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Slow wave dynamics stalls tropical tropopause ice clouds

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Water vapour is the most important natural green house gas. However, in the stratosphere an increase in water vapour would possibly result in a cooling. The major entrance of trace substances into the stratosphere is the tropical tropopause layer (TTL), localized between the main level of convective outflow, 150 hPa, and 70 hPa. The TTL water vapour budget, and thus the exchange with the stratosphere, depends crucially on the occurrence and properties of ice clouds in this cold region ($T < 200$ K).
It is believed that homogeneous freezing of liquid solution particles, which predominate the particle population, is the preferred pathway of ice formation. High water vapour supersaturation with respect to ice is required to initiate homogeneous ice nucleation. The number of emerging ice crystals depends on temperature and the ambient relative humidity over ice (RHi). Strong increase in RHi due to rising vertical velocity will produce large amounts of ice crystals. In the TTL, very slow large-scale updraughts prevail ($\leq 0.01\,\mathrm{m/s}$), which would lead to low ice crystal concentrations ($\leq 0.1\,\mathrm{cm}^{-3}$). However, tropical deep convection initiates intrinsic gravity waves and consequently, we would expect much higher vertical velocities and therefore higher ice crystal number concentrations. Since the many ice crystals rapidly grow by water vapour diffusion it is also expected that the initially high ice supersaturation quickly reduces to saturation after ice formation.

Contrarily, during the last years high and persistent ice supersaturations were observed in the cold TTL in several airborne field campaigns inside and outside of ice clouds (Peter et al., 2006), creating a discussion called the 'supersaturation puzzle'. A step forward in that discussion was made recently: Krämer et al. (2009) observed ice crystal concentrations much lower than expected (most often $< 0.1\,\mathrm{cm}^{-3}$), but consistent with the measured high supersaturations. These observations turned the 'supersaturation' into a 'nucleation puzzle'. The 'nucleation puzzle' is currently intensely discussed and other nucleation pathways suppressing, modifying or replacing homogeneous freezing are proposed. All these approaches to explain the TTL ice nucleation are of chemical or microphysical nature.

Here, we present intense model studies of ice cloud formation under dynamical conditions typical for the TTL. From direct comparison of model simulations and observations we claim that the special TTL dynamics – namely a superposition of very slow large-scale updraughts with high-frequency short waves – can produce the observed low numbers of ice crystals solely by 'classical' homogeneous freezing.

References:

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