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Scaling properties of cirrus clouds

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The 3D spatial structure of clouds is crucial for determining their radiative effects, but most previous work has concentrated on stratocumulus. Here the scaling behaviour of cirrus clouds is examined, and used as input to a new stochastic model that is capable of simulating the structural proerties unique to cirrus: fallstreak geometry and shear-induced mixing.

Analysis of time-height cloud radar sections through cirrus reveals that horizontal PDFs of ice water content (IWC) may be described by a lognormal distribution, and that power spectra of ln(IWC) typically exhibit a spectral slope of around $-5/3$ near cloud top that decreases with depth into the cloud, to values as low as -3.5 in some cases. This decrease can be explained by wind shear coupled with a spread of particle fall speeds leading to a homogenization that acts preferentially at smaller scales. The power spectra exhibit a distinct scale break, becoming flat at scales larger than around 50 km. The orientation of the fallstreaks may be predicted from the profile of mean wind and mean ice fall speed.

The stochastic model takes as input profiles of the mean and fractional standard deviation of IWC, spectral slope, outer scale and wind speed. It first generates an isotropic 3D fractal field by performing an inverse 3D Fourier transform on a matrix of simulated Fourier coefficients with amplitudes consistent with the observed 1D spectra. Random phases for the coefficients allow multiple realisations of a cloud with the same statistical properties to be generated. Then horizontal slices from the domain are manipulated in turn to simulate horizontal displacement and changes to the spectra with height. Finally the field is scaled to produce the observed mean and fractional standard deviation of ice water content. Vertical 2D slices extracted from the domain are very similar in appearance to cloud radar observations.

Radiative transfer calculations are used to show that the different fallstreak orientation

resulting from different wind shears can change mean top-of-atmosphere radiative fluxes by in excess of 45 W m^{-2} in the shortwave and 15 W m^{-2} in the longwave. The effect of wind shear to induce horizontal mixing causes an additional but smaller radiative effect.