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Cloud whitening with sea spray injections: direct and indirect forcings and effect of injected particle size

Hannele Korhonen (1), Antti-Ilari Partanen (1,2), Sami Romakkaniemi (2), Veli-Matti Kerminen (3), Kari E.J. Lehtinen (1,2), and Harri Kokkola (1)

(1) Finnish Meteorological Institute, Kuopio Unit, Kuopio, Finland (hannele.korhonen@fmi.fi), (2) Department of Applied Physics, University of Eastern Finland, Kuopio, Finland, (3) Finnish Meteorological Institute, Climate Change, Helsinki, Finland

Deliberate manipulation of the Earth's climate by injecting vast amounts of sea spray into the atmosphere in persistent marine stratocumulus regions has gained interest in recent years. To date, most studies have assumed a prescribed uniform cloud droplet number concentration (CDNC) in the geoengineered regions irrespective of the environmental conditions and have therefore not been able to address the aerosol-cloud interactions or the direct radiative effects of the injected sea spray.

Here we present simulations with the aerosol-climate model ECHAM5-HAM which includes explicit and prognostic calculation of cloud microphysics and interaction of aerosol particles with clouds. We assume a wind-speed dependent number flux for the injected particle population and follow its transport and transformation due to microphysical processes in the atmosphere. This additional sea spray flux is simulated either over all the oceans or in three optimized regions which have the strongest radiative flux perturbations (RFP) and cover altogether 3.3% of the Earth's surface.

Applying the baseline scenario (i.e. injected particle size 250 nm) in the optimized regions, we predict a global mean RFP of -0.8 Wm^{-2}. This compares well with an earlier published estimate of -0.97 Wm^{-2} which assumed a fixed prescribed CDNC of 375 cm^{-3} in the geoengineered regions. In our simulations the mean regional CDNC varies between 194 and 286 cm^{-3} but cloud cover increases by 2-5 percentage points. It is noteworthy that both the absolute CDNC values as well as their relative changes (74-80%) are clearly higher than predicted in an earlier study using similar emission fluxes. In the ECHAM simulations, multiples of the baseline sea spray flux cause almost a linear increase in CDNC but the RFP is clearly sublinear (global mean RFP with $5\times$baseline flux is -2.2 Wm^{-2}).

Since the three optimal geoengineering regions are characterized with persistent stratocumulus decks, inside them practically all of the radiative effect originates from aerosol indirect effects. However, the direct effect can be significant outside these regions: when all oceanic regions are seeded, the direct effect is about 65% of the aerosol indirect effects.

For a constant volume emission flux of sea spray, the size at which the individual particles are injected becomes very important. Reducing the injection size from 250 nm to 100 nm, which is typically still large enough for cloud activation in marine boundary layer, increases the global mean RFP in the run of optimized regions to -2.1 Wm^{-2}. On the other hand, injection at 500 nm has only very minor effects on CDNC due to the low number flux (13% of the baseline flux) and produces roughly the same direct forcing as the baseline simulation.