COMMENTS TO THE FOUR REVIEWERS AND REVISED MANUSCRIPT WITH CHANGES

GENERAL COMMENT

We have changed the tittle by removing SHORT COMMUNICATION in the beginning so that the manuscript will be labelled so by the journal.

REFEREE 1

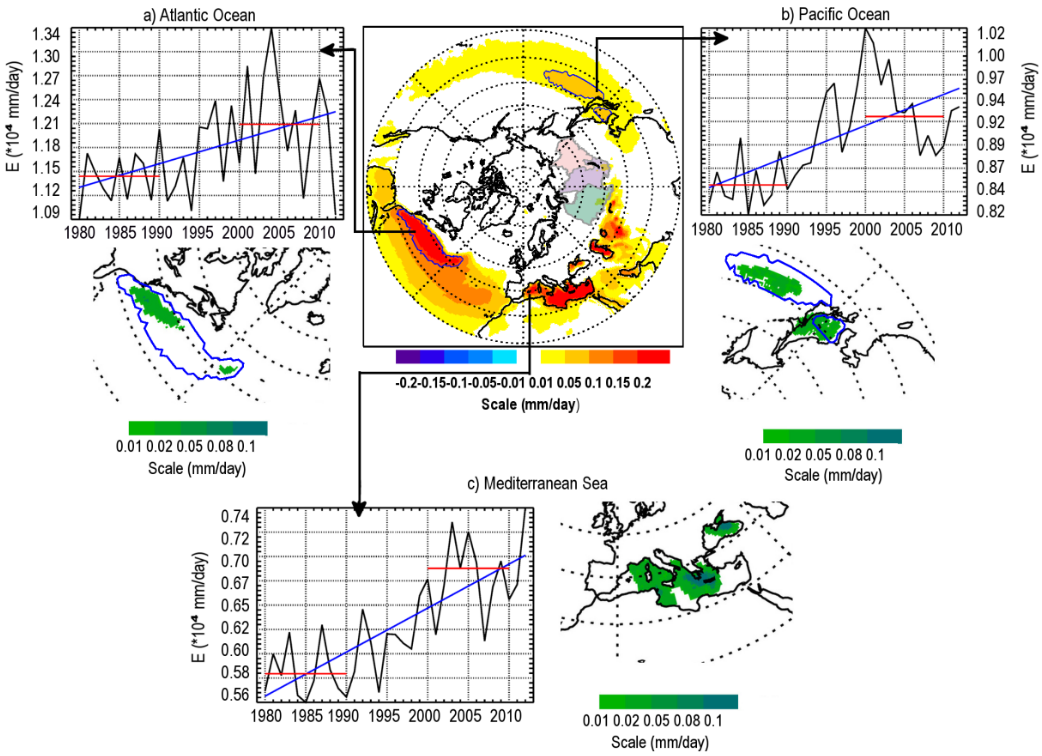
1) I suggest to shorten and to rewrite the abstract. The first sentence is confusing.

Shortened and rewritten also taking into account comments from other reviewers. The first sentence was deleted (Strikethrough text shows what is old and removed and text in red shows what is new and added)

~~" If we could choose a region where the effects of global warming are likely to be pronounced and considerable, and at the same time one where the changes could affect the global climate in similarly asymmetric way with respect to other regions, this would unequivocally be the Arctic. The atmospheric branch of the hydrological cycle lies behind the linkages between the Arctic system and the global climate.~~ Changes in the atmospheric moisture transport have been proposed as a vehicle for interpreting any of the most significant changes in the Arctic region. The increasing moisture over the Arctic during last decades it is not strongly associated with the evaporation that takes place within the Arctic area itself, despite the fact that the sea-ice cover is decreasing. Such increment is consistent is more dependent on ~~but to the fact that~~ the transport of moisture from the extratropical regions to the Arctic that has increased in recent decades, and is expected to increase within a warming climate. This increase could be due either to changes in circulation patterns which have altered the moisture sources, or to changes in the intensity of the moisture sources because of enhanced evaporation, or a combination of these two mechanisms. In this short communication we focus on the assessing more objectively the strong link between ocean evaporation trends and Arctic Sea ice melting. We will critically analyze several recent results suggesting links between moisture transport and the extent of sea-ice in the Arctic, this being one of the most distinct indicators of continuous climate change both in the Arctic and on a global scale. To do this we will use a sophisticated Lagrangian approach to develop a more robust framework on some of these previous disconnecting results, using new information and insights. Results reached in this study seems to stress the connection between two climate change indicators, namely an increase in evaporation over source regions (mainly the Mediterranean Sea, the North Atlantic Ocean and the North Pacific Ocean in the paths of the global western boundary currents and their extensions) and Arctic ice melting precursors. ~~Among the many mechanisms that could be involved are hydrological (increased Arctic river discharges), radiative (increase of cloud cover and water vapour) and meteorological (increase in summer storms crossing the Arctic, or increments in precipitation)"~~

2) Figure 1 is difficult to understand and too small. I suggest to separate it into 3 different Figures.

We appreciate the reviewer comment. The idea of plotting results in a single figure is to have a global vision of three sources of moisture together. We modified the figure as suggested the other reviewers and we hope that now it could be easier to follow than the original one.



3) The trends in the 3 regions show a pronounced decadal-scale variability and the authors should reflect about that.

We have added this to the sentence (in red)

"Although superimposed to a pronounced decadal-scale variability trends are significant in most of the grid points encircled, and are especially clear for the Atlantic, Pacific and Mediterranean sources"

4) What is the origin of the enhanced evaporation over the 3 ocean regions?

There are different factors that can affect the oceanic evaporation. Yu (2007) or Yu and Weller (2007) realized some studies on this topic finding a relationship between enhanced evaporation trends over the XXI century and wind speed or SST. In Yu (2007) it is reported:

"The analysis suggested a dominant role of the wind forcing in the decadal change of evaporation. It is hypothesized that wind impacts Evp in two ways. The first way is direct: the greater wind speed induces more evaporation by carrying water vapor away from the evaporating surface to allow the air–sea humidity gradients to be reestablished at a faster pace. The second way is indirect: the enhanced surface wind strengthens the wind-driven subtropical gyre, which in turn drives a greater heat transport by the western boundary currents, warms up SST along the paths of the currents and extensions, and causes more evaporation by enlarging the air–sea humidity gradients"

Despite its relevance we are not going to include this long reasoning in the text but only a reference to the wind forcing suggested by Yu (2007) article.

"The spatial distribution of these trends (Yu, 2007) shows that while the increase in evaporation has occurred globally, it has primarily been observed during the hemispheric winter and is strongest along the paths of the global western boundary currents and any inner Seas with wind forcing playing a dominant role."

REFEREE 2

1) I think the authors can more emphasize, in the title or abstract, the fact that the recent moisture increase over the Arctic is not highly linked with an evaporation within the Arctic. This is because the ice-albedo feedback, which is very well-known and notable hypothesis, argues that an evaporation from the Arctic Ocean that is uncovered by sea-ice is an important source of the wintertime Arctic moisture. However, some of the recent studies showed that the evaporation from the Arctic surface appears not to be an important moisture source (e.g., Graversen et al. 2008; Park et al. 2015).

Graversen, R. G., T. Mauritsen, M. Tjernstrom, E. Kallen, and G. Svensson, 2008: Vertical structure of recent Arctic warming. Nature, 541, 53-56.

Park, D.-S. R., S. Lee, and S. B. Feldstein, 2015: Attribution of the Recent Winter Sea Ice Decline over the Atlantic Sector of the Arctic Ocean. J. Climate, 28, 4027–4033.

We agree with the reviewer's suggestion and have therefore changed by adding the comment in the abstract and in the introduction (last sentence paragraph 3)

IN THE ABSTRACT:

(Strikethrough text shows what is old and removed and text in red shows what is new and added)

~~" If we could choose a region where the effects of global warming are likely to be pronounced and considerable, and at the same time one where the changes could affect the global climate in similarly asymmetric way with respect to other regions, this would unequivocally be the Arctic. The atmospheric branch of the hydrological cycle lies behind the linkages between the Arctic system and the global climate.~~ Changes in the atmospheric moisture transport have been proposed as a vehicle for interpreting any of the most significant changes in the Arctic region. The increasing moisture over the Arctic during last decades it is not strongly associated with the evaporation that takes place within the Arctic area itself, despite the fact that the sea-ice cover is decreasing. Such increment is consistent is more dependent on ~~but to the fact that~~ the transport of moisture from the extratropical regions to the Arctic that has increased in recent decades, and is expected to increase within a warming climate. This increase could be due either to changes in circulation patterns which have altered the moisture sources, or to changes in the intensity of the moisture sources because of enhanced evaporation, or a combination of these two mechanisms. In this short communication we focus on the assessing more objectively the strong link between ocean evaporation trends and Arctic Sea ice melting. We will critically analyze several recent results suggesting links between moisture transport and the extent of sea-ice in the Arctic, this being one of the most distinct indicators of continuous climate change both in the Arctic and on a global scale. To do this we will use a sophisticated Lagrangian approach to develop a more robust framework on some of these previous disconnecting results, using new information and insights. Results reached in this study seems to stress the connection between two climate change indicators, namely an increase in evaporation over source regions (mainly the Mediterranean Sea, the North Atlantic Ocean and the North Pacific Ocean in the paths of the global western boundary currents and their extensions) and Arctic ice melting precursors. ~~Among the many mechanisms that could be involved are hydrological (increased Arctic river discharges), radiative (increase of cloud cover and water vapour) and meteorological (increase in summer storms crossing the Arctic, or increments in precipitation)"~~

IN THE INTRODUCTION:

"In particular, changes in the atmospheric moisture have been proposed as a vehicle for interpreting the most significant changes in the Arctic region either due to increase transport from middle latitudes (Lucarini and Ragone, 2011; Zhang et al., 2013) or via enhance local evaporation (Bintanja and Seltan, 2014). However, some of the recent studies showed that the evaporation from the Arctic surface appears not to be an important moisture source (e.g., Graversen et al. 2008; Park et al. 2015)".

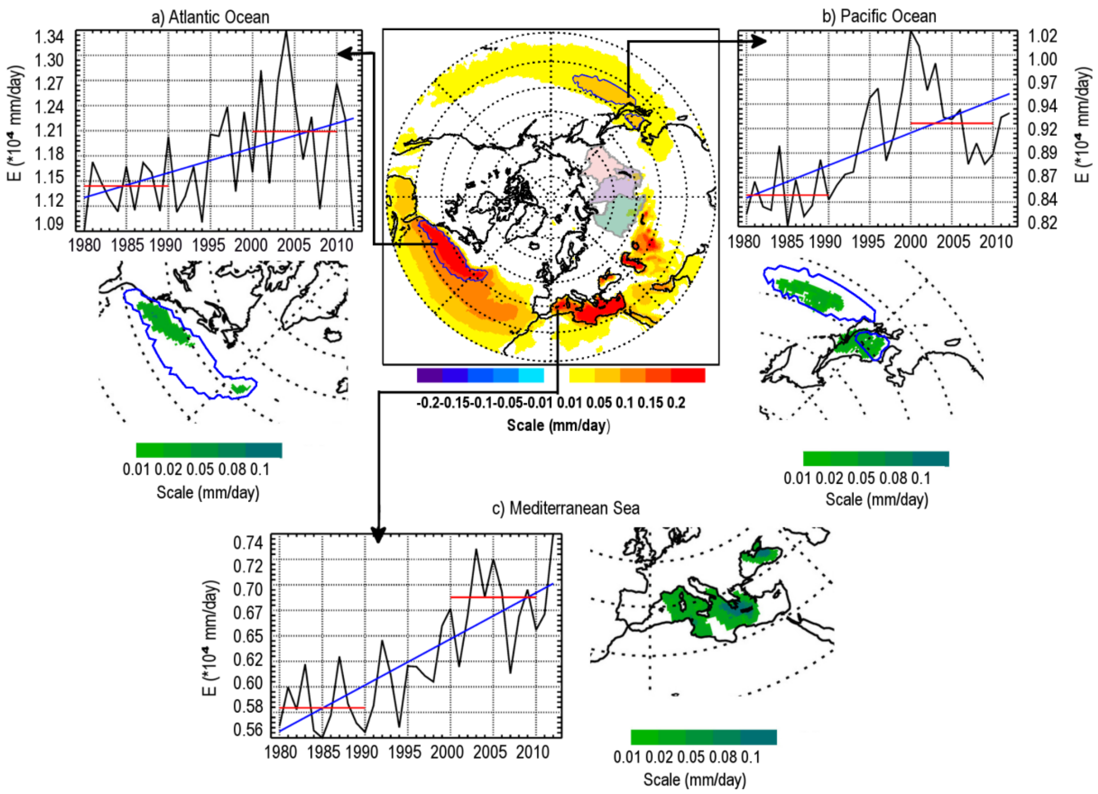
2) Please describe more detailed processes of sea-ice melting due to the Arctic river discharge and moistened Arctic troposphere. For example, a moisture increase over the Arctic can absorb the outgoing long-wave radiation from the surface while reemit the radiation toward the Arctic surface, resulting in the surface warming and sea-ice decline.

We have added the comment in the introduction (THIRD paragraph)

"Nevertheless, the opposite evolution of AST and SIE indices in recent decades emphasize that both phenomena are not independent and, actually, are known to reinforce each other (Tang et al., 2014), as changes in surface albedo (associated with melting snow and ice) tend to enhance warming in the Arctic (Serreze and Francis, 2006) as shown in the recent review paper Cohen et al. (2014). Nevertheless both indicators (AST and SIE) may also respond to other mechanisms including changes in atmospheric circulation patterns (Graverson et al., 2008), ocean circulation (Comiso et al., 2008), or changes in radiative fluxes associated to cloud cover and water vapour content in the atmosphere (Schveiger et al. 2008; Kapsch et al., 2013), though the absorption of the outgoing long-wave radiation from the surface by the increased atmospheric moisture and then remitted toward the Arctic surface, resulting in the surface warming and sea-ice decline (Kapsch et al., 2013). In particular, changes in the atmospheric moisture have been proposed as a vehicle for interpreting the most significant changes in the Arctic region either due to increase transport from middle latitudes (Lucarini and Ragone, 2011; Zhang et al., 2013) or via enhance local evaporation (Bintanja and Seltan, 2014). However, some of the recent studies showed that the evaporation from the Arctic surface appears not to be an important moisture source (e.g., Graversen et al. 2008; Park et al. 2015)."

3) In the manuscript, there are many river basin names, but if someone is not familiar with the basins, it is hard to understand the results. If possible, the authors can represent geographical locations of the basins in Figure 1.

We agree with the reviewer's suggestion, therefore we have re-done the Figure 1 in this way, modified the figure according also to the other reviewer's comments.



New Caption:" Figure 1. (Central panel) Climatological October-March 10-day integrated (E-P) values observed for the period 1979 – 2012, for all the particles bound for the Ob, Yenisei and Lena rivers basins (green, purple and pink areas respectively ~~grey contour line~~ indicate the basin area), determined from backward tracking. Warm ~~Reddish~~ colours represent regions acting as moisture sources for the tracked particles. Plots in green show the significant positive differences at the 95% level after bootstrap test (1000 interactions) in the composites of the moisture sources of the Arctic river basins between the decades 2001-10 ~~(the highest evaporation)~~ and 1981-90 ~~(the lowest)~~. Temporal series show the evolution of the average evaporation derived from OAFLUX dataset for the main moisture sources for the Arctic river basins (the Atlantic and Pacific sources, those circled with a blue line in the central figure, and for the whole Mediterranean Sea basin). ~~And plots in green show the significant positive differences at the 95% level after bootstrap test (1000 interactions) in the composites of the moisture sources of the Arctic river basins between the decade 2000-10 (the highest evaporation) and the decade 1980-90 (the lowest).~~ The blue lines are the linear trend and the red ones denoted the 10-year periods used on composites."

REFEREE 3

1) The abstract needs major revision. For example: a) The abstract, in its current form, does not present the main results of the study. It presents a great deal of background material and the methods used. However, I do not believe it states in a clear and concise fashion the problem being addressed nor the main conclusions of the paper. The background information should be shortened to make room for the authors to more clearly state the previous results, what is still "disconnecting" in those results, and what the authors find in their study. b) Page 1034 Line 2: The first sentence is confusing: "could affect the global climate in similarly asymmetric way with respect to other regions" c) Page 1034 Line 5: This line seems to suggest that the "atmospheric branch of the hydrological cycle" is the only thing linking the Arctic system and the global climate. d) Page 1034 Line 20: The main results of the paper should be here rather than a listing of mechanisms that contribute to sea-ice loss.

Shortened and rewritten. The first two sentences were deleted and main results were added in the last sentence (Strikethrough text shows what is old and removed and text in red shows what is new and added)

~~" If we could choose a region where the effects of global warming are likely to be pronounced and considerable, and at the same time one where the changes could affect the global climate in similarly asymmetric way with respect to other regions, this would unequivocally be the Arctic. The atmospheric branch of the hydrological cycle lies behind the linkages between the Arctic system and the global climate.~~ Changes in the atmospheric moisture transport have been proposed as a vehicle for interpreting any of the most significant changes in the Arctic region. The increasing moisture over the Arctic during last decades it is not strongly associated with the evaporation that takes place within the Arctic area itself, despite the fact that the sea-ice cover is decreasing. Such increment is consistent is more dependent on ~~but to the fact that~~ the transport of moisture from the extratropical regions to the Arctic that has increased in recent decades, and is expected to increase within a warming climate. This increase could be due either to changes in circulation patterns which have altered the moisture sources, or to changes in the intensity of the moisture sources because of enhanced evaporation, or a combination of these two mechanisms. In this short communication we focus on the assessing more objectively the strong link between ocean evaporation trends and Arctic Sea ice melting. We will critically analyze several recent results suggesting links between moisture transport and the extent of sea-ice in the Arctic, this being one of the most distinct indicators of continuous climate change both in the Arctic and on a global scale. To do this we will use a sophisticated Lagrangian approach to develop a more robust framework on some of these previous disconnecting results, using new information and insights. Results reached in this study seems to stress the connection between two climate change indicators, namely an increase in evaporation over source regions (mainly the Mediterranean Sea, the North Atlantic

Ocean and the North Pacific Ocean in the paths of the global western boundary currents and their extensions) and Arctic ice melting precursors. ~~Among the many mechanisms that could be involved are hydrological (increased Arctic river discharges), radiative (increase of cloud cover and water vapour) and meteorological (increase in summer storms crossing the Arctic, or increments in precipitation)"~~

2) The first paragraph of the introduction (Page 1034 Line 25 through Page 1035 Line 14) makes a strong case that the "hiatus" does not actually exist. However, to me, this discussion seems somewhat tangential and distracting (due to the controversy surrounding it) to the rest of the paper. I suggest the possibility of using this space to expand the discussion on Arctic climate change and/or possible mechanisms that are contributing to Arctic amplification.

We partially agree with the reviewer in this issue. Before tackling the main topic of our work we tried to provide a convincing link between global warming and the Arctic amplification. In this context, it is important to realize that both phenomena are not abating, despite the strong inter-annual or inter-decadal variability superimposed.

It is now known that 2014 was the warmest year on record according to NOAA (BAMS, Vol 96, Nº7, 2015, "State of the climate in 2014", a fact that was not clear when we submitted the manuscript). Furthermore, there is a good chance that 2015 will be even warmest than 2014 (partially due to the ENSO phase). According to NOAA (http://www.ncdc.noaa.gov/sotc/): "During January–June, the globally-averaged land surface temperature was 2.52°F (1.40°C) above the 20th century average. This was the highest for January–June in the 1880–2015 record, surpassing the previous record of 2007 by 0.23°F (0.13°C)."

In fact most recent literature on the issue has reinforced the idea that there is no hiatus at all, taking into account the level of heat incorporated by the Pacific (Kosaka and Xie, 2013) or the Atlantic (Chen and Tung, 2014) Oceans. Furthermore, the evolution of major external forcing factors in the last 20 years (solar, volcanic and aerosols) have dampened observed warming trends since 1992 (Schmidt, Shindell and Tsingaridis, 2014. Nature Geoscience).

Nevertheless, we agree we the reviewer that this is a bit lateral to the main focus of the paper, therefore, we have shortened this paragraph. Additionally, when answering some of the other issues raised by all the reviewers implied to incorporate some additional material concerning Arctic climate change mechanisms, as when answering questions 4, 8, 11 of reviewer #3.

3) Page 1035 Lines 20-26: The authors should discuss the seasonality of sea-ice loss and snow cover extent here, as I believe it is relevant to their study. With respect to SCE, there are clearly strong downward trends during spring and summer, but the trends actually reverse and are positive in fall and early winter (http://climate.rutgers.edu/snowcover/). Considering J. Cohen's identification of increasing Eurasian snow cover build-up during the fall, I think these positive trends have ramifications with respect to enhanced river discharge during the following melt season.

Clarification included in the text with respect to the summer and autumn sea-ice-extent (SIE) and the spring and summer snow-cover extent (SCE). The positive trend in fall and early winter is addressed in Q11.

"….the evolution of the climate in the Arctic region is often associated to two important indicators; the summer and autumn sea-ice-extent (SIE) and the spring and summer snow-cover extent (SCE), both characterized by a very significant decline since the 1970s and widely recognized as some of the most undeniable indicators of continuous climate change affecting the climate system (Tang et al., 2014; IPCC 2013)."

4) Page 1036 Line 15: Baggett and Lee (2015) find the existence of a planetary-scale wave life cycle that is highly amplified (blocking) despite a reduced meridional temperature gradient (consistent with Francis et al. 2012). Furthermore, the life cycle is preceded by enhanced warm pool tropical convection (consistent with the hypothesis presented in Palmer (2014)).

We have added the suggested comment in the text

"According to some authors, the recent rise on the incidence of summer extreme weather events over northern hemisphere continental land masses (Coumou and Rahmstorf, 2012; Seneviratne et al., 2014) is probably driven by the accelerated decline of summer SIE and SCE observed in recent decades (Francis and Vavrus, 2012; Tang et al., 2014). According to this hypothesis, the observed weakening of poleward temperature gradient triggered changes in atmospheric circulation namely slower progression of Rossby waves (Francis and Vavrus, 2012) and the existence of a planetary-scale wave life cycle (Bagget and Lee, 2015) that is highly amplified (blocking) despite a reduced meridional temperature gradient (consistent with Francis and Vavrus, 2012).These mechanisms have favored more persistent weather conditions that are often associated to extreme weather events, such as …"

5) Page 1036 Line 26: The confusing sentence from the abstract is more or less repeated here.

Rewritten

~~"For all the above mention reasons if we could choose a region where the effects of global warming are likely to be particularly noticeable, and on the other hand, one where the changes could affect the global climate in a similarly asymmetric way with respect to other regions, this would unequivocally be the Arctic (Screen and Simmonds, 2010; Tang et al., 2014, Cohen et al, 2014)."~~

"Considering all the above reasons the Arctic sector emerges as the most sensitive region of the climate system to the effects of global warming but it also represents an area where current and future changes are bound to affect the climate at a much larger scale (Screen and Simmonds, 2010; Tang et al., 2014, Cohen et al, 2014)."

6) Page 1037 Lines 5-14: Woods et al. (2013) and Liu and Barnes (2015) may be good references here, as they have done some work with respect to the atmospheric branch of the hydrological cycle. They discuss extreme atmospheric moisture transport into the Arctic through Rossby wave breaking and atmospheric rivers.

We have added the following comment in the text and the corresponding references:

"Some works try to explain extreme events of atmospheric moisture transport to the Arctic throughout the occurrence of atmospheric rivers (Woods et al., 2013) and Rossby wave breaking events (Liu and Barnes, 2015)."

7) Page 1037 Line 23: Do the authors mean "these methods" or "Lagrangian techniques"?

The authors refer to the Lagrangian techniques

8) Page 1038 Lines 15-26: Zhang et al. (2012) makes a nice connection between atmospheric moisture transport and increased river discharge, but, in my opinion, they do not provide a strong link between an increase in discharge and an increase in sea ice melt. They rely on the 2007 melt season as an example of a high discharge/high melt relationship. To me, the high discharge/high melt relationship is intuitive. However (and it may be outside the scope of this paper), it would be beneficial if there were quantitative evidence to support the relationship.

We agree with the reviewer in both stances, i.e. in what concerns to the comment and also in relation to the fact that this specific issue could be out of the scope of the article. However we would like to add additional examples of works done over Canadian Arctic region that support these results. These two references were added concerning this comment.

"The increase in Arctic river discharge is a possible cause of melting sea-ice in agreement with several studies realized over the Canadian Arctic region support these results (e.g. Dean et al., 1994; Nghiem et al., 2014)."

Dean, K. G., Stringer, W. J., Ahlnas, K., Searcy, C. and Weingartner, T.: The influence of river discharge on the thawing of sea ice, Mackenzie River Delta: albedo and temperature analyses. Polar Research, 13: 83–94, doi: 10.1111/j.1751-8369.1994.tb00439.x, 1994.

Nghiem, S. V., Hall, D. K., Rigor, I. G., Li, P. and Neumann, G.: Effects of Mackenzie River discharge and bathymetry on sea ice in the Beaufort Sea, Geophys. Res. Lett., 41, 873–879, doi:10.1002/2013GL058956, 2014.

9) Page 1039 Lines 20-27: The description of the method provided by the authors is sufficient, but I needed to read Stohl et al. (2004) to fully understand. Perhaps the authors should emphasize that Stohl et al. (2004) is a good reference near Page 1040 Line 5-7.

Done.

"For further information on FLEXPART model see Stohl el al. (2004)."

10) Page 1039 Line 19: It is not clear to me what constitutes the 3-D wind field. The authors state that October-March trajectories are calculated to test Zhang et al. (2012)'s results. Is the climatological October-March wind field used or are daily wind fields used to calculate the trajectories? I.e., are backward trajectories calculated for each day during October through March for the entire 1979-2013 dataset (initialization on ~ 6300 individual days)?

The trajectories are tracked every 6 hours for all the period (October-March), and then added day by day. So the 3D wind field data was used every 6 h in the model for the period October-March (initialization on ~6300x4 = 25300 individual time steps).

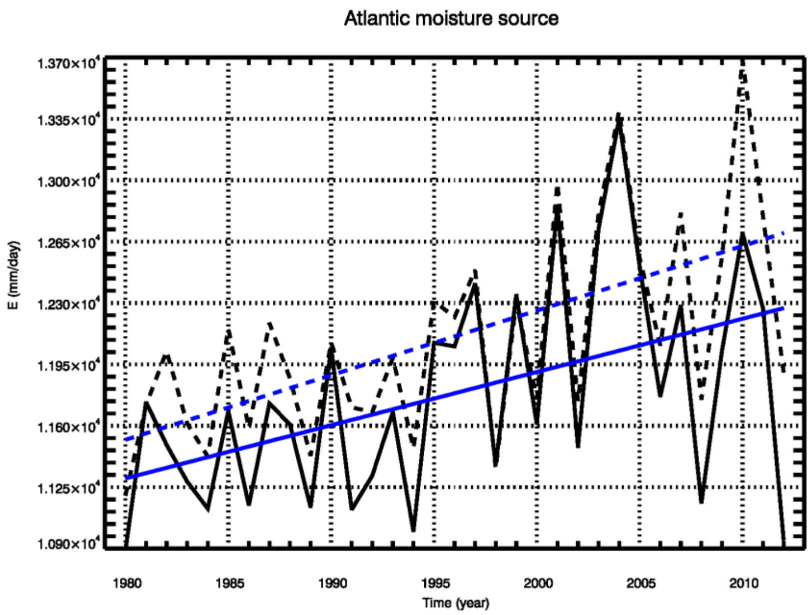
11) Page 1040 Lines 9-21: This may be a good area of the paper to discuss the increasing trend in SCE over Eurasia during fall and winter. Although, I am admittedly unsure if an increasing trend in SCE actually corresponds to an increasing trend in snow-liquid-water content found in the Eurasian Arctic river basins.

Yang et al. (2003) JGR, 10.1029/2002JD003149 shows good agreement between SCE and Eurasian rivers streamflow. However it is difficult to include this discussion in this section because of possible discrepancies between moisture source regions for Arctic rivers basin and areas of SCE positive trends, so we have preferred to include a reference in the third paragraph of the introduction as show below:

"In recent years a number of mechanisms have been put forward relating the strength of moisture transport and Arctic SIE. These mechanisms vary significantly in the nature of their main driver, including; i) hydrological, such as increments in Arctic river discharges (Zhang et al., 2012) or increments in precipitation due to enhanced local evaporation due to less SIE (Bintanja and Selten, 2014), ii) radiative, particularly through rises in cloud cover and water vapour (Kapsch et al., 2013), iii) dynamical, namely more summer storms with unusual characteristics crossing the Arctic, (Simmonds and Rudeva, 2012). Most likely these different mechanisms coexist to a certain extent and are not necessarily mutually exclusive (for instance the autumn and early positive trend is SCE (Estilow et al., 2015) can be closely related to positive trends in Eurasian rivers (Yang et al., 2007)…"

12) Page 1040 Line 23: The authors use OAFlux data to calculate trends in evaporation over the oceans. The authors use the wind field and q data from ERA-Interim to calculate E-P along the Lagrangian trajectories. Since q is clearly related to evaporation, it would be nice if the authors linked the two datasets to show that they are consistent with each other. I suggest recalculating the trend lines as seen in Figure 1 using ERA-Interim evaporation data to see how well they match the OAFlux results.

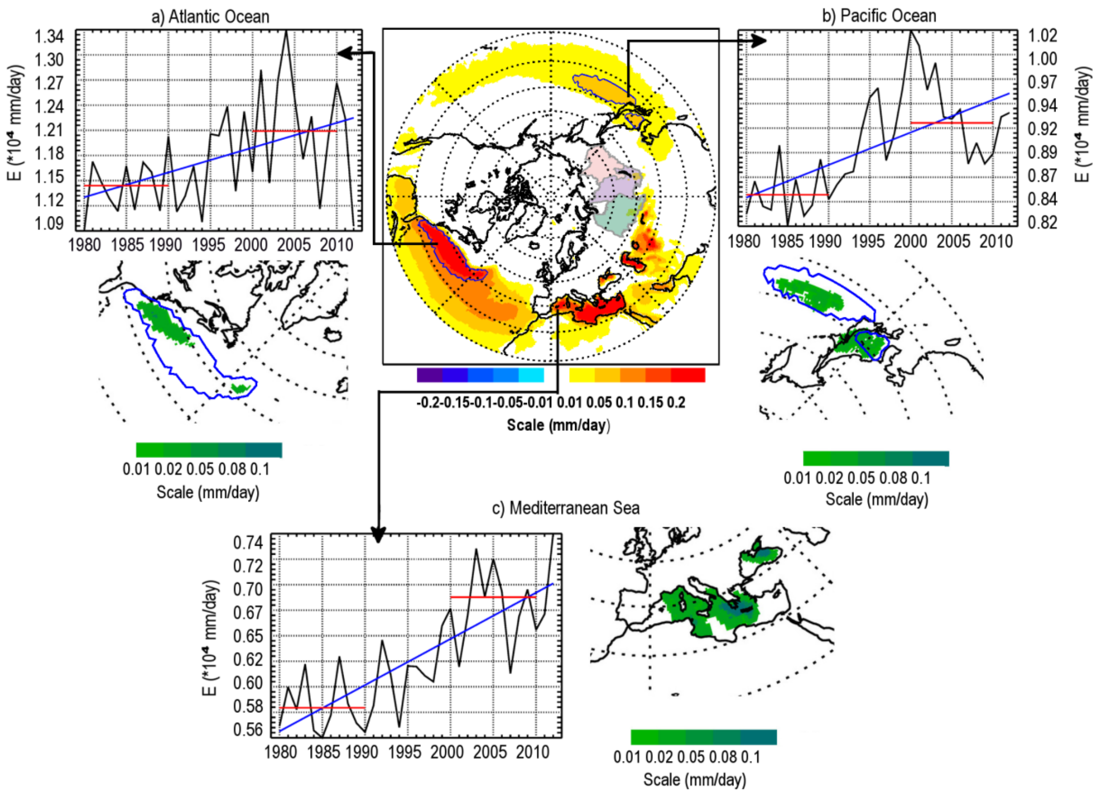
Done, they match pretty well. Figures are not included in the text, nevertheless a comment explaining that both dataset were used with similar results was included in the manuscript. We are including in this comment to reviewers the figure for the Atlantic comparing evaporation for both set of data (ERA-Interim data in dotted line).



13) Page 1041 Line 2: Rather than referring to the panels as “lateral”, I suggest giving the panels letters to designate them clearly.

We have redone the Figure 1 and we added “Letters” [a, b and c] to each “lateral panel”, and we modified the figure according with the other reviewer’s comments. The text were modified.

“The a), b) and c) ~~three lateral~~ panels in Figure 1 also show the evolution of the average evaporation …”



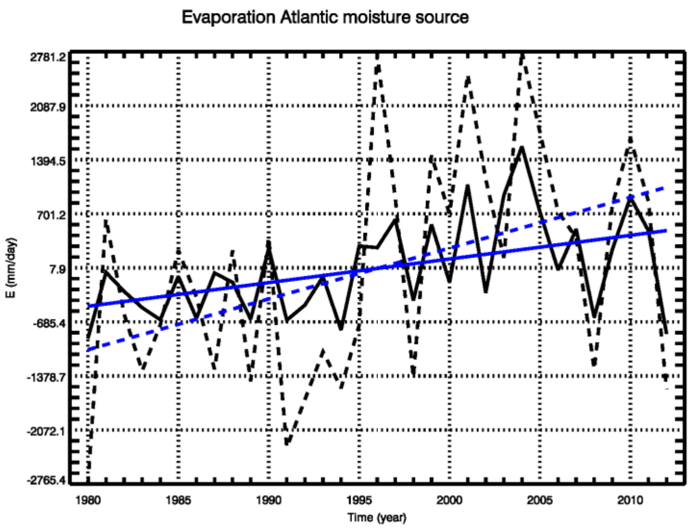
14) Page 1041 Line 4: How is the blue contour chosen? It appears that it is chosen via a specific contour line for each basin, but it also appears the value of the contour line is different for each basin. Also, there is no blue line for the Mediterranean. Is the whole Mediterranean basin used? If so, the blue line in that basin would not follow a particular contour. Is the OAFlux trend sensitive to the choice of the blue contour?

As the reviewer noticed the entire Mediterranean Sea basin was chosen as source. We have added this comment in the text and in the caption of the figure 1.

The blue contour in figure, as the review noticed, has a different value between the Atlantic source and the Pacific one. Our intention was not to compare the influence among sources but to take into account for each basin the main area of influence. So, we selected the 0.1 mm/day contour for the Pacific (the higher E-P value over this ocean) and the 0.2mm/day contour for the Atlantic (the higher in this case)

Trends were significant for both 0.1 mm/day (dotted line) and 0.2 mm/day (figure not included in the text but added to this comment of reviewers)

"Although superimposed to a pronounced decadal-scale variability ~~The~~ trends are significant in most of the grid points encircled, and are especially clear for the Atlantic, Pacific and Mediterranean sources. Similar results were reached when evaporation taken form ERA-Interim was used (not shown)."



15) Page 1041 Line 13: Which months are used for spring trajectories? Also, referring to my question (10), are trajectories calculated for every spring day?

We have specified in the text the month used: April and May.

See response to Q10. The trajectories were calculated every 6h.

16) Page 1041 Lines 13-21: The discussion concerning the results of Kapsch et al. (2013) seem quite rushed (although the authors state the figure is similar, it may still be nice to show it). The net result of the short discussion and lack of figure is to seemingly emphasize the results of Zhang et al. 2012 when perhaps that is not the intention of the authors.

We have included the figure for Kapsch et al. (2013) in the text in a similar way to that for Zhang et al. (2012) commenting the dominant role of the Pacific source.

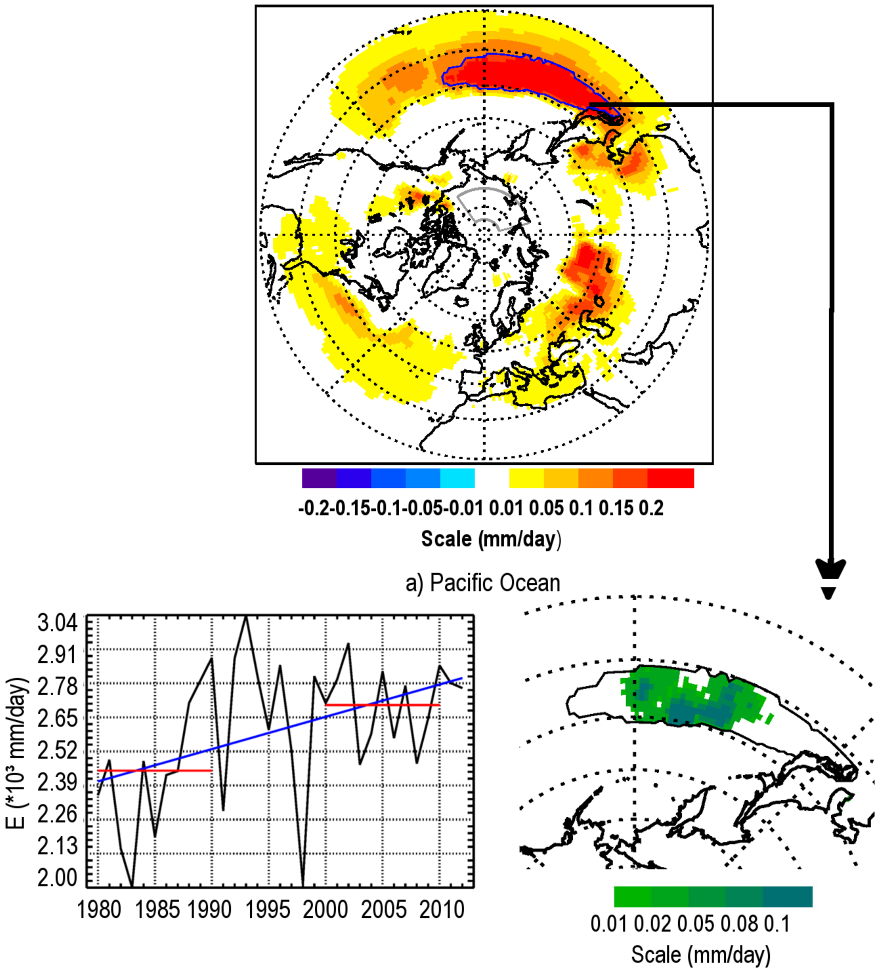


Figure 2. As Fig.1 but for the Kapsch area (115º-215º E ; 75º-85º N), denoted with the grey contour in the bottom panel.

New TEXT: "We have repeated the procedure considering the region analyzed by Kapsch et al. (2013), i.e. in this case, the late spring (April and May) moisture sources detected are related to the area where the September sea-ice anomaly is encountered. Overall results (Figure 2) are quite similar to those presented for the Arctic river basins, ~~in Figure 1 (figure not shown),~~ and the main moisture sources are also placed in the paths of the global western boundary currents in both the North Atlantic and the North Pacific Oceans (the main one in this case), and in the Mediterranean basins (more moderated in this case)."

17) Page 1042 Lines 1-5: These lines should be incorporated in some fashion into the abstract.

The abstract has been rewritten. See Q1

18) Page 1045 Caption: a) Rather than say "reddish colours" maybe use "warm colours" or "contours only show positive moisture sources"

Modified in the text

b) What are the units for the green shading?

The units used in the green shading of the figure are mm/day. Now all the units in the figure are the same.

c) The period 2000-2010 does not appear to be the highest period of evaporation for all source regions. For example, it appears the Pacific source regions peaked between 1995-2005. Perhaps the authors are just being consistent by using the same period for all three sources, but, regardless, I think something needs to be corrected here.

The referee is right. The sentence could get confuse. We selected the same period for all the analyzed sources. We have re-written the sentence in the text and in the caption of the figure.

Text: "The differences in the composites of the moisture sources of the Arctic river basins between the decade 2001-10 ~~(the highest evaporation)~~ and the decade 1981-90 ~~(the lowest)~~ are also shown in Figure 1, …"

Caption: "Figure 1. (Central panel) Climatological October-March 10-day integrated (E-P) values observed for the period 1979 – 2012, for all the particles bound for the Ob, Yenisei and Lena rivers basins (green, purple and pink areas respectively ~~grey contour line~~ indicate the basin area), determined from backward tracking. Warm ~~Reddish~~ colours represent regions acting as moisture sources for the tracked particles. Plots in green show the significant positive differences at the 95% level after bootstrap test (1000 interactions) in the composites of the moisture sources of the Arctic river basins between the decades 2001-10 ~~(the highest evaporation)~~ and 1981-90 ~~(the lowest)~~. Temporal series show the evolution of the average evaporation derived from OAFLUX dataset for the main moisture sources for the Arctic river basins (the Atlantic and Pacific sources, those circled with a blue line in the central figure, and for the whole Mediterranean Sea basin). ~~And plots in green show the significant positive differences at the 95% level after bootstrap test (1000 interactions) in the composites of the moisture sources of the Arctic river basins between the decade 2000-10 (the highest evaporation) and the decade 1980-90 (the lowest).~~ The blue lines are the linear trend and the red ones denoted the 10-year periods used on composites."

REFEREE 4

1) I would suggest to rewrite the abstract to make it more clear and concise. For example, authors should include some more information about the relationship between evaporation over source regions and river discharges. In addition, I do not understand very well what do the first sentence in the abstract mean: '... and at the same time one where the changes could affect the global climate in similarly asymmetric way with respect to other regions...' (same problem applies later in page 1036, line 26).

Shortened and rewritten also taking into account comments from other reviewers. The first sentence was deleted (Strikethrough text shows what is old and removed and text in red shows what is new and added)

~~" If we could choose a region where the effects of global warming are likely to be pronounced and considerable, and at the same time one where the changes could affect the global climate in similarly asymmetric way with respect to other regions, this would unequivocally be the Arctic. The atmospheric branch of the hydrological cycle lies behind the linkages between the Arctic system and the global climate.~~ Changes in the atmospheric moisture transport have been proposed as a vehicle for interpreting any of the most significant changes in the Arctic region. The increasing moisture over the Arctic during last decades it is not strongly associated with the evaporation that takes place within the Arctic area itself, despite the fact that the sea-ice cover is decreasing. Such increment is consistent is more dependent on ~~but to the fact that~~ the transport of moisture from the extratropical regions to the Arctic that has increased in recent decades, and is expected to increase within a warming climate. This increase could be due either to changes in circulation patterns which have altered the moisture sources, or to changes in the intensity of the moisture sources because of enhanced evaporation, or a combination of these two mechanisms. In this short communication we focus on the assessing more objectively the strong link between ocean evaporation trends and Arctic Sea ice melting. We will critically analyze several recent results suggesting links between moisture transport and the extent of sea-ice in the Arctic, this being one of the most distinct indicators of continuous climate change both in the Arctic and on a global scale. To do this we will use a sophisticated Lagrangian approach to develop a more robust framework on some of these previous disconnecting results, using new information and insights. Results reached in this study seems to stress the connection between two climate change indicators, namely an increase in evaporation over source regions (mainly the Mediterranean Sea, the North Atlantic Ocean and the North Pacific Ocean in the paths of the global western boundary currents and their extensions) and Arctic ice melting precursors. ~~Among the many mechanisms that could be involved are hydrological (increased Arctic river discharges), radiative (increase of cloud~~

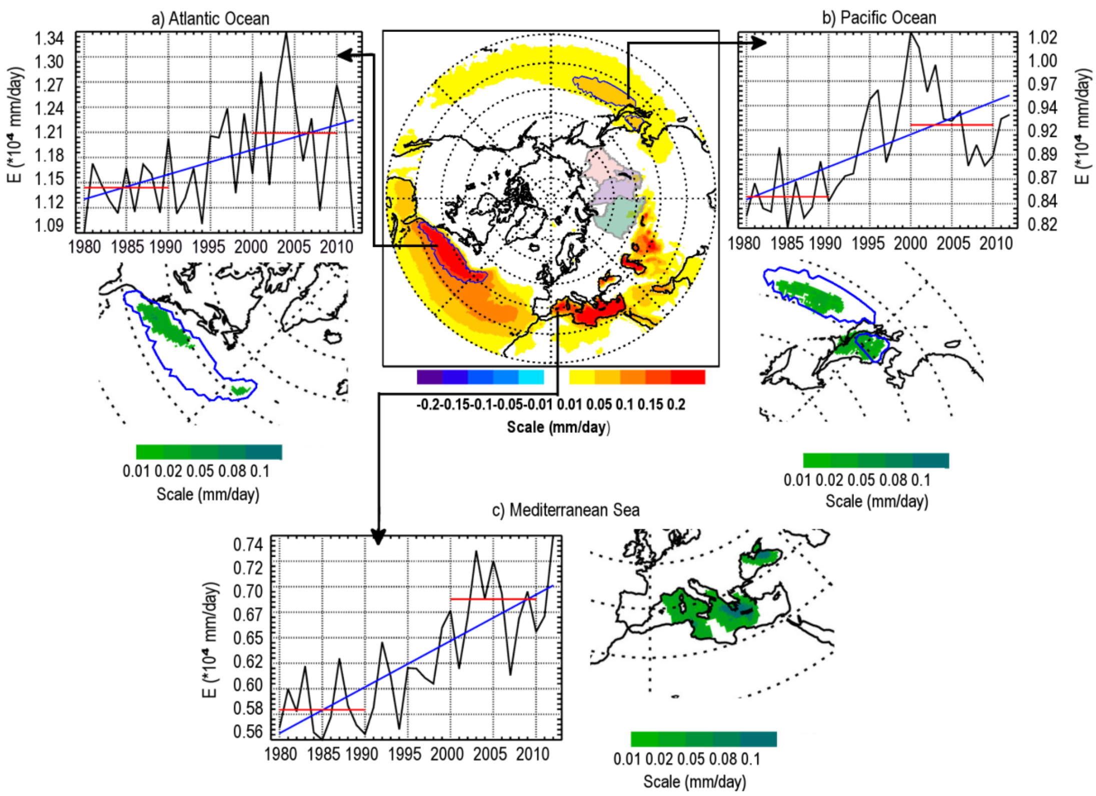
~~cover and water vapour) and meteorological (increase in summer storms crossing the Arctic, or increments in precipitation)"~~

2) Some comments related to Figure 1. This figure contains a lot of information but some of it is not clearly explained or, in some cases, I think it is wrongly described.

First, what are blue and red lines in 'temporal series' in lateral panels? I guess blue lines are linear trends (it is no stated anywhere nor any confidence level is provided). Red lines in the same 'temporal series' show the period used in the composites of moisture sources, is this right?

We understand the reviewer's criticism in this regard. Thus we have made an effort to improve the readability of the figure in the revised manuscript also taking into account the suggestions raised by other reviewers.

As the reviewer notes the blue lines are the linear trends and the red lines mark the 10-year periods used on composites. The caption was also modified to state this clearly.



Caption: "Figure 1. (Central panel) Climatological October-March 10-day integrated (E-P) values observed for the period 1979 – 2012, for all the particles bound for the Ob, Yenisei and Lena rivers basins (green, purple and pink areas respectively ~~grey contour line~~ indicate the basin area), determined from backward tracking. Warm ~~Reddish~~ colours represent regions acting as moisture sources for the tracked particles. Plots in green show the significant positive differences at the 95% level after bootstrap test (1000 interactions) in the composites of the moisture sources of the Arctic river basins between the decades 2001-10 ~~(the highest~~

~~evaporation)~~ and 1981-90 ~~(the lowest)~~. Temporal series show the evolution of the average evaporation derived from OAFLUX dataset for the main moisture sources for the Arctic river basins (the Atlantic and Pacific sources, those circled with a blue line in the central figure, and for the whole Mediterranean Sea basin). ~~And plots in green show the significant positive differences at the 95% level after bootstrap test (1000 interactions) in the composites of the moisture sources of the Arctic river basins between the decade 2000-10 (the highest evaporation) and the decade 1980-90 (the lowest).~~ The blue lines are the linear trend and the red ones denoted the 10-year periods used on composites."

Anyway, why do authors use 2000-2010 and not the last available decade (2002-2012) in this comparison?

There is nothing magical in using entire decades. Results are similar. We have preferred to use entire decades as done in Yu et al. (2007).

Second, in the caption it is written that 'the main moisture sources for the Arctic river basins (those circled with a blue line in the central figure)' are circled in blue. This is not true for the Mediterranean. In the main text, p1041l4, the same cite to areas circled with a blue line has the same error.

Modified in the caption and in the text

Third, if one looks at the colour scale in figure 1 central map, the Mediterranean (and Caspian and Black seas) seem to be more important as a source of water for the rivers basin than the North Pacific. This is not very clear in the main text (p1040, l16-19).

We modified the text to indicate better the main oceanic sources of moisture for the Arctic.

"The central panel of ~~figure~~ Fig. 1 shows that the main moisture sources are located over the Mediterranean Sea, and the smallers Caspian and Black Seas, as well as the North Atlantic Ocean and to a somewhat lesser degree the North Pacific Ocean in the paths of the global western boundary currents and their extensions ~~the North Atlantic and North Pacific Oceans in the paths of the global western boundary currents and their extensions, as well as the Mediterranean, Caspian and Black Seas~~."

In addition, a reference would be welcome in p1040l21.

We could have been added again Zhang et al. (2012) and Kapsch et al. (2013) but they were intensively referenced before.

3) Finally, I think that it would be easier for the reader to include an additional section with the summary and conclusions which included the last paragraph (from p1041l22).

We added the title "Summary and conclusions" to this last paragraph.

4) Some typos:

p1034l19: '...disconnect ng results...'

p1037l3: 'The main mechanisms...', delete 'The'

P1038l8: through?

p1038l9: What do authors mean with '...more unusual summer storms crossing the Arctic...'? Is it a lower number of summer storms or is it that there are more 'unusual (very intense, very humid...) storms'?

p1039l12: mod-e FLEXPART.

Thanks for spotting these typos; we have corrected all of them and some more.

~~SHORT COMMUNICATION:~~ Atmospheric moisture transport, the bridge between ocean evaporation and Arctic ice melting

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Abstract

~~If we could choose a region where the effects of global warming are likely to be pronounced and considerable, and at the same time one where the changes could affect the global climate in similarly asymmetric way with respect to other regions, this would unequivocally be the Arctic. The atmospheric branch of the hydrological cycle lies behind the linkages between the Arctic system and the global climate.~~ Changes in the atmospheric moisture transport have been proposed as a vehicle for interpreting any of the most significant changes in the Arctic region. The increasing moisture over the Arctic during last decades it is not strongly associated with the evaporation that takes place within the Arctic area itself, despite the fact that the sea-ice cover is decreasing. Such increment is consistent is more dependent on ~~but to the fact that~~ the transport of moisture from the extratropical regions to the Arctic that has increased in recent decades, and is expected to increase within a warming climate. This increase could be due either to changes in circulation patterns which have altered the moisture sources, or to changes in the intensity of the moisture sources because of enhanced evaporation, or a combination of these two mechanisms. In this short communication we focus on the assessing more objectively the strong link between ocean evaporation trends and Arctic Sea ice melting. We will critically analyze several recent results suggesting links between moisture transport and the extent of sea-ice in the Arctic, this being one of the most distinct indicators of continuous climate change both in the Arctic and on a global scale. To do this we will use a sophisticated Lagrangian approach to develop a more

robust framework on some of these previous disconnecting results, using new information and insights. Results reached in this study seems to stress the connection between two climate change indicators, namely an increase in evaporation over source regions (mainly the Mediterranean Sea, the North Atlantic Ocean and the North Pacific Ocean in the paths of the global western boundary currents and their extensions) and Arctic ice melting precursors. ~~Among the many mechanisms that could be involved are hydrological (increased Arctic river discharges), radiative (increase of cloud cover and water vapour) and meteorological (increase in summer storms crossing the Arctic, or increments in precipitation).~~

The outstanding role of Arctic climate within the global climate system

The last IPCC Assessment Report has confirmed that the main components of the climate system have been warming (atmosphere, oceans) or shrinking (cryosphere) since the 1970s, as a result of global warming induced by the significant increment in concentration of Greenhouse Gases of anthropogenic origin (AR5, IPCC, 2013). The so called hiatus in the rise of global air temperature since the late 1990s is not observed in the relentless decadal shift of temperature distributions in both hemispheres (Hansen et al., 2012) neither in the frequency of extreme hot events over the continents (Seneviratne et al., 2014). The much larger capacity of the oceans to store heat, in respect to the atmosphere, has played a fundamental role storing the excessive heat retained in the climate system either in the Pacific (Kosaka and Xie, 2013) or the Atlantic (Chen and Tung, 2014) oceans.

However, global warming is a very uneven phenomena impossible to be encapsulated by a single indicator relative to one subsystem, such as the global average of near surface atmospheric temperature. The spatial pattern of observed temperature trends is very asymmetrical and regionalized, with continents warming more than oceans, and with high latitudes also presenting considerably higher warming rates than mid-latitude and tropical regions. In particular, several authors have shown that the rise in Arctic near surface temperature (AST) has been twice as large as the global average throughout most of the year (e.g. Screen and Simmonds, 2010; Tang et al., 2014, Cohen et al., 2014). Additionally, the evolution of the climate in the Arctic region is often associated to two important indicators; the summer and autumn sea-ice-extent (SIE) and the spring and summer snow-cover extent (SCE), both characterized by a very significant decline since the 1970s and widely recognized as some of the most undeniable indicators of continuous climate change affecting the climate system (Tang et al., 2014; IPCC 2013).

Nevertheless, the opposite evolution of AST and SIE indices in recent decades emphasize that both phenomena are not independent and, actually, are known to reinforce each other (Tang et al., 2014), as changes in surface albedo (associated with melting snow and ice) tend to enhance warming in the Arctic (Serreze and Francis, 2006) as shown in the recent review paper Cohen et al. (2014). Nevertheless both indicators (AST and SIE) may also respond to other mechanisms including changes in atmospheric circulation patterns (Graverson et al., 2008), ocean circulation (Comiso et al., 2008), or changes in radiative fluxes associated to cloud cover and water vapour content in the atmosphere (Schweiger et al. 2008; Kapsch et al., 2013), though the absorption of the outgoing long-wave radiation from the surface by the increased atmospheric moisture and then remitted toward the Arctic surface, resulting in the surface warming and sea-ice decline (Kapsch et al., 2013). In particular, changes in the atmospheric moisture have been proposed as a vehicle for interpreting the most significant changes in the Arctic region either due to increase transport from middle latitudes (Lucarini and Ragone, 2011; Zhang et al., 2012) or via enhance local evaporation (Bintanja and Seltan, 2014). However, some of the recent studies showed that the evaporation from the Arctic surface appears not to be an important moisture source (e.g., Graversen et al., 2008; Park et al., 2015).

According to some authors, the recent rise on the incidence of summer extreme weather events over northern hemisphere continental land masses (Coumou and Rahmstorf, 2012; Seneviratne et al., 2014) is probably driven by the accelerated decline of summer SIE and SCE observed in recent decades (Francis and Vavrus, 2012; Tang et al., 2014). According to this hypothesis, the observed weakening of poleward temperature gradient triggered changes in atmospheric circulation namely slower progression of Rossby waves (Francis and Vavrus, 2012) and the existence of a planetary-scale wave life cycle (Bagget and Lee, 2015) that is highly amplified (blocking) despite a reduced meridional temperature gradient (consistent with Francis and Vavrus, 2012). These mechanisms have favored more persistent weather conditions that are often associated to extreme weather events, such as the mega-heatwave in Russia in 2010 (Barriopedro et al., 2011) or long drought in central USA (Coumou and Rahmstorf, 2012). However, there is currently a wide debate on the nature of mechanism(s) responsible for this increment of persistent weather patterns associated to such extreme climatic events (Cohen et al., 2014), with some authors suggesting other drivers (albeit equally exacerbated by global warming) such as the role of drying soils associated with earlier SCE melting (Tang et al., 2014) or simply related to tropical extra-tropical interactions (Palmer, 2014;).

~~For all the above mention reasons if we could choose a region where the effects of global warming are likely to be particularly noticeable, and on the other hand, one where the changes could affect the global climate in a similarly asymmetric way with respect to other regions, this would unequivocally be the Arctic~~ Considering all the above reasons the Arctic sector emerges as the most sensitive region of the climate system to the effects of global warming but it also represents an area where current and future changes are bound to affect the climate at a much larger scale (Screen and Simmonds, 2010; Tang et al., 2014, Cohen et al., 2014).

~~The m~~ Main mechanisms relating sea ice decline and increase moisture transport

The atmospheric branch of the hydrological cycle plays a fundamental role establishing the link between the Arctic system and the global climate. However, to the best of our knowledge, this role has not been fully accounted objectively, although the transport of moisture from the extratropical regions to the Arctic has increased in recent decades (Zhang et al., 2012), and is expected to further increase under global warming, independently of the climate change scenario considered (Kattsov et al., 2007). Some works try to explain extreme events of atmospheric moisture transport to the Arctic throughout the occurrence of atmospheric rivers (Woods et al., 2013) and Rossby wave breaking events (Liu and Barnes, 2015). The general~~is~~ increase of moisture could be due either to changes in circulation patterns which have altered the location of the most important moisture sources, or result from changes in the magnitude of the existing moisture sources as a consequence of enhanced evaporation, or a combination of these two mechanisms (Gimeno et al., 2012; 2013).

Most studies of changes on moisture transport towards the Arctic Climate make use of one of three possible techniques, namely (1) Eulerian approaches (e.g. Jakobson and Vihma, 2010), which can be used to estimate the ratio of advected-to-recycled moisture and to calculate the moisture transport between predetermined source and sink regions; (2) isotope analysis (e.g., Kurita, 2011), but neither this nor the Eulerian techniques are capable of a proper geographical identification of the sources; or (3) more complex Lagrangian computational techniques that are able to infer the sources of the precipitation that falls in a target region and thus overcome the limitations of (1) and (2). An analysis of the performance of these Lagrangian techniques ~~methods~~ and their advantages over Eulerian and isotope analysis was recently given by Gimeno et al. (2012). Here we will critically analyze some of the previous assessments that have established the link between moisture transport from mid-latitudes towards the Arctic region and changes in Arctic SIE. In addition, we will use a sophisticated Lagrangian approach to contrast these existing results using new information and insights.

In recent years a number of mechanisms have been put forward relating the strength of moisture transport and Arctic SIE. These mechanisms vary significantly in the nature of their main driver, including; i) hydrological, such as increments in Arctic river discharges (Zhang et al., 2012) or increments in precipitation due to enhanced local evaporation due to less SIE (Bintanja and Selten, 2014), ii) radiative, particularly through rises in cloud cover and water vapour (Kapsch et al., 2013), iii) dynamical, namely more ~~unusual~~ summer storms with unusual characteristics crossing the Arctic, (Simmonds and Rudeva, 2012). Most likely these different mechanisms coexist to a certain extent and are not necessarily mutually exclusive, for instance the autumn and early positive trend is SCE (Estilow et al., 2015) can be closely related to positive trends in Eurasian rivers (Yang et al., 2007). In particular, two of these works (Zhang et al., 2012; Kapsch et al., 2013) provide novel insight on the role played by the transport of moisture and the melting of sea ice or snow cover. Their main findings are summarized below:

1. According to Zhang et al. (2012) in their work entitled ”Enhanced poleward moisture transport and amplified northern high-latitude wetting trend”, the authors provide strong evidence to support; i) that there is a trend in the net poleward atmospheric moisture

transport (AMT) towards the Eurasian Arctic river basins , ii) that this net AMT is captured in 98% of the gauged climatological river discharges, iii) that the upward trend of 2.6% net AMT per decade is in good agreement with the 1.8% increase per decade in the gauged discharges.

The increase in Arctic river discharge is a possible cause of melting sea-ice in agreement with several studies realized over the Canadian Arctic region support these results (e.g. Dean et al., 1994; Nghiem et al., 2014). Thus, AMT can be seen to have an important role to play in this process. Nevertheless, Zhang et al. (2012) used a very simple analysis of integrated moisture fluxes, in which they calculated moisture transport from predetermined source and sink regions, and were unable to identify the moisture source regions directly.

2. Using a very different methodology Kapsch et al. (2013) in the paper entitled "Springtime atmospheric energy transport and the control of Arctic summer sea-ice extent" demonstrated that i) enhanced water vapour and clouds in spring, together with the associated greenhouse effect, are related to the extension of sea-ice during the summer; and ii) in areas of summer ice retreat, a significantly enhanced transport of humid air is evident during spring, producing increased cloudiness and humidity resulting in an enhanced greenhouse effect.

As for Kapsch et al. (2013), global balances of atmospheric moisture flux were used, which allowed neither the identification of the moisture sources nor any assessment of their role in the variability of the moisture transport.

Identifying objectively the main sources of moisture for large Eurasian rivers basins

The analysis adopted here to discuss existing results is mostly based on the Lagrangian particle dispersion model FLEXPART (Bintanja and Selten, 2014; Stohl and James, 2004), using data from 1979 to 2013 obtained from the ERA-Interim reanalysis of the ECMWF (Dee et al., 2011), which can be considered the state of the art reanalysis in terms of the hydrological cycle (Trenberth et al., 2011; Lorenz and Kunstmann, 2012). The analysis will be restricted to years after 1979 in order to avoid working with results obtained prior to the incorporation of satellite data in the reanalysis. Using a horizontal resolution of 1º in latitude and longitude and a resolution of 61 vertical levels, the algorithm tracks atmospheric moisture along trajectories. A 3-D wind field moves a large number of so-called particles (air parcels) resulting from the homogeneous division of the atmosphere. The specific humidity (q) and the position (latitude, longitude and altitude) of all the particles are recorded at 6-hour intervals. The model then calculates increases (e) and decreases (p) in moisture along each trajectory at each time step by means of variations in (q) with respect to time i.e., e-p = m dq/dt. The quantity (E-P) is calculated for a given area of interest by summing (e-p) for all particles crossing a 1º grid column of the atmosphere, where E and P are the rates of evaporation and precipitation, respectively. The particles are tracked and a database is created with values of E-P averaged and integrated over 10 days of transport, this being the average residence time of water vapour in the atmosphere (Numaguti, 1999). The main sources of moisture for the target area (in terms of when and where the air masses that reach the target area acquire or lose moisture) are shown through the analysis of the 10-day integrated (E-P) field. For a comprehensive review see Gimeno et al. (2012), which provides details of the limitations of this Lagrangian approach, its uncertainty and significance, and its advantages and disadvantages with respect to other methods of estimating moisture sources. For further information on FLEXPART model see Stohl el al. (2004).

According to Zhang et al. (2012), temporal lags must be considered when linking AMT from lower latitudes with snowpack accumulation and also between this and Arctic river discharges. Thus, summer Arctic river discharge can be related to the result of the melting of the snowpack that accumulated during the preceding months, while the AMT most related to the summer river discharge corresponds to that resulting from snowpack accumulation during the period October - March. We therefore choose this period to estimate the moisture sources for the target region formed by the Ob, Yenisei and Lena rivers basins, as in the work of Zhang et al. (2012). The central panel of ~~figure~~ Fig. 1 shows that the main moisture sources are located over the Mediterranean Sea, and the smallers Caspian and Black Seas, as well as the North Atlantic Ocean and to a somewhat lesser degree the North Pacific Ocean in the paths of the global western boundary currents and their extensions~~the North Atlantic and North Pacific Oceans in the paths of the global western boundary currents and their extensions, as well as the~~

Mediterranean, Caspian and Black Seas. This result is striking because these source regions seem to match those areas with the highest trend in terms of evaporation in the past few decades.

Trends in evaporation from main sources: possible consequences

Using some of the best estimates of evaporation, namely those derived from the OAFlux data (Yu and Weller, 2007), strong increasing trends can be seen in evaporation from the oceans since 1978, with the upward trend being most pronounced during the 1990s. The spatial distribution of these trends (Yu, 2007) shows that while the increase in evaporation has occurred globally, it has primarily been observed during the hemispheric winter and is strongest along the paths of the global western boundary currents and any inner Seas with wind forcing playing a dominant role. The a), b) and c) three lateral panels in Figure 1 also show the evolution of the average evaporation derived from OAFLUX for the main moisture sources for the Arctic river basins (those circled with a blue line and the entire Mediterranean basin sea). Although superimposed to a pronounced decadal-scale variability The trends are significant in most of the grid points encircled, and are especially clear for the Atlantic, Pacific and Mediterranean sources. Similar results were reached when evaporation taken form ERA-Interim was used (not shown). The differences in the composites of the moisture sources of the Arctic river basins between the decade 2001-10 (the highest evaporation) and the decade 1981-90 (the lowest) are also shown in Figure 1, with greenish colours indicating regions where their contribution as a source intensified over these years. From these results it seems clear that there is an enhanced moisture contribution from those moisture regions where the evaporation increased.

We have repeated the procedure considering the region analyzed by Kapsch et al. (2013), i.e. in this case, the late spring (April and May) moisture sources detected are related to the area where the September sea-ice anomaly is encountered. Overall results (Figure 2) are quite similar to those presented for the Arctic river basins, in Figure 1 (figure not shown), and the main moisture sources are also placed in the paths of the global western boundary currents in both the North Atlantic and the North Pacific Oceans (the main one in this case), and in the Mediterranean basins (more moderated in this case).

In this regard the intensification of evaporation in these source regions could have a dual effect on the reduction of September Arctic ice, through (1) intensification of summer river discharge and (2) enhancement of the greenhouse effect due to an increase in cloudiness and humidity over the ice-melting regions.

Summary and conclusions

~~In summary, w~~ We have made a critical assessment of the results obtained in two important recent works that offer new understanding on the role played by the transport of moisture and the melting and the melting of sea ice or snow cover (Zhang et al., 2012; Kapsch et al., 2013). The Lagrangian analysis adopted in our approach seems to stress the connection between two climate change indicators, namely an increase in evaporation over source regions and Arctic ice melting. We are confident that our results provide the necessary link between these two realms and suggest an intricate chain of events related to (1) positive trends in evaporation in specific ocean areas that correspond to the main moisture source regions of Eurasian rivers, (2) upward trends in atmospheric transport from these regions to the Arctic river basins/ regions where ice-melting occurs, and (3) trends in river discharges/moisture and cloud cover. These developments merit further and more comprehensive study in terms of their effects on present and future climates.

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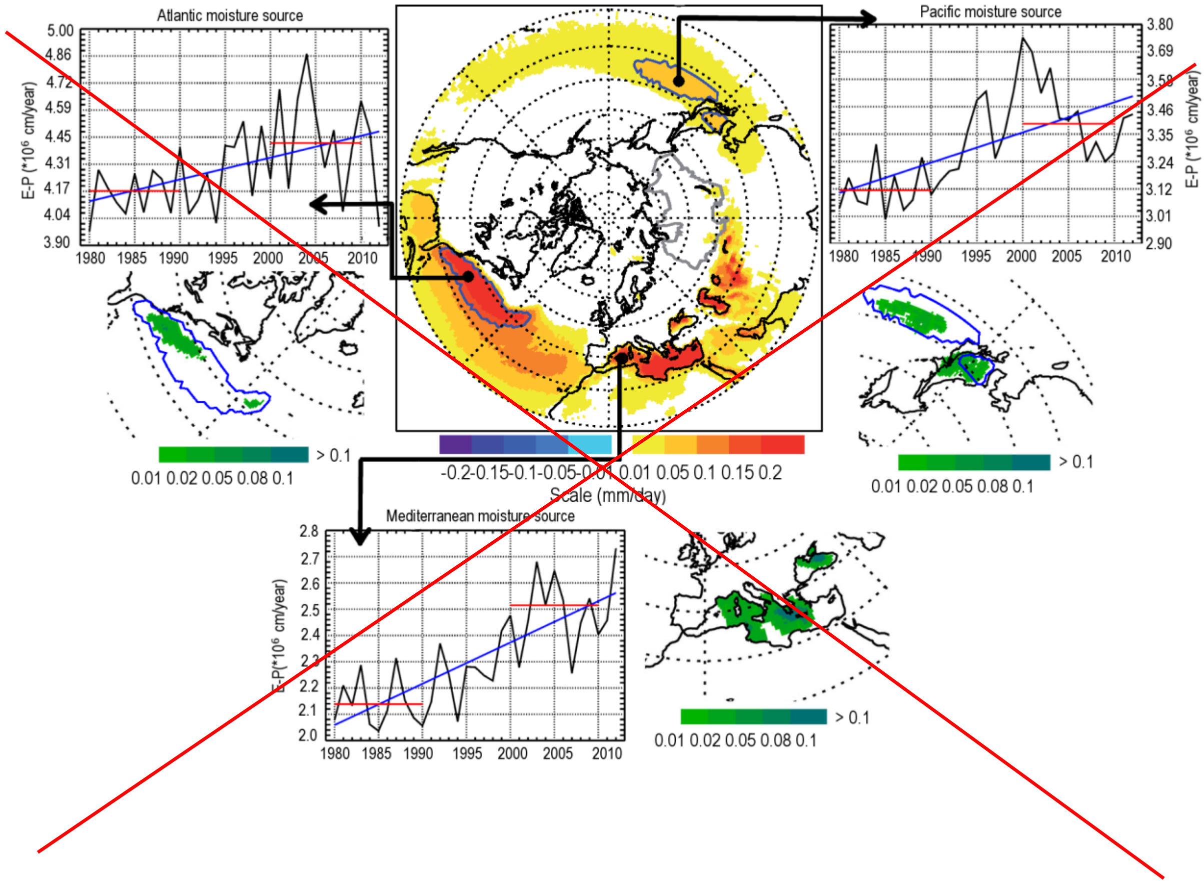
Atlantic moisture source
E-P (*10⁶ cm/year)
Pacific moisture source
E-P (*10⁶ cm/year)
Mediterranean moisture source
E-P(*10⁶ cm/year)
-0.2 -0.15 -0.1 -0.05 -0.01 0.01 0.05 0.1 0.15 0.2
Scale (mm/day)
0.01 0.02 0.05 0.08 0.1 > 0.1

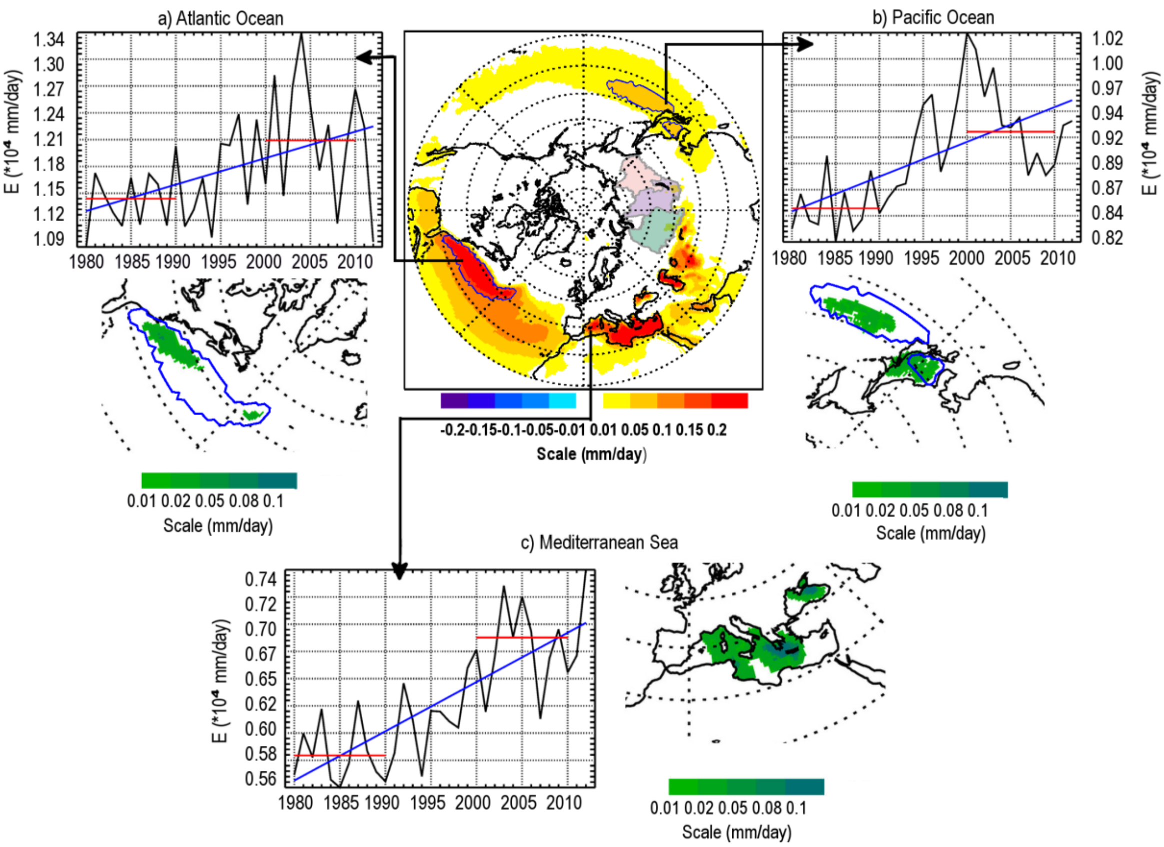
a) Atlantic Ocean
E (*10⁴ mm/day)
b) Pacific Ocean
E (*10⁴ mm/day)
c) Mediterranean Sea
E (*10⁴ mm/day)
-0.2 -0.15 -0.1 -0.05 -0.01 0.01 0.05 0.1 0.15 0.2
Scale (mm/day)
0.01 0.02 0.05 0.08 0.1
Scale (mm/day)

Figure 1. (Central panel) Climatological October-March 10-day integrated (E-P) values observed for the period 1979 – 2012, for all the particles bound for the Ob, Yenisei and Lena rivers basins (green, purple and pink areas respectively ~~grey contour line~~ indicate the basin area), determined from backward tracking. Warm ~~Reddish~~ colours represent regions acting as moisture sources for the tracked particles. Plots in green show the significant positive differences at the 95% level after bootstrap test (1000 interactions) in the composites of the moisture sources of the Arctic river basins between the decades 2001-10 ~~(the highest evaporation)~~ and 1981-90 ~~(the lowest)~~. Temporal series show the evolution of the average evaporation derived from OAFLUX dataset for the main moisture sources for the Arctic river basins (the Atlantic and Pacific sources, those circled with a blue line in the central figure, and for the whole Mediterranean Sea basin). ~~And plots in green show the significant positive differences at the 95% level after bootstrap test (1000 interactions) in the composites of the moisture sources of the Arctic river basins between the decade 2000-10 (the highest evaporation) and the decade 1980-90 (the lowest).~~ The blue lines are the linear trend and the red ones denoted the 10-year periods used on composites.

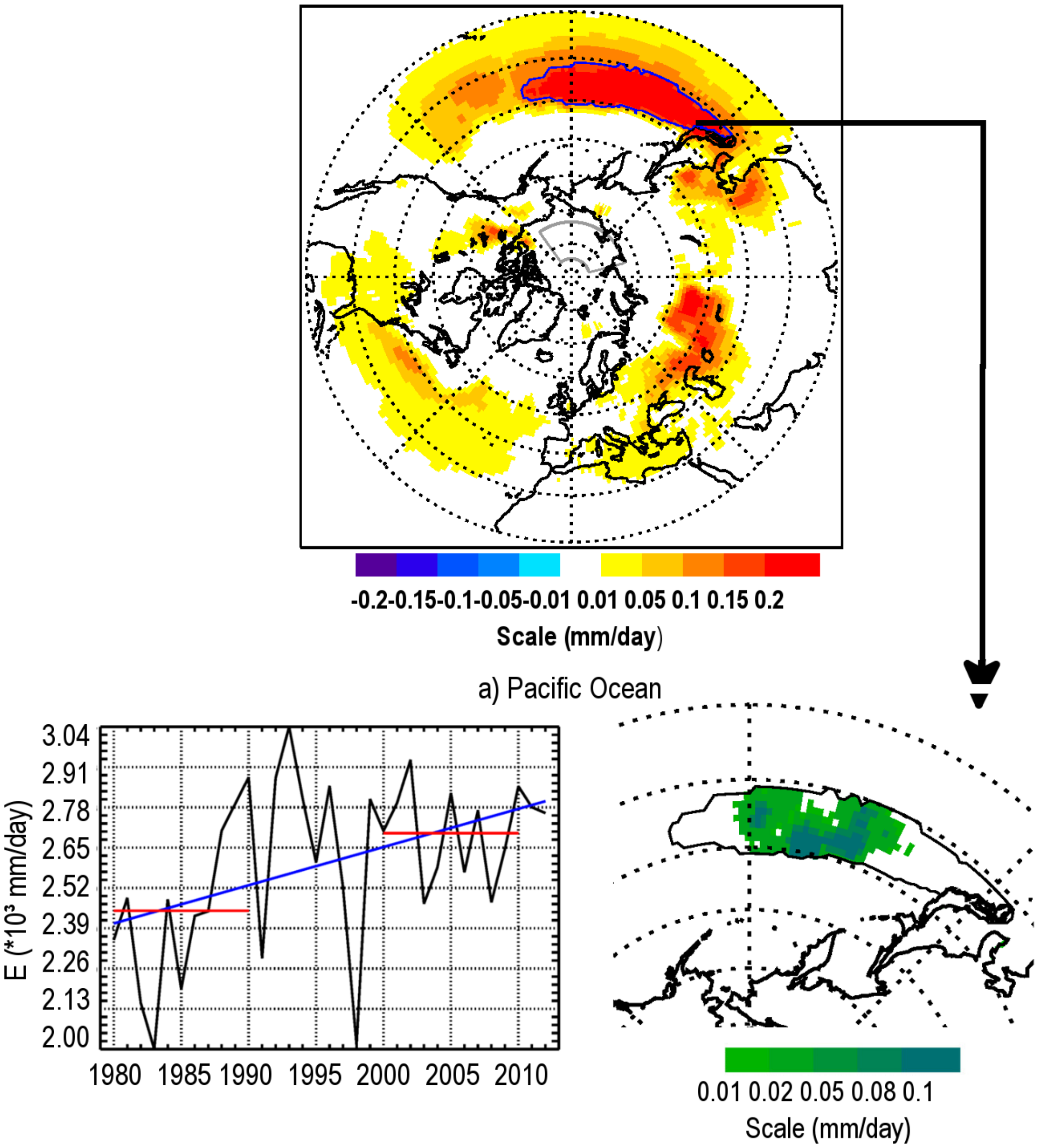

Figure 2. As Fig.1 but for the Kapsch area (115º-215º E ; 75º-85º N), denoted with the grey contour in the bottom panel.