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The impact of vertical velocity variability on indirect aerosol radiative effects in the HadGEM-UKCA aerosol–chemistry climate model

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A crucial link between aerosol and cloud is the ability of aerosols to act as cloud condensation nuclei (CCN) on which cloud droplets form. We use the Abdul-Razzak and Ghan aerosol activation parameterisation to represent this process in the Hadley Centre Global Environmental Model, coupled to UKCA (the UK Chemistry and Aerosols community model). UKCA incorporates an online coupled tropospheric–stratospheric chemistry–climate model and the aerosol microphysics model, GLOMAP-mode (GLobal Model of Aerosol Processes). The combination of an explicit aerosol activation scheme with UKCA allows improved representation and online modelling of chemistry–aerosol–climate interactions, which provides the opportunity for detailed investigation into the indirect radiative effects of anthropogenic aerosol.

Variations in updraught velocity have a significant effect on the number of aerosols that activate and hence the cloud droplet number concentration. In this study we have incorporated the sub-grid-scale variability of vertical velocity with a Gaussian probability density function (pdf) derived from the turbulent kinetic energy in the boundary layer. We examine the effectiveness of this TKE-based approach by comparing results to other simulations with Gaussian pdfs with fixed variances. We show how the results from each of these configurations compare with observed vertical velocity distributions and cloud droplet number concentrations measured in situ by a dozen flight campaigns. We also compare the pdf-based approach itself with that of using a single characteristic updraught velocity.

The resulting cloud droplet number concentration is used by the model to calculate the cloud droplet effective radius, which determines the magnitude of the cloud albedo effect, and the rate of autoconversion of cloud water to rain water, which defines the secondary indirect aerosol effects. For each configuration of vertical velocity, we estimate the radiative flux perturbations due to these indirect effects of anthropogenic aerosol by calculating the difference in net radiation at the top of the atmosphere between annual means of parallel present day and pre-industrial GCM simulations with fixed sea surface temperatures and sea-ice extent. We estimate the uncertainty in these estimates due to the uncertainty introduced by the vertical velocity parameterisation, and compare this to estimates of other sources of uncertainty. These results highlight the need for more in situ measurements to further constrain model pdfs of vertical velocity in order to improve the representation of indirect aerosol effects in global aerosol–climate models.