The Cryosphere Discussions

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Reply on RC2

Dongyang Fu et al.

Author comment on "Multiscale variations in Arctic sea ice motion and links to atmospheric and oceanic conditions" by Dongyang Fu et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2020-324-AC2, 2021

First of all, we (the authors) would like to express our sincere gratitude to the Anonymous Referee for their time, effort, and recognition given to our manuscript. Secondly, it is worth pointing out that Referee comments and suggestions have really helped us improve the quality and presentation of our manuscript further. In light of such inspiring comments and suggestions, we have revised the original manuscript duly and carefully, with the answer to the Referee comments listed below.

Major comments:

- **The correlation is estimated to assess the linkage of sea ice drift to atmosphere and ocean dynamics. As we all know, correlation does not necessarily means a causal relationship. How would you explain the validity of just using the correlation.**

Response: Thanks so much for your comment. As you stated, correlation does not necessarily mean a causal relationship. For example, ocean currents can affect sea ice motion by drag, but ocean current speed and direction can also be impacted by the movement of the sea ice. We know that large-scale oceanic currents, like those in the thermohaline circulation, are driven by sea ice melting/freezing. I think it's difficult to explain the causal relationship between the sea ice motion and the sea ice motion influencing the ocean. It may be better to conclude that the relationship between sea ice motion and ocean movement is strong in certain areas and periods, rather than the influence of the ocean environment of sea ice movement. Combined with the comment of the RC1, we have modified the word "influence" in the manuscript to "relationship" or "correlation".

- **A discussion about the relationship between Arctic sea ice drift and large-scale atmosphere circulation, such as Arctic Oscillation, North Atlantic Oscillation should be given.**

Response: Thanks so much for your comment. we have added a discussion about the relationship between Arctic sea ice drift and large-scale atmosphere circulation, such as Arctic Oscillation (AO) and North Atlantic Oscillation (NAO). As can be seen from Table 1, the correlation between the three sea ice drift patterns on most of the scale and atmospheric index is low. Among them, the decadal variation (C6) of the first pattern has

a high negative correlation with the AO index (correlation coefficient is -0.71), which indicates that an anticyclonic circulation of the sea ice drift around the entire Arctic Ocean has a high correlation with the large-scale Arctic circulation. In addition, the trend changes of the three sea ice movement patterns are highly correlated with the large-scale atmospheric indices, which indicates that the large-scale atmospheric changes have a strong correlation with the changes of sea ice movement patterns, while some high-frequency changes of sea ice movement (interannual and multi-year changes) are not highly correlated with the large-scale atmospheric circulation.

Table 1. The correlations between the first three EOF sea ice drift patterns on various time scales and a variety of large-scale atmospheric index

PC1			PC2			PC3		
IMF	NAO	AO	IMF	NAO	AO	IMF	NAO	AO
C2	0.05	0.04		-0.02	-0.13		0.09	-0.01
C3	-0.55	-0.40		-0.08	-0.18		-0.03	-0.05
C4	0.30	0.46		0.27	0.39		-0.46	-0.24
C5	0.13	-0.20		-0.13	0.01		-0.49	-0.28
C6	-0.24	-0.71		0.03	0.53		0.31	-0.11
trend	0.83	0.41		0.77	0.75		-0.79	-0.74

- **The discussion should be revised and clearly illustrate the main finding of this study. The current version is not easy to follow by the readers.**

Response: Thanks so much for your comment. we have revised and clearly illustrate the main finding of the study in the discussion part. Details are as follows:

(1) We have revised the third last paragraph of the Discussion section:

The trend changes of the second and the third main patterns of Arctic sea ice drift retrieved by applying the EOF analysis are mainly correlation with ocean environmental factors. However, the first main pattern showed a more significant correlation with atmospheric environmental factors. What more, the second EOF pattern representing sea ice output from Fram Strait shows an increasing trend, while the third EOF pattern shows a decreasing trend. This indicates that the export of Arctic sea ice from Fram Strait increases, while that from Bering Strait decreases. However, the export of Arctic sea ice is mainly through Fram Strait, so in general, the export of Arctic sea ice shows an increasing trend in the last decades. With the variation trend of sea ice movement, the Arctic sea ice concentration attempt to indicate a decreasing trend in the future, especially from the Eurasian Basin to the Fram Strait. Furthermore, the extent to which sea ice export through Fram Strait controls ice conditions (thickness and motion) upstream the Transpolar Drift system. And the export influences a large area upstream in the Trans-Polar Drift stream, and that high volume export events lead to a thinner thickness.

(2) We have added a paragraph at the end of the Discussion section, as follows:

As discussed above, the analysis of the spatiotemporal patterns of Arctic sea ice circulation is of intrinsic value in identifying and understanding general patterns in the behavior of the atmosphere-ice-ocean system. We know that the atmospheric and ocean environmental factors we use for analysis are relatively easy to obtain compared to sea ice condition parameters, and that some large-scale climate signals of the atmosphere or

ocean are predictable. The occurrence of signals like ENSO can be predicted 6-12 months in advance. However, large scale climate fluctuations such as ENSO will affect the atmosphere and ocean environment, thus affecting sea ice conditions. Therefore, our study establishes the relationship between sea ice movement and atmospheric and oceanic factors on different time scales, making it easier to predict future sea ice conditions.

Minor comments:

L1 'global material balance' -> global ice mass balance. And the Abstract should be revised for a clear expression of the key points of this study.

L23 'global material balance' -> global ice mass balance

Response: Thanks so much for your comment. As far as we know□The material exchange process mainly takes place at the sea-ice - air interface. Therefore, the Arctic sea ice/climate system and its impact on global climate occupy a prominent position in Arctic and Arctic research. Therefore, we think it is appropriate to use "global material balance" here.

We have revised the Abstract part as follow:

Arctic sea ice drift motion affects the global material balance, energy exchange and climate change and seriously affects the navigation safety of ships along certain channels. Due to the Arctic's special geographical location and harsh natural conditions, observations and broad understanding of the Arctic sea ice motion of sea ice are very limited. In this study, sea ice motion data released by the National Snow and Ice Data Center (NSIDC) were used to analyze the climatological, spatial and temporal characteristics of the Arctic sea ice drift from 1979 to 2018 and to understand the multiscale variation characteristics of the three major Arctic sea ice drift patterns. The empirical orthogonal function (EOF) analysis method was used to extract the three main sea ice drift patterns, which are the anticyclonic sea ice drift circulation pattern on the scale of the Arctic basin, the average sea ice transport pattern from the Arctic Ocean to the Fram Strait and the transport pattern moving ice between the Kara Sea (KS) and the northern coast of Alaska. By using the ensemble empirical mode decomposition (EEMD) method, each temporal coefficient series extracted by the EOF method was decomposed into multiple time-scale sequences. We found that the three major drift patterns have 4 significant interannual variation periods of approximately 1, 2, 4 and 8 years. Furthermore, the second pattern has a significant interdecadal variation characteristic with a period of approximately 19 years, while the other two patterns have no significant interdecadal variation characteristics. Combined with the atmospheric and oceanic physical environmental data, the results of the correlation analysis show that the first EOF sea ice drift pattern is mainly related to atmospheric environmental factors, the second pattern is related to the joint action of atmospheric and oceanic factors, and the third pattern is mainly related to oceanic factors. Our study suggests that the ocean environment also has a strong correlation with sea ice movement. Especially for some sea ice transport patterns, the correlation even exceeds atmospheric forcing.

L41 the format of the citation of the reference is incorrect.

Response: Thanks so much for your comment. We have revised the incorrect format "(Xiaoyu and Jinping, 2013)." to "(Xiaoyu and Jinping, 2012)." in the manuscript accordingly.

L42-45 The sentence is lengthy and should be revised. For example: The Arctic Ocean system is characterized by a unique anticyclonic circulation pattern

associated with atmospheric and oceanic forcing. These forcing are related to the climate change of Arctic and beyond.

Response: Thanks so much for your comment. We have revised the sentence as the comment of the reviewer in our manuscript accordingly.

L55 'possess' -> 'shows' or 'exerts'

Response: Thanks so much for your comment. We have revised word "possess" to "shows" in the manuscript accordingly.

L56 'over the 25-year period' which period ?

Response: Thanks so much for your comment. We have revised "over the 25-year period" to "over the 25-year period from 1988 to 2012" in the manuscript accordingly.

L57 ' its patterns' -> 'temporospatial patterns'

Response: Thanks so much for your comment. We have revised "its patterns" to "temporospatial patterns" in the manuscript accordingly.

L58 'whereas it overall influences the ...' -> 'Moreover, ice drift influences...'

Response: Thanks so much for your comment. We have revised "whereas it overall influences the ..." to "Moreover, ice drift influences..." in the manuscript accordingly.

L60 'multiscale variation'-> multiscale temporal variations'

Response: Thanks so much for your comment. We have revised "multiscale variation" to "multiscale temporal variations" in the manuscript accordingly.

L60 'the determining factors of the ...' As I have suggested, the correlation obtained in this study does not means a causal relationship, and this sentence should be rewritten.

Response: Thanks so much for your comment. We have rewritten this sentence as "due to a complex superposition effect of the atmospheric and oceanic physical environment in the Arctic Ocean, the multiscale characteristics of the BG and TPD may show a changeable characteristics both in intensity and oscillation frequency."

L63 ' aims to understand..' -> 'aim to outline...'

Response: Thanks so much for your comment. We have revised "aims to understand…" to "aim to outline..." in the manuscript accordingly.

L67 'exceeds' -> 'dominates over...'

Response: Thanks so much for your comment. We have revised "exceeds…" to "dominates over..." in the manuscript accordingly.

L68-69 'The results can provide...' this sentence is unnecessary.

Response: Thanks so much for your comment. We have removed this sentence in the manuscript accordingly.

Figure 1. Caption. 'the colors ...' Normally, it should be 'the shading...'

Response: Thanks so much for your comment. We have revised "the colors ...'" to "the shading..." in the manuscript accordingly.

L75 'by combining...' -> ' by combining the data observed from...'

Response: Thanks so much for your comment. We have revised "by combining...'" to "by combining the data observed from..." in the manuscript accordingly.

L79 'Physical environmental factors...' -> 'geophysical variables'. Some similar usage should be revised throughout the paper.

Response: Thanks so much for your comment. We have revised "Physical environmental factors...'" to "geophysical variables..." in the manuscript accordingly. And revised all 8 similar expressions throughout the paper.

L83. SIC data should be correctly referenced.

Response: Thanks so much for your comment. We have added the reference of the SIC data.

Cavalieri, D. J., C. L. Parkinson, P. Gloersen, and H. J. Zwally. 1996, updated yearly. Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center.
doi: https://doi.org/10.5067/8GQ8LZQVL0VL.

L111 'makes...' -> 'with..'

Response: Thanks so much for your comment. We have revised "makes..." to "with..." in the manuscript accordingly.

L114 'solving the problem of pattern confusion' -> 'reducing the uncertainty due to confusion'

Response: Thanks so much for your comment. We have revised "solving the problem of pattern confusion" to "reducing the uncertainty due to confusion" in the manuscript accordingly.

L119 'confidence line' -> 'confidence level'

Response: Thanks so much for your comment. We have revised "confidence line" to "confidence level" in the manuscript accordingly.

L121 ' contains a true signal'-> 'includes useful signal'

Response: Thanks so much for your comment. We have revised "contains a true signal" to "includes useful signal" in the manuscript accordingly.

L130 remove 'safely'

Response: Thanks so much for your comment. We have removed "safely" in the manuscript accordingly.

L132 'considered' -> 'considered as...'

Response: Thanks so much for your comment. We have revised "considered" to

"considered as..." in the manuscript accordingly.

Figure 3. caption. 'colors' -> 'shading'. This kind of wording error should be revised throughout the paper.

Response: Thanks so much for your comment. We have revised "colors ..." to "the shading" in the manuscript accordingly. And revised all 2 similar expressions throughout the paper.

'the arrows represent the direction and magnitude of ice drift.'

Response: Thanks so much for your comment. We have revised "the arrows represent the drift direction" to "the arrows represent the direction and magnitude of ice drift" in the manuscript accordingly.

L143 explain why divide the Arctic annual to winter and summer for the period of May-Oct and Nov-Apr, respectively.

Response: Only winter data have been used in the EOF analysis because effects of weather, atmospheric moisture, and surface melt during the summer can have a detrimental effect on the data quality and the analysis. In order to make the sea ice motion dataset have better continuity in spatial and temporal distribution, we found that the data from November to April had a relatively high coverage rate in each month in the whole period from 1979 to 2018, basically covering most Arctic regions. The obtained spatial pattern coverage of EOF is good, and the result is stable. Therefore, in order to facilitate EOF analysis later and make the full text consistent, we divide the Arctic annual to winter and summer for the period of May-Oct and Nov-Apr, respectively.

'the main form'-> 'the main pattern'

Response: Thanks so much for your comment. We have revised "the main form" to "the main pattern" in the manuscript accordingly.

L147-148. the sentence should be revised by native English counterparts.

Response: Thanks so much for your comment. We have revised this sentence as "The above indicates that even if we use only the winter months data set, we can describe the large-scale circulation regimes and their variability of Arctic sea ice motion over time very well. In the following analysis, in order to make the sea ice motion dataset have better continuity in spatial and temporal distribution, we found that the data from November to April had a relatively high coverage rate in each month in the whole period from 1979 to 2018."

L154 should be 'the sea ice motion and its zonal and meridional components are available for the period from 1979 to 2018.

Response: Thanks so much for your comment. We have revised this sentence as "the sea ice motion (Figure 4c) and its zonal (Figure 4a) and meridional (Figure 4b) components are available for the period from 1979 to 2018"

Figure 4 caption. 'sea ice drift velocity' is a weird usage. You should say 'sea ice motion or sea ice drift' is enough. 'red filled values' 'blue filled values' why just say 'red shading' or 'blue shading'

Response: Thanks so much for your comment. We have revised "sea ice drift velocity" to "sea ice motion" in the manuscript accordingly. We want to better express the direction of

the monotonic variation trends, so using the red shading indicate sea ice motion increases, while blue shading indicates sea ice motion decreases.

L186 'periods'-> 'a 30-day period'

Response: Thanks so much for your comment. We have revised "periods" to "a 30-day period" in the manuscript accordingly.

L190 'this phenomenon' -> 'this pattern of ice drift'

Response: Thanks so much for your comment. We have revised "this phenomenon" to "this pattern of ice drift" in the manuscript accordingly.

L190 ''-> 'manifests itself as..

Response: Thanks so much for your comment. We have revised "manifests as" to "manifests itself as" in the manuscript accordingly.

L193 'cyclonic circulation weak anticyclonic circulation' I don't get the idea you want to tell

Response: Thanks so much for your comment. We have revised this sentence as "cyclonic circulation or weak anticyclonic circulation."

L201. 'three pattern's variation...' -> 'the variations of the patterns of Arctic sea ice drift retrieved by applying the EOF analysis for the period ...'

Response: Thanks so much for your comment. We have revised "three pattern's variation..." to "the variations of the patterns of Arctic sea ice drift retrieved by applying the EOF analysis for the period ..." in the manuscript accordingly.

L209 should be ' we explored the relationship between the sea ice drift pattern and atmospheric and oceanic forcing on different temporal scales.

Response: Thanks so much for your comment. We have revised this sentence as "we explored the relationship between the sea ice drift pattern and atmospheric and oceanic forcing on different temporal scales."

TABLE 1 the middle column 'PC2' , and the third column should be ' PC3'

Response: Thank you for carefully pointing out the mistakes in our manuscript. We have revised them in the manuscript.

L239. 'For the trend variation...' should be removed.

Response: Thanks so much for your comment. We have removed "For the trend variation..." in the manuscript accordingly.

L256 the reference is used incorrectly.

Response: Thanks so much for your comment. We have revised the incorrect format "(Xiaoyu and Jinping, 2013)." into "(Xiaoyu and Jinping, 2012)." in the manuscript accordingly.

Table 2. You mentioned in the text that the correlation exceeding 0.6 is marked by asterisk, while it is not always. Please check out.

Response: Thanks so much for your comment. Of the three principal components, the PCs with the highest correlation values greater than 0.6 are marked. Some correlations are greater than 0.6, but not the highest of the three. And we have revised the word "star" to "asterisk" in the manuscript accordingly.

L285 'appeared to be the strongest in around 2013 and 2017'

Response: Thanks so much for your comment. we have revised "appeared the strongest in approximately 2013 and 2017" to "appeared to be the strongest in around 2013 and 2017" in the manuscript accordingly.

Table 3 the first column should be 'PC2 IMF'. Also is the Table 4, where it should be 'PC3 IMF'.

Response: Thank you for carefully pointing out the mistakes in our manuscript. We have revised them in the manuscript.

L298. 'the change curve of ....' just the 'temporal curve...'

Response: Thanks so much for your comment. we have revised "the change curve of ..." to "temporal curve..." in the manuscript accordingly.

L303 DON'T use ' makes...have...' this kind of use is so weird in a scientific report. You can use alternative expression in other a lot of ways. For instance, 'allows a significant sea ice motion'. Why adopt a complexes and ambiguous expression to describe such a simple idea. I hope this kind of problem should be fixed throughout the manuscript in the revision.

Response: Thank you for carefully pointing out the mistakes in our manuscript. We have revised them in the manuscript, and fixed throughout the manuscript in the revision.

L317-319 Rewritten the sentence to express your idea simply and correctly.

Response: Thanks so much for your comment. We have revised the sentence as "The trend changes of the second and the third main patterns of Arctic sea ice drift retrieved by applying the EOF analysis are mainly correlation with ocean environmental factors. However, the first main pattern showed a more significant correlation with atmospheric environmental factors."

L352. 'Generally....' this sentence is a well-known information and not your conclusion.

Response: Thanks so much for your comment. Although this is well-known information, this study again summarizes and verifies this result by using long-term series climatological data. Therefore, I have written this in my conclusions.