

THE TROPOPAUSE IN THE ASIAN SUMMER MONSOON ANTICYCLONE

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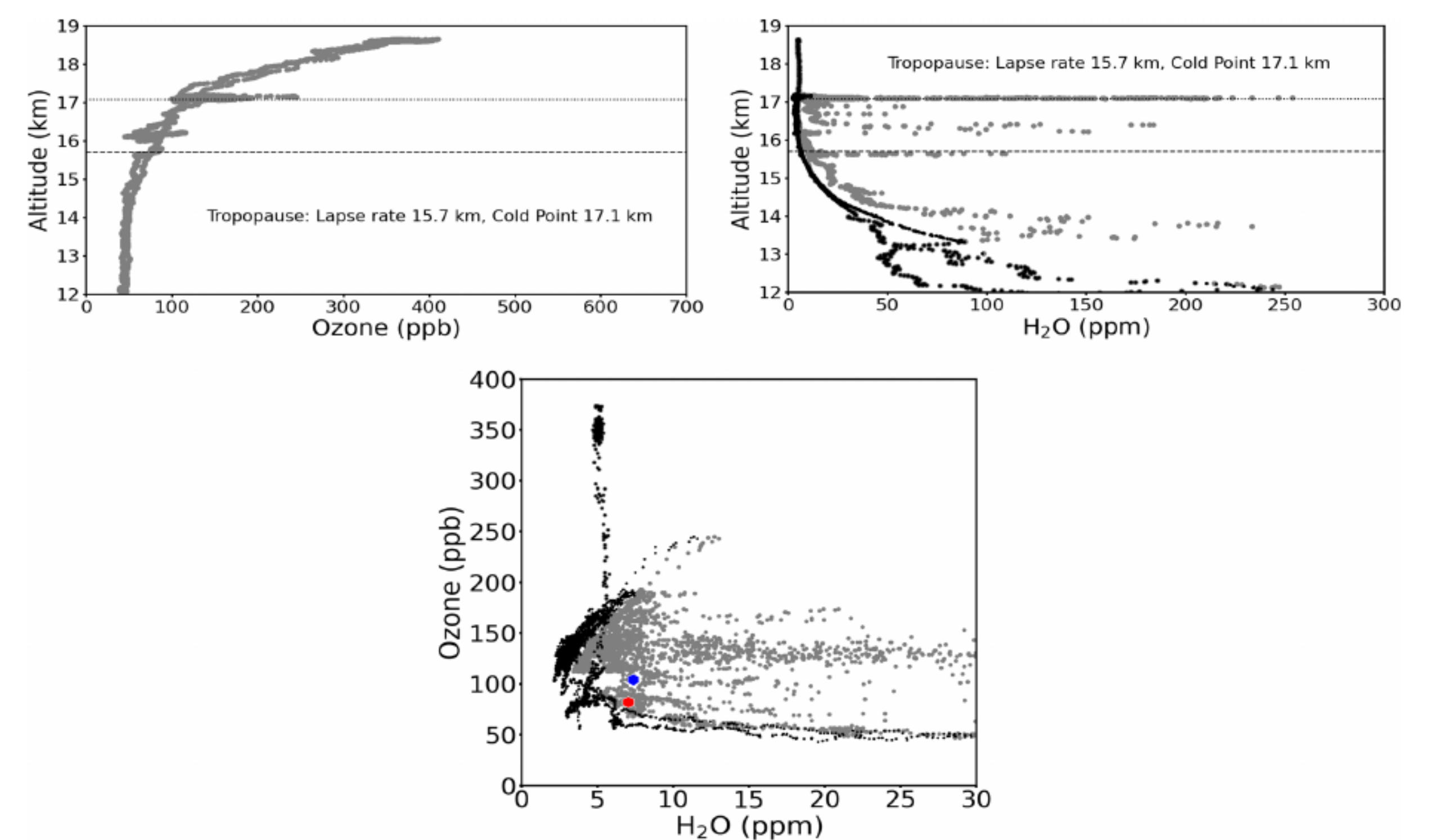


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Overview and Summary

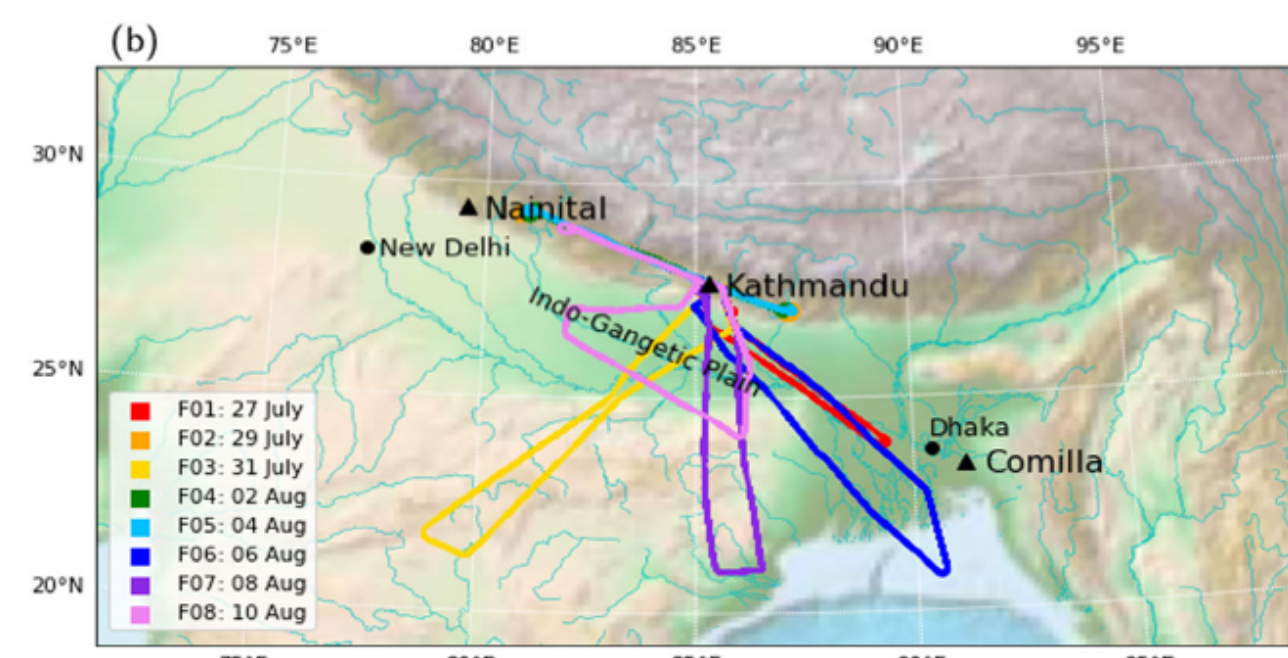
Tropospheric and stratospheric airmasses are separated by the tropopause. Here we investigate the lapse rate tropopause and the cold point tropopause in the Asian summer monsoon anticyclone (ASMA) based on high-altitude airborne measurements in summer 2017. We find that the lapse rate tropopause, and not the cold point, constitutes a good estimate of the upper boundary of the well mixed tropospheric air for many species. There is slow, diabatic, upward transport in the vicinity of the lapse rate tropopause and above. The cold point is located on average about 1 km above the lapse rate tropopause and is about 3 K colder (pressure lower by about 12 hPa). The cold point is in particular important for water vapour. Above the cold point in the ASMA molar water vapour mixing ratios (including hydration patches) range between ~ 3 and 10 ppm. In the StratoClim observations (2017), no indication of substantial dehydration above the cold point was found. Ozone mixing ratios increase substantially with altitude; between the lapse rate and the cold point tropopause molar ozone mixing ratios are in the range of 50-200 ppb. For strong convection (flight on 10 August 2017) there is substantial dehydration at the cold point tropopause (indicated by high values of total water, ice particle occurrence, and strong supersaturation). Above the cold point, under such conditions, neither ice particle occurrence, nor enhanced molar mixing ratios of water vapour (above about 6 ppm) are observed.

Flight on 10 August 2017



Measurements of ozone (top left) and water vapour (top right) versus altitude in the vicinity of the tropopause for the scientific flight on 10 August 2017. The dashed line shows the altitude of the lapse rate tropopause and the dotted line the altitude of the cold point tropopause. Tropopause information is for the first three hours of the flight, ozone and water vapour measurements are for the entire flight. In top right panel and in the scatter plot in the bottom panel, grey symbols indicate the FISH total water vapour measurements and black points show the gas-phase water vapour measurements by the FLASH instrument. The red symbol in the bottom panel indicates the location of the lapse rate tropopause; the blue symbol the location of the cold point tropopause.

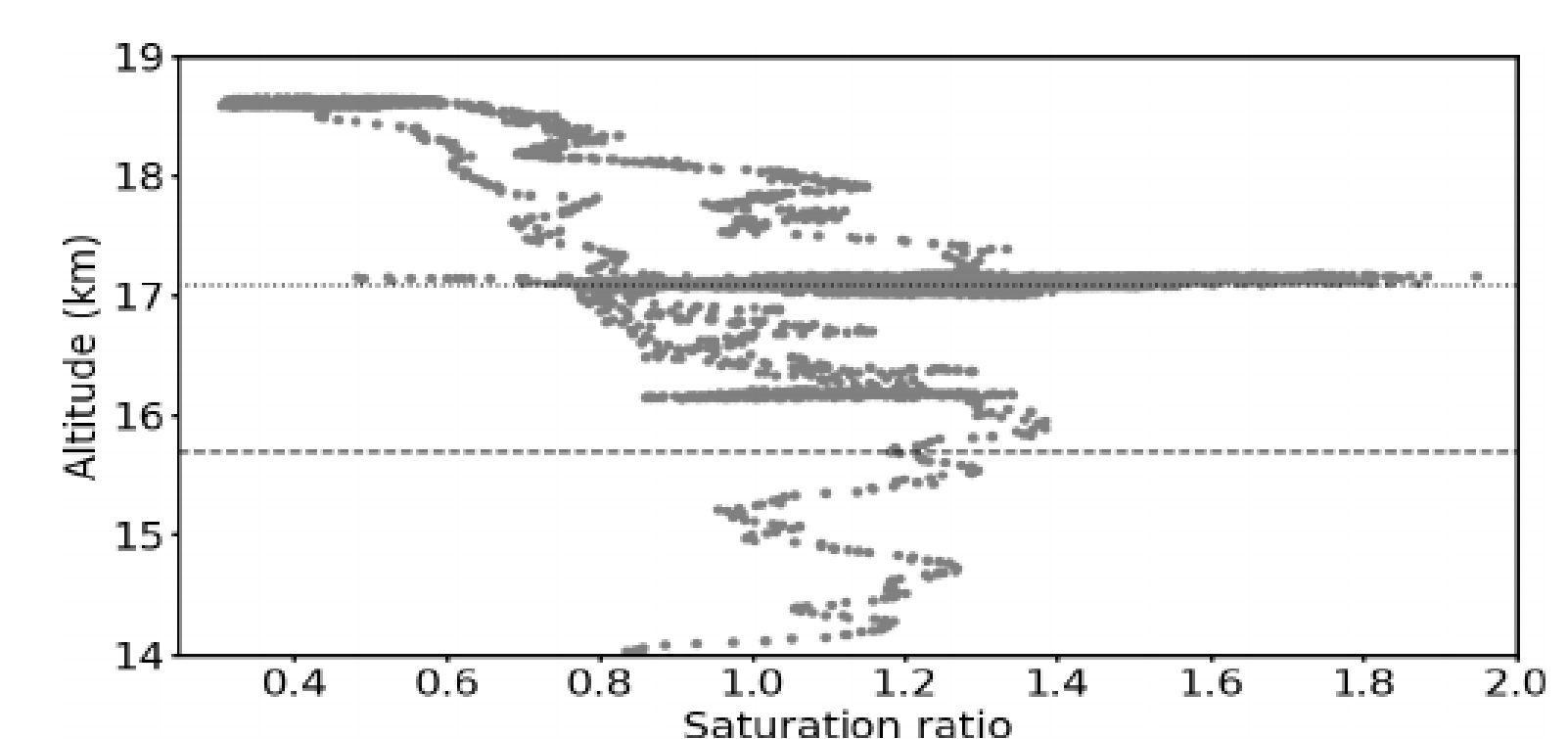
Flights during StratoClim 2017



Flight No.	Date	Lapse rate (LR)				Cold point (CP)			
		Temp. (K)	Alt. (km)	Theta (K)	Press. (hPa)	Temp. (K)	Alt. (km)	Theta (K)	Press. (hPa)
F1	27 July 2017	198.2	15.6	372.7	109.6	194.6	17.4	337.7	82.2
F2	29 July 2017	198.6	15.5	372.6	110.6	194.4	16.8	383.2	90.8
F3	31 July 2017	192.9	17.0	386.7	87.7	192.7	17.0	388.1	87.7
F4	2 August 2017	192.7	17.7	398.9	78.3	191.7	17.9	398.7	76.5
F5	4 August 2017	191.5	15.9	371.8	104.6	191.5	16.2	368.0	99.7
F7	8 August 2017	192.9	16.3	374.8	97.9	187.5	17.4	382.6	82.6
F8	10 August 2017	194.3	15.7	366.7	108.3	186.7	17.1	375.8	86.7
mean		194.4	16.2	377.6	99.6	191.3	17.1	376.3	86.6

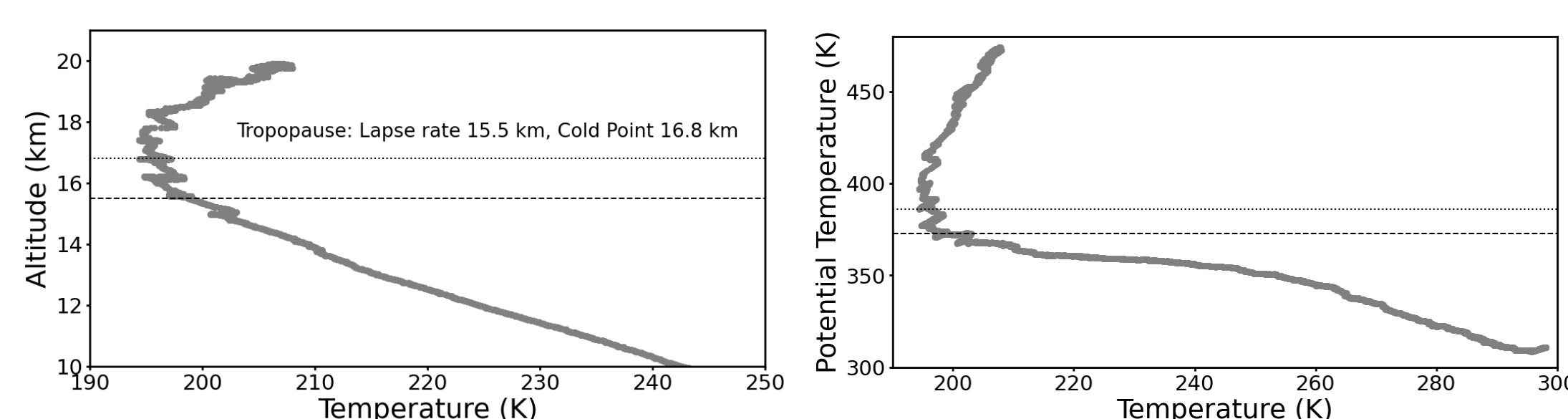
The flights during StratoClim. Top: Flight paths. Bottom: Lapse rate and cold point tropopause.

Flight on 10 August 2017; Saturation



Saturation ratio of H_2O over ice versus altitude for the scientific flight on 10 August 2017 in the vicinity of the cold point and the lapse rate tropopause. Gas-phase H_2O measurements are from the FLASH instrument; these measurements are used to calculate the water vapour saturation ratio. The dotted line shows the cold point for this flight (17.1 km) and the dashed line the lapse rate tropopause (15.7 km). The top altitude for which FISH observed ice particles is 17.1 km.

Flight on 29 July 2017

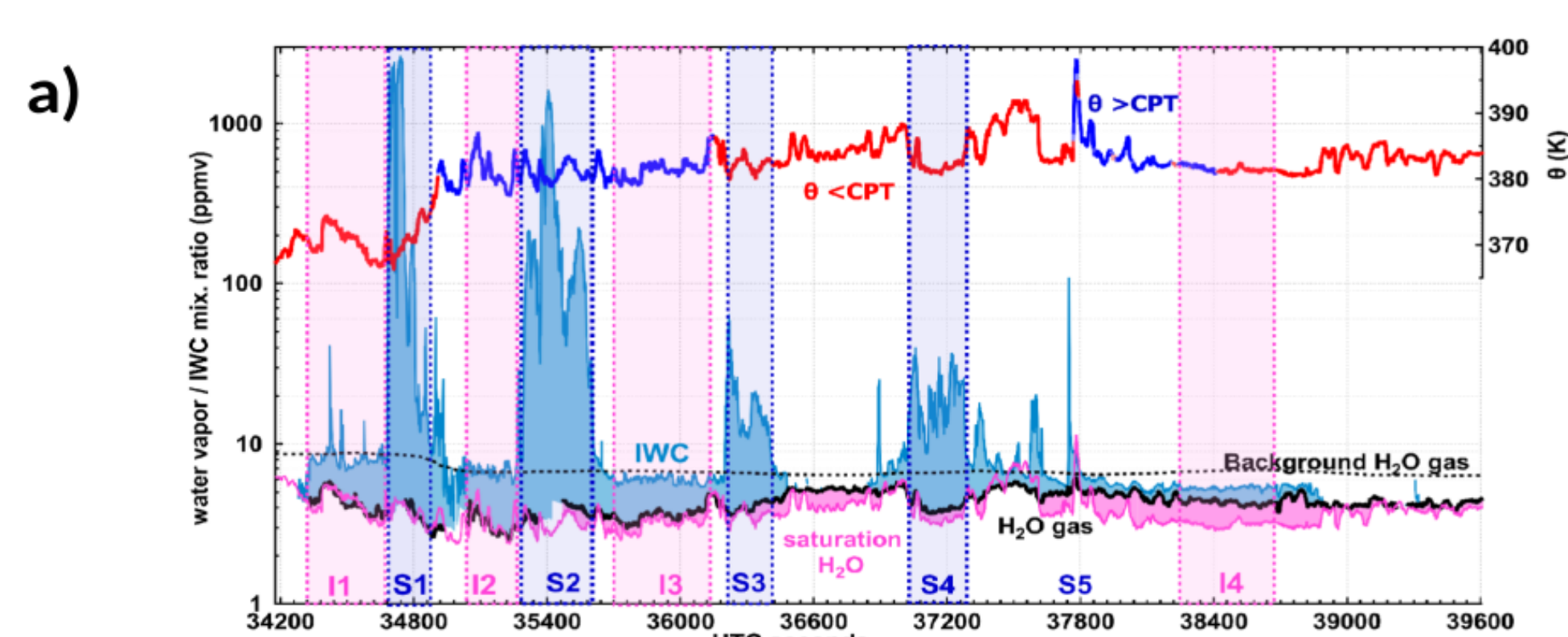


The temperature profile versus altitude (left) and potential temperature (right) in the vicinity of the tropopause for the scientific flight on 29 July 2017. The dashed line shows the altitude of the lapse rate tropopause (15.5 km and 372.6 K, respectively) and the dotted line the altitude of the cold point tropopause (16.8 km and 383.2 K, respectively). Tropopause and temperature information is for the first three hours of the flight.

References

- Müller, R., Vogel, B., Krämer, M., Rolf, C., Spelten, N., and Ravegnani, F. (2026) The lapse rate and the cold point tropopause in the Asian Summer Monsoon anticyclone, *Atmos. Chem. Phys.*, 26, 4359–4376, <https://doi.org/10.5194/acp-26-4359-2026>
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- Vogel, B., Volk, C. M., Wintel, J., Lauther, V., Müller, R., Patra, P. K., Riese, M., Terao, Y., and Stroh, F. (2023) Reconstructing high-resolution in-situ vertical carbon dioxide profiles in the sparsely monitored Asian monsoon region, *Commun. Earth Environ.*, 4, 72, <https://doi.org/10.1038/s43247-023-00725-5>

Flight on 10 August 2017: Time series



Time series of key chemical, thermodynamical and optical parameters observed during the 10 August 2017 Geophysica flight. (a) Total water (blue curve) and water vapour (black curve) as well as ice saturation mixing ratio (pink line) are plotted versus left axis. The Ice Water Content (IWC) is expressed as a blue-shaded region between the total water and vapour mixing ratio. The pink shading represents the degree of supersaturation (difference between the observed and saturated water vapour mixing ratios). Potential temperature curve (right axis) is coloured blue and red respectively for the flight portions below and above the Cold Point Tropopause level, Dashed curve represents the background water vapour mixing ratio derived as an average from the previous flights from Kathmandu (F1 - F7) at the given potential-temperature level.