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Interactive comment on "Contributions from intrinsic low-frequency climate variability to the accelerated decline in Arctic sea ice in recent decades" *by* Lejiang Yu and Shiyuan Zhong

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We greatly appreciate the insightful reviews by the reviewers. Below are our responses (in red) to each of the review comments (in black)

Response to Reviewer 1

Specific comments: Representation of sea ice concentration anomalies with 9 SOM spatial patterns (nodes, provided in Fig. 1) was selected. It is stated that results are similar with larger numbers of nodes, while smaller numbers are less representative. It is not clear how the spatial correlation coefficient (Table 1) was calculated however, and

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a change from 0.59 (2x4 nodes) to 0.64 (3x3 nodes) does not seem 'large' as stated on line 84. The spatial correlation values in Table 1 are obtained by two steps. First, for each autumn, spatial correlation between the sea ice anomaly pattern and the best matching SOM pattern is calculated (Lee and Feldstein, 2013). Second, the spatial correlations for all 38 autumns are averaged to obtain the mean spatial correlations shown in Table 1. These steps are repeated for the 8 pre-determined SOM grids in Table 1. The change from 0.59 to 0.64 is not large, but it is the largest gain between any two grids among the 8 grids tested. The choice of the grid is, admittedly, subjective. Obviously, higher spatial correlation can be achieved with larger grids. The 3x3 grid is able to capture the main variability pattern at the sacrifice of some details that can be depicted by larger grids. We have added clarification about the values in Table 1 and further justification of the choice of the grid.

For each of the 38 seasons available the best-matching node is tabulated (Fig 2). The'frequency of occurrence' is defined as the number of times a pattern is thus selected, divided by 38: thus both node 1 and node 9 have a frequency of occurrence of 23.7% (9/38) in Fig. 1.Nodes 1 and 9 have similar spatial distribution but opposite sign: node 9 (positive anomalies) is prominent early in the analysed period, and node 1 (negative anomalies) late in the period. Fig. 3 shows trends associated with each node: this seems to be the node spatial pattern multiplied by a rate. (It is not clear how the rate is determined: possibly temporal linear regression of the projections of each pattern each season?) Nodes 1 and 9 are the main contributors. The reviewers are correct about how the frequencies of occurrences and the trends or the rates of the change are determined. We have added clarification for these calculations Fig. 4 illustrates how much of the total observed trend is associated with the SOM nodes. (It is not clear how this is calculated, but the text states about 60% in all is associated with the selected SOM nodes.) The contribution of each SOM pattern to trends in Arctic sea ice concentration is calculated by the product of each SOM pattern and the rate, defined as temporal linear regression of the number of the projections of each pattern for each autumn. The sum of contributions from each node presents the total observed trend associated with the SOM nodes. The 60% is estimated by the ratios of residual trends to the total trends that range from 10 to 90% across grid points with statistically significant trends. This has been clarified in the manuscript Composites of sea surface temperature anomalies and various atmospheric quantities (anomalies from ERA-interim: 500hPa geopotential height, 850hPa wind, surface air T, surface downward longwave radiation, surface-to-750hPa water vapour) are made using years indicated in Fig. 2 for node 1 (2007-2013, 2015-2016), and, separately, for node 9 (1980-1982, 1986-1989, 1992, 1996). Effectively the SOM analysis provides the basis for these composites, which are illustrated in Figs. 5-7. The composites are likely quite similar to composites of years when autumnal Arctic sea ice coverage was high versus low according to various other criteria: this should be discussed. The authors claim SOM allows 'better depiction of atmospheric circulation patterns that have significant impact on sea ice trends' (line 175), but no evidence is provided to support this claim, and this is a major weakness of this article. The following paragraph and a new figure (Figure 8) have been added that compares SOM-based composites with typical time-series based composite approach. The SOM-based composites in the above discussion, which are made using years indicated (Fig. 2) by the occurrences for Node 1 (2007-2013, 2015-2016), and, separately, for node 9 (1980-1982, 1986-1989, 1992, 1996), are compared to composites of years of high (before 2000) and low (after 2000) Arctic sea ice coverage according to the Autumn Arctic sea ice time series (Figure 8). The composited SST patterns over the North Pacific are almost a mirror image to each other, indicating a positive (negative) phase PDO before (after) 2000 (Fig. 8). On the other hand, the composited SST patterns corresponding to Node 1 and Node 9 are not symmetrical (Fig. 5). Similar situations occur over North Atlantic. The magnitude and significant level of SOM-based SST composites in Fig. 5 are also higher than the time-series-based composites in Fig. 8. Similarly, in mid-latitudes, the composites of the anomalous 500hPa geopotential heights before and after 2000 are nearly symmetrical (Fig. 8) and the significant level and amplitude of the wave train are also lower than those in Fig. 5. At high latitudes, the anomalous atmospheric circulations

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in Fig. 8 show a mixed pattern of AO and AD and have no extreme centers. However, Fig. 5 exhibits clear AO and AD patterns and extreme centers, revealing more clearly the relationship between the anomalous sea ice concentration and anomalous atmospheric circulations. Based on these examples, the SOM-based composites allows for better depiction of atmospheric and SST conditions corresponding to sea ice anomaly patterns compared to typical time-series-based composite approach.

With a relatively small number of cases (9) in each composite, some discussion of whether the composites are dominated by a few 'extremes' should be provided. The following paragraph, along with three new figures, has been added. One drawback of the SOM-based composite is the relatively small number of composite members (Node 1 and Node 9 each has 9 members), which makes the composite more vulnerable to the influence of extreme cases. To examine this issue, the standard deviations of the SOM-based composites are compared to those of time-series-based composites that have much larger members (17 members for after-2000- composites and 21 members for before-2000-composites) and the results for the anomalous SST and 500-hPa height are shown in Figs. S1 and S2. The spatial patterns and magnitudes of the standard deviations are similar between the Node-1 and after-2000 composites and between Node-9 and before-2000 composites. The F-test indicates that except for small patches there are no statistically significant differences in the standard deviations between the small member SOM-based composites and the large-member typical composites (Fig.3), suggesting it is unlikely the SOM-based composites are strongly influenced by extreme cases as a result of small composite members.

The analysis is largely descriptive. Various features in the composites are noted that are consistent with Arctic changes: e.g. for node 1 there are influences that favour sea ice reduction. Although suggestive in appearance, it is not evident that the SST anomalies and geopotential height anomalies in Fig. 5 are related as described. A zonal wavenumber 2 wavetrain (lines 134, 152) is not obvious. We have added OLR composite analysis to determine the source of the wave train and further explain the relationship between SST and geopotential height anomalies. The anomalous convection activity over the tropical western Pacific Ocean can excite a wave train that propagates northeastwards. Over the mid-latitude North Pacific, the different local interaction between anomalous SST and wave train for Nodes 1 and 9 leads to different and asymmetrical pattern in the high latitudes.

Regarding downward longwave radiation and water vapour, how reliable are the ERA analyses in the Arctic? Ding et al. (2017) noted that the ERA-Interim analysis can represent reliably the observed circulation, radiation flux, temperature, and water vapour. Serreze et al. (2012) assessed humidity data from ERA-Interim analysis and found small bias of less than 8% at 1000 hPa for boreal autumn and smaller bias above 1000 hPa. Hence we considered ERA-Interim can represent reasonably well the observed downward longwave radiation and water vapour.

While the analyses demonstrate associated changes in sea ice and in SST and atmospheric circulation, they do not in themselves seem to indicate cause and effect, so it is difficult to draw conclusions regarding mechanisms. The 'important finding' relating sea ice changes to asymmetry in North Pacific SST anomalies (lines 184-188) is not well justified. The claim of 'large contributions from the decadal-scale natural climate variability to Arctic climate change' (lines 193-194) does not seem well justified. We added OLR analysis to show the source of the wave train. Local and asymmetrical interactions of SST and the node of wave train produce anomalous atmospheric circulations over the mid-high latitudes, which are related to anomalous Arctic sea ice concentrations. We agree that this and other analyses, which reveal the associations, do not demonstrate cause and effect. This is the major limitation of these types of climate diagnoses. We have softened the languages, e.g. important finding to major results, to reflect this point.

Other suggestions for technical corrections:

The term 'explained' is often used, but in the sense of statistical rather than physical

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explanation, which should be made clear. We added ‘in the statistical sense’ in the sentence where ‘explained’ is used, or replaced the word ‘explained’ by ‘is shown to be related’ The acronyms PDO, AMO, AD, AO are used without definition. The definitions of PDO, AMO, AD, and AO were added in Dataset and Methods section The title is rather misleading: the article is more about ‘SST and atmospheric patterns associated with reductions in sea ice cover in recent decades’ The title is changed to ‘The changes in sea-surface temperature and atmospheric circulation patterns associated with reductions in Arctic sea ice cover in recent decades’

Please also note the supplement to this comment:
https://www.atmos-chem-phys-discuss.net/acp-2018-127/acp-2018-127-AC1-supplement.pdf

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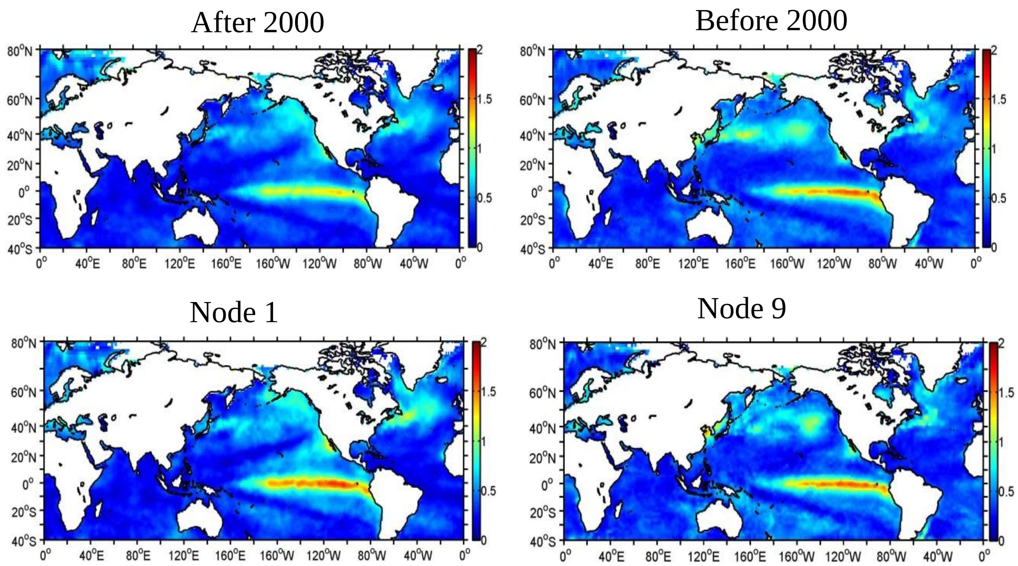

Figure S1 The standard deviations of composite SST for Nodes 1 and 9, and after and before 2000.

Fig. 1.

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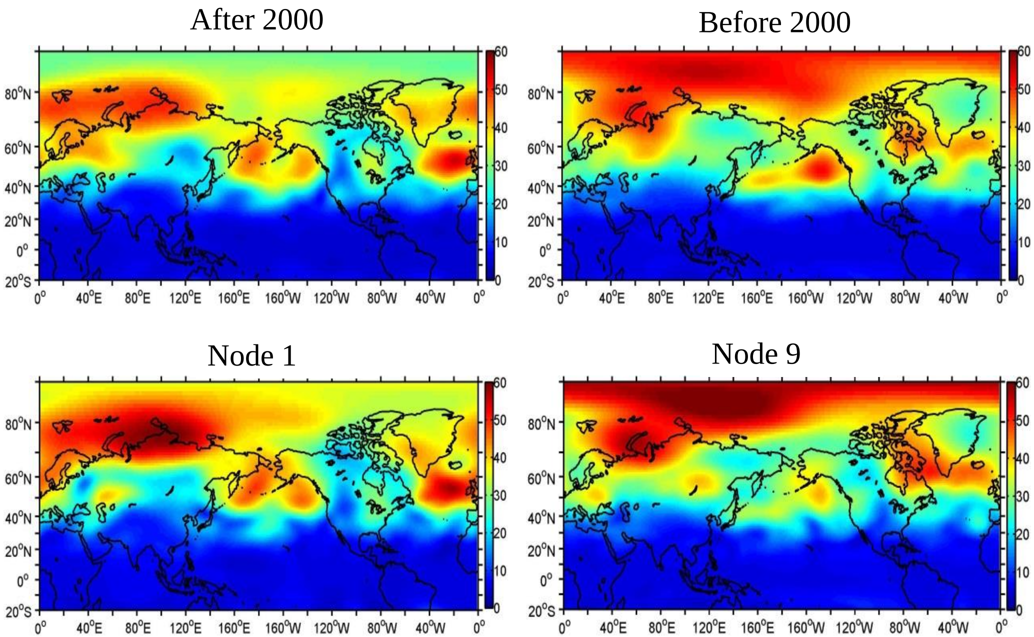

Figure S2 The standard deviations of composite 500-hPa height for Nodes 1 and 9, and after and before 2000.

Fig. 2.

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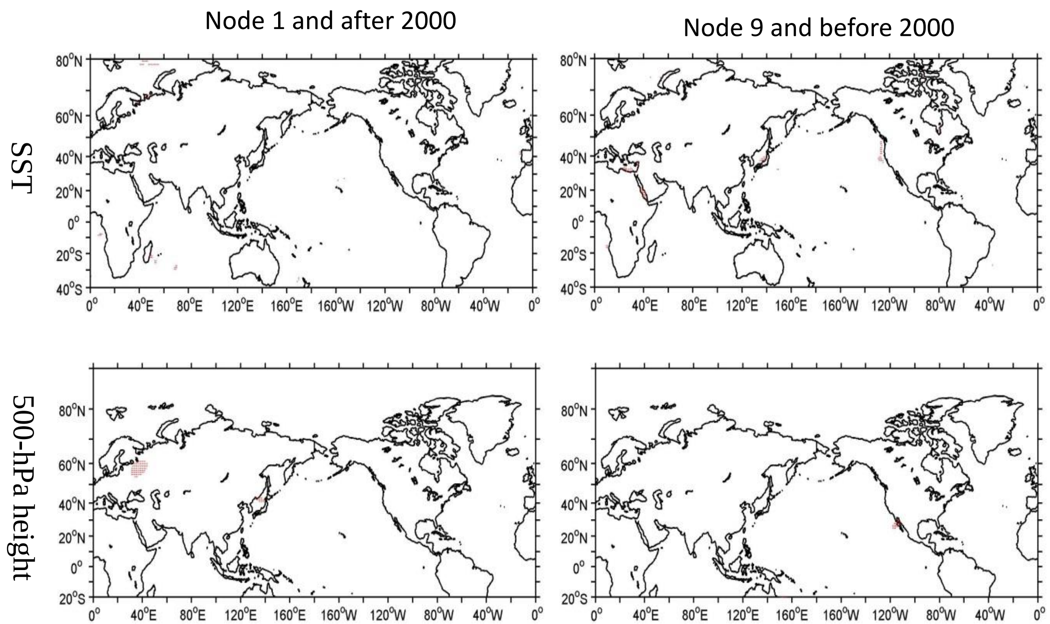

Figure S3 The significant test of standard deviation for SST and 500-hPa height between Node 1 and after 2000, and Node 9 and before 2000 using F test. Red dots denote above 95% confidence level.

Fig. 3.