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Moisture origin, transport pathways, and driving processes of intense wintertime moisture transport into the Arctic

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Reply

We would like to thank the two reviewers for their positive evaluation of the revised manuscript and for their thoughtful suggestions, which we again find very helpful. In the following, the reviewer's comments are given in **blue** and our responses in **black**.

Comments from Reviewer 1

This revised manuscript has been greatly improved compared to its original version. However, this revised manuscript still has some confusing descriptions even a misunderstanding on what is Scandinavian blocking. Thus, I suggest that the authors should revise it.

(1) In subsection 4.5.2 (lines 410-435), blocking patterns in Clusters 1 and 2 are not Scandinavian blocking patterns (Figs. 10a, b, d, e, g, h). Instead, they belong to Ural blocking pattern centered near 60E as defined in Luo et al. (2016, JC, 29, 3925-3947). In contrast, blocking in Cluster 3 belongs to a Scandinavian blocking (Figs. 10c, f, i). Thus, Clusters 1-2 and Cluster 3 correspond to different types of blocking in different regions. The authors should distinguish the two types of blocking patterns rather than consider them as a Scandinavian blocking. In fact, the different roles of Ural blocking and Scandinavian blocking (or high-latitude European blocking) in transporting moisture to BKS and generating the BKS sea ice decline has been discussed in their subsequent CD paper (B. Luo et al. 2019).

Reply: We agree with the reviewer that it is important to distinguish Scandinavian from European blocking, as well as Ural blocking. However, we don't agree in terms of the suggested nomenclature. We follow the well-established nomenclature in the literature, see for example Grams et al. (2017) for a distinction between Scandinavian and European blocking in the context of geopotential height anomalies. Scandinavian blocking is associated with geopotential height or blocking frequency anomalies over Scandinavia, often extending into the adjacent Nordic Seas and the Barents Sea. In the case of European blocking, the corresponding geopotential height and blocking frequency anomalies are shifted away from Scandinavia towards the British Isles. Ural blocking, finally, is associated with a geopotential height anomaly east of Scandinavia over or near the Ural mountains.

Now, clusters 1 and 2 have a clear blocking frequency anomaly over Scandinavia. We do agree, though, that cluster 3 shows a slight shift towards the British Isles and has features of European blocking. However, the blocking frequency anomaly for this cluster is generally weak. None of the clusters shows a pronounced anomaly over or near the Ural mountains. Thus, we prefer to stick to the nomenclature we have used so far in order to remain consistent with the literature.

Grams, C. M., Beerli, R., Pfenninger, S., Staffell, I., & Wernli, H. (2017).

Balancing Europe's wind-power output through spatial deployment informed by weather regimes. Nature Climate Change, 7, 557–562. <https://doi.org/10.1038/NCLIMATE3338>

Tyrlis E, Bader J, Manzini E, Ukita J, Nakamura H, Matei D. On the role of Ural Blocking in driving the Warm Arctic–Cold Siberia pattern. Q.J.R. Meteorol. Soc.2020;1–16. <https://doi.org/10.1002/qj.3784>

Comments from Reviewer 2

I thank the authors for carefully addressing my major and minor comments on the original manuscript submission. While I find the revised manuscript to be in good shape science wise, the writing needs to be cleaned up in certain areas. The abstract is much improved and clearly summarizes novel findings. However, statements/phrasing or whole sentences in other sections of the manuscript need clarification or rephrasing. I would ask that the authors please consider the following minor comments and suggestions for the final draft. I believe this manuscript will be a valuable contribution to Weather and Climate Dynamics.

Minor comments:

(1) Line 6 in the abstract. “zonal mean moisture transport”. Suggested change: poleward moisture transport.

Reply: The events are defined in terms of the zonal mean of the meridional moisture transport. We think it should be stated in the abstract already that we consider the zonal mean. Furthermore, as we phrase it, it should also be clear that we consider transport into the polar cap. For this reason, we have kept the phrasing as is, i.e.,

*For that purpose, 597 moist-air intrusions, defined as daily events of intense (exceeding the 90 th anomaly percentile) **zonal mean moisture transport into the polar cap** ($\geq 70^\circ N$), are identified.*

(2) Line 35. “A substantial portion of the poleward moisture transport occurs”. Suggested change: A substantial portion of the poleward moisture transport into the polar cap occurs.

Reply: Thanks, we have adopted the wording as suggested.

(3) Line 36. “that account for a substantial portion of the mean poleward moisture transport”. Suggest removing or including in a new follow-up sentence.

Reply: We agree and have removed the sentence, merging the following references with the previous ones.

(4) Line 63. Suggest removing “zonal mean”

Reply: Adopted.

(5) Line 120. “the average moisture” Insert an “is” before “the average moisture”

(6) Same as comment 5 on Line 121. Insert an “is” before “the mass of the polar cap”

Reply: Yes, indeed “is” was missing twice. Thanks!

(7) Suggest removing the phrase “(...)denotes again the daily mean” as it seems unnecessary.

Reply: We agree.

(8) Line 122-123. Suggest changing “Finally, we remove the...” to the following: “Finally, since we are interested in the H_L anomaly, we remove the...”

Reply: Adopted.

(9) Line 125-126. “At the beginning and end of the timeseries”. A comma is needed after timeseries.

In addition, the next sentence uses the phrase “moist-air intrusion” which is not defined until Line 130. Perhaps “moisture-air intrusion” in this sentence could be rephrased to “ H_L anomaly selection” or something similar at this point?

“This is to ensure that neither the seasonality nor the long-term increase of poleward moisture transport bias the selection of moist-air intrusions based on a fixed percentile threshold towards the warmer (and more humid) extended winter months or the later years in the study period.”

Reply: Thanks, we have added a comma after timeseries and have replaced “moist-air intrusions” by “anomalous events”, consistent with the adopted phrasing in the last sentence of the paragraph.

(10) Line 129-130. Suggest removing “the” from the following: “We then select all 597 timesteps for the further...”

Reply: Done.

(11) Line 130. Suggest changing the following: “From here on, these timesteps, will referred to as moist-air intrusions.” to: “From here on, these anomalous events of daily moisture transport will be referred to as moist-air intrusions or intrusions.”

Reply: Changed accordingly.

(12) Line 138. Suggest changing the following: “points are ranked according to this transport.” to the following: “transport values at potential trajectory starting points are ranked from highest to lowest.”

Reply: This is better, thanks.

(13) Line 140-142. Suggest changing the following: “With this approach we ensure that selected trajectories represent the most intense poleward moisture transport and they explain a substantial portion of the zonally and vertically integrated flux of moisture into the polar cap on the day of the intrusion.” to: With this approach we ensure that selected trajectories provide a representative sample of the upper half (or top 50%) of the daily moist-air intrusion flux into the polar cap.

Reply: Changed accordingly.

(14) Line 155-157. Suggest changing the following: “As opposed to Sodemann et al. (2008), also moisture uptakes above the planetary boundary layer are taken into account in order to include moistening caused by convective transport of moisture from the boundary layer into the free troposphere.” to: And in contrast to Sodemann et al. (2008), moisture uptakes above the planetary boundary layer are included to account for moistening caused by convective transport of moisture from the boundary layer into the free troposphere.

Reply: Adopted.

(15) Line 226-227. Suggest changing the following: “In the following, we first consider the spatial distribution of the sources of moisture transported into the Arctic across 70° N during all moist-air intrusions (Fig. 3).” to: “In the following, we first consider the spatial distribution of moisture sources for intrusion events (Fig. 3).”

Reply: Rephrased to

In the following, we first consider the spatial distribution of moisture sources for all intrusions (Fig. 3).

(16) Line 239. Suggest changing “if moisture transport is strong” to the following: “if an intrusion is present”. This is one example of when the phrase “moisture transport” is better stated as “moist-air intrusion” or “intrusion”, as it has been defined earlier. I believe this phrasing exists elsewhere in the manuscript, and if so, it should be revised for consistency and clarity according to the definition established. Please recheck throughout.

Reply: We don't fully agree since the moist-air intrusions as we define them are based on the zonal mean transport. Our point here is that such a moist-air intrusion can result from strong poleward moisture transport in more than one zonally confined region. We reworded “... if moisture transport is strong in two sectors simultaneously” to

... if intense poleward moisture transport occurs in two sectors simultaneously.

(17) Line 240. Suggest changing “of latitude segments” to the following: “by latitude segments”

Reply: Changed, thanks.

(18) Line 260. Should the following “warmed by surface sensible heat fluxes” to: warmed by surface sensible and latent heat fluxes

Reply: Surface latent heat fluxes only contribute to warming once the latent heat is released when condensation takes place. Hence, the latent heat fluxes only indirectly contribute to the warming of the air. Here, we are referring to the direct warming effect of the surface sensible heat fluxes.

(19) Line 307. What is the “classical case” of an intrusion? Please defined or rephrase.

Reply: We realize that this sentence was unclear and we have removed it.

(20) Line 316. “contribute substantially more”. The usage of “substantially” needs to be quantified. Figure 6 shows that for $\Delta\theta+\Delta T-$ trajectories contribute 15 (10) % more to moist-air intrusions that occur in the Labrador (North Pacific) sectors than the North Atlantic.

Reply: We have replaced “substantially” by “10% to 15%”.

(21) Line 357-358. Replace “are” with “is” and replace “remain” with “remains” in the following: “moisture are picked up earlier or remain”

Reply: Changed.

(22) Line 393. Change “Ward’s method is to merge element” to the following: “Ward’s method is to merge elements”

Reply: Changed.

(23) Line 398. Is the phrase “in terms of zonal mean poleward moisture transport” needed here? Confirm phrase usage of poleward moisture transport, with and without zonal mean qualifier, moist transport etc.. Please use the moist-air intrusion phrase which defines anomalous moisture transport into the Arctic greater than 90th percentile. I realize sometimes both phrases are needed in a description but there are redundancies and/or combined usage sprinkled throughout.

Reply: We have removed the term “zonal mean” here and checked the remaining usage of the term throughout.

(24) Line 429. “substantially” Again, this should be quantified. Check on this word throughout.

Reply: We have rephrased this to “increased by roughly 10 %”.

(25) Line 447. Rephrase “in the one single”

Reply: Rephrased.

(26) Figure 7 caption should describe SST contours and label increment.

Reply: We have added information on the SST contours to the captions of Figs. 4 and 7.