Interactive comment on "Annual variation in precipitation δ 2H reflects vapor source region at Barrow, AK" by Annie L. Putman et al.

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General comments

This paper presents a new dataset of isotopic composition of precipitation sampled in the Barrow, AK, Arctic station, together with an innovative method to analyze and interpret its seasonal and event time scales variations. The authors propose interesting tools to use the Lagrangian atmospheric backtrajectory model for a quantitative and statistical evaluation of the observed isotopic variations. They conclude that the seasonal variations of water isotopic values are partly due to migration of the moisture origins. They focus on the influence of three parameters which are shown to explain a large part of the observed variations of the isotopic composition: the cooling along atmospheric transport, the dew point at the moisture source and the presence of mountains along the transport. The authors made a good effort to provide a rich interpretation of their observations. The manuscript is well organized and provides necessary tables and figures. There are, however, several issues regarding discussion of the results. I recommend accepting the article after the authors address the points listed below.

The authors thank J.L. Bonne for his helpful and insightful comments. Substantial effort was put toward fully addressing the critiques.

Specific comments

Modeling:

The moisture source modeling used in this paper relies on strong assumptions. However, potential errors caused by these assumptions are poorly pointed out. A companion paper describing the method is currently under review and might contain these information. As this paper is not yet readable, one would need a summary of these information and eventually more details in the method description or in supplementary material, in particular concerning the points addressed below. Contrary to Sodemann et al. 2008b method, the moisture source modeling used here does not take into account variations of the specific humidity in the air parcels along the trajectory. Processes such as the lost moisture through precipitation or reevaporation of already condensed droplets along transport are not taken into account, but could have a strong impact on the isotopic composition. Can you give more details on the potential errors inherent to this moisture sources modeling? Also concerning the moisture sources modeling, moisture uptakes are assimilated to air masses sinking into the planetary boundary layer (PBL) above the ocean surface. Nothing is written about the potential presence of sea ice above the ocean in the region where the PBL is reached, which could however have a strong influence on the evaporation. Do you also take into account the sea ice cover in the region were the air parcels sink into the planetary boundary layer? For example: the moisture sources for the winter events are originating from a very wide range of latitudes. If most sources are originating from the south, some sources are coming from high latitudes, up to 85◦N (see winter sources latitudes on Figure 2). Can we really expect strong evaporation in those regions, over a potentially closed ocean? Have you checked the presence of sea ice in the moisture sources regions for this type of events?

The reviewer has a point, although we still consider our approach adequate for our purpose. We point out that assessment of "the potential errors inherent to this moisture sources modeling" is difficult for any model because true observations of moisture sources for a given event do not exist. Any assessment would be model dependent. Admittedly, the method of tracking the air parcels' moisture evolution through time, such as the one used by Sodemann et al., (2008a), is a more sophisticated way of identifying the source near the PBL than the method presented in this paper, but the model by Sodemann et al. (2008a) is not designed for the event scale moisture tracking in that 1) their parcels do not always start within precipitating clouds, and 2) the vertical distribution of parcels does not reflect condensation rates (precipitation events). Arguably, it would be ideal to combine the two methods. However, we think that for our purpose, which is to characterize the moisture source regions for observed and measured precipitation events, the initial starting points of parcels are most important, because the height of these parcels often primary dictate the source area, in our experience.

Details about modeling that have been added include enhanced discussion of the validity of our 'moisture source' decisions, in particular, our decision to use the last interaction with the PBL as the vapor source. We feel that this choice is justified, though less precise than Sodemann et al (2008a)because the dominance of turbulent transport relative to advective transport within the PBL (p. 4 l. 8-14).

As well, the sea ice presence and concentration is recorded. Air parcels were allowed to sink over sea ice, but were only considered to be a vapor source if the sea ice concentration was < 96% in order to allow for the presence of leads to contribute vapor to the PBL (p. 4 l. 13).

Interpretation of results:
Concerning the interpretation of results at the seasonal scale, the seasonal variations described in the article are mostly the result of the relative preponderance of different types of synoptic scale events across the seasons. The intra-seasonal variability of the different events is often on the same order of magnitude than the variations of seasonal averages, which is too rarely pointed by the author. The clarity of the explanations might benefit from a more stronger distinction of the synoptic scale and seasonal scale variations.
This is a very good point, and useful to understand when interpreting monthly, seasonal and interannual variability. Language to clarify the similarity in magnitude of the event to event and seasonal variability has been added on p. 7 l. 31-33, and the captions of Figs 3 and 4.

Technical corrections

Abstract: The abstract is quite long and could be more concise.
P.1, L.1 to 5: The first three sentences of the abstract could rather be at the beginning of the introduction, as they don't describe the work presented in this article but general situation of research in the domain.
The content of these sentences is covered in the introduction, so they were removed from the abstract, which helps to reduce the length of the abstract.
P.1, L.8: "occurred" > "occuring"
This was changed in the text.

As well, we have added the following to the beginning of the abstract. "In this study, precipitation isotopic variations are linked to conditions at the moisture source region, along the transport path, and at the site of precipitation. Seventy precipitation events…" (p. 1 l. 1-2)

Methods:
P.3, L.13-14: There might be an effect of sublimation of snow which could influence the isotopic composition of water, particularly for sunny periods, even within 24 hours. Did you make some experiments to test the evolution of fresh snow on your sampling site?
The reviewer is correct that this is possible. However, for much of the season when Barrow receives snow, there is little sun to drive sublimation, and the Arctic tends to be quite cloudy. There is also little evidence of sublimation from the data distribution along the meteoric water line. Nonetheless, clarification was added on p. 3, l. 13-16. We have also added a paragraph at the end of Section 3.2 (p. 11, l. 13-20) with a list of all potential sources of error that contribute to the unexplained variance in d2H.

P.3, L.14: At which temperature were the samples stored, and how long?
Clarification was added to the text. Samples were stored at less than 5 C, shipped every 3 months, and analyzed within 6 months. (p. 3, l. 17-18)
P.4, L.1-4: Considering that a moisture source is corresponding to an air parcel sinking into the PBL is a strong assumption. More justifications of this method would be expected. If this method is described in Putman et al. (2015), add a reference here.
The assumption has been more clearly stated and justified in the text (p.4, l. 8-14). Also see our response, at the beginning, to "Specific comments: Modeling"
P.4, L11-12: By "the most temporally homogeneous three-hour time window", do you mean homogeneity in the precipitation amount or in the meteorological records? Do you have particular criteria to define the preference for the middle of the event? Were the event times defined automatically or manually?
This section has been clarified. Homogeneity is in reference to the radar returns, which give us an idea of precipitation intensity. Event times were selected manually, based on multiple streams of evidence: radar returns, sampling records and surface analysis maps.(p. 4, l. 16-24)
P5., L.5: "The same was done for an array...": explicit that this is to calculate Qsat,z and define Qsat,z.
The section on p. 5, l. 21-24 was updated to reflect the calculation was performed on an array of altitudes.
P.5, L.5-6: Explicit hz, Tz, Pz: fractional relative humidity, temperature and pressure at elevation z.

The text has been rephrased to state this explicitly (p. 5, l. 21-23).

P.5, L.25: Are mtn values assigned manually or automatically? If automatic, then explicit the criteria.

Mtn was assigned manually based on maps of trajectory results. Text has been updated for clarity on p.6, l. 17-18..

Results and discussion

P. 6, L.6-15: This is a very qualitative description of Figure 1. The mean latitude of moisture sources could be introduced before and used to give quantitative aspects to this description. This description focuses on the seasonal averages of the moisture sources, but Figure 2 shows a very strong variability at the event time scale, which can be of a larger order of magnitude than the variations of the seasonal average for the mean latitude of the moisture source. For example, some events in winter have moisture sources located as north as in summer, or even further north. The normalisation of the maps from Figure 1 can also give an impression of wider or more local moisture sources depending on the total number of events and the difference between each event. Is this description of moisture sources regions still valid for absolute values without normalization to the number of events, or for individual events instead of the average of all events?

The authors agree that there is substantial variation among events, even within a given season. This has been indicated in the revised version on p. 7 l. 31-33, and the captions of Figs 3 and 4.

P. 6, L. 30-32: Not clear if the last sentence refers to Feng et al. (2007).

Modified sentence to 'Feng et al. (2007) documented southward migration of the polar cell during the last glacial maximum.' for clarity. (p. 7, l. 17)

P. 7, L. 6-7: This sentence is really affirmative, whereas Figure 4 shows a very strong dispersion, particularly for the averaged VLAT. This affirmation should be tempered and a statistical evaluation of the spline fits and there correlations should be given, as well as the standard deviations of the data series. The seasonal scale might not be the better scale to look at.

This is true, in particular for the V_{lat} variable. The variance captured by the spline fits has been added, and the text has been adjusted to better describe the similarity in magnitude between among-event variability and mean seasonal variability. (p. 7 l. 29-31, and the captions of Figs 3 and 4.)

P. 8, L.3: How did you choose the temperatures from 10C to -15C in you theoretical cooling experiments? What would be the effect on the slopes of a variation of these temperatures on the order of magnitude of the observed variations?

The temperature range encompasses the temperature change experienced by most trajectories. Making the warmest temp even warmer would yield slightly shallower slopes, and making colder temperatures even colder would yield steeper slopes. The coldest average final temperatures in our dataset are substantially below -15C, though the majority of each trajectory occurs within the 10 to -15C temperature range, and all events except one begin in the selected range.(p. 8, l. 27-29)

P. 8, L. 18: Rather write “more than 20C” instead of “> 20C”.

Changed.

P. 9, L. 1: “amount” instead of “amounts”?

Changed.

P.9, L.5: How was the 7C criteria chosen? Is it close to the median of the distribution of ΔTcool?

The 7C criterion was chosen to preserve the power of the short trajectories while encapsulating the relationship to local conditions, as described in p. 10, l. 21. Though we have presented the results as categorical, this is for simplicity. It is likely that this feature of isotope systematics is actually continuous.

P. 9, L.12: Insert a reference to figure 6 to show the repartition of small and large ΔTcool across seasons.

Added phrase to sentence: '...and Figure 6 indicates that all the seasons are distributed across the two categories.'

P. 10, L.6: This is not directly about precipitation d-excess but can be of interest: some studies of water vapour d-excess in Arctic regions have depicted a partial conservation of the source d-excess signal under certain atmospheric transport conditions, with relations between observed d-excess and moisture source relative humidity.

Bonne, J.-L., Masson-Delmotte, V., Cattani, O., Delmotte, M., Risi, C., Sodemann, H., and Steen-Larsen, H. C.: The isotopic composition of water vapour and precipitation in Ivittuut, southern Greenland, Atmos. Chem. Phys., 14, 4419-4439, doi:10.5194/acp- 14-4419-2014, 2014.

Bonne, J.-L., et al. (2015), The summer 2012 Greenland heat wave: In situ and remote sensing observations of water vapor isotopic composition during an atmospheric river event, J. Geophys. Res. Atmos., 120, 2970–2989, doi:10.1002/2014JD022602.

Steen-Larsen, H. C., A. E. Sveinbjörnsdottir, Th. Jonsson, F. Ritter, J.-L. Bonne, V. Masson-Delmotte, H. Sodemann, T. Blunier, D. Dahl-Jensen, and B. M. Vinther (2015), Moisture sources and synoptic to seasonal variability of North Atlantic water vapor isotopic composition, J. Geophys. Res. Atmos., 120, 5757–5774, doi:10.1002/ 2015JD023234.
Interesting work, thank you for the citations. The discussion of d-excess has been updated to include these publications, on p. 11, l. 31-32.

Conclusions
P. 10, L. 29-31: This conclusion on the origins of moisture is valid for the average of the seasonal moisture sources, but should be tempered by pointing out the event to event variation of the moisture sources.
This caveat was added to the conclusions "However, substantial intra-season variability occurs in both source and d2H, indicating scatter in the seasonal relationship." (p. 12, l. 30-31)

References
P.13, L. 32-36: Logically, the two papers numbering should be inverted (2008a and 2008b).
Changed.

Tables and figures
Table 1 and 2: The legends do not clearly describe the contents of the tables. Why are different intercepts given for each variable in Table 2 and only one value in Table 1, if the only difference between the two tables are the division of all samples in two groups?
The captions of the tables have been updated to explain that Table 1 contains the results from a single multivariable regression, while Table 2 contains the results from 3 simple linear regressions.

Figure 7: Parenthesis not closed in right y-axis label.
Fixed.
Figure 3 and 7: It would be more readable with x-axis ticks corresponding to the beginning of the years instead of the beginning of each December.
Fixed.