In the present work, the authors used downscaled versions of global climate simulations from the CMIP5 ensemble using RCA-NEMO to study the atmospheric rivers over Europe in the present and future climates and compared the same with runs using ERA-I and using different RCPs. Results show that ARs will become more frequent and stronger in the future. Furthermore, the authors highlighted the variability of precipitation in different scenarios and different model simulations.

Though the study consists of some interesting results, the presentation of results, description and quality need to be improved. Information on the methods and quality of the figures including the methodology needs to be elaborated. Many typos, Grammar, missing words are found. Therefore, I would recommend the manuscript for major revision before accepting it for publication.

We thank the reviewer for a thorough review of our manuscript and his/her valuable suggestions that really help to improve the manuscript. We regret that we were too short in the description of the methods and other parts of the text. We will be more comprehensive in a revised version and give lacking details.

Major comments:

L100: Please elaborate on the purpose of the study.

We will make the purpose of this study more clear. The main purposes are:

1) Presentation of the first AR analysis of downscaled CMIP5 model ensemble.
2) Investigate added value of high resolution for AR analysis
3.) Investigate future changes in AR characteristics

L105: Please rephrase the sentence and carefully check the text corrections.

We will split this sentence into two sentences and apply corrections.

Section 2.1:

Please give more details on the model setup, spatial and temporal resolutions of climate models, comparison with ERA-I etc.

We regret that some information is missing in the current manuscript. We will make clear this in another version.

Also, it would be interesting to see a case study showing how later boundary forcing is influencing the AR characteristics in the RCA-climate model.

The lateral boundary forcing is extracted from the global CMIP5 models and prescribed at the lateral boundaries. There is no feedback from RCA to outside the model domain. This means ARs enter the model domain at the lateral boundaries from the parent global model but then they develop freely and independent from the parent global model. We will make this more clear in a revised version.

A comparison of ARs representation in RCA with ARs in the parent global model would be of course interesting but would require exhaustive additional analysis work for each of the global models. Therefore we think, such case study would be better pursued in a specific process study. For the conclusion of the current study we think this is not necessary.

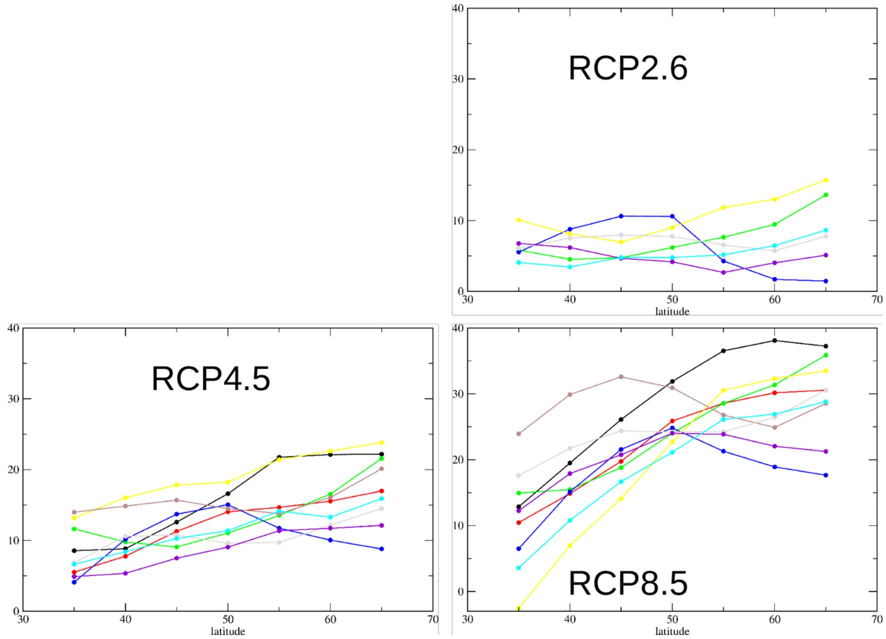
Section 2.2:

Table 2: Please provide a reason for leaving out the RCP2.6 cases for RCA – IPSL-CM5A-MR, RCA – CanESM2 and RCA – CNRM-CM5 despite their availability to force the RCA.

There were technical reasons why these scenarios are lacking. We will add this information. The producer of the model ensemble, our co-author Christian Dieterich meanwhile suddenly deceased shortly after our submission of the current paper. Therefore we can not give more technical details here.

Section 2.3: In addition to figure 2, a figure with the IVT threshold difference w.r.t historical mean in different RCPs

would give a robust picture of the difference in magnitude of IVT thresholds.



The above plot shows the differences (future minus historical) of the IVT thresholds for the respective GHG scenarios. The plot gives indeed a more robust picture and allows more insights. For example, the yellow curve (RCA-HAD) suggests dynamical changes in addition to the thermodynamic effect of increased moisture load in a warmer climate. Hence, in RCP26 and RCP45 at 35°N the RCA-HAD IVT increases by 10% and 15%, but decreases in RCP85. This could be interpreted e.g. with a meridional shift of the core zone of westerly moisture transport in RCA-HAD.

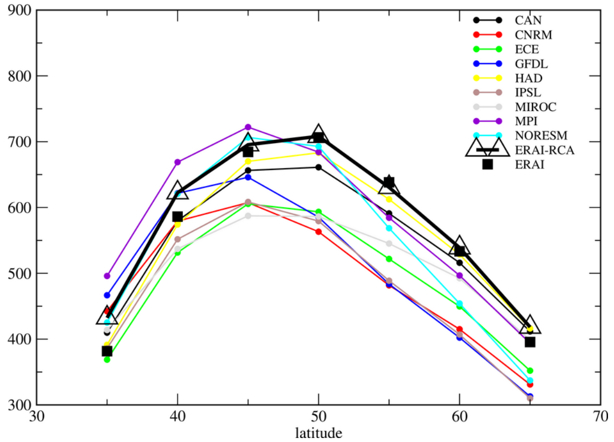
How do the discrepancies in IVT thresholds from different models and different RCPs are attributed to? Please give a brief note on the reasons for the biases in the IVT thresholds. Could it be due to bias in RCA runs or due to bias in the lateral boundary conditions from the GCMs?

The discrepancies are most likely related to the different climates provided by the global models at the lateral boundary. First, all parent global models have a different thermodynamical equilibrium state and with this air temperatures and moisture load will be different. In connection with this, the large scale atmospheric circulation will differ (e.g. Brands, 2021) among the global models as the equator to pole temperature gradients are likewise different (Harvey et a., 2013). Consequently, the large differences in the IVT thresholds are not so surprising but he magnitude of difference is noteworthy. We will add a short paragraph to discuss these discrepancies.

Brands, S.: A circulation-based performance atlas of the CMIP5 and 6 models for regional climate studies in the northern hemisphere, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2020-418, in review, 2021

Harvey, B.J., Shaffrey, L.C. & Woollings, T.J. Equator-to-pole temperature differences and the extra-tropical storm track responses of the CMIP5 climate models. *Clim Dyn* **43,** 1171–1182 (2014). https://doi.org/10.1007/s00382-013-1883-9

Figure 3: How do authors justify the large difference in IVT of ARs in hindcast and reanalysis? Though both reanalysis and hindcast data use observations, I would assume that the model parameters such as lead time, assimilation methods etc might be causing the bias here. Please discuss the same.



We have to apologize for the bad quality of Figure 3 in the manuscript which makes it difficult to distinguish ERAI-RCA and ERA properly. We replotted Figure 3 and marked both curves with symbols (see above). Hence, notable differences between ERAI (black curve triangles) and ERAI-RCA (black curve filled squares) occur only south of 40°N. The largest difference, equals ~11% (at 35°N). That's not so much but nevertheless notable. Due to the rotated grid of RCA, the positions 35°N and 40 °N at 10°W are closest to the lateral boundary of RCA. Thus, the most likely explanation is, that we see here an effect of the errors associated with the lateral boundary coupling which are well known in regional models with one-way coupling to the driving coarse resolution models (e.g. Davies, 2013; Chikhar and Gauthier 2017).

Furthermore, the southern model boundary at 35°N lies in the transition zone from dry air masses of the subtropics and the wet air masses of the humid westerlies i.e. where high gradients in moisture content over short distances can be expected. Here, small differences in the mean position of the transition zone can cause large differences in local moisture content. We will discuss this in a potentially revised version.

Davies, T. (2014), Lateral boundary conditions for limited area models. Q.J.R. Meteorol. Soc., 140: 185-196. https://doi.org/10.1002/qj.2127
Chikhar, K., & Gauthier, P. (2017). Impact of Lateral Boundary Conditions on Regional Analyses, *Monthly Weather Review*, *145*(4), 1361-1379.

Section 3.1:

L235: I would agree with the authors that the RCA impact on detecting the number would be less. However, it is to be noted that RCA could impact the strength of the ARs including the length to width ratio, footprint over a region, persistence etc. Please discuss these issues here.

Good point. We agree RCA leaves it's own footprint on ARs within the domain and with this it influences geometry, duration and intensity. The alteration, and thus RCAs imprint on ARs, is likely stronger the more the RCA domain extends westward over the open Atlantic. We will include a short paragraph on this.

Table 3: Why is RCA-MIROC showing a different trend in frequency expressed as the number ARs detected in a 30 year period of different climate scenarios? I suspect the value 445 8 from RCP45 in RCA-CAN. Please verify it.

This was a mistake RCA-CAN has a value of 445. Thank you for the correction.
We agree there is apparently a different trend in RCA-MIROC. It is very likely that we see here dynamical effect that outcompedes the thermodynmic effect of increased temperature/ moisture load. This could indicate a shift in the meridional position of the westerlies in the global model or local circulation changes in RCA for example due to different warming patterns over land and over sea. We will include a remark in the manuscript to discuss this. However, this is difficult to diagnose in our regional model without further expensive experiments.

Section 3.2:

L290: I would recommend authors include more details on rainfall variability by describing the dynamics and synoptic conditions responsible, rather than simply showing some stats.

Our main point here was to show that even despite ARs are a very rare phenomenon (< ~3% of all days in a 30 year period are impacted by ARs) they can contribute significant amounts to the local yearly rainfall amount particularly in dry regions.

We agree more details on the dynamics of synoptic weather system would be interesting. However, this would need much more statistical analysis on detecting synoptic weather systems and would go beyond the purpose of this paper. However, there is literature about relationship between ARs and synoptical weather systems and we will include appropriate references (e.g. Pasquier et al., 2018).

Section 3.2.3:

L325: Please verify the Figures numbers cited here. Through precipitation patterns are modulated by stochastic processes and further modulated by topography, the magnitude of IVT is affected by the small scale processes such as fluxes, SST and winds etc. Please go through the literature and discuss the same here.

We meant Fig. 5c and 5d here (not 5b). Our main point here is that the high resolution RCA exhibit much more spatial noise here than the ERAI dataset. We attribute this to the different resolution of ERAI (0.75°) and RCA (0.22°). We appreciate the suggestion to discuss the relevant small scale processes responsible for that in a potentially revised version.

L335: Please describe the reasons for the bias in RCA ARs inland propagation.

This is likely related to a more rapid moisture loss of AR over land in RCA. It could also be related to the fact that in RCA-NEMO the North Sea and Baltic Sea is interactively simulated with a an high resolution ocean model, while in the ECMWF-IFS model that produced the ERAI reanalysis these two seas are implemented only a fixed surface scheme. This means basically that SST, sea ice boundary fields are prescribed from ERA data while in RCA4-NEMO they are calculated during simulation. We will describe this in more detail and include a short paragraph on this.

Section 4.2:

L385: Not sure if the figures cited here are relevant to the context. Please verify
we will carefully check this and change if necessary.

L400: Increase in AR forced heavy precipitation over Eastern Europe may also associate with changes in absolute path of the ARs, increase in IVT/moisture availability and duration/persistency of the ARs over the land. Please discuss these issues.

Good point! We completely agree. We will definitely add a paragraph on this.

Section 4.3:

It is a good practice to present figures with lat-long labels which are missing for almost all spatial figures in the manuscript. Please redraw them in the revised manuscript.

We agree and will redraw all the maps.

L450: The approach selected by the authors in finding the source region of ARs raises many questions. For example, earlier the authors mentioned that As originate from open oceans. But taking 10W as a reference for finding the source region does not line up with the earlier statement and may induce errors in results. Furthermore, it is not customary to find the source region according to the AR incidence/landfalling.

Sorry, we have to pass the manuscript to a professional native speaker before potentially resubmitting. We did not want to evaluate the source region (unfortunately we used this wording) but we meant the meridional bin where ARs were for the first time was detected. We agree this doesn’t say anything about the source region where the ARs formed. As you mentioned in your previous comment (L400), this says something about the absolute path of the AR after entering Europe at 10°W. We will rewrite the whole section and make the purpose of this section more clear.

L460, 465, 470: Please rephrase the sentences with proper citations to the figures.
Will be done.

L475: " we can conclude that ARs from the southern Atlantic sectors are more present over most land regions in a warmer climate" is a strong statement in this context.
We will rephrase this and make it consistent with our analysis

Section 5.1: Please describe how and why the higher latitudes experience increasing precipitation despite the decrease in ARs.

We will make this more clear in an appropriate place in 5.1. ARs do also increase in the high latitudes >°60°N but ARs <45°N increase even more. Consequently the relative contribution on land from ARs entering Europe north of 60°N lowers. The more "southern ARs" may carry warmer and wetter air masses.

P495: How the decreased AR impact over Norway can be explained with the decrease of ARs arising from >60N. Earlier authors claim that Scandinavian ARs originate from the south.

Yes, we claim here that in the future climate, ARs originate more from latitude <60° thereby carrying warmer air and more moisture. We will rephrase this paragraph and make this more consistent with other text passages.

L515: A figure showing regional mean precipitation change in the historical/future scenarios from individual models with error bars would give a better idea of the magnitude of precipitation changes.

That's true. However, in the context here we aim to explicitly refer to the strengthened AR influence on heavy precipitation. The mean changes even on a seasonal resolution have been investigated in Gröger et al. (2021, https://link.springer.com/article/10.1007/s00382-020-05489-8, Figs 2 & 3).

Section 6:

L590: Figure 9 shows the opposite result. Please explain the same.
We agree, we will remove this sentence.

Minor comments:

1. Please carefully go through the text and sentences and correct the typos, values, and grammar.

2. Authors are requested to re-check the references as some of them are not matching the context they are cited.

3. Please improve the quality of the figures

We agree the manuscript needs a careful major revision of figures and and in particular language style.