Monitoring Arctic Sea Ice During One Year: Linearly Polarized GNSS-Reflectometry at the MOSAiC Campaign

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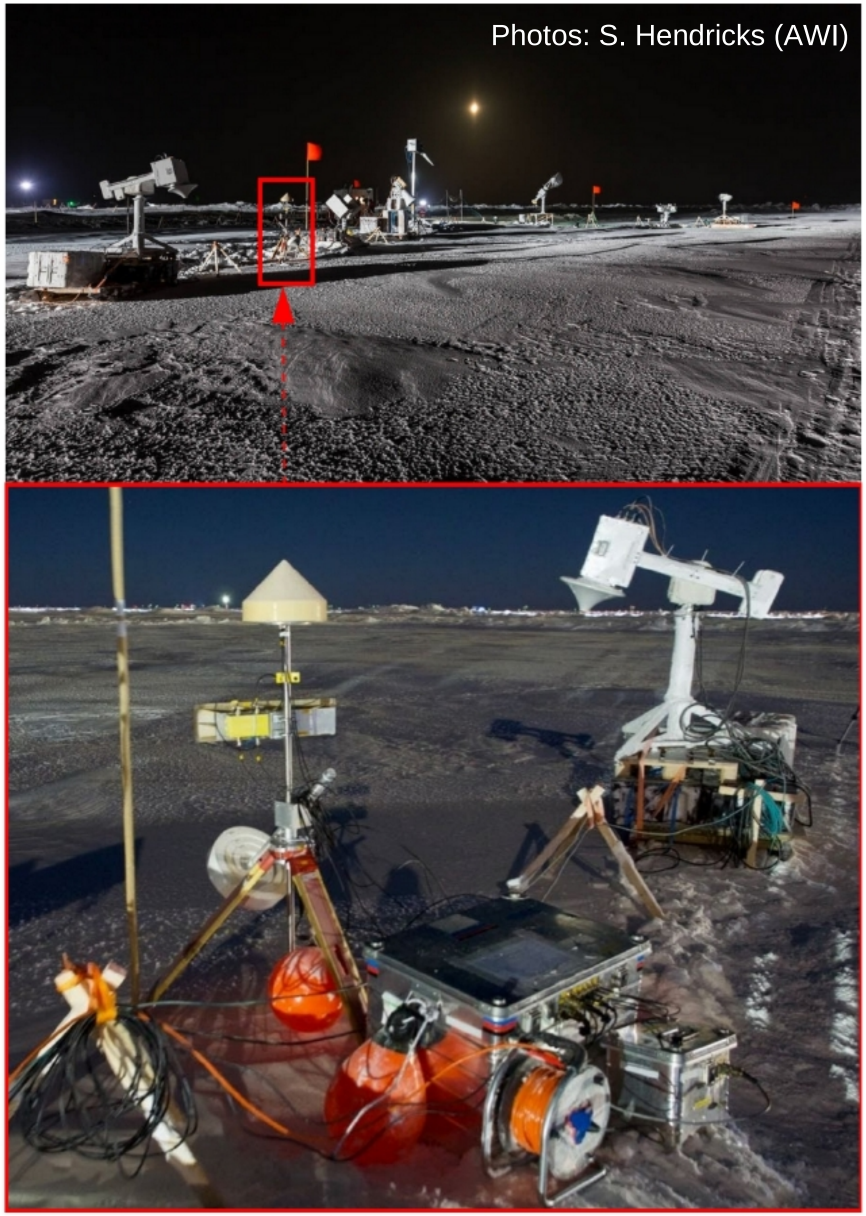
MOSAiC Expedition:

- **MOSAiC: M**ultidisciplinary drifting **O**bservatory for the **S**tudy of **A**rctic **C**limate
- RV Polarstern, **drifted with the sea ice** across the central Arctic for **one year** (September 2019 - October 2020)
- Study of key aspects of the coupled Arctic climate system
- Led by the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI)
- Sensors in a distributed network up to ~50km distance from Polarstern
- Nearby research camps, among others, **ICE camp** (snow and ice measurements) with a **Remote Sensing site**

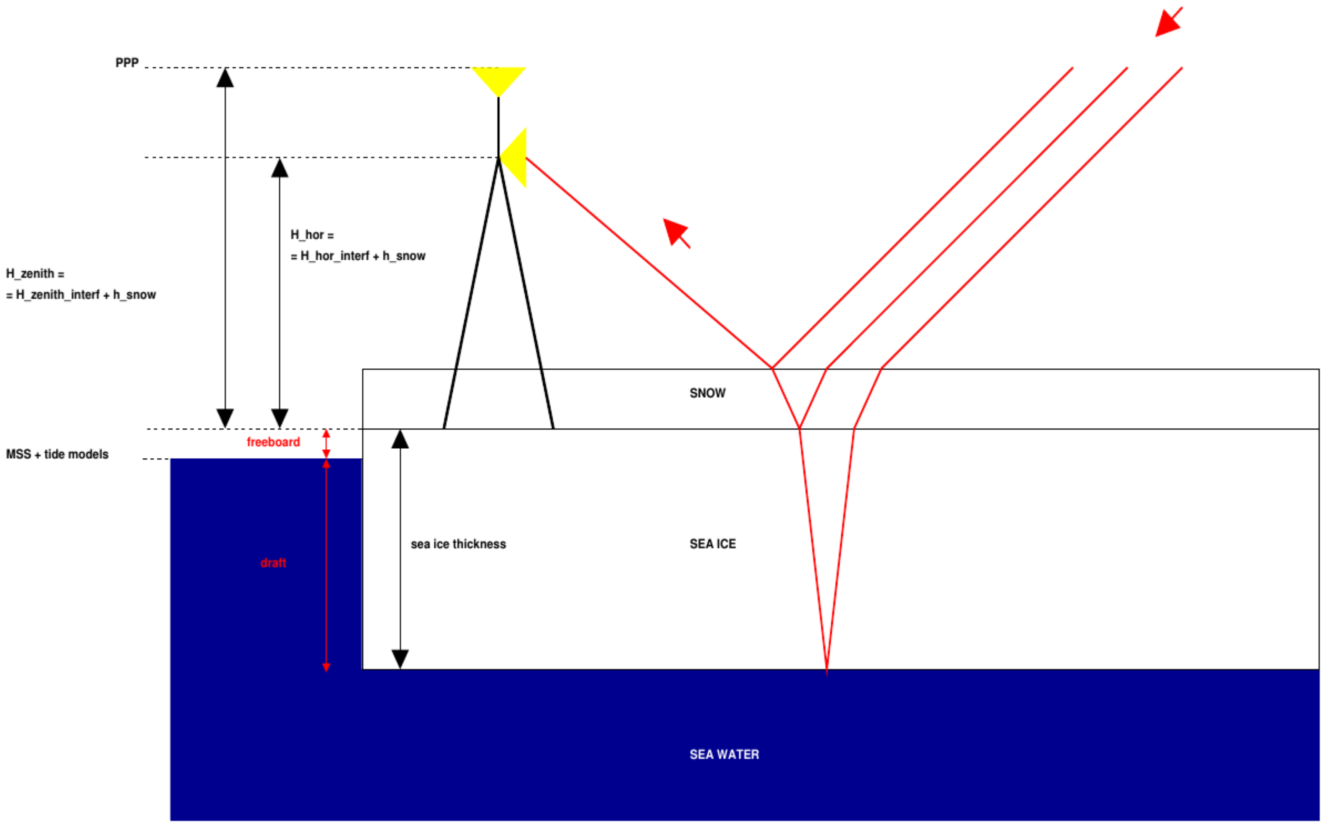
- A system to collect **signals emitted by the navigation satellites** (GNSS) and **reflected off the ice floe** structure was deployed at the Remote Sensing site

- Our GNSS-R system captured, simultaneously, the **H- and V-pol components** of the direct and reflected L1 and L2 frequency bands signals transmitted by the GPS, Galileo, and GLONASS constellations.



To which parameters of the air+snow+ice+water system are GNSS-R signals sensitive?

Scattering process:



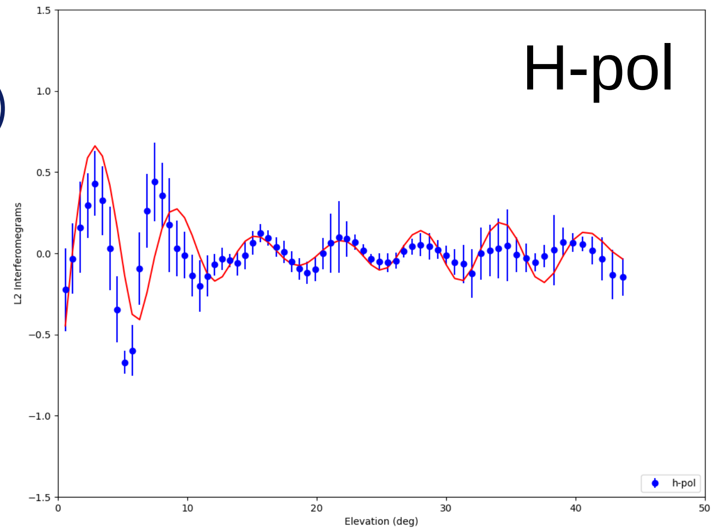
- **Forward scattering** in specular direction
- L-band (~1.5 GHz): **penetration** into snow and ice
- The splitted rays suffer **coherent scattering**
- These rays **interfere** with each other and with the direct line-of-sight signals: Observable Interferogram
- Do interferences depend on **snow and ice thickness and permittivities?**

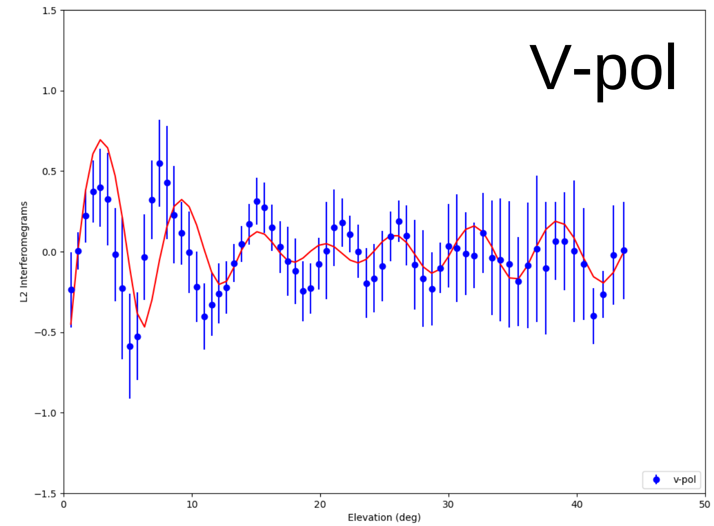
Model & Data:

Institute of Space Sciences

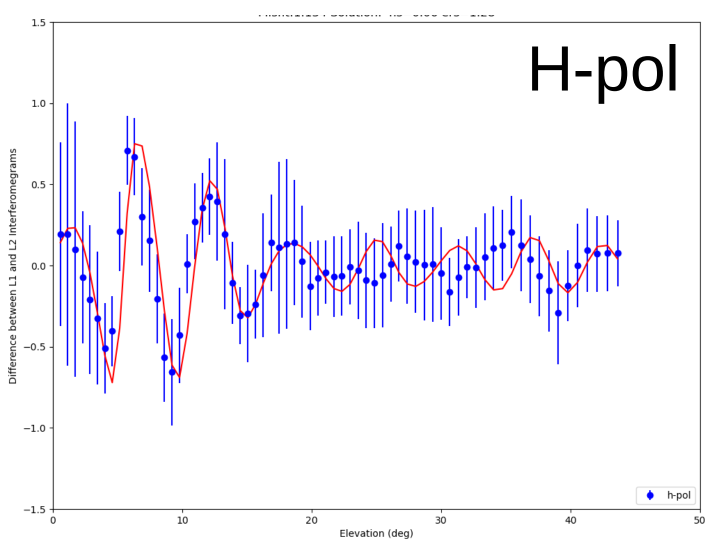
- **Examples for frequency band L2 (top) and L1-L2 interferograms (bottom)**

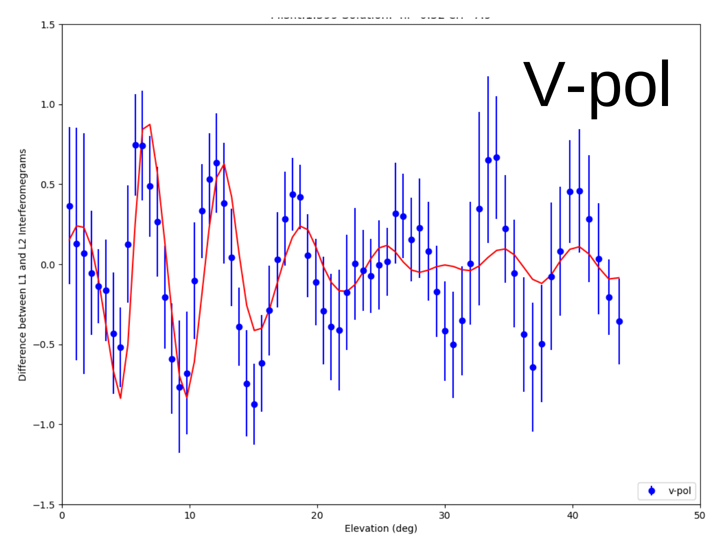
L2 interferogram, 2020-02-03 (blue)
Model (red): 0.1m snow thickness, 1.13 permitt snow, 0.57 m SIT, 3.5 permittivity





L1-L2 interferogram, 2019-11-12 (blue)
Model (red): 6cm snow thickness, 1.28 permitt snow, 0.52 m SIT, 3.21 permittivity





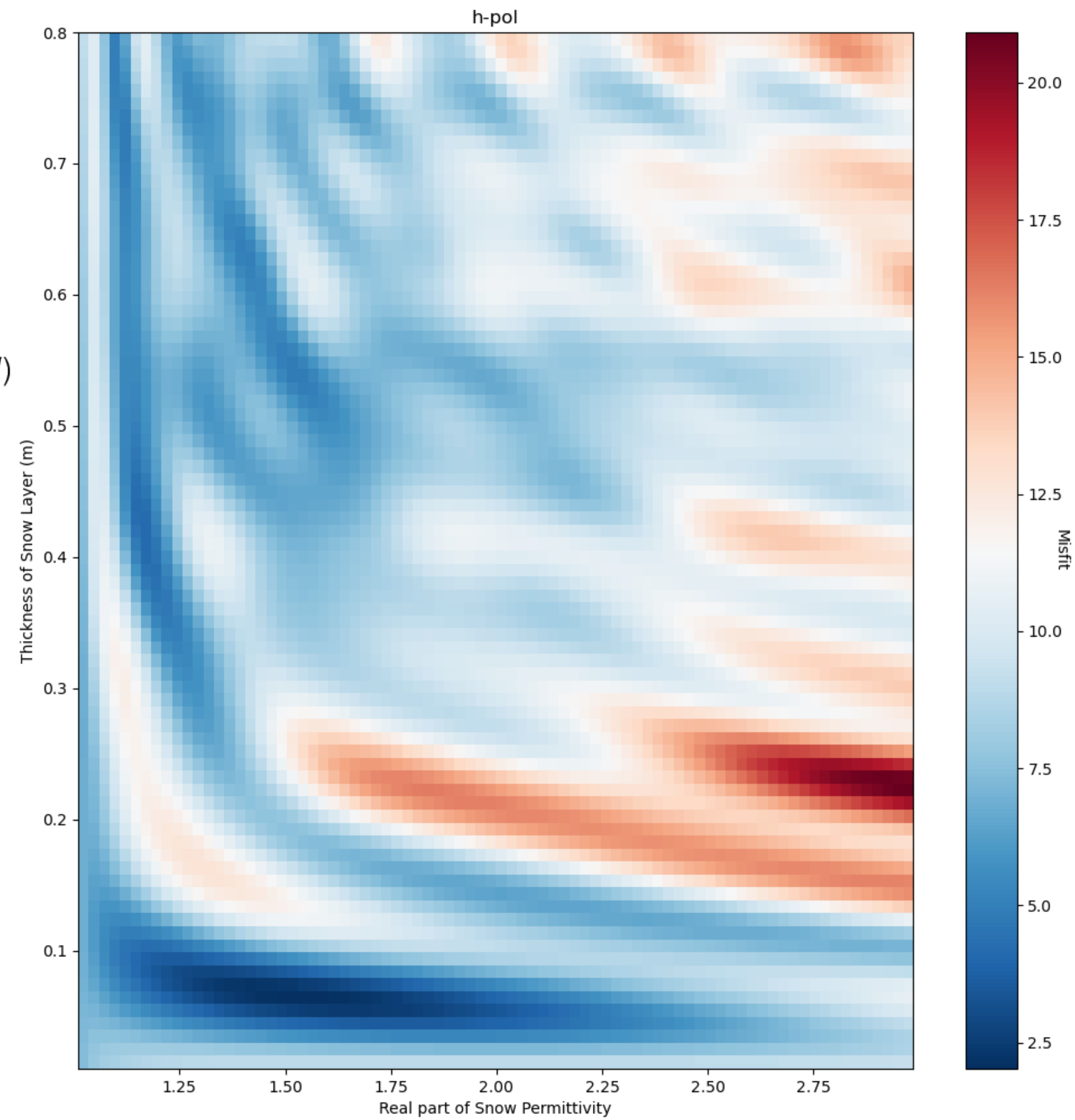
Sensitivity:

- **Metrics to quantify mismatch between observables (obs) and parameterized model (mod(parameters)):**

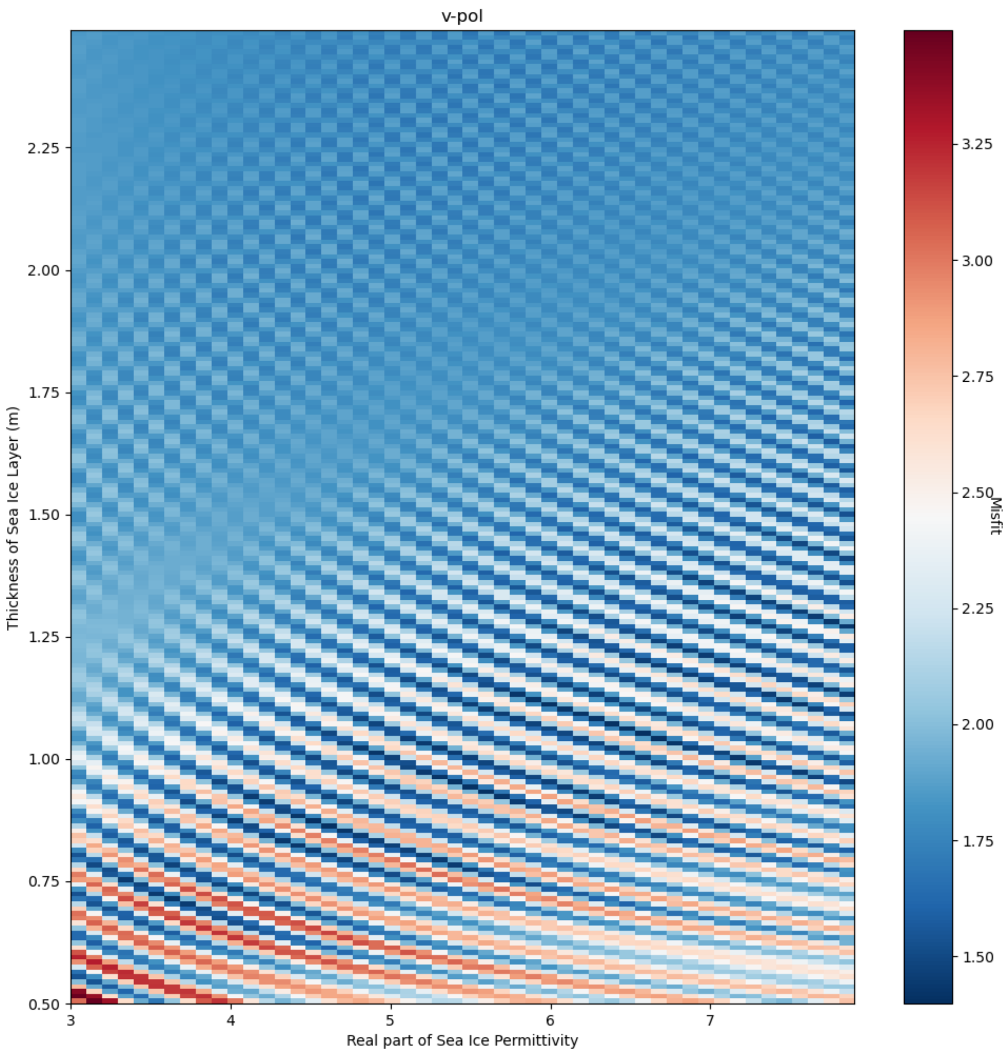
$$Misfit = \vec{r}^T C^{-1} \vec{r} = (\vec{obs} - \vec{mod})^T diag\{\frac{1}{\sigma^2}\}(\vec{obs} - \vec{mod})$$

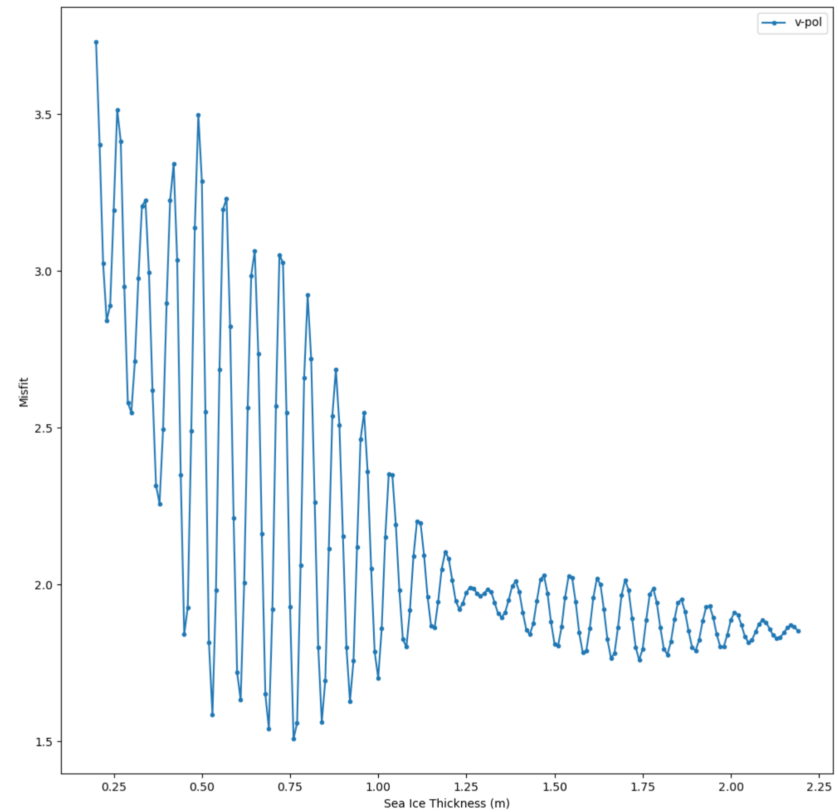
- **Misfit evaluated at different parameters: Misfit(snow & ice parameters)**

- Example: 2019-11-15 H-pol, using L1-L2 together with L2 interferograms as observables



Example: 2019-11-15 V-pol, using L1-L2 together with L2 interferograms as observables



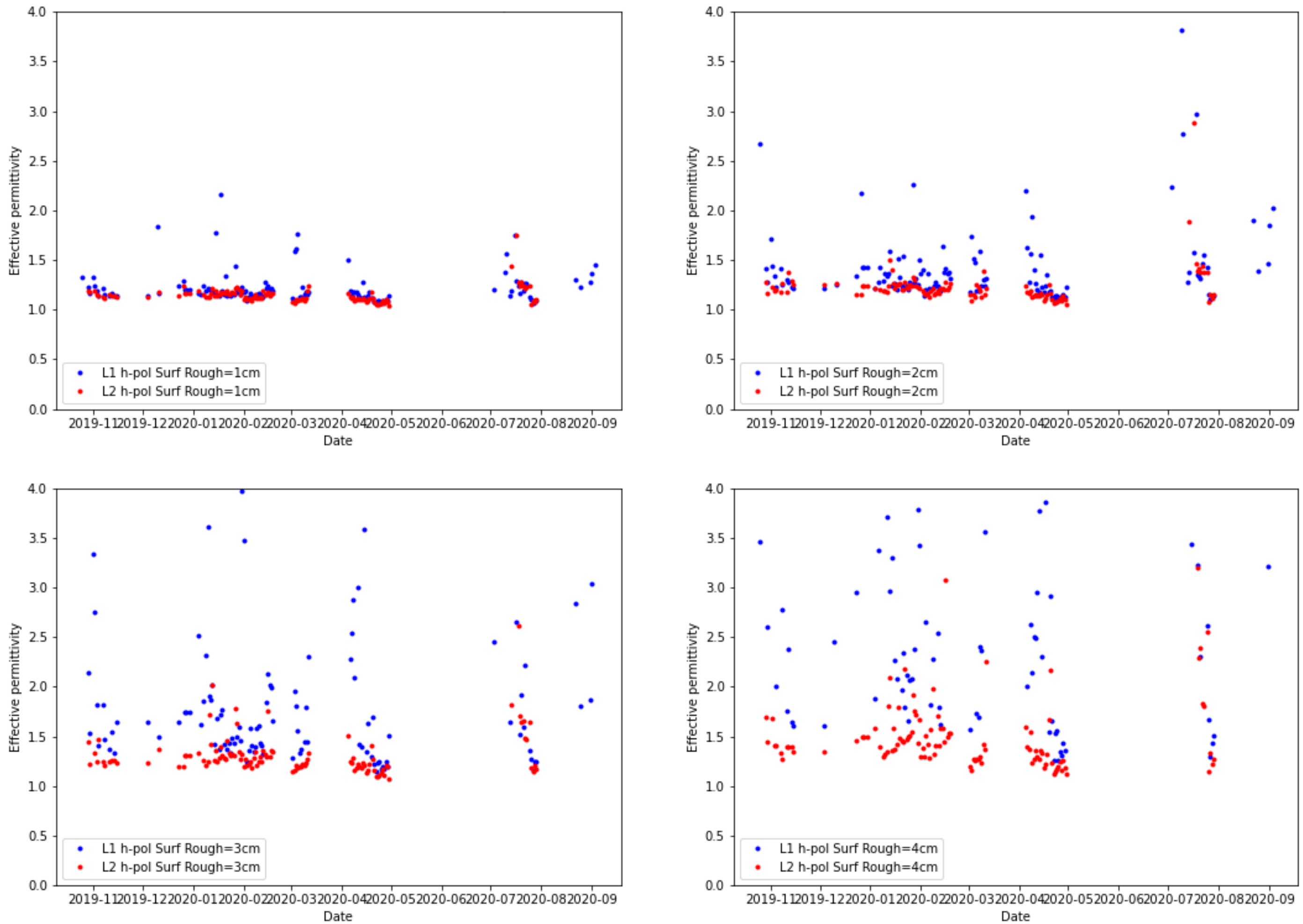


Effective values:

- Overall response of the floe → effective values (e.g., reflectivity of the system rather than each layer) → effective permittivity:

$$Envelope^2_{pol,freq}(\theta) = \Gamma_{pol,freq}(\theta) = |R_{pol}(\theta,\epsilon)|^2 e^{-4k_{freq}\sigma_{rough}\cos(\theta)}$$

- Example: effective permittivity assuming different surface roughness



Discussion:

- A **GNSS-R** equipment with **linearly polarized** antennas was deployed at the Remote Sensing site, ICE camp, of the **MOSAiC expedition**
- The collected EM fields present **interferograms,** compatible with a scattering model of multiple rays reflecting at multiple layers (snow, ice, water).
- The mismatch or misfit function is defined to analyze the sensitivity of the observables to snow and sea ice parameters
  - Sensitivity to **snow thickness and permittivity**
  - Sensitivity to **sea ice thickness and permittivity**, but multiple parameter combinations lead to a good match with the data → ancillary information would help breaking possible ambiguities
- Response of the overall snow+ice structure → effective values