Climaviation

Action de recherche sur **Aviation** et **Climat**

Demonstrating the capability of an instrumental synergy to characterize contrails at the SIRTA observatory

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RÉPUBLIQUE FRANÇAISE — Liberté Égalité Fraternité
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Context

- Two impacts of air traffic on global warming (CO2 and non-CO2)

- Difficulty of the Numerical Weather Prediction models to simulate the contrails (ISSR):
  - Geometry, optical and microphysical properties
  - Large uncertainties in quantifying their radiative effect (Lee et al., 2021)

- Quantification of **Non-CO2 effect** of aviation (Climaviation project, https://climaviation.fr/)

- Workpackage 4 aiming to document contrails based on in-situ and remote sensing measurements

(@Cheikh DIONE (IPSL-SIRTA))

Objective

- Demonstrate the capability of the instrumental synergy at the **SIRTA Observatory** in **Palaiseau (Ile-de-France, France)** to document contrails,

- Identify a case study of contrail outbreaks with isolated contrails, in order to further estimate their **optical, microphysical, and macrophysical characteristics**

SIRTA Observatory, Paris

Location

- 20 km Southwestern Paris @Palaiseau
- Sub-urban plateau

Air corridor

Large occurrence of contrails in all seasons

(@ Marc-Antoine Drouin (LMD-SIRTA))

More than 150 meteorological variables collected continuously

- In-situ and remote sensing measurements (cloud Radars, Lidars, instrumented mast of 50 m height, sun photometer, etc.)
- An ACTRIS Centre for Cloud Remote Sensing (CCRES) – calibration of Radars

Instrumental Synergy to document contrails

Lidar IPRAL

- 6 wavelengths (355, 387, 408, 532, 607 and 1064 nm)
- **Depolarization (355 nm)** and extinction coefficient
- vertical resolution **15 m - range 15 m - 60 km a.g.l**
- Temporal resolution **30 s**
- Estimate the geometrical and optical characteristics of cirrus/contrails

Trappes Radiosoundings

- 13 km from the SIRTA
- Vertical resolution: range 2 m -25 km
- Time resolution: 11:00 and 23:00 UTC
- Variables : **T, RH, wind, pressure**
- Estimate the ice supersaturation regions (ISSR) (*Schmidt-Appleman criteria*) β_m
- contrail optical thickness (Lidar) –

Sky Camera EKO

- Total sky 360°
- Temporal resolution : 2 min
- Spatial resolution: range 1 km radius
- Identification of contrails

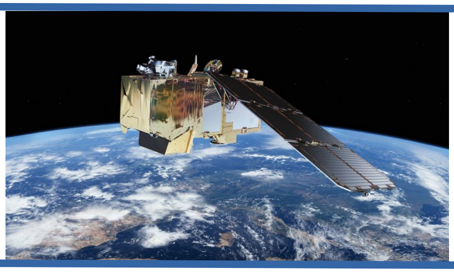
ADS-B

- Flight altitude – altitude of contrails formation
- Flight identification

Sentinel-2

Band 10 – SWIR around 1375 nm

- Occurrence of contrails



Cimel CE-318 sunphotometer (340 - 1020 nm)

- Time resolution: variable
- Aerosol Optical Depth (AOD) – cloud optical depth
- Calibrate the IPRAL effective Lidar ratio

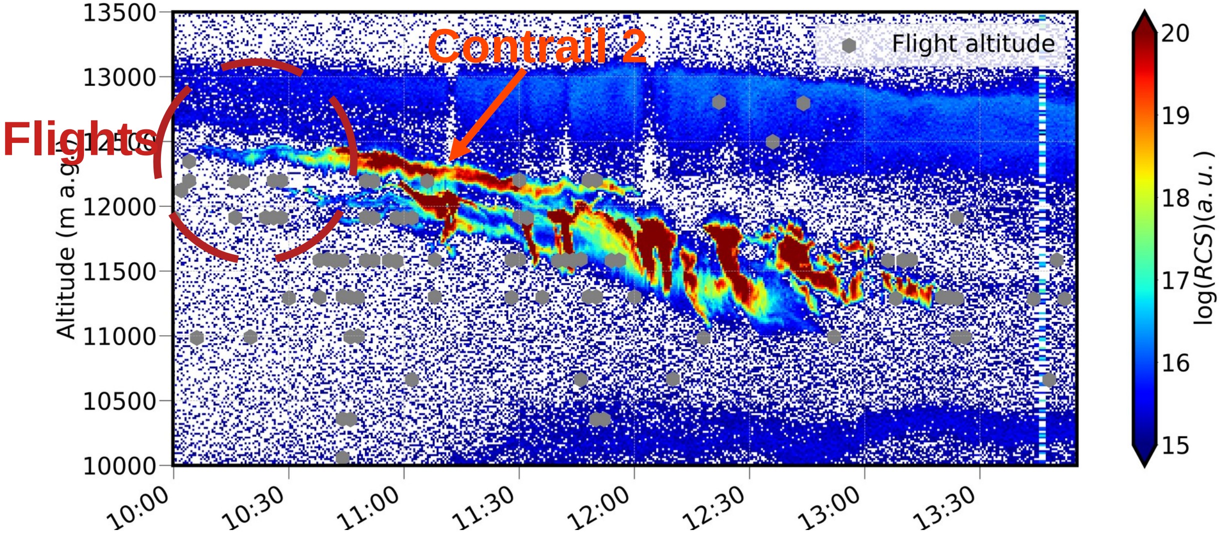
- **ReOBS – https://reobs.aeris-data.fr/**
  - **Near surface radiation fluxes**
    - Contrail radiative forcing (CRF)

Contrails identification

1. IPRAL

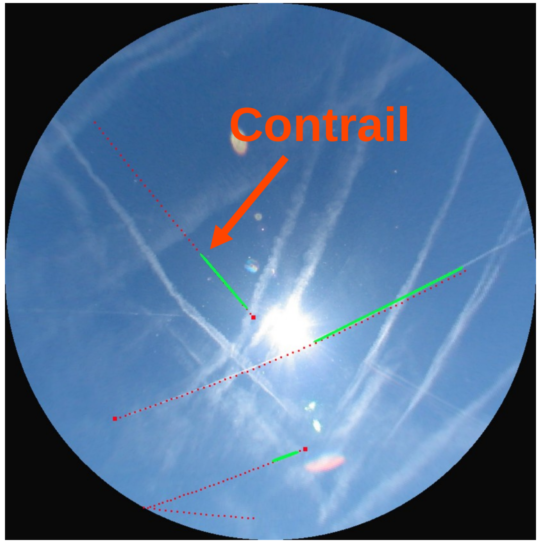
- Explore the 1064 nm channel – Lidar backscatter (RCS)
- Coherent structures in high levels [9-13 km a.g.l]
- Link the structures with the flight altitudes and the occurrence of the contrail in the Sky Camera

5th July 2019



2. Sky Camera EKO

- SIRTA quicklooks
- https://sirta.ipsl.polytechnique.fr/sirta/data/quicklooks/
- Complex Algorithm combining AI
- Formation of contrails – lifetime (from formation to the detection by the lidar)
- Association between contrails & flight altitudes



Gourgue et al.2025

Contrails identification

Sentinel-2

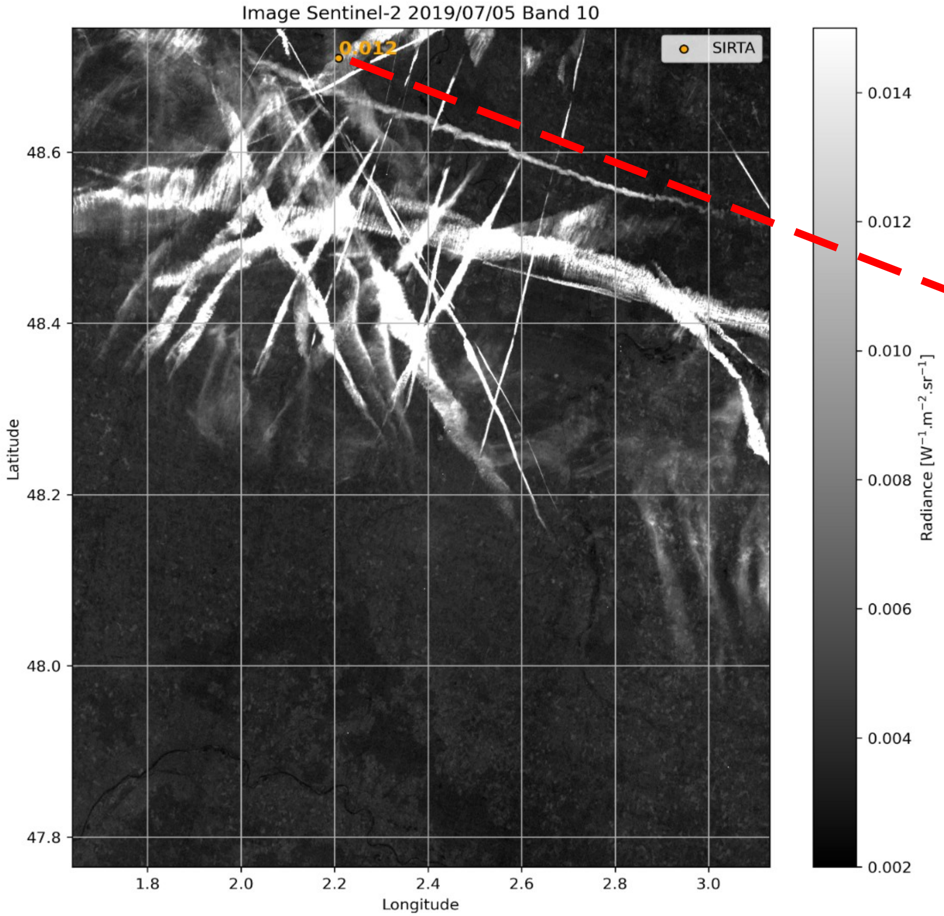


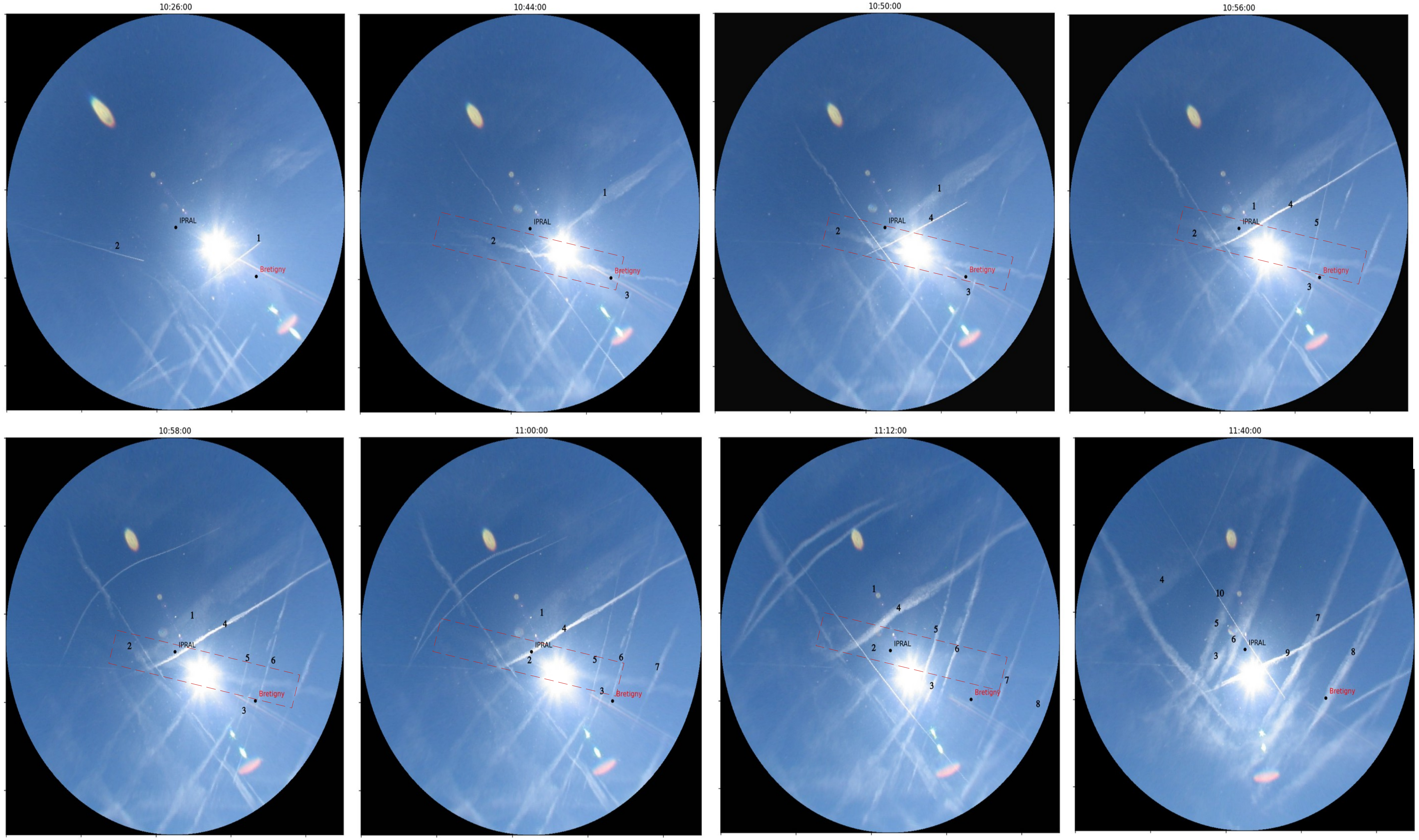
Image Sentinel-2 @Karine Caillault ONERA

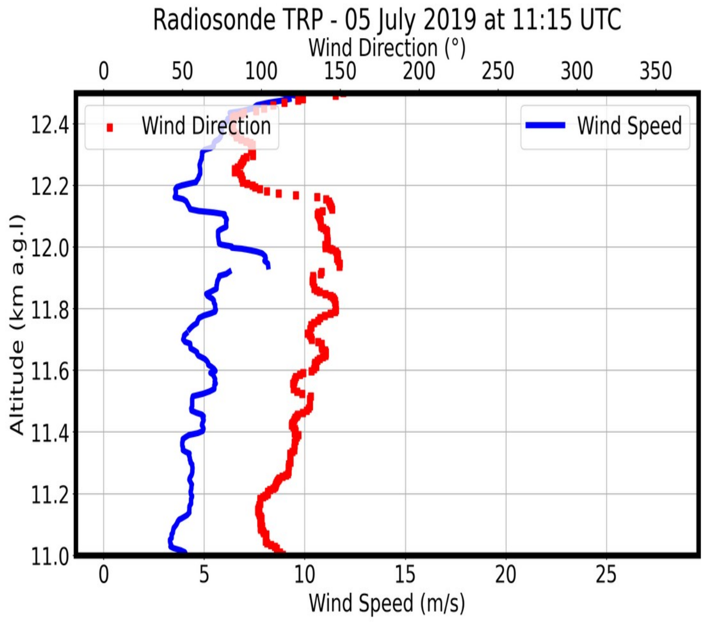
Sky-Camera at 10:50 UTC

- Consistency between satellite and Sky camera
- A large contrail outbreak

Contrail occurrence and evolution

Evolution of contrails



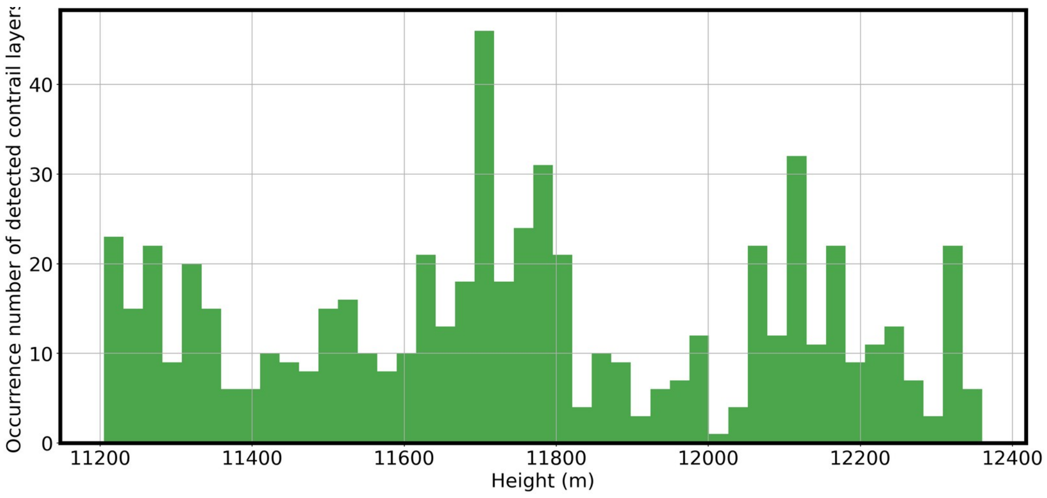


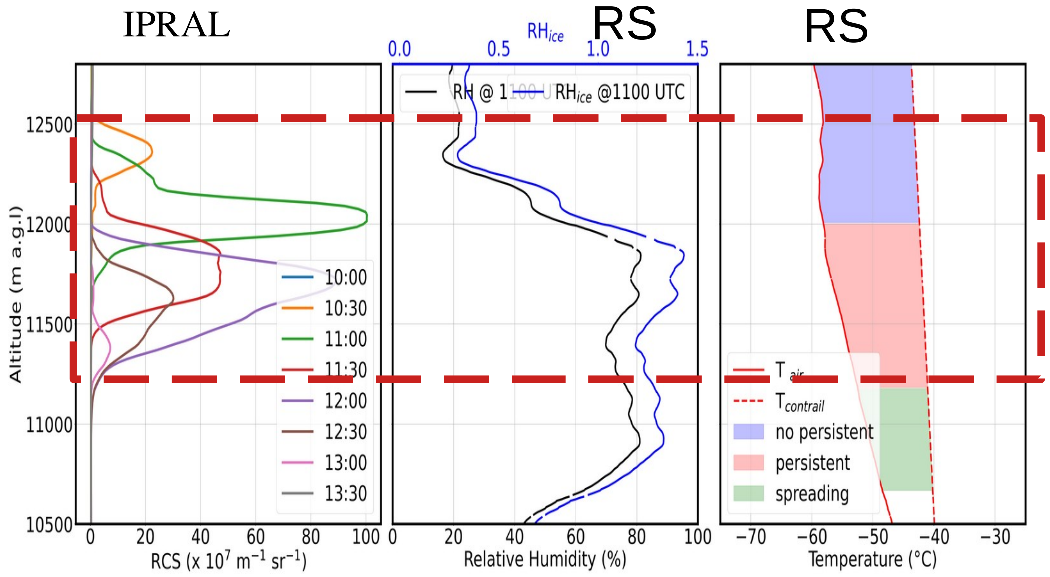
Contrails move // Wind direction – southeasterly

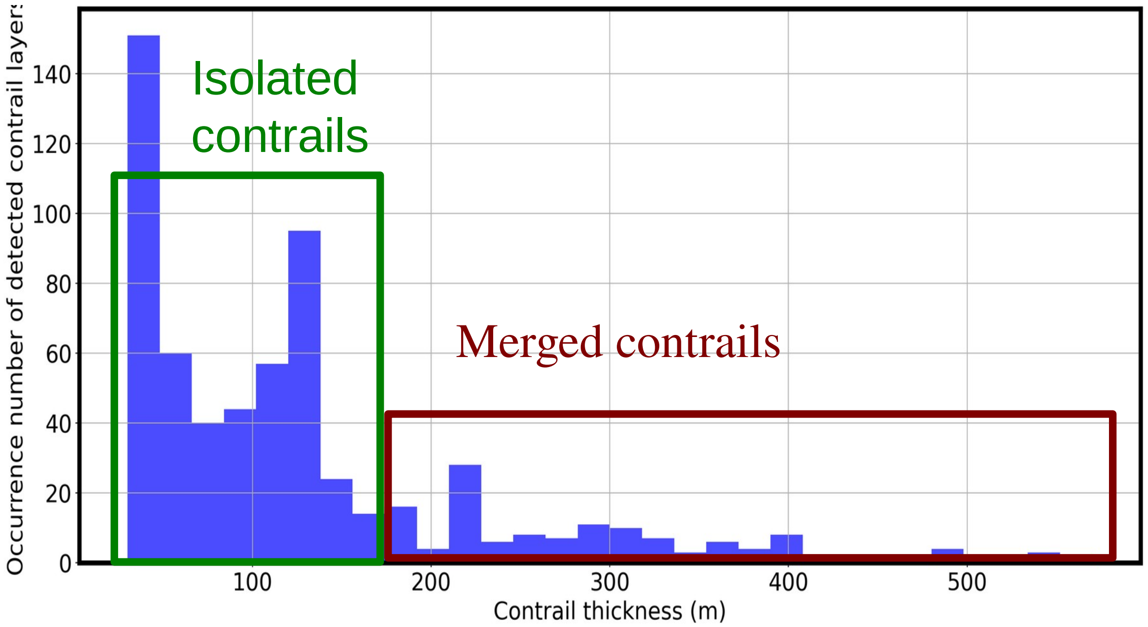
Contrail 2 is relatively stable & parallel to the wind direction

Contrail geometrical characteristics estimation

Contrail base height (CBH)







- Large ISSR [11200 – 12400 m] is associated with low winds, which allowing contrails to persistent.
- Large variability in the geometrical characteristics of contrails (young, old and merged)

Contrail optical thickness estimation (COT)

Particular Integration method

5 July 2019

Optical depth $\tau_c = \int_{CBH}^{CTH} \alpha_c(z')dz'$

α_c *the extinction coefficient*

Lidar Ratio $LR(z) = \alpha_c(z)/\beta_c(z)$

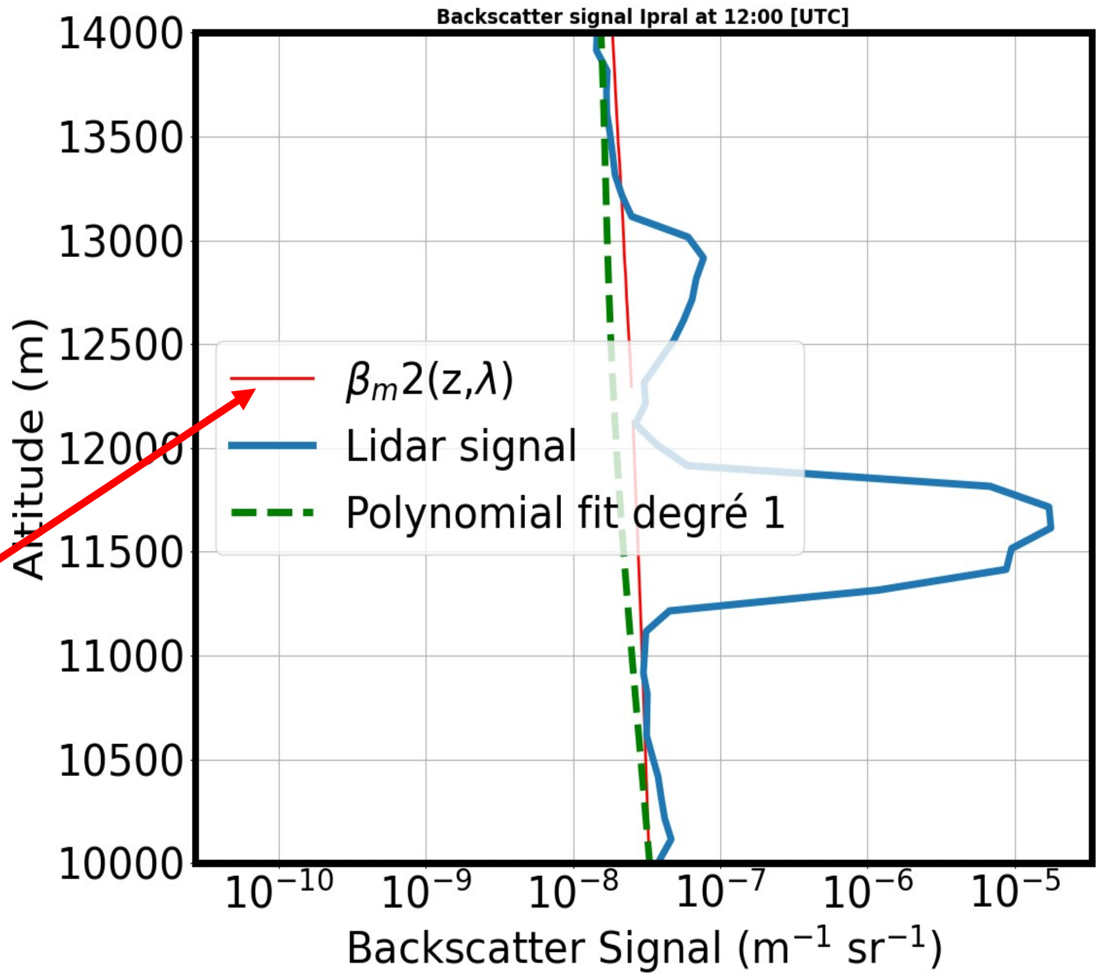
$$\tau_c = \int_{CBH}^{CTH} LR(z')\beta_c(z')dz'$$

Backscatter ratio $R(z) = 1 + \frac{\beta_c(z)}{\beta_m(z)}$

$$\tau_c = LReff . \int_{CBH}^{CTH} [R(z)-1]\beta_m(z')dz'$$

$$\beta_m(z) = K.\sigma_m.\frac{Na}{M_{air}}.\frac{P(z)}{R_{air}T(z)}$$

RS @ 11:00 UTC



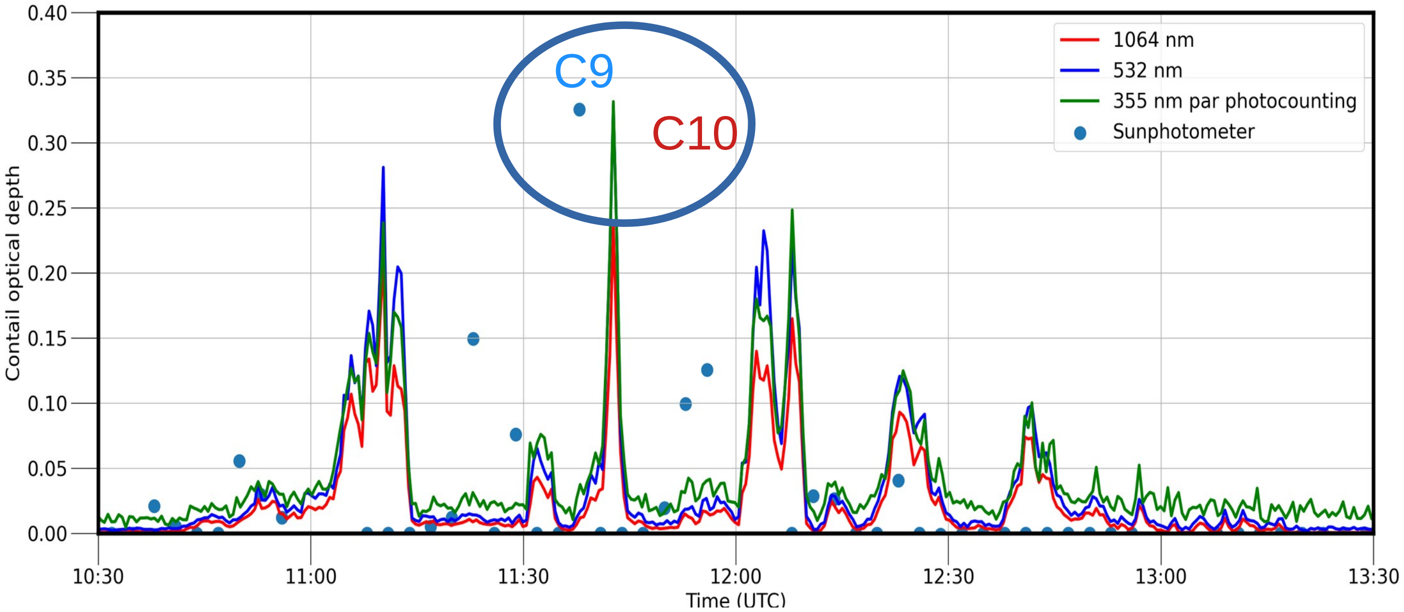
Contrail optical thickness estimation (COT)

Effective lidar ratio validation

AOD (sun photometer) + Lidar

- Contrails C9 and C10 observed around the zenith

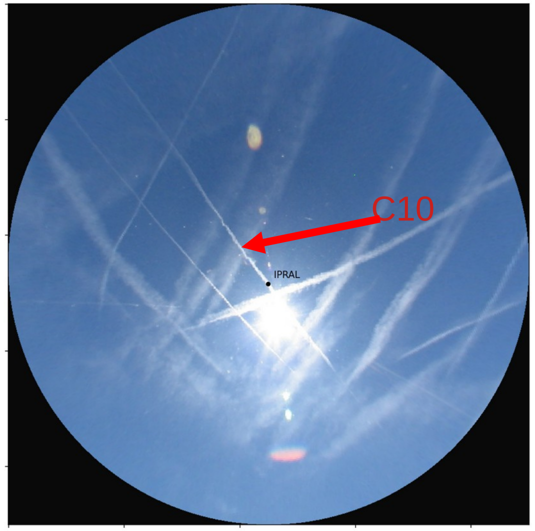
Sensitivity test on the **LReff** around the zenith
LReff = 18



Max COT = 0.33

11:38

11:42



Consistency between the sun photometer and the Lidar on contrail optical depth

Contrail microphysical characteristics

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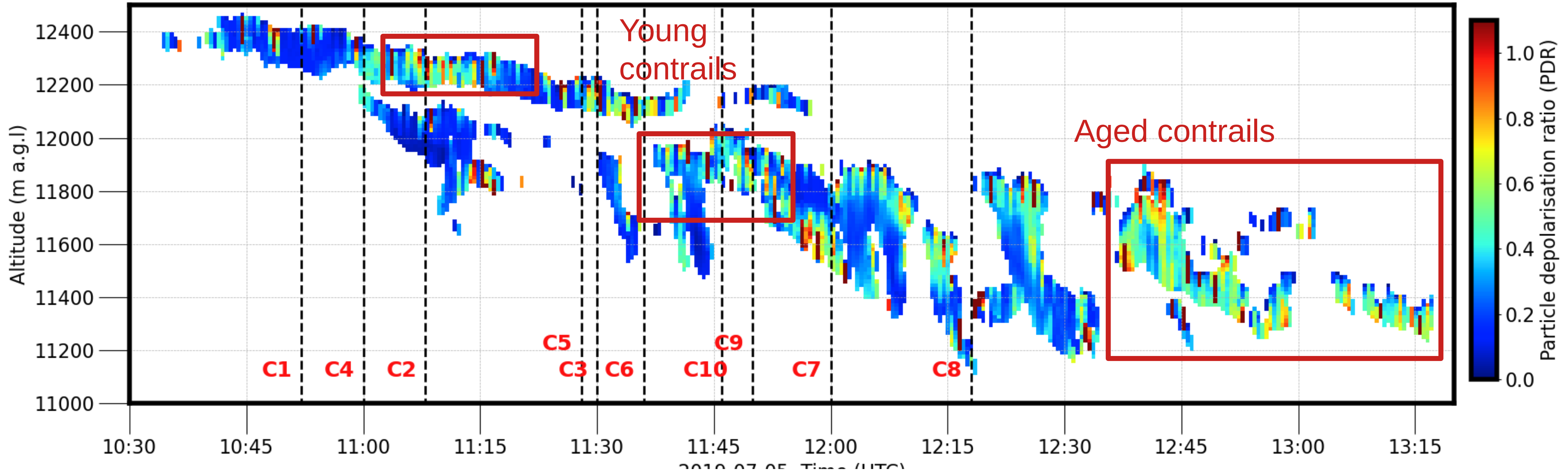
Particle depolarisation ratio (PDR) @ 355 nm Photocounting



- Variability in PDR in the contrail
- No-spherical ice crystal in the contrail

Identified flights generating contrail

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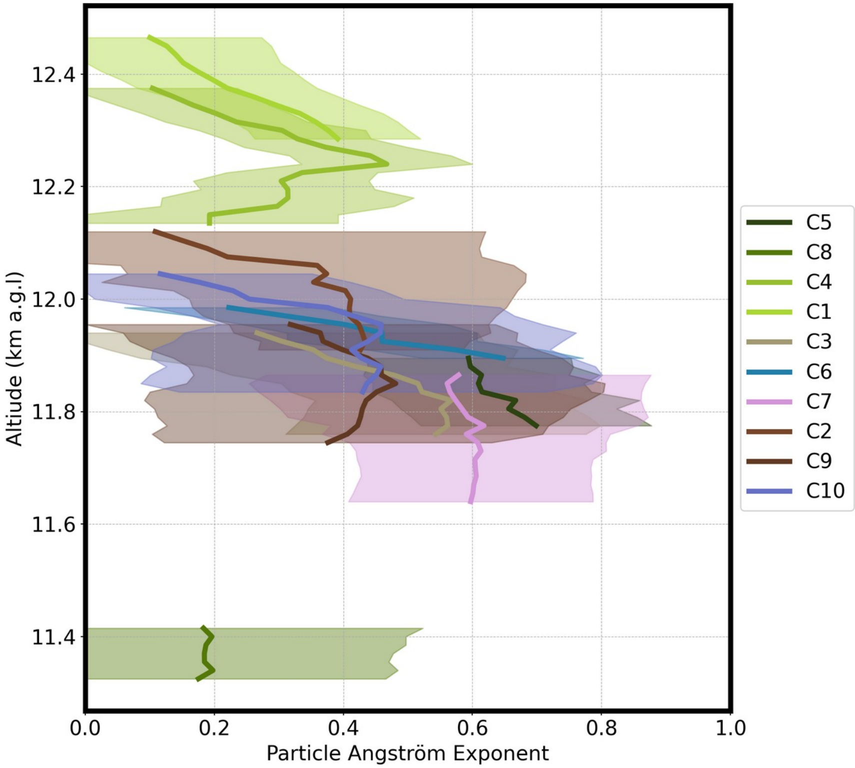
Contrail number	Flight Id	Aircraft Company ID	Aircraft type	Aircraft registration	Number of engines	Engine type	Departure	Destination	Flight altitude (m)
C1	RYR90ED	4CAFB5	Boeing 737-800	EI-GSI	2	CFM56-7B	Faro Airport	Berlin-Tegel Otto Lilienthal Airport	11913
C2	EDW25	4B1900	Airbus A340-313	HB-JME	4	CFM56-5C4/P	Aeropuerto Internacional de Cancùn	Zürich Airport	12197
C3	IBK7MA	4CA7E9	Boeing 737-800	EI-FVL	2	CFM56-7B	Copenhagen Kastrup Airport	Malaga-Costa del Sol Airport	11581
C4	RYR44W	4D21ED	Boeing 737-800	9H-QAE	2	CFM56-7B26	Cologne Bonn Airport	Vitoria Airport	12193
C5	SAS6351	4CACB6	Airbus A320neo	EI-SIA	2	CFM LEAP-1A26	Oslo Airport, Gardermoen	Malaga-Costa del Sol Airport	11582
C6	NAX9ER	47878E	Boeing 737-8JP	LN-NIA	2	CFM56-7B	Stockholm-Arlanda Airport	Bordeaux-Marignac Airport	11579
C7	VLG3961	34258F	Airbus A320-216	EC-KDX	2	CFM56-5B4/P	Bilbao Airport	Berlin-Tegel Otto Lilienthal Airport	11301
C8	GAC699V	44052D	Cessna 510 Citation Mustang	OE-FHK	2	PW615F	//	//	10988
C9	BCS6824	3C70B3	Boeing 757-200	D-ALES	2	Pratt & Whitney PW2000	Leipzig/Halle Airport	Adolfo Suárez Madrid-Barajas Airport	11588
C10	//	//	//	//	//	//	//	//	//

From cleanest to dirtiest engine

C5 > C8 > C4 > C1 > C3 > C6 > C7 > C2 > C9 & ?? C10

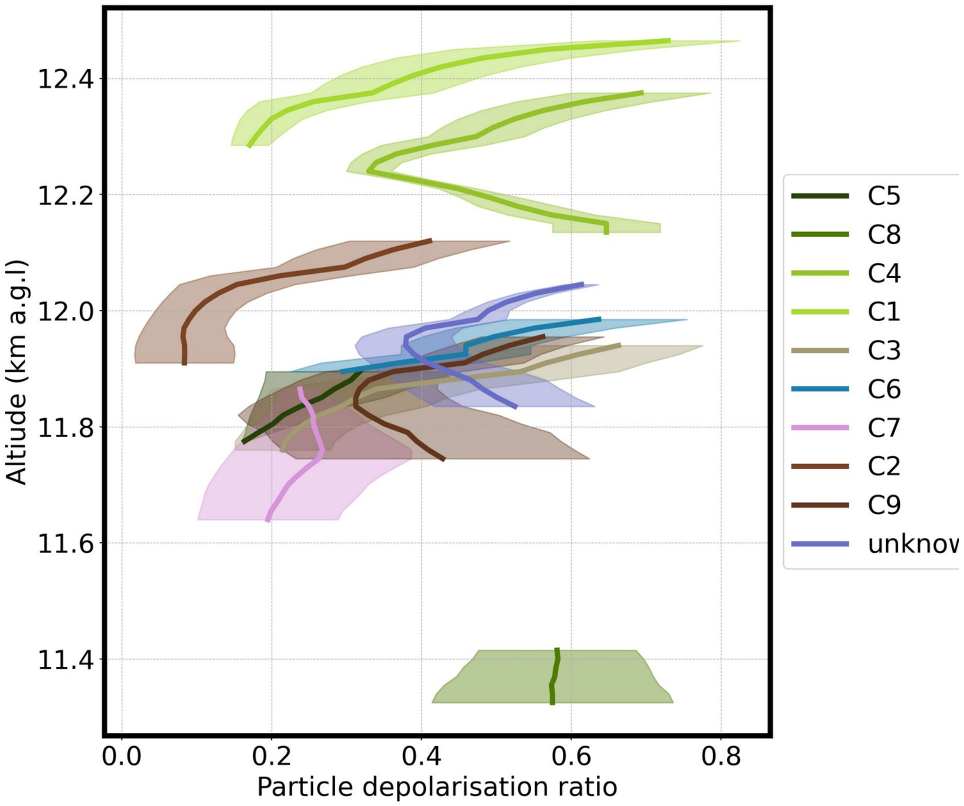
Contrail microphysical characteristics

Vertical profile of Angström Exponent (AE)
Channels: 1064 nm & 532 nm



AE (4 min average)

Particle depolarisation ratio (PDR)
Channel: 355 nm



Contrail number	Duration from formation time
C5	34
C8	64
C4	10
C1	26
C3	46
C6	38
C7	52
C2	44
C9	22
C10	6

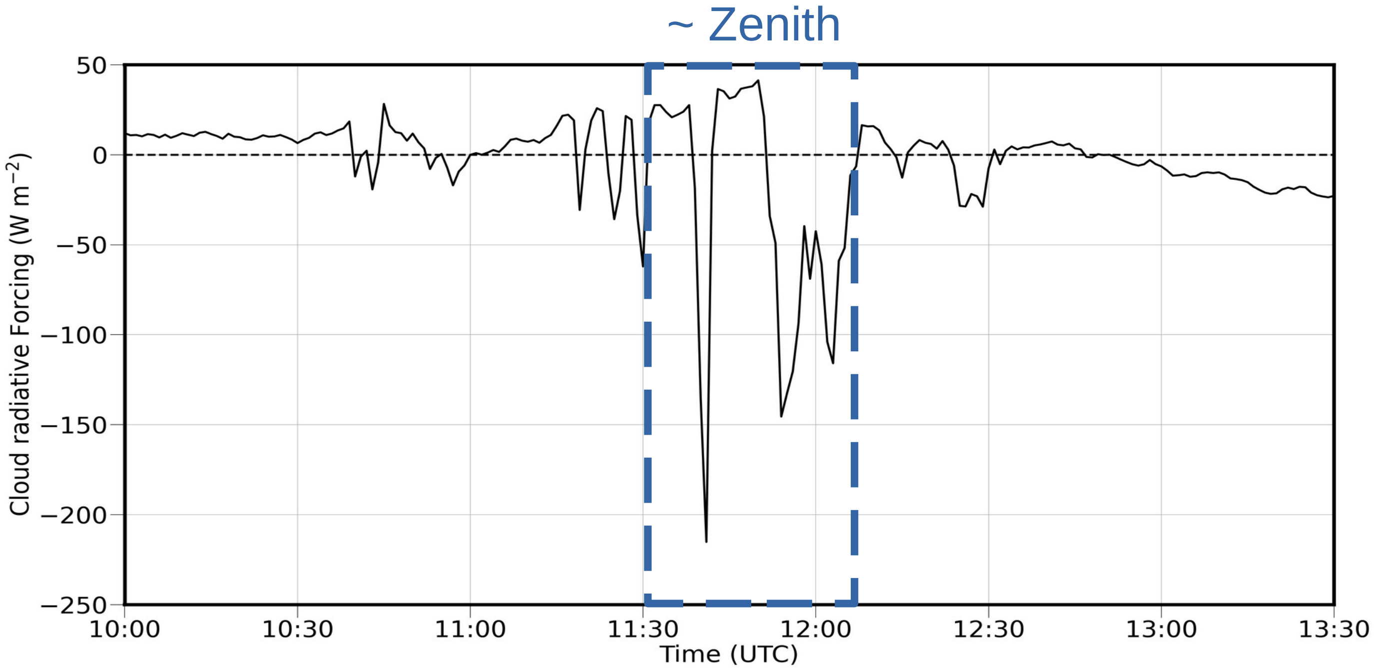
- Clear engines – low AE and high PDR … high shape
- dirtiest engines – high AE and low PDR … low shape

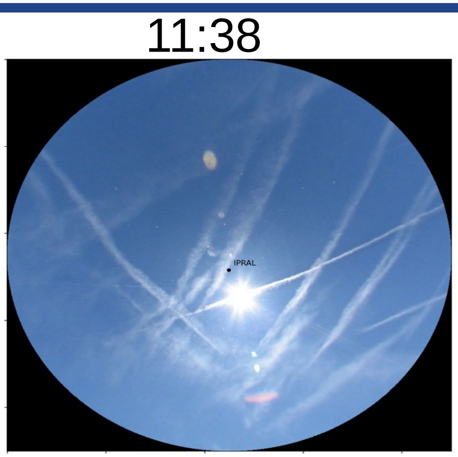
Contrail radiative forcing

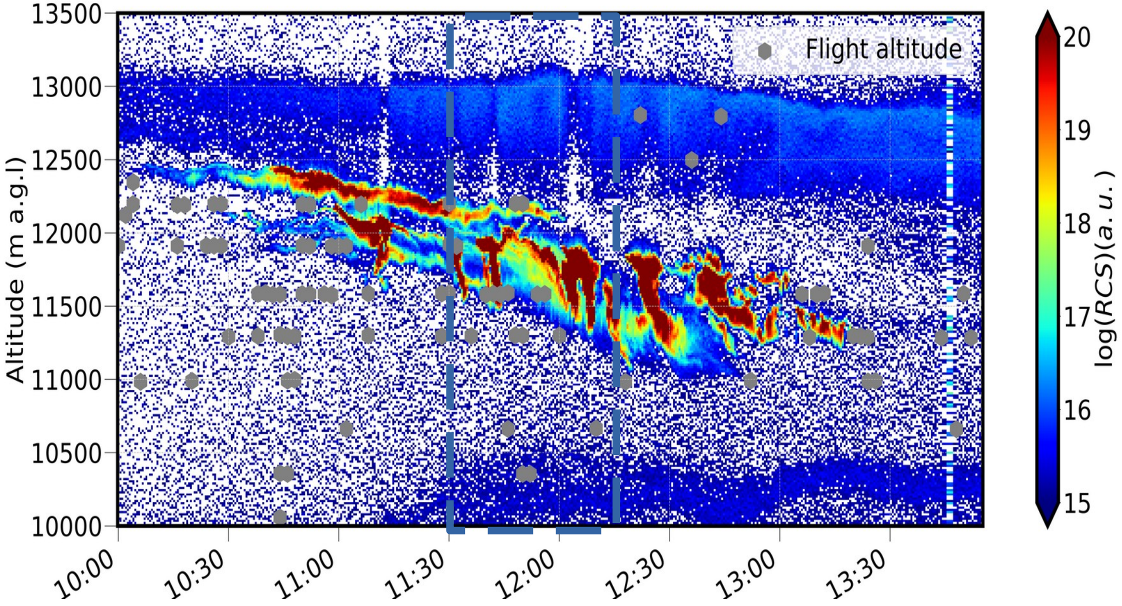
Cloud Radiative Forcing

$CRF = (SW_{cloud} - SW_{clear}) + (LW_{cloud} - LW_{clear})$

SW_{clear} and LW_{clear} estimated using *Long and Turner (2008)*







Cooling effect on average

Max CRF -218 W m^{-2}

Summary and Future works

- There is large variability in contrail geometrical characteristics (thickness ranging from 90 to 500 m), linked to their age and the level at which they form (i.e. atmospheric conditions – ISSR).
- The optical depth of the contrail, as estimated by the particular integrated method is consistent with the AOD of the sun photometer – validation of the lidar effective ratio
- Variability in contrail optical depth and depolarization ratio between young and aged contrails
- The shape of ice crystals within contrails appears to be correlated with the level of pollutant emissions from aircraft engines
- The maximum optical depth of the isolated contrail is around 0.17, which indicates a semi-transparent cloud – cooling effect (-218 W m^{-2}) at surface
- The Lidar is an effective instrument for monitoring locally contrails and can be used for contrail avoidance nowcasting.

- Simulate the radiative forcing of contrails using the MATISSE model developed by ONERA
- Conduct a statistical analysis to document the radiative impact of contrails over the SIRTA Observatory

Thank you for your attention !
Questions ?

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