Review for: "Brief Communication: Comparing ICESat-2 Altimetry and COSMO-SkyMed Synthetic Aperture Radar Interferometry Grounding Zone Products over Antarctica"

This manuscript compares published grounding zone (GZ) observations derived from COSMO-SkyMed differential SAR interferometry (CSK DInSAR; Ross et al., 2025) and ICESat-2 repeat-track laser altimetry (Li et al., 2022) across 73 Antarctic glaciers. The authors evaluate offsets between ICESat-2-derived Point F, I_b and H grounding line (GL) proxies and the CSK DInSAR GL product, and make comparisons between East Antarctica, West Antarctica, and the Antarctic Peninsula.

I support the motivation for a systematic comparison of altimetry- and DInSAR-derived GZ proxies, and the study has the potential to provide a useful assessment of the strengths and limitations of combining these observation types. However, I have several major concerns regarding the methodology and interpretations presented here, which undermine the conclusions of the paper. I suggest that substantial reanalysis and reframing is required to address the major and specific comments outlined below. In its current form, I do not consider the reported conclusions to be sufficiently robust for publication.

Major Comments:

1. Treatment of DInSAR GL as the 'true' and 'instantaneous' grounding line

The authors treat the CSK DInSAR GL as the "true" GL, Point G, which is misleading. As has been established in the literature (including the review by Friedl et al. (2020)), DInSAR identifies the inland and seaward limit of detectable vertical tidal flexure in the GZ, corresponding to Points F and H. These are effectively the same proxies derived using ICESat-2. Comparing GZ proxies derived from two measurement techniques is itself a valid exercise, but it should be made clear that it is not validating ICESat-2 GZ points against a "true" GL measured using CSK DInSAR.

The statement *"DInSAR remains the gold standard for pinpointing the instantaneous grounding line"* is also inaccurate. As discussed in previous studies (including Ross et al. (2025) from which this dataset is taken), each CSK-derived GL is determined from a differential interferogram constructed from four separate SAR images acquired at different times and tidal states. In this dataset, each differential interferogram is formed from a pair of interferograms generated from 1-day repeats, with the two interferograms separated by 16 to 64 days. Therefore, the resulting GL cannot be described as "instantaneous".

I recommend revising this terminology throughout the manuscript and ensuring that the physical interpretation of the DInSAR-derived features remains consistent with the established literature.

2. Temporal mismatch between datasets

The comparison uses GLs derived from non-contemporaneous datasets: March 2019 to September 2020 for ICESat-2, and 2020-2021 for CSK (exact dates not specified). The authors justify this on the basis that GL positions are expected to have migrated relatively slowly over this period. However, this assumption may not hold for some rapidly changing. Because ICESat-2 observations overlap with the CSK acquisition period, the authors could reduce this limitation by reproducing the approach of Li et al. (2022) using the overlapping ICESat-2 ATL06 data.

More importantly, the analysis does not account for tidal sampling. The inland flexure limit (Point F) has been shown in both DInSAR and ICESat-2 studies to migrate over tidal timescales, in some locations by up to 15 km (Freer et al., 2023; Milillo et al., 2017. 2019, 2022; Rignot et al., 2024; Chen et al., 2023…). An ICESat-2 observation acquired at one combination of tidal states could therefore differ substantially from a DInSAR-derived position sampled a different combination of tidal states, even if both methods are accurate.

This is a critical limitation because the reported offsets may reflect real tidally-driven migration rather than a discrepancy between measurement techniques. The authors should engage more fully with literature on this process and quantify differences in acquisition timing, absolute tidal height, and differential tidal forcing of each GL measurement being compared. They should then test whether their observed offsets vary systematically with these differences.

I note that the authors acknowledge this issue in the conclusions, but do not address it in the analysis. In my view, such a limitation that is likely to have a non-trivial influence on the main result cannot be treated only as a caveat.

3. Offset distance calculation method

The methods described in Section 2.3 for filtering observations and calculating distances between GL proxies require further explanation. If I have interpreted this correctly, the authors have calculated the distance between each ICESat-2 GL points and the nearest part of the DInSAR GL. Several aspects of this require clarification:

(a) The Ross et al. (2025) DInSAR GL product contains multiple GLs derived from different combinations of CSK acquisitions. Which GL is used to calculate the offset from each ICESat-2 GL point? Is it the closest in acquisition time, the closest in distance, or some mean position? This choice should be clearly described and justified.
(b) Does the offset measurement account for ice-flow direction or the orientation of the ICESat-2 track from which the different GZ proxies were derived? I would think that in locations with more sinuous grounding lines or towards the edges of the main glacier trunk, simply measuring the distance between an ICESat-2 GL point and the nearest section of the DInSAR GL would be misleading.

The authors should describe and, where possible, quantify the uncertainties associated with both the filtering procedure and distance-calculation method. Sensitivity tests are needed to establish whether the main results are affected by these methodological choices.

4. Point H comparison

The rationale for comparing ICESat-2 Point H directly with a DInSAR Point F proxy is unclear. These features are expected to be offset from each other as they provide the bounds of the flexure zone. Point H can also be identified from the DInSAR observations, so suggest a comparison of the ICESat-2 Point H with the DInSAR Point H would be more appropriate. Otherwise, the authors should explain the physical purpose of the H–F comparison and avoid presenting the separation simply as disagreement between measurement techniques. A comparison of flexure zone width, defined by the separation between Points F and H in the ICESat-2 and DInSAR observations, may be more physically meaningful.

5. Regional statistics

The comparison of offsets between methods in East Antarctica vs West Antarctica vs Antarctic Peninsula is too broad, and likely obscures the physical controls that may explain the observed differences. Each region contains glaciers with widely varying dynamic settings, ice thicknesses, bed slopes, tidal ranges, grounding zone widths, etc., all of which may influence the relationships between the mapped GZ proxies.

For example, the discrepancy between ICESat-2 Point I_b and the DInSAR GL is found to be -108±972 in East Antarctica, 206±674 m in West Antarctica, and 12±732 m in the Antarctic Peninsula. These values are not especially informative because the standard deviations are an order of magnitude higher than the mean values, suggesting the mean is not representative of the underlying distributions.

I recommend a more detailed statistical analysis, breaking the analysis to the glacier or ice shelf level, and including additional statistics like median, IQR, and respective sample sizes. Some large discrepancies may contain geophysical information rather than simply representing measurement error. For example, the expected ordering of GZ proxies has been found to differ at ice plains and other non-idealized GZs, where Point I_b may be located upstream of Point F. Relevant studies discussing these settings, including Corr et al. (2001), Fricker et al. (2009), Brunt et al. (2011), Ochwat et al. (2025), should be considered when interpreting these results.

Specific Comments:

- The manuscript would benefit from a careful proofread to address typographical errors, missing spaces, and inconsistent capitalization. Some figures also appear stretched and should be reproduced with their original aspect ratios. I have not identified every instance individually here.
- There is a notable imbalance between length of the Results and Discussion section (1 page) and Conclusions section (2 pages). I suggest moving much of the discussion material currently in the Conclusions into the Results and Discussion. This restructuring may also help the authors align the conclusions more clearly with the presented results, which in places appear to be inconsistent.
- **L30-33.** Please provide appropriate citations for these statements and engage more fully with the relevant literature.
- **L34.** This section would benefit from a brief explanation of why the 'true' GL is challenging to directly observe, and why several surface proxies are therefore used to infer its location. I also suggest using the term "proxies" rather than "points".
- **L37-40.** Here and elsewhere, the manuscript relies heavily on the review by Friedl et al. (2020). It would strengthen the paper to cite more of the original studies that developed and applied each measurement technique.
- **L42.** Please check the citations associated with this statement. Li et al. (2020/2022) use altimetry to determine the break in slope, not digital elevation models or optical imagery.
- **Figure 1 –**
  - The labeled GL proxies in the DInSAR and the cross section do not appear to line up with either the DInSAR, BedMachine, or ICESat-2 features. Please check these and explain how you are identifying each of these points.
  - Adding the ICESat-2 ground tracks to panel C would provide useful spatial context.
  - As discussed in major comment 1, the DInSAR inland flexure limit should not be labelled as the "Grounding Line".
  - Please include citations for the Ross et al. (2025) and Li et al. (2022) datasets in the figure caption.
- **L69.** The phrase "ideal location of GZ points" is potentially ambiguous, as it could imply that the positions were selected based on an expected configuration rather than identified from the observations. Please clarify what is meant here.
- **Figure 2** –
  - The inset panels are currently too small to interpret easily. I would suggest presenting a smaller subset of glaciers in this main figure and, if permitted by the journal format, providing the remaining examples in the Supplementary Material.
- **L81.** This section requires additional detail. Please explain which DInSAR proxy is mapped (i.e. Point F), and describe the number and temporal separation of SAR scenes used to derive each GL. The precise date range of the DInSAR dataset should also be provided; the Introduction currently states that the observations were collected during 2020-2021.
- **L94.** Please revise this section to make clear that the analysis uses the existing published dataset of Li et al., (2022) and that this text is describing the method used in that study to produce the dataset. As currently written, it could be misinterpreted that the authors have generated these ICESat-2 GLs from the ATL06 product themselves.
- **L107.** To avoid ambiguity, I suggest specifying "ICESat-2-derived" or "DInSAR-derived" when referring to each GZ product, GL proxy, or point throughout the manuscript.
- **L111.** Should be "grounding zone" not "ground zone".

- **Table 1 –** The table contains a large amount of information and is difficult to read in its current format. The authors could consider narrowing some columns, simplifying the content, or moving less essential information to a supplementary table so that it fits more clearly on a single page.
- **L122.** Please clarify whether the number is 'about' 6305 or exactly 6305 points.
- **L149.** Presumably the H points are mostly downstream, not upstream?
- **L152.** It is unclear what trend this is referring to.
- **L156.** This wording suggests that the authors have derived a new set of ICESat-2 observations themselves, rather than using the Li et al. (2022) dataset. This is misleading.
- **L157.** Please explain the basis for the conclusion made that "DInSAR grounding lines serve as a primary reference for validation"? As discussed in Major Comment 1, both datasets represent observational GZ proxies with their own sampling characteristics and uncertainties, rather than one providing a direct measurement of the "true" GL.

References

Brunt, K. M., Fricker, H. A., and Padman, L.: Analysis of ice plains of the Filchner–Ronne Ice Shelf, Antarctica, using ICESat laser altimetry, Journal of Glaciology, 57, 965–975, https://doi.org/10.3189/002214311798043753, 2011.

Chen, H., Rignot, E., Scheuchl, B., and Ehrenfeucht, S.: Grounding Zone of Amery Ice Shelf, Antarctica, From Differential Synthetic-Aperture Radar Interferometry, Geophysical Research Letters, 50, e2022GL102430, https://doi.org/10.1029/2022GL102430, 2023.

Corr, H. F. J., Doake, C. S. M., Jenkins, A., and Vaughan, D. G.: Investigations of an "ice plain" in the mouth of Pine Island Glacier, Antarctica, Journal of Glaciology, 47, 51–57, https://doi.org/10.3189/172756501781832395, 2001.

Freer, B. I. D., Marsh, O. J., Hogg, A. E., Fricker, H. A., and Padman, L.: Modes of Antarctic tidal grounding line migration revealed by Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) laser altimetry, The Cryosphere, 17, 4079–4101, https://doi.org/10.5194/tc-17-4079-2023, 2023.

Fricker, H. A., Coleman, R., Padman, L., Scambos, T. A., Bohlander, J., and Brunt, K. M.: Mapping the grounding zone of the Amery Ice Shelf, East Antarctica using InSAR, MODIS and ICESat, Antarctic Science, 21, 515–532, https://doi.org/10.1017/S095410200999023X, 2009.

Friedl, P., Weiser, F., Fluhrer, A., and Braun, M. H.: Remote sensing of glacier and ice sheet grounding lines: A review, Earth-Science Reviews, 201, 102948, https://doi.org/10.1016/j.earscirev.2019.102948, 2020.

Milillo, P., Rignot, E., Mouginot, J., Scheuchl, B., Morlighem, M., Li, X., and Salzer, J. T.: On the Short-term Grounding Zone Dynamics of Pine Island Glacier, West Antarctica, Observed With COSMO-SkyMed Interferometric Data: PIG Grounding Line Dynamics, Geophys. Res. Lett., 44, 10,436-10,444, https://doi.org/10.1002/2017GL074320, 2017.

Milillo, P., Rignot, E., Rizzoli, P., Scheuchl, B., Mouginot, J., Bueso-Bello, J., and Prats-Iraola, P.: Heterogeneous retreat and ice melt of Thwaites Glacier, West Antarctica, Sci. Adv., 5, eaau3433, https://doi.org/10.1126/sciadv.aau3433, 2019.

Milillo, P., Rignot, E., Rizzoli, P., Scheuchl, B., Mouginot, J., Bueso-Bello, J. L., Prats-Iraola, P., and Dini, L.: Rapid glacier retreat rates observed in West Antarctica, Nat. Geosci., 15, 48–53, https://doi.org/10.1038/s41561-021-00877-z, 2022.

Ochwat, N., Scambos, T., Anderson, R. S., Winberry, J. P., Luckman, A., Berthier, E., Bernat, M., and Antropova, Y. K.: Record grounded glacier retreat caused by an ice plain calving process, Nat. Geosci., 18, 1117–1124, https://doi.org/10.1038/s41561-025-01802-4, 2025.

Rignot, E., Ciracì, E., Scheuchl, B., Tolpekin, V., Wollersheim, M., and Dow, C.: Widespread seawater intrusions beneath the grounded ice of Thwaites Glacier, West Antarctica, Proceedings of the National Academy of Sciences, 121, e2404766121, https://doi.org/10.1073/pnas.2404766121, 2024.