Balloon-borne lidar observations of tropical cirrus clouds

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Poster related to : Lesigne et al. (in press),
Extensive coverage of ultrathin Tropical Tropopause Layer cirrus clouds revealed by balloon-borne lidar observations, ***Atmospheric Chemistry and Physics***

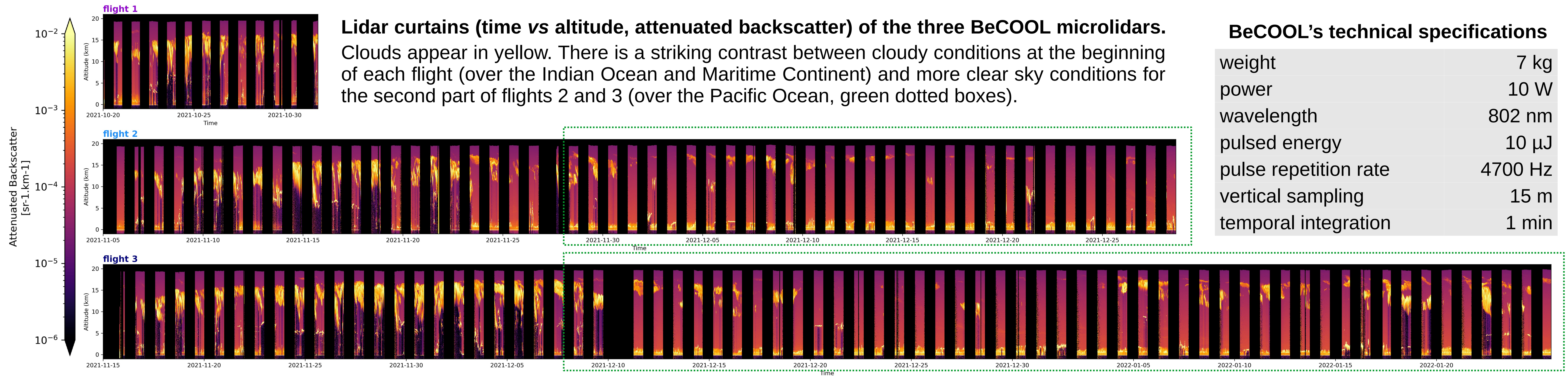
Clouds in the tropical upper troposphere have a significant impact on the Earth radiative budget and are linked with the dehydration of air masses transported to the stratosphere. Still, observing those clouds remains a challenge. We report here the first long-duration observations of tropical clouds from lidars flying onboard stratospheric balloons. Comparisons with space-borne observations reveal an higher sensitivity of balloon-borne lidar observations to optically thin cirrus clouds.

BeCOOL : Balloon-borne Cirrus and convective overshOOt Lidar [1]

- designed to operate in the extreme conditions of the lower stratosphere
- nighttime observations only
- nominal duty cycle of 10 min ON / 10 min OFF
- clouds' optical depth retrieved from 10-minutes averaged profiles

Strateole-2 project [2]

- in situ and remote sensing balloon-borne observations of the Tropical Tropopause Layer (TTL)
- long duration super-pressure balloons flying at targeted levels (~20 km) for several weeks
- balloons released from Seychelles Islands, drifting with the wind along the equator
- first scientific campaign : October 2021 – January 2022, 17 balloons, 3 of them carrying BeCOOL



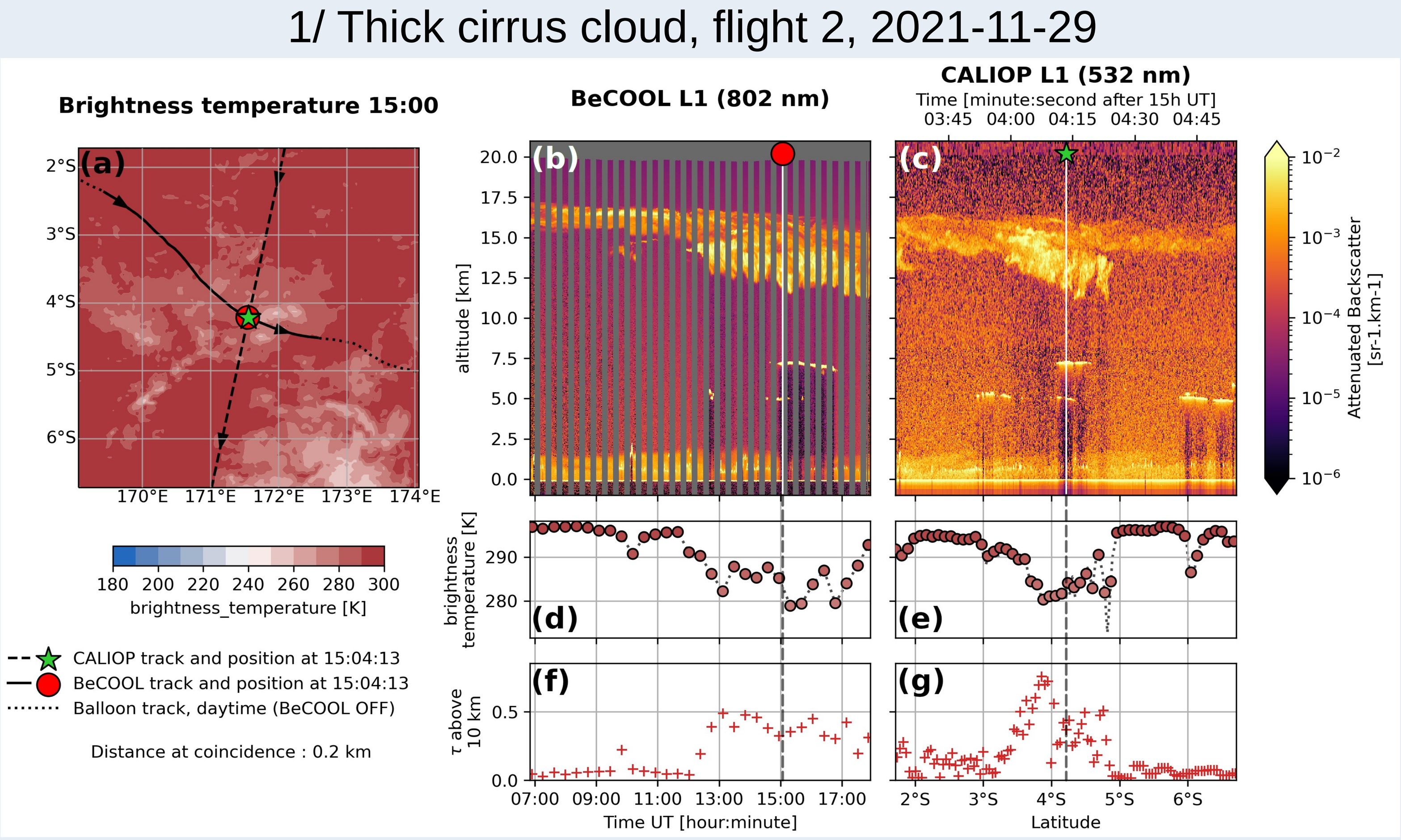
Lidar curtains (time *vs* altitude, attenuated backscatter) of the three BeCOOL microlidars. Clouds appear in yellow. There is a striking contrast between cloudy conditions at the beginning of each flight (over the Indian Ocean and Maritime Continent) and more clear sky conditions for the second part of flights 2 and 3 (over the Pacific Ocean, green dotted boxes).

BeCOOL's technical specifications

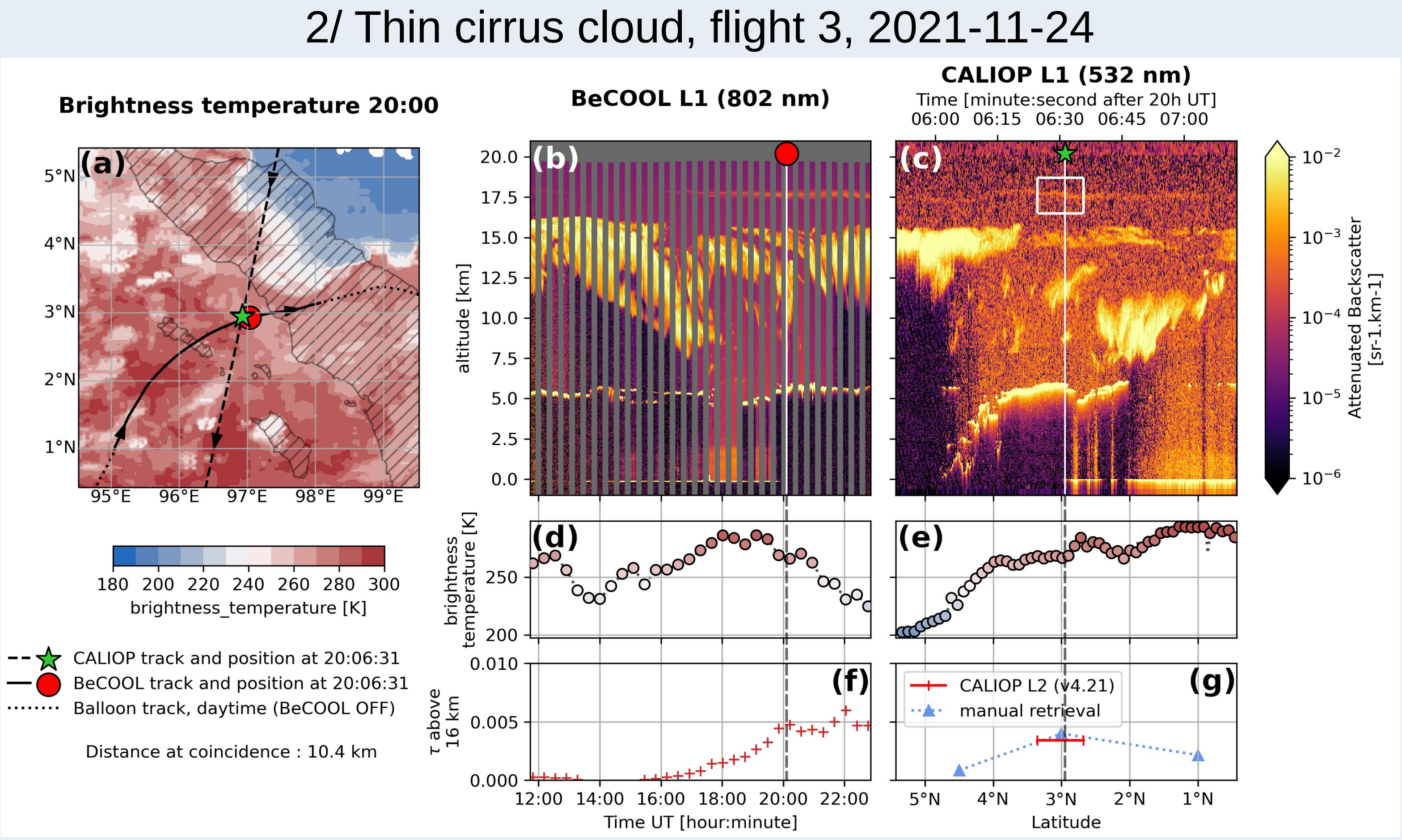
weight	7 kg
power	10 W
wavelength	802 nm
pulsed energy	10 µJ
pulse repetition rate	4700 Hz
vertical sampling	15 m
temporal integration	1 min

Two case studies of collocated BeCOOL/CALIOP observations

1/ Thick cirrus cloud, flight 2, 2021-11-29



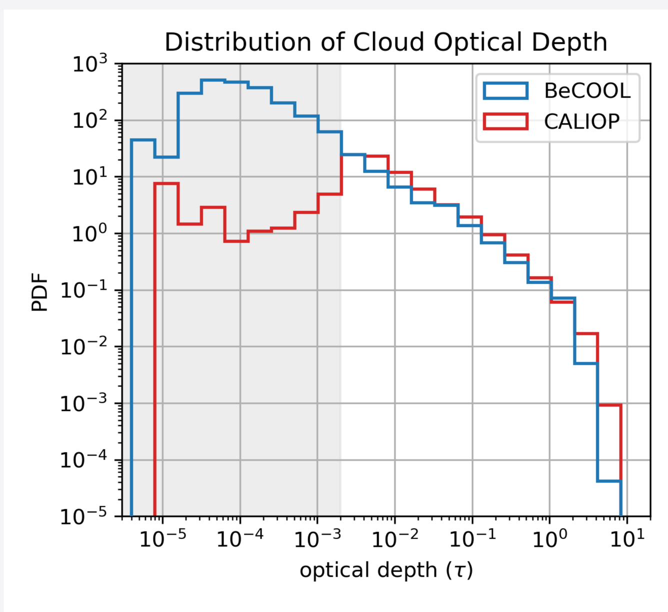
2/ Thin cirrus cloud, flight 3, 2021-11-24



a: 11 µm brightness temperature map at coincidence; b: BeCOOL L1 curtain (along the solid line on the map); c: CALIOP L1 curtain (along the dashed line on the map); d, e: time series of brightness temperature under the balloon and the satellite; f, g: time series of optical depth τ above 10 km (case study 1) or 16 km (case study 2) retrieved from BeCOOL and CALIOP.

Both case studies illustrate the excellent agreement between the two lidars. On the second case study, the thin cirrus at 17.5 km is only partially detected by CALIOP (white box on panel c). Thanks to the small distance to the observed clouds and to the low speed of the balloons (which allow to integrate the lidar measurements for a whole minute), BeCOOL benefits from a unique sensitivity to ultrathin TTL clouds.

Statistical comparison of cloud optical depth from BeCOOL and CALIOP



Optical depth distributions of all clouds above 5 km retrieved from BeCOOL and from CALIOP nighttime profiles over the same period and region.

- very good agreement for $\tau > 2{\cdot}10^{-3}$ with a τ^{-1} slope
- clear cut-off in CALIOP's distribution at $\tau = 2{\cdot}10^{-3}$
- for BeCOOL, the power law extends down to $\tau = 10^{-4}$

Ultrathin clouds ($\tau < 2{\cdot}10^{-3}$) are reported in less than 1 % of CALIOP's profiles while they appear in more than 30 % of BeCOOL's, mainly within the TTL (above 14 km, 23 % of the profiles).

Properties of Tropical Tropopause Layer cirrus clouds

Frequencies of occurrence (% of 10 min profiles) and geometrical properties (top altitude z_top and vertical extension Δz) of TTL cirrus clouds detected by BeCOOL for different bins of optical depth τ.

$\tau = 2{\cdot}10^{-3}$ CALIOP's detection lower limit
$\tau = 3{\cdot}10^{-2}$ lower limit for sub-visible clouds (Sassen et al., 1989)
$\tau = 10^{-1}$ detection lower limit of passive radiometer (McFarquhar et al., 2000)

	% of TTL cirrus	% of 10 min profiles	$\overline{z}_{top}$	$\overline{\Delta z}$
All TTL cirrus	100 %	48 %	17.1 km	1070 m
$\tau < 2\cdot10^{-3}$	46 %	23 %	17.1 km	440 m
$2\cdot10^{-3} < \tau < 3\cdot10^{-2}$	29 %	16 %	16.9 km	1190 m
$3\cdot10^{-2} < \tau < 10^{-1}$	19 %	11 %	17.1 km	1890 m
$10^{-1} < \tau$	5 %	3 %	17.5 km	2800 m

Tropical Tropopause Layer (TTL) cirrus clouds are detected in almost half BeCOOL's profiles and have a mean vertical extension of 1 km. The microlidar's enhanced sensitivity to optically very thin features reveals the significant coverage of ultrathin TTL cirrus undetected from space (optical depth τ below $2{\cdot}10^{-3}$). Such clouds appear in 23 % of BeCOOL's profiles and have a mean vertical extension lower than 500 m [3]. They share characteristics with laminar cirrus reported by Winker & Trepte (1998) from LITE space-borne lidar observations and with Ultrathin Tropical Tropopause clouds reported by Peter et al. (2003) from airborne observations.

REFERENCES :

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