Response to Reviewer 1:

Thank you for your valuable comments, we will work to incorporate them to improve our revised manuscript.

Line 27-28: The reason why this is the case should be clarified to the reader. How does a decline in manual meteorological observations pose a challenge to LIT retrieval?

We thank the reviewer for pointing out the need to clarify the connection between the decline in manual meteorological observations and challenges in LIT retrieval. We will revise the sentence to explicitly explain that reduced meteorological observation networks limit the availability of forcing data required for ice growth models and decrease the availability of in situ observations for retrieval validation. The revised sentence now reads:

"The decline in manual meteorological observation networks is posing increasing challenges to LIT retrieval by limiting the availability of meteorological forcing data required for ice growth models and reducing in situ observations needed for retrieval validation (Vincent et al., 2012)."

Line 28-30: This is not necessarily true. LIT is difficult to retrieve using remote sensing technologies and only recently through altimetry (Beckers et al, 2017; Mangilli et al., 2022; 2024) have methods developed closer to operational algorithms. Arguably early work on bedfast ice using SAR reveals information on approximate thickness but not true quantitative retrievals. It would be truer to state that there is an interest in the use of remote sensing technologies as a solution to the current issues with monitoring LIT. To amend this a note stating the large body of work using InSAR would be good. The decision to cite Duguay et al., 2015, instead of a list of key papers from the use of InSAR (Lines 65-82) could reinforce this statement.

We thank the reviewer for this valuable clarification. We agree that the previous statement overstated the current capability and operational maturity of remote sensing-based LIT retrieval. We will revise the sentence to clarify that remote sensing technologies represent an emerging solution to overcome limitations associated with declining ground-based monitoring networks, rather than the dominant approach for quantitative LIT retrieval. We will also expand the discussion to acknowledge previous InSAR-based studies and recent advances in satellite altimetry approaches for LIT retrieval. We will revise line 28-30 as below:

As a result, there has been increasing interest in the use of remote sensing technologies as a potential solution for addressing the limitations of traditional LIT monitoring networks. Previous studies have demonstrated the potential of Synthetic Aperture Radar (SAR) for estimating lake ice growth and thickness variations indirectly (Duguay and Lafleur, 2003; Wegmüller et al., 2010; Duguay et al., 2015), while recent advances in satellite altimetry have enabled progress toward operational LIT retrieval approaches (Beckers et al., 2017; Mangilli et al., 2022, 2024).

Line 31-32: This should be more specific, and SAR is a poor example. It would be better to use radar altimeters as an example here.

We thank the reviewer for this helpful suggestion. We agree that the previous statement was too general and that SAR alone was not the most representative example of active remote sensing techniques for LIT retrieval. We will revise the sentence to provide a more specific description of active microwave approaches by including radar altimeters, which estimate ice thickness from surface elevation measurements, while also acknowledging SAR-based methods that use interferometric phase information for monitoring ice growth and thickness variations. We will revise line 31-32 as below:

Active microwave remote sensing technologies have shown significant potential for LIT retrieval, including radar altimeters that estimate ice thickness from surface elevation measurements and SAR-based approaches that exploit interferometric phase information to monitor ice growth and thickness variations (Murfitt and Duguay, 2021).

Line 45-47: Why? What is it about radar systems that make this interaction useful for determining LIT? As of this point in the manuscript the main conclusion is that roughness is what drives the backscatter response from lake ice. How does this interaction translate into the retrieval of LIT?

We thank the reviewer for pointing out the need to better explain the relationship between ice-water interface scattering and LIT retrieval. We agree that the original statement did not sufficiently clarify how the backscatter response from the ice-water interface can provide information on ice thickness. We will revise the text to explain that the LIT retrieval mechanism is not directly based on the magnitude of the backscatter response, but rather on the location of the interferometric phase center. Since microwave signals can penetrate freshwater ice, the phase center of interferometric radar measurements can be located near the dominant scattering interface (i.e., the ice-water interface), allowing the retrieved elevation information to be related to ice thickness. We will revise Line 45-47 as below:

"Overall, the dominant source of radar returns from freshwater ice has been observed to originate from the roughness of the ice-water interface; microwave penetration through freshwater ice causes the interferometric phase center to be located near the dominant scattering interface which provide height information at the ice-water interface (Gunn et al., 2018)."

Line 48-59: The discussion on radar altimeter methods is quite short despite the promising recent advances in algorithms. The discussion on the method used here should be expanded.

We thank the reviewer for highlighting that the previous discussion of radar altimeter-based LIT retrieval methods was too brief given recent advances in retrieval algorithms. We will *expand this section to provide a more detailed explanation of the physical principles and processing approaches used in radar altimetry. We will revise line 48-59 as below:*

This has led to increased use of radar altimeters for LIT retrieval on satellites such as CryoSat-2, the Jason series, and Sentinel-6 in recent years (Beckers et al., 2017; Li et al., 2022; Mangilli et al., 2024; Zhang et al., 2026). Radar altimeter-based LIT retrieval over freshwater ice exploits the penetration of microwave signals through the ice column and their interaction with multiple scattering interfaces, where the separation between waveform double peaks (or step-like break, depending on altimetry mode) at the ice surface and the ice-water interface can be converted into ice thickness (Beckers et al., 2017; Mangilli et al., 2024). Recent developments in waveform retracking and peak detection algorithms have improved the identification of these scattering interfaces, enabling more accurate and robust LIT retrieval from radar altimetry observations (Li et al.,2022; Mangilli et al., 2022, 2024).

Line 60-62: It is worth stating here that fully-focuses SAR altimetry has the capacity to have a resolution of 0.5m which exceeds that of imaging SAR. One aspect missing from the discussion here is that imaging SAR can provided gridded data compared to altimetry which is restricted to tracks. I note only one mention of SWOT which is the exception via the KaRIn sensor.

We thank the reviewer for this important clarification. We agree that the previous comparison between SAR interferometry and radar altimetry based solely on spatial resolution was inaccurate, particularly given recent developments in fully focused SAR altimetry that can provide very high along-track resolution. We will revise the text to clarify that the main advantage of imaging SAR interferometry is its ability to provide two-dimensional gridded observations of lake ice conditions, whereas most radar altimeter measurements remain constrained to satellite ground tracks. The KaRIn sensor of SWOT would not be an exception as a radar altimeter, since it is more closed to a bistatic interferometry. We will revise line 60-62 as below:

SAR interferometry has significant potential for LIT retrieval because it provides larger-scale gridded imaging at meter-scale spatial resolution. While recent developments in fully focused SAR altimetry can achieve sub-meter along-track resolution, conventional radar altimeter observations remain primarily limited to measurements along satellite ground tracks (Li et al., 2022; Mangilli et al., 2024; Zhang et al., 2026).

Line 180-188: Because of the lack of citations, to confirm this method is developed by the authors and has not been previously used in the literature?

From former studies that used interferometry for lake ice thickness, Wegmuller et al., 2010 that stated that "From those ice thickness values were then calculated using (4) and starting from a reference height corresponding closely to the height of the ice surface." But the methodological approach wasn't yet fully developed. We will clarify this section in the revision.

To account for the difference between the surface water level and the height of the shoreline, the difference between both surfaces was calculated to obtain the height to be referenced by the ice bottom height in the generated digital elevation model. This has not been previously used in literature that uses InSAR to retrieve ice thickness (i.e. Wegmuller et al., 2010).

Line 298: The selection of the 99.7th percentile for ice thickness is unclear. There is expected spatial variability in ice thickness, as authors have mentioned, why use the 99.7th percentile for validation when the maximum retrieved value could not be used instead? This may not need to be clarified in text and just a further explanation in response to the comment here.

We used the 99.7th percentile instead of the maximum retrieved value because consideration of remained interferometric noises, speckle effect, and potential outlier pixel values that might overestimate lake ice thickness. Based on observations that the LIT distribution in each lake is normal, we used the 99.7th percentile as the threshold.

Table 3: This chart is oddly set up. Why are observation data separated by CLIMo simulations? It would make more sense to show observation data versus CLIMo results. I believe it is to display it as increasing values, however, it did not hold for ice thickness, so it does not make sense to do it just for snow depths.

Thanks for the reviewer pointing out this formatting issues. We will revise the chart for better illustrations.

Figure 7: The boxplots are very confusing. The results presented in the text are difficult to interpret with the box plots. Primarily because when initially looking at the box plots it appears that the method has done a poor job retrieving ice thickness with mean values being >20 cm less than the CLIMo values. However, re-reading the text does help to clarify a bit the meaning and what should be examined (the red triangles). The recommendation would be to improve the text describing these figures as well as the figures themselves.

Showing the distribution of LIT using boxplots is still important for clarity and transparency, and allows us to present the systematic underestimation of ice thickness in bubbled ice if using mean or median instead of the 99.7th percentile.
We will change the figure caption to improve its clarity to readers.

Figure 8: Similar comment to Figure 7. Does not clarify if this is all values or just the 99.7th percentile as specified in the methodology. Why use R^2? You are not performing a linear regression. Additionally, the data does not appear normal, was a normality test performed? Likely a non-parametric correlation coefficient (Spearman's Rho or Kendall's Tau-b) would be better suited.

We will change the figure caption to improve its clarity to readers, and using spearman correlation coefficient instead.

Discussion: The results should be placed in the context of existing literature. How does it compare to the results of other studies? Other methods (e.g., altimetry)?

We will revise the Discussion section to include more comparisons with existing remote sensing approaches, including radar altimetry-based LIT retrieval methods. We will compare how other studies validated their remote sensing-derived ice thickness and RMSE.

References

Beckers, J. F., Casey, J. A., and Haas, C.: Retrievals of lake ice thickness from Great Slave Lake and Great Bear Lake using CryoSat-2, IEEE Trans. Geosci. Remote Sens., 55, 3708–3720, https://doi.org/10.1109/TGRS.2017.2677463, 2017.

Duguay, C. R. and Lafleur, P. M.: Determining depth and ice thickness of shallow sub-Arctic lakes using space-borne optical and SAR data, Int. J. Remote Sens., 24, 475–489, https://doi.org/10.1080/0143116031000066327, 2003.

Duguay, C. R., Bernier, M., Gauthier, Y., and Kouraev, A.: Remote sensing of lake and river ice, in: Remote Sensing of the Cryosphere, edited by: Tedesco, M., John Wiley & Sons, Ltd., 273–306, https://doi.org/10.1002/9781118368909.ch12, 2015.

Gunn, G. E., Duguay, C. R., Atwood, D. K., King, J., and Toose, P.: Observing scattering mechanisms of bubbled freshwater lake ice using polarimetric RADARSAT-2 (C-band) and UW-Scat (X- and Ku-bands), IEEE Trans. Geosci. Remote Sens., 56, 2887–2903, https://doi.org/10.1109/TGRS.2017.2786158, 2018.

Li, X., Long, D., Huang, Q., and Zhao, F.: The state and fate of lake ice thickness in the Northern Hemisphere, Sci. Bull., 67, 537–546, https://doi.org/10.1016/j.scib.2021.12.015, 2022.

Mangilli, A., Thibaut, P., Duguay, C. R. and Murfitt, J.: A new approach for the estimation of lake ice thickness from conventional radar altimetry, IEEE Trans. Geosci. Remote Sens., 60, 1–15, https://doi.org/10.1109/TGRS.2022.3169923, 2022.

Mangilli, A., Duguay, C. R., Murfitt, J., Moreau, T., Amraoui, S., Mugunthan, J. S., Thibaut, P. and Donlon, C.: Improving the estimation of lake ice thickness with high-resolution radar altimetry data, Remote Sens., 16, 2510, https://doi.org/10.3390/rs16142510, 2024.

Murfitt, J. and Duguay, C. R.: 50 years of lake ice research from active microwave remote sensing: Progress and prospects, Remote Sens. Environ., 264, 112616, https://doi.org/10.1016/j.rse.2021.112616, 2021.

Vincent, L. A., Wang, X. L., Milewska, E. J., Wan, H., Yang, F., and Swail, V.: A second generation of homogenized Canadian monthly surface air temperature for climate trend analysis, J. Geophys. Res. Atmos., 117, D18110, https://doi.org/10.1029/2012JD017859, 2012.

Wegmüller, U., Santoro, M., Werner, C., Strozzi, T., and Wiesmann, A.: Estimation of ice thickness of tundra lakes using ERS-ENVISAT cross-interferometry, in: 2010 IEEE International Geoscience and Remote Sensing Symposium, Honolulu, HI, USA, 25–30 July 2010, 316–319, https://doi.org/10.1109/IGARSS.2010.5649507, 2010.

Zhang, M., Chen, F., Guan, W., and Zhao, H.: Rapid thinning of lake ice for Himalayan glacial lakes since 2010, Remote Sens. Environ., 332, 115062, https://doi.org/10.1016/j.rse.2025.115062, 2026.