InSAR Time Series Analysis of Seasonal Active Layer Dynamics in Low-Land Permafrost Terrain

Northwest Territories, Canada

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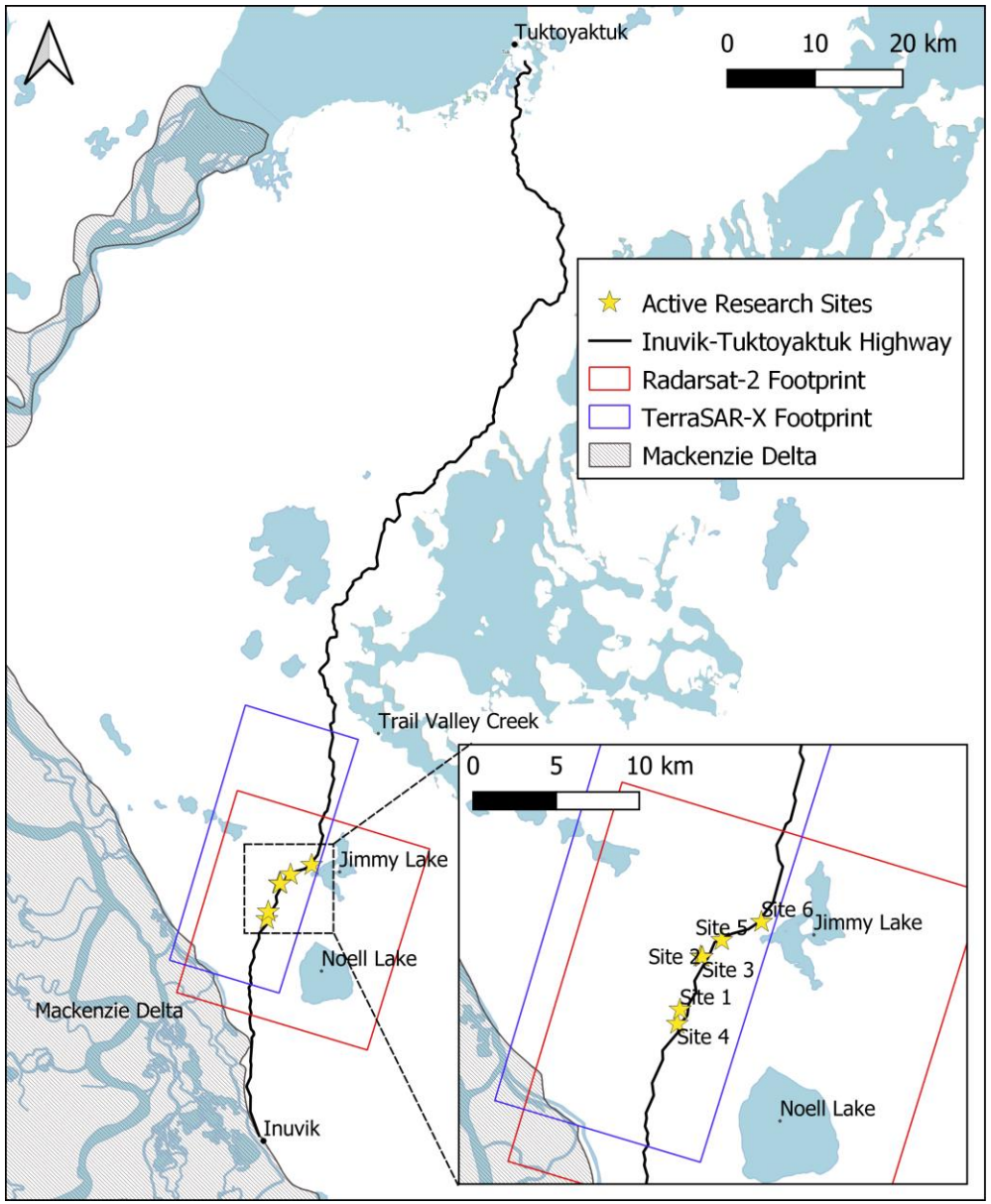
Fall 2023

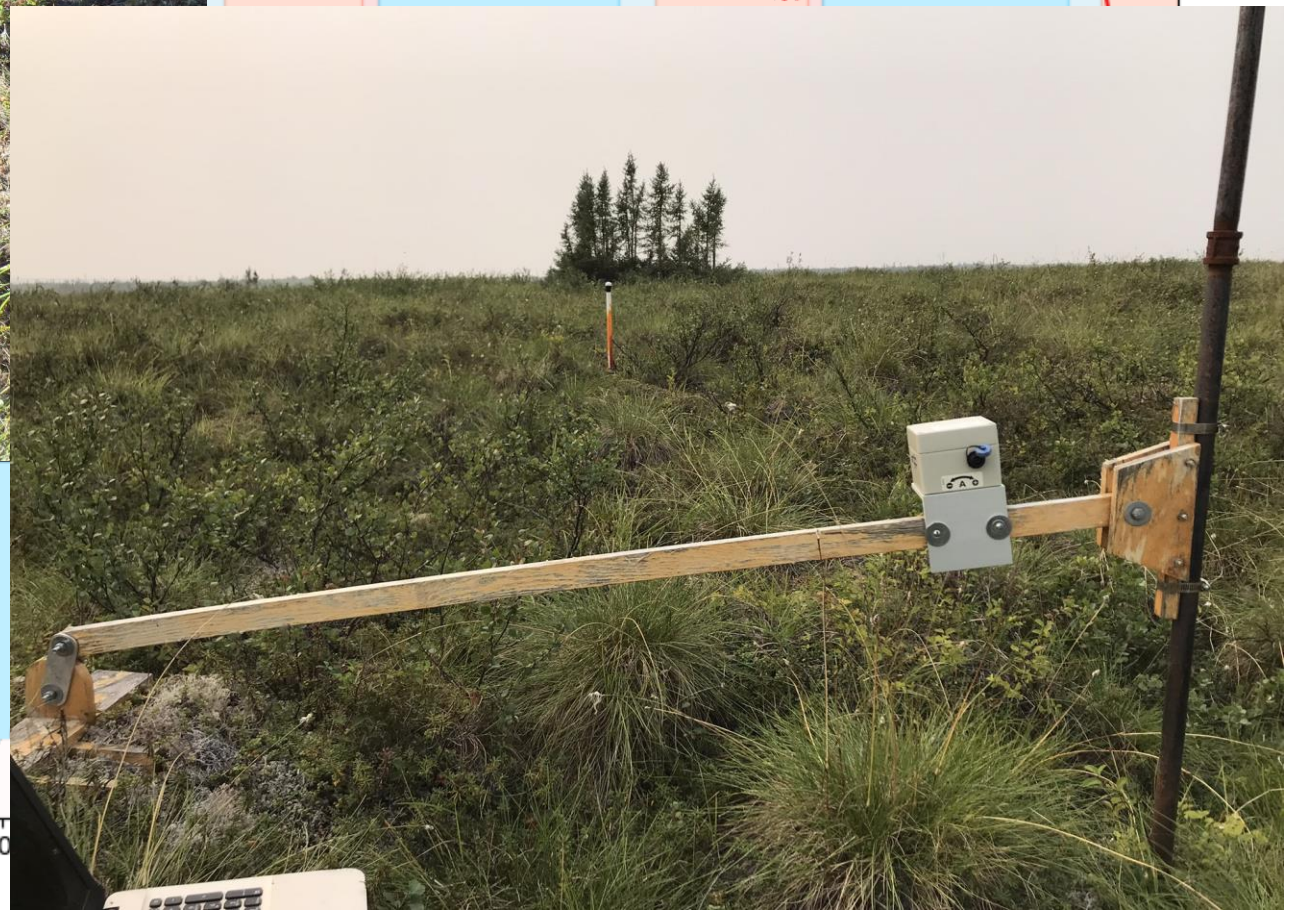
Project Overview

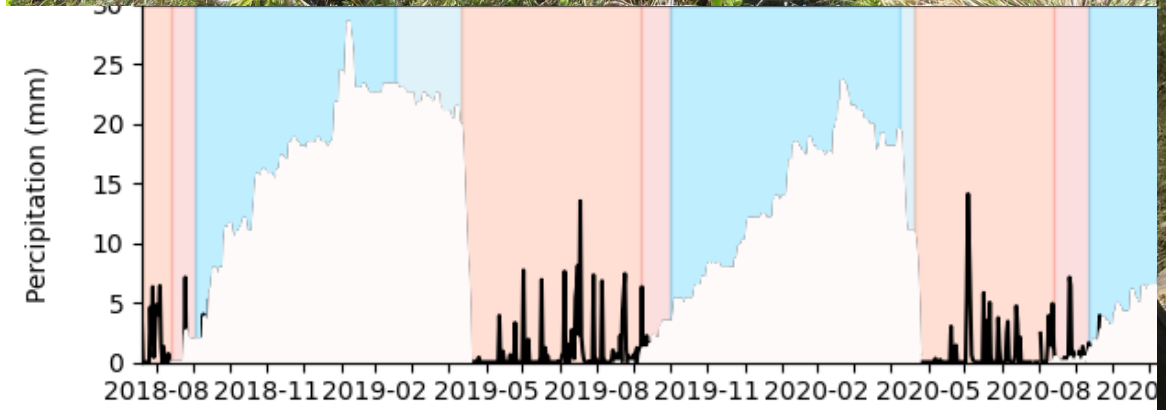
- 6 in-situ research stations
  - Measuring vertical deformation and snow depth
  - 1 anchored, 1 floating Corner Reflector
- 2 InSAR stacks
  - RADARSAT-2 Ultrafine
    - C-band, 24-day repeat, 3x3m resolution
    - 22km x 23 km
  - TerraSAR-X Stripmap
    - X-band, 11-day repeat, 3x3m resolution
    - 13kmx30km



18 - 2023


Thaw Tube: 5.3cm
Inclinometer Reading: 6.1 cm
(Since August 2018)



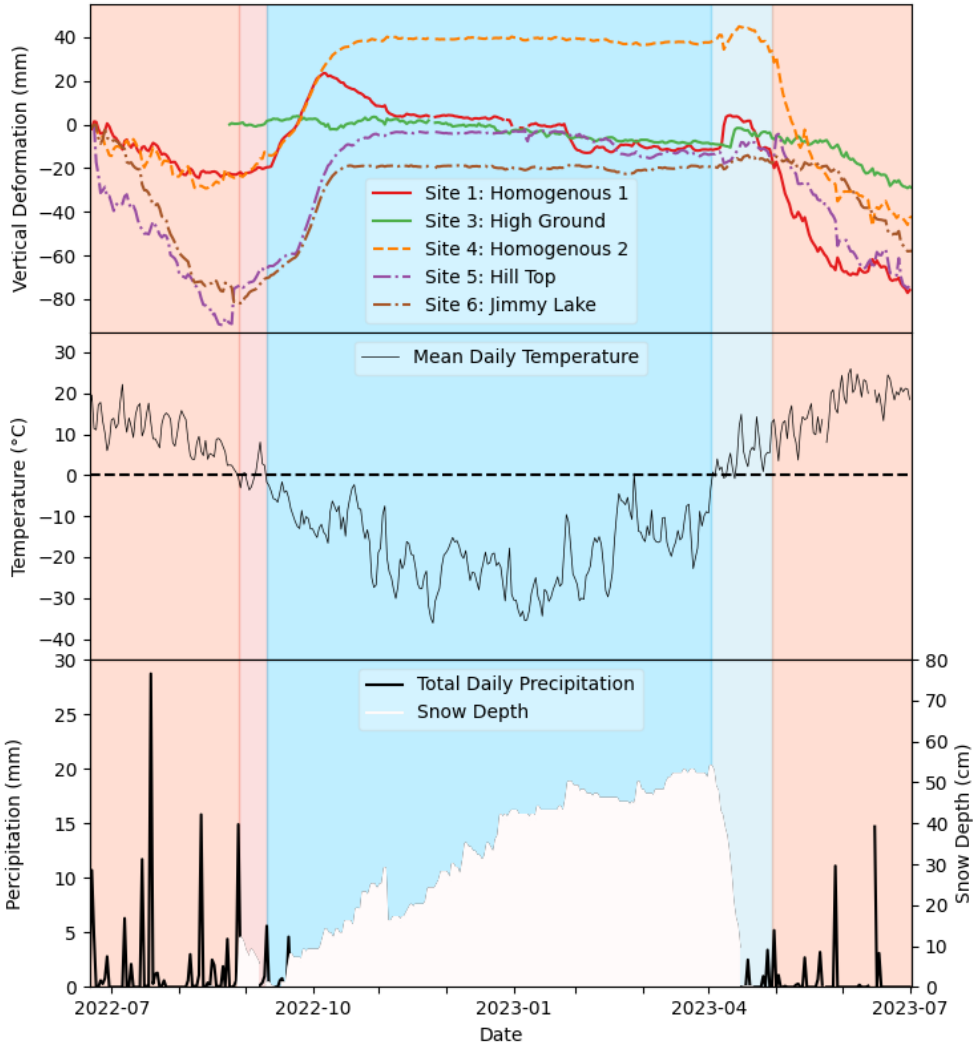

Percipitation (mm)
0
5
10
15
20
25
2018-08
2018-11
2019-02
2019-05
2019-08
2019-11
2020-02
2020-05
2020-08

Inclinometer Measurements

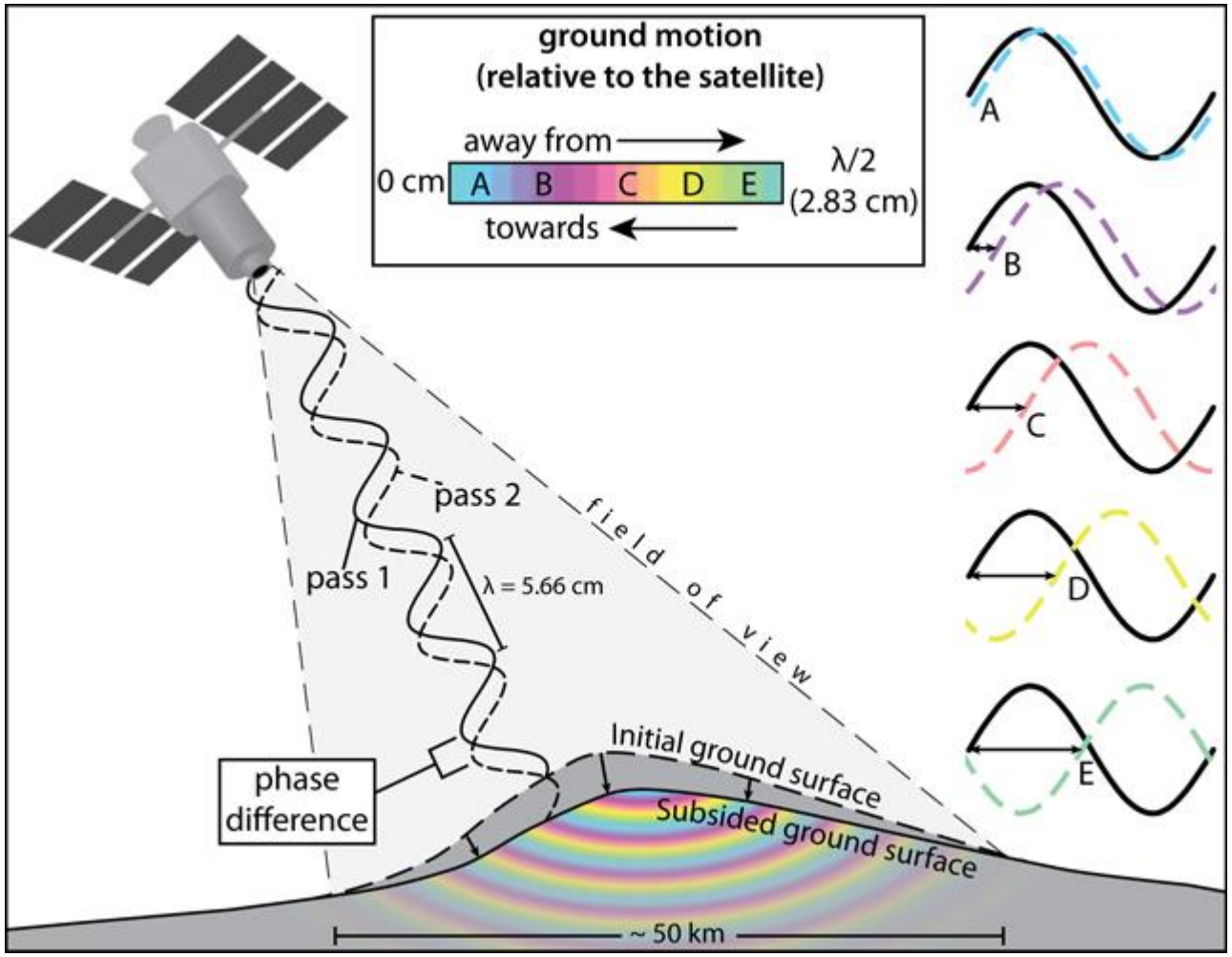
2022 - 2023

- Site 1 shows subsidence during winter
- Sites 4, 5, 6 have similar amplitudes/patterns
- Significant subsidence at sites 5 and 6 between July and August
- Site 2 malfunctioned due to water infiltration
- Site 3 reinstalled September 2022

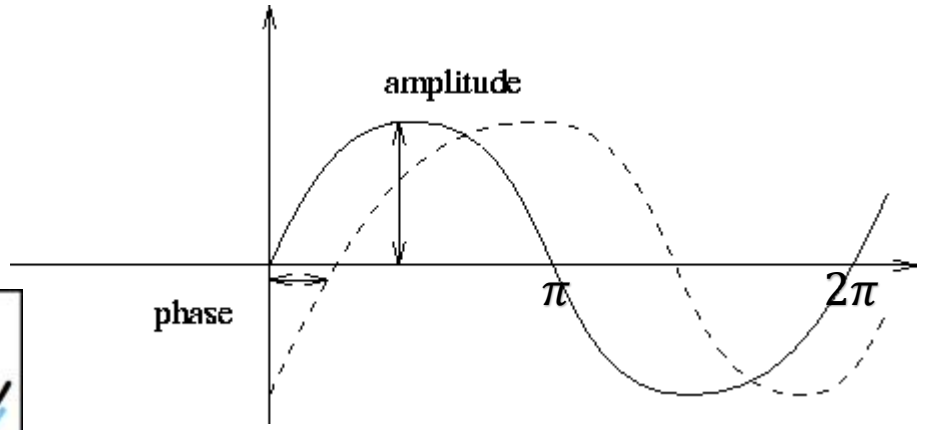
	Site 1	Site 4	Site 5	Site 6
Seasonal Amplitude (cm)	4.8	6.9	8.8	6.3



InSAR Fundamentals

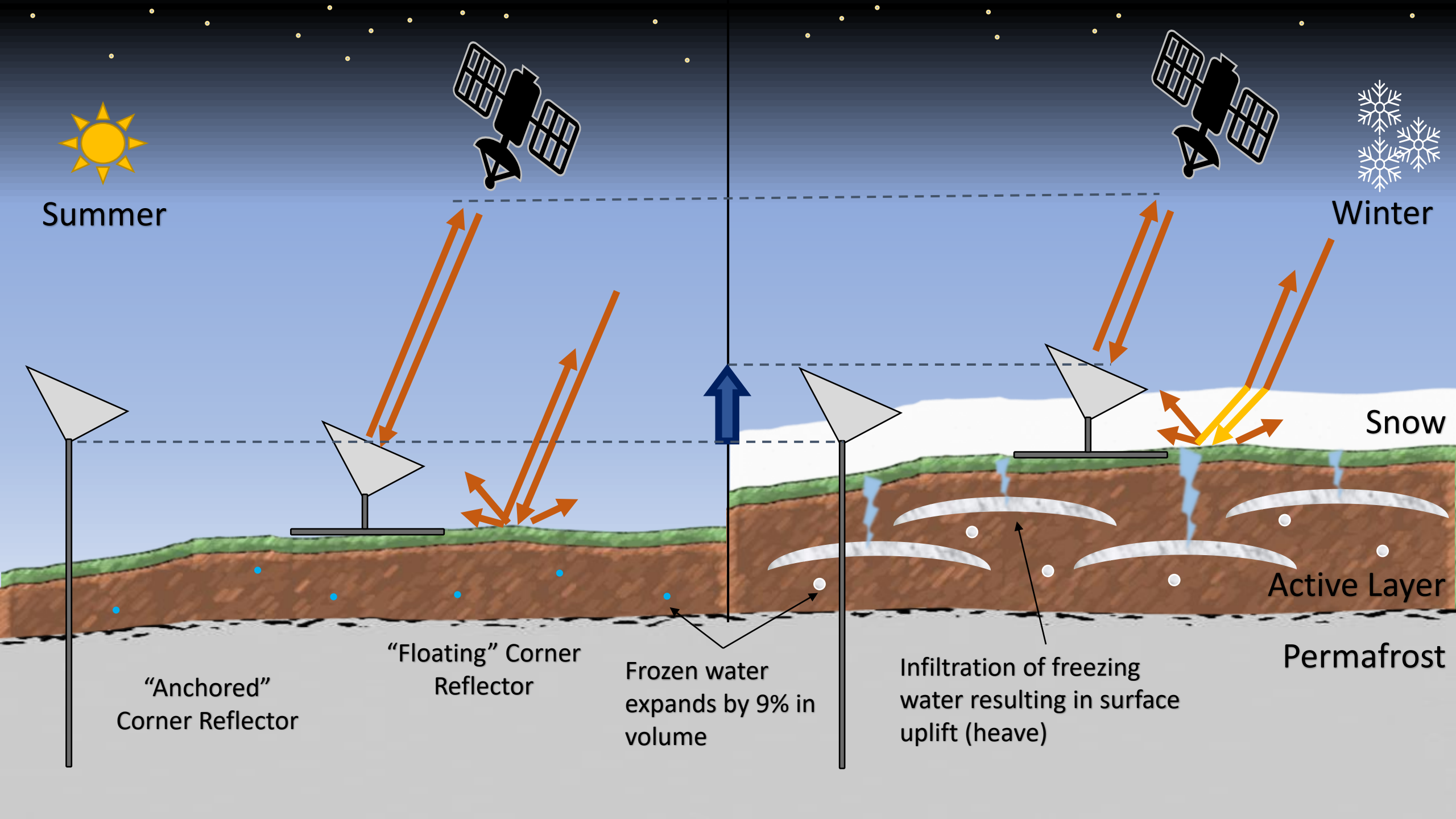


Source: https://insar.space/insar-technology/



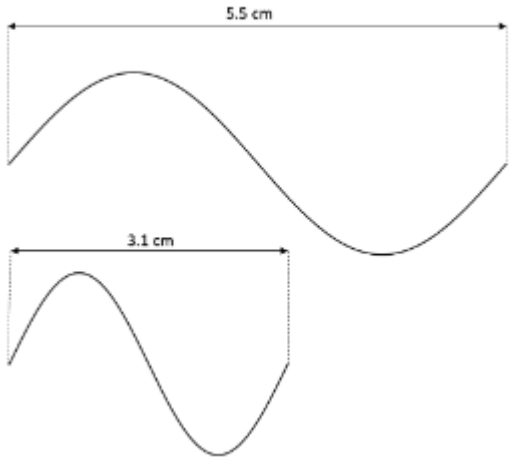
$$\Delta\phi = \phi_1 - \phi_2$$

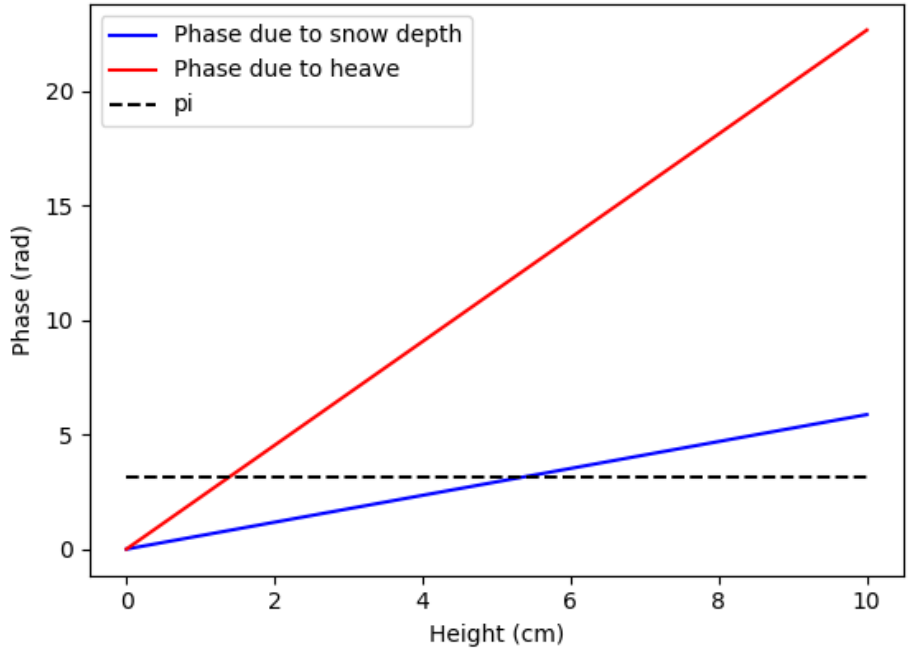
$$\Delta\phi = \Delta\phi_{deformation} + \Delta\phi_{atmosphere} + \Delta\phi_{topography} + \Delta\phi_{snow} + \Delta\phi_{other\ surface\ changes} + \Delta\phi_{sensor\ noise}$$


Summer
Winter
Snow
Active Layer
Permafrost
"Anchored" Corner Reflector
"Floating" Corner Reflector
Frozen water expands by 9% in volume
Infiltration of freezing water resulting in surface uplift (heave)

Phase Resolution

- InSAR phase is measured between $\pm\pi$
- InSAR phase is proportional to half the radar wavelength





Phase due to Snow Depth:

$$\Delta\phi_{snow} = \frac{4\pi}{\lambda} D_s \left(\sqrt{(e - 1 + \cos^2\theta)} - \cos\theta\right)$$

Phase due to Vertical Surface Deformation:

$$\phi_{heave} = \frac{4\pi}{\lambda} D_H \cos\theta$$

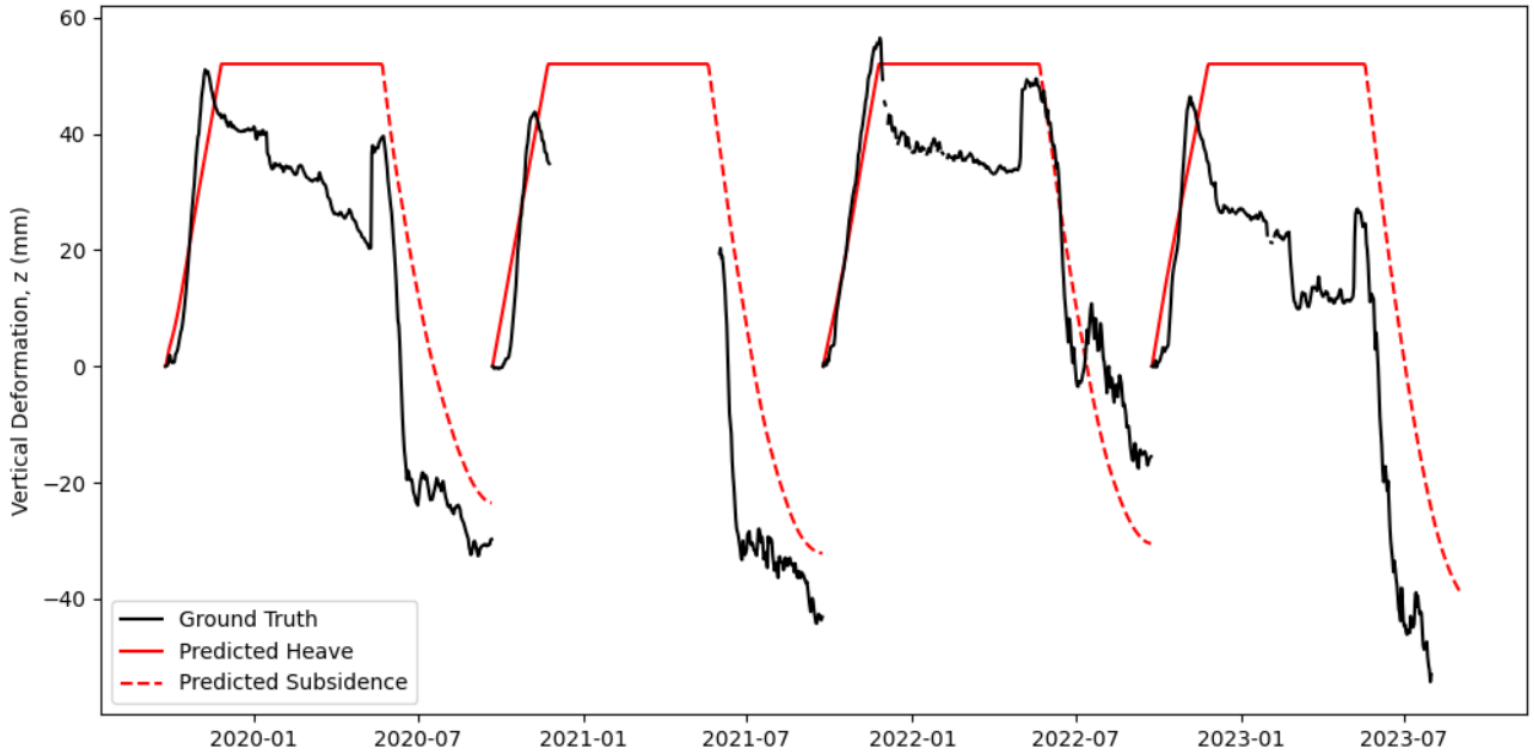
2π Ambiquity

Component	**RS2**	**TSX**
Surface Deformation	2.8 cm	1.6 cm
Snow Depth (derived from SWE)	11.6 cm	6.6 cm

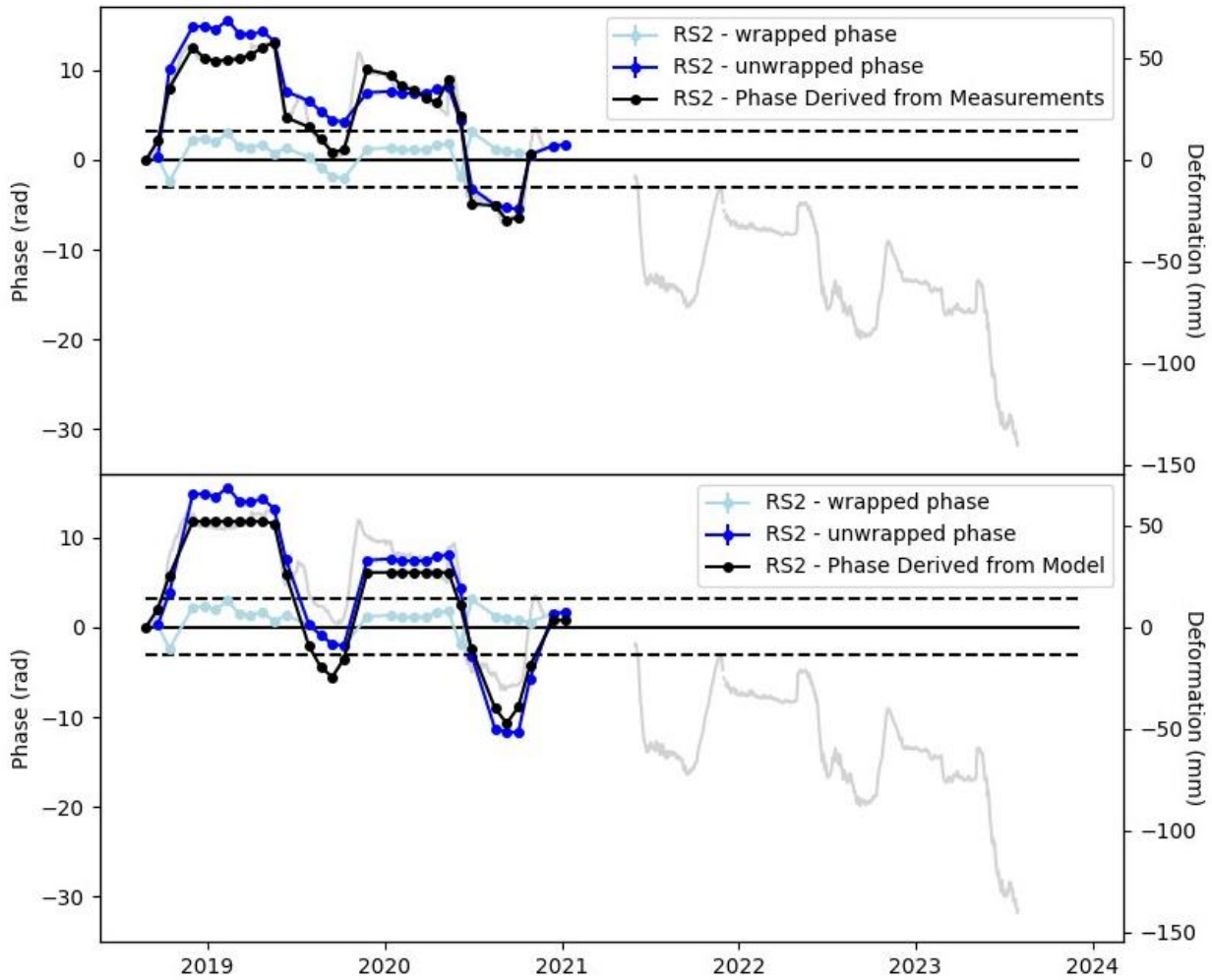
Model Derived from Stefan Equation

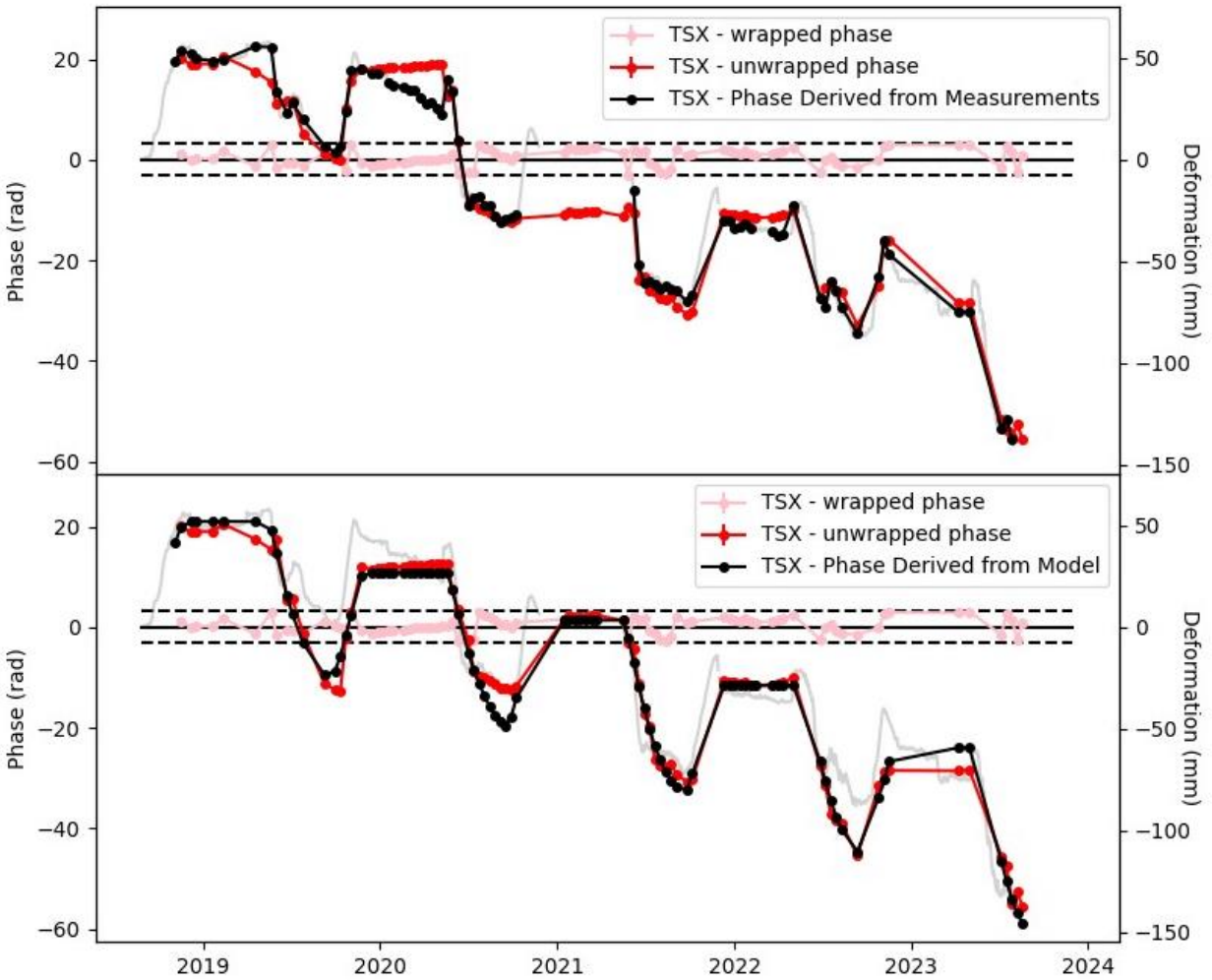
$$z \propto \sqrt{I(t)}$$

- Where $I(t)$ is cumulative degree days derived from air temperature data
- Proportionality constant derived separately for freeze and thaw season
- Inclinometer data used to fit the model
- Average over 4 seasons is used for final result



Corner Reflector Timeseries





Discussion

- Overfitting model?
  - InSAR results are only as good as the model used to unwrap
- Incorrect assumption of stability of the anchored corner reflector?
  - Accurate phase unwrapping requires a stable reference point
  - Same method used to secure inclinometer, thaw tube, and anchored reflector to the permafrost
- Possible Mitigations:
  - Increased temporal frequency
  - Longer radar wavelength (L-band)
  - Increase redundancy of field observations