

The manuscript titled “Evolution of L-band SAR Response for Soil Freeze/Thaw Monitoring: A Case Study Over Snow-Covered Canadian Mid-latitude Agricultural Region” presents an application of L-band SAR observations for FT mapping. While the topic is relevant and potentially valuable, I believe the manuscript requires substantial revision to improve its overall presentation, organization, consistency, and clarity. A primary concern is that several statements and interpretations are presented without sufficient supporting evidence or analysis, which makes some conclusions difficult to evaluate. In addition, the Introduction should be strengthened to more clearly establish the scientific motivation, knowledge gap, and specific objectives of the study. The overall flow of the manuscript also needs considerable improvement. In several sections, the text shifts repeatedly between background information, methodology, results, and interpretation, making it difficult for the reader to follow the progression of the study and its main findings. Reorganizing some of the content and moving details to more appropriate sections would greatly improve readability and coherence. Also, several figures and captions require improvement in terms of clarity, readability, and presentation quality. Other main comments are:

- Observations from the 2023–2024 season are repeatedly discussed throughout the manuscript; however, the corresponding results are not shown. This makes it difficult to evaluate the interpretations and conclusions associated with that season.
- The use of the term “dry snow” is very questionable, as no observations or analyses are presented to support the snow wetness classification. Please see my detailed comments below
- Several figure numbers are incorrectly referenced throughout the manuscript.

Please see the detailed comments below, which further outline these major concerns and provide specific suggestions for revision.

1. “Microwave remote sensing, both passive and active, has been applied for this purpose (Bateni et al., 2015; Prince et al., 2019; Rowlandson et al., 2018; Cohen et al., 2021).” Consider including more recent studies to better reflect the current state of the literature.
2. The schematic presented in Figure 1 is overly simplified, particularly for the higher microwave frequencies. It does not represent scattering processes occurring within the snowpack itself. Including these interactions would improve the physical realism and clarity.
3. The phrase “dense time series of L-band airborne polarimetric” is vague
4. The Introduction provides a good background of microwave remote sensing of soil FT processes. However, the current narrative does not sufficiently establish the scientific gaps, motivation, or the specific questions the study aims to address. At present, the objectives read more as methodology or analysis oriented tasks rather than clearly defined scientific objectives or hypotheses. The repeated use of the terms “high” and “low” is ambiguous. Please clarify these definitions and their scientific relevance. The scientific purpose of the study should be articulated more clearly, and vague terminology should be reduced throughout the Introduction and objectives. It would also help to more explicitly state the central goal of the study.

5. The Introduction also largely overlooks the role of C-band microwave observations in FT mapping. Providing this context would help better justify the scientific need for the present study and clarify how it addresses existing gaps in FT monitoring.
6. Figure 2: Please indicate on the map the locations corresponding to panels (c)–(e). Adding these locations would improve figure clarity and help readers better understand the spatial context of the site photographs/views.
7. The first few sentences of Section 2.1 appear to fit more appropriately in Section 2.2. Moving this material may improve the organization and overall flow of the manuscript.
8. Line 135: Please specify the distance between the two sensors.
9. Figure 5: The caption states that “the bottom plot presents snow temperature measured at three heights just above the ground surface, highlighting the evolution of snowpack temperatures as the snow depth varied throughout the observation period.” However, for example, in mid-January around the time of the first flight, the reported snow depth is approximately 20 cm while a temperature measurement at 25 cm above the ground is still shown as snow temperature. Please either revise the time series to account for periods when the probe was likely not in contact with the snowpack, or clarify in the caption that these measurements do not necessarily represent snow temperatures throughout the entire observation period.
10. Figure 5 (and, more generally, all figures): Please consider using a color-blind-friendly color palette. The current use of red and green together is difficult to distinguish for some readers and reduce figure accessibility.
11. Figure 6: The figure quality and resolution need to be improved. In its current form, it is difficult to distinguish between the temperature time series from Sensors 1 and 2.
12. Figure 6: It would be helpful to include an additional panel showing the variability in temperature across the different sites. For example, an envelope representing the minimum and maximum temperatures among the stations at each time step could provide a clearer view of the spatial variability and its evolution over time.
13. Figure 6: Please clarify in the caption what the red and gray shaded regions represent.
14. Line 250: More detail is needed regarding the permittivity criterion. For example, was a range of threshold values tested, and was any validation performed to support the selected threshold? In addition, the statement “This approach reduced false detections caused by temperature sensor noise or permittivity variability” requires supporting evidence or analysis.
15. Lines 253–254: Please consider adding these site characteristics (e.g., vegetation type, grazing condition/stage, elevation, etc.) to Table 1. In particular, elevation information does not currently appear anywhere in Section 2.1.
16. Lines 256–257 appear to fit better within the methodology section, preferably near Table 1 where the monitoring stations are introduced and described.
17. Instead of numbering the stations in Figure 2, consider using the original station names to provide more context for the reader and make it easier to distinguish differences among

the sites. This would also improve consistency, as the stations are referred to by their original names throughout the text. At minimum, please ensure a consistent naming convention is used across the manuscript (e.g., original names in both text and figures, or numbering consistently throughout).

18. “Missing soil temperature values were filled using Inverse Distance Weighting (IDW), with available measurements from other stations at the same timestamp weighted by the inverse square of their geographic distance, ensuring temporal continuity for analysis.” Consider moving this description to the methodology section, as it describes a data processing procedure.
19. Consider summarizing some of the detailed descriptions in Lines 265–285 using visualizations or summary tables. For example, precipitation could be added to Figure 6 as an additional axis with color coding by precipitation type, while the number and timing of freeze–thaw events could be summarized in a table. This would improve readability and make the temporal patterns easier to interpret.
20. “Cross-polarized channels showed less consistent variation, underscoring VV’s sensitivity to dielectric changes.” Please provide supporting evidence or a direct reference to the corresponding analysis/figure that supports this statement.
21. Section 3.2: The first paragraph reads more as background information or discussion rather than presentation of results. The Results section should focus more directly on the findings of the study, with clear reference to the supporting analyses, figures, or observations.
22. Figures 7, 9, 10, and 13: Please consider using a more conventional and readable date format for the panel titles. In addition, while the station locations are outlined with red boundaries, it would be helpful to label the stations directly on the figures, particularly since they are discussed in detail in Lines 315–320.
23. Figure 7: Consider using a color palette
24. Lines 300–310: Time series from the 2023–2024 winter season are needed to support and contextualize the discussion of the 12 January 2024 observations. This becomes particularly important later when the authors state that “The winter of 2023–24 displayed unique characteristics compared to typical mid-latitude Canadian winters. November 2023 did not experience persistent cold conditions, resulting in an unusually high backscatter response, which confirmed that soil remained unfrozen.” Without showing the corresponding time series, it is difficult for the reader to evaluate and interpret the results for this season.
25. “In contrast, 1 March 2024 exhibited a high backscatter response, coinciding with thaw conditions, an increase in 2 m air temperature, and higher soil permittivity across all stations (Fig. 6).” Please verify the year in this statement. Should this refer to 1 March 2023 or 1 March 2024?
26. “These examples illustrate how VV backscatter distinctly separates frozen from thawed soil states, even under dry snow cover.” The use of the term “dry snow cover” needs

further clarification. For example, Figure 6 shows snow temperatures near 0°C for several consecutive days around 1 March 2023, which could indicate an isothermal and potentially melting snowpack rather than dry-snow conditions. Please clarify what is meant by “dry snow” in this context and, more importantly, describe the criteria used in this study to classify snow as dry versus wet.

27. Line 310: Some of the discussed dates appear to correspond to periods when the snowpack may have been at or near the melting stage. Therefore, the use of the term “dry snow” is questionable in this context, particularly when attributing changes in backscatter primarily to soil freeze–thaw conditions. Additional evidence or clearer justification is needed to separate the influence of snowpack wetness from soil-state effects on the radar response.
28. Line 314: Please clarify what is meant by “within soil moisture regions of interest.” The terminology is currently unclear
29. Line 317: I am not entirely sure how Figure 7 supports the stated finding.
30. Figure 8: Since the backscatter measurements represent discrete observations, it would be more appropriate to display them as scatter points rather than as continuous lines.
31. Section 3.3: Similar to Section 3.2, the distinction between background/discussion and presentation of results is not always clear.
32. Line 33: It would be helpful to clarify what the authors mean by “high” and “low” responses. Relative to what reference or baseline are these terms defined?
33. Line 333: Figure 9?
34. Figure 9 and all similar figures: Please add the monitoring stations to the maps and label them with their station names.
35. Figures 9–10: The color bars are missing units.
36. Line 420: Could you clarify whether any analysis was performed to attribute the observed errors to soil moisture or surface roughness effects? Please provide the supporting evidence for this statement. If this interpretation is only a hypothesis, it should be clearly stated as such and would be more appropriately placed in the Discussion section rather than the Results section.
37. Line 430: The use of the term “homogeneous” to describe the study region appears inconsistent with earlier sections of the manuscript, where spatial variability in soil moisture, surface roughness, elevation, and other site characteristics is discussed. Please clarify what is meant by “homogeneous” in this context and specify which properties or spatial scales this description refers to.