Unprecedented evidence for deep convection hydrating the tropical stratosphere

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Abstract: We report on in situ and remote sensing measurements of ice particles in the tropical stratosphere found during the Geophysica campaigns TROCCINOX and SCOUT-O3. We show that the deep convective systems penetrated the stratosphere and deposited ice particles at altitudes reaching 420 K potential temperature. These convective events had a hydrating effect on the lower tropical stratosphere due to evaporation of the ice particles. In contrast, there were no signs of convectively induced dehydration in the stratosphere.

Observations

Date YYMMDD	380 K altitude km	Ice particles ≤ km (K)	RHI %
TROCCINOX			
050204	17.0	18.0 (410)	66
050204	17.0	18.0 (410)	66
050205	17.1	17.5 (387)	48
SCOUT-O3			
051119	17.8	18.2 (390)	74
051125	17.5	18.9 (415)	54
051129	17.5	18.2 (395)	65
051130	17.4	18.8 (417)	74

Table 1. List of flights on which ice particles have been observed in the stratospheric overworld (above 380 K potential temperature) during TROCCINOX and SCOUT-O3 tropical campaigns. Date of flight, mean altitude of 380 K potential temperature, highest altitude and potential temperature of ice particle observation, mean relative humidity over ice between 380 and 400 K potential temperature.

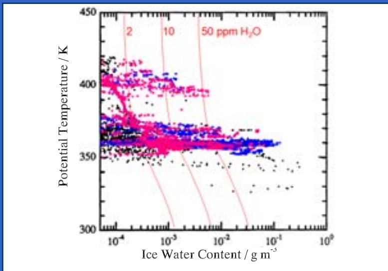


Figure 1. Ice water content. Black: STEP Tropical 1987. Blue: TROCCINOX Feb. 2005; red: SCOUT-O3 Nov. 2005 derived from the measurements by the two water vapour instruments (FISH and FLASH) during the flights listed in Table 1. Contours: Lines of constant volume mixing ratios. Observations suspected to stem from contrail sampling were excluded (see below).

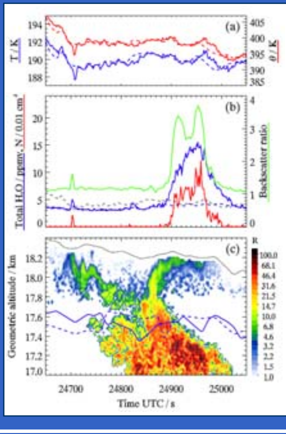


Figure 2. Observation on 30 November 2005 in Darwin.

(a) Temperature (blue) and potential temperature (red) (solid TDC; dashed MTP).

(b) Total water (solid blue), gas phase water (dashed blue), and water vapor saturation mixing ratio over ice (dashed gray); FSSP particle number density (r > 0.25 µm) (red); MAS total backscatter ratio (green).

(c) Backscatter ratio from the downward looking lidar MAL (color coded). Black curve: aircraft altitude. Blue curves: MTP 380 K (solid) and cold point tropopause (dashed).

Hypotheses

In situ formation?

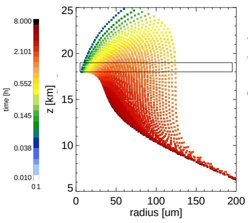


Figure 3. Growth and sedimentation assuming 130% relative humidity over ice.

- Supersaturation required → but subsaturation observed
- Some particles would have had nucleated at around 23 km and grown during 1 h to reach the observed size of 100 µm →unrealistic.

Contrail sampling?

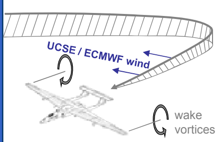
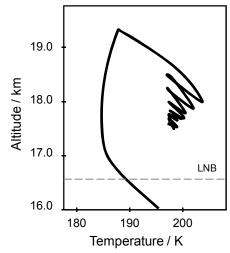


Figure 4. Contrail tracking using measured wind (UCSE) and wind from ECMWF operational data, taking the contrail's spreading into account.

→ In some cases, contrail sampling was impossible because some convective systems were overflown only once.

→ Some ice particle observations (~3%) might have originated from contrail sampling. These observations were excluded from Figure 1.

Convective overshoots!



- Supported by downward looking lidar MAL (Figure 2c)
- Air parcel model shows that such overshoots are possible (Figure 5).

→ The only plausible explanation.

Figure 5. Air parcel trajectory for an overshooting event following Adler and Mack [1986] for 30 November 2005. Level of neutral buoyancy (LNB) at 16.5 km, equivalent potential temperature 360K.

Impact

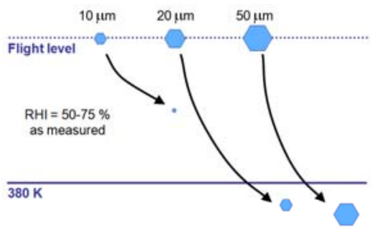


Figure 6. Modelling the sedimentation and evaporation of observed ice particles.

Typical:
r < 15 µm → evaporation in the stratosphere
r > 40 µm → sedimentation back to troposphere

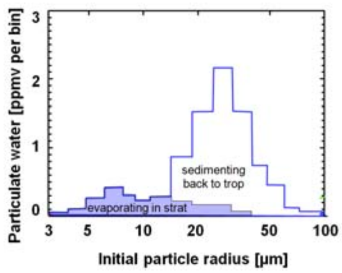


Figure 7. Size dependent particulate water concentration. Upper blue line: observations. Shaded area: water remaining above 380 K determined from sedimentation/evaporation calculations.

→ The overall evaporated particulate water amounts to 1.6 ppmv on average.

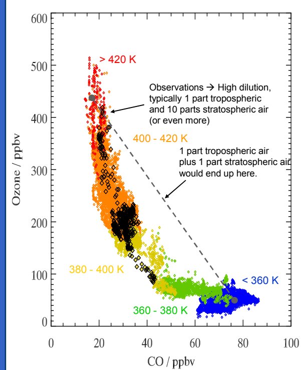


Figure 8. 30 November 2005 (first flight). Ozone vs. CO measurements. Colours indicate potential temperature. Black symbols: Air influenced by convective overshoots

→ Mixing of lower tropospheric air (blue) (after latent heat release and overshooting) with stratospheric air (yellow, orange or red)

→ Mixing occurs along mixing lines (e.g., dashed grey line). Different levels of dilution of tropospheric air are indicated.

→→ High dilution.

Upscaling

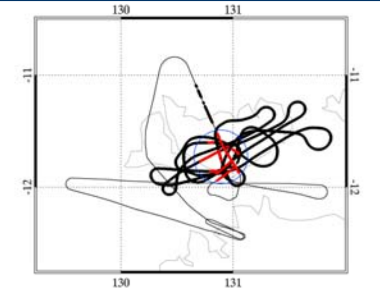


Figure 9. Geophysica flight path for first flight on 30 November 2005 (thin line). Black symbols: flight above 380 K potential temperature. Red symbols: Convective influence (ice particle observations). Blue circle: Main area influenced by convective overshoot (approx. 2000 km^2)

Estimating transport of particulate water

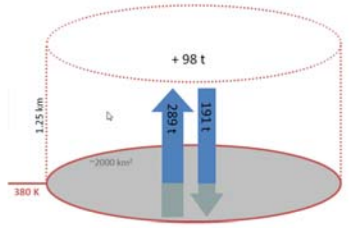


Figure 10. Particulate H_2O budget
→
98 t input of water vapour into stratospheric overworld
→
this volume is moistened on average by 1.6 ppmv

Attempt of an Upscaling (tropics, 20°N–20°S)

Using global statistics of convective overshooting [Liu and Zipser, 2005]

Assumption 1:
H_2O transport ~ duration of overshoot

Hector: 10^5 kg H_2O/hr
TRMM: 12 events on average at any time
→ 12 × 24 × 10^5 = 3 × 10^7 kg H_2O per day
→ Compared to 10^9 kg H_2O per day from large scale upwelling
→ **3 % contribution from convection**

Assumption 2:
H_2O transport ~ duration × area of overshoot

Hector: 10^5 kg H_2O/(hr x 40 km^2)
TRMM: 12 events on avg. at any time with 722 km^2 mean area
→ 12 × 24 × 722/40 × 10^5 = 5 × 10^8 kg H_2O per day
→ Compared to 10^9 kg H_2O per day from large scale upwelling
→ **50 % contribution from convection**

This remains inconclusive ☹

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