Geophysical Research Abstracts
Vol. 15, EGU2013-10528, 2013
EGU General Assembly 2013

Tropical tropopause ice clouds: A new approach to answer the mystery of low crystal numbers

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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 net cooling of the earth-atmosphere system. The major entrance pathway of trace substances into the stratosphere is the tropical tropopause layer (TTL). The TTL water vapor budget, and thus the exchange between troposphere and stratosphere, depends crucially on the occurrence and properties of ice clouds in this cold region ($T < 200$ K). New observations indicate that very low ice crystal numbers frequently occur in the TTL. This phenomenon is not yet understood and is not compatible with the idea that homogeneous freezing of solution droplets is the major pathway of ice formation. These low ice number concentrations are consistent with observed persistent high ice supersaturations inside cold TTL cirrus clouds, which in turn control the exchange of water vapor with the stratosphere.

Here, we reproduce in-situ measurements of frequencies of occurrence of ice crystal concentrations by extensive model simulations, driven by the special dynamical conditions in the TTL, namely the superposition of slow large-scale updrafts with high-frequency short waves. The simulations show that about 80% of the observed incidences of low ice crystal concentrations can be explained by 'classical' homogeneous ice nucleation in the very slow updrafts (< 1cm/s), about 19% stem from heterogeneous freezing, while the remaining of about 1% originates from homogeneous freezing in slightly faster updrafts (> 1cm/s). The mechanism limiting the ice crystal production from homogeneous freezing in an environment full of gravity waves is that freezing events are stalled -due to the shortness of the gravity waves- before a higher number concentration of ice crystals can be formed.