Evaluation of C-Band Freeze-Thaw Retrievals: A Field-Scale Case Study in New Hampshire, USA

Mahsa Moradi (mm1631@usnh.edu)[1], Simon Karaatz[2], Jennifer M. Jacobs[1]

[1] Department of Civil and Environmental Engineering, University of New Hampshire, Durham, NH 03824
[2] USDA-ARS Hydrology and Remote Sensing Laboratory

Background

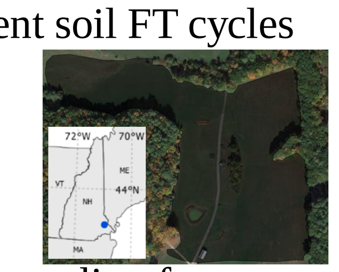
- Soil freeze/thaw (FT) processes play a critical role in crop production due to their impacts on soil nutrient and moisture availability, health of microbial communities and risk of flooding and erosion.
- For agricultural applications, sub-field-scale resolutions are needed to provide actionable information to stakeholders.
- FT detection approaches developed for passive remote sensing are computationally expensive for SAR images with 10s of meters resolution.

Objectives

- Investigate the application of Sentinel-1 SAR images at C-band for field-scale FT mapping
- Compare the performance of three FT detection approaches
- Develop an effective and computationally efficient framework for FT detection using SAR over agricultural landscape

Study Area / Methods

- **Study Area:**
  - University of New Hampshire's Thompson Farm Research Station, situated in southeast New Hampshire, United States (0.83 km^2)
  - Mild winter with shallow, non-persistent snowpack and frequent soil FT cycles



- **FT Detection Approaches:**
  - Seasonal Threshold Approach (STA)
    - Low seasonal scale factor (SSF) ---> Frozen soil
    - Thaw references: based on shoulder season SAR data preceding frozen conditions (instead of summer season)
    - Find an optimal threshold for each individual pixel
  - General Threshold Approach (GTA):
    - Low radar cross section (RCS) ---> Frozen soil
    - Find a single optimal threshold for the entire study area
  - Interferometric Coherence Approach (ICA):
    - Low coherence between two acquisition dates ---> change in soil FT state
    - Find a single optimal threshold for the entire study area
- **Data Processing:**
  - Winters 2019/20, 2020/21 and 2021/22 (1 Sep – 30 April)
  - In-situ air temperature data to determine observed soil state

Alaska Satellite Facility's (ASF) Vertex Interface

Terrain corrected Sentinel-1A images in Interferometric Wide Swath (IW) beam mode and ascending direction

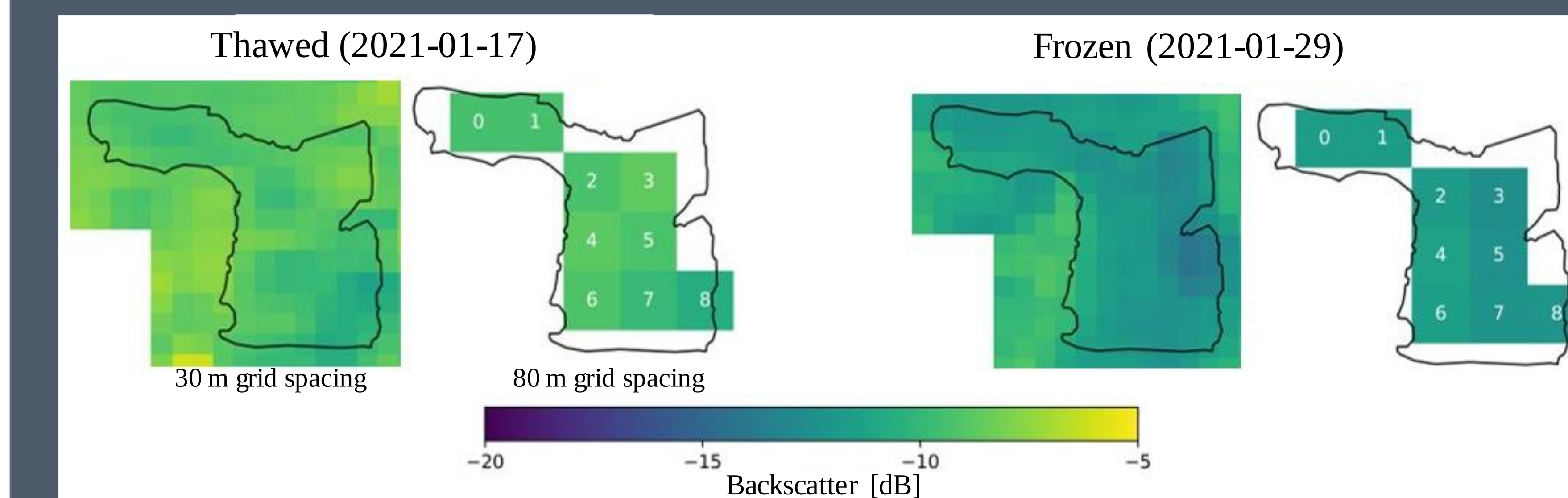
VV and VH polarization (30 m grid spacing)
RCS and Coherence grid alignment
GTA **STA**

Find the optimal threshold with the highest average Cohen's Kappa value using leave-one-out cross validation

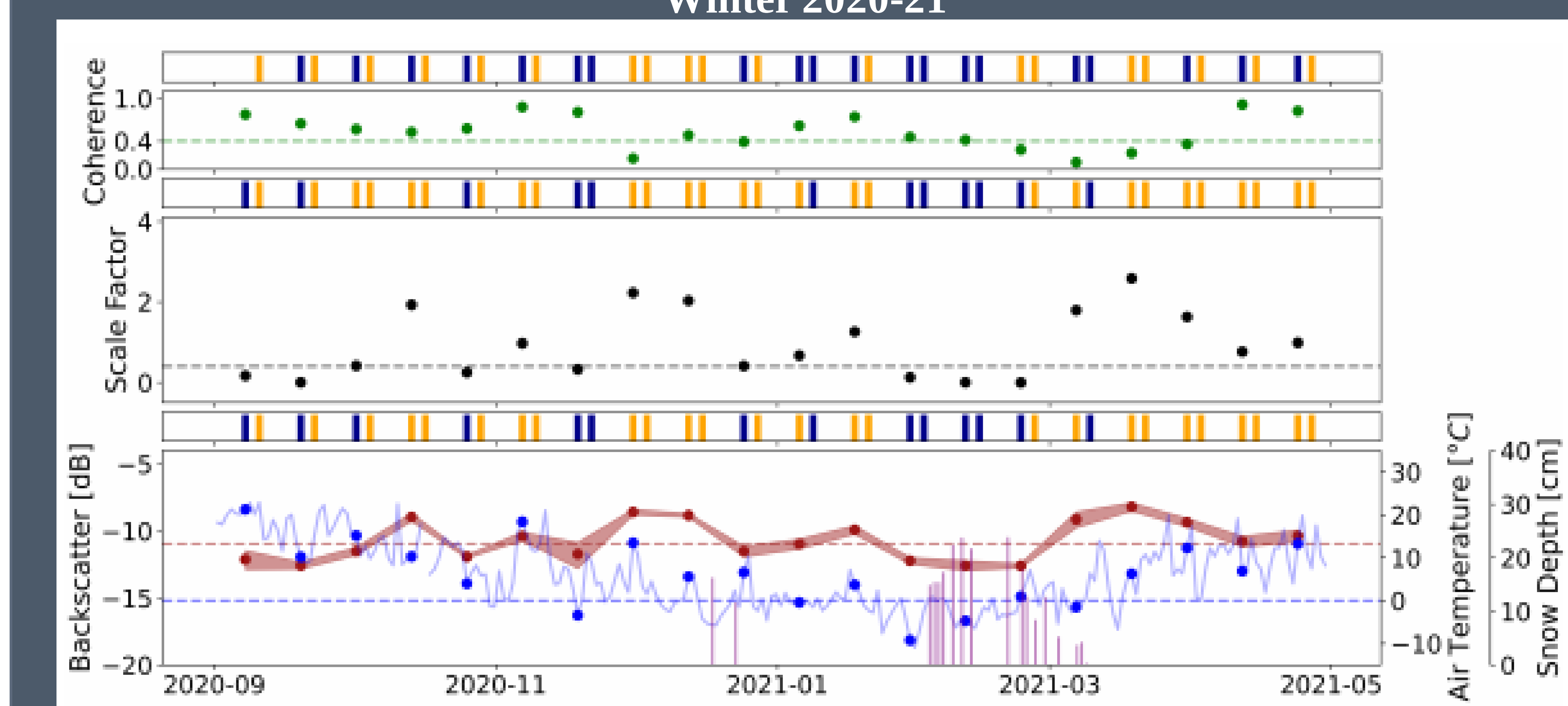
VV polarization (80 m grid spacing)

ICA
- Start from thaw state
- Change soil state when coherence drops below the threshold
- Potential thresholds : [0.3,0.4.0,5]

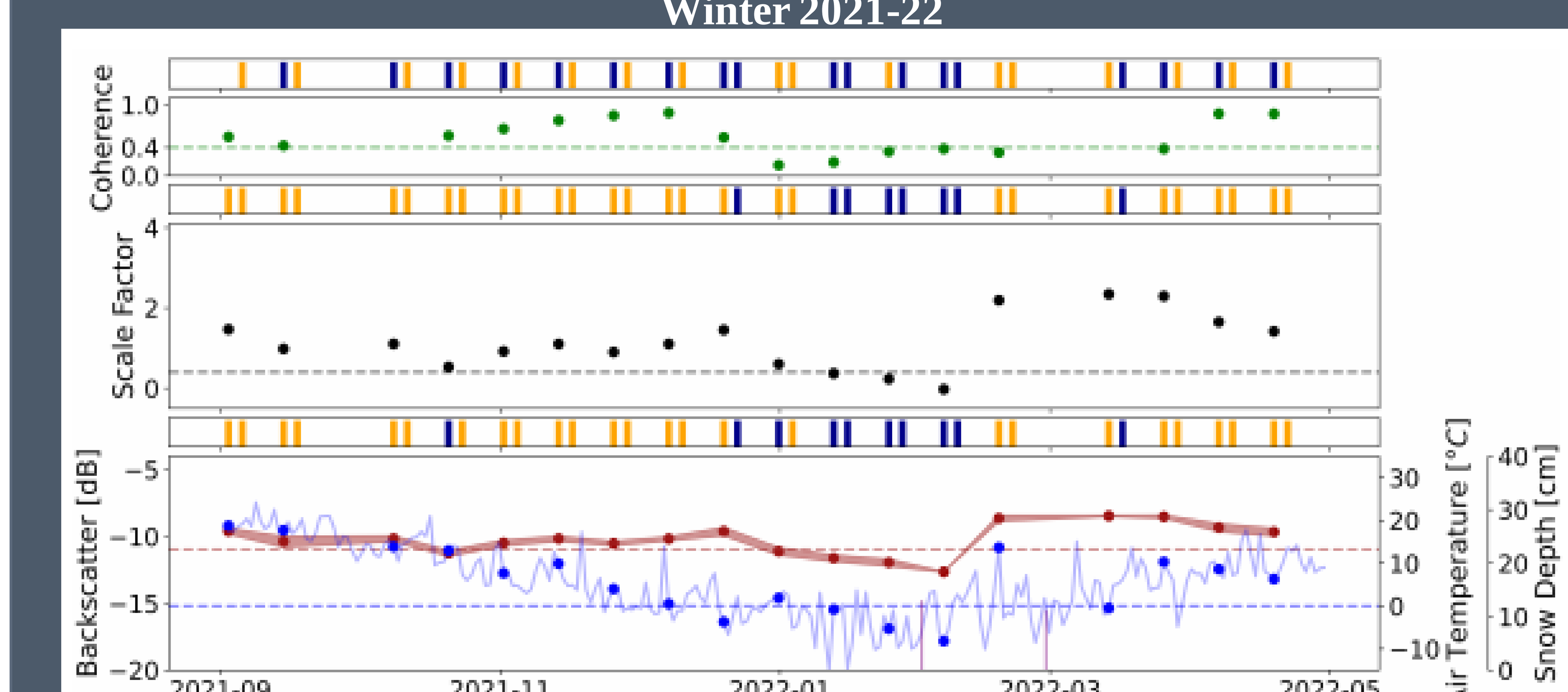
Sentinel-1 C-band SAR images can retrieve soil FT state over agricultural landscapes using STA and GTA approaches with approximately 80% overall accuracy.



Winter 2020-21



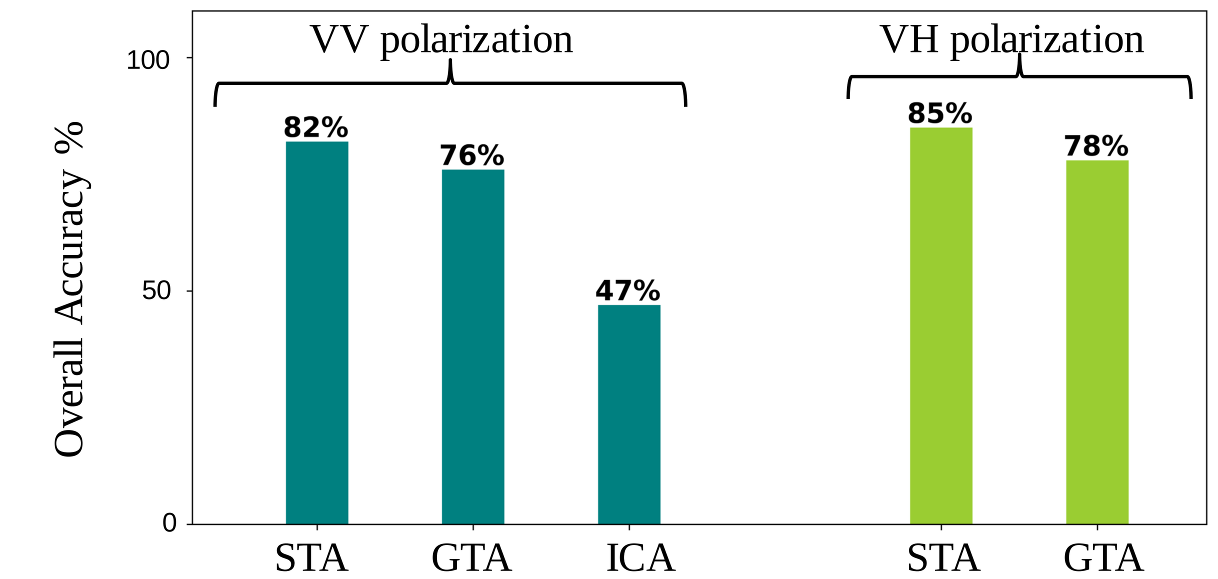
Winter 2021-22



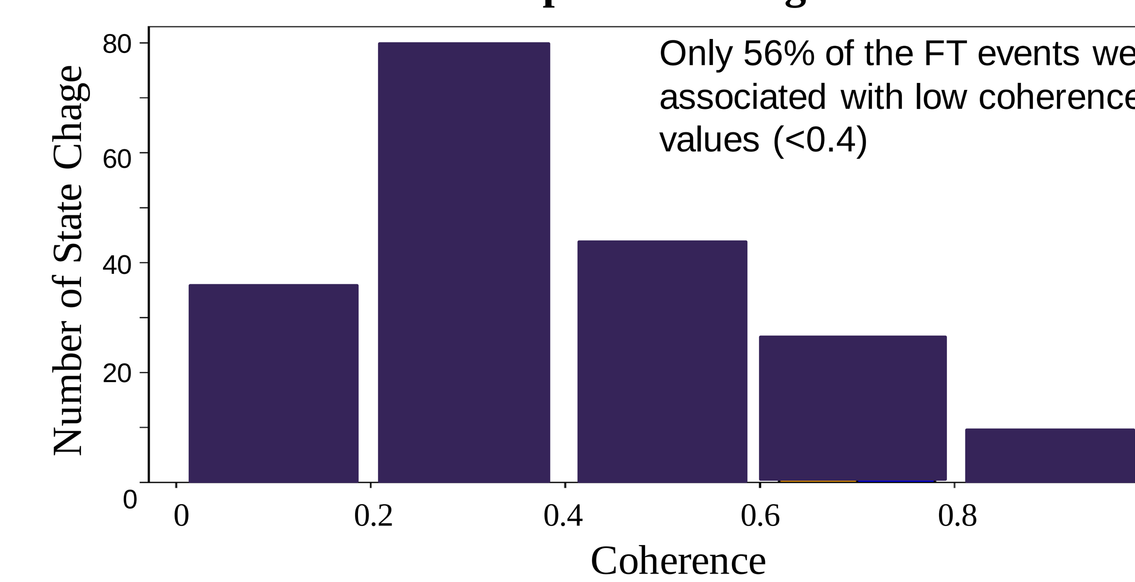
Time series of VV polarized SAR backscatter (red dots) and coherence (green dots), along with air temperature (blue line, blue dots) and snow depth (purple vertical lines) at pixel #7. The yellow and blue vertical lines represent the thaw and freeze state, respectively. At each acquisition date, the first vertical line shows the retrieved FT state while the second line shows observed FT state.

Results

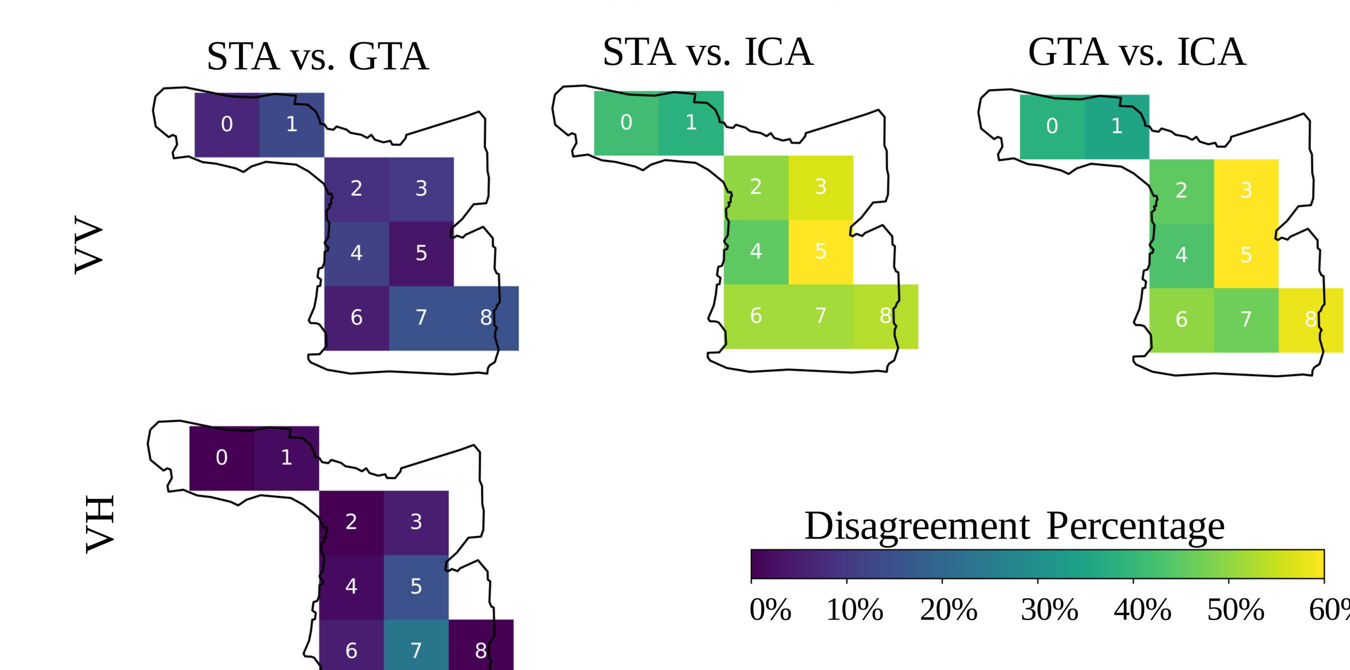
How did the three FT detection approaches perform?



How did the coherence values correspond to changes in soil state?



How did the three FT detection approaches agree on the retrieved soil FT state?



Conclusion

- **GTA** and **STA** performances were **comparable** (with approximately **6% difference** in the overall accuracy for both polarizations).
- **GTA** requires **less computational steps** which makes it a **more suitable** approach for FT detection across large study domains.
- Our analysis did not support a consistent relationship between interferometric coherence and soil FT states.

Acknowledgement

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