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Cloud glaciation by mineral dust, soot and biological particles

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An ice nucleation parameterization based on classical nucleation theory, with aerosol-specific parameters derived from experiments, has been implemented into the global climate model CAM-Oslo. The parameterization treats immersion, contact and deposition nucleation by mineral dust, soot, bacteria, fungal spores and pollen in mixed-phase clouds. The role of primary biological aerosol particles (PBAP) as heterogeneous ice nuclei is investigated for the first time with a global model. Emission parameterizations for bacteria, fungal spores and pollen based on recent literature are introduced. The simulated PBAP number concentrations are compared to data from various locations. Taking into account the uncertainties in measurement methods and the possibly limited representativeness of short-term, locally influenced observations for a larger region and longer time span, the agreement between measurements and observations is overall satisfactory. While the simulated bacteria and fungal spore concentrations are of the correct order of magnitude, the model tends to underestimate total PBAP number. This likely indicates that either pollen or other (possibly submicron) PBAP that are not considered here contribute significantly to the total PBAP number at the measurement locations. Immersion freezing by mineral dust is found to be the dominating ice formation process, followed by immersion and contact freezing by soot. The simulated biological aerosol contribution to global atmospheric ice formation is marginal, even with high estimates on their ice nucleation activity, because the number concentration of ice nucleation active biological particles in the atmosphere is low compared to other ice nucleating aerosols. The ice nuclei concentrations in the model agree well with in-situ continuous flow diffusion chamber measurements, and reflect a correlation between ice nuclei at temperatures below $-20°$C and coarse-mode aerosol particles. Their simulated composition (82% mineral dust, 18% soot and 10^{-5}% biological particles) lies in the range of observed ice nuclei and ice crystal residue compositions. Even with high estimates for bacteria emissions and unrealistically high PBAP freezing efficiency assumptions, it is not higher than 1%. Observed biological ice nuclei concentrations in snow are reasonably well captured by the model. This implies that 'bioprecipitation' processes (snow and rain initiated by PBAP) are of minor importance on the global scale. The observed high biological IN/ice crystal residue concentrations in specific cases and events are possibly linked to variations in PBAP concentrations and/or ice nucleation efficiencies far above the average.