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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Precipitation response to Aerosol-Radiation and Aerosol-Cloud Interactions in Regional Climate Simulations over Europe" *by* José María López-Romero et al.

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1 Main comments

This paper shows results from 20 year run with regional climate model WRF-chem. Experiment setup includes simulations with different aerosol interaction. One clear conclusion of this paper is that both ACI and ARI lead to decrease of precipitation in Europe. Aerosols regional climate effects are still very uncertain and authors have carried out valuable simulations to increase our knowledge of aerosols regions effect on precipitation. Main question of this paper is what is the role of ACI and ARI in

regional precipitation observations. However, I find some major comments on authors study. This paper is in scope of ACP and I recommend it to be published after major revisions.

We strongly appreciate the very positive and constructive comments of the reviewer and kindly acknowledge the time devoted to the revision of the manuscript. Please find below an item-by-item response to the Reviewer's ♯2 comments.

2 Major comments

1. Authors clearly list their findings on how ARI and ACI affects on rainy days, overall precipitation and low clouds. In figures term CLL is not opened, however in text this is indicated as low clouds. Text should mention what aerosol-cloud processes are included in the simulations, direct, indirect, semi-indirect, how these depend on aerosol type. How the aerosols itself formed in these experiments?

   CLL stands Clouds at Low Levels. The definition of this abbreviation has been added to the revised version of the manuscript. We agree with the Reviewer that the definition of the processes included in the different experiments lacks some detail. In the revised version of the manuscript, the Section devoted to the description of the experiments has been widely extended. Here, detailed descriptions of the processes involved in each experiment and the differences among them have been included. Basically, the BASE experiment does not include interactive aerosols. The ARI experiment introduces the aerosol-radiation interactions and the ACI experiments adds the aerosol interactions with the microphysics (aerosol-cloud interactions) in addition to the ARI simulations. Moreover, we have added some text explaining the origin and the formation of the different types of aerosols in the simulations. Basically, natural aerosols are generated by the interactions of atmospheric conditions with the land characteristics (vegeta-

tion, soil moisture, composition, etc.). Anthropogenic emissions of aerosols are taken from the ACCMIP initiative (Lamarque et al., 2010), as stated in the revised version of the manuscript.

2. It's unclear was there simulation where both ACI and ARI were included. Authors mention that there are areas where ACI and ARI effects cancel each other out. However due to non-linearities of aerosol-cloud effects, this conclusion would benefit from additional simulation where both ACI and ARI are included.

   As previously stated, the revised version of the manuscript includes a more detailed description of the experiments, where the issues raised by the Reviewer have been clarified. The ARI experiment includes only the aerosol-radiation interactions (mainly direct effects); in addition, the ACI experiments includes both the interactions of aerosols with radiation and with the cloud microphysics (indirect effects).

3. Also basic aerosols effect information should be shown, radiative forcing, direct and indirect. This helps reader to better understand the real effect of aerosols.

   We thank the Reviewer for his/her comment. In the revised version of the manuscript the results of all the experiments are shown regarding different aerosol-related variables, like AOD, PM10, PM2.5 and PMratio. Undoubtedly, this will help the reader to better understand the processes involved. Moreover, some complementary information has been added regarding the seasonal cycle of these variables

4. Only uncertainty regarding the model here is the aerosol setup. What is the role of model uncertainty? Example how much base case precipitation changes differs if you have slightly different initial condition in the model?

   The Reviewer raises a good point. Evidently, the internal variability plays an important role. In previous works of the research group (e.g. Jerez et al., 2020) the

   role of the model initialization has been widely studied. However, in the revised version of the manuscript we analyze the impact of the aerosols on precipitation on a climatological scale. All the simulations have been identically initialized starting from the same chunks composing the different numerical experiments. We have to start from the hypothesis that the differences between the simulations come from the effects of the aerosols and their different treatment (only aerosol-radiation interactions or adding aerosol-cloud interactions). These aforementioned differences will be related both with direct, semi-direct and indirect effects, and their interaction with the internal variability of the model. Running new experiments analyzing that effect is unaffordable from a computational point of view at this time. In addition, the scientific literature consulted points to a negligible influence of the internal variability in this kind of experiments. On the other hand, the analysis conduced searches for the relationship between the changes obtained with the different concentration of different types of aerosols. In this analysis we include the statistical significance, so that we can corroborate the differences that can depart from the mere internal variability.

5. ARI simulations are not discussed except in Figure 6. Similar analysis should be made also for ARI as done for ACI. I highly recommend also showing the results for ARI simulations.

   In the original version of the manuscript we decided to include only the ARI analysis when the differences between the simulations were caused essentially by the changes induced by the microphysics of the model. This was initially done in order to minimize the number of Figures and the length of the text. Nevertheless, we fully understand the Reviewer's concern. The revised version of the manuscript includes the analysis of the differences of the fields obtained both for ARI and ACI experiments.

6. 6. In conclusion paper says that aerosol both decrease or increase precipitation , here it should also be stated why and where, what are the mechanisms causing

these changes based on these simulations. Example in line 313 author says that decrease of precipitation is due to decrease of rainy days. What causes the decrease of rainy days?

The scientific literature that covers the topic of the effects of aerosols on precipitation -and the physical processes involved- focus mainly on study cases. The objective of the work includes the analysis of changes in precipitation, amount and regimes, together with its relationship with different types of aerosols from a climatological perspective. This approach slightly hampers the direct association to physical processes, because the effects of aerosols depend on the meteorological situation, the type of aerosols, and in our case of the differences in the time evolution. The straightforwards effect produced can evolve in time and space indirectly due to the internal variability of the model, since simulations do not use nudging in the inner domain and simulations are transient (continuous). The statistical analysis carried out shows how diverse areas respond differently to the aerosol feedbacks. While in some areas precipitation is reduced when including aerosol interactions (Central Europe), this impact is low for total precipitation. However, if we focus in the number of rainy days, this impact is noticeable, affecting days with less precipitation. Conversely, in the Mediterranean the response of precipitation is the contrary, and the type of aerosols and the environmental conditions also differs. Therefore, we understand that the physical explanations of the results found are not fully included in the manuscript; however, in the revised version, this discussion about physical processes has been extended based on the results from other studies. As an example, Khain et al. (2008) indicate the high variability of the changes in precipitation due to modifications in the type of aerosols and environmental conditions.

7. Model aerosol configuration should be explained clearly, what natural and anthropogenic aerosols are included.

   As aforementioned, the Methodology section has now included a detailed de-

scription on the setup of the experiments and the aerosols involved in the simulations.

3 Minor comments

1. Figure text in figure 2. I suggest changes letters to beging of each sentence. (Toprow) (a) Relative differences for precipitation between ACI and BASE experiments;(b)number of days of precipitation>0.1mm ; (c) and low clouds. Squares indicate points whose differences are significant for a p-value of 0.05.

   Done as suggested.

2. In abstract line 9 spatially averaged should also mention the spatial region of the simulations which is the averages.

   The averages are estimated over the whole domain. Done as suggested.

3. In method section I would recommend to include model section to describe the model itself

   As mentioned before, a much more detailed description of model and experimental setup has been added to the manuscript.

4. In line 91. Author states “In the BASE experiment aerosols are not treated interactively.... ” Is this meaning that aerosol itself develops from vapors or aerosols are interaction with clouds?

   This section has been modified. In the BASE experiment aerosol properties affecting the physics of the model are constant in space and time (for radiation, AOD; and for microphysics, the cloud condensation nucleii are constant).

5. In line 131. “). The simulations were run splitting the full period into sub-periods of 5 years with a spin-up period of 4 months,” this is unclear what has been done?

The total period simulated for each experiment (BASE, ARI and ACI) is of 20 years. Instead of doing a run of 20 years long, we split each simulation in 4 chunks of 5 years with an spin-up period of 4 months. This spin-up time is removed and the 4 chunks are pasted. This is done following the recommendation of Jerez et al. (2020) in order to make experiments faster.

6. In line 134, "The evolution of greenhouse gases CO2, CH4 and N2O were considered in accordance with the recommendation of Jerez et al. (2018)." This should be opened and explained the Jerez et.al paper

   Done as suggested.

7. In line 150, "the relative differences.." relative to what?

   The relative differences are calculated as the differences among the experiments (ACI-BASE) divided by the BASE case and multiplied by 100, therefore relative to the BASE case.

8. In line 151 they refer tern "criteria" is unclear what criteria.

   The criteria defined in the above paragraph, the intensity and and extension over the defined thresholds. It has been clarified in the new version of the manuscript.

9. In line 160, clustering method used should be mentioned.

   The clustering method is composed by several steps, the final one is the K-means method. This has been clarified in the text.

10. Titles in figure 5 should be changed to clusters. Also results in figure 4 and 5 should be discussed more. Figure 5 is somewhat puzzling.

    As suggested, some more discussion has been added and zones are renamed as clusters in Figure 5.