Comments to Interactive comment on "The perfect pattern of moisture transport for precipitation for Arctic sea ice melting" by Luis Gimeno-Sotelo et al.

Anonymous Referee #2 Received and published: 6 March 2018 "The perfect pattern of moisture transport for precipitation for Arctic sea ice melting"

First, I find the title confusing and even misleading. Which perfect pattern is meant? Also, the statement "moisture transport for precipitation for Arctic sea ice melting" sounds rather awkward. I suggest to modify the title.

The reviewer is right. The term "perfect pattern" is disconcerting. We´ll change the title to something less confusing such as "The pattern of long-term changes in the moisture transport for precipitation with Arctic sea ice melting". We prefer to keep the term moisture transport for precipitation because it is the usual term in previous studies using the same methodology

The authors present a detailed analysis with clear graphical representations, however methodology description is unfortunately too vague to appreciate and understand the results. I invite the authors to explain the concept of the change points in relationship to its application to the Arctic sea ice extent data. Further, it is not clear how the results shown in Fig 6 have been obtained and how these results can be interpreted.

We have used several methods to estimate change points in sea ice extension to detect when the main long-range change occurred. As usual in time series analysis a change point detection tries to identify times when the time series in mean or variance changed. In this case we were interested mainly in mean changes (in the Arctic sea extension the change means decrease, higher values before the change point and lower after it)

Three different change point detections were used for different sea ice extension time series, as explained in the manuscript. As an example we´ll included in the paper a new figure (above) for two series and one method, AMOC. The top plot represents the 13505-values Arctic ice extent anomalies series consisting of all days from 1st January 1980 to 31st December 2016. There are two horizontal lines in the left panel representing the mean of the values before and after the change point identified by the AMOC method (8660th day-22th September 2003). Those means are 0.27 and -0.91, respectively. The graphic at the bottom portrays the 444-values Arctic ice extent anomalies series consisting of all months from January 1980 to December 2016. As in the previous one, in the left panel there are two horizontal lines which correspond to the mean of the data before and after the AMOC change point (286-October 2003). Those means are 0.41 and -0.74, respectively.

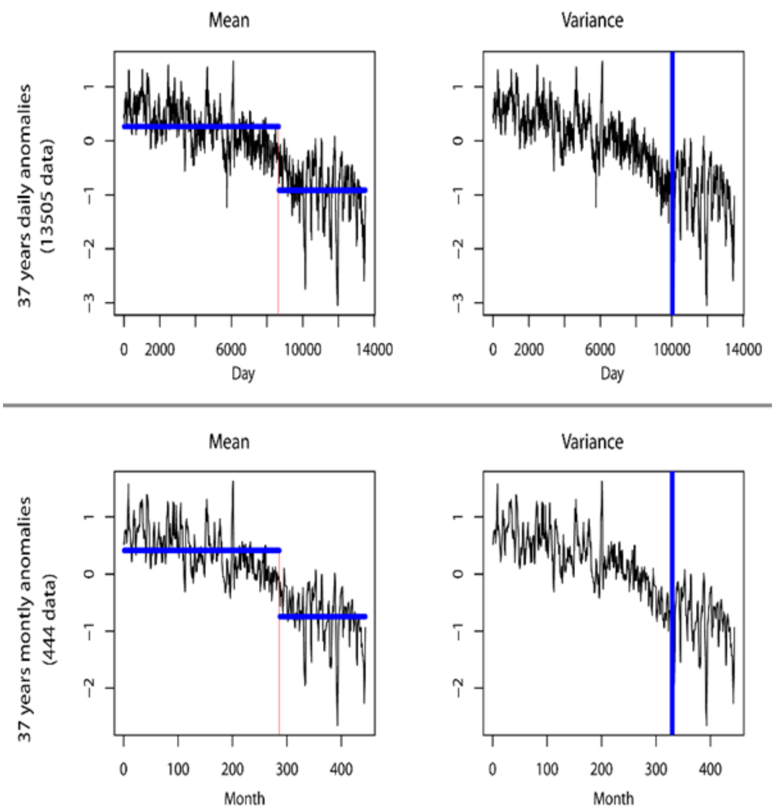


Figure 6 tries to summarize results of the change points estimation in mean identified by the AMOC method for the four different kinds of series of Arctic ice extent anomalies from 1980 to 2016 (as described in the methods section). So:

**A blue point refers to the change points in DS; for instance, the 21 July daily anomaly series (size of the series: 37 data points, representing 37 annual anomalies of the values of the sea ice extension for the 37 values on 21 July); occurred in 2004.*

** A red line portrays change points in the MS (July–October). For instance, for July monthly anomaly series (size of each series: 37 data points, representing 37 annual anomalies of the values of the sea ice extension for the 37 values in the average monthly July); occurred in 2004.*

** The single green square corresponds to the change point in the ADS, only one series of all daily anomalies (size of the series: 13,505 data points) built by ordering the daily anomalies in DS from 1 January 1980 to 31 December 2016 and the change point occurred the 22^{nd} September 2003*

** The single purple line represents the change point in the AMS, only one series of all monthly anomalies (size of the series: 444 data points) built by ordering the monthly anomalies in MS from January 1980 to December 2016 and the change occurred in October 2003*

This plot was designed to show the big coherence of results for the different built series, what permitted us to select 2003 as the CHANGE POINT of the sea ice extent for our analysis

We´ll try to explain a bit more the figure 6 with examples in the revised paper to do easier the reading and interpretation of the results

Section 3.2 text is very descriptive and lacks interpretation. The methodology of the E-P analysis along the trajectories also needs to be better described. The moisture source regions are predefined from another study without any explanation - I invite the authors to explain the method in more details.

In view to not enlarge the paper with wide methodological description (what has been done in many of our previous papers) we preferred to condense the information, lacking any details that probable difficult the correct understanding of the approach and the own meaning of the MTP, we´ll extend this description in the revised paper

The wording itself "moisture transport for precipitation" sounds confusing and has to be rephrased and better defined.

We prefer to keep the term moisture transport for precipitation because it is the usual term in previous studies using the same methodology, however we´ll try to explain better its meaning

The sentence explaining the methodology ("Then, we selected all particles losing moisture, (e − p) < 0, at the sinks (whole Arctic or any of the subregions), and by adding e − p for all of these particles, we estimated moisture transport for precipitation from the source to the sink (E − P) < 0 at daily, monthly or yearly scales.") needs more clarification with an extended explanation.

We´ll extend the explanation in the revised paper

This approach also doesn't imply that precipitation results exclusively from the moisture transport and local paper moisture re-circulation can also contribute.

Of course, and this is without any doubt an important contribution, but not addressed in this study, limited to the influence of remote sources. We´ll add any sentence in the revised manuscript to account for this, which is important for the correct interpretation of the results

I find a lot of similarities of this manuscript with another article by a coauthor of the present article Vasquez et al 2017 (www.mdpi.com/2073-4433/8/2/32/pdf), which is not somehow in the reference list. Can the authors put this manuscript in context of Vasquez et al 2017 explaining the novelty of the results?

Although the objective of Vazquez et al. (2017) was too to analyze the effect of moisture transport on the Arctic ice melting and the Lagrangian approach is the same both studies differ a lot. In Vazquez et al. (2017) we analyzed the influence of the transport on the two most important sea ice minimum events (2007 and 2012) and the analysis is based mostly on an analysis of anomalies. In this paper we analyzed the long-term changes in the moisture transport concurrent with long-term changes in sea ice (sea ice decline). However we´ll add a comment on this in the introduction to contextualize the study.

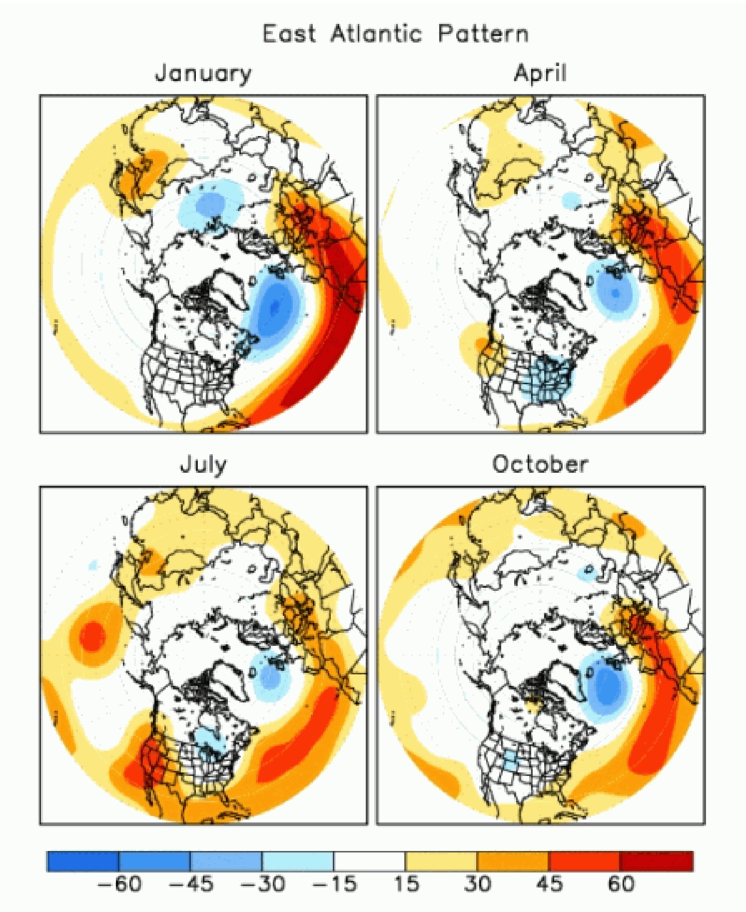
"We grouped individual days into four circulation types using the methodology developed by Fettweis et al. (2011) and explained in the Data and Methods sections." - in the Methods section the authors mention five (not four) circulation types and give no further explanations (which types, how they were defined...). Abbreviations used for the circulation types are not explained.

The reviewer is right; there is an error in the number of classes. It will be corrected in the manuscript. More details on the circulation types methodology will be included in the revised version of the manuscript.

The abbreviations will be included in the methods section.

What does it mean "the positive phase of the East Atlantic pattern" or " the negative phase of the East Atlantic/western Russia"?

You are right. We have supposed readers familiar with teleconnection patterns and their phases. According to the NOAA definition "The term teleconnection pattern alludes to a to a recurring and persistent large-scale pattern of pressure and circulation anomalies that spans vast geographical areas. These patterns have strong influence on temperature, rainfall, storm tracks, and jet stream location/ intensity over vast areas and consequently are often assumed as responsible for abnormal weather patterns occurring simultaneously over seemingly vast distances". We included in the main text of the manuscript the known web page from NOAA http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml where the patterns are described and their phases plotted. For instance, the East Atlantic pattern consists of a north-south dipole of anomaly centers spanning the North Atlantic from east to west with the positive phase with positive anomalies in the south pole, the one placed in the subtropics (see figure below)



We´ll describe a bit in the revised version of the manuscript what a teleconnection pattern is and the structure of those patterns referred in the main text

I find that many statements in the Conclusions are not supported by the results. A major change seems to occur in 2003 - however unclear how this was obtained and what does it mean exactly (from the conclusions one can deduce that it means a drastic sea ice decline - I suppose the "change point" technique allows to detect that the mean SIE over the period after 2003 is significantly smaller than before). And the "perfect pattern of MTP for Arctic sea ice melting consists of a general decrease in moisture transport in summer and an increase in fall and early winter", as stated in the Conclusions section, refers to this year as I understand (no longer mentioned in the Conclusions).

We´ll re-write these sentences in the conclusions. You are right, the 2003 change means a drastic sea ice decline and a decrease in moisture transport in summer and an increase in fall and early winter after 2003 vs before 2003

"This pattern is not only statistically significant but also consistent with Eulerian flux diagnosis, changes in circulation type frequency, and known mechanisms affecting snowfall or rainfall on ice in the Arctic." - which other known mechanisms affecting precipitation the authors refer to?

Basically we are referring to the mechanisms summarized in the introduction

"Snowfall on sea ice enhances thermal insulation and thus reduces sea ice growth in winter (Leppäranta, 1993), but increases the surface albedo and thus reduces melt in spring and summer (Cheng et al., 2008). In contrast, rainfall is generally related to sea ice melt, and for both snowfall and rainfall, flooding over the ice favors the formation of superimposed ice and potentially increases in the Arctic sea ice thickness"

The implications of these mechanism coherent with our results would be:

A lower MTP in early summer (as occurred since 2003) is consistent with lower precipitation in snowfall decreasing the surface albedo and thus increasing melt (Cheng et al., 2008)

A lower MTP in late summer (as occurred since 2003) is consistent with less probability of occurrence of rainfall storms with possible flooding over the ice which would favor the formation of superimposed ice

A higher MTP in early fall (September) (as occurred since 2003) is consistent with higher precipitation as rainfall, something generally related to sea ice melt

A higher MTP in late fall and early winter (as occurred since 2003) is consistent with higher precipitation as snowfall, enhancing thermal insulation and thus reducing sea ice growth in (Leppäranta, 1993)

Of course to check these implications rigorously is clearly out of the scope of this manuscript, since it would imply to know details over the precipitation form (snow or rain) for the different Arctic regions with good temporal and geographical resolution, and even to analyze specific precipitation episodes to know if these are responsible for flooding or not.

The comment in the conclusion has as objective to reinforce the creditability of the significant results from the Lagrangian analysis.

We´ll extend the comment in the line of described in this comment

"it is clear beyond doubt that an increment in moisture transport during this month favours ice melting, regardless of the source of moisture." - how is that clear? September's increase in MTP according to the methodology used here (if I understood correctly) means increased local precipitation vs evaporation (not necessarily increased moisture transport), and its impact to the SIE has not been established in this study. There are previous studies showing that the linkage can be the other way that precipitation has increased because of the decreased sea ice extent (eg, Bintanja, R. & Selten, F. M. Future increases in Arctic precipitation linked to local evaporation and sea ice retreat. Nature 509, 479–482 (2014).).

Not at all. I´m afraid that the reviewer has not understood properly the methodology and the meaning of MTP, probably for any lack of detail in the explanation of it (see previous comments). We´ll extend this explanation to avoid fails in the interpretation of the results. An increment in MTP in our study means exactly an increment in the moisture transported from the four major remote sources which then result in precipitation in the target region (Arctic region, subregions…). Changes in the precipitation in the Arctic could be of course due to changes in the moisture transport from remote sources but also and not less important to changes in evaporation from the own Arctic (a major factor, according to previous studies, but not evaluated in this paper).

We´ll try to clarify this in the revised version of the manuscript to avoid misunderstanding in the interpretation of the results

"Snowfall is the dominant (almost unique) form of precipitation during most of the year, with the exception of late summer." - there is frequent rain during summer (and not only later summer), especially in the peripheral Arctic regions. Even in the central Arctic rain can occur in the very beginning of the melt period (like during SHEBA, eg Perovich et al 2002).

We´ll re-write this to avoid so categorical affirmation

" when precipitation is produced in the form of snowfall on sea ice, it enhances thermal insulation, and reduces sea ice growth in winter (Leppäranta, 1993), but increases the surface albedo, and thus reduces melt in spring and summer (Cheng et al., 2008). These phenomena justify the opposite change in moisture transport for fall and winter versus spring." - how can these phenomena justify any changes in moisture transport?

These phenomena do not justify changes in the moisture transport but changes in the effect of precipitation on the sea ice. As we estimate changes in the moisture transport for precipitation (MTP), higher MTP results in more precipitation, this is the basis of the argument.

The manuscript has to be checked for language and consistency - there are many vague, incomplete phrases.

The first version was edited by a professional English service, in any case we´ll check carefully the revised version of the manuscript