

## RC1, Anonymous Referee #1

Accurate SWE estimate from satellite is critical for hydrological and climate modelling. InSAR SWE estimation technique as the potential to offer SWE at the required resolution (spatially and temporally) but further investigation is necessary. This works offer insight on the challenges of this technique using C-band data from Sentinel-1. Similar to the work in (Oveisgharan et al. 2024) Lidar and Snotel sites are used to evaluate the retrieval at several sites in the Western US. The paper would benefit from clearly stating what is the difference between this previous work. At first glance, it looks similar even though the analysis goes further in the parameter affecting the temporal coherence.

- We would like to thank the reviewer for great feedback. We address all of the concerns below. As seen below, we tried to distinguish and highlight the contribution of this work better.

I think focus on the soil background is missing on the analysis on the temporal coherence. It seems that the C-band decorrelation would highly be link to changes in the soil background (Tampuu et al. 2020, Ouaadi et al. 2024) since the soil is probably not frozen. A 6-days revisit seems to also be crucial in coherency (Ouaadi et al. 2024). This not good for NISAR since the revisit is 12 days. However, L-band seems to be less sensitive to decorrelation from the ground, and a 12-day revisit is probably fine. I suggest discussing this because someone could easily conclude that this method won't be successful with NISAR because of the revisit time.

- Thank you for bringing up these concerns. We discuss about the 6-day vs 12-day for NISAR as you can see below in your last note. We added this to the paper to address your concern: “In contrast, longer wavelengths such as L-band are intrinsically less sensitive to small-scale scattering changes and therefore maintain higher temporal coherence over longer revisit intervals. As a result, missions such as NISAR are expected to enable robust SWE retrieval despite a 12-day repeat cycle, while also benefiting from reduced phase ambiguity.”
- However, soil moisture's impact should be minimal. When snow is wet the microwave signal barely penetrates all the way to the ground. Therefore, most of the decorrelation should come from wet snow itself. We added this to the text to mention that soil permittivity change due to soil moisture also impacts temporal coherence but since there has been no indication of such in the snow accumulation season in the literature, we leave that discussion out. “In practice, however, temporal variations in scatterers—such as freeze/thaw, soil permittivity change, the movement of leaves, branches, or snow particles, reduce this correlation, leading to temporal decorrelation (Zebker and Villasenor, 1992; Kellndorfer et al., 2022; Lavalley et al., 2012; Tampuu et al., 2020; Ouaadi et al., 2024).”

Specific comments:

L11: The main driver is temporal coherence followed by temperature, wetness... Those factors affect the coherence as well. So it's still the same driver? Maybe rephrase.

- They impact coherence too but not in the same way. So, we first mentioned the parameters impacting retrieval and then the ones impacting temporal coherence. I added this sentence to make it clearer “*The influence of these parameters on temporal coherence is only partially consistent with their effect on SWE retrieval performance.*”

L22: “shifting snow accumulation toward higher”. Is it really shifting the accumulation or just lowering accumulation down south?

- As stated in Klos et al. “As demonstrated through the mapped temperature-precipitation phase relationship across the western U.S., the climatic rain-snow transition zone will move up in altitude and latitude. The western U.S. is projected to see an average monthly reduction from ~53% to ~24% in the extent of the land area within a wintertime snowfall regime”. Therefore, it seems that these regions are shifting.

L25: Suggest modified to “if the snowpack completely melts”

- Done

L31: I think the resolution of GlobSnow is still 25km.

- I changed it to “(tens of km)” to include the improvement reported in Kelly 2009 paper using AMSR-E data with 10km resolution.

L48: If the ratio picks up volume scattering, an incoherent process... then this would contribute to losing coherency faster at C-band than L-band due to volume scattering. I don’t think it’s the case, but I think it needs to be mentioned at some point.

- We think this method needs more validation. Therefore, we just mentioned some studies evaluating it. Getting into details of this method and what we think should impact it is beyond the scope of this paper.

L55: I would specify microstructure here. Stratigraphy (permittivity changes) is also “layering” which is what you want here.

- We changed it to: “key advantage of the interferometric approach is that SWE retrieval is largely insensitive to snowpack stratigraphy, permittivity changes, and layering (Yueh et al., 2017), and does not require prior knowledge of snow micro-structural properties.”

L60: How is this different than Oveisgharan et al., 2024? Stating the difference here would be nice because it looks really similar at first.

- Very fair point, I address this in several places in the paper to make it clear the main contribution of the paper
  - In the abstract we added: “While previous work demonstrated the feasibility of SWE retrieval using Sentinel-1 interferometry over limited sites, this study provides a systematic, multi-site evaluation across diverse snow and land-cover conditions to identify the key factors controlling retrieval performance.”

- At the end of introduction “While (Oveisgharan et al., 2024) established the feasibility of SWE retrieval using Sentinel-1 interferometry and demonstrated its performance over a limited number of sites, this study extends that work by providing a systematic, multi-site evaluation across diverse snow and land-cover conditions. In particular, we investigate the environmental and geophysical factors controlling retrieval performance, including temporal coherence, temperature, vegetation, and terrain, and validate the approach using a significantly larger set of LIDAR and in situ observations. This analysis provides new insight into where and under what conditions InSAR-based SWE retrieval is reliable, moving beyond proof-of-concept toward broader applicability. The methodology developed here is also directly applicable to the recently launched L- and S-band NASA–ISRO’s NISAR mission.”
- At the end of section 2 (before 2.1): “The main contributions of this study are: (1) a comprehensive multi-site validation of InSAR-based SWE retrieval using an expanded set of LIDAR and in situ observations, (2) a systematic analysis of environmental and geophysical factors controlling retrieval performance, and (3) identification of the conditions under which reliable SWE retrieval is achievable using C-band SAR data.”
- Beginning of section 4: “Unlike (Oveisgharan et al., 2024), which focused on demonstrating the feasibility of SWE retrieval using Sentinel-1 interferometry over a limited number of sites, this section evaluates retrieval performance across a broader range of snow conditions and land-cover types to identify the key factors controlling retrieval accuracy.”
- Beginning of section 5: “While previous work (Oveisgharan et al., 2024) established the capability of InSAR to retrieve SWE, it did not systematically assess the environmental and geophysical controls on retrieval performance. Here, we extend that work by analyzing how factors such as temporal coherence, temperature, vegetation, and terrain influence retrieval accuracy across multiple sites.”
- At the beginning of section 5.1: “This analysis builds on the limited LIDAR validation presented in (Oveisgharan et al., 2024) by incorporating a larger number of LIDAR scenes across diverse environments, enabling a more comprehensive assessment of retrieval performance and its controlling factors.”
- At the beginning of section 5.2: “In contrast to the site-specific validation in (Oveisgharan et al., 2024), this section leverages multi-site SNOTEL time series to investigate how environmental variability affects SWE retrieval performance and temporal coherence.”
- End of the section 5: “This study moves beyond demonstrating the feasibility of InSAR-based SWE retrieval by providing a systematic evaluation of its performance across varying environmental conditions. The results identify the dominant controls on retrieval accuracy and define the conditions under which the method is reliable, which are critical steps toward operational SWE monitoring using current and future SAR missions.”
- At the beginning of the conclusion section: “While previous work demonstrated the feasibility of SWE retrieval using Sentinel-1 interferometry, this study provides the first comprehensive, multi-site evaluation of retrieval performance and its controlling factors. By quantifying the roles of temporal coherence, temperature, vegetation, and terrain, we establish the conditions under which InSAR-based SWE retrieval is reliable, representing a key step toward large-scale and operational applications. These results also provide a foundation for quality assurance (QA) in future SWE

products by identifying the key parameters that control retrieval reliability and uncertainty.”

L72: True at C-band and L-band. I would be precise here

- Done: “For terrestrial snow, the contribution of volume scattering to the interferometric phase is minimal compared to the strong ground return at high radar frequencies such as C- and L-band.”

L76: Suggest changing “dual-polarization dual-frequency retrieval approaches” to “intensity based-approaches”

- Done

L124: freeze/thaw or soil permittivity change of the ground could change the backscatter response.

- I added this: “In practice, however, temporal variations in scatterers—such as freeze/thaw, soil permittivity change, the movement of leaves, branches, or snow particles, reduce this correlation, leading to temporal decorrelation (Zebker and Villasenor, 1992; KelIndorfer et al., 2022; Lavallo et al., 2012; Tampuu et al., 2020; Ouaadi et al., 2024).”

L129: Can you explain why?

- I added this to explain why: “This is because higher frequencies (shorter wavelengths) are more sensitive to small-scale variations in the scattering medium, such as snow microstructure and vegetation elements. These small scatterers introduce phase variations within a resolution cell that change between acquisitions, leading to increased decorrelation.”

L135: Would be nice to mention quickly how temporal coherence is calculated even if its just a reference.

- We added this to the beginning of section 2.2: “The correlation between two signals is computed as the normalized cross-correlation of two complex SAR images (Oveisgharan and Zebker, 2007).”

L163: Are comparing the depth for lidar and InSAR at every 5m for each site?

- Good point, we added this: “To enable direct comparison with Sentinel-1–derived SWE, the LIDAR data were resampled to 80 m resolution.”

Figure 10: It seems like soil moisture content would highly impact the temporal coherence at C-band. This effect seems to be less of a problem at L-band.

- We added this to the paper to address your concern: “While soil moisture can influence temporal coherence, its impact is expected to be limited during the snow season, as the ground is typically frozen under dry-snow conditions. In situations where the ground is not frozen, the snowpack is likely to be wet, violating the assumptions required for InSAR-based

SWE retrieval. Therefore, the effect of soil moisture on temporal coherence is considered negligible for the dry-snow conditions analyzed in this study.”

L357: “increase particle motion” Do you mean water percolation?

- We meant snow particle motions. When the snow becomes wet, snow particles start to move or slide. We add “increase snow particle motion”.

L374: NISAR is a 12-day repeat cycle, and you just said its bad for coherence...

- We added this to the paper to address your concern: “In contrast, longer wavelengths such as L-band are intrinsically less sensitive to small-scale scattering changes and therefore maintain higher temporal coherence over longer revisit intervals. As a result, missions such as NISAR are expected to enable robust SWE retrieval despite a 12-day repeat cycle, while also benefiting from reduced phase ambiguity.”

#### Reference

Oveisgharan, S., Zinke, R., Hoppinen, Z. and, Marshall, H. P. Snow water equivalent retrieval over Idaho– Part 1: Using Sentinel-1 repeat-pass interferometry. *The Cryosphere*, <https://doi.org/10.5194/tc-18-559-2024>

Tampuu, T., Praks, J., Uiboupin, R., & Kull, A. (2020). Long Term Interferometric Temporal Coherence and DInSAR Phase in Northern Peatlands. *Remote Sensing*, 12(10), 1566. <https://doi.org/10.3390/rs12101566>

Nadia Ouaadi, Lionel Jarlan, Ludovic Villard, Adnane Chakir, Saïd Khabba, Pascal Fanise, Mohamed Kasbani, Zoubair Rafi, Valerie Le Dantec, Jamal Ezzahar, Pierre-Louis Frison. Temporal decorrelation of C-band radar data over wheat in a semi-arid area using sub-daily tower-based observations, *Remote Sensing of Environment*, Volume 304, 2024, <https://doi.org/10.1016/j.rse.2024.114059>