Interactive comment on "The role of moisture transport for precipitation on the interannual and inter-daily fluctuations of the arctic sea ice extension" by Luis Gimeno-Sotelo et al. Anonymous

Referee #1 Received and published: 13 October 2018

Summary statement This paper explores the very timely topic of moisture transport into the Arctic and the consequences for sea ice extent. Previous work has identified key moisture sources for the Arctic and variations in moisture transport into the Arctic. This study focuses on the interannual variations around the declining trend in sea ice. We know from the Sea Ice Outlook (https://www.arcus.org/sipn/sea-ice-outlook) synthesis research that sea ice forecasts are able to forecast the September minima well if it is close to the trend rather than if it deviates far from the trend (Hamilton and Stroeve 2016). So, understanding the causes of variations around the trend is really important for improving sea ice forecasts. C1 ESDD Interactive comment Printer-friendly version Discussion paper This study finds that monthly negative ice extent anomalies (from the trend) are associated with increased moisture transport in summer, fall and winter and decreased moisture transport in spring. Extremes in humidity transport have a slightly different relationship with sea ice extent. The results are publication-worthy and the topic timely but before being publishable the manuscript needs revisions to refine the interpretation and to make the material more easily understandable.

Major comments

1) All of the relationships that are explored are contemporaneous on a monthly time scale between moisture transport and sea ice. I am not sure if moisture transport into the Arctic can have an impact on sea ice extent within a month of falling. It is not obvious to me that the moisture is causing the changes in sea ice extent. This is my biggest sticking point for the presentation of the results of this paper. Maybe this causality is clear in the authors minds but it has not been explained clearly enough in the paper. I feel that there is a gap in this part of the story. It could be that more extreme precipitation in winter and increased sea ice are both the results of some other factor. It is an interesting result but I think the explanation/interpretation needs to be refined. Large changes to sea ice in the winter occur in the marginal ice zone. Perhaps if there is lots of moisture transported then the wind forcing of sea ice leads to a northward movement of the ice edge. The changes at the southern perimeter of the ice have the biggest impact on the hemispheric sea ice extent (larger proportion of total area). So I think there could be other mechanisms that favor both more moisture and less ice. These ideas need more attention in this paper.

Answer: We agree with the Reviewer on this point. We have added some text to include a brief overview of the effects of changes in moisture on the Arctic Sea Ice, which complements point 5, in which the links of MTP with fusion mechanisms are described. Concerning the multiplicity of causes of the variations in Sea Ice Extent and the difficulty of establishing causal relationships with a single factor, we have added a paragraph in the introduction together with a short comment in the conclusions.

Changes in the manuscript:

We have added a paragraph to the introduction to account for the possible multiplicity of causes of melting

Lines 63 to 70 *" It is important to note that there is no a single cause of the change in sea ice extent, and indeed, different factors could come into play at the same time, making it difficult to identify a causal relationship. For example, changes in circulation might imply changes in the transport of moisture, with consequent changes in radiative forcing due to changes in water vapour or cloud formation, but there might also be changes in the wind, with the consequent displacement of ice or changes to the heat flux; changes in circulation would thus both encompass and cause other effects. This multiplicity of causes together with the difficulty of establishing causal relationships via a single factor should be always taken into account when analysing drivers of sea ice melting".*

We have added an overview of the effects of changes in moisture on the Arctic Sea Ice, together with the physical mechanisms involved, to point 3, which is now retitled: **3. Overview of the effects of changes in moisture on the Arctic Sea Ice and moisture transport to the Arctic**

Lines 128 to 140 *" Changes in moisture in the Arctic lead to effects on the Arctic ice, which do not always result in the same direction of change. Without considering changes in the albedo and the resulting feedback, or changes in the vertical profiles of temperature and humidity, the direct interaction can be summarised in four main actions, i) changes in the balance of infrared (IR) radiation given the importance of water vapour as a greenhouse gas, the general effect being to increase the incident IR radiation causing heating of the surface (e.g., Bagget et al., 2016), ii) changes in condensation processes due to enhanced water vapour, which necessarily affect the surface temperature by emission of sensible heat to the atmosphere due to the release of latent heat, iii) changes in cloud cover, which can alter the incident radiation at the surface, and in this case the effect will depend on the height of the cloud cover and seasonality, and iv) changes in precipitation where there are dynamical or thermodynamical forcing mechanisms, the relationship between precipitation and melting ice being variable depending on the type of precipitation and the season (e.g., Vihma et al., 2016). All these actions can have different effects on the Sea ice cover at the time scales of our study, from daily to decadal variations.*

We have added a paragraph at the end of the conclusions to account for the possible multiplicity of causes of variations in the extent of sea ice, and the need for careful interpretation of the results

Lines 313 to 320 *"The results of both this and our previous article (Gimeno-Sotelo et al, 2018) must be interpreted with care, given that there is no single cause of the variability of the ice extent, and it could be the case that just as changes in the same direction as the MTP do not influence the extent of the ice through a single mechanism, so the MTP could have an influence through changes in*

precipitation but also through changes in the wind forcing of the ice, leading to a northward movement of the edge of the ice, with consequent changes in the extent of the sea ice in the Arctic. A more detailed analysis to try to isolate regions and situations in which a particular mechanism predominates could help to understand the causes of variations in SIE with respect to the trend of interest, with important implications for improving forecasting (Hamilton and Stroeve 2016)".

2) I found the paper hard to read in places because it is not self-contained. There are multiple places in the text where I am referred to the supplement or previous work to understand the concept. I think referencing published works for details is fine, but a conceptual description of the method or result is needed to make this paper more self-contained. For example, the following text does not help me understand what the CTC method uses without having to dig out this paper. It does not require a lot of input a concise description would make the paper flow better. Below is just one example but this happens throughout the paper. line 170-171 The circulation types (CTCs) used in this study are the same as those described in Gimeno-Sotelo et al (2018), based on a approach developed by Fettweis et al. (2011) and shown in Supplementary Figure S3.

Answer: We agree with the Reviewer on this point, so we have expanded our explanation of CTCs

Changes in the manuscript: We have expanded our explanation to make it more 'self-contained'.

Where it reads (lines 170-171) : The circulation types (CTCs) used in this study are the same as those described in Gimeno-Sotelo et al (2018), based on an approach developed by Fettweis et al. (2011) and shown in Supplementary Figure S3.

This now reads

Lines 206 to 220 *The circulation types (CTCs) used in this study are the same as those described in Gimeno-Sotelo et al (2018), based on an approach developed by Fettweis et al. (2011). The CTCs were obtained individually for each source region, based on a correlation analysis, where atmospheric circulation is categorised into four discrete CTCs, each containing days that showed similar patterns of circulation. In essence, the method is used to calculate a similarity index based on correlations with the geopotential height field at 850 hPa obtained from ERA-Interim for each pair of days. It uses the highest number of similar days and a high correlation threshold (0.95) to define the first class; it then uses a lower similarity threshold with the remaining days to define the second class, and so on. The procedure is repeated using different thresholds to optimise the percentage of variance explained (Philipp et al., 2010). The CTCs are shown in Supplementary Figure S3 and in general they resemble known teleconnection patterns in the four regions analysed (Barnston and Livezey, 1987, and http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml). For the Atlantic sector, for example, CTC1 resembles the positive phase of the eastern Atlantic pattern and CTC2 resembles the negative phase of the eastern Atlantic and western Russia. CTC3 resembles the negative phase of*

the North Atlantic Oscillation, and CTC4 resembles the positive phase of the Scandinavian pattern.

3) This is something between a major and a minor comment. . . lines 158-169, Would this fit better in the introduction? This is published work that is relevant for this study.

Answer: We agree with the Reviewer on this point

Changes in the manuscript: We have moved part of this paragraph to the introduction

Minor comments

All the minor changes have been addressed according to the Reviewer´s comments

1) line 43-45, increased moisture in the summer typically is associated with cooling and slower sea ice melt, so the statement as it stands pertains to the cool season (sept-april).

2) line 81, I am more used to seeing the phrase 'vertically integrated moisture transport'

3) line 90, change 'rewides' with 'resides'

4) line 107-110, This sentence seems repetitive. The amounts of moisture provided by each of the four sources is listed twice.

5) line 115-116, 'The Pacific source dominates in the Barents.' I think the authors mean Bering not Barents.

6) Figure 3 caption, needs some more descriptive text. List the chosen high and low years in the caption and identify them with a star on the time series.

7) Line 124, the definition given here for the smoothing would be an 11-year running mean.

8) lines 126-128, the discussion of the standard deviation lines would fit better in the caption of Figure 3. Lines 128-136, The general discussion of how the extreme years are chosen can be tightened to use this space elsewhere.

9) line 140, 'for years' is repeated

10) The phrase 'annual march' is used throughout. It is confusing on one of the figures which are labeled 'Annual March'. I suggest 'seasonal cycle' instead in order to avoid C3 ESDD Interactive comment Printer-friendly version Discussion paper any confusion with the month of March when the Arctic sea ice maximum occurs.