Supplementary Material for
Aerosol indirect effects in complex orography areas: a numerical study over the Great Alpine Region

Anna Napoli[1,2], Fabien Desbiolles[3,4], Antonio Parodi[1], and Claudia Pasquero[3,5]

[1]CIMA Research Foundation, Savona (Italy)
[2]Università degli studi di Genova, Genova (Italy)
[3]Università degli studi di Milano-Bicocca, Milano (Italy)
[4]Osservatorio Geofisico Sperimentale, Trieste, Italy
[5]ISAC-CNR, Torino (Italy)

S1 Sea pattern

In the main article we do not present any result over the sea, as the aerosol load in the POLLUTED experiment is highly irrealistic for marine areas, that typically have a very different concentration and distribution of cloud condensation nuclei than continental areas. We here report those results as, even being irrealistic, they provide interesting information: in Figure S1 we can notice that the Adriatic Sea and the Ligurian Sea are characterized by different behaviours. In particular, while the conditions in the Adratic Sea have a strong similarity with the Po Valley conditions, a sharp boundary separates the different conditions between the Gulf of Genoa and the coastal area nearby. These results can be rationalized in terms of the different depth of the two basins: the very shallow Adriatic Sea has much larger thermal seasonal excursions than the deep Ligurian Sea. A large difference exists between the thickness of the boundary layer over the two basins (thick over the Adratic and thin over the Ligurian Sea during summers and opposite during winter), resulting in very different concentrations of aerosols. Moreover, during summer, the warm waters in the Adriatic favor convection, while in the Ligurian Sea convective events are much more rare. For those reasons, over the Ligurian Sea summer clouds (mainly non convective clouds) are very sensitive to aerosol concentration.

S2 Control run

In this section, the climatological conditions of the PRISTINE run are shown.
Figure S2, and S3 show respectively the maps of the seasonal mean temperature, and of cloud event number in winter (DJF) and in summer (JJA). Figures S4, and S5 show the daily cycle of the seasonal mean temperature and of the seasonal mean relative occurrence of the number of cloud events as a function of surface elevation. Figure S2 highlights seasonal temperature characteristics: during winter the land is warmer than the sea, while in summer the opposite happens: the sea has lots of stored heat from the summer, which takes time to dissipate. Due to the vertical gradient of temperature, mountains are always colder than lowlands. The seasonal mean number of hourly cloud events is shown in Figure S3: the altitudinal dependence of cloud is clearly visible, associated to the orographic lifting of air masses that favors condensation and cloud formation on the upslope of the mountains, favoring a corresponding increase in precipitation (Fig. S7).

Figure S8 represents the seasonal mean number of convective events (maximum daily vertical velocity greater than 3.5m/s) in the Summer season (JJA) as a function of surface elevation. In Figure S6 we show the daily cycle as a function of altitude for winter (a) and summer (b): during cold (warm) months the atmospheric column is more (less) stable and the PBL is thin (thick).

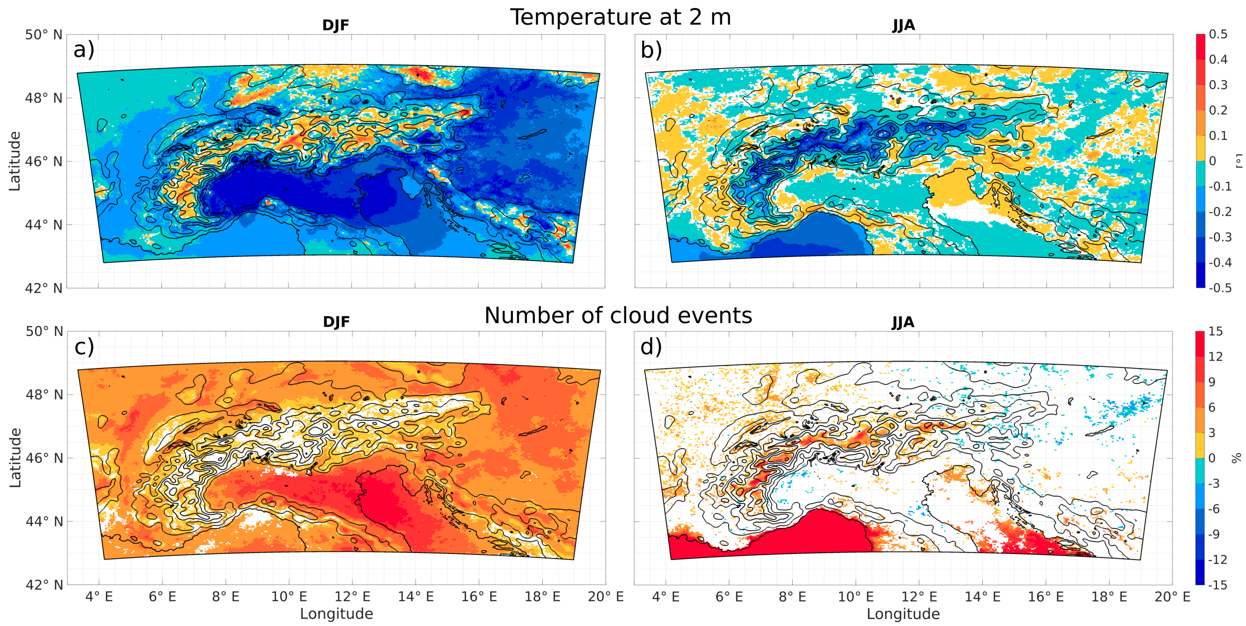

Figure S1: *Seasonal mean difference in 2 m temperature in DJF (a) and JJA (b). Relative variation of seasonal mean number of cloud events in DJF (c) and in JJA (d). Coloured pixels represent points that are significant at the 95% confidence level. Elevation contours are shown every 500 m.*

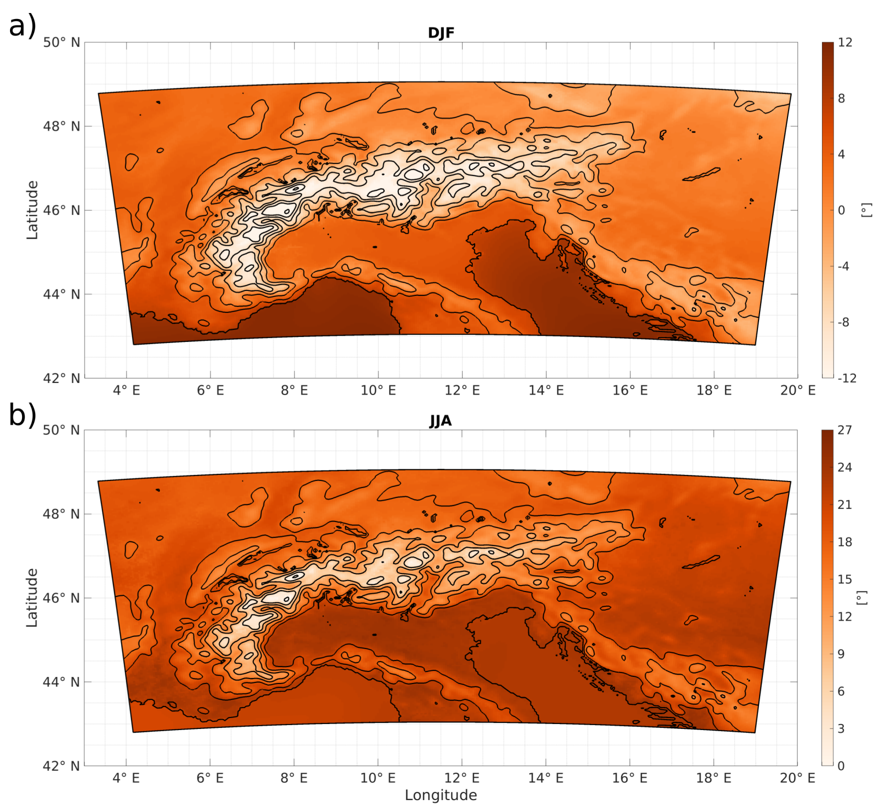

Figure S2: *Daily mean temperature in DJF (a) and JJA (b) of the PRISTINE run.*

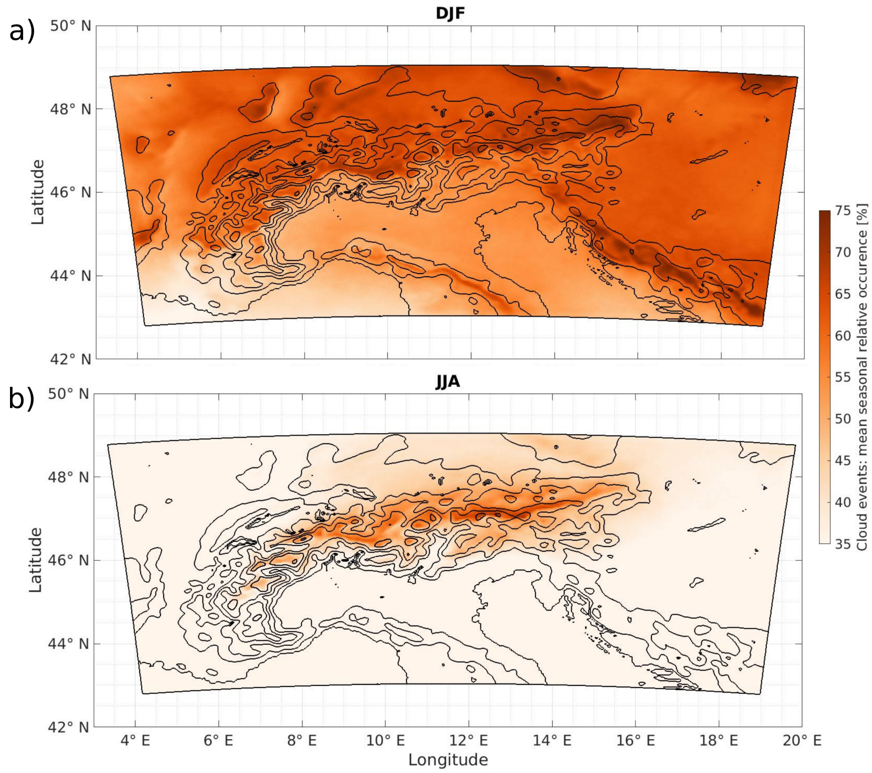

Figure S3: *Mean seasonal relative occurence of cloud events in the PRISTINE run in DJF (a) and JJA (b).*

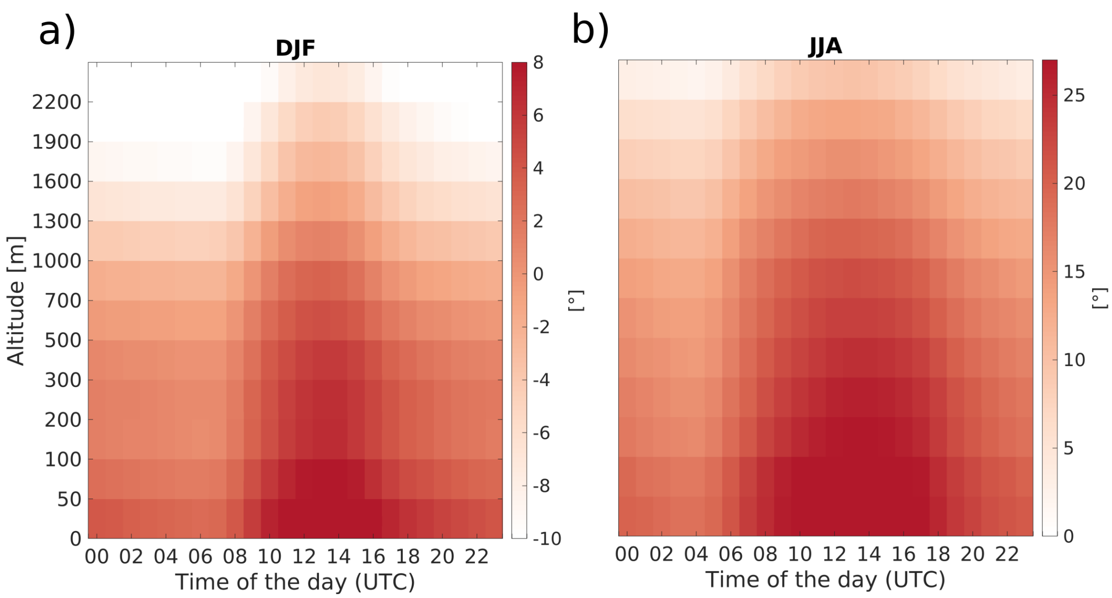

Figure S4: *Daily cycle of temperature at 2 m as a function of ground elevation in DJF (a) and JJA (b) for the PRISTINE run. Only land points have been taken into account to make this figure.*

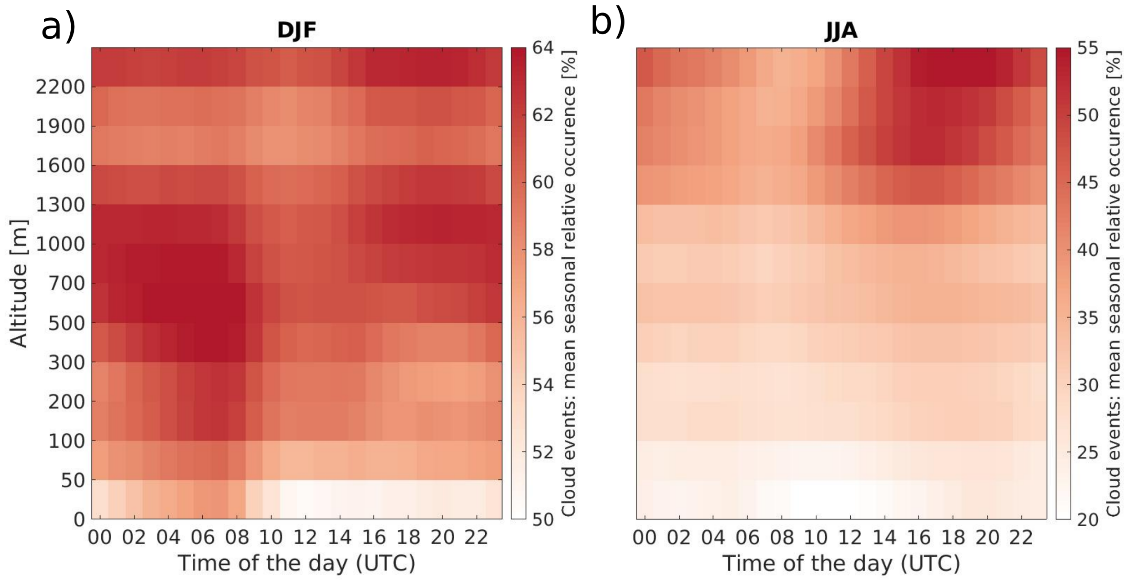

Figure S5: *Daily cycle of relative occurrence of cloud events as a function of ground elevation in DJF (a) and JJA (b) for the PRISTINE run. Only land points have been taken into account to make this figure.*

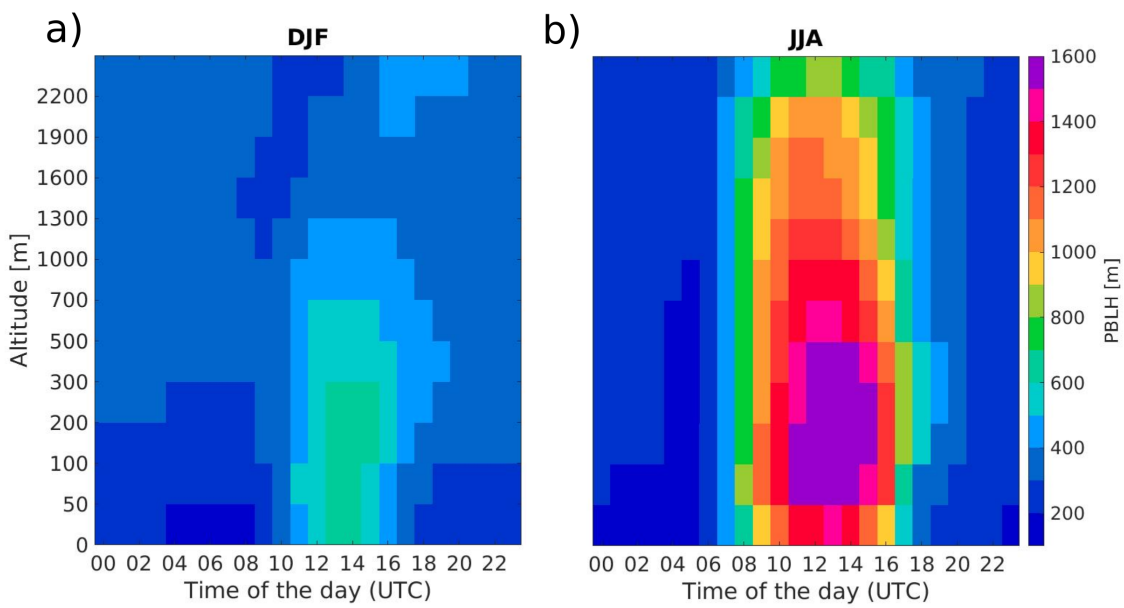

Figure S6: *Daily cycle of PBLH as a function of ground elevation in DJF (a) and JJA (b) for the PRISTINE run. Only land points have been taken into account to make this figure.*

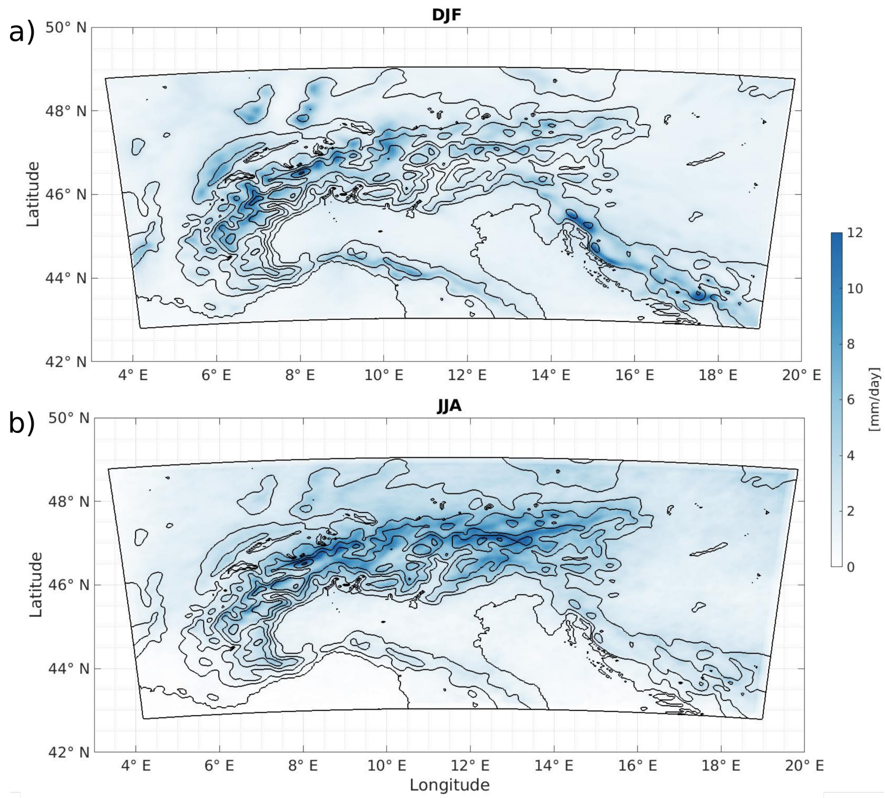

Figure S7: *Seasonal mean precipitation in DJF (a) and JJA (b) for the PRISTINE run.*

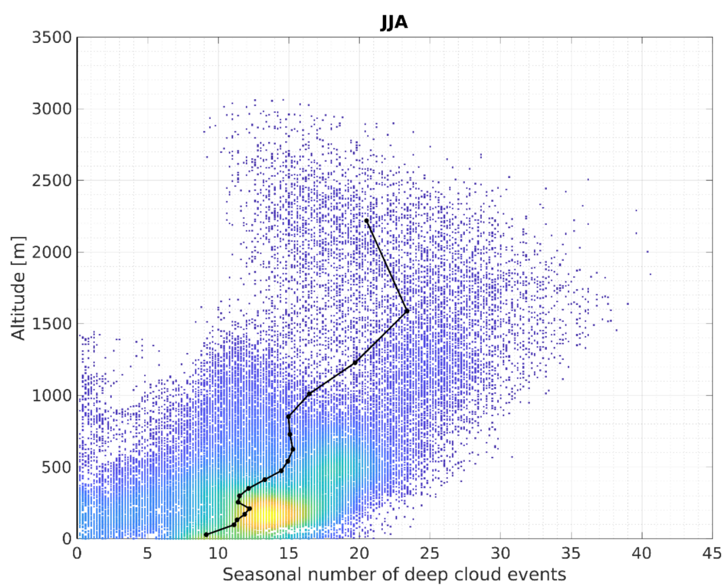

Figure S8: *Seasonal mean number of deep convective events (maximum daily vertical velocity greater than 3.5m/s) in Summer as function of surface elevation. Only land points have been taken into account to make this plot.*

S3 Concentration aerosols

The Thompson aerosol aware microphysic schemes computes a surface emission flux of aerosols, computed from vertical concentration profiles that are equal for all grid points at the same altitude. The definition of the vertical profiles is in module *module_mp_thompson.F*, *SUBROUTINE thompson_init*:

```
if (max_test .lt. eps) then
   write(mp_debug,*) ' Apparently there are no initial CCN aerosols.'
   CALL wrf_debug(100, mp_debug)
   write(mp_debug,*) '   checked column at point (i,j) = ', its,jts
   CALL wrf_debug(100, mp_debug)
   do j = jts, min(jde-1,jte)
   do i = its, min(ide-1,ite)
      if (hgt(i,1,j).le.600.0) then
         h_01 = 0.8
      elseif (hgt(i,1,j).ge.1500.0) then
         h_01 = 0.01
      else
         h_01 = 0.8*cos(hgt(i,1,j)/600.0 - 1.0)
      endif
      niCCN3 = -1.0*ALOG(naCCN1/naCCN0)/h_01
      nwfa(i,1,j) = naCCN1+naCCN0*exp(-((hgt(i,2,j)-hgt(i,1,j))/1000.)*niCCN3)
      do k = 2, kte
         nwfa(i,k,j) = naCCN1+naCCN0*exp(-((hgt(i,k,j)-hgt(i,1,j))/1000.)*niCCN3)
      enddo
   enddo
   enddo
else
   has_CCN   = .TRUE.
   write(mp_debug,*) ' Apparently initial CCN aerosols are present.'
   CALL wrf_debug(100, mp_debug)
   write(mp_debug,*) '   column sum at point (i,j) = ', its,jts, SUM(nwfa(its,:,jts))
   CALL wrf_debug(100, mp_debug)
endif
```

The vertical profile is a combination of naCCN0 (naIN0) and naCCN1 (naIN1) input variables, and it depends on surface elevation through the naCCN3 (naIN3) value for water-friendly (ice-friendly) aerosols. The input variable values are defined as follows, in POLLUTED and PRISTINE respectively:

- naCCN0: 10000 cm^{-3}, 10 cm^{-3}
- naCCN1: 10 cm^{-3}, 10 cm^{-3}
- naIN0: 10000 cm^{-3}, 0.005 cm^{-3}
- naIN1: 0.005 cm^{-3}, 0.005 cm^{-3}

The values highlighted in orange in the subroutine have been modified from the original code to better represent the aerosol concentrations in the Great Alpine Region. In Figure S9 the resulting surface input flux of water-friendly aerosols is shown for the POLLUTED run. In the PRISTINE run the input of water-friendly aerosols is characterized by a single low flux value, and it is homogeneous over the whole domain.

The concentration of aerosols depends on the height of the Planetary Boundary Layer: during winter the PBLH is shallow (Fig. S6a) and thus more pollution is trapped, while during summer the greater instability in the lower troposphere favors thickening the PBL (Fig. S6b) and, consequently, aerosols are more dispersed in the air column. Figure S10 shows the mean concentration in the PBL of the water-friendly aerosols at 3a.m. in winter and in summer for both experiments. During summer the aerosol concentration is smaller than in winter as the thicker PBL allows for a larger dispersion.

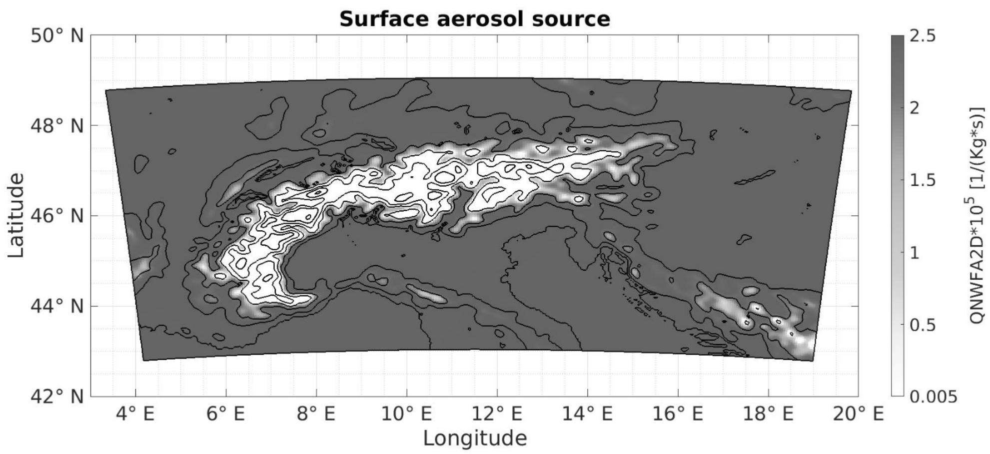

Figure S9: *QNWFA2D variable: surface input flux of water-friendly aerosols.*

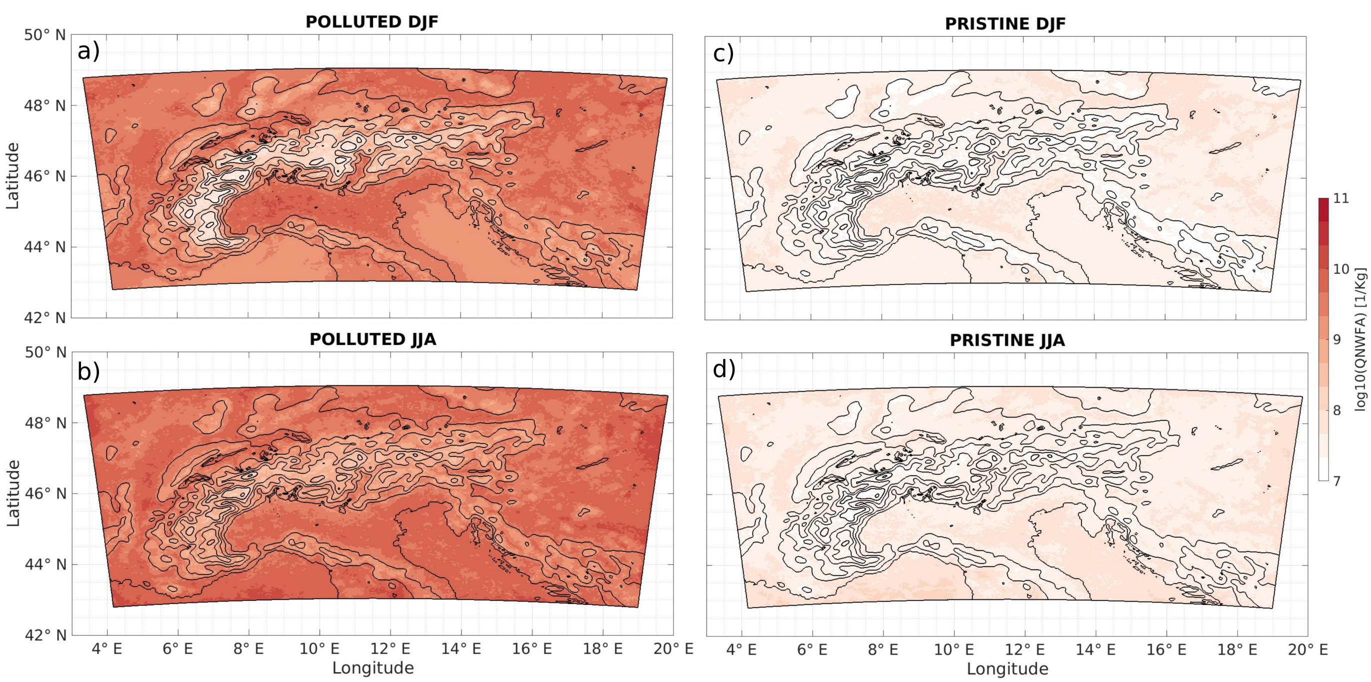

Figure S10: *Seasonal mean concentration of water-friendly aerosols over the PBL.*

S4 Precipitation maps: relative variation

In Figure S11 the map of the relative variation of daily seasonal precipitation is shown.

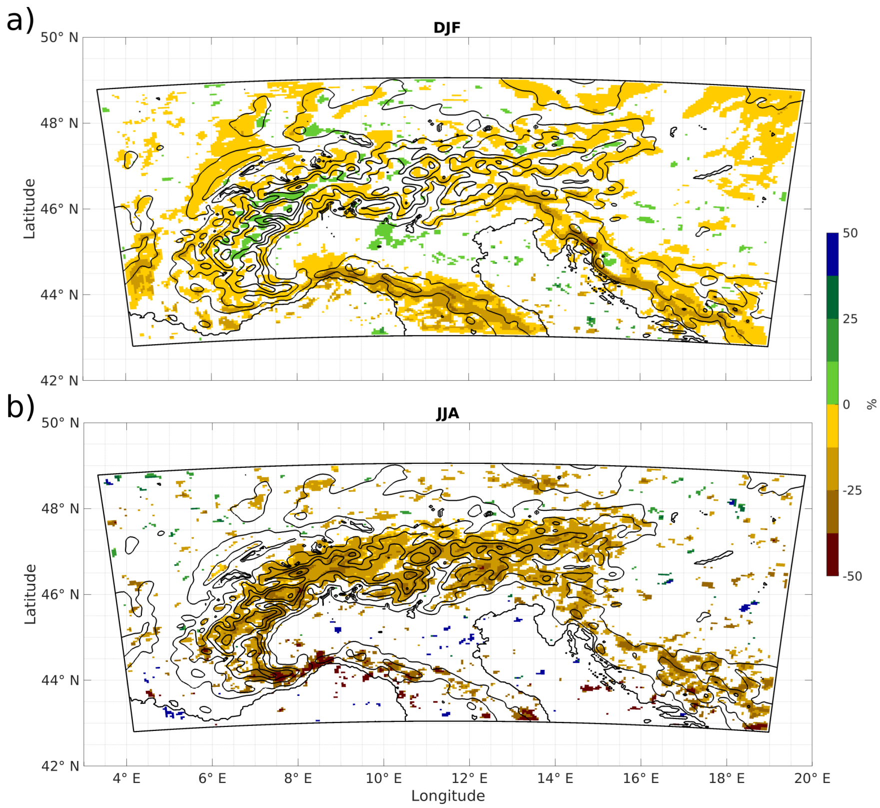

Figure S11: *Relative variation of the seasonal mean precipitation in DJF (a) and JJA (b) between the POLLUTED and the PRISTINE runs. Coloured pixels represent points that are significant at the 95% confidence level. Elevation contours are shown every 500 m.*

S5 Vertical velocities: relative variation

For the summer season, we computed the daily maximum vertical velocity in the air column for each grid point. We then made histograms of their occurrence and finally computed the relative variation in this occurrence between POLLUTED and PRISTINE runs. The results are shown in Figure S12. It can be seen that convective updrafts are inhibited in the POLLUTED run, which has a strong reduction of intense events (reduction of the order of 30-40% for updrafts of 20m/s and higher).

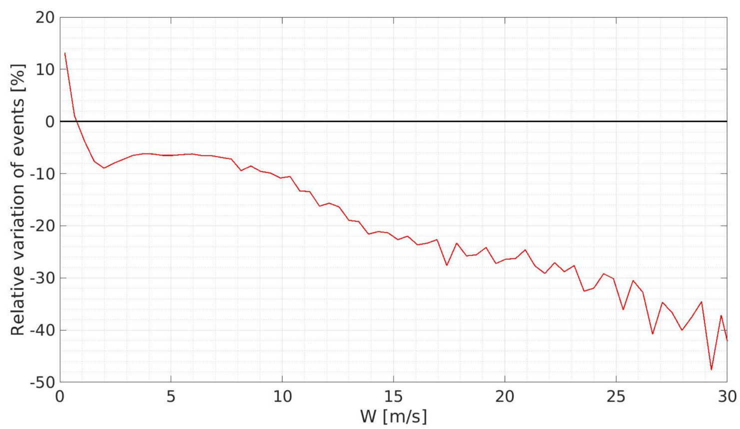

Figure S12: *Relative variation of the number of updrafts per each class of daily maximum vertical velocity in JJA, between POLLUTED and PRISTINE runs. Only land points have been taken into account.*