DETECTION OF ULTRA-THIN TROPICAL CIRRUS DURING TROCCINOX – A CASE STUDY PERFORMED BY TWO AIRBORNE LIDARS

Giovanni Martucci [(1)], Renaud Matthey[(1)], Valentin Mitev[(1)], Andreas Fix[(2)], Christoph Kiemle[(2)]

[(1)] Observatory of Neuchâtel, rue de l'Observatoire 58, CH-2000 Neuchâtel, Switzerland
E-mail:gianni.martucci@ne.ch
[(2)] DLR Oberpfaffenhofen, Institut für Physik der Atmosphäre, Postfach 1116, D-82230 Wessling, Germany
E-mail: andreas.fix@dlr.de

ABSTRACT

Observation of ultra-thin tropical cirrus clouds (UTTC) is essential for a better evaluation of their dehydration potential in the vicinity of the tropical tropopause. Airborne lidars are appropriate tools for such studies as they can operate in a flexible way over large areas, as well as close to the interesting altitudes. Here we present collocated measurements of UTTC by two lidars: one is a compact backscatter lidar on board the M55 Geophysica and the other one a differential absorption lidar (DIAL) on the DLR Falcon research aircraft. The measurements reveal a complex three-layered structure above the Atlantic Ocean with likely fast temporal changes, as well as a thin layer above the continent. The collocated cloud detection of the two instruments contribute to the validation of the measurements of the compact lidar MAL and help to determine its detection limits for extremely low backscatter in conditions of tropical daylight.

1. INTRODUCTION

Ultra-thin tropical cirrus clouds (UTTCs) impact the radiative balance and play an important role in the water vapour budget in the stratosphere [1, 2]. However, the processes leading to their formation, coverage and lifetime are still under investigation [3-5]. Airborne backscatter lidars expand the geographical reach of the measurements and contribute substantially to the collection of UTTC databases.

One of the objectives of the EC project TROCCINOX (TROpical Convection, Cirrus and Nitrogen OXides experiment) was aerosol and cirrus measurements in tropical upper troposphere and lower stratosphere, both over the ocean and the continent. The campaign TROCCINOX2 took place in Araçatuba, Brazil, performed with two research aircrafts (see Fig. 1). The Falcon carried the DLR water vapour differential absorption lidar [6] in an upward pointing configuration. The payload on M55 included the backscatter depolarisation lidar MAL2 [7, 8], realised by Observatory of Neuchâtel, installed in a downward probing configuration.

Fig. 1. The research aircrafts participating in the TROCCINOX2: upper panel - Falcon (DLR); lower panel - M55 "Geophysica".

The transfer flights from Europe to Brazil over the Atlantic and the South America equatorial regions were coordinated between both aircraft. This provided the opportunity to observe UTTC above the ocean and the continent nearly simultaneously by both lidars. The variety of the detected clouds in altitude, scattering and depolarisation ratios provided also inputs to evaluate the detection limit of the low-power and autonomously operating lidar MAL2 on the M55 "Geophysica".

2. WATER VAPOUR DIAL ON DLR FALCON

The $H2O$ DIAL transmitter is based on a Q-switched, diode-pumped Nd:YAG laser operating at a repetition rate of 100 Hz providing an average output power of about 22 W in a single longitudinal mode at 1064 nm. Approximately 50% of the fundamental energy at 1064 nm is converted to the second harmonic which is used to pump an injection seeded optical parametric oscillator at a wavelength of ~925-940 nm to generate the required on- and off-line wavelengths for water vapour measurements. We focus here on the 1064 nm and 532 nm backscatter signals used for high-spatial-resolution aerosol measurements.

The system can be positioned aboard the aircraft to look either downward or upward. The latter was done during the flights considered within this study. The backscattered photons are collected by means of a Cassegrain-type telescope with a diameter of 35 cm. The received light is split into three channels: one for water vapour measurements at 935 nm and two for aerosol measurements at 532 nm and 1064 nm which are further divided to sub-channels for depolarization detection. The backscattered light, appropriately filtered for solar background radiation, is detected by means of silicon avalanche photodiodes and photo multipliers, respectively. The signals are digitized with a resolution of 14 bit at a sampling rate of 10 MHz. The raw data spatial resolution is 2m horizontal and 15 m vertical.

3. LIDAR MAL2 ON M55 "GEOPHYSICA"

The lidar MAL2 (Miniature Aerosol Lidar Mk.2) is realised in Observatory of Neuchâtel and is installed on M55 "Geophysica" for measurements in downward direction. The lidar is backscatter/depolarisation, with probing wavelength 532 nm. This instrument is one unit with dimensions: 510x320x170 mm³ and mass 33.4 kg. It participated in a number of campaigns and is described elsewhere [7-9]. Its specifications are given in Table 1. The following values are determined: total backscatter ratio (BR) and the aerosol depolarisation ratio (DR). The determined values are filtered and whitened for signal-to-noise ratios SNR < 1.5. In Figs. 4, 5 and 8, the black line shows the flight level of M55 "Geophysica", while the BR and the DR are colour coded.

Table 1. Performances of MAL2 subsystems

Laser type	Nd-YAG micro-chip, passive Q-switched
Wavelength	532 nm
Laser output power	16-18 mW
Laser pulse rep. rate	approx. 5 kHz
Polarisation	linear
Laser beam divergence	0.25 mrad full angle
Receiver/aperture	refractor, 50 mm ∅
Receiver field of view	0.5 mrad full angle
Detectors	PMT, photon counting
Dark noise	35 – 160 cps
PMT output pulses	TTL positive, 30 ns width
Count rate sensitivity	typ. 3 x 10^5 cps/pW
Acquisition range resolution	21.432m
Duration of single acquisition	3 s
Consumed current / voltage	max. 3 A / 28 VDC

4. OBSERVATIONS DURING THE FLIGHT CAPO VERDE – RECIFE, 23 JANUARY 2005

The flight path for M55 "Geophysica" is presented in Fig. 2. The flight took place over the Atlantic Ocean. The results of the water vapour DIAL from this flight are depicted in Fig. 3. Three distinct features can be clearly distinguished: (a) A high level ultra-thin cirrus structure (~16:30 UTC) at 16.5-17 km altitude showing backscatter ratios on the order of 1.5-2 and a volume depolarisation of 5-10%. (b) A second thin cirrus (~17:20 UTC) at 17 km altitude with similar characteristics and thicker cloud patches beneath. (c) An extended cirrus anvil ~ 18-19 UTC close to South America.

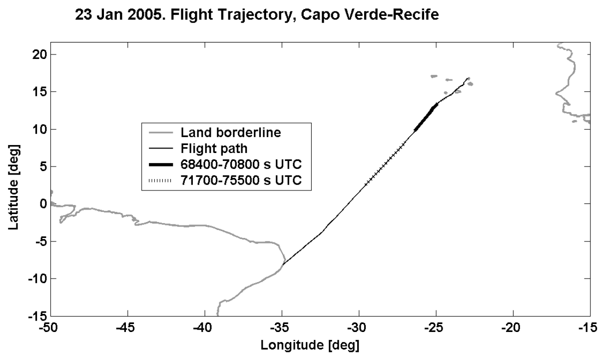

Fig. 2. The flight-path for M55 Geophysica for the flight Capo Verde (Sal) – Recife on 23 January 2005.

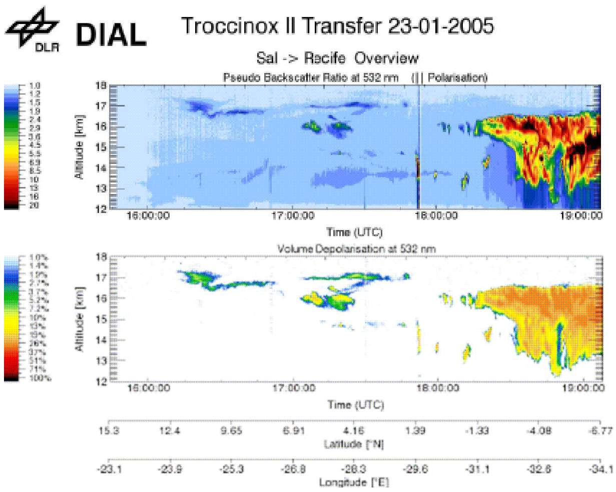

Fig. 3. DIAL observations of the entire Falcon flight on 23 January, above flight level. Upper panel: BR at 532 nm; Lower panel: Volume DR at 532 nm

The compiled results from MAL2 for the whole flight are presented in Fig. 4. The flight took place during dusk and night. Due to this, the signal is with a high signal-to-noise ratio, which enables the detection of low altitude clouds and sea surface. The large thick cloud close to South America is also observed with details, coinciding well with the observations from the DIAL. Also, there is a good coincidence between the values of the BR and the DR observed by MAL and the DIAL. This good coincidence even in details of this cloud yields a good validation case and shows that the two instruments may be used for combined measurements.

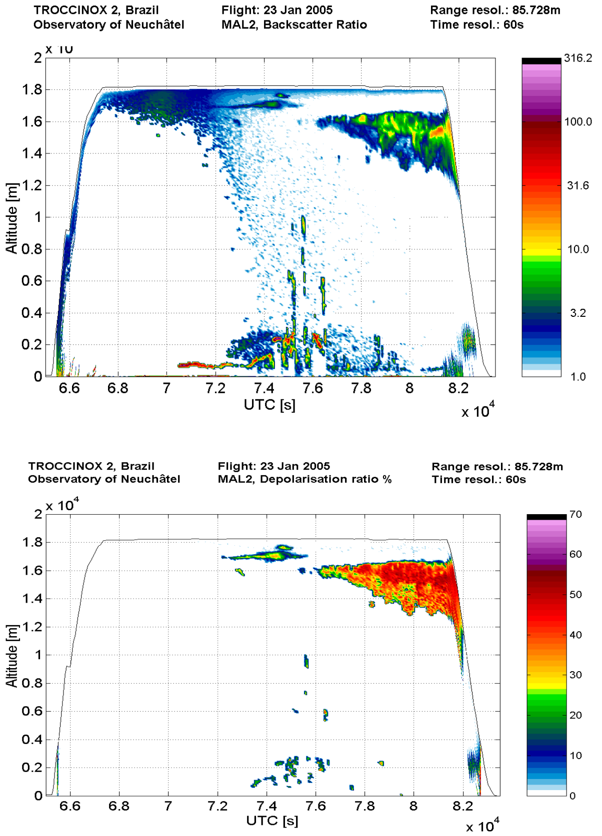

Fig 4. MAL2 observations of the entire flight on 23 January. Upper panel: BR; Lower Panel: DR.

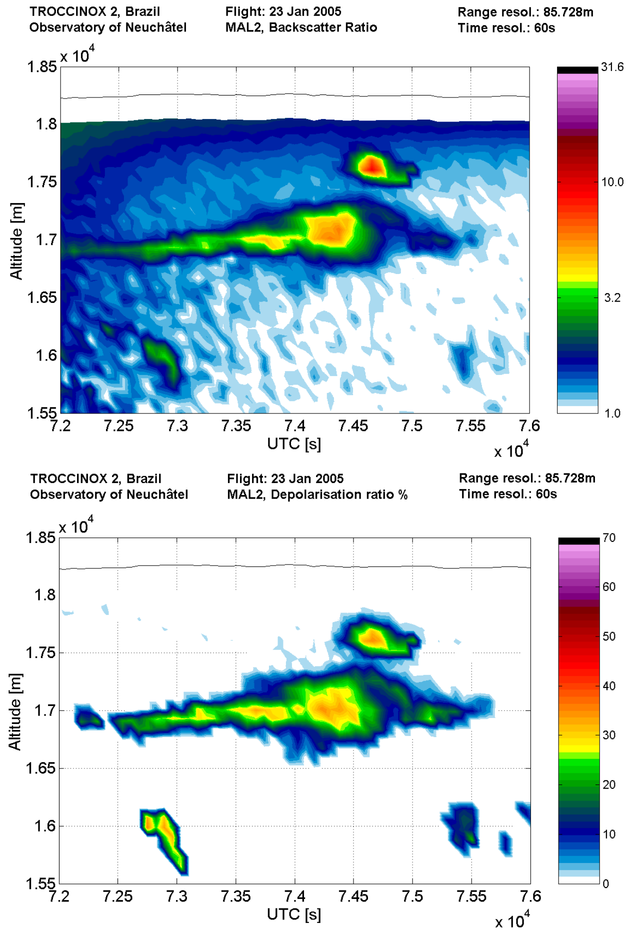

Fig. 5. Same as in Fig 4 but with a zoom on the part with the high-altitude UTTC.

The observation of the high ultra-thin cirrus took place between 72'000s and 76'000s above the central part of the Atlantic – see in Fig. 5, where the location of the cloud is shown in Fig. 2. The three-layered structure is very similar to the one observed by the DIAL, but with differences in the observed BR and DR. MAL determines lower BR value for the lowest of the three layers than DIAL, higher BR for the upper layer than DIAL, while the BR value for the central layer is approximately the same. Such difference may be explained by the absence of precise coincidence of the measurements of the two lidars in time and position i.e. assuming a time and space variable structure of the observed cloud.

5. OBSERVATIONS DURING THE FLIGHT RECIFE - ARAÇATUBA, 27 JANUARY 2005

The path of the M55 "Geophysica" during this flight took place above the continent and is presented in Fig. 6. Around 39°W the DIAL detected a UTTC at ~17.3 km altitude with a geometrical thickness of less than 200 m. The BR at 532 nm and 1064 nm are depicted in Fig. 7. They are as low as ~ 2 and 4, respectively. The depolarisation of this cloud is ~7% (not shown).

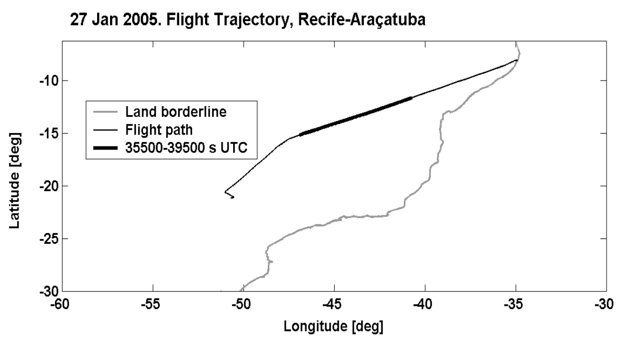

Fig. 6. The flight-path for M55 Geophysica for the flight Recife- Araçatuba on 27 January 2005.

The observations of MAL for this flight are in Fig. 8. This flight took place in high daylight what decreases the detection capabilities of this lidar. As we see, the BR reveals a presence of a UTTC at the place where it was detected also by the DIAL, but with lower confidence. The DR is determined also only for a part of the flight. Comparing the measurements we may evaluate the

MAL2 detection limits in the worst measurement conditions of tropical daylight, where the OD of the observed UTTC is ~1-1.5x10^{-4}: BR~1.5-2, volume DR ~4 – 5 %.

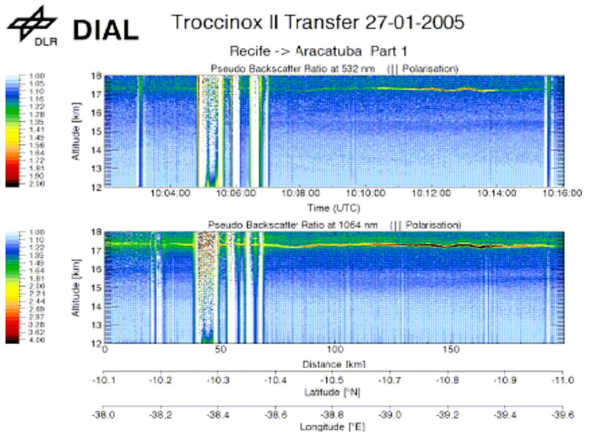

Fig. 7. UTTC as seen with the DIAL. Upper panel: BR at 532 nm; lower panel: BR at 1064 nm

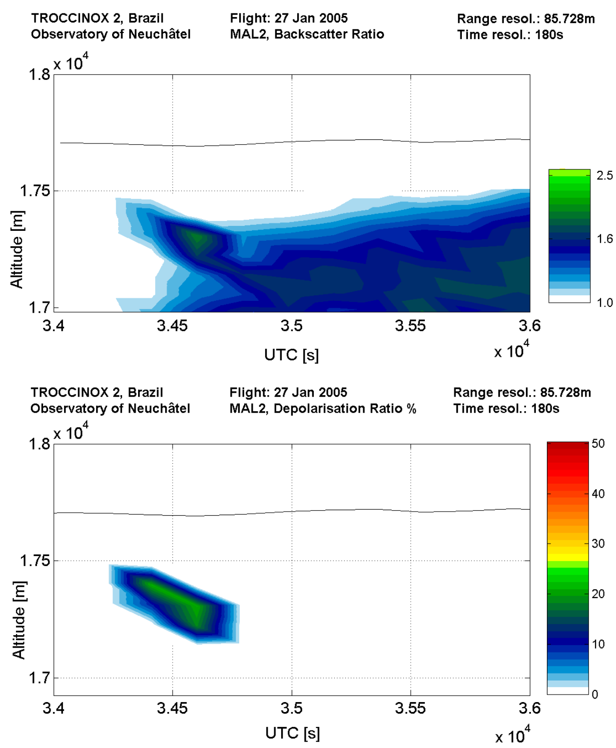

Fig. 8. MAL: zoom of the part with the UTTC. Upper panel: BR; Lower Panel: DR

ACKNOWLEDGMENTS

This work is supported by EC project TROCCINOX (EVK2-CT-2001-00122) and, for the ON team, by the Swiss Ministry of Education and Research. Thanks are due to the efficient co-operation with the M-55 "Geophysica" flight and technical teams, and to the DLR Flight Department. The authors would like to acknowledge the logistic support from Dr. Stefano Balestri and Heinz Finkenzeller.

REFERENCES

1. McFarquahar G. M. et al, "Thin and Subvisual TropopauseTropical Cirrus: Observations and Radiative Impact", J. Atmos. Sci., v. 57, 1841-1853, 2000.

2. Jensen E. and L. Pfister, "Transport and freeze-drying in the tropical tropopause layer", J. Geophys. Res., V. 109 D2, 10.1029 (2003JD004022), 2004.

3. Boehm M. T. et al., "On the maintenance of high tropical cirrus", J. Geophys. Res., V. 104 D20, 24'423-24'433, 1999.

4. Peter Th. et al, "Ultrathin Tropical Tropopause Clouds (UTTCs): I. Cloud morphology and occurrence", Atmos. Chem. Phys, v. 3, 1083-1091, 2003.

5. Luo B. P. et al "Ultrathin Tropical Tropopause louds (UTTCs): II. Stabilization mechanisms", Atmos. Chem. Phys, v. 3, 1093-1100, 2003.

6. Poberaj, G., et al.: "All-Solid-State Airborne DIAL for Water Vapour Measurements in the Tropopause Region: System Description and Assessment of Accuracy," Appl. Phys. B 75, 165-172, 2002.

7. Mitev V. et al, Miniature backscatter lidar for cloud and aerosol observation from high altitude aircraft, Recent Res. Devel. Geophysics, Vol. 4, p.p. 207-223, ISBN:81-7736-076-0, Research Signpost, 2002.

8. Matthey R. et al, "Lidar Detection of Thin Clouds from a High-Altitude Aircraft M55 "Geophysica", 22nd ILRC, 12-16 July 2004, Matera, Italy, Proc. (ESA SP-561), 95-98, 2004.

9. Cairo et al., "Polar stratospheric clouds observed during the Airborne Polar Experiment–Geophysica aircraft in Antarctica (APE-GAIA) campaign", J. Geophys. Res., 109 (D7), D07204 10.1029/2003JD003930), 2004.