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Effects of aerosols and greenhouse gases on the radiation budget and the climate forcing in and around the Alps

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While central Europe's temperature rose by more than 1°C since the early 1980s, the overall surface of the glaciers declined by about 20%, and total ice volume decreased by more than 30% in the Alps. This analysis shows measured shortwave and longwave surface forcings in and around the Alps and relates them to humidity and temperature increases through the radiation and energy budget. At low altitudes around the Alps, shortwave climate forcing, primarily related to declining air pollution and solar brightening by the direct aerosol effect, is found to be considerably larger than longwave forcing due to rising greenhouse gases. However, in the Alps, where there is low air pollution at high altitudes, solar radiation increase over the last decades has been small, whereas longwave radiation increase due to the rising greenhouse effect is similar to that at low altitudes. At low and high altitudes, shortwave and longwave forcing energy increases the turbulent fluxes, which raise atmospheric humidity, and enhance the longwave forcing through water vapour feedback. Overall, the analysis shows that during the last two decades, declining aerosols had an important effect on climate forcing at low altitudes, superimposing a shortwave forcing on the longwave greenhouse warming. At high altitudes however, this shortwave component is missing and climate forcing is primarily due to the rising greenhouse effect, which resulted in a lower surface warming in the Alps when compared to the temperature rise at low altitudes in central Europe.