Review: Rivers in the sky, flooding on the ground

This paper investigates the relationship between atmospheric rivers and extreme flooding in the lower Rhine basin. So far, studies mostly investigated this relation between extreme rainfall (or flooding) and ARs for coastal regions. Therefore, the objectives to analyze the connection between ARS and floods occurring more inland is relevant and interesting, and fits the scope of HESS. The study describes the hydrometeorological situation of the three most extreme flood events over the lower Rhine basin in the last 180 years, and the connection with atmospheric rivers. In addition, composites of the large-scale circulation and IVT describing atmospheric rivers are analysed for the 10 most extreme flood events.

Although the analyses answer the research objectives, in my view there is much more potential and knowledge to gain from the dataset and method then is done so far in the manuscript. In fact, the section on the composites of the 10 largest flood events is very short, and has much more potential. I will give a few suggestions on additional questions/ experiments, and leave it up to the author/editor if these analyses are needed in this manuscript or can be potentially used as research questions for further studies.

In addition, I have some major comments and unclarities on the paper below, which should be addressed before publishing. Furthermore, the writing of the manuscript can be improved, being consistent in tense, English language, and use of units throughout the manuscript. Please find my minor comments at the end of this document.

Additional questions arising from the manuscript:

- How are the trends in flooding and ARs over the dataset? The dataset spans quite a substantial time (1836-2015) and in the method section it is indicated that floods probably would happen more frequently (Line 101-110), so it would be nice to explore this further using this dataset. You can also assess if Atmospheric Rivers are going to be more frequent and intense over the lower Rhine catchment as you refer to that is the case over the North Atlantic (line 370)
- As Atmospheric Rivers are associated with the Warm Conveyor Belt of extratropical cyclones, besides holding a lot of moisture, temperatures are often warmer than normal within these ARs. The effect of temperature on snow melt in the Alps or lower Rhine basin could positively influence discharge peaks. This aspect remains underexposed in this study. For example in the case of high temperature inducing snow melt could be related.
- I miss the explanation of the mechanism how Atmospheric Rivers result in extreme rainfall (for coastal areas; when an AR reaches a topographical barrier air parcels are lifted and adiabatically cooled, resulting in clouds and precipitation). For the lower Rhine this lifting mechanism is probably related to the Ardennes area? I am wondering if these mountains trigger enough uplift to result in precipitation or that the amounts of moisture during the three investigated cases is so high that only little uplift is needed.
- You have selected the 3/10 most extreme flood events in the lower river Rhine area and linked those to Atmospheric Rivers. In a dataset of 180 years, more flood events could be selected and their link with Atmospheric Rivers can be investigated.

With that, the robustness of the link between ARs and extreme rainfall and flooding over the lower Rhine basin can be analyzed and put into perspective

Major comments:

The title is illustrative, although does not exactly reflect the novelty of this research with the focus on the link between large-scale circulation (ARs) and floods **inland**.

Atmospheric studies such as Helen Dacre (2015) argue that atmospheric rivers are a result of constant local recycling of water along the cold front of an extratropical cyclone. This suggests that precipitation related to ARs originates more locally rather than from sub-tropical regions as is indicated in line 68, 74 , 336 etc. Please discuss or revise.

In the introduction ARs and the relation with different teleconnections is mentioned, but I don't see that coming back in the rest of the paper. Have you checked NAO indices for the events you studied? This could be interesting, as you often refer to a low south of Greenland (Iceland) and a high over the coast of North Africa (Azores), which gives indication for a positive NAO resulting in strong flows to northwestern Europe. It would be interesting to invest the index of NAO for the selected flood events.

Although your showing IVT in the figures, I miss the embedding in the text. The case studies could have more focus on this IVT values and how anomalous they are, as to my knowledge values in IVT of 800 kg/m/s are quite exceptional. It would be nice to put this a bit more in perspective

The lag between AR/extreme precipitation is interesting and could deserve some more attention throughout the manuscript. Of course this mainly depends on local timing and location, indicating the importance of local processes (to be added on line 40) although it depends on the size of your catchment.

Both in the conclusion as in the abstract I miss quantification of the results. Can you give some numbers to align your statements? For example indicate how anomalous the selected events were in terms of discharge and IVT related to the AR. I think an important conclusion from this research is that in these extreme events, large-scale circulation are rather similar but local conditions leading to the flood not. This is an interesting conclusion which could be highlighted more, and could be strengthened if it was further quantified in the conclusion and abstract as well.

Minor comments:

Line 8: The role of ~~the~~ large scale atmospheric circulation

Line 13: sentence: The influence of ... In my view atmospheric rivers are part of the large-scale circulation, the .. is done via the prevailing large-scale atmospheric circulation.. sounds very odd to me

Line 34: that coping with floods is not **trivial**

Line 40: I would argue that for flood forecasting and the time of occurrence, location and magnitude scales from mesoscale to local scale are important. Especially knowledge on local orography is needed to get the location of the flooding right

Line 42: Same sentence as last sentence of previous paragraph.. combine?

Line 49: This sentence is not clear. What do you mean with regional and local climates?

Line 115: Rhein --> Rhine

Line 118: what is the time resolution of the reanalysis data?

Line 119: I am confused that a re-analysis dataset has ensemble members, could you explain that?

Line 121: has several improvements > vague statement, either name improvements or leave out

Line 133: divided by gravity (*g*).

Lines around 133: What is the vertical resolution of your wind and specific humidity data?

Line 152: Where do you show the EOBS gridded precipitation dataset? Not clear how and if this comes back in your results. Although it would be good to analyse a gridded precipitation field over the lower Rhine basin instead of a point observation at Trier.

Line 161: .. in ~~the~~ large parts of the Rhine catchment..

Line 164: od -> of

Line 167: Can you quantify the total amount of precipitation over the lower Rhine basin area instead of showing the gridpoint values in the appendix. That would give more quantification to the results.

Line 169: This sounds like a positive North Atlantic Oscillation. Would be good to check the index for the selected events.

Lines around 170: Miss numbers of IVT in 1925 case, that would give indication of the 'severity' of AR. Can you give some IVT values here to give some indication as you do for the hydrometeorological situation of 1993 (line 229). In general it would be good to embed the values of IVT a bit more within the text as I think they are quite exceptional, can you compare with climatology? Or average value of ARs at this latitude (as the value of IVT is latitude dependent)

Line 180: specific humidity or moisture

Line 183 etc: Why do you talk about wind and moisture separately here? You can refer to IVT and Figure 3 and in my opinion there is no need in showing figure 4 as it gives the same information as Figure 3.

Line 223: too should be to

Line 228: Again, could you give precipitation values averaged over the basin? And compare that to climatology?

Line 238: Where is statement based on? Add reference

Line 268: become > became. Keep tenses consistent throughout the result section.

Line 268: Where is Berus meteorological station located? Indicate in map

Line 298: driver > driven

Line 319: plum should be plume?

Line 321: by a south-westerly wind (Figure 11) > you are showing IVT vectors and no wind vectors in Figure 11 so wrong reference

Line 322: By visual inspection.. etc. Are you referring to the individual ARs per event or the composites here? If you refer to the composites I would not expect to see individual ARs as the composite gives an average and the ARS are therefore smoothed and you can expect IVT with widths bigger than 1000 km wide.

Line 336: Sentence 2 in the conclusion is not a conclusion of your work, but new information: I would move it to the introduction

Line 346: what is meant by westerly, southwesterly and north-westerly large-scale circulation types? Do you mean prevailing winds? Please clarify.

Line 358-363: This sentence is an explanation why more storms (ARs) occur in winter and should be moved to the methodology section to explain why this study focuses on wintertime.

Line 363: .. is done .. this sentence is not very easy to read

Line 379: I guess this research is about the UK? Maybe good to add that in the sentence to be more specific

Table & Figures

- I see in Table 1 that the magnitude of the flood of 1995 is as high as the one in 1920, so why was the case of 1995 described and not the one from 1920? Or is it because these stream flows are from Koln while you based your analysis on the ones from Trier? This should be stated more clearly in the text, as it is not clear from the methods.
- Also streamflow in Trier station is mentioned in Figure 4 and similar figures, while I understand from the Composite events section that you base your analysis on flood peaks measured at Koln (should be Cologne) gauging station. This is confusing.
- Missing units in Figure 3, 4 and all similar figures
- In my opinion the figures with daily specific humidity and wind at 900 hPa do not add enough additional information to be shown in the main manuscript.

- Figure 2: alone should be along
- Figure 2b and all subsequent figures. Is it needed to show daily streamflow from all these locations and for the whole year? If so, those locations should also be located in Figure 1 or mentioned in the methods section. In my opinion the a figures with discharge at Trier and Cologne give enough information and I would rather show the spatial distribution of precipitation as an addition.
- Figure 12: Not sure what the colors present here? Are these the colours for the 10 different extreme events? I cannot imagine that the orange AR just south of Greenland at Lag0 leaded to a flooding in the Alps, can you comment? This figure needs more explanation in the caption and also a color scale.

Some figures in the additional material miss units and the data sources should be clarified in more detail, are these gridded observation data, re-analysis?

References

Dacre, H.F., Clark, P.A., Martinez-Alvarado, O., Stringer, M.A. and Lavers, D.A., 2015. How do atmospheric rivers form?. *Bulletin of the American Meteorological Society*, *96*(8), pp.1243-1255.

I just wanted to refer to this article which just appeared in Journal of Hydrometeorology which also makes the connection between Atmospheric Rivers and floodings, but then for western Norway:

Hegdahl, T.J., Engeland, K., Müller, M. and Sillmann, J., 2020. An event-based approach to explore selected present and future Atmospheric River induced floods in western Norway. *Journal of Hydrometeorology*, (2020). https://journals.ametsoc.org/doi/10.1175/JHM-D-19-0071.1