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Estimation of the indirect radiative effects of aerosol on climate using 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 (2000) aerosol activation parameterisation to represent this process in the Hadley Centre Global Environmental Model coupled to UKCA-MODE (UK Chemistry and Aerosols community model, Mann et al., 2010). UKCA-MODE incorporates an online coupled tropospheric–stratospheric chemistry–climate model with an aerosol microphysics model, allowing improved representation and online modelling of chemistry–aerosol–climate interactions. The combination of an explicit aerosol activation scheme with UKCA-MODE provides the opportunity for detailed investigation into the indirect radiative effects of anthropogenic aerosol.

In this study, the configuration of UKCA-MODE consists of an external mixture of five aerosol modes composed of internal mixtures of prognostic sea spray, anthropogenic black carbon, organic carbon, secondary organic carbon and sulphate. Mineral dust is transported separately. For evaluation purposes, the model meteorology is nudged to ECMWF re-analysis temperature and horizontal wind data over the years 2005–2010, including the period of the VOCALS regional experiment in 2008. This enables validation of the modelled cloud and aerosol properties against in situ measurements from a region of persistent marine stratocumulus cloud, as well as comparisons with recent satellite data.

Variations in updraught velocity have a significant effect on the number of activated particles. In this study we have incorporated the sub-grid-scale variability of updraught with a probability density function (pdf) constrained by the turbulent kinetic energy in the boundary layer. We show how this approximation compares with observed vertical velocity distributions from in situ measurements and compare this pdf approach with that of using a single characteristic updraught velocity.

We approximate the cloud droplet number concentration (CDNC) in warm clouds by the number of aerosols which activate at cloud base. This diagnostic CDNC is then used to calculate the cloud droplet effective radius which determines the cloud albedo effect, and the rate of autoconversion of cloud water to rain water which defines the secondary indirect aerosol effects.

We estimate the radiative flux perturbations due to i) cloud albedo effect only, ii) non-albedo (secondary) effects only and iii) all indirect effects. These are derived from the difference in net radiation at the top of the atmosphere between five-year means of parallel present day and pre-industrial GCM simulations with fixed sea surface temperatures and sea-ice extent. We also present a preliminary quantification of the uncertainty in these estimates.