Response to the reviewer n.1 of the manuscript by Napoli et al. 'Aerosol indirect effects in complex orography areas: a numerical study over the Great Alpine Region'

Reviewer n. 1

1. *The WRF model is driven in the experiments by a GCM (EC-EARTH). Since this is a sensitivity study for a past period, I would expect that the standard would be to use reanalysis data to conduct the experiments. This would safeguard in the case the GCM has some major biases in the region and time chosen and fails to capture the climatology. I would be interested to know whether there is a specific reason for choosing the GCM instead of reanalysis. I understand that we are mainly interested in the differences between the polluted and the pristine experiments and not whether they sufficiently capture the climatology, so this is not a huge deal. However, since we are interested in the Alpine region it would be nice to know whether the experiments do capture the basic features of the climate there. Maybe a quick qualitative validation with some plots of observational/reanalysis in the supplement next to the control run?*

   Thank you for your suggestion. The reason for using EC-Earth output as the boundary conditions is because part of these simulations were done for another project where historical and future scenario simulations were compared. Having verified the consistency of the results with the observations and with the climatology of the same model forced with the reanalysis, we are confident that, for the aim of this work, the use of EC-Earth is appropriate.
   Below we show a brief validation of the two experiments to verify that they capture the basic features of the climate of the Great Alpine Region. To evaluate the simulations, we carried out comparisons in the seasonal cycles of temperature (Figure R1-1a) and precipitation (Figure R1-1b) with the E-OBS dataset version 23.1 at 0.1°x0.1° (this new version provides daily gridded land-only observational dataset over Europe). To represent the climatological mean over the GAR, we analyze 30-years of the dataset. POLLUTED and PRISTINE temperatures are interpolated over the E-OBS grid resolution using the bilinear method, while precipitation datasets have been interpolated using the First-order Conservative Remapping Method [1]. As we can notice, the seasonal cycle of temperature (Figure R1-1a) is well captured, showing high mean temperatures during the summer season and lower temperatures in winter. Precipitation (Figure R1-1b) is characterised by greater variability, nevertheless we can notice the increase of the mean precipitation during the spring season with a stronger decrease between August and September. The same model, forced with reanalysis data, was used in the work of [2] and showed consistent results. Spring season and June are characterized by a slightly overestimation of monthly precipitation compared to observational dataset, characteristic already observed and probably due to the complex terrain of this area [2, 3, 4].

2. *Is there a specific reason for choosing the specific time period of 1979-1983 for the experiments?*

   Thanks for pointing this out. We realized that mentioning the years is misleading and totally irrelevant, considering that the runs are forced with the EC-Earth boundary conditions that certainly have not much in common with the precise years. We indeed have modified the manuscript removing the reference to the specific years used (line 50 in the Method section of the new manuscript: *"Two 5-years long simulations have been run with initial and boundary conditions provided by the Earth System Model EC-Earth in a historical scenario on a 25 km horizontal grid"*). Clearly, the choice of time period in this study is not significant because the purpose is to investigate the role of aerosols and not the effects of global climate change nor other climate variability patterns. We only need a long enough period in order to have statistically significant results, and to have an adequate number of years with realistic circulation patters.

3. *I do not have any major issues with the domain setup. However, I would prefer the outer (larger) domain to be bigger. I would extent it more to the west, so that the distance between the outer and inner domains would be larger. In the current setup, any disturbance coming from the west would enter, pass through the relaxation zone and only after a few grid points would reach the inner domain. I don't know whether it has the distance to be sufficiently analyzed. Also, I would probably extend it more to the south to fully capture the Ligurian Sea thus better capture any possible cyclogenesis events. Just a few thoughts for future consideration.*

   Thank you for your comment about the domain setup, we will certainly keep it in mind for future work. It would certainly have been wiser to do what you suggest, but it's now too much computational demanding to rerun everything. We believe however that the results of the present study are not significantly impacted by this setup.

4. *I would like to see some more technical information in the methods regarding the WRF setup, like the number of vertical levels and the top pressure level used. Especially, in a highly mountainous regions this could be important.*

   We added in the manuscript, in the updated Methods section lines 58-59, some more technical information. The text reads now: *"The vertical structure of both domains consist of 50 terrain-following levels with a top pressure level set at 50hPa. The vertical resolution is finer near the ground (order of metre), while it coarser aloft (order of hundreds of metres)"*

5. *As far as I understand you used the 'use_aero_icbc=false' option in the namelist regarding the Thompson aerosol aware mp. It would be interesting for WRF users to state this in the methodology. It can be in a parenthesis.*

   Thank you, we added it in line 69 of the new version of the manuscript: *"By using the option (use_aero_icbc=false), the Thompson aerosol aware microphysics scheme computes a fake surface aerosol emission."*.

6. *In the supplement S3 it is stated that some changes have been made in the code (orange highlights) to "better represent the aerosol concentrations in the Great Alpine Region." I would like a further elaboration on that. What is the rationality behind the changes?*

   The initial vertical profile of aerosols in the out-of-the-box microphysics 28 scheme has been designed to fit the Continental U.S. in which the near-surface value is found to exist within an idealized layer of approximately 200 to 1000 meters depending on starting elevation. The formulation tries to account for a very thin idealized layer height of tens of meters in high terrain above 2500 meters but closer to 1000 meters thick for grid points at elevations lower than 1000m. Considering the situation in the Great Alpine Region, we slightly modified the values such that the near-surface value of aerosols is found in a shallow layer for elevations above 1500m (rather than 2500m) and in a thicker layer for elevations lower than 600m. In any case, the memory of the initial profile is lost within an initial spin up, and only the initial near surface value is used to defined the forcing fields at any time step (fixed flux). We have added few lines in the revised supplementary material, section S3.

7. *Also in supplement S3, the aerosol number concentrations used in the experiments of the various variables (naCCN, naIN) are given. I think it would be important to state: Did you also change the numbers for the PRISTINE experiment from the original code? How did you choose the numbers for the POLLUTED run? Any possible references this was based on?*

   Thank you for the question, this is absolutely an information that it is needed: we followed the procedure adopted by Da Silva et al. 2018, who chose values that *"ensure that aerosol indirect effects emerge from the "natural noise" between MIN and MAX simulations"* [5]. To this aim, Da Silva et al. define for the PRISTINE experiment profiles that are nearly independent of height (see Fig. R1-2) and for the POLLUTED experiment profiles that have the same upper level aerosol concentrations, but about one thousand times larger values near the surface in the valley. We used exactly the same values. The choice has been based on the observation that 10,000 /cc is a realistic value, measured in urban areas in the region under study (by counting particles larger than 0.01 μm [6]). This information has been added to the new Supplementary Material version, section S3.

8. *One major concern I would have regarding the Thompson aerosol aware mp in the 'use_aero_icbc=false' mode would be the aerosol concentrations over time. As far as I understand there are no aerosol coming from the lateral boundaries only the (fake) ground emissions. I don't know how this would affect aerosol concentrations throughout long term simulations. Have you checked how the aerosol concentrations over the domain for a specific experiment and season change throughout the years? Do they remain stable? Any large differences? If so, this could affect results from year to year. I would be really interested to know.*

Excellent point. Thanks. Although there are no lateral fluxes of aerosols at the edges of the outer domain, the nested domain over which we analyze the results exchanges aerosols at the boundaries with the outer domain. We verified that the aerosol concentration in the planetary boundary layer does not significantly change through time. We show this in Figures R1-3 and R1-4, added here for your reference. Figure R1-4 shows the daily time series of the mean concentration over the PBL at 3 a.m. averaged over the domain of the POLLUTED experiment, for the first 34 months of the simulation (we don't have the same data for the remaining of the simulation). It can be seen than no clear trend appears. To explore weather a different behavior appears in the last couple of years in the simulation, we show in Fig. R1-3 the same variable over the five years of simulation, where only 1 datum per month is collected (at 3a.m. of the first day of the month). No clear trend appears in this time series either. Thus, we are quite confident that the results that we show do not have any dependency on long term changes in aerosol concentration. Regarding the seasonality that can be seen in Fig. R1-4, please notice that we only have data for 3 a.m. in the morning, when the PBL is very shallow and similar in thickness between summer and winter. For this reason, the timeseries does not reproduce the expected seasonality, with larger values during winter when the air column is more stable and lower values during winter when the PBL becomes very thick.

9. *I think it would be interesting to note whether the aerosol concentrations produced in each experiment are plausible. For example, is the POLLUTED experiment something that can actually happen or is it an idealized case of unrealistically high aerosol pollution? Are the aerosol concentrations seen in the PRISTINE experiment a typical example of low pollution over the area? It would help to frame the overall research as being either mainly idealized or having ties with reality.*

   Thank you for the comment. The aim of this study was not to represent the real concentration of the aerosols in the Great Alpine region, although we have tried to describe the vertical profile in such a way that it better represents the area of our interest, as we replied to question number 6. In any case, the surface values corresponding to the POLLUTED experiment are values that have been observed in urban areas in Europe [6]. In that paper, seasonal mean values up to 80,000 /cc are reported (fig. 9). The low values used in our study (three order of magnitude smaller) correspond to concentration typical of the upper troposphere. In this sense, the PRISTINE simulation is probably not realistic. We decided to use those extreme values in order to maximize the effects of the changes and to explore the role of the surface emission.

10. *Page 4, lines 83-84. How much did you play with the cloud fraction threshold? If you could back up the cloud fraction threshold (in) sensitivity with a plot in the supplement the better (not necessary though).*

    We verified that the difference in the total number of cloud events doesn't change significantly in function of the cloud fraction (Figure R1-5). We worked on three different thresholds, that are all shown in Figure R1-5: 0.1, 0.5 and 0.9. The figure has been added to Supplementary materials, new Section S6.

11. *In the Results section, impacts on shortwave and longwave radiation are mentioned. Since these are key to the interpretation of the impacts on temperature it would be nice to include figures on shortwave and longwave impacts in the supplement.*

    Thank you for your comment about this aspect. Figure R1-6 shows the daily cycles of the difference of the mean hourly short-wave radiation (a, b) and downward long-wave radiation (c, d) in the two different seasons. We have added it to the supplementary material (new section S7) together with the climatological conditions for PRISTINE run added in section S2 (Fig. R1-7 and Fig. R1-8). We also made reference to the daily cycles of the difference of the mean hourly shortwave radiation and downward longwave radiation in the new version of the manuscript, Result section. These figures support our interpretation of the results, and make our point stronger. Thanks for the suggestion!

12. *Figures 4 and 5 in the captions. You use the term 'station altitude'. If I am not mistaken, isn't this supposed to be "grid cell altitude"? Also please comment on what the colors mean in these figures.*

    Thank you for your advice: we have changed in Figure 4 and 5 the term "station altitude" and we have added the description about the colors in the scatter plots.

13. *Page 10.line 177. 'Convective cloud evolution...". Makes sense but I would like to see a reference.*

We modified these sentences to better clarify and we added some references in the new version of the manuscript:
"Convective cloud evolution is very fast, characterized by large supersaturation values that lead in a short time to big raindrops. Aerosols can modify convective cloud evolution through effects on cloud microphysics and dynamics that involve complex processes dependent on their chemical composition and on the environmental conditions, leading to contrasting results [7, 8, 9, 10, 11, 12, 13]. The short lifetime of convective clouds and their limited occurrence in the mid-latitude region under study imply that the variations in convective cloud cover in response to aerosol loading are small and do not significantly modify the daily mean insolation.
For those reasons, we call them Aerosol Independent Clouds (AIC) to imply that their daily mean radiative effects are not substantially affected by pollution, and to distinguish them from the Aerosol Dependent Clouds (ADC) linked to synoptic scale disturbances and low level clouds."

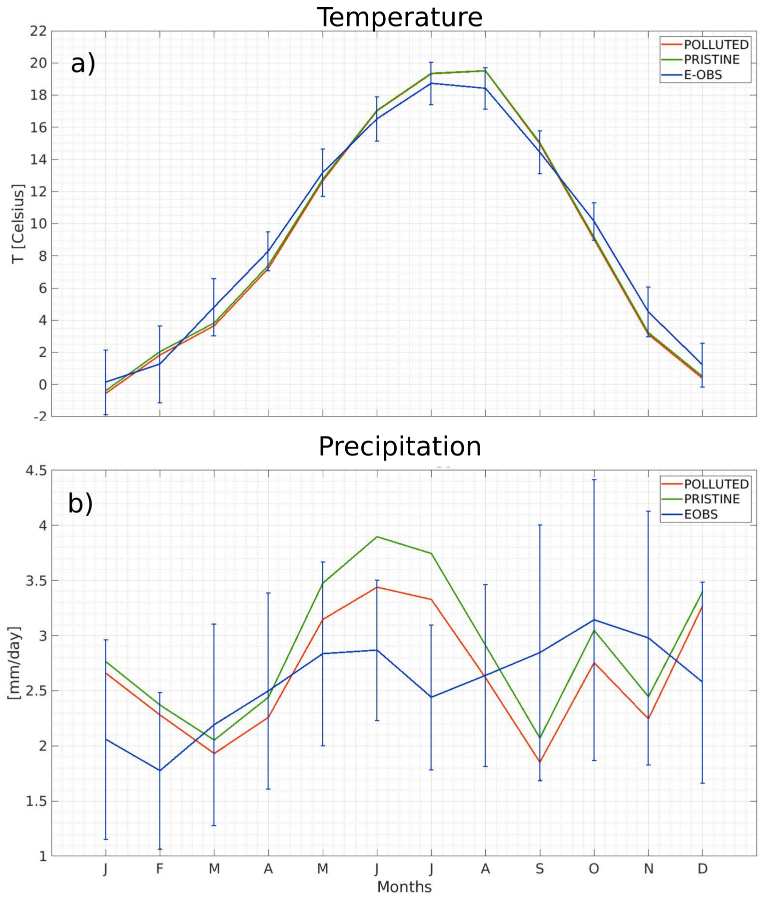

Figure R1-1: Seasonal cycle of temperature at 2m from the surface (a) and monthly mean precipitation over land points averaged over the GAR (b). Error bars represent the standard deviation of the monthly mean for E-OBS data calculated over land points of the entire domain and the full dataset (i.e, 30 years). The analysis has been done over the same domain for both POLLUTED and PRISTINE experiments and E-OBS dataset.

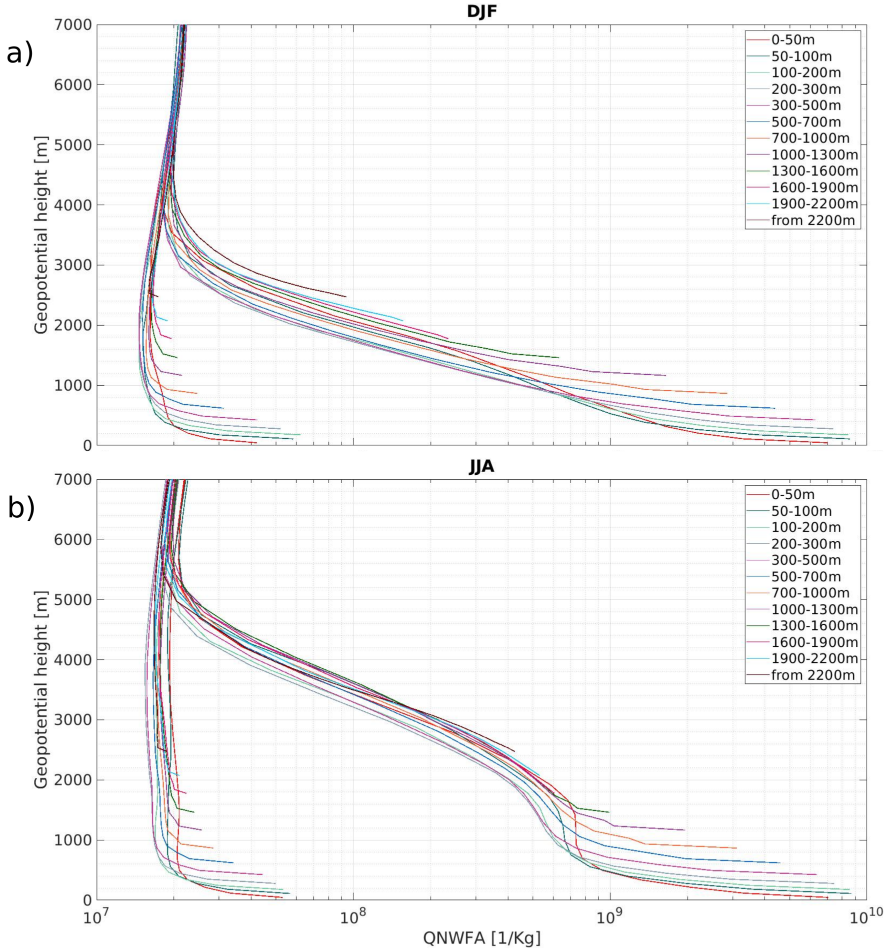

Figure R1-2: *Mean vertical profile of QNWFA concentration for ranges of altitudes in Winter (a) and Summer (b) of the POLLUTED and PRISTINE experiments.*

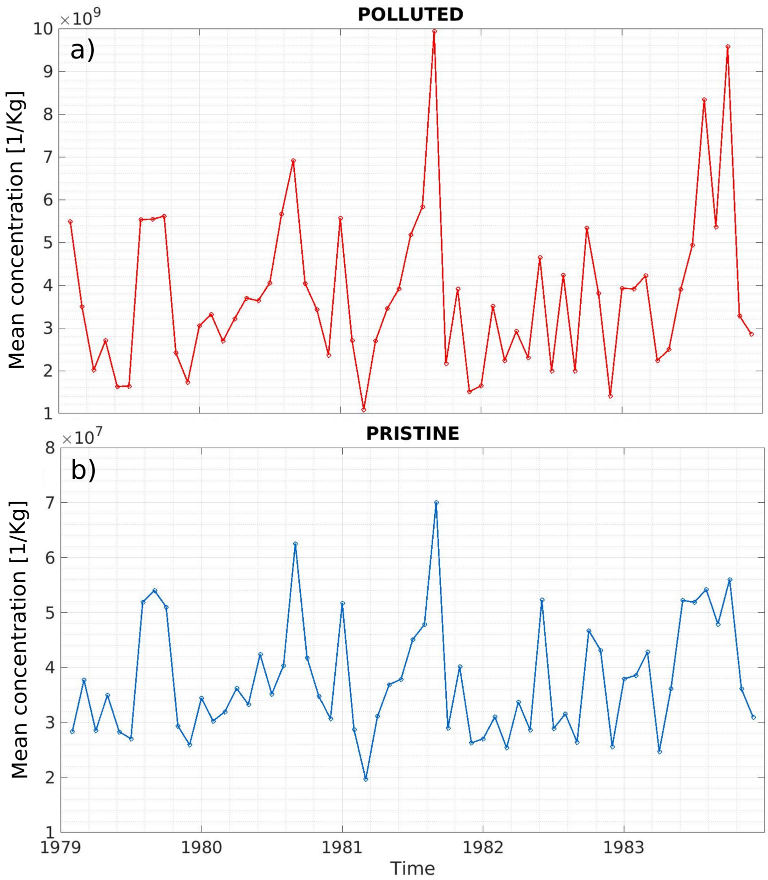

Figure R1-3: *Time series of the mean concentration over the PBL in the entire domain, one data per each month at 3a.m. in POLLUTED (a) and PRISTINE (b) experiment.*

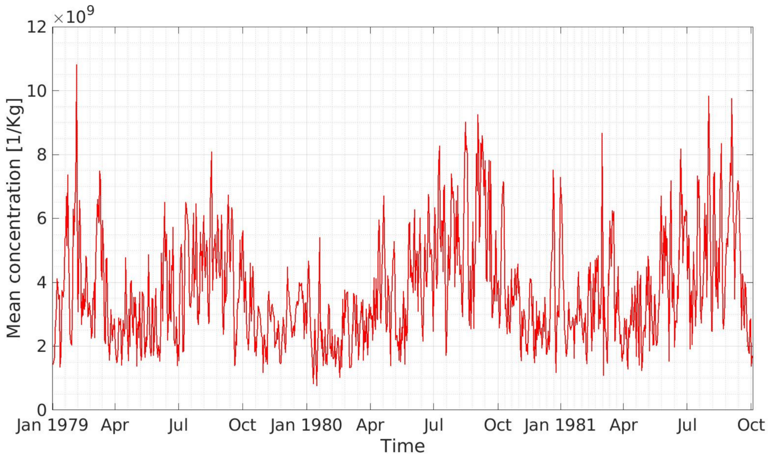

Figure R1-4: *Time series of the mean concentration over the entire domain, daily data at 3a.m. of a POLLUTED experiment.*

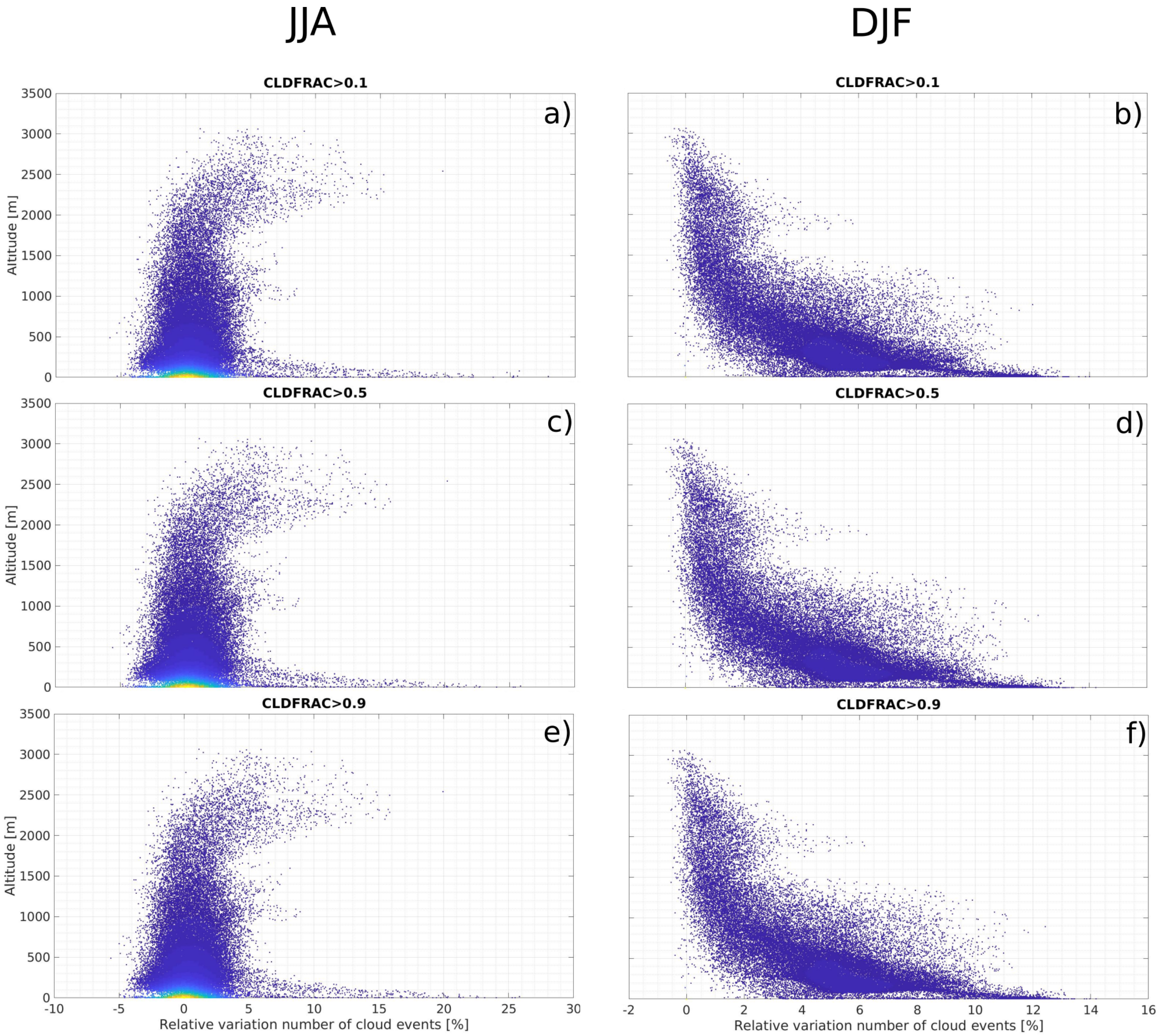

Figure R1-5: *Relative variation of the total number of cloud events in JJA and in DJF: a), c) and d) show the relative variation of three different cloud fraction thresholds during JJA, while b), d) and f) show the relative variations during DJF.*

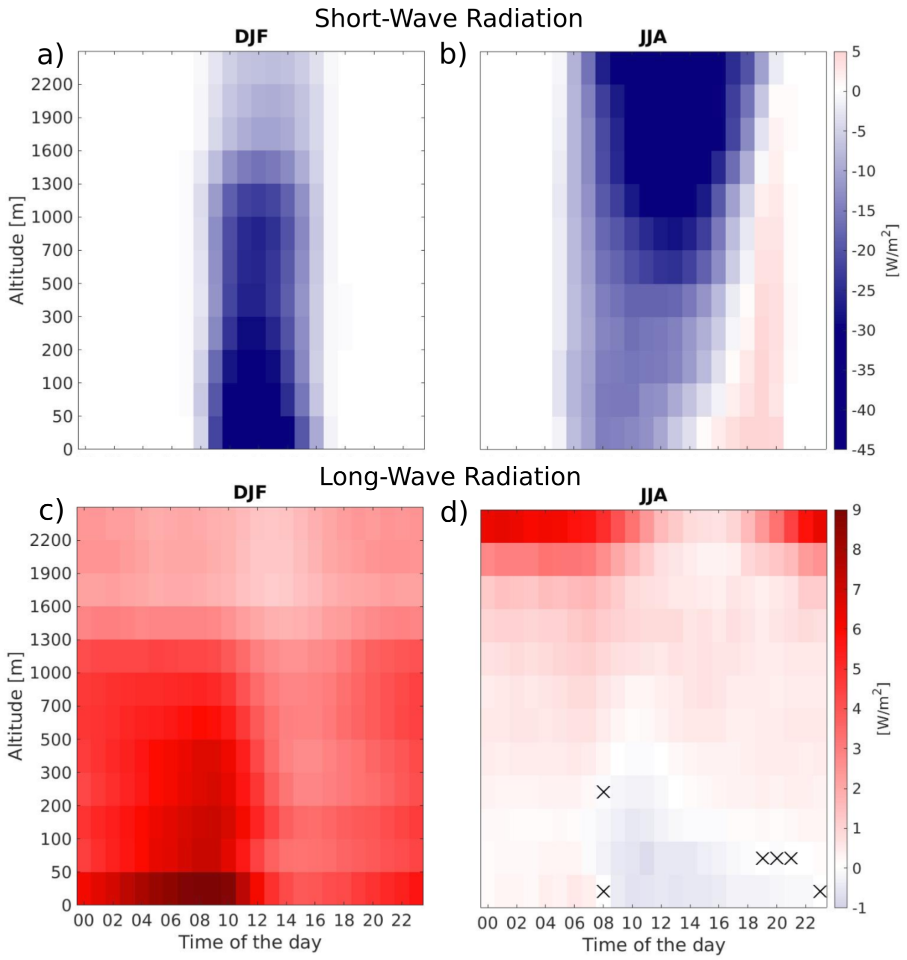

Figure R1-6: *Daily cycle at local time of the difference of the mean hourly short-wave radiation at the ground in DJF (a) and in JJA (b). Daily cycle at local time of the difference of the mean hourly long-wave radiation at the ground in Winter (c) and in Summer (d). Crosses represent points that are not significant at the 95% confidence level.*

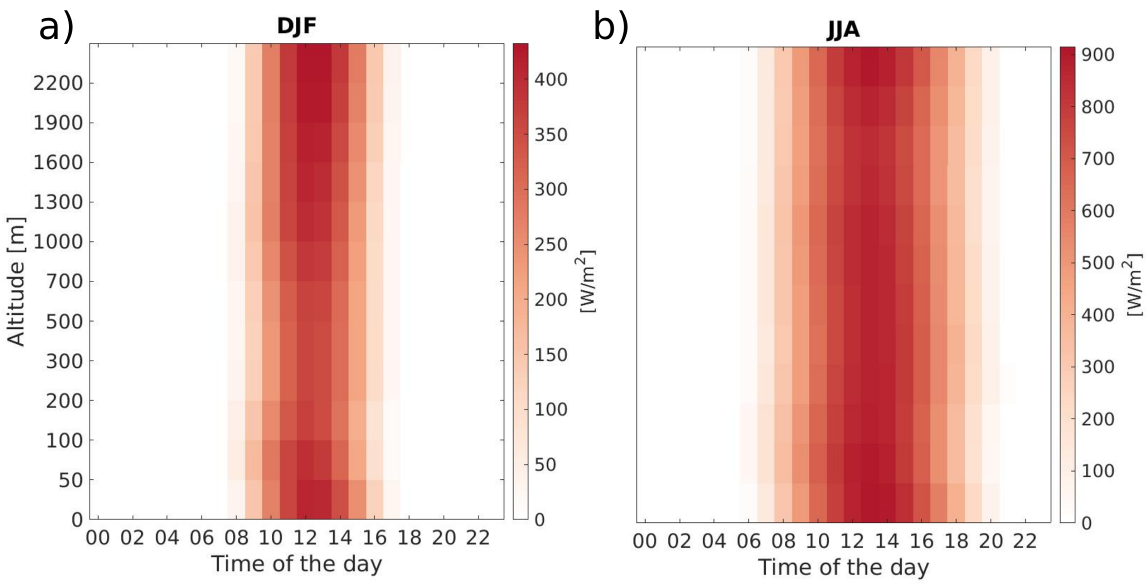

Figure R1-7: *Daily cycle of short-wave radiation as a function of ground elevation in DJF (a) and JJA (b) for the PRISTINE run. Only land points have been taken into account to make this figure.*

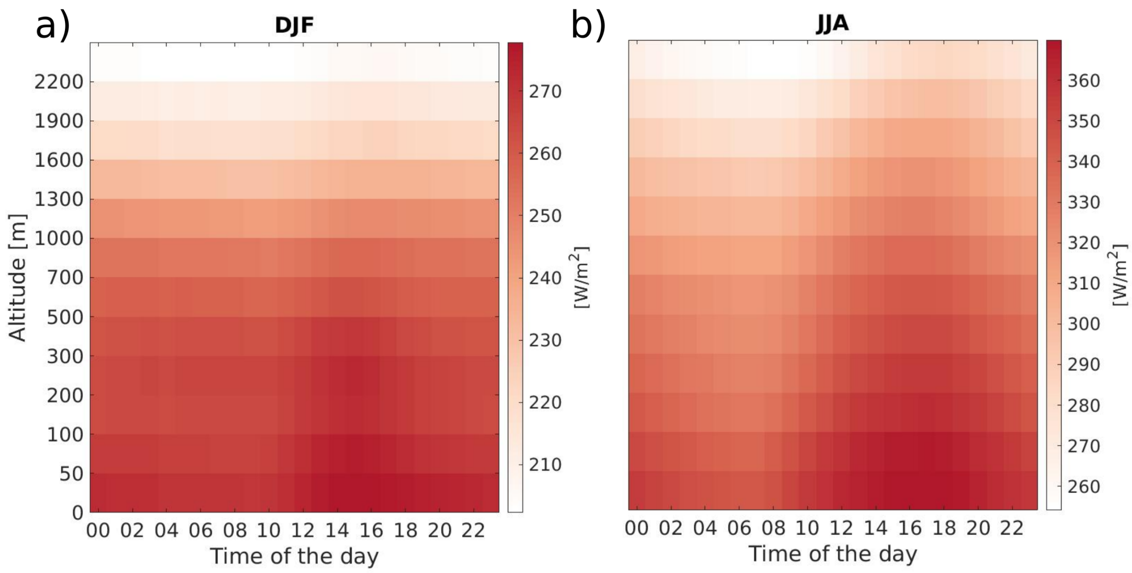

Figure R1-8: *Daily cycle of downward long-wave as a function of ground elevation in DJF (a) and JJA (b) for the PRISTINE run. Only land points have been taken into account to make this figure.*

Technical corrections

- *Abstract, line 4. Probably "the highest mountains" should change to "some of the highest mountains". Minuscule issue, however technically the highest mountain peak in Europe (the continent) is in Caucasus.*

  Thank you, done.

- *Introduction, page 1, line 18. "precipitations" -⟩ precipitation"*

  Done.

- *Methods, page 2 line 52-53: The term "grid step" is understandable but I would probably change it to "grid resolution".*

  Done.

- *Page 7, line 144: "this aspects" -⟩ this aspect"*

  Done.

- *Discussion. Page 9. line 167: "are reduced" -⟩ is reduced"*

  Done.

- *Supplement page 6: In the code segment there is the "niCCN3" variable whereas in the text below it is discussed as "naCCN3". I suspect one of the two must change.*

  Yes, thank you, I wrote the correct one.

References

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