Tropical upper tropospheric clouds and diabatic heating

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Upper tropospheric clouds are most abundant in the tropics and often form as cirrus anvils from convective outflow, building mesoscale systems (MCS). While latent heating is released into the atmosphere via condensation mainly within the precipitating parts of these MCSs, the long-lasting and horizontally extended anvils play a crucial role in modulating the Earth's energy budget and heat transport. Convective organization changes the relationship between latent and radiative heating within and around the MCSs.

I) Synergistic description from satellite observations & ML: towards enhanced process understanding

A coherent long-term dataset is presented which describes tropical UT cloud systems for process and climate studies. This dataset combines cloud properties from CIRS (Clouds from IR Sounders), rain rate classification and cloud vertical structure, in particular radiative heating rates, from CloudSat-CALIPSO radar-lidar data, and latent heating rates derived from TRMM. As the overlap between the CIRS cloud systems and the additional vertical information is small, we have developed artificial neural network models to expand the latter in space and in time. This dataset is now available.

In combination with a cloud system analysis we found that deeper convection leads to larger heavy rain areas, with a slightly smaller thick anvil emissivity. Convective organization enhances the mean atmospheric cloud radiative effect (ACRE) of the MCSs by about 10 Wm^{-2}. The projection of different MCS properties in the LP-ACRE plane can be further used for a process-oriented evaluation of parameterizations in climate models.

II) Radiative-dynamical interaction: sensitivity to ice cloud parameterizations

Changes in atmospheric heating gradients influence the atmospheric circulation which then affects patterns of intense precipitation. We have used climate simulations to address the following question: How does the radiative heating from UT clouds affect the large-scale circulation and how in turn does the circulation influence precipitation?

First, we present new observational metrics derived from satellite observations to demonstrate how much the simulated UT cloud properties (ice water path and radiative heating rates) depend on the parameterizations of UT cloud ice and microphysics.

We then investigate the consequences of UT cloud – radiation interactions on the Hadley circulation by performing two sets of experiments, one making only semi-transparent UT clouds transparent and one making opaque UT clouds transparent to radiation. Using ensemble simulations, we are also able to distinguish between immediate effects and feedbacks which build up later.

The distribution of UT clouds with respect to their optical depth is key in the sign of the dynamical effect: Semi-transparent cirrus weaken the Hadley circulation by decreasing the meridional heating gradients, whereas opaque UT clouds strengthen the circulation by concentrating radiative heating in the centre of ITCZ. Furthermore, the radiative heating of the opaque UT clouds is strong enough to affect the precipitation at the edges of the ITCZ through following changes in moisture convergence and atmospheric static stability. The sensitivity to the parameterizations is larger for semi-transparent than for opaque clouds.