Conference Proceedings Paper

Extreme Sea Ice Loss over the Arctic: An Analysis Based on Anomalous Moisture Transport

M. Vázquez [1,*], R. Nieto [1,2], A. Drumond [1] and L. Gimeno [1]

Published: 15 July 2016

[1] Environmental Physics Laboratory (EPhysLab), Facultade de Ciencias, Universidad de Vigo, Ourense, Spain
[2] Department of Atmospheric Sciences, Institute of Astronomy, Geophysics and Atmospheric Sciences, University of São Paulo, São Paulo, Brazil
* Correspondence: martavazquez@uvigo.es.

Abstract: Recently, the Arctic system has been suffering an extreme reduction in its sea ice extension. 2007 and 2012 represent those years showing the maximum sea ice loss. This rapid decrease has been suggested to have important implications on climate not only over the system itself but also globally. Understanding the causes of this sea ice loss is key to analyzing how future changes related to climate change can affect the Arctic system and the global system. For this purpose, we have applied the Lagrangian model FLEXPART to study the anomalous transport of moisture for these years and to analyze the implications on the sea ice it may produce. Throughout this model, we will analyze the variation in the sources of moisture for the system (backward analysis), and how the moisture supply from these sources is affected (forward analysis). From the results an anomalous transport of moisture have been proved to occur for both years. However, the pattern is different for each event, being the anomalous moisture supply different in both intensity and spatial distribution from every source.

Keywords: Arctic system, moisture supply, Lagrangian method

1. Introduction

The Arctic system have been experiencing strong sea ice reductions in their sea ice over the past several decades [1–3] and it is expected to continue decreasing under global warming conditions [4,5]. Observed decreases affect not only the extent but also the thickness and the volume [6] having this reduction important implication locally, by affecting heat budgets [7] or precipitation [8], and showing external and global effects too. Some studies suggest that sea ice reduction have implications on atmospheric circulation by affecting mid-latitudinal winter snowfall [9] or summer precipitation [10]. A detailed review on sea ice reductions and its effects have been realized by Vihma [11].

2007 and 2012 are those years that show minimums in sea ice extension in recent decades, showing anomalies of −1.6 and −2.3 million km^2 respectively referred to the 1981–2010 climatological mean. On Figure 1 it appears the minimum September sea ice extent for both 2007 (green color) and 2012 (blue color) compared to 1981–2010 mean extent (red contour line). Sea ice data was obtained from the National Snow and Ice Data Center (NSIDC) [12]. Recently, several causes have been suggested to the dramatic sea ice reductions, the recent change in perennial sea ice is considered one of the most important reasons of the decreasing sea ice mass for several authors [13,14]. However, variations in the hydrological cycle can affect sea ice too. Some studies have related sea ice reductions with increased river discharge [15–17] or with storm activity [18,19].

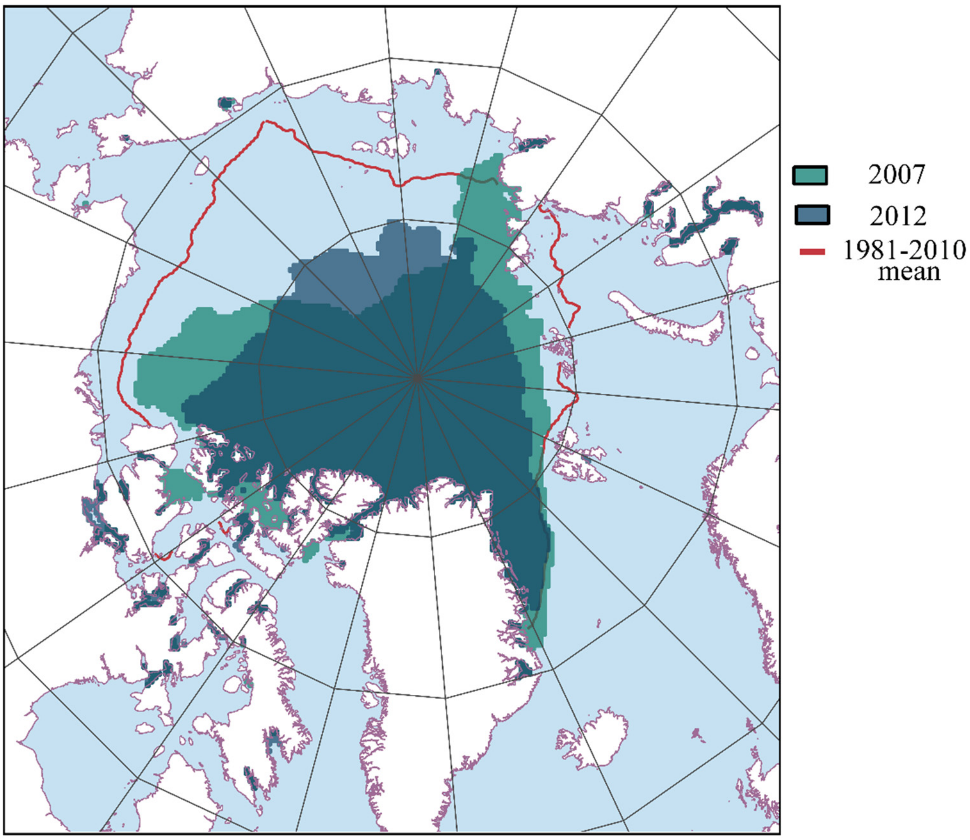

Figure 1. September minimum sea ice extent for the year 2007 (**green**), 2012 (**blue**) and climatological 1981–2010 mean (**red** contour). Data obtained from National Snow and Ice Data Center (NSIDC) [12].

In the present study, we will try to analyze anomalous moisture transport into the Arctic system for those years reaching minimum sea ice extent. For this purpose, we employ the Lagrangian model FLEXPART [20,21] to study variations on arctic moisture sources and to observed how moisture contribution from main sources into the Arctic changed for 2007 and 2012.

2. Experiments

In order to analyze anomalous moisture transport into the Arctic linked to sea ice retreat, a Lagrangian methodology based on FLEXPART v9.0 particle dispersion model [20,21] was applied. FLEXPART model employs global reanalysis data ERA-Interim, obtained from the ECMWF [22], to track atmospheric moisture along trajectories. 3-D wind field at 1° regular grid into 61 vertical levels is used to move a large number of so-called particles (air parcels) resulting from the homogeneous division of the atmosphere, and specific humidity (q) and position for every air parcel are stored at the 6 h interval.

Changes in specific humidity are related with increases (e) and decreases in moisture (p) by the equation:

$$e - p = m(dq/dt)$$

where m being the mass of the particle and t the time. The total surface freshwater flux (E-P) is obtained by adding (e-p) from individual air parcels at every grid area. (E) and (P) are the rates of evaporation and precipitation, respectively.

On this work, we studied (E-P) changes for 2007 y 2012 by analyzing anomalies vs. the 1980–2012 climatological mean. First of all trajectories for particles reaching the complete Arctic system were follow backward for 2007, 2012, and the complete 1980–2012 period. From this analysis, we were able to analyze where particles took moisture ((E-P) > 0) and to compare variations on this moisture uptake for those years that show minimum sea ice extension. This allowed us to investigate how moisture sources have changed and how it could affect the sea ice extension. Secondly, trajectories can be followed forward in time from main Arctic sources to analyze variation in moisture supply ((E-P) < 0) into the Arctic in 2007 and 2012 from these sources. Moisture sources used for the forward experiment were defined by backward tracking, considering as sources those regions that show mean (E-P) values greater than 4 mm/day and have a major seasonal importance.

As river discharge has been suggested to have an important implication on sea ice extent, anomalous moisture transport over main Arctic river basins were studied for 2007 and 2012. We consider Eurasian and Canadian basins separately as they have influence over the different region on the Arctic Ocean. Eurasian river basins considered on this work are Lena, Ob, Yenisey and Kolyma; for the Canadian one, main basins are McKenzie and Yukon.

The analysis previously described was applied on the seasonal and annual basis. As minimum sea ice extension occurs in September, we consider in the study the period September 2006 (2011) to August 2007 (2012). Seasons were defined as follows: autumn as September to November (SON), winter as December to February (DJF), spring as March to May (MAM) and summer as June to August (JJA).

3. Results

3.1. Changes on Moisture Sources

Figure 2 shows 2007 and 2012 anomalies in moisture uptake ((E-P) > 0) for backward analysis from the Arctic system. Contour lines represent seasonal moisture sources defined as previously described. From this figure, we can observe variations in moisture sources for those years showing a minimum sea ice extent.

For the year 2007, in the case of **autumn** 2006, it seems that the Atlantic moisture source decreased its moisture uptake. In the case of the Pacific ocean, in general, the source itself got weaker and the moisture uptake increased over some area in and out the source. In spite of not being the main source, for this season Norwegian and Barents Seas increased its moisture potential contribution to the system and some Eurasian continental areas gained importance too. In **winter** the Atlantic moisture source clearly increased its moisture uptake, meanwhile, Pacific Ocean gained importance as source over the Northeast part of the climatological source and over Okhotsk Sea. In **spring** 2007, the Atlantic source showed positive anomalies on its northcentral area. Pacific source had an uneven pattern with negative anomalies over most of the source and positive over the Southeast of the source and over Japan and East China Seas. Important positive anomalies appeared over the Bering Sea and Europe too. Finally, in **summer**, North American source increased its moisture uptake over most of its area. Over Eurasia, in general, positive anomalies appeared around the latitudinal 50° N band. For the Atlantic ocean, the moisture uptake increased over most of the area despite de fact that this source is not really important for this season. Pacific source showed negative anomalies over most of its area.

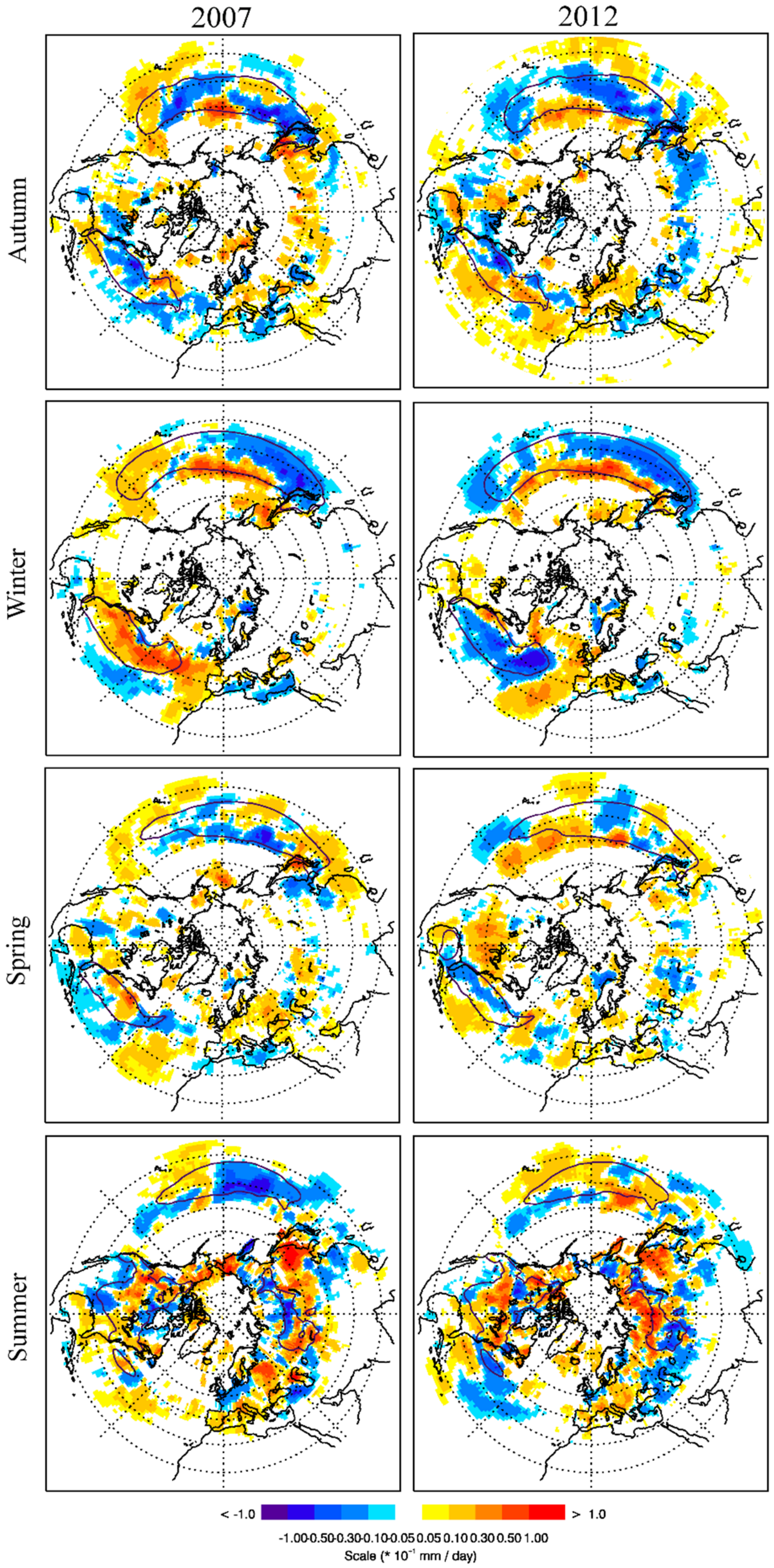

Figure 2. Seasonal (E-P) > 0 anomaly for 2007 (**left-hand** column) and 2012 (**right-hand** column) referred to 1980–2012 climatology. Reddish colors represent areas over which moisture uptake is greater on that year (positive anomalies) and bluish color represents areas where moisture uptake have decreased on that year (negative anomalies). Contour lines represent main climatological moisture sources for the Arctic system.

Analyzing the year 2012, in **autumn** the moisture uptake over Pacific moisture source decreased considerably. Atlantic moisture source seems to be displaced southward and in general, moisture contribution from this source increased over the ocean and the Gulf of Mexico. Positive anomalies over Europe for this season also remarkable. In the **winter**, the Atlantic source weakened and the ocean around it gained importance. The Pacific Ocean showed negative anomalies over most of its area, with the exception of a band with positive anomalies between 30° and 40° N. Positive anomalies appeared too over Okhotsk Sea and Western Bering Sea. In **spring**, the behavior of the Atlantic source was similar to the previous season, decreasing its moisture uptake over the source and increasing around it. Over the Pacific Ocean, positive anomalies appeared northeast of the source. It is important to highlight positive anomalies over the North American source, suggesting an earlier development of this source which usually only appears in summer. Finally, and referred to **summer**, in general Atlantic Ocean showed negative anomalies. Pacific Ocean had an uneven pattern showing positive and negative anomalies over its area. Talking about continental moisture sources, North America seems to increase its moisture uptake over most of their area. Moreover, Alaska gained important as a source for this season. The Siberian source was northward-displaced, being positive anomalies very strong north of the source. China and Europe increased moisture uptake too.

3.2. Anomalous Moisture Contribution from Every Moisture Source

The forward analysis allows us to analyze anomaly transport of moisture from main moisture sources (red contour lines) into the arctic system for those years showing minimum sea ice extension. For this purpose, Figures 3 and 4 shows 2007 and 2012 seasonal moisture transport anomalies respectively for each of the four main sources.

For the year 2007 (Figure 3) and analyzing **Pacific moisture source** (Figure 3a) we can observe important differences on moisture transport anomaly season by season. On the autumn previous to the minimum (year 2006) in general moisture contribution increased northward the sources over the Gulf of Alaska, Eastern Russia and most of the nearby Arctic seas; including Okhotsk Sea, Bering Sea and Beaufort, Chukchi and East Siberian Seas. On winter months, the Pacific moisture transport into the Arctic seems to be more eastward, and positive anomalies appeared over most of the Canadian Arctic and this anomaly expanded toward the Davis Strait and the Labrador Sea. The same situation occurred in spring, however during this season, important positive anomalies appeared over Kamchatka Peninsula and their surroundings. Finally, in summer moisture contribution from Pacific Ocean positive anomalies only occurred over some oceanic areas north of the source and the East Canadian Arctic. In Figure 3b **Atlantic ((E-P) < 0) anomaly** is shown and we can observe how in autumn the eastward moisture contribution over the path between Greenland and Scandinavia diminished but an increased contribution occurred over Davis Strait, Baffin Bay, and the Labrador Sea. In winter, moisture transport from the Atlantic Ocean had an eastward increased contribution with an area of positive anomalies that extended from the Labrador Seas and reach the Eurasia and Barents and Kara Seas. In this season, moisture contribution over the Canadian arctic decreased. For spring, the moisture anomalies over the oceanic area between Greenland and Scandinavia and Western Eurasia remained positive and moisture contribution from the sources increased over Canada too. However, negative anomalies appeared southwest of Greenland over Labrador Sea, Hudson Bay, and the Davis Strait. Finally, in summer positive anomalies only appeared over the Labrador Sea and Davis Strait, Kara Sea and Northwestern Russia and Canada. Referred to **continental moisture sources** (only important in summer), Figure 3c shows as moisture transport from North America amplified over west of Greenland and over Northeastern Canadian arctic and Alaska. In the case of Siberian moisture source (Figure 3d) their contribution highly increased over northern source, with amplified contribution from the Pacific ocean and Scandinavia and Atlantic oceans. An important increased moisture contribution appeared over the Arctic Ocean between the Laptev Sea and the East Siberian Sea.

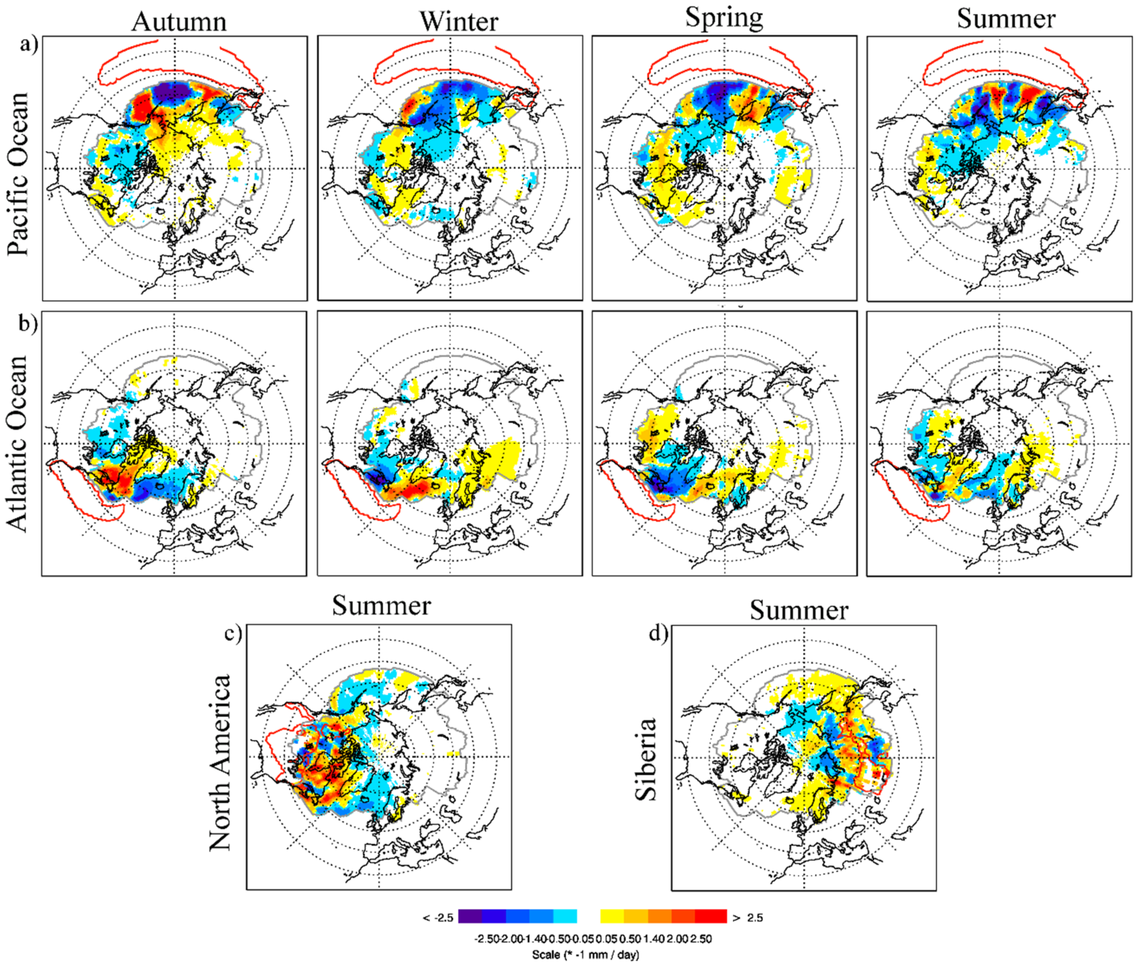

Figure 3. Seasonal (E-P) < 0 anomalies for 2007 on the forward experiment from (**a**) Pacific Ocean; (**b**) Atlantic Ocean; (**c**) North America and (**d**) Siberia. Reddish colors represent areas over which moisture supply is greater on that year from the selected source (positive anomalies) and bluish color represent areas where moisture uptake have decreased on that year (negative anomalies). Contour lines represent climatological moisture sources for the Arctic system.

Analyzing 2012 situation (Figure 4), for the **Pacific source** (Figure 4a) moisture transport increased more than 2.5 mm/day over the most Pacific Ocean itself, excluding the Gulf of Alaska with high negative anomalies. In winter, moisture transport was similar than for the year 2007 but with an increase in moisture contribution over Canadian arctic much more intense. In this case positive anomaly area extended into the Atlantic Ocean reaching Scandinavia coast. In spring it was especially relevant that the moisture contribution increased over Eastern Russia and Okhotsk Sea, and over central Canadian Arctic. In summer the moisture contribution increased, as in autumn, north of the source. Positive anomalies also appeared over the East Siberian Sea. For **Atlantic Ocean** (Figure 4b) in autumn, positive anomalies appeared over most of the Canadian arctic, Atlantic Ocean between Greenland and Scandinavia, Norwegian and Barents Seas and Pacific Ocean. Strong negative anomalies appeared over Labrador Sea, the Baffin Bay and the Davis Strait; however, this area had positive anomalies in winter, spring, and summer. Aside from this area, positive anomalies appeared in winter and spring over southwestern Canadian arctic and Atlantic Ocean between Greenland and Scandinavia. **North American** (Figure 4c) moisture transport increased mainly north of the source, over Alaska, Pacific Ocean, Greenland and the Norwegian Sea. Finally, for the **Siberian moisture source** (Figure 4d) moisture contribution anomalies north of the source were mainly negative. Positive anomalies appeared over the source itself and south of it and over Eastern Russia, Alaska and East Siberian Sea.

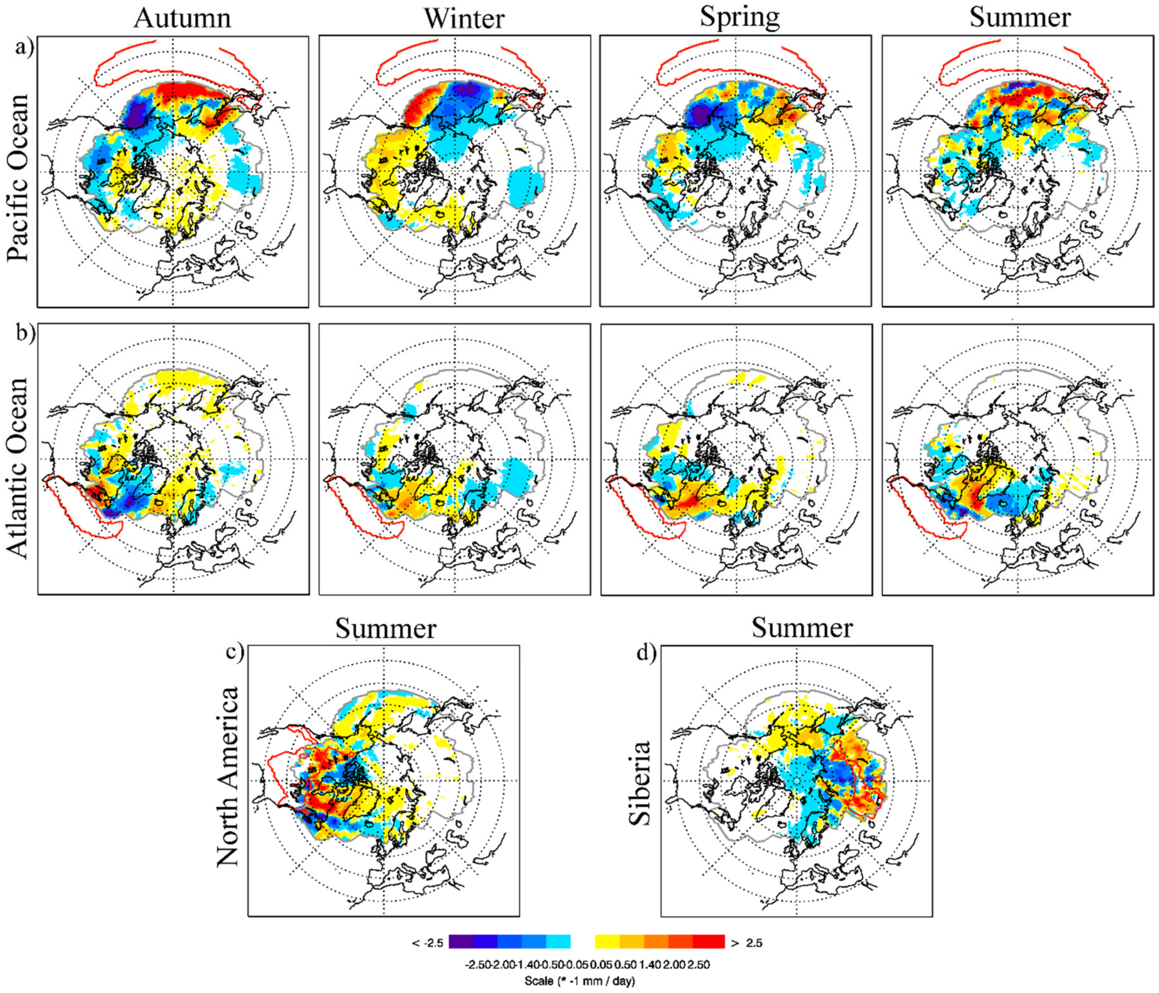

Figure 4. Seasonal (E-P) < 0 anomalies for 2012 on the forward experiment from (**a**) Pacific Ocean; (**b**) Atlantic Ocean; (**c**) North America and (**d**) Siberia. Reddish colors represent areas over which moisture supply is greater on that year from the selected source (positive anomalies) and bluish color represent areas where moisture uptake have decreased on that year (negative anomalies). Contour lines represent climatological moisture sources for the Arctic system.

3.3. River Basins

Because of the influence of river discharge on sea ice extent, an analysis on moisture contribution over major Arctic river basins results of special interest. Figure 5 shows seasonal moisture contribution from every moisture source over main Eurasian arctic river basins (left-hand column) and main Canadian arctic river basins (right-hand column). This contribution was calculated for the complete climatology (yellow bar) and for individual 2007 and 2012 years (blue and green bars, respectively) with the purpose of analyzing possible variations.

For 2007 year (blue bar), Pacific moisture sources supplied a greater amount of moisture over the Eurasian river basin in almost every season (with the exception of summer). Over the Canadian river basins (basins over which its moisture contribution is greater compared to Eurasian ones) moisture contribution increased only during autumn, showing, in general, a decrease in comparison with the remaining seasons. The Atlantic Ocean is one of the areas that bring more moisture into the Eurasian river basins, and during 2007 its contribution extremely increased during all seasons (especially in winter). In spite of not being the main source for Canadian basins, on this year, its contribution increased on winter, spring and summer. Finally, North American and Siberian sources showed an increased moisture contribution over Canadian and Eurasian basin respectively.

On the year 2012 (green bar), Pacific moisture contribution showed a general reduction. Moisture supply from Atlantic Ocean decreased over Eurasian basins during autumn and winter, and increased slightly during spring and summer. Over Canadian basins, these sources showed a rising on autumn and a similar contribution to the climatology amount during remain seasons. As is 2007, North American source increased its moisture contribution over Canadian river basins and Siberian source over Eurasian ones.

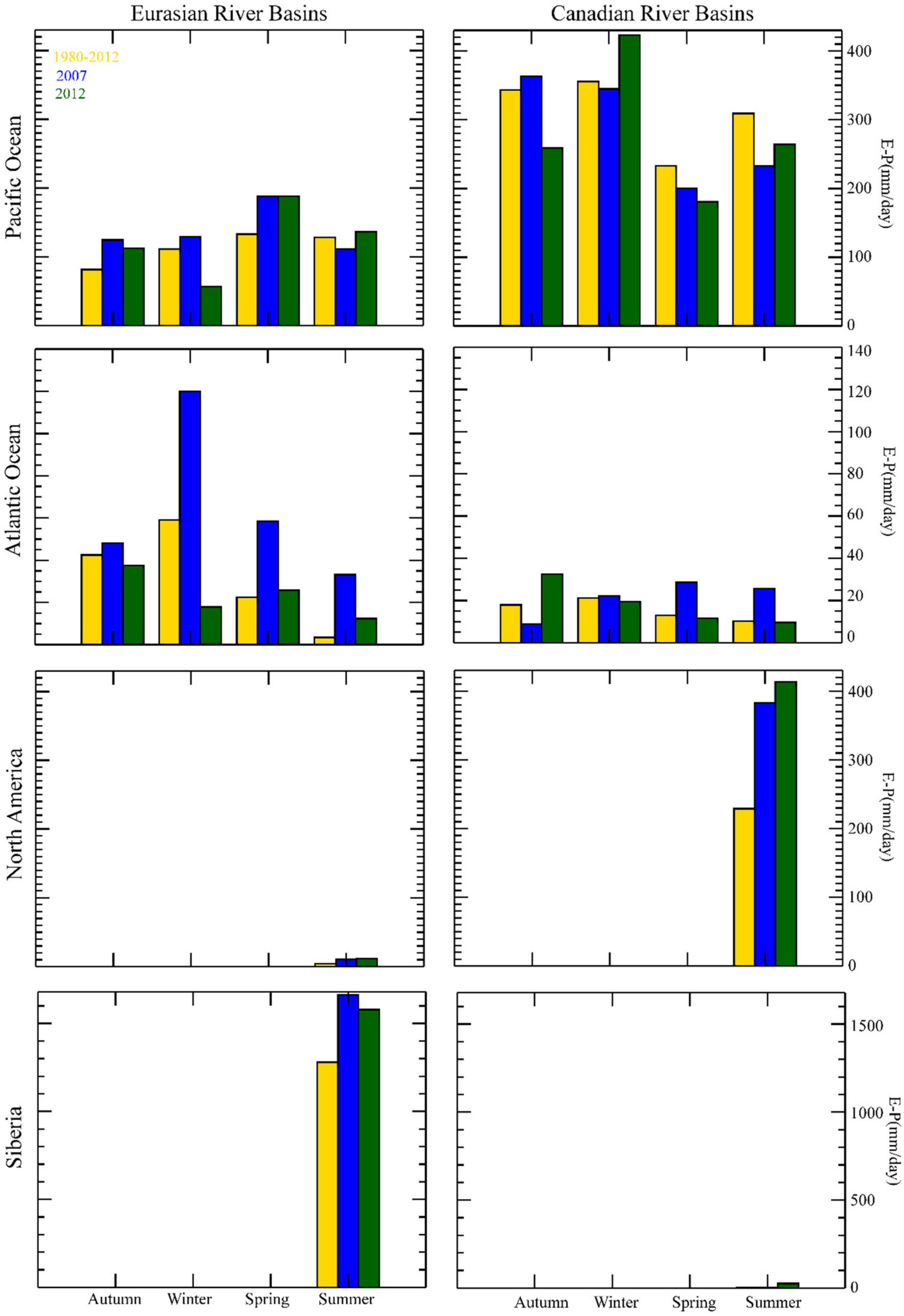

Figure 5. Mean moisture contribution over Eurasian (**left-hand** column) and Canadian (**right-hand** column) river basins from Pacific Ocean (**first row**), Atlantic Ocean (**second row**), North America (**third row**) and Siberia (**fourth row**) for 1980–2012 (**yellow** bar), 2007 (**blue** bar) and 2012 (**green** bar).

4. Discussion

Moisture transport shows important variation for those years showing a minimum sea ice extent compared with 1980–2012 climatology, however, the situation is different for each year.

Concerning 2007, the Pacific Ocean seems to lose importance as moisture source (Figure 2). However, its moisture contribution (Figure 3) into the Arctic increased over some regions as southern Canada, Gulf of Alaska or Okhotsk Sea and the oceanic area south of Kamchatka. Especially remarkable is the result about the increased moisture supply of this source over East Siberian Sea (area showing and important sea ice retreat on summer) especially on spring and summer. Kapch et al. [23] have suggested a relation between increased humidity over an area and an intensification on sea ice retreat over there. Moisture uptake (Figure 2) increased over continental areas in North America and Asia, and Siberian moisture contribution was greater than average north of the source. It is important to highlight the intensification of Atlantic Ocean as a moisture source. Except for autumn 2006, this source showed positive anomalies during all seasons. This moisture source amplification resulted on increased moisture contribution over oceanic areas around Greenland and Eurasia (Figure 3b). The increment on moisture supply over Eurasia produced an increase on moisture contribution over main Arctic river basin greater than 100% on the annual basis (result not shown). In agreement with our result, Zhang et al. [24] have observed an increased moisture transport into Eurasian river basins and Shiklomanov and Lammers [25] a peak on river discharge in 2007. Some studies have suggested a link between increased Eurasian river discharge and sea ice decline [16,17]. This relation agrees with our results, an important sea ice retreat occurred north of main Eurasian Arctic river estuaries (Figure 1). Moisture contribution over Canadian Arctic river basins also increased associated with North American moisture source, however, this increase was not as bigger as Eurasian one.

In 2012, the North America was the only source showing a remarkable intensification (Figure 2). Atlantic source experimented an important decrease in moisture uptake and the remaining sources had an uneven pattern with some areas showing positive anomalies and others negative. Associated with North American source an intensification on moisture contribution into Canadian river basins occurred, with higher contribution than in 2007 (Figure 4c). In this case, we can observe how the sea ice retreat was higher north of McKenzie Estuary. Nghiem et al. [17] suggested previously the influence of McKenzie river discharge on sea ice extent reduction on 2012 associated with the warmer water transported by the river into the ocean. On this year, sea ice reductions not only occurred over the Beaufort Sea but also took place north of Russia (Figure 1). Most of the studies have related sea ice reduction over this area with the occurrence of a great cyclone originated on Siberia on August [26–28], however from our results, it cannot be proved.

Finally, if we compare sea ice extent over Barents and Kara seas (Figure 1) an important difference can be observed for both years. This difference seems to be related to the path of moisture transport associated with the Atlantic moisture source. On Figure 3b we can observe how moisture transport from Atlantic moisture source had an eastward movement into Eurasia on 2007, meanwhile, in 2012 (Figure 4b) moisture contribution had a major influence northeastward. An important amount of moisture from Atlantic Ocean is transported by cyclones, especially in winter. Storms play an important role in sea ice reduction [18] so an increased number or cyclones going through the Arctic Ocean may affect sea ice over that area.

5. Conclusions

We have analyzed the variation on moisture transport occurred in the year 2007 and 2012 and we have tried to relate it to minimum sea ice extent observed over these years.

From our results an increased on moisture transport over main Arctic river basins seems to have some implications on the sea ice reductions observed over the Arctic Ocean. Moisture transport over these basins was not the same in both years. On 2007 Atlantic moisture contribution have been increased by more than 100% over Eurasian river basins. However, on 2012 the increase have occurred over Canadian river basin. In both cases, anomalous sea ice reductions occurred over the Arctic Ocean north of the basins.

The Atlantic moisture source seems to be especially related to sea ice extent over the Barents and Kara Sea regions. Over this area, greater sea ice reductions were observed on 2012, when the moisture transport from Atlantic source had a northward component bringing moisture over the area of major retreat.

Acknowledgments: The authors acknowledge funding by the Spanish government within the EVOCAR (CGL2015-65141-R) project, which is also funded by FEDER (European Regional Development Fund). Raquel Nieto was also supported by the Brazilian government through the CNPq grant 314734/2014-7.

Author Contributions: R.N., A.D. and L.G. designed, proposed and conducted the research; M.V. performed the experiments and analyzed the data; M.V., R.N., L.G. and A.D. wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

ECMWF	European Centre for Medium-Range Weather Forecasts
SON	September to November
DJF	December to February
MAM	March to May
JJA	June to August

References

1. Stroeve, J.C.; Kattsov, V.; Barrett, A.; Serreze, M.; Pavlova, T.; Holland, M.; Meier, W.N. Trends in Arctic sea ice extent from CMIP5, CMIP3 and observations. *Geophys. Res. Lett.* **2012**, *39*, L16502, doi:10.1029/2012GL052676.
2. Stroeve, J.; Holland, M.M.; Meier, W.; Scambos, T.; Serreze, M. Arctic sea ice decline: Faster than forecast. *Geophys. Res. Lett.* **2007**, *34*, L09501, doi:10.1029/2007GL029703.
3. Comiso, J.C.; Parkinson, C.L.; Gersten, R.; Stock, L. Accelerated decline in the Arctic sea ice cover. *Geophys. Res. Lett.* **2008**, *35*, L01703, doi:10.1029/2007GL031972.
4. Holland, M.M.; Bitz, C.M.; Tremblay, B. Future abrupt reductions in the summer Arctic sea ice. *Geophys. Res. Lett.* **2006**, *33*, L23503, doi:10.1029/2006GL028024.
5. Gregory, J.M.; Stott, P.A.; Cresswell, D.J.; Rayner, N.A.; Gordon, C.; Sexton, D.M.H. Recent and future changes in Arctic sea ice simulated by the HadCM3 AOGCM. *Geophys. Res. Lett.* **2002**, *29*, 2175, doi:10.1029/2001GL014575.
6. Laxon S.W.; Giles, K.A.; Ridout, A.L.; Wingham, D.J.; Willatt, R.; Cullen, R.; Kwok, R.; Schweiger, A.; Zhang, J.; Haas, C.; *et al.* CryoSat-2 estimates of Arctic sea ice thickness and volume. *Geophys. Res. Lett.* **2013**, *40*, 732–737, doi:10.1002/grl.50193.
7. Screen, J.A.; Simmonds, I. The central role of diminishing sea ice in recent Arctic temperature amplification. *Nature* **2010**, *464*, 1334–1337, doi:10.1038/nature09051.
8. Kopec, B.G.; Feng, X.; Michel, F.A.; Posmentier, E.S. Influence of sea ice on Arctic precipitation. *PNAS* **2016**, *113*, 46–51, doi:10.1073/pnas.1504633113.
9. Tang, Q.; Zhang, X.; Yang, X.; Francis, J.A. Cold winter extremes in northern continents linked to Arctic sea ice loss. *Environ. Res. Lett.* **2013**, *8*, 014036.
10. Screen, J.A. Influence of Arctic sea ice on European summer precipitation. *Environ. Res. Lett.* **2013**, *8*, 044015.
11. Vihma, T. Effects of Arctic Sea Ice Decline on Weather and Climate: A Review. *Surv. Geophys.* **2014**, *35*, 1175–1214, doi:10.1007/s10712-014-9284-0.
12. Fetterer, F.; Knowles, K.; Meier, W.; Savoie, M. *Sea Ice Index*; National Snow and Ice Data Center: Boulder, CO, USA, 2002; updated daily, doi:10.7265/N5QJ7F7W.
13. Nghiem, S.V.; Rigor, I.G.; Perovich, P.C.-C.D.K.; Weatherly, J.W.; Neumann, G. Rapid reduction of Arctic perennial sea ice. *Geophys. Res. Lett.* **2007**, *34*, L19504, doi:10.1029/2007GL031138.

14. Maslanik, J.; Fowler, C.; Stroeve, J.; Drobot, S.; Zwally, J.; Yi, D.; Emery, W. A younger, thinner Arctic ice cover: Increased potential for rapid, extensive sea-ice loss. *Geophys. Res. Lett.* **2007**, *34*, L24501, doi:10.1029/2007GL032043.
15. Nummelin, A.; Ilicak, M.; Li, C.; Smedsrud, L.H. Consequences of future increased Arctic runoff on Arctic Ocean stratification, circulation, and sea ice cover. *J. Geophys. Res. Oceans* **2016**, *121*, 617–637, doi:10.1002/2015JC011156.
16. Bauch, D.; Hölemann, J.A.; Nikulina, A.; Wegner, C.; Janout, M.A.; Timokhov, L.A.; Kassens, H. Correlation of river water and local sea-ice melting on the Laptev Sea shelf (Siberian Arctic). *J. Geophys. Res. Oceans* **2013**, *118*, 550–561, doi:10.1002/jgrc.20076.
17. Nghiem, S.V.; Hall, D.K.; Rigor, I.G.; Li, P.; Neumann, G. Effects of Mackenzie River discharge and bathymetry on sea ice in the Beaufort Sea. *Geophys. Res. Lett.* **2014**, *41*, 873–879, doi:10.1002/2013GL058956.
18. Simmonds, I.; Keay, K. Extraordinary September Arctic sea ice reductions and their relationships with storm behavior over 1979–2008. *Geophys. Res. Lett.* **2009**, *36*, L19715, doi:10.1029/2009GL039810.
19. Mesquita, M.; Hodges, K.I.; Atkinson, D.E.; Bader, J. Sea-ice anomalies in the Sea of Okhotsk and the relationship with storm tracks in the Northern Hemisphere during winter. *Tellus A* **2011**, *63*, 312–323.
20. Stohl, A.; James, P.A. A Lagrangian Analysis of the Atmospheric Branch of the Global Water Cycle. Part I: Method Description, Validation, and Demonstration for the August 2002 Flooding in Central Europe. *J. Hydrometeorol.* **2004**, *5*, 656–678, doi:10.1175/1525-7541(2004)005<0656:ALAOTA>2.0.CO;2.
21. Stohl, A.; James, P.A. A Lagrangian Analysis of the Atmospheric Branch of the Global Water Cycle. Part II: Moisture Transports between Earth's Ocean Basins and River Catchments. *J. Hydrometeorol.* **2005**, *6*, 961–984, doi:10.1175/JHM470.1.
22. Dee, D.P.; Uppala, S.M.; Simmons, A.J.; Berrisford, P.; Poli, P.; Kobayashi, S.; Andrae, U.; Balmaseda, M.A.; Balsamo, G.; Bauer, P.; et al. The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. *Q. J. R. Meteorol. Soc.* **2011**, *137*, 553–597, doi:10.1002/qj.828.
23. Kapsch, M.L.; Graversen, R.G.; Tjernström, M. Springtime atmospheric energy transport and the control of Arctic summer sea-ice extent. *Nat. Clim. Chang.* **2013**, *3*, 744–748, doi:10.1038/nclimate1884.
24. Zhang, X.; He, J.; Zhang, J.; Polyakov, I.; Gerdes, R.; Inoue, J.; Wu, P. Enhanced poleward moisture transport and amplified northern high-latitude wetting trend. *Nat. Clim. Chang.* **2012**, *3*, 47–51, doi:10.1038/nclimate1631.
25. Shiklomanov, A.I.; Lammers, R.B. Record Russian river discharge in 2007 and the limits of analysis. *Environ. Res. Lett.* **2009**, *4*, 045015, doi:10.1088/1748-9326/4/4/045015.
26. Parkinson, C.L.; Comiso, J.C. On the 2012 record low Arctic sea ice cover: Combined impact of preconditioning and an August storm. *Geophys. Res. Lett.* **2013**, *40*, 1356–1361, doi:10.1002/grl.50349.
27. Zhang, J.; Lindsay,R.; Schweiger, A.; Steele,M. The impact of an intense summer cyclone on 2012 Arctic sea ice retreat. *Geophys. Res. Lett.* **2013**, *40*, 720–726, doi:10.1002/grl.50190.
28. Simmonds, I.; Rudeva, I. The great Arctic cyclone of August 2012. *Geophys. Res. Lett.* **2012**, *39*, L23709, doi:10.1029/2012GL054259.