Simultaneous observation of contrails from the ground and space: first attempt with EarthCare

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INTRODUCTION

Cloud formation also results from human activity, as evidenced by aircraft condensation trails created by the release of water vapor and soot. These contrails rapidly change shape after their formation and can persist in the atmosphere if the air is supersaturated with ice. They can then evolve into cirrus clouds, depending on atmospheric thermodynamic conditions. These artificial clouds, which contribute to additional radiative forcing on the climate, warrant further investigation, especially given the significant increase in air traffic. The formation thresholds of these artificial clouds, the growth rate of persistent contrails, and their optical characteristics remain areas requiring further research. This objective motivated the episodic and/or continuous temporal monitoring of condensation trails with the installation of ground instruments at SIRTA (Site Instrumental de Recherche par Télédétection Atmosphérique), SIRENE and OHP (Observatoire de Haute-Provence) observatories in France. They are mainly composed of a Lidar, radiosondes and one or two fisheye cameras recording hemispherical images of the sky in the visible and thermal infrared for nighttime observations. The Global Horizontal Irradiance (GHI) of the Sun and some meteorological data on ground are also recorded together with the images. The use of simultaneous space-based observations is also an asset for identifying the properties of condensation trails. The idea is to consider EarthCARE MSI (Multi Spectral Imager) images that have a spatial resolution of 500 m at ground level over a 150 km wide swath perpendicular to the satellite's orbit, thus increasing the probability of detecting contrails at a given location on the ground. Furthermore, EarthCARE's synergistic radar-lidar AC-TC products, acquired simultaneously, will also be used to obtain aerosol and cloud profiles during the MSI image acquisition process.

This work presents a first attempt at a joint ground-space observation of a contrail, based on images recorded on June 18, 2025, by MSI and the thermal camera at the SIRTA site.

The SIRTA facilities

The SIRTA facilities include the **IPRAL LIDAR** whose laser operates at wavelengths of 355, 532 and 1064 nm (https://www.lmd.ipsl.fr/en/actulmd/the-new-life-of-the-ipral-lidar/). It is dedicated to the study of dynamic processes in semi-urban environments in order to improve the understanding of the interactions between clouds and radiative and dynamic processes. They include also **radiosondes** and **a fisheye camera** recording hemispherical images of the sky in the thermal infrared useful for night-time observations (Fig. 1).

(Some meteorological data (humidity and temperature) and global horizontal solar irradiance (GHI) are also recorded on the ground, along with the images. An Automatic Dependent Surveillance-Broadcast (ADS-B) receiver provides data from aircraft flying over the SIRTA sky. This helps identify the aircraft responsible for the contrails.

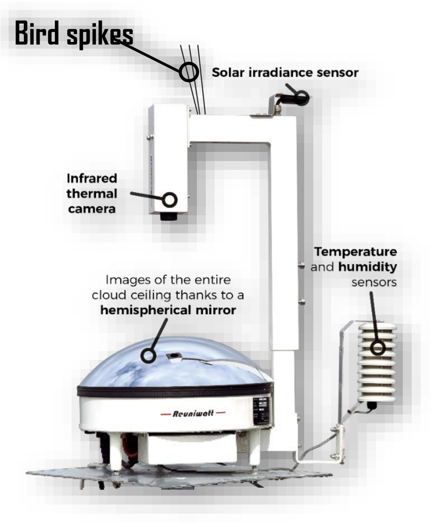

Fig.1 Sky InSight™: Thermal infrared all-sky imager (reproduced courtesy Reuniwatt)

Data and calibration

- Images taken every 30 seconds: **2880 images/day**
- Image size: **480x640 px** for the Thermal camera
- Reuniwatt calibration matrices: each image pixel is located on the sky by its azimuth and its zenith angle. These matrices allow each pixel to be transformed into the coordinate system (longitude, latitude) by making an assumption on the altitude.

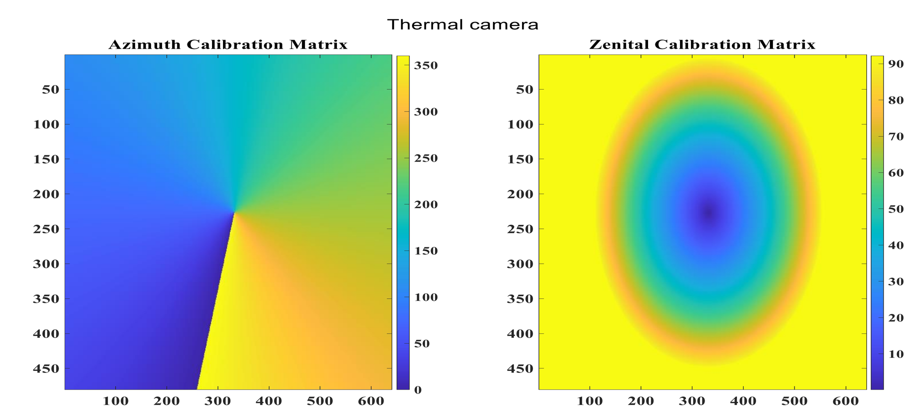

Fig. 2 Calibration matrices.

METHODS and RESULTS

Image processing of thermal images – Contrail extraction

June 18, 2025, is a particularly interesting day, as images taken by the SIRTA observatory's Sky InSight™ thermal camera revealed the presence of a nighttime contrail as EarthCare passed over the site. The images were first processed using the method described in Irbah *et al.*, 2025 (1), and then the contrails were extracted. The image recorded at 0:30 a.m., under clear skies, served as the reference image for the processing. Figure 3 shows, from left to right, the raw reference image, followed by the processed result. The third image is the result obtained from the same processing applied to an image of interest recorded on June 18, 2025 at 1:15 a.m., and the fourth is the image obtained when the reference is subtracted. The last image in Figure 3 clearly shows the highlighting and extraction of the condensation trail using the k-means method. However, slight cloud cover prevented complete detection of the trails.

(**1**) irbah et al., Proc. SPIE 13668, Remote Sensing of Clouds and the Atmosphere XXX, 136680P (29 Oct 2025); https://doi.org/10.1117/12.3070145

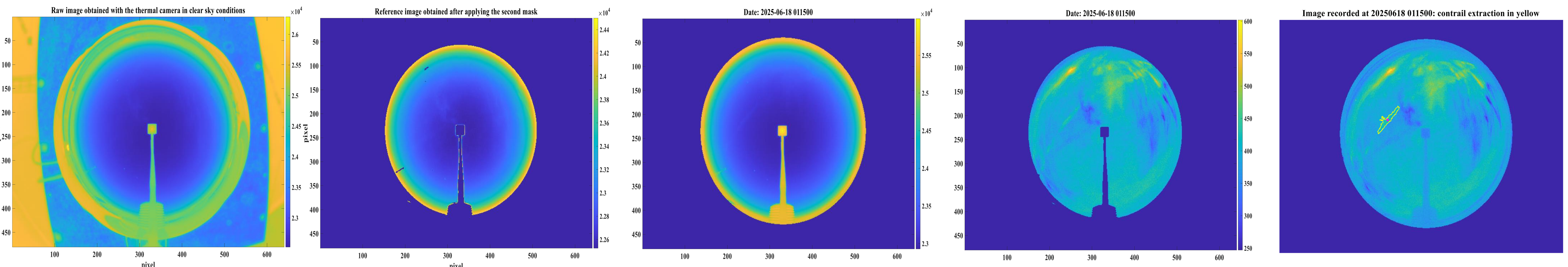

Fig. 3 From left to right: raw reference image, reference image after processing, image recorded at 1:15, the same after removing the reference and then the contrail shape extraction

Visualization of the image sequence showing the contrail reveals that the first signs of its detection appear around 00:50. Analysis of the ADS-B data then identifies aircraft **3C7424**, flying at an altitude of **11.6 km**, as being responsible for its creation. Figure 4 shows all contrail shapes detected between 0:50 a.m. and 1:30 a.m. converted into the aircraft's geographic coordinate system using its altitude. The aircraft trajectory is also plotted in the figure Plotting the centroid of the condensation trail and the position of the aircraft over time allows, through linear interpolation, the determination of the initial time of its formation. This corresponds to the intersection of both trajectories: the beginning of the condensation trail emission is around 00:44:30 (Fig. 5).

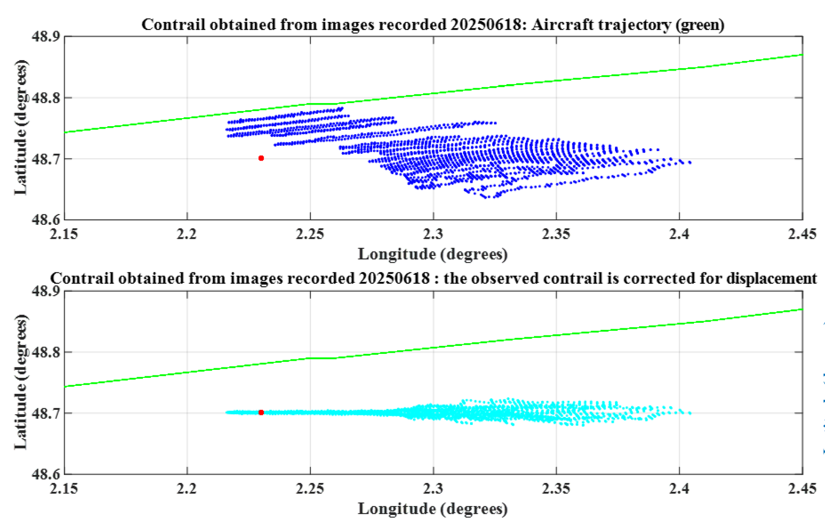

Fig. 4 Contrail extracted from images plotted in the geometric coordinate system using the aircraft's altitude

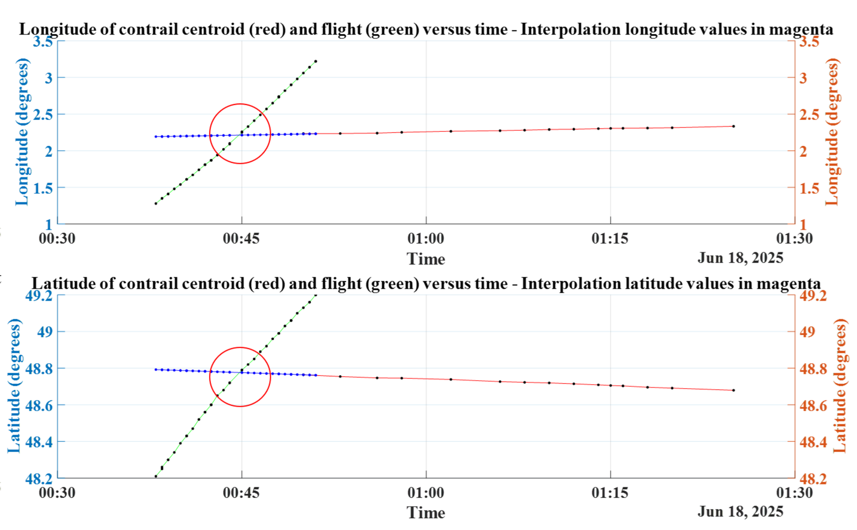

Fig. 5 Estimated of the initial time of the contrail

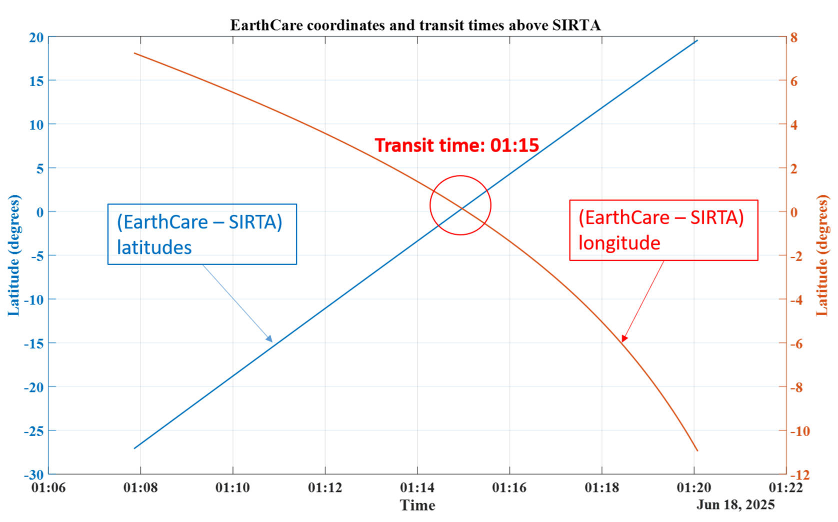

Fig. 6 Estimated transit time of EarthCare over SIRTA

EarthCare MSI Brightness temperature – Colocalization with ground observations

The period of formation of the observed contrails coincides with the passage of the EarthCare satellite over SIRTA. The transit time of EarthCare over SIRTA is estimated by plotting its coordinates (longitude, latitude) against those of SIRTA over time: **EarthCare passes over SIRTA at 1:15 a.m.** (Fig. 6). The Multi Spectral Imager (MSI) recorded atmospheric brightness and radiance along the satellite's trajectory over a 150 km swath with a resolution of 500 meters. Figure 7 shows the brightness temperature obtained from the TIR3 channel (12 µm), seemingly indicating the presence of a contrail. Figure 8 shows the difference in brightness temperature obtained from the TIR3 and TIR2 channels (10.8 µm), highlighting brightness temperature fluctuations favorable to contrail identification. The joint ground-space observation attempt was made using observations recorded by MSI and the thermal camera at SIRTA. The **shape of the condensation trail extracted from the ground image at 1:15 a.m. perfectly matches that observed by MSI**.

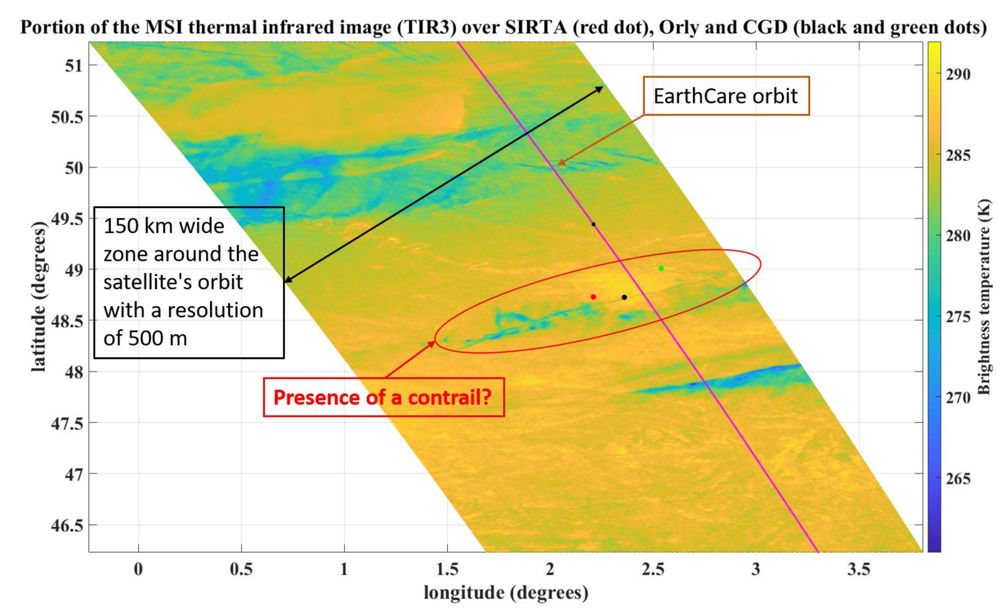

Fig. 7 MSI TIR3 image over SIRTA showing the contrail detected from ground. SIRTA is the red dot while, Orly and CDG airports are in black and green

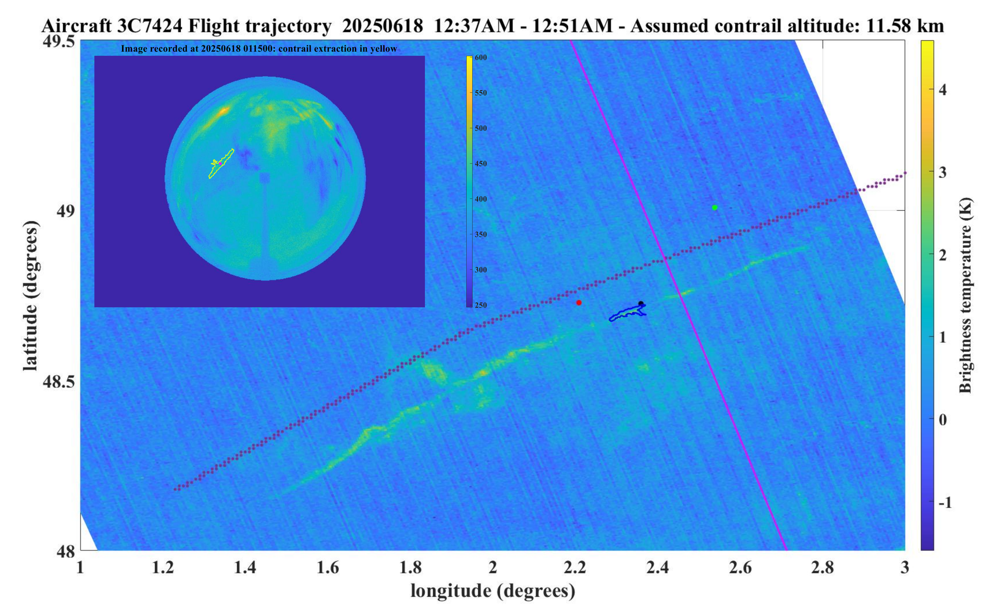

Fig. 8 MSI image (TIR3-TIR2) taken above SIRTA highlighting the contrail and its co-location with the ground image (see upper left corner)

A close-up of Figure 8 on SIRTA clearly shows that the satellite's orbit crosses the extent of the condensation trail. A close-up of figure 8 on SIRTA clearly shows that the satellite's orbit crosses the extent of the contrail. This means that the EarthCare instruments (ATLID and CPR) which point towards the nadir also probe the condensation trace, thus enabling the creation of the AC-TC product, which is obtained from the synergy of the observations of ATLID and CPR. Figure 9 shows the **AC-TC** profile over SIRTA, locating the **contrail** at **11.58 km** and classifying it as **dusty mix**. Figure 10 plots IPRAL's observations as the contrail passed over the site. It is clear that **IPRAL** observed the contrail at an altitude of **11.5 km**, which then increased slightly by approximately 300 m.

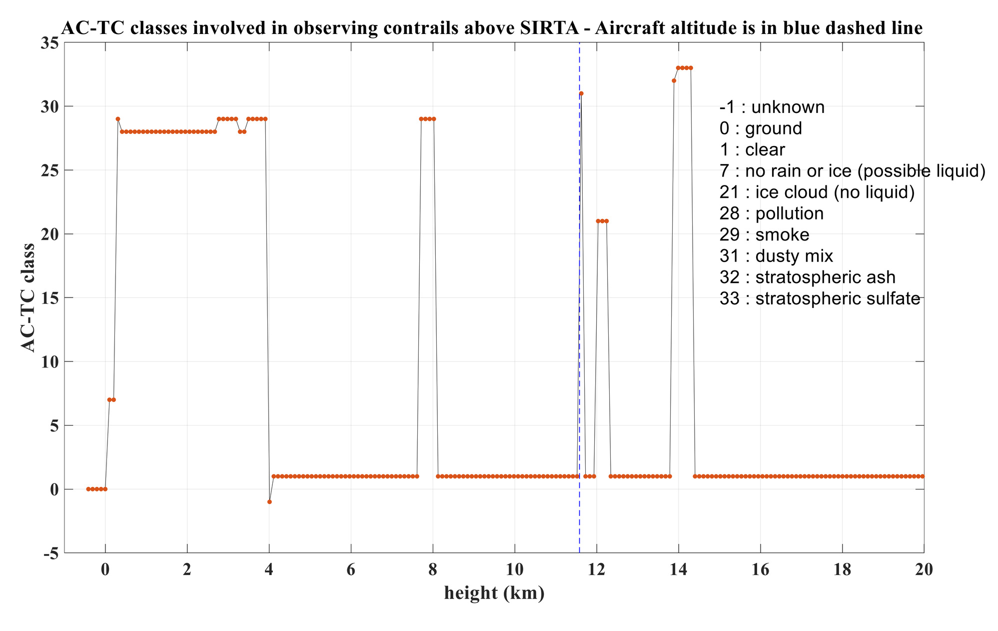

Fig. 9 AC-TC profile above SIRTA probing the condensation trail: it is located at 11,58 km and classified as dusty mix.

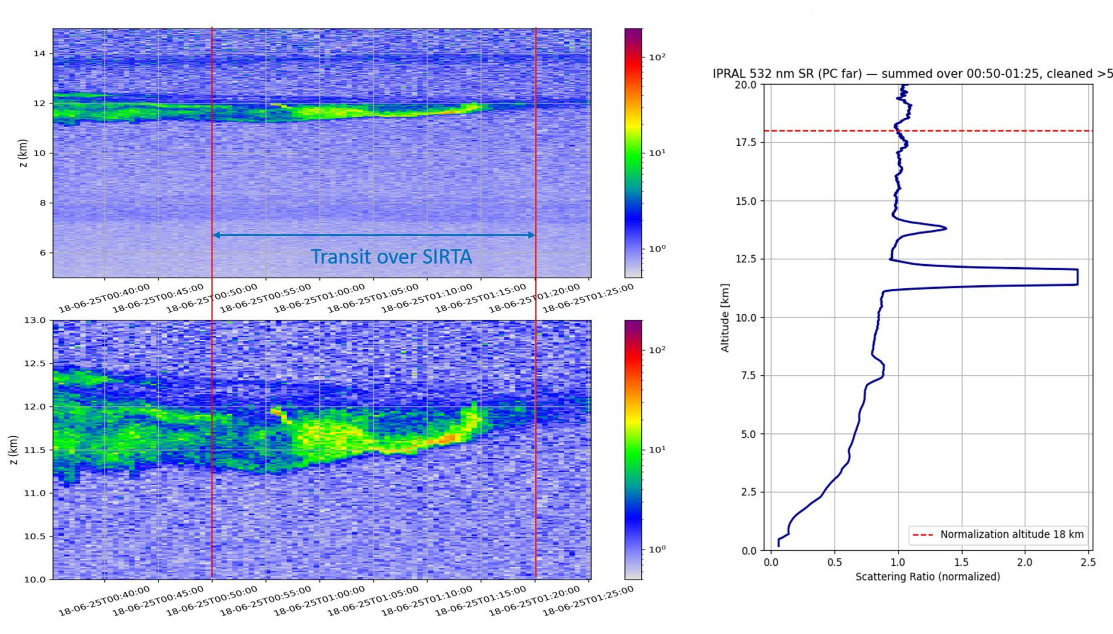

Fig. 10 Contrail detected by the IPRAL lidar @ 532 nm