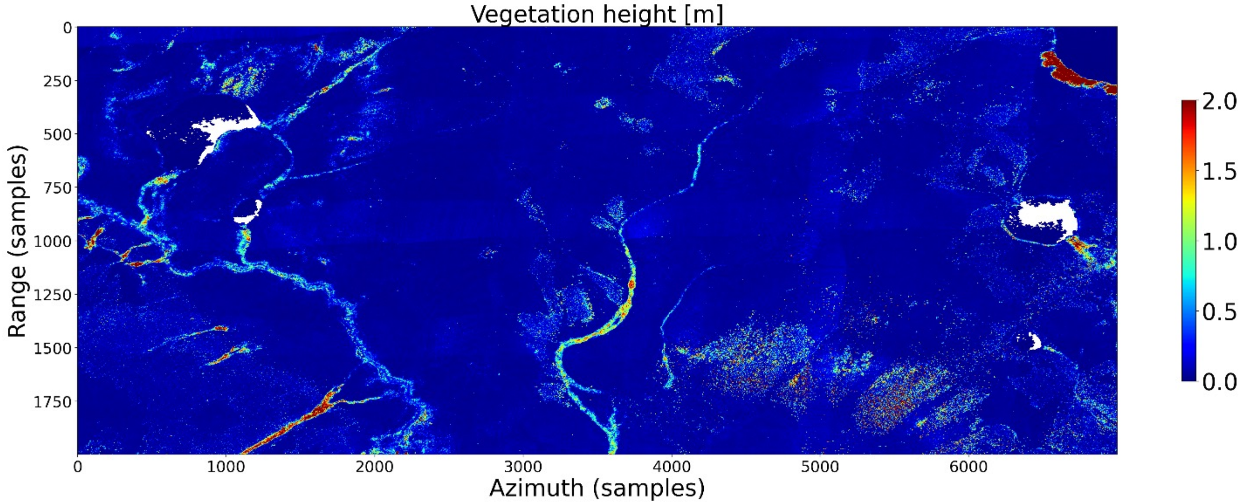


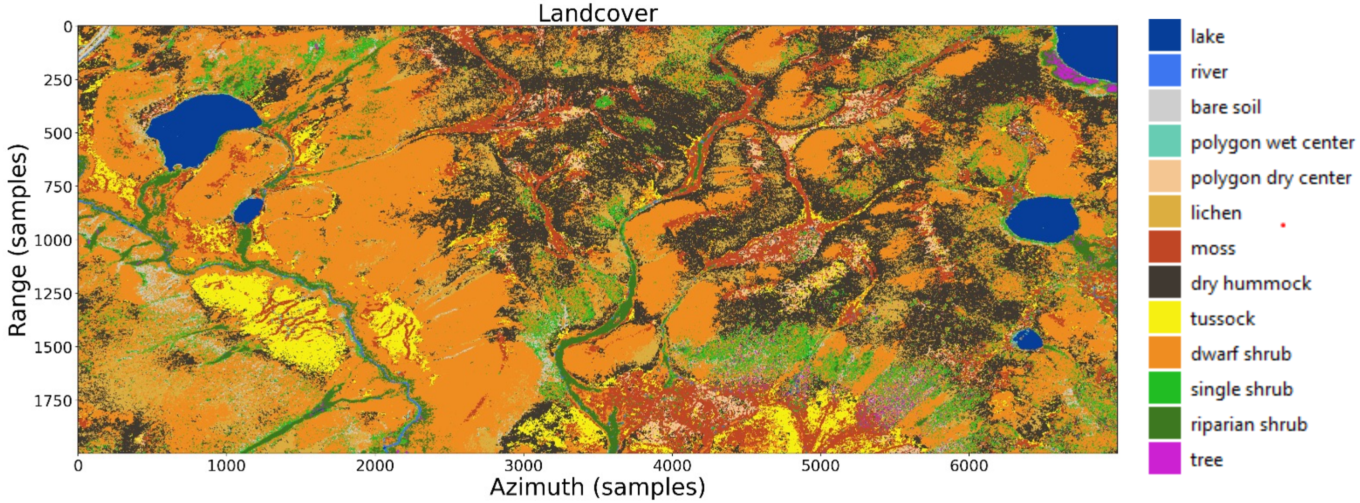


Focus on a small area (zoom!)

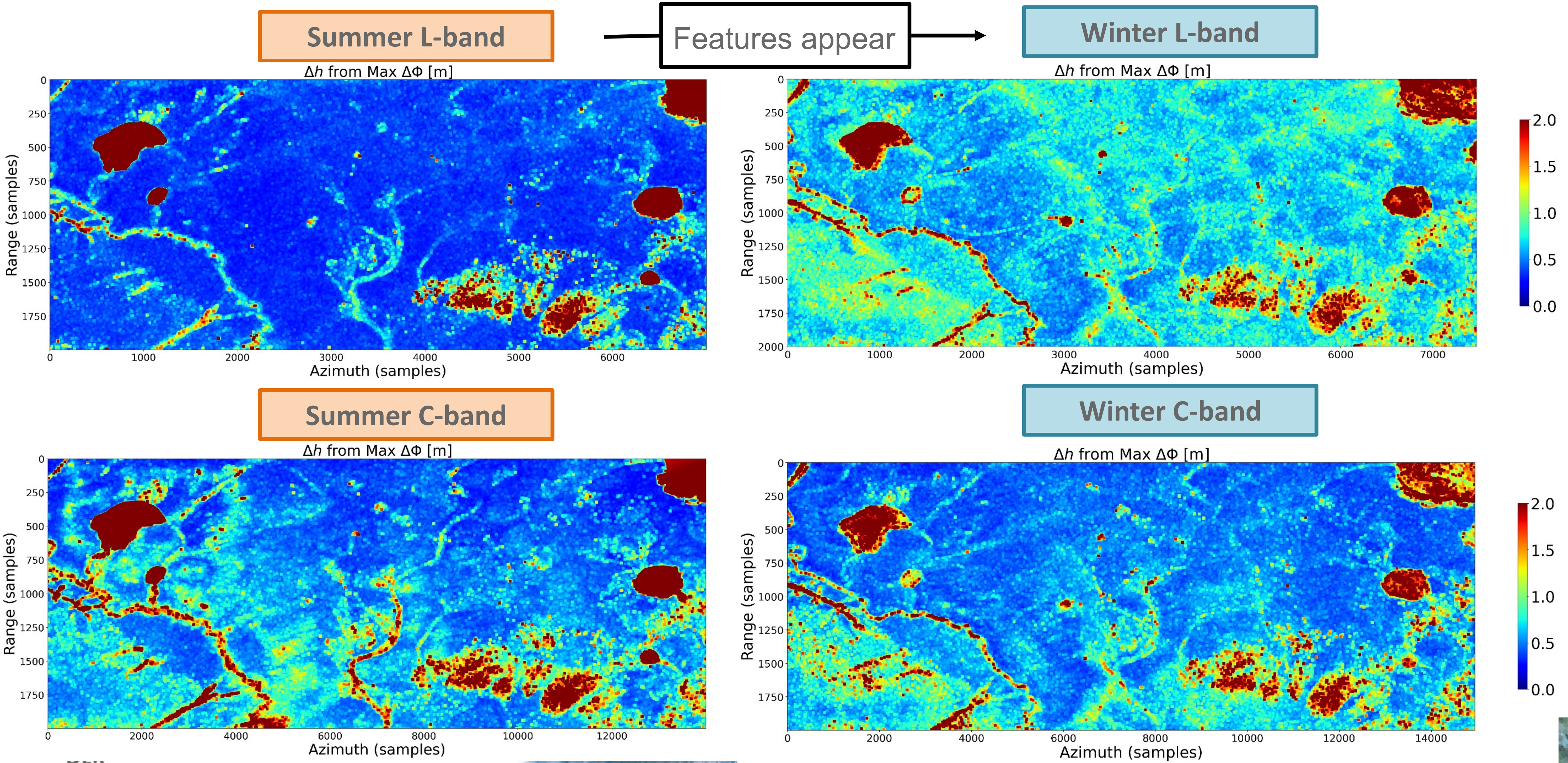
Summer L-band



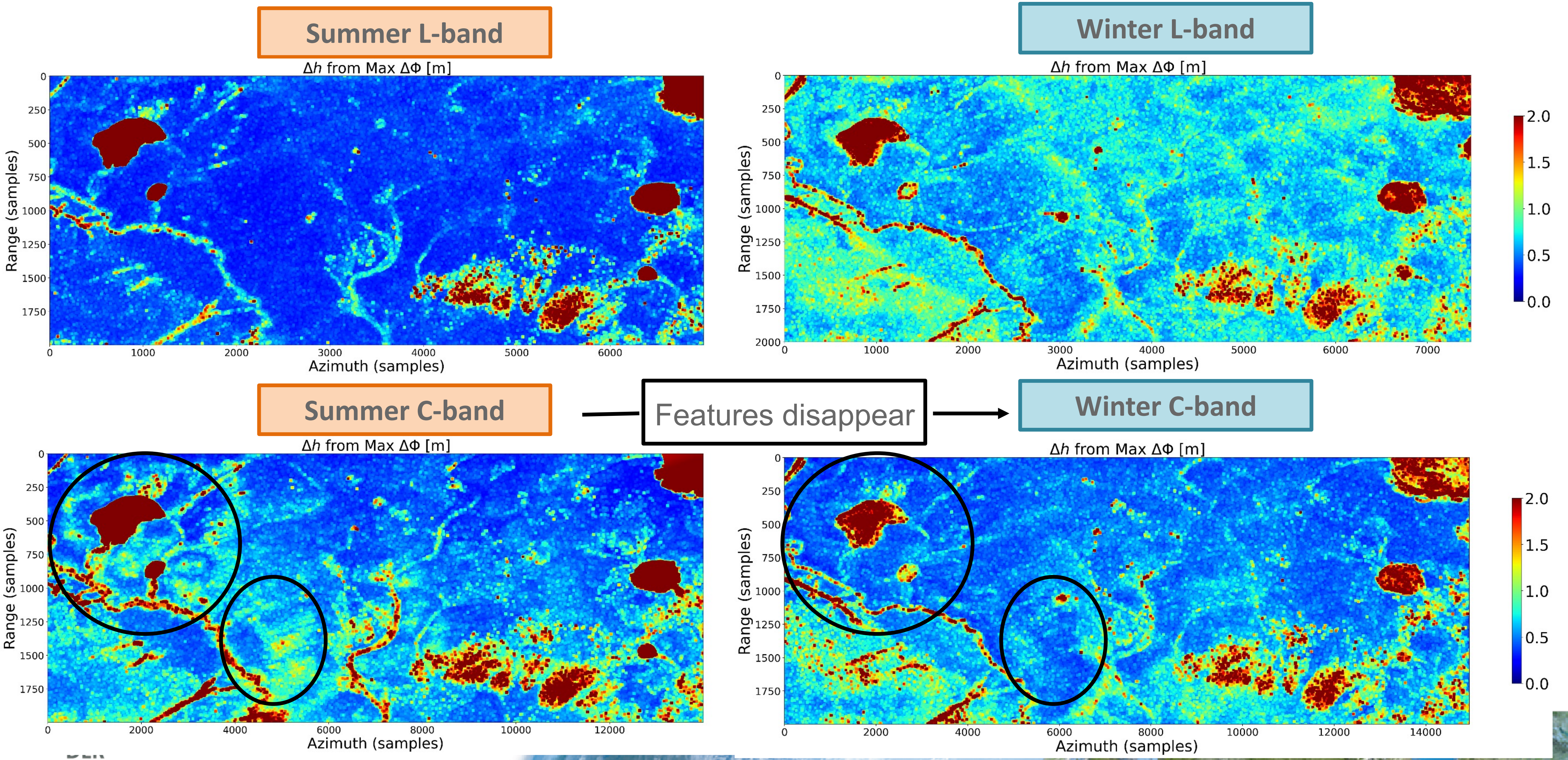




Focus on a small area (zoom!)

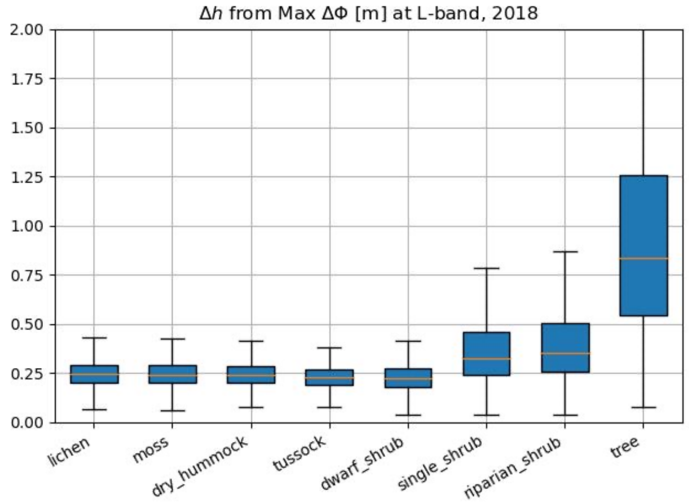


Focus on a small area (zoom!)

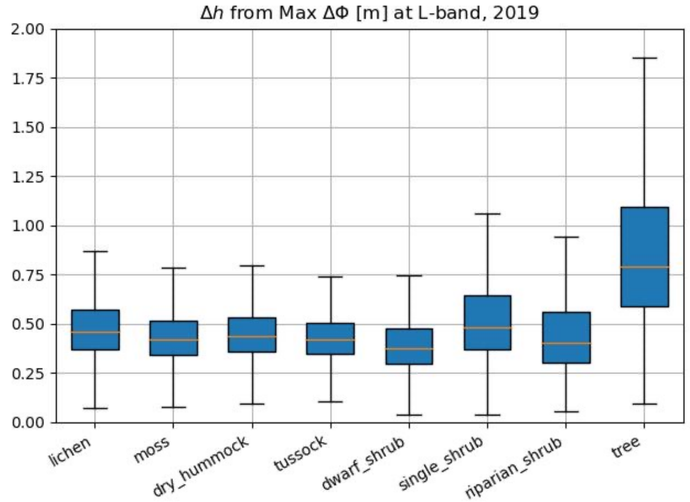


Dependence on vegetation type

Summer L-band

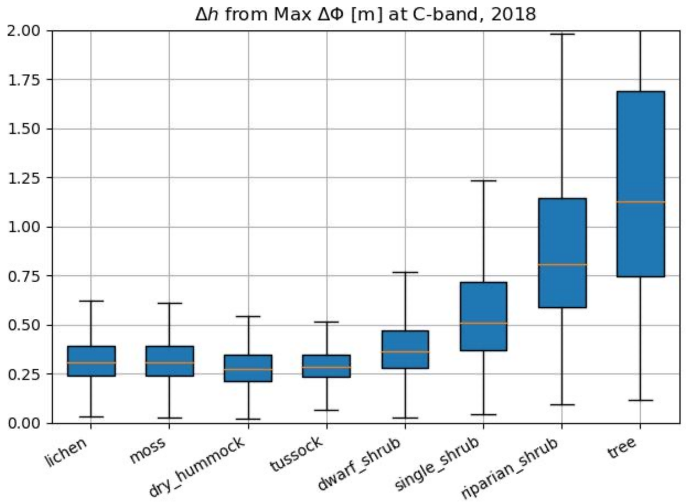


Winter L-band

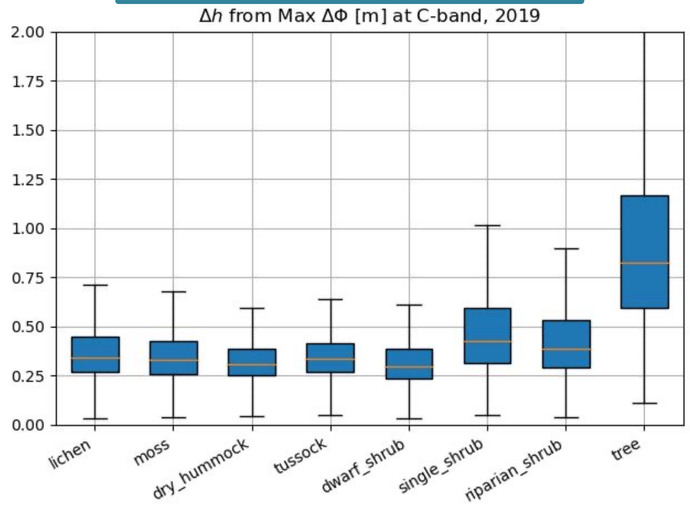


Overall increase

Summer C-band



Winter C-band

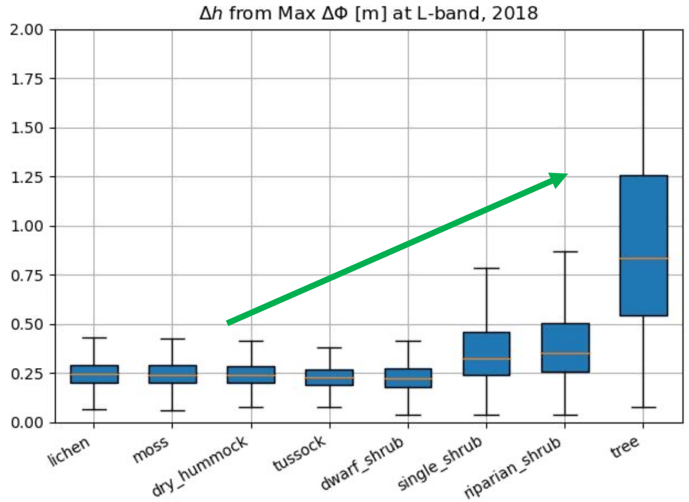


No change or decrease

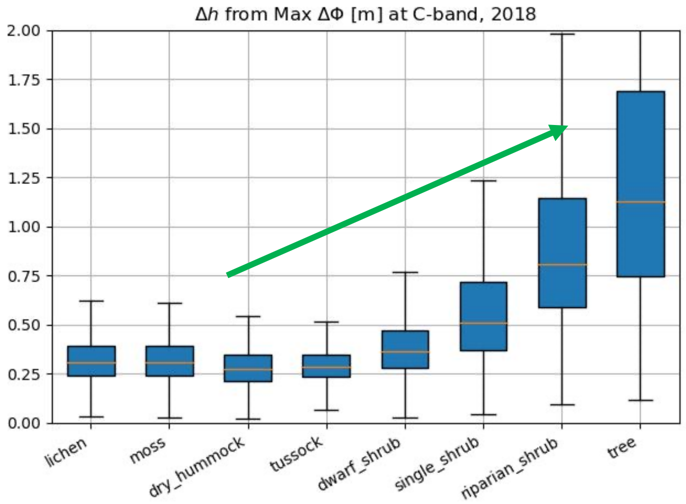
Dependence on vegetation type

Clear discrimination with landcover

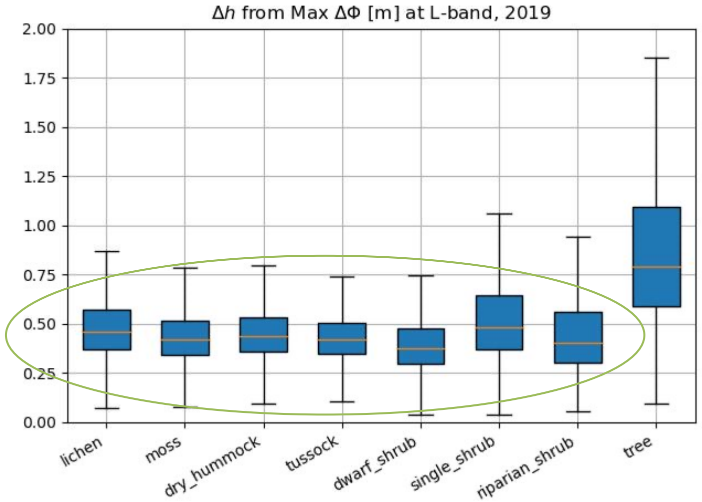
Summer L-band



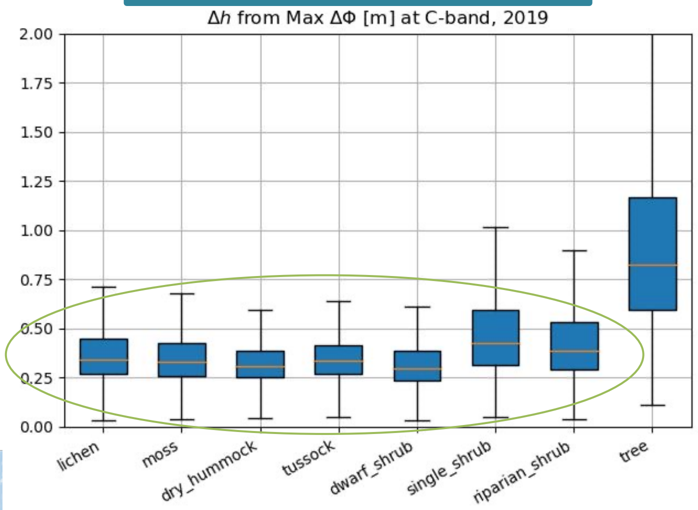
Summer C-band



Winter L-band



Winter C-band



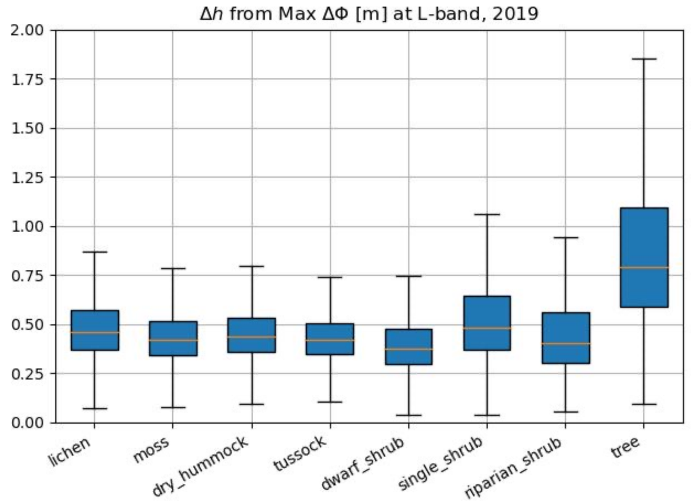
No clear discrimination with landcover

Outlook

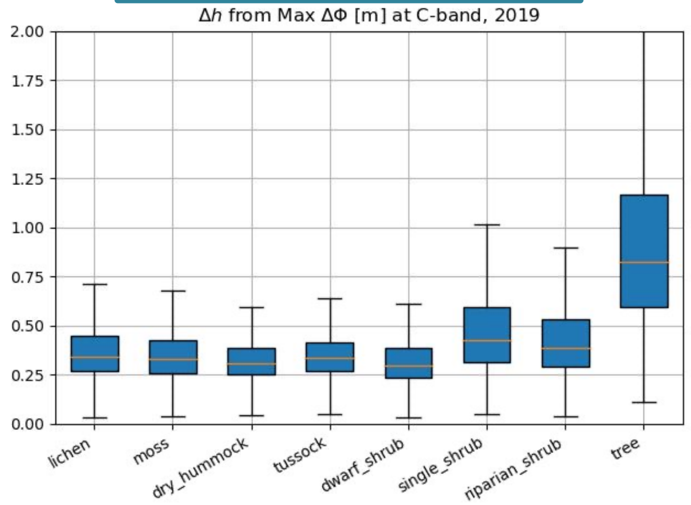
- First polarimetric coherence region analysis over permafrost at L-band and C-band
- PolInSAR coherence region extent main outcome
  - Summer: discriminate with landcover type/height
  - Winter (ground and vegetation is frozen – low dielectric contstant)
    - → L-band: increase of Δ height
    - → C-band: no change between summer and winter

- Further research:
  - Introducing EM model for permafrost: relating observations to snow, ground penetration and vegetation transparency

Winter L-band



Winter C-band



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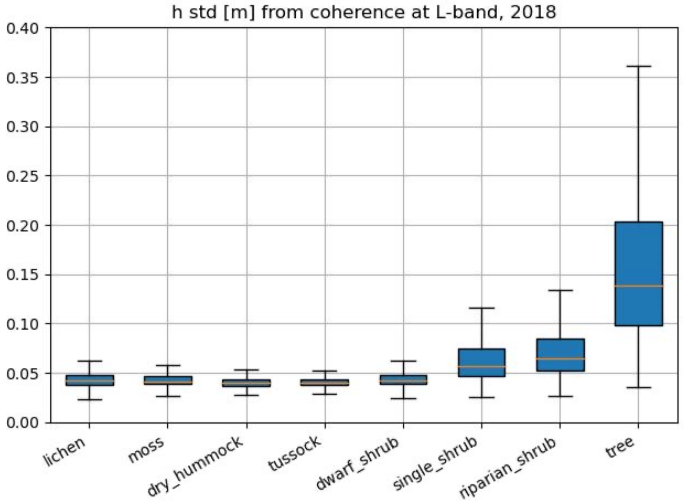
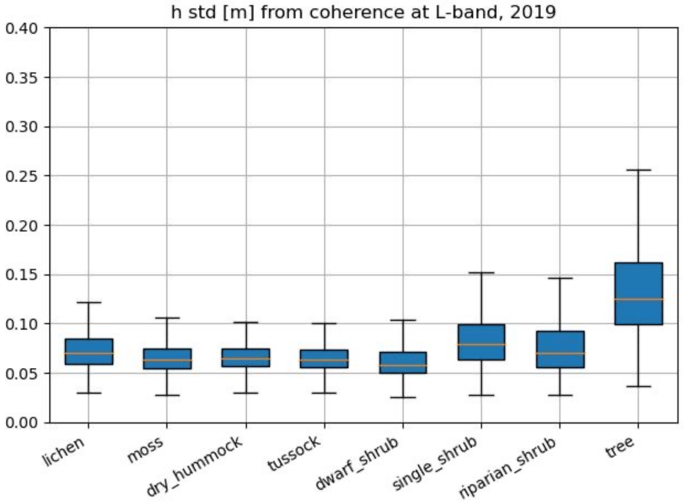
Thanks!

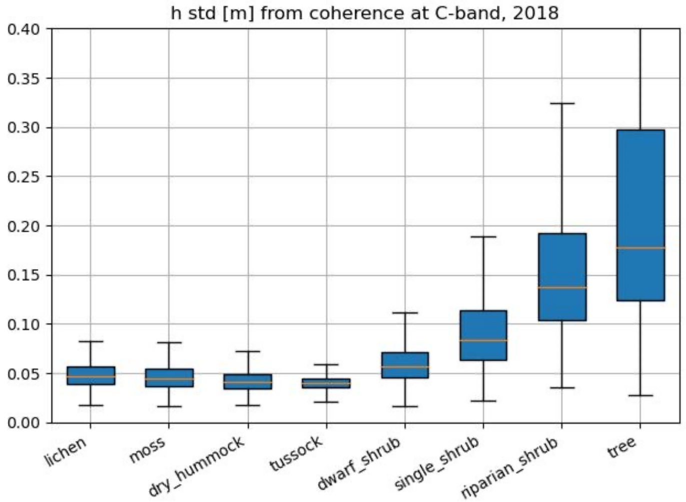
Summer L-band



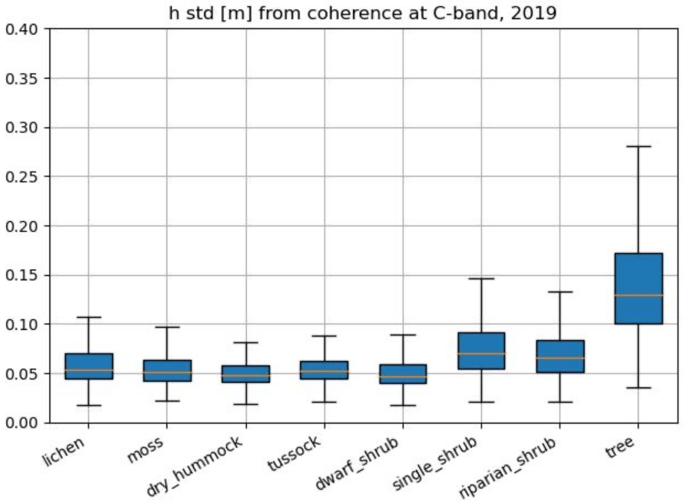
Winter L-band



Summer C-band

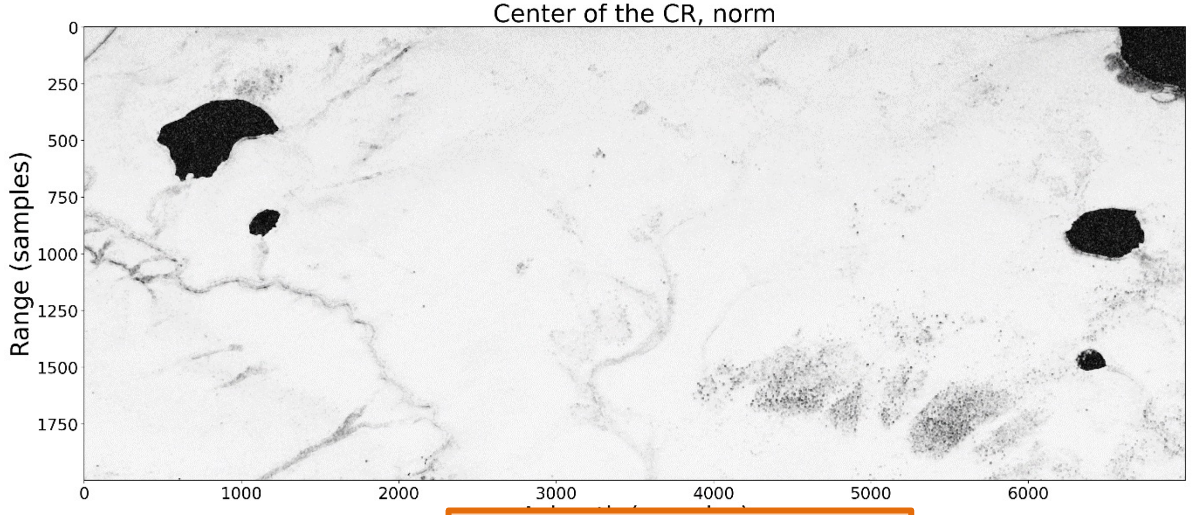


Winter C-band

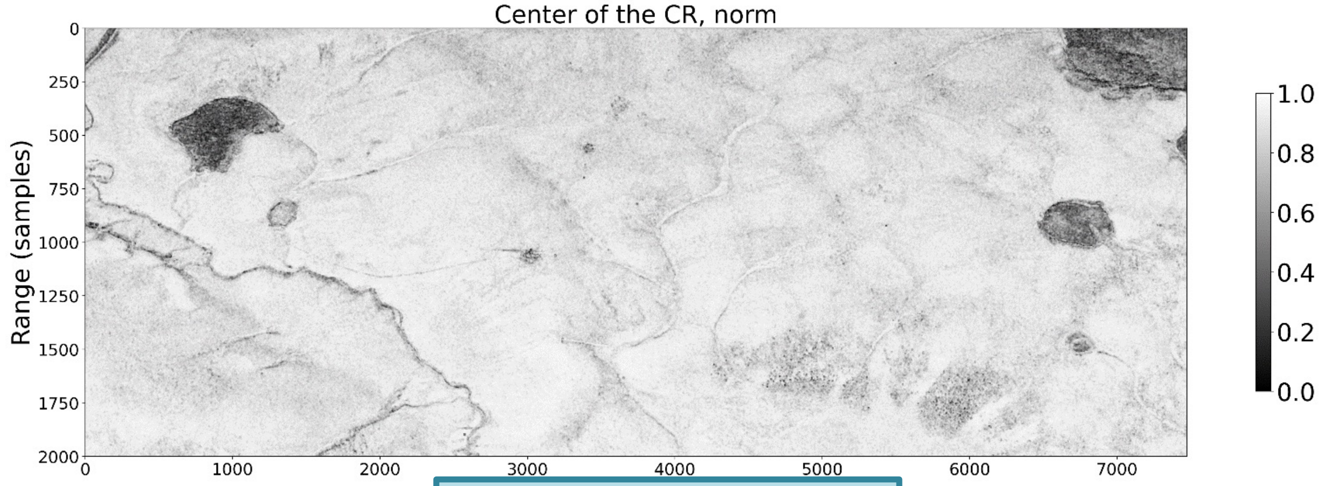


Coherence region center

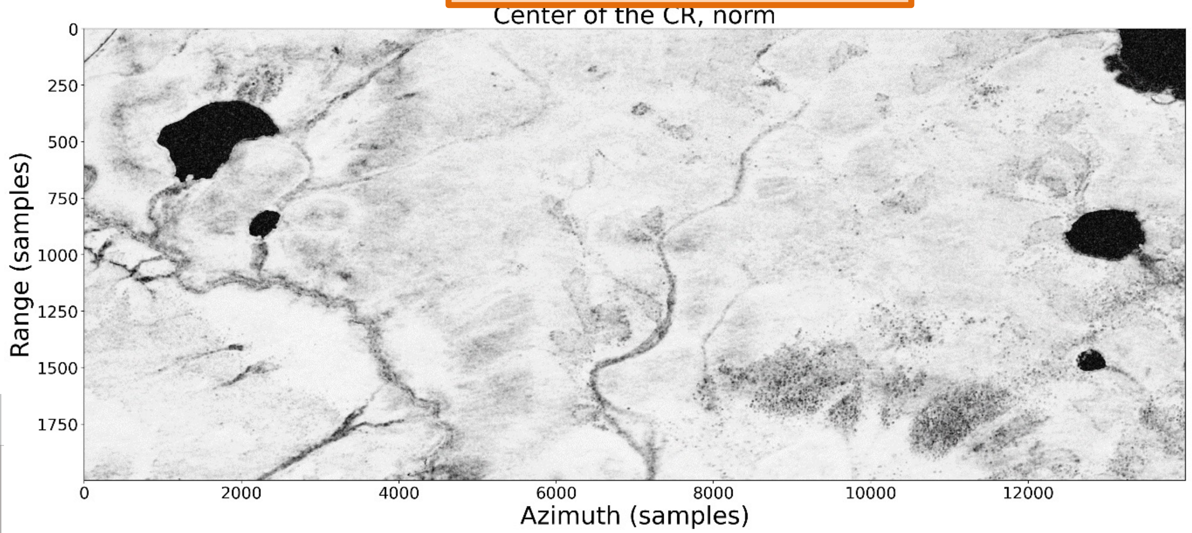
Summer L-band



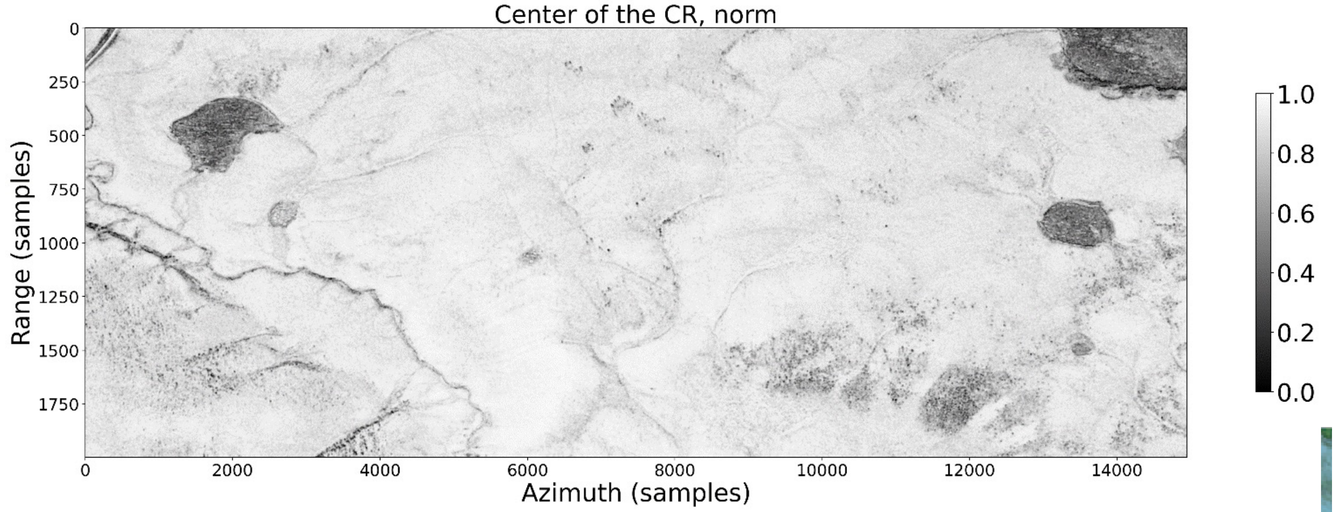
Winter L-band



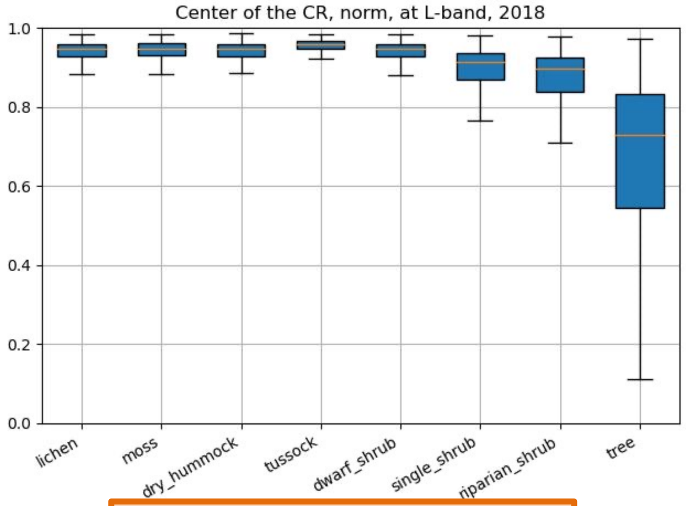
Summer C-band



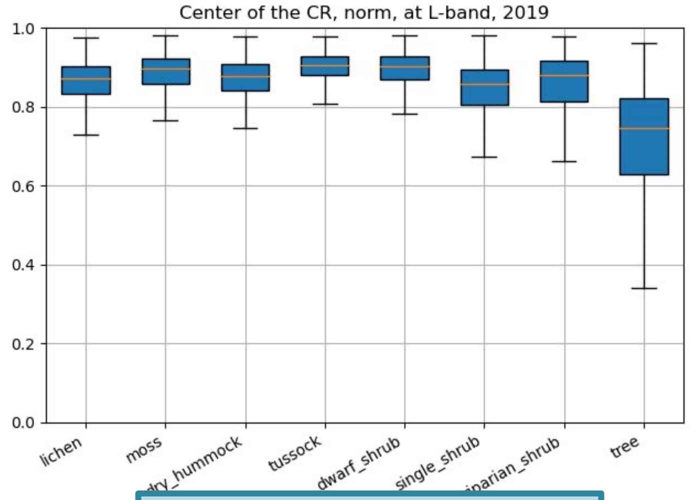
Winter C-band



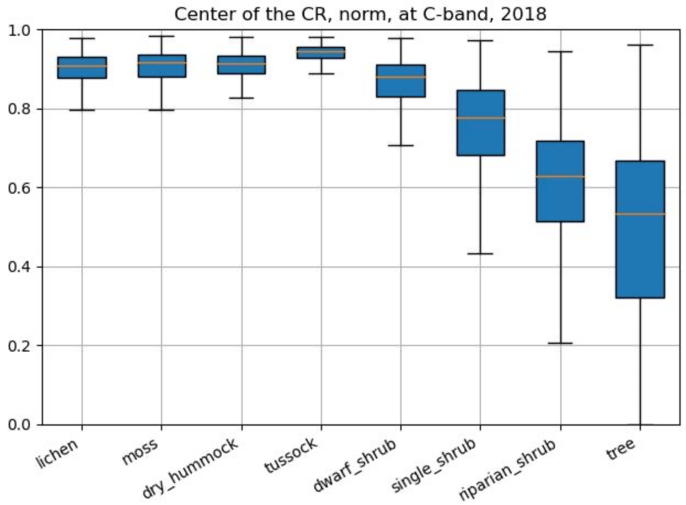
Summer L-band



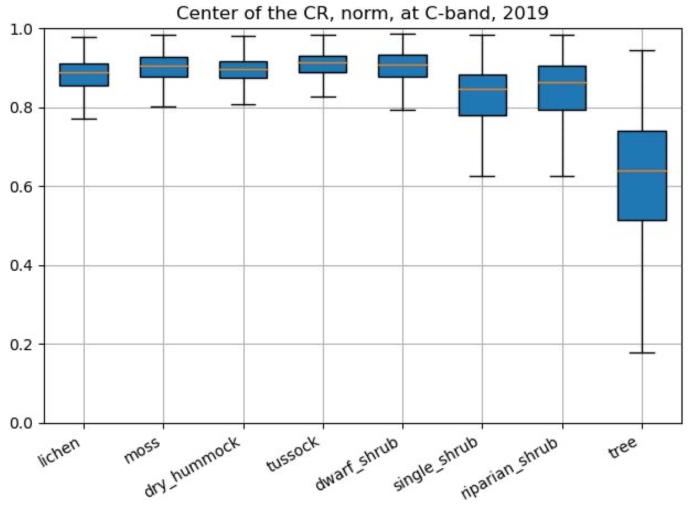
Winter L-band



Summer C-band

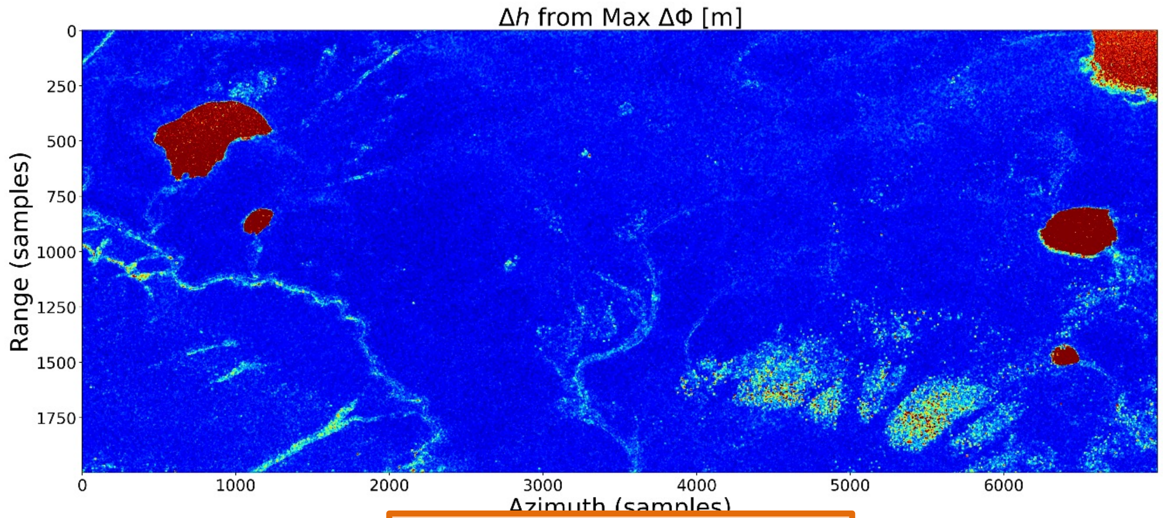


Winter C-band

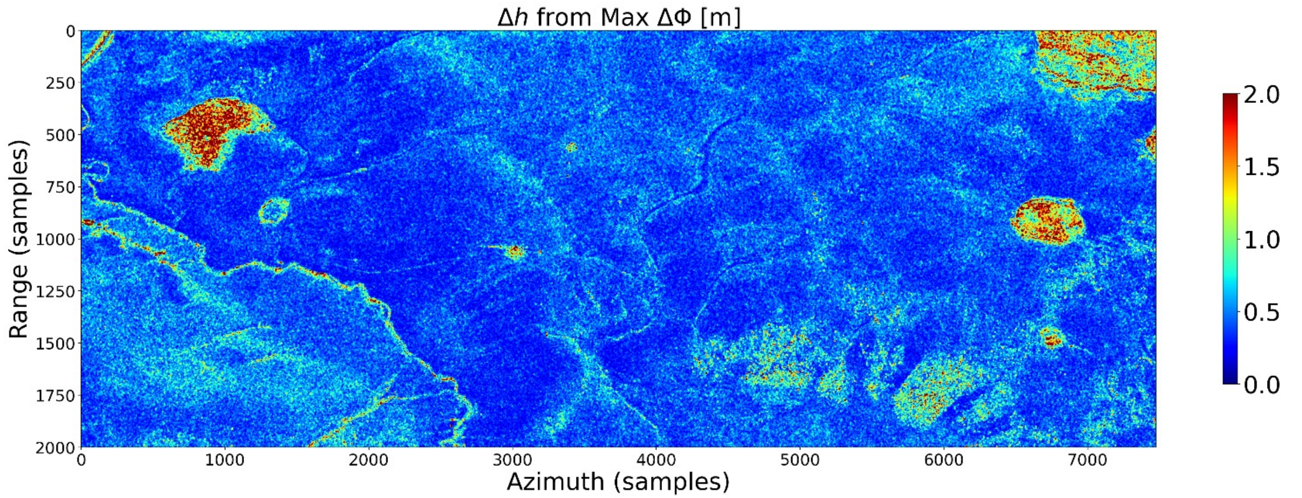


Original phase extent

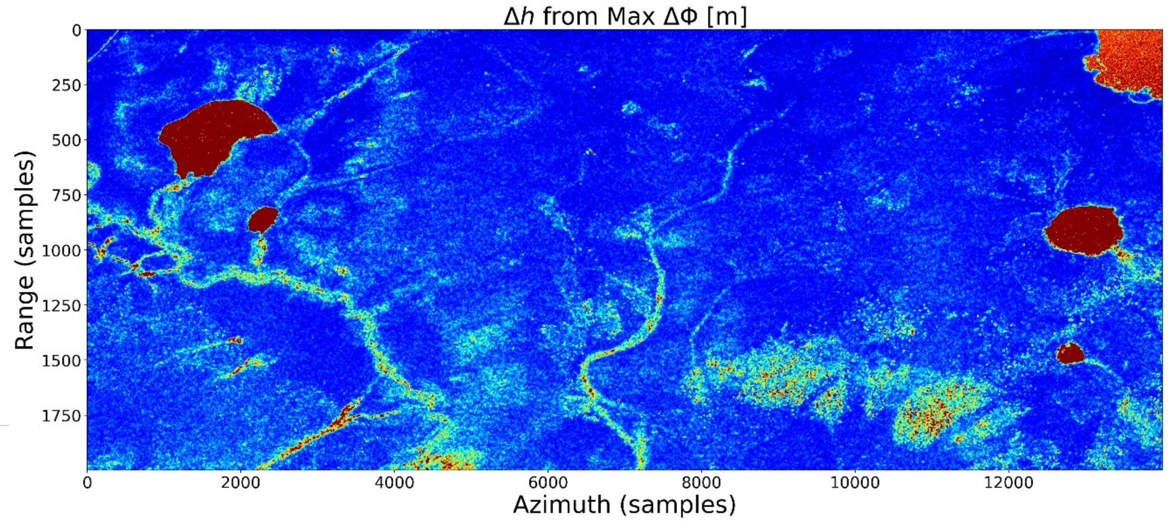
Summer L-band



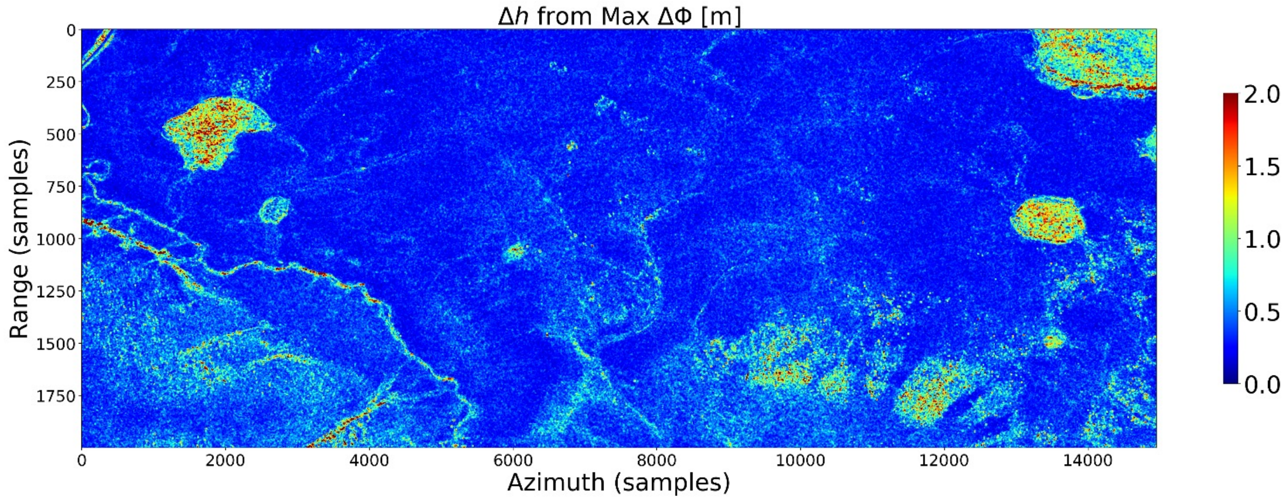
Winter L-band



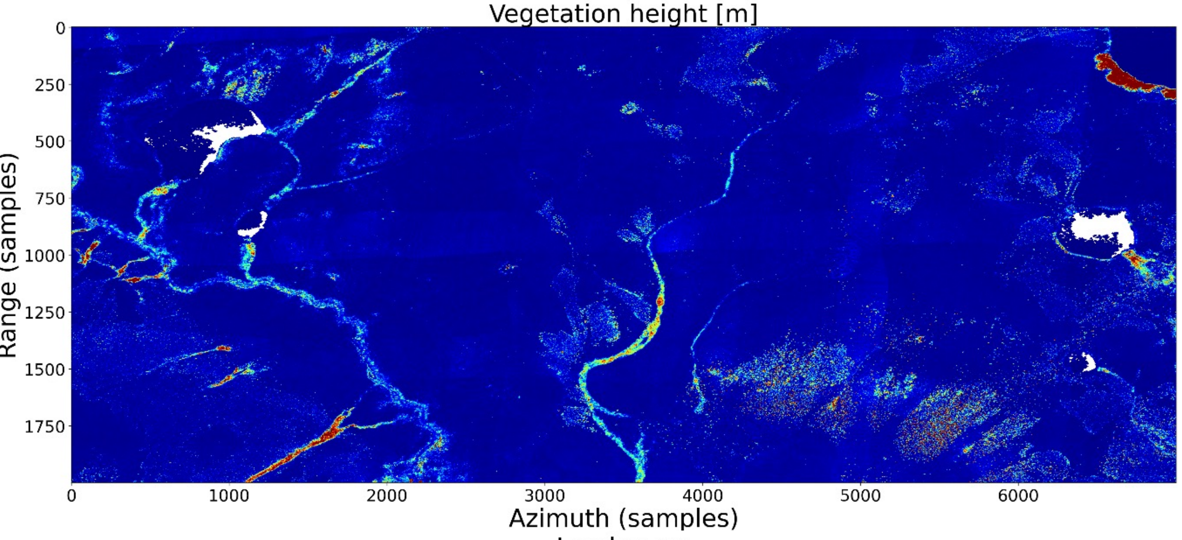
Summer C-band

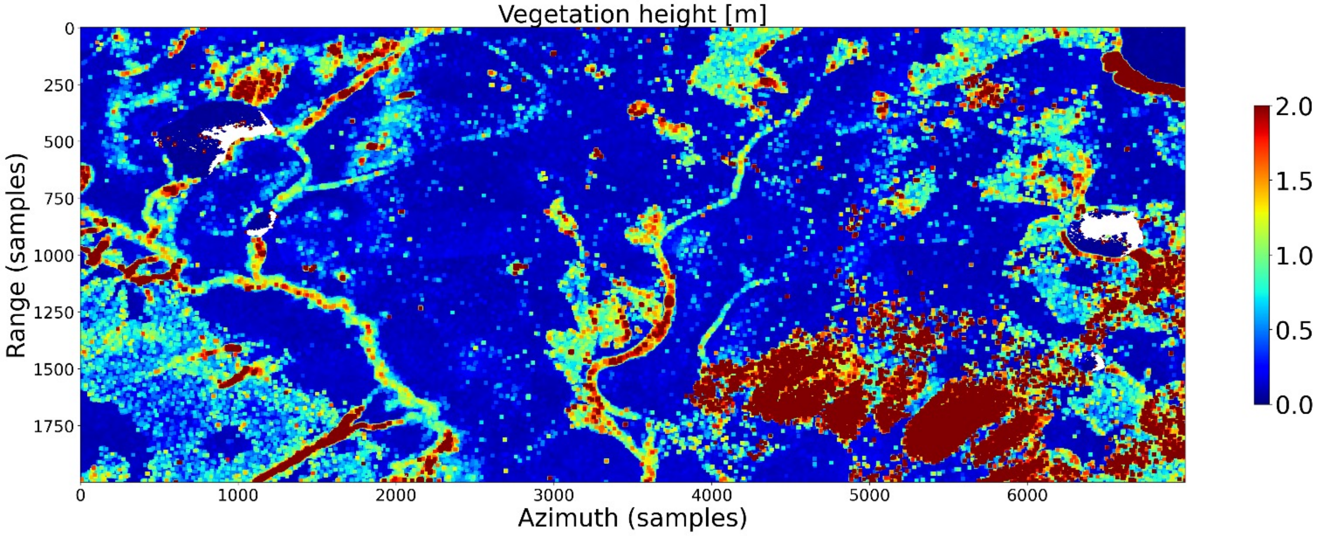


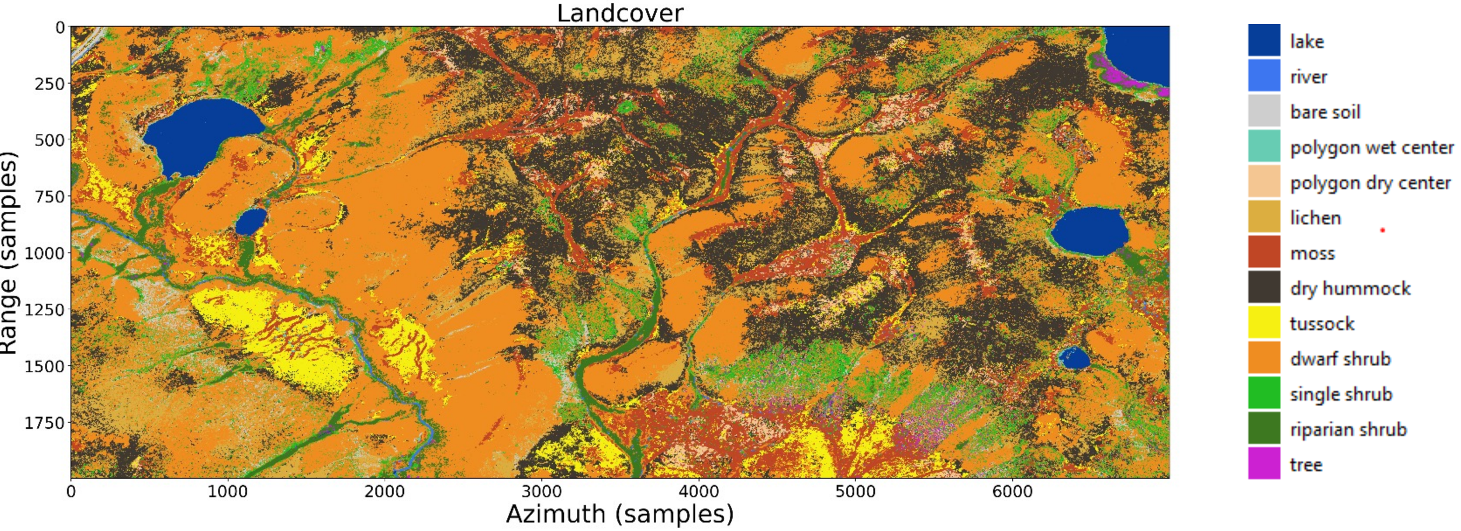
Winter C-band



External data on the smaller zone

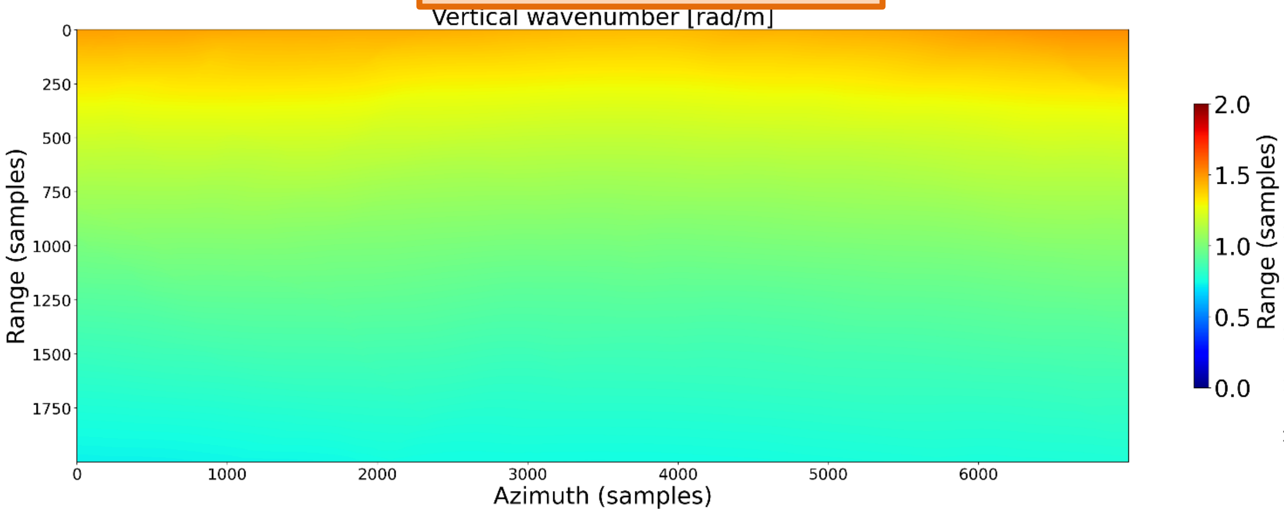




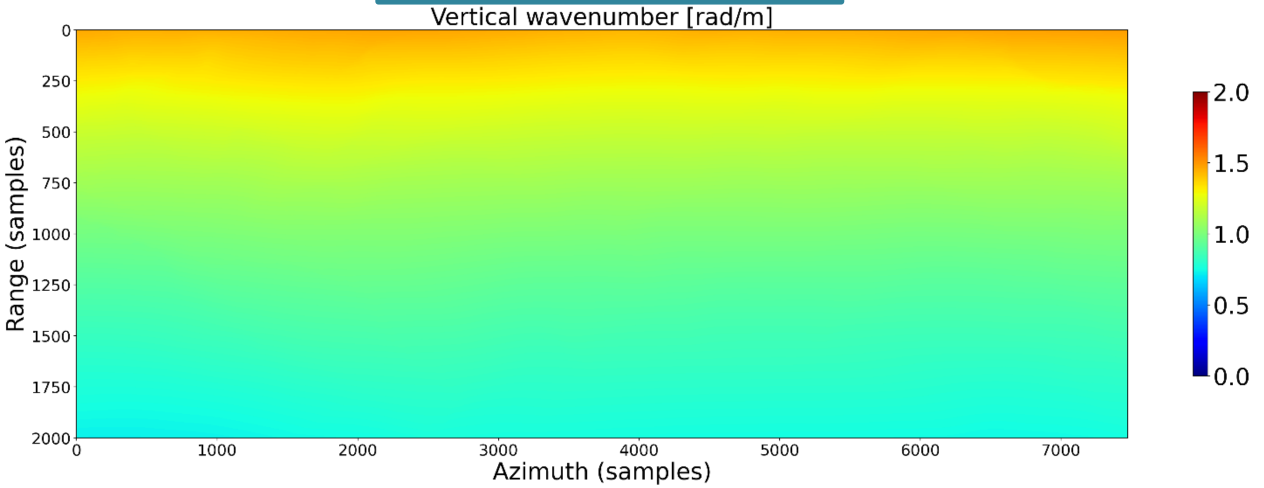


Vertical wavenumbers

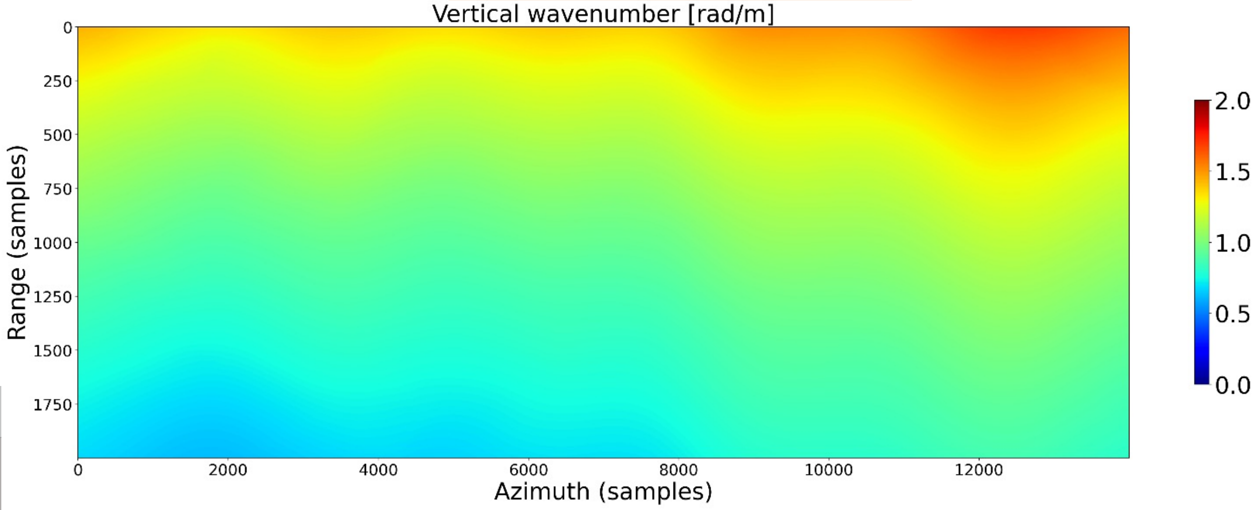
Summer L-band



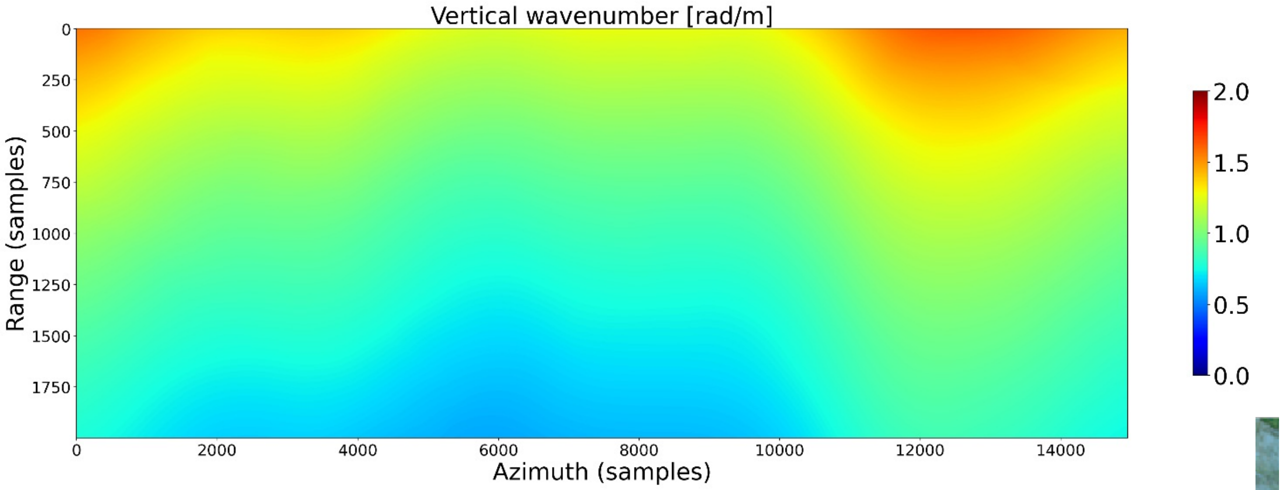
Winter L-band

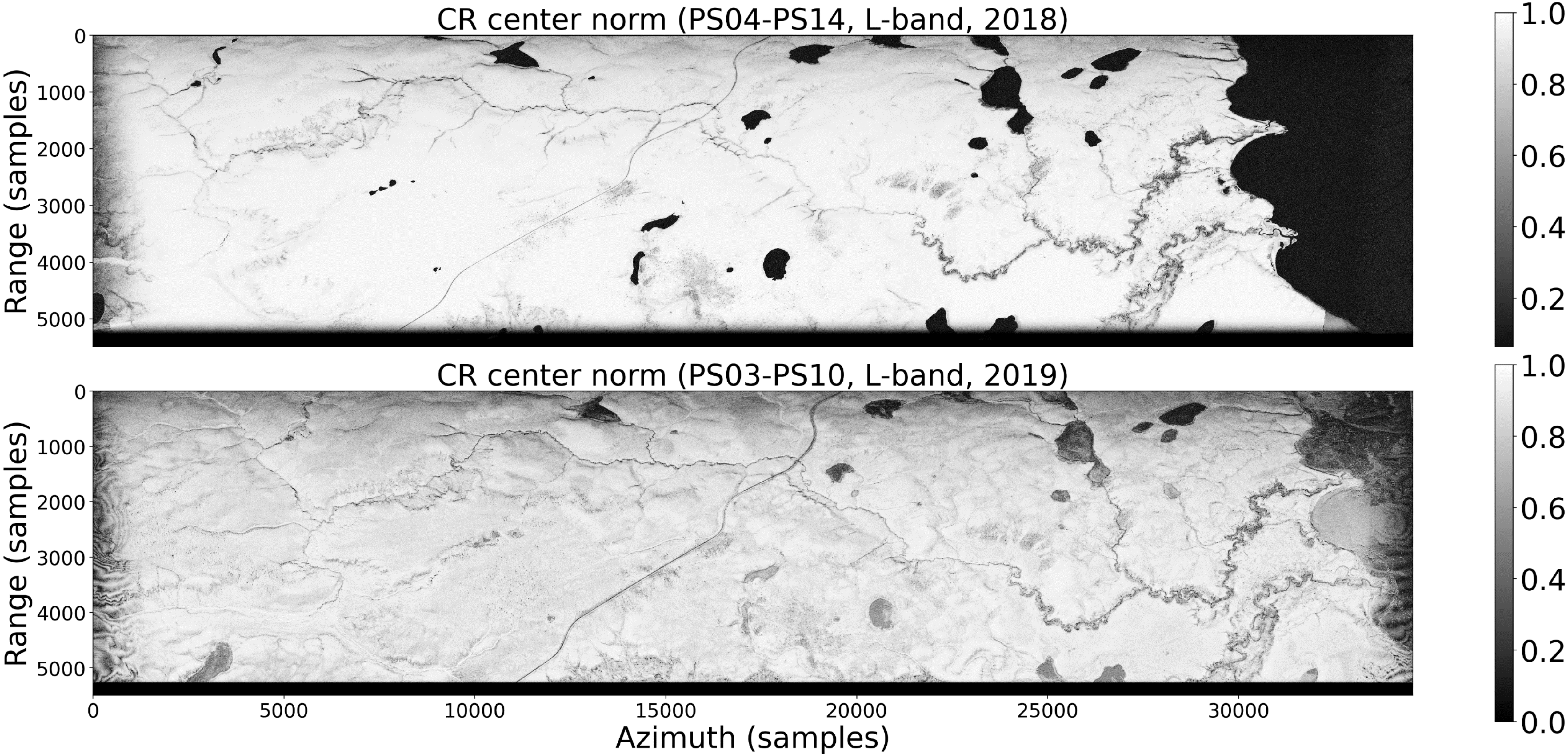


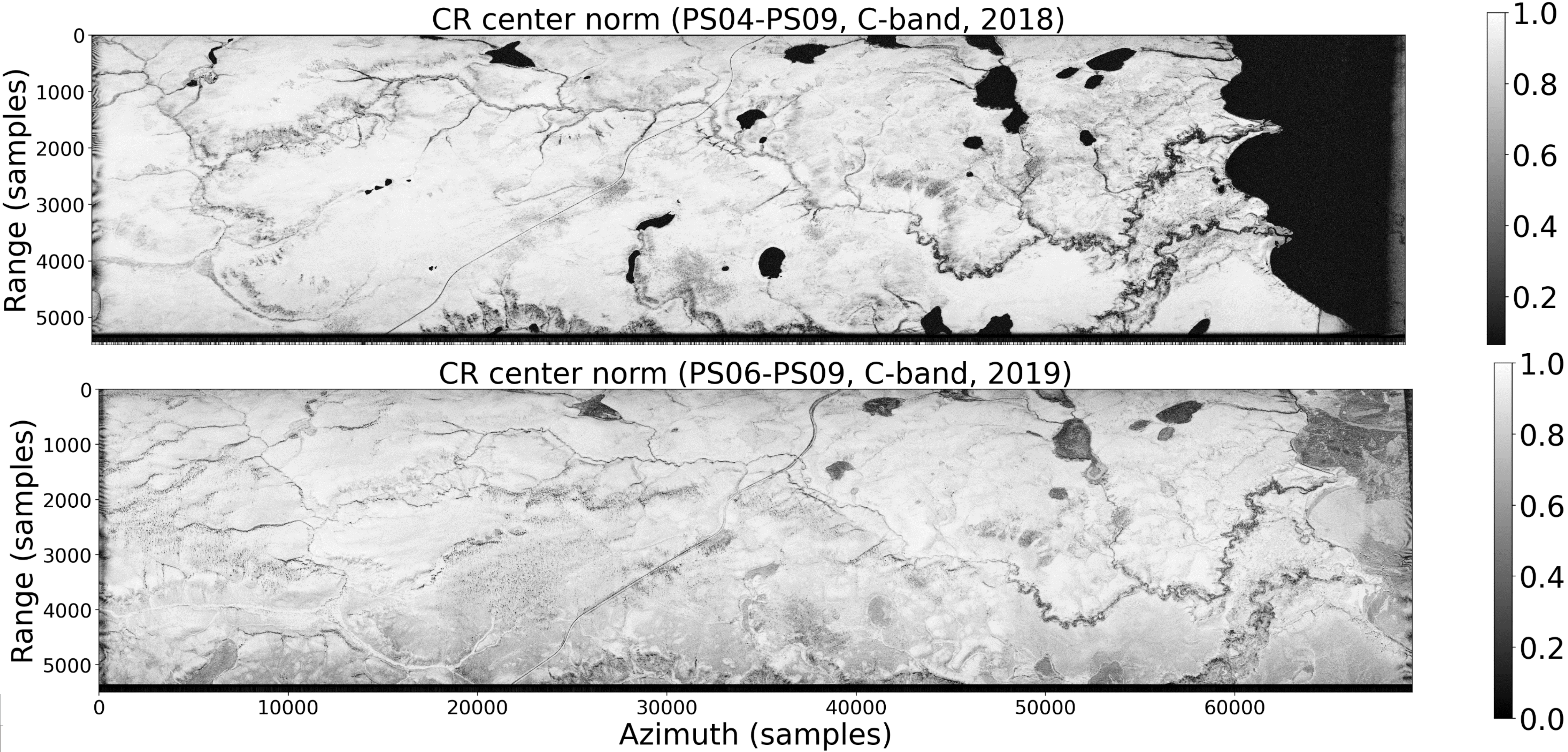
Summer C-band

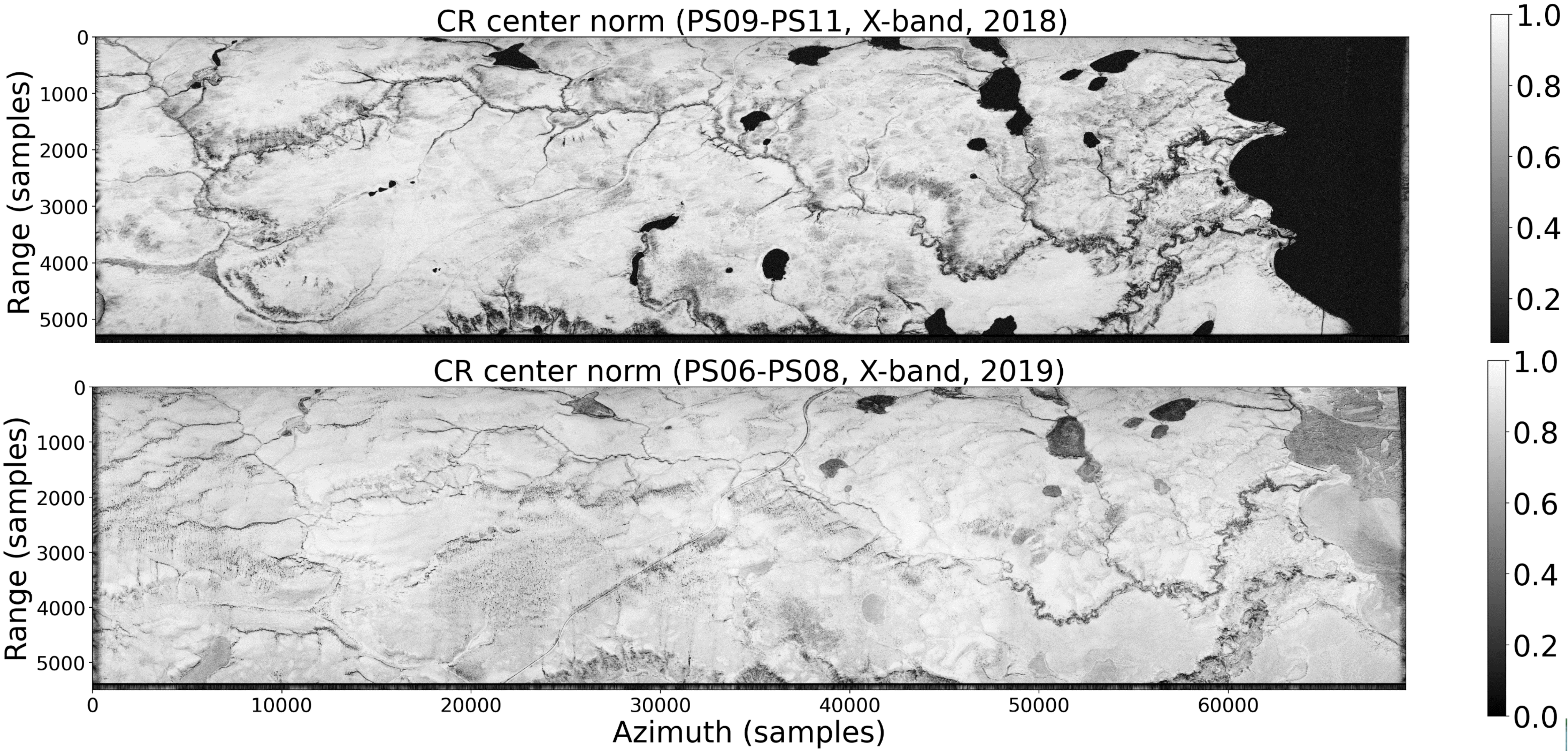


Winter C-band




CR center norm (PS04-PS14, L-band, 2018)
CR center norm (PS03-PS10, L-band, 2019)
Range (samples)
Azimuth (samples)
0
1000
2000
3000
4000
5000
10000
15000
20000
25000
30000
0.0
0.2
0.4
0.6
0.8
1.0


CR center norm (PS04-PS09, C-band, 2018)
CR center norm (PS06-PS09, C-band, 2019)
Range (samples)
0
1000
2000
3000
4000
5000
Azimuth (samples)
0
10000
20000
30000
40000
50000
60000
1.0
0.8
0.6
0.4
0.2
0.0


CR center norm (PS09-PS11, X-band, 2018)
CR center norm (PS06-PS08, X-band, 2019)
Range (samples)
0
1000
2000
3000
4000
5000
Azimuth (samples)
0
10000
20000
30000
40000
50000
60000
0.0
0.2
0.4
0.6
0.8
1.0