The authors would like to thank the editor and the referee's comments on our manuscript. Following the comments, we make the following replies and corresponding revisions to the manuscript. Each item of the original comments from the referee is in *blue italic*, followed by our reply. Moreover, in the marked version of the revised manuscript, the revisions are highlighted with 'REV1'.

**REVIEW 1**

*This study introduces an online Lagrangian tracking module implemented in the CICE under the coupled model system of CESM to enhance Lagrangian diagnostics in sea ice models. The authors validated their module through numerical experiments focusing on sea ice deformations and kinematics. These experiments revealed multi-fractal characteristics in both spatial and temporal domains, as well as spatial-temporal coupling. The novelty of this work lies in the development of the Lagrangian tracking module and its emphasis on the importance of the Lagrangian perspective. This contributes significantly to the field of sea ice research. While the work is of sufficient quality and depth for publication, I have a few minor inquiries that I would like to discuss:*

1. *The authors outline the general structure of Lagrangian tracking within the time step of CICE. Lagrangian tracking was conducted prior to ridging and rafting. However, in these phenomena, multiple Lagrangian points may overlap or intersect. It would be helpful to clarify whether, in cases of strong ridging or rafting, these overlapping or intersecting Lagrangian points were considered as a single point or if they were treated separately in the tracking process. Could you elaborate more about ridging and rafting?*

**Reply**: we totally agree with the referee on this comment on sea ice ridging. During ridging events, especially over longer periods during which several ridging events are possible, the overlapping between Lagrangian points' tracks is possible. In the Lagrangian tracking we implement in CICE, these points are considered individually, fully allowing these cases.

We would also like to emphasize that: the linear kinematic features (LKFs), such as ridging/shear belts, mostly manifest at the spatial scale larger than the model grid's native resolution. The potential reason is that the effective resolution of the model is coarser for resolving sea ice dynamic processes. Consequently, we also carry out the scaling analysis for the spatial scales beyond 3x the original resolution of the grid.

On the other hand, at each step, the Lagrangian tracking is carried out within a single grid cell or between adjacent grid cells (i.e., on the scale of the grid cells). This limitation arises naturally with the numerical stability limitation in CICE. Therefore, there exists a scale separation between Lagrangian points' tracking and the detectable LKFs.

A further clarification is: during ridging/rafting, the shrinkage of the cell area occurs, but the Lagrangian points in the cell do not *feel* the ridging directly.

Lastly, the potential loss of Lagrangian points due to sea ice mechanical processes is planned for future development, but not available in the current implementation.

2. *The authors discuss the climatology of Lagrangian points under NYF (figure 6), supplemented with video. This discussion is valuable for understanding the functionality of Largrangian tracking module and visualizing sea ice export and melting. While direct comparison to observations is constrained, it would be beneficial to discuss the convergence of results concerning the number of Lagrangian points. In addition, exploring sea ice transport using non-uniform or localized distributions of Lagrangian points could provide further insights into sea ice dynamics. Understanding how variations in Lagrangian point distribution influence sea ice transport patterns would enhance the comprehensiveness of the study's findings.*

**Reply**: as pointed out by the referee, the NYF is annually repeating, therefore only representative of the climatology of the sea ice status, and not directly comparable to observations. Hence we further provide a newly added figure (below) to demonstrate the effect of AO's different phases on the points' track, using the NYF-based experiment.

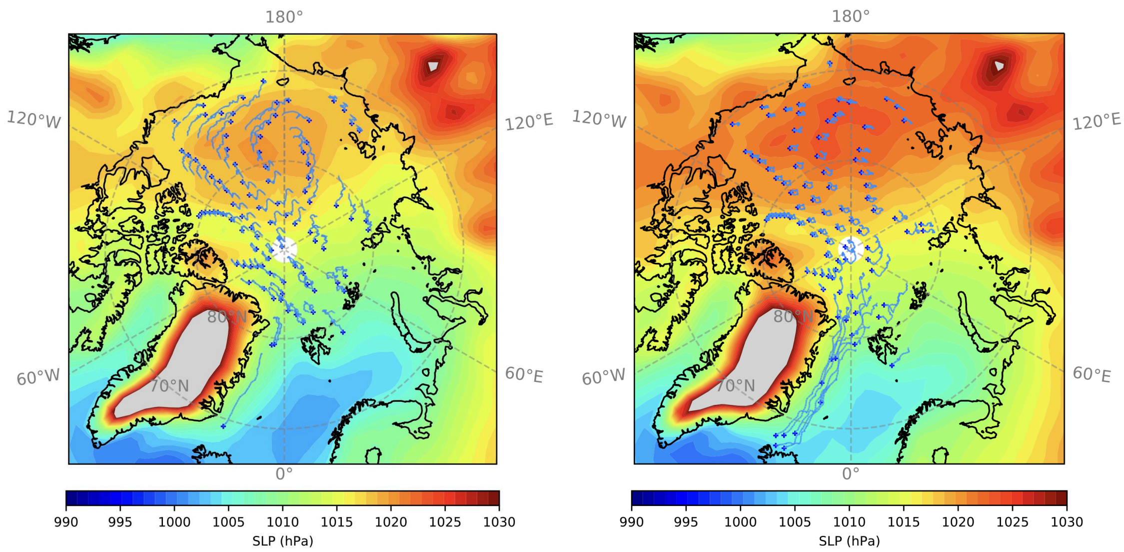



Figure. Sea-level pressure (SLP) and the tracks of Lagrangian points for two bi-monthly periods: November-December (left) and February-March (right) for the NYF-based simulation with the GX1V6 grid. The tracks during the second year of the Lagrangian tracking are shown.

We agree with the comments on using the Lagrangian tracking for the study of sea ice transport through localized distribution of points. We have investigated the transport and loss of Lagrangian points in Sec. 3.1, showing 30.1% of all points are lost through Fram Strait export, while others are lost within the basin due to melting. Further analyses of Lagrangian points' drift, especially with densely deployed points, are planned for future study with high-resolution and historical simulations.

3. *The authors compare the model track with buoy track (figure 7) and evaluate differences between the model points and the corresponding buoys (figure 8). While three possible reasons for the tracking uncertainties are outlined, additional details on each factor would enhance the understanding of their impact. For example, the authors could explore the effects of spatial resolution by conducting sensitivity analyses with varying resolutions and comparing results for different cases. The authors could try to quantify the effects of uncertainty in atmospheric forcing on tracking, if possible. Can you also increase the size of '+' markers on the map? It is hard to see in the printed version.*

**Reply**: we agree with the referee for pointing out the 3 major contributing factors, which we list here for discussion: (1) limited model/grid resolution; (2) initial displacement between physical buoys and the nearest Lagrangian points; (3) the forcing's spatial & temporal resolution and model's inherent uncertainty (to simulate the drift). In general, we totally agree with the referee's suggestion for potential directions for analysis.

First, the model's resolution we use for the historical run (over 60 years in length) is nominally 1 degree. We plan to use LKF-capable resolutions for a historical simulation. At the coarsest, the TS015 grid (7km in the Arctic) should be used. Preferably, the 2.4km-resolution TS005 grid is much finer for deformation fields (Xu et al., 2021). However, such simulations incur much longer simulations, which is a compromise we had to make during this whole work was carried out. We are also actively gathering resources to carry out such a multi-decadal run with LKF resolving resolution in the near future.

Second, the exact matching between the buoys' initial location and deployment time and those of the Lagrangian points is planned in the second version of the Lagrangian tracking in CICE. Other collateral updates include a namelist-based configuration of the tracking module, as well as the implementation in CICE6. With these supports, the sensitivity of tracking results to the initial locations' mismatch can be examined in a systematic way.

Third, the IAF forcing is from NCEP and CORE2 datasets, which we plan to update with the JRA55-do dataset for simulating sea ice. JRA55 has a much higher spatial resolution (>4x). A comparative study between JRA55-do-based and CORE2-based historical experiments is planned, focusing on sea ice tracking. Specifically, we plan to utilize the coupling framework of CESM2 to carry out the new experiments.

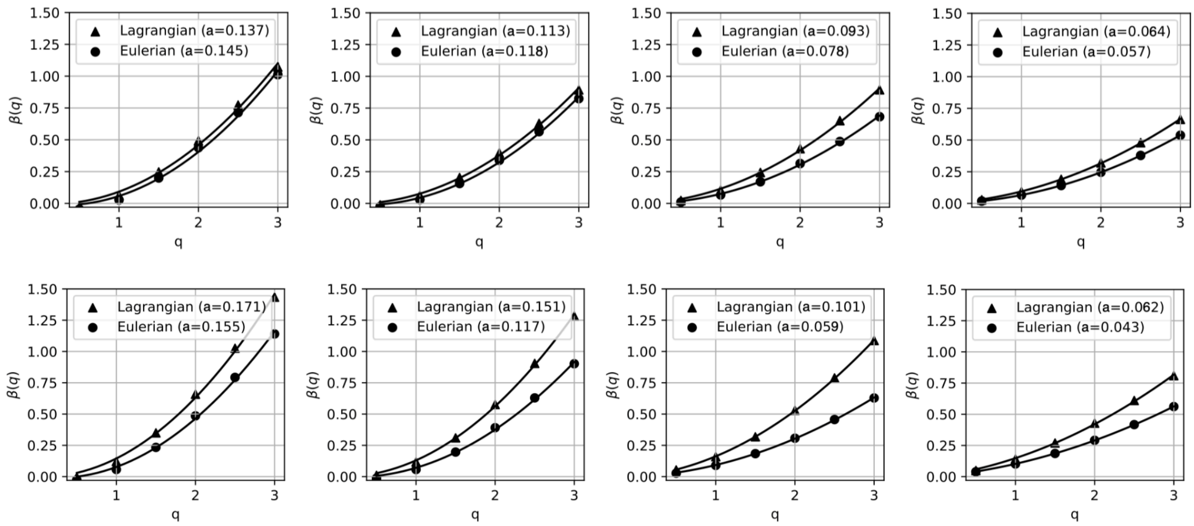
Besides, according to the suggestion on the readability of the figure, we have increased the size of '+' markers in Fig. 8, as well as the overall size of the map.

4. *The authors used convex structure functions to fit sea ice deformation trends. While referencing observed multi-fractal deformations is valuable, further discussion on the selection of this specific form of function would enhance clarity.*

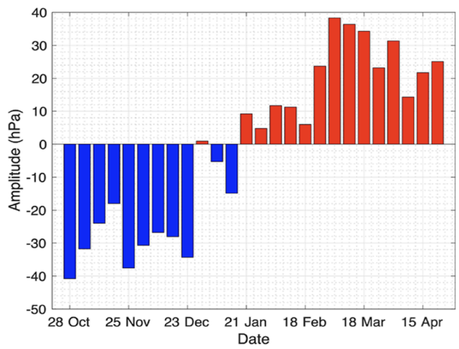
**Reply**: as suggested by the referee, we made revisions by adding the following sentence to the manuscript: "A generalized analysis framework with non-fixed degree of multifractality for the sea ice formations is also available (Weiss 2008; Bouchat et al., 2022). For comparison, the forms in Eqs. 6 and 7 also assume the underlying multi-fractal, long-normal multiplicative model. In this study they are adopted, because their quadratic form is sufficient in capturing the convex shape of the structure functions (Marsan et al., 2004; Rampal et al., 2019)".

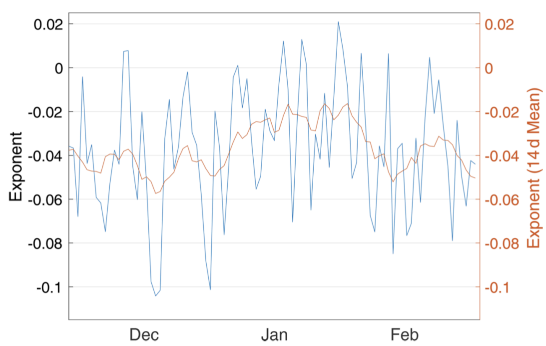
5. *In the discussion of spatial scaling around Dec. 20th and Feb. 6th for four different temporal scales (figures 10 and 11), the 3-day and 10-day cases exhibit a larger difference in beta compared to the 1-day and 30-day cases for both dates. Could you provide the reason for this?*

**Reply**: we agree with the referee's comment on the spatial scaling properties at different temporal scales around Dec-20 and Feb-6. The structure functions of β are shown in the figure below (segmented from Fig. 10 and Fig. 11), with the first (second) row showing the results for days around Dec-20 (Feb-6).




Several contributing factors could lead to the differences in the β function, including the convexity parameter ($a$ in Eqs. 6) which decreases more evidently between 10-day and 30-day scale for Dec-20, compared to that of Feb-6, for which $a$ decreases more between 3-day to 10-day scale. We conjecture that the different weather processes during the two periods are the major reason. Below is the Arctic Oscillation (AO) index of the NYF dataset which characterizes the large-scale atmospheric circulation and hence the sea ice drift pattern, as well as the value of β(1) simulated with a similar CICE configuration (Xu et al., 2021).



As shown, the value of the structure function undergoes large changes throughout the winter (esp., note the large day-to-day change). Combined with other factors such as the sea ice parameters (thickness distribution and deformation history), much variability in the structure function is present. First and foremost, the analysis should differentiate the weather events, so that the sensitivity to both typical circulation patterns and temporal scales can be elucidated. However, this analysis is not the focus of this study, we plan to carry out the analysis with historical simulations (with more events, as well as Arctic warming) and sufficient, LKF resolving resolutions.

6. *In appendix B detailing the calculation of sea ice deformation, it is important to consider scenarios where the grid becomes highly deformed, akin to figure B1.C. I am curious whether the patch is redrawn at every time step. If not, how could sea ice deformation be calculated in the case of highly deformed grids?*

**Reply**: we would like to clarify that: Fig. B1 only shows schematics of deformation fields.

The highly deformed cases usually correspond to extreme samples in the statistics of $\dot{\epsilon}$, mainly due to the localization (or intermittency) of the deformations. However, even if the grid is highly deformed, the deformation rate can still be computed through line integral over the area covered by the same set of Lagrangian points (methods in Appendix B).

It is worth noting that, existing scaling analysis works that utilize Lagrangian points in the Arctic are usually based on simple quadrilaterals [involving 4 corner points, see Marsan et al. (2004)] or even point pairs (Rampal et al., 2008), the lack of available data being a key reason. Highly deformed cases are definitely possible, but they do not hinder the overall statistical analysis. Preferably, the cells with high deformations can also be avoided to reduce the potential uncertainty in the estimated deformation rates, as is carried out in Marsan et al. (2004). We also adopt this strategy for our analysis, as introduced in Sec. 3.3.

**References**:

Marsan, D., Stern, H., Lindsay, R., and Weiss, J. (2004), *Scale Dependence and Localization of the Deformation of Arctic Sea Ice*, Phys. Rev. Lett., 93, 178 501, https://doi.org/10.1103/PhysRevLett.93.178501, 2004.

Rampal, P., J. Weiss, D. Marsan, R. Lindsay, and H. Stern (2008), *Scaling properties of sea ice deformation from buoy dispersion analysis*, J. Geophys. Res., 113, C03002, doi:10.1029/2007JC004143.

7. *The figure numbers in lines 94 and 96 on page 4 are typos. Figure 1 should be there.*

**Reply**: corrected.

8. *In line 101, there is a typo: “the cell the point” needs correction.*

**Reply**: corrected.