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Radiative heating in contrail cirrus

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In the course of analysis and modeling of aviation induced contrail cirrus, we found that observed time scales of contrail cirrus and thin cirrus in general requires particle losses by radiative heating besides other loss processes.

For thin cirrus near the tropopause, radiative warming dominates over cooling in most cases, in particular in the lower part of cirrus layers. Both terrestrial and solar radiances contribute to warming, but the terrestrial part is often the larger one.

The radiation is absorbed mainly by the ice particles while a smaller fraction is absorbed by water vapor and other gases inside the cirrus. The heating directly absorbed in the ice particles causes a temperature difference between the ice particles and ambient air. Because of the small heat capacity of the ice particles and because of the small particle scales, local equilibrium between radiative heating and conductive cooling is reached quickly. In agreement with Gierens (1994) and others, this causes a temperature surplus of order 0.1 K for ice particles larger than about 100 micro meters. For smaller particles, the temperature increases about linearly with the particle radius. The contribution is important for very low ice particle concentrations (below 0.1/cm**3) and solar optical depth larger 0.1.

After heat exchange with the ambient air, and by additional absorption of radiation in the gas phase, the radiation also causes a bulk warming of the cirrus, again of order 0.1 K. The contribution is important for high ice particle concentrations (> 1 /cm**3) and for rather modest optical depth values (0.01 to 0.1). Quasi equilibrium is reached in proportion to the inverse heating rate, which may take hours.

In case of heating the increased ice particle temperature causes reduced water vapor saturation at the ice surface and hence sublimation. Hence, both effects may contribute to a loss of ice particles in cirrus, in particular, when relative humidity inside the cirrus is close to ice saturation.

In addition, the radiative heating may cause convective turbulence because of warm air masses rising and cold air masses sinking. Finally, the whole cirrus may rise slowly rise by the diabatic heating.

In order to simulate these effects in contrail cirrus we developed an effective model (within our contrail cirrus prediction model, CoCiP) which computes the radiative heating rate in both the longwave and shortwave spectral ranges. The model parameterizes the impact of radiative heating on turbulent mixing and sublimation of ice particles in a thin cirrus layer.

The heating rate is modeled as a function of cirrus properties (optical depth, temperature, humidity, effective particle radius, and particle habit), solar radiation, solar zenith angle, and the radiances at the top of the atmosphere (solar direct radiation, reflected solar radiation, and outgoing longwave radiation). The model parameters were determined by least square fits of the model results to the results of forward calculations with the libRadtran system using the DISORT 2.0 solver with 16 streams for about 32000 cases with different atmospheres, surface properties and cloud parameters.

The model has been applied for various test cases in comparison to cirrus cover derived from SEVIRI-IR data from Meteosat (MSG) observations. The comparison shows that radiative heating may enhance vertical mixing and reduce the life time of contrail cirrus (and thin cirrus in general) by factors of order two.