Response to the Reviewer Comments on Manuscript “Scale invariance in kilometer-scale sea ice deformation” “Reviewer #2”

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We would like to thank the reviewer for the encouraging comments and the positive assessment of our dataset’s potential for exploring small-scale sea ice dynamics. We share the reviewer’s enthusiasm for the potential in finding new insights from the fine-resolution deformation maps and look forward to expanding our analysis in future work. Below, we provide responses to the reviewer comments one by one.

General comments

We would like to thank the reviewer for the encouraging comments and the positive assessment of our dataset’s potential for exploring small-scale sea ice dynamics. We share the reviewer’s enthusiasm for the potential in finding new insights from the fine-resolution deformation maps and look forward to expanding our analysis in future work. Below, we provide responses to the reviewer comments one by one.

We initially shared the reviewer’s concerns about uncertainty in the deformation estimates. To address this, we incorporated an error assessment approach similar to the one proposed in (1). In the methods paper (2) and its Supporting Information, we show the end-point errors (EPE) computed using synthetic ice motion fields, where we know ground-truth displacements at each pixel. We also quantify signal-to-noise ratios for the real radar-derived strain rates. Even at the highest spatiotemporal resolutions, these ratios remain comfortably above unity in areas undergoing deformation, implying that the extracted signals are not buried by radar noise. We will add further clarifications in the revised manuscript on how these uncertainties translate into error in the strain estimates.

Regarding the choice to focus on time periods of relatively large deformation, we are very happy about the idea of the reviewer to show a continuous time series over the whole MOSAiC data set and agree that it is interesting to see how the scaling analysis holds for the entirety of the MOSAiC measurements. We have performed exactly this type of a broad scaling analysis, where scaling was performed with a sliding window over the whole winter. The results of this analysis, though, are planned to be published in another paper later. Additionally, since this paper is first to publish results over these scales with new results, we wanted to concentrate on highly active deformation periods where the signal-to-noise ratios can be ensured to be consistently high enough.

The reviewer suggests comparing the scaling of divergence and shear separately at these small scales, given the possibility that individual floes might not converge as much as they shear. We have performed only some small analysis at this question but hope to expand on this and integrate such this with a discrete element modeling framework in future work. Additionally, we’d like to use multifractal analysis to for this comparison to better describe their individual characteristics.

As the reviewer rightly points out, scaling alone cannot capture all the complexities of ice mechanical behavior. Our results expand one of these properties to smaller scales to provide empirical observations on the varying behavior of these methods at unexplored scales. We will add a comment in the article that while the fractal properties are a major properties of large-scale ice covers, there are many properties that current models cannot capture yet.

Specific comments

1.1 *Comments on the introduction*

We thank the reviewer for their kind words about the introduction. The current text uses a structure in which we highlight our study's novelty early on, without forgetting the state-of-the-art review. Although this way departs from the traditional style, we felt it would help the reader in understanding what our paper is about and to high-resolution radar dataset and the results from the outset.

2.1 *p4, L94: am really confused by this, do you use 24h trajectories or 10min trajectories? this is not clear to me.*

We use 24-hour trajectories that are generated based on sequential radar images with 10-minute intervals. We will clarify this further in the revised article.

3.1 *p5, L121: do you mean: "Figure 2 shows deformation rate averaged for the* 10 *km* $\times$ 10 *km sea ice area around . . . "*

This is what was tried to communicate. We will change the "*records for the* 10 *km* $\times$ 10 *km*" to "*averaged over the* 10 *km* $\times$ 10 *km"*.

3.2 *figure 2 and 3: I was wondering if the average deformation rate is the best to show here, wouldn't the maximum deformation be more adapted, we are interested in the localization of the deformation rate?*

We use the average deformation rate for the time series as this supports the analysis of the first moment fractal dimensions. Using the maximum deformation rates will suit our future analysis concentrating on multifractals, where the higher moments will provide better description on the scaling of the extreme values.

3.3 *p6, figure 3: The units are missing on the left side of the plots, I would recommend to put the season names as subplot titles.*

Although originally trying a slightly unconventional visualization of the data, we agree with the reviewer that having the case names in subplot titles will make the figure easier to read. We will change this.

3.4 *p6, figure 3: Is the "core" vertical scale (not the extensions for very high or small values) is at the same scale in all the panels? please check.*

Different vertical limits were originally used to highlight the individual deformation behavior during the different cases. We find the reviewers approach to make the figure more easily interpretable and will modify the figure to have identical core vertical scales for all winter cases. For July cases we double the scale on vertical axis due to the intensity of deformation but this will be pointed out in the figure caption.

3.5 *p7, figure 4: a video of the sea ice deformation (shear and divergence) as supplementary material would be very interesting to understand better the dynamics and what is happening here. I especially see that* *for November, there is an alternance of divergence and convergence withing the studied period. One could add the the radar field as well. Also showing how the deformation looks like at a single 10minute period would be nice as it is what is used for the scaling analysis.*

We are preparing a follow-up article where the November and other sea ice deformation events are analyzed in details. The animation of sea ice deformation will be included as to that manuscript. Examples of a 10-minute deformation map are shown in (2), which we will point out in the revised version of our paper.

3.6 *p7, figure 4: Zooming on the figure, we can clearly see an grid like pattern in the deformation which I assume arises from the deformation calculations and uncertainty or noise. We see the same in our recent publication (Plante et al., 2025). I feel this should be described and its impact on results assessed.*

We will elaborate on this in the revised paper. Concerning the grid pattern that occurs in regions of very small deformation and where radar noise partially obscures the signal. According to (3), these features may appear when the nominal resolution is not sufficient to capture the gradients in sea ice displacement.
Concerning the scaling analysis, the deformation rate distributions over areas that only contain this grid-like patterns contain only values smaller than the mean of the whole deformation field and are roughly two to three magnitudes lower than the identified large deformation features. The increased values over quiescent areas might decrease the spatial scaling exponent, β, as the field becomes slightly more homogeneous but should not affect the result of scaling collapse.
We find it more likely that there might be smaller deformation features that cannot be distinguished from the radar images, which would result in the loss of scale invariance. As this cannot be determined from the radar data, we suggest in the revised article that the lower bound for scale invariance should be sought also in other data sets and methods in future work.

3.7 *p8, L156: "Figure 5a depicts how the scaling exponent β behaved in the case of observations made over various spatial and temporal scales, L and T, respectively." respectively of what? something is missing here.*

The word respectively here links spatial and temporal scales to L and T. We will reword the sentence.

3.8 *p8, figure 5: The figure caption should state that the deformation rate for B are for the 10 minutes interval*

This is a good catch by the reviewer. We will add this mention into the caption of Figure 5.

4.1 *p11, L229: like said in the general comment, I feel there is not only sea ice scaling that need to be addressed for sea ice models.*

We will extend the discussion in the revised paper to point out that while scaling and fractal analysis are a major component of model validation in recent years, it is most certainly not the only one.

5.1 *p12, L246: "this paper" I would suggest "Our analysis of high resolution MOSAiC deformation data..." or something like that to be more precise.*

We will change the wording from "this paper" to the revised version of the article.

References

[1] A. Bouchat and B. Tremblay, “Reassessing the quality of sea-ice deformation estimates derived from the radarsat geophysical processor system and its impact on the spatiotemporal scaling statistics,” *Journal of Geophysical Research: Oceans*, vol. 125, no. 8, p. e2019JC015944, 2020.

[2] M. Uusinoka, J. Haapala, and A. Polojärvi, “Deep learning-based optical flow in fine-scale deformation mapping of sea ice dynamics,” *Geophysical Research Letters*, vol. 52, no. 2, p. e2024GL112000, 2025.

[3] M. Plante, J.-F. Lemieux, L. B. Tremblay, A. Bouchat, D. Ringeisen, P. Blain, S. Howell, M. Brady, A. S. Komarov, B. Duval, *et al.*, “A sea ice deformation and rotation rates dataset (2017–2023) from the environment and climate change canada automated sea ice tracking system (eccc-asits),” *Earth System Science Data Discussions*, vol. 2024, pp. 1–19, 2024.