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Cross-tropopause transport by deep convective clouds and its implications in climate and chemistry

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Clouds have great impact in the atmosphere and their radiative forcing has been thought to be the largest uncertainty in climate model predictions. They also influence the chemistry via direct chemical reactions with other species, including trace gases and aerosol, and by providing transport pathways.

Among all cloud species, deep convective clouds play a unique role in their ability to rapidly transport trace species vertically due to the strong updraft in them. Recent studies show that many intense deep convective clouds even transport materials through the tropopause into the stratosphere. The most notable species so transported is water (including water vapor and ice crystals) which is known to have great influence on radiative forcing, especially in the stratosphere. Observations of fire-induced thunderstorms ("pyrocumulonimbus" or "pyroCb") also clearly show that some of these cumulonimbi transport aerosol particles into the high stratosphere, which implies that the possibility that regular cumulonimbi can transport aerosol into the stratosphere as well albeit in a less visible way. Undoubtedly, these species would have significant impact on the stratospheric chemistry.

This paper will review ground-based, aircraft and satellite observational evidence of the cross-tropopause transport. Phenomena such as storm top plumes and jumping cirrus will be discussed and cloud resolving model simulations will be used to explain the physical mechanisms responsible for this transport. Cloud modeling results show that cloud top convective instability and gravity wave breaking play a very important role in this irreversible process. The airborne and space-borne measurements of the stratospheric HDO/H2O ratio will be discussed in light of the deep convective transport.

Finally, possible impacts of this cross-tropopause transport in the global climate and atmospheric chemistry will be discussed.