Comparisons of radiosonde water vapor measurements with ECMWF ERA-5 and contrails observations above Clermont-Ferrand (France)

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1 | Context and motivation

The cirrus clouds impact on the radiation budget of the Earth depends mainly on their optical thickness and altitude (Heymsfield et al., 2017). The contrails formed from aircraft emissions bring an additional impact to that of natural cirrus clouds (Kärcher et al., 2018). To quantify this impact, it is necessary to better understand the contrails formation and persistence which depends on the thermodynamical conditions at local scales and notably on the saturation of water vapour with respect to ice. However, at their altitude of formation (around 10 km), few reliable measurements of the water vapour are available. The aim of this work is first to evaluate the capacity to get reliable radiosondes measurements in this altitude range and second to present a methodology allowing to study contrails from full-sky camera images and lidar measurements in the framework of the European project BeCoM.

2 | Data

- Humidity measurements performed by M10 radiosondes launched by MeteoFrance from the Nîmes (43.87°N and 4.40°E) and Trappes (48.77°N and 2.10°E) sites near 12:00 am and pm for January and July 2022, as well as the Trappes GRUAN data (Dupont et al., 2020)
- ECMWF ERA5 specific humidity at 1 hour time-resolution on 137 vertical levels at 0.125° horizontal resolution.
- Images from full-sky camera (EKO, SRF-02) located on the roof of the LaMP building at 45.76°N and 3.11°E to identify contrails with a two-minutes time-resolution.
- Aircraft position records every second with an ADS-B system within a 50-km radius from the camera.
- Aerosols and clouds measurements by the Rayleigh-Mie and Raman COPLid LIDAR (located at 63 m of the camera) at 355 nm, 532 nm and 1064 nm (backscatter and depolarization) and water vapor measurements at 407 nm at 1-minute time resolution and 7.5 m vertical resolution (Peyrin et al., 2023).

3 | ERA5 and M10 relative humidity comparison above Nîmes (France)

- Monthly-mean vertical profiles of relative humidity (RH) provided by M10 (MeteoFrance) and ERA5 **(Fig. 1)** indicate that the mean RH from ERA5 (ECMWF) is lower than that from M10, with slight differences observed between noon (bottom figures) and midnight (top figures), and between January 2022 (left figures) and July 2022 (right figures).
- The distributions of relative humidity values in the zone of potential cirrus/contrail formation between 200-300 hPa **(Fig. 2)** show that at the daytime ERA5 (ECMWF) clearly presents more wet situations than radiosondes, between 50-100%

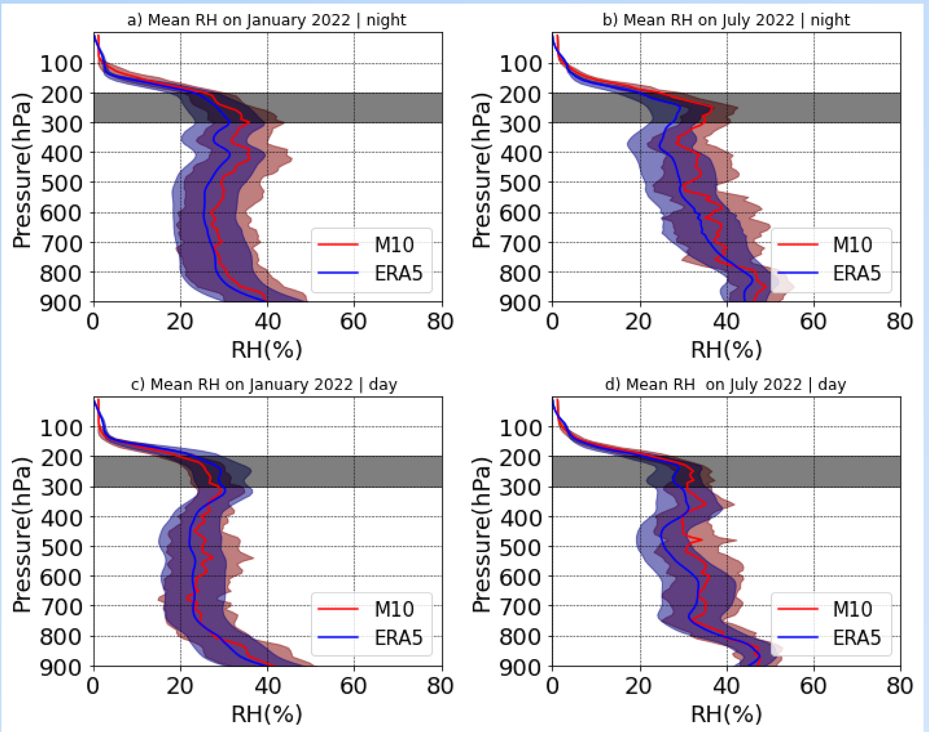

Fig 1 : Monthly mean vertical profiles of relative humidity provided by M10(MeteoFrance) (red) and ERA5(ECMWF)(blue) for Nîmes site.

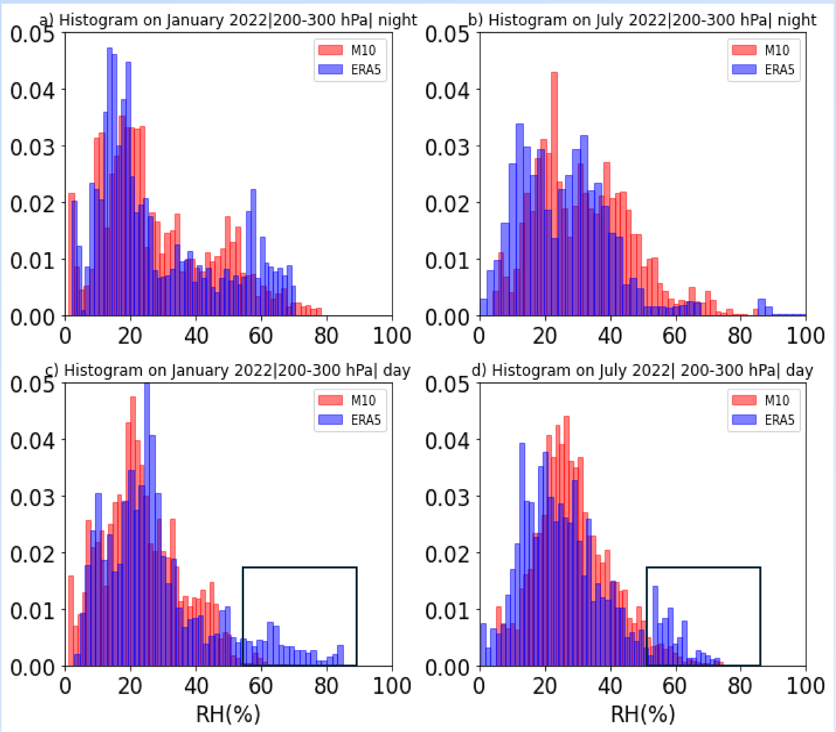

Fig 2 : Distribution of RH for ERA5(ECMWF)(blue) and M10(MeteoFrance) (red) for the month of July 2022 at 200-300hPa) for Nîmes site.

4 | ERA5 and M10 relative humidity comparison above Trappes (France)

- Monthly-mean vertical profiles of relative humidity (RH) provided by M10 (MeteoFrance), M10 (GRUAN), and ERA5 **(Fig. 3)** indicate that ERA5's mean RH is lower than that of M10 (MeteoFrance), and M10 (MeteoFrance)'s mean RH is lower than that of M10 (GRUAN). There is a slight variation between noon (bottom figures) and midnight (top figures), as well as between January 2022 (left figures) and July 2022 (right figures).
- The distributions of relative humidity values in the zone of potential cirrus/contrail formation between 200-300 hPa **(Fig. 4)** show that M10 (GRUAN) presents more wet situations than ERA5(ECMWF) and M10(MeteoFrance) between 50-100%.

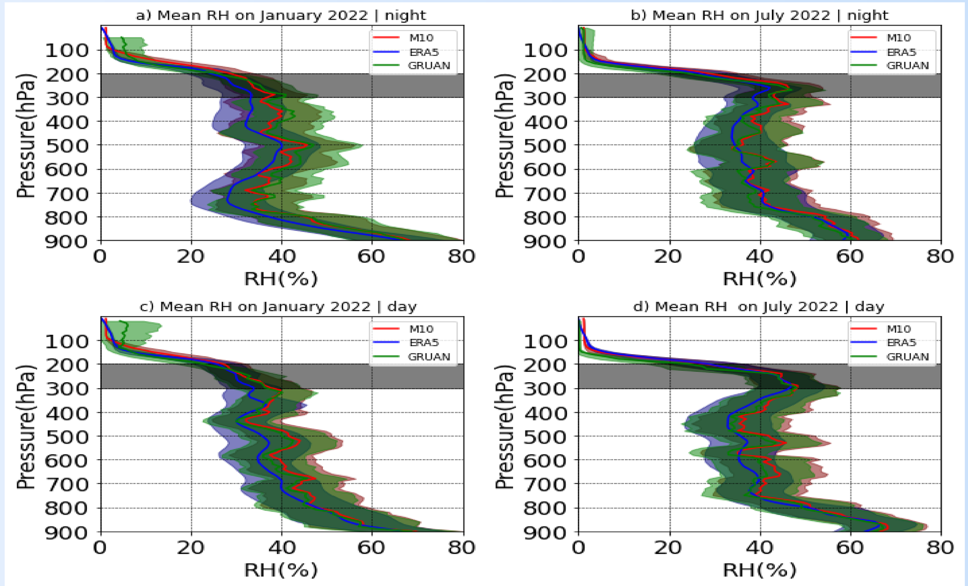

Fig 3 Monthly mean vertical profiles of relative humidity provided by M10(MeteoFrance)(red) , ERA5 (blue) and M10(GRUAN)(green) for Trappes site.

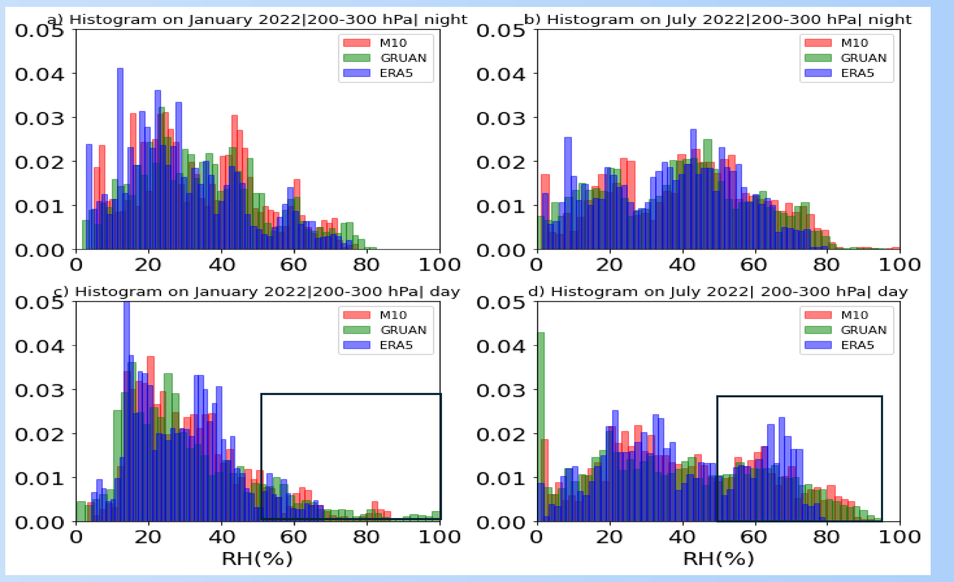

Fig 4 : Distribution of RH for ERA5 (blue) and M10(MeteoFrance) (red) and M10(GRUAN)(green) for the month of July 2022 at 200-300hPa.

5 | Contrail observed over Clermont-Ferrand in June 2, 2023

To investigate contrail formation observed over Clermont-Ferrand (France), contrails are first identified on the full-sky camera **(Fig 5).** Then the aircraft responsible of the contrail is identified with the ADS-B system. Relative humidity is provided by ERA5 (ECMWF) at the altitude of the aircraft **(Fig 6)**. LIDAR measurements provide backscatter signals as a function of time and altitude and allows to determine the contrail extension **(Fig 7).**

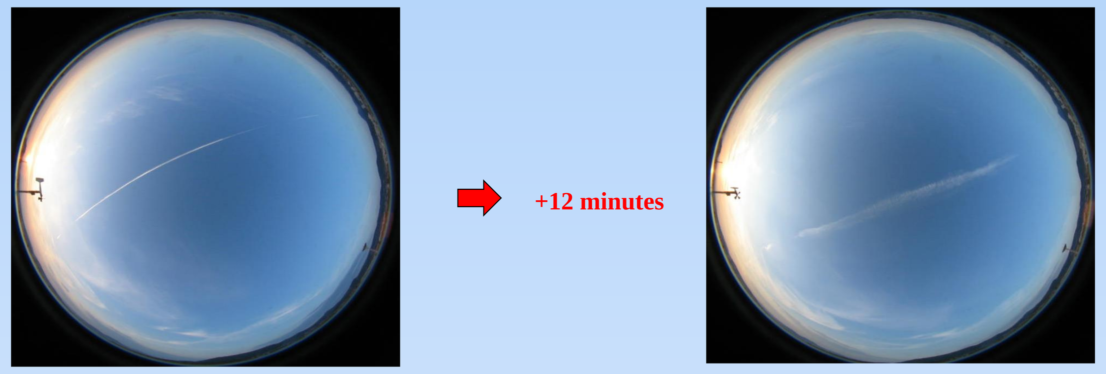

Fig 5 : Full-sky camera images taken at 4:20 UTC (left) and at 4:32 UTC(right)

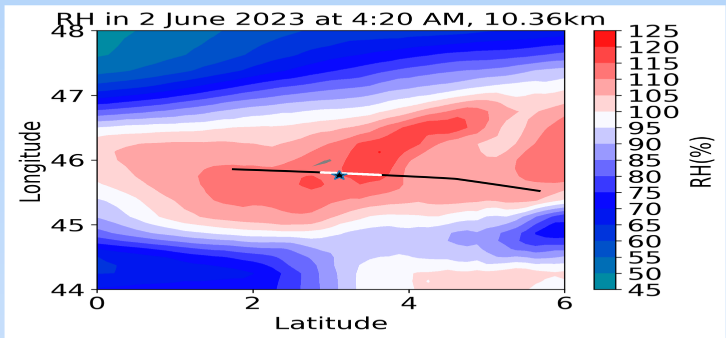

Fig 6 : ERA-5 relative humidity field around Clermont-Ferrand interpolated at 4:20 UTC. Aircraft trajectory in black and period of camera observation in white.

Aircraft	Engine	Altitude	Camera	LIDAR	RH	T
Boeing 777-224	twin-engine	10363 m	4:20 AM	4:32 AM	120%	217 K
Boeing 777-2DZLR	twin-engine	10363 m	4:50 AM	5:14 AM	116%	217K
Boeing 777- 36NER	twin-engine	10363 m	5:04 AM	5:23 AM	116%	217K
Boeing 777- 31HER	twin-engine	9753 m	5:30 AM	5:42 AM	110%	222 K
Boeing 777- 31HER	twin-engine	10363 m	5:32 AM	5:50 AM	113%	217K
Boeing 787-9DRL- 37174	twin-engine	10969 m	4:52 AM		95%	214K
Airbus A380-842	four-engine	11582 m	4:52 AM		75%	213K
Airbus A350-1041	twin-engine	11582 m	4:58 AM		75%	213 K
Boeing 787-9 DRL- 39657	twin-engine	10966 m	6:04 AM		92%	214K

Tab 1 : Summary of cases studied on June 2, 2023, at Clermont-Ferrand, Time in UTC

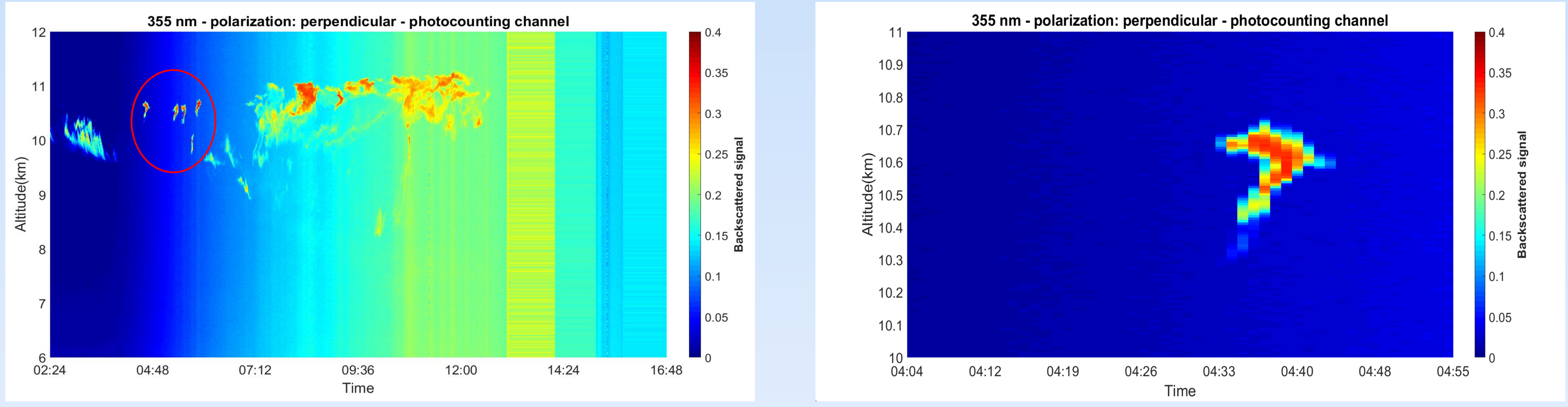

Fig 7 : Lidar backscattered polarized signal at 355 nm for the 2nd of June 2023 (left) and zoom on the contrail signature observed on (right). The five persistent contrails listed in **table 1** are circled in red.

- For the first case studied, ERA5 indicates a relative humidity of 120 % at the location of the contrail **(Fig 6).** Twelve minutes after its formation, the contrail has a horizontal extension of 132 m and a vertical extension of 340 m observed by the LIDAR **(Fig 7b).**
- During this day, persistent contrails occur when aircraft are between 9.7-10.4 km altitude and the relative humidity (RH) is ≥ 110%. Non-persistent contrails occur when aircrafts are between 10.9-11.6 km altitude and the RH is ≤ 95% **(Tab 1)**.

6 | Conclusion and outlook

- At all pressure levels, ERA5 relative humidity (RH) measurements show lower monthly-average values compared to M10(MeteoFrance, GRUAN) for both site analyses.
- Between the 300 and 200 hPa pressure levels, ERA5 relative humidity (RH) reanalysis show higher monthly wet values compared to M10(MeteoFrance) analysis, ranging between 50-100% for the Nîmes site. For the Trappes site, M10(MeteoFrance) and M10(GRUAN) relative humidity (RH) measurements show higher monthly wet values compared to ERA5 analysis, ranging between 50-100%.
- This result need to be confirmed with an extended data series, and the study should encompass all months over a prolonged period to ascertain if there are significant differences between night and day, summer and winter, and across multiple years, as indicated by these preliminary findings
- ERA5 shows that there is supersaturation every time a persistent contrail occurs in the cases studied on June 2, 2023. It also shows that there is no supersaturation when a non-persistent contrail forms **(Tab 1).**
- The Lidar can identify contrails, allowing for the determination of their horizontal and vertical extent shortly after their formations **(Fig 7).**

Combination of these instruments on a larger dataset will allow to investigate contrails formation, extend and optical properties.

References

Kärcher et al., (2018). Formation and radiative forcing of contrail cirrus. Nature communications, 9(1), 1824.
Heymsfield et al., (2017). Cirrus clouds. Meteorological Monographs, 58, 2-1.
Peyrin et al. (2023). Original and Low-Cost ADS-B System to Fulfill Air Traffic Safety Obligations during High Power LIDAR Operation. Sensors, 23(6),2899
Dupont et al., (2020). Characterization and corrections of relative humidity measurement from Meteomodem M10 radiosondes at midlatitude stations. Journal of Atmospheric and Oceanic Technology, 37(5), 857-871.

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