Review
EGUsphere
Manuscript Number: egusphere-2025-704
Title: Arctic regional changes revealed by clustering of sea-ice observations
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General comments:

Arctic sea ice is one of the most affected components by climate change. Understanding its evolution over the last 40 years is key to prepare for further amplification of Arctic warming. As such, physical variable can be used to examine the different behaviors of sea ice. The present study addresses the following question: What insights can be gained about sea ice behavior trends through the application of clustering techniques?

In this work, the authors relied on sea ice concentration (SIC) seasonal cycle to identify 4 sea ice behaviors instead of the classical approach of splitting the Arctic based on geographical regions. The study spams from 1979 to 2023, with daily values averaged as 5-day mean and SIC are from passive microwave satellite observations. The four optimal clusters can change over time and are identified as: open ocean, permanent sea-ice, partial winter freezing and full winter freezing. The authors show the long term changes of the 4 types of seasonal cycle of SIC. They also introduce transitions from one behavior to another, which are either stabilization (typically any ice regime to open ocean) and destabilization (typically permanent ice to any winter freezing regime).

The paper is well structured and clear, which makes it pleasing to read. The context and method are thoughtfully described. The results are clearly explained, properly analyzed. Especially the section 3.4.2. which shows a very interesting analysis.
In my opinion, this is a great paper which could be improved by discussing the limitations of this study in section 4. Some additions can be added to the text for clarification.

In the following pages, I address several points that requires the authors' attention and I hope they will help improving the present manuscript:

The SIC product is presented, yet no limitations nor assumptions made to obtain SIC are presented. Is there any reason to pick this product compared to another SIC product? I believe 1-2 sentences of this topic would bring perspective to the text and remind the reader that this dataset differs from reality. Either in section 2.1 or section 4. Is the product consistent over the 40 years? What is the uncertainty of the measure?

At several occasions (l.216, l.378, l.422, l.600, l.621, l.658), the authors write 'sea-ice seasonal cycle'. In my understanding, the seasonal cycle can refer to different variables such as concentration, thickness, albedo, etc. For sake of clarity, I suggest either:
- add a sentence stating that throughout the manuscript, sea-ice will always relate to concentration,
- add 'concentration' to each instance of term 'seasonal cycle'.

The authors uses the clustering analysis to identify sea-ice precursors for one given point (3.1, L. 325-328). While I find this analysis interesting, I believe using the term 'predictor' is misleading. To my understanding, there is no prediction in this manuscript; the dataset is entirely based on past data. Therefore, the clustering outputs do not predict the behavior of sea-ice, but indicate general behavior for a given grid cell. I do agree that the clustering relies heavily on the start of melting and freezing periods. Using the term 'indicator' would remove this potential confusing.

Figure 10 appears before Figure 9 in the text. Figure 9 is actually not cited in the text directly. I would recommend swapping order of Figure 10 and 9, and adding a citation of former Figure 9 in the paragraph between l. 554-562, where the "star" and "triangle" examples are described.

Overall, the section "conclusion and discussion" present the final results and compare them with the literature. This comparison is satisfactory, however it lacks discussion on the limitation of this study regarding the data and the method.

Need for clarifications:

On l.128, the authors state that 'usual descriptors… do not account/consider for the full seasonal cycle' of sea ice. I find this statement unclear (also in the abstract., l.40). Are the cited studies only considering part of seasonal cycle (by choice, lake of data, lack of mean) ? Are they using SIC as well or another variable which could be partially unavailable (such as thickness during melting period) ? Why SIE or type of sea-ice can not consider the full sea-ice seasonal cycle (also L.131)?

L. 116: 'do not consider changes in sea-ice features'. "Features" is used several times throughout the manuscript (l. 637), and I think concrete examples of features should be given by the authors at the first reference. By the end of the manuscript, I understand that such 'feature' means the duration of ice season, or duration of open ocean. At my first reading, it could also have been the sea ice thickness distribution or other properties of sea ice which are not tackled here.

L. 317: When writing the dates of melting and freeze up, the authors mention first the permanent, followed by full winter-freezing and partial winter-freezing. However, throughout the paragraph, the seasonal cycles are presented in a different order: open-ocean, partial winter-freezing, full winter-freezing, and permanent ice clusters.
For consistency, I recommend keeping the same order as initially mentioned.

L. 635: "The major limit of our approach": I find that this major limitation is explained relatively shortly. In addition, I do not really understand this sentence. Some rephrasing or additional explanation are necessary. Do you mean to say that a lot of different seasonal cycle of SIC (grid cells) are reduced to one single seasonal cycle through clustering?

Specific comments:

L. 136: citation from Lebrun et al. (2019) is missing.

L. 173: "for the first time". Is this really the first time? This is quite surprising! The authors did a great job in showing the potential of such a method.

Few sentences are very long: I could suggest rephrasing them: L. 177, l. 301.

L. 234: 'influencing'. As influence could be positive, I had to keep reading that this influence was undesired, regardless of it being beneficial or not. Maybe use 'biasing'.

L. 238-239: Quantiles are given both with % (33%, 66%) and as float (0.25, 0.50). Please, pick one way and stick with it. I would advise for %, as it is used again later in the manuscript.

L. 248: At the end of "Mahalanobis distance to constrain the clustering with physical information.", I was expecting to find the definition of Mahalanobis distance which is L.255. Please, consider putting the definition as soon as possible.

L. 249: Parenthesis is not closed. "(as shown in Figure 2 by…"

L. 301: "They exhibit the expected physical behavior that, ...maximum solar insolation (Parkinson et al. 1987)." Although I see what the authors want to express, this sentence appears difficult to read and cumbersome. Please, rephrase and make this sentence lighter.

L. 423: "(from no ice to 70% SIC for the partial winter freezing clusters and to 100% SIC for the full winter freezing cluster)". I find this information relevant and I think it would fit better in an addition sentence than in parenthesis.

L. 476: "and to a smaller extent, of the full winter-freezing cluster." What about the decrease in partial winter freezing? It could also be compensated by a gain in full winter-freezing?

Figure 8: There are common markers between the subplots. While the open-ocean category can share the same marker and color, the square and diamond markers indicate different categories in both subplots. I would recommend changing the markers in subplot b) to eliminate any possible confusion (especially if printed in black and white). Additionally, adding a vertical line at the year 2000 can enhance the graphical readability.

L. 498: ") The area of the MIZ" > "t"

L. 508: It would be interesting to add one sentence about the supposed reason why the sea-ice loss signature is only visible in the permanent sea-ice cluster. I expected to find this in the discussion section but did not see it.

L. 547: "As shown Figure 10" > "in" missing

L. 612: "the area between the Central Arctic and the open-ocean does not" > I suggest adding "permanent ice" for clarity. " the area between the permanent ice Central Arctic and the open-ocean does not"

L.652: "The year of loss in the likelihood to belong to the permanent sea-ice shows" is heavy to read for my tastes.