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Climate impact assessment using ATMLab
Preliminary results

Antoine JOULIA, Judicaël BEDOUET, Claire SARRAT, Céline PARZANI, Thomas DUBOT
ONERA, Université de Toulouse

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Outline

- ATMLab
  - Overview
  - Simulation services
- Simulation services validation
  - Fuel consumption
  - Contrails detection
- Conclusion

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ATMLab

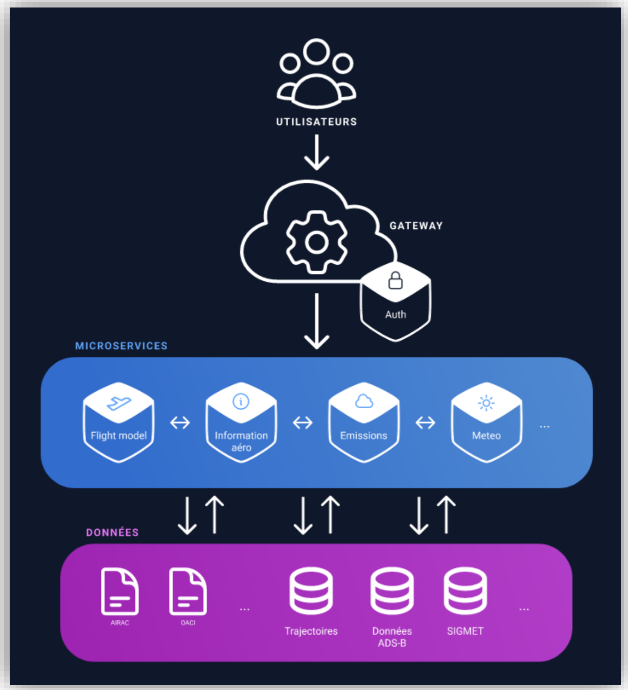
ATMLab overview

- Support for Onera ATM-related activities
- Set of hardware and software tools
- Hardware
  - ADS-B antennae
  - Simulation/demonstration facilities

ATMLab overview

- Software
  - Simulation
  - Visualization

- Microservices architecture



Simulation services

Meteorological data provider

- Integration of weather variables
  - pressure, temperature, wind, humidity…
- Data from

Provider	Météo France	ECMWF
Model	ARPEGE & AROME	ERA5 (re-analysis data set)
Horizontal resolution	0.025º (over France) 0.1º (over Europe) 0.25º (global scale)	0.25º
Vertical resolution	24 vertical levels from 1000hPa to 100hPa	37 vertical levels from 1000hPa to 1hPa
Forecast frequency	6 hours from 0 to 114 h	N/A

Simulation services

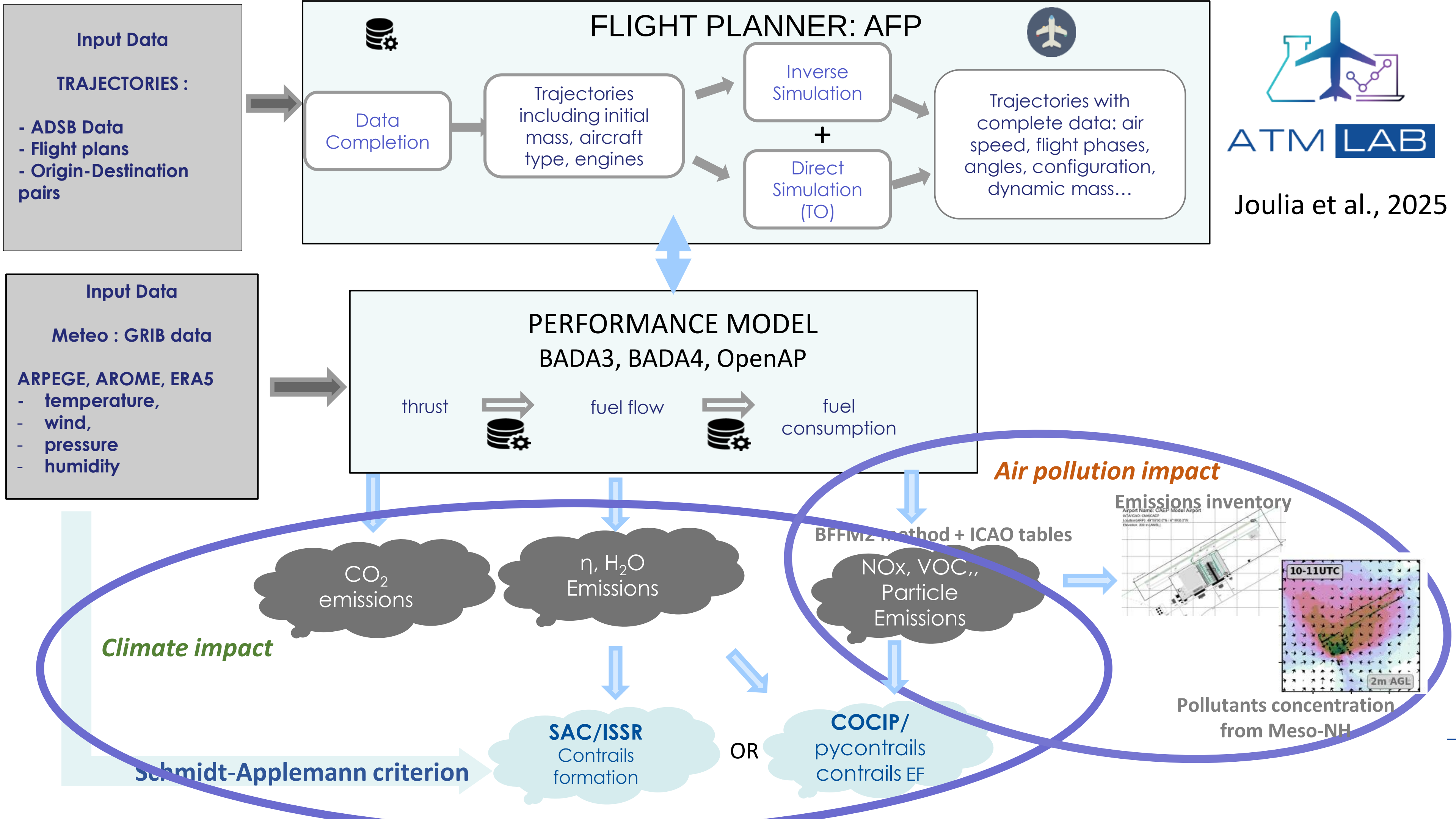
Flight simulator

- Simulation methods
  - Direct simulation: state vectors computed from flight plans, or from departure/arrival airports pairs
  - Inverse simulation: real flight data analyzed to determine state vectors (ADS-B data, radar stream)
- Performance models
  - Necessary to estimate drag and fuel flow → fuel consumption
  - Multiple models available
    - **BADA**: **v3** & v4
    - OpenAP

Simulation services

Emissions and contrails

- Emissions
  - Emissions Indices of CO_2, H_2O and SO_x
  - NO_x, CO and unburned hydrocarbons, particles: BFFM2, based on
    - ICAO engine emissions databank (turbofans)
    - FOI database (turboprops)
- Contrails
  - Vapor condensation on soot particles emitted from engine exhaust
  - Persistent or non-persistent
  - Major non-CO_2 climate impact
  - Depends on local atmospheric conditions (ISSR) and Schmidt-Appleman Criterion (SAC)



Joulia et al., 2025

Simulation services validation

Fuel consumption

Methodology

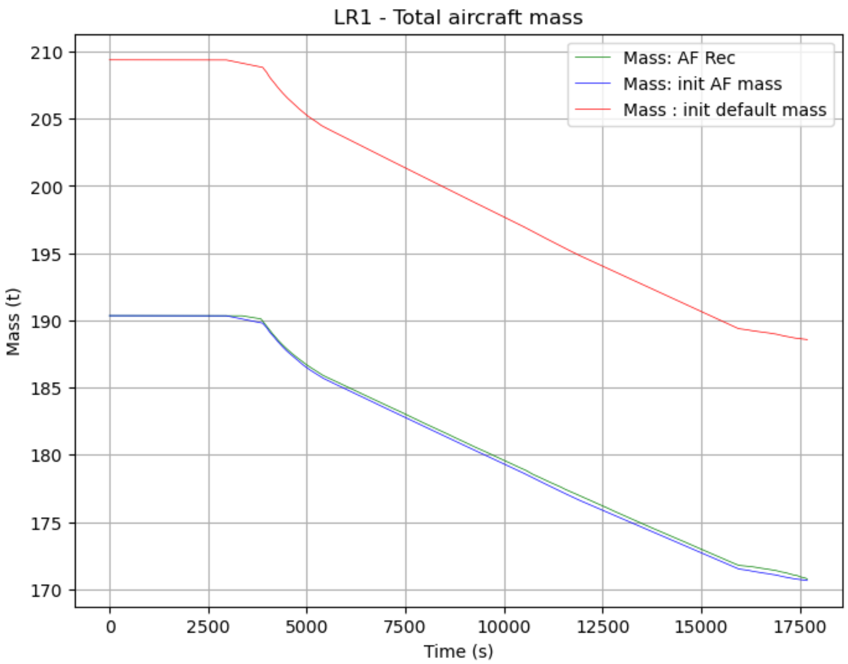
- Quick Access Recorder data provided by Air France
- Comparison with simulation results (inverse simulation, BADA3 performance model)
  - Aircraft mass
  - Fuel flow
  - Total fuel consumption and CO_2 emissions
- Two sets of simulations with different aircraft masses initialization
  - BADA reference mass
  - QAR mass

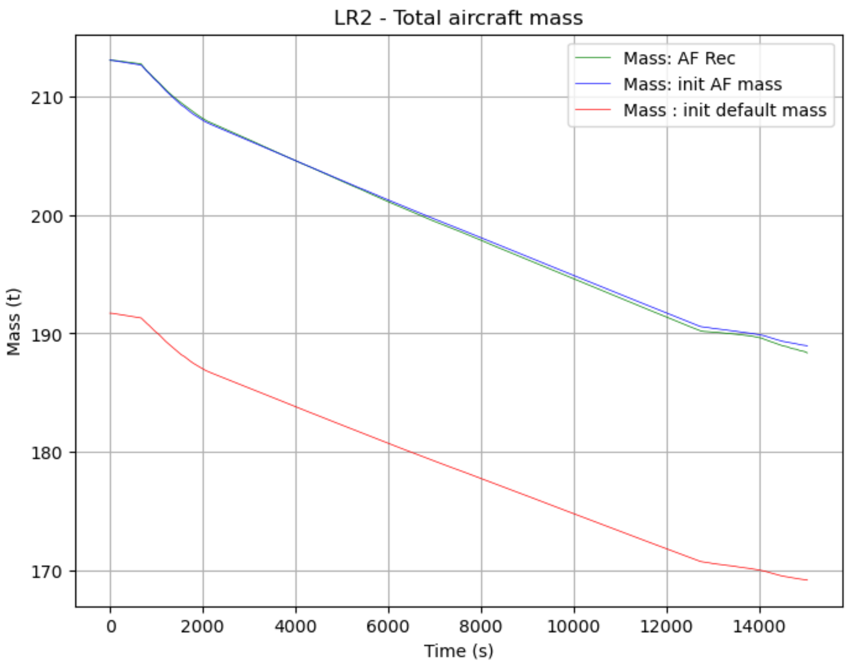
Data input

- Trajectories set
  - 6 trajectories
    - 6 different aircraft types
    - 3 short-range
    - 3 long-range

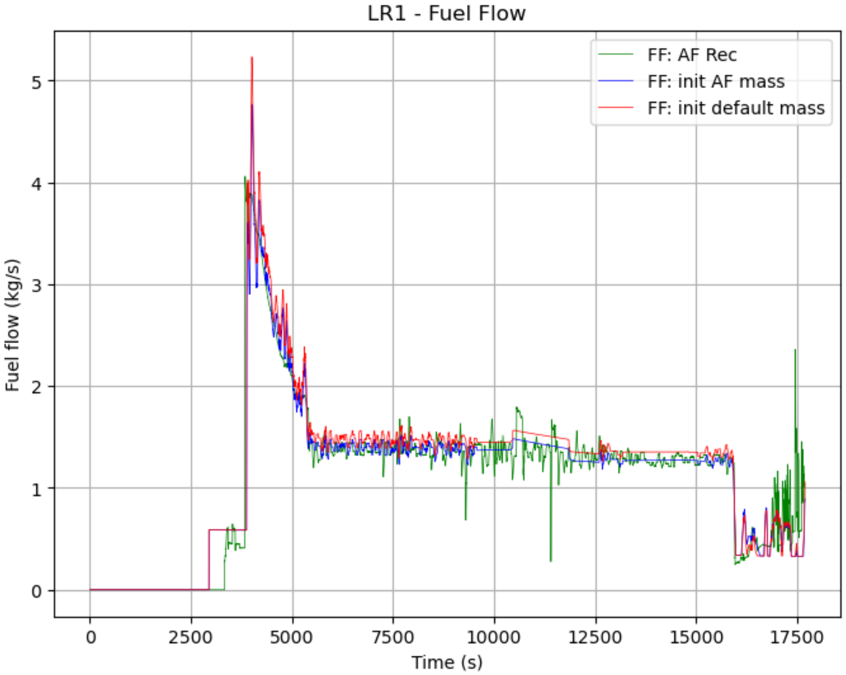
→ **Limited set**

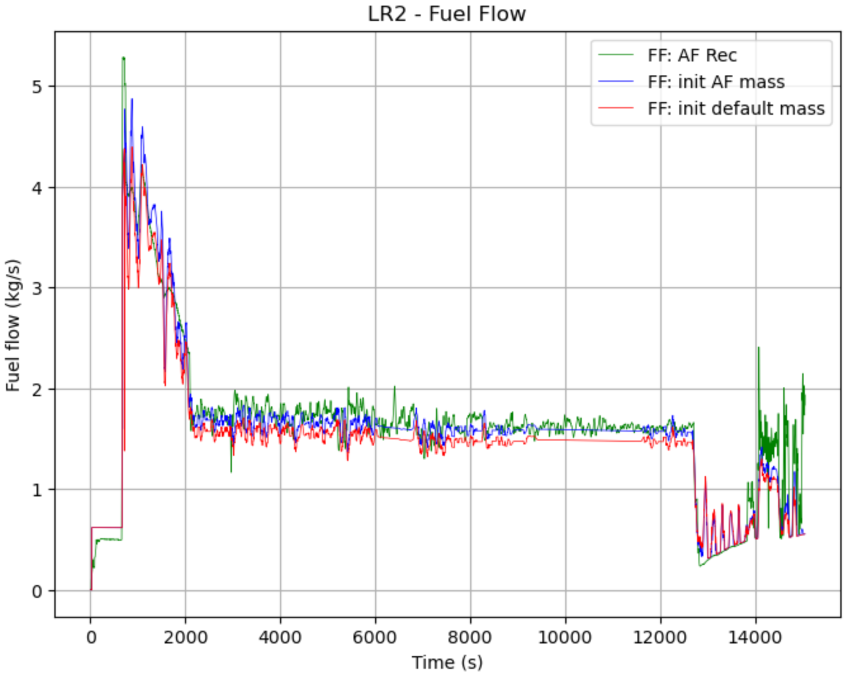
Mass evolution



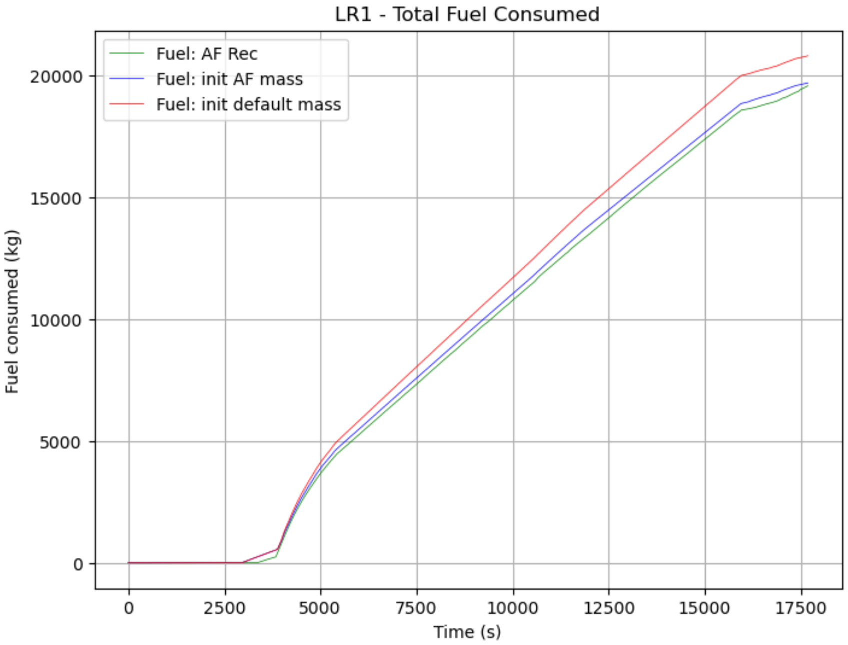


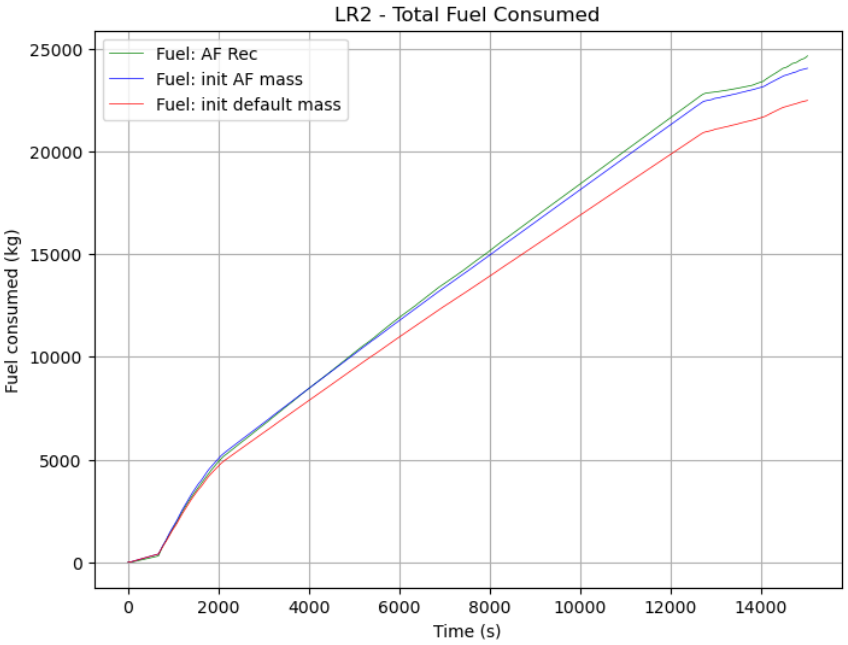
Fuel flow evolution





Total fuel consumption





Fuel consumption - Summary

- Slight underestimation of fuel consumption
  - Descent and landing phases

- Improvement of the simulation results when the initial mass is more accurate

Aircraft type	Δ recorded vs initial mass	Δ fuel consumption (default mass initialisation)	Δ fuel consumption (recorded mass initialisation)
SR1	-10%	-9.2%	-3.9%
SR2	+10%	1.5%	-5.2%
SR3	-10%	-10.5%	-4.2%
LR1	+10%	6.2%	0.6%
LR2	-10%	-2.4%	-8.8%
LR3	+10%	3.5%	-1.9%

Simulation services validation

Contrails

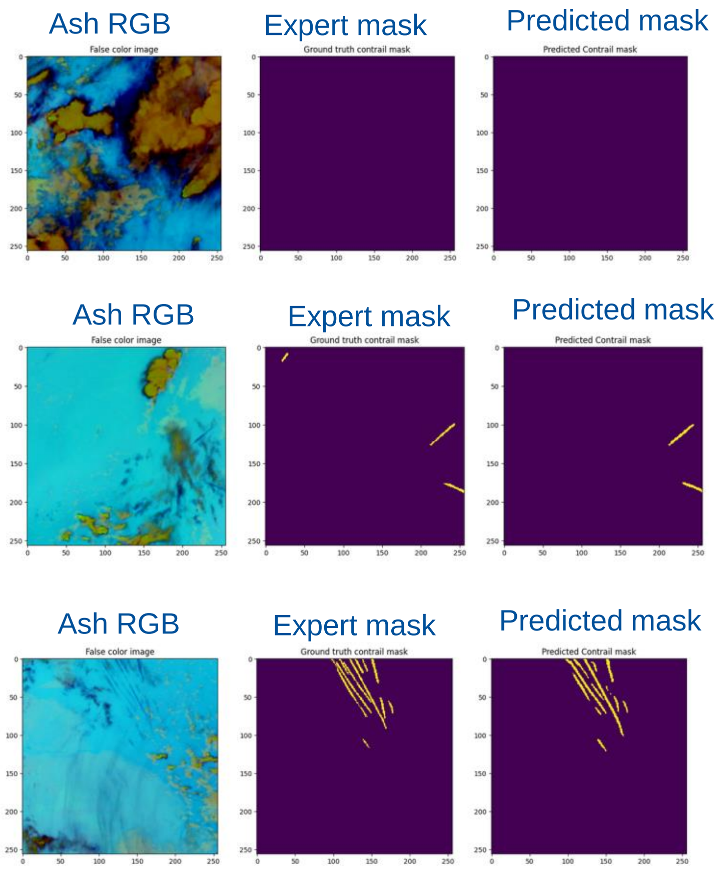
Contrails and traffic association

- Contrails images
  - Satellite-based
  - Ground camera-based
- Traffic data
  - ADS-B position
- Machine Learning algorithm

➡ **Which flight is responsible for which contrail**

Satellite images

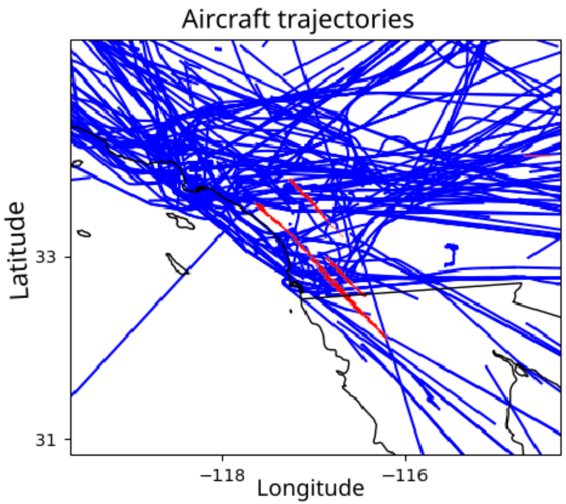
- GOES-16 dataset
  - 9 available channels + Metadata
  - Training dataset
    - 20529 images.
  - Validation dataset
    - 1856 images



Contrails and flights matching

Satellite

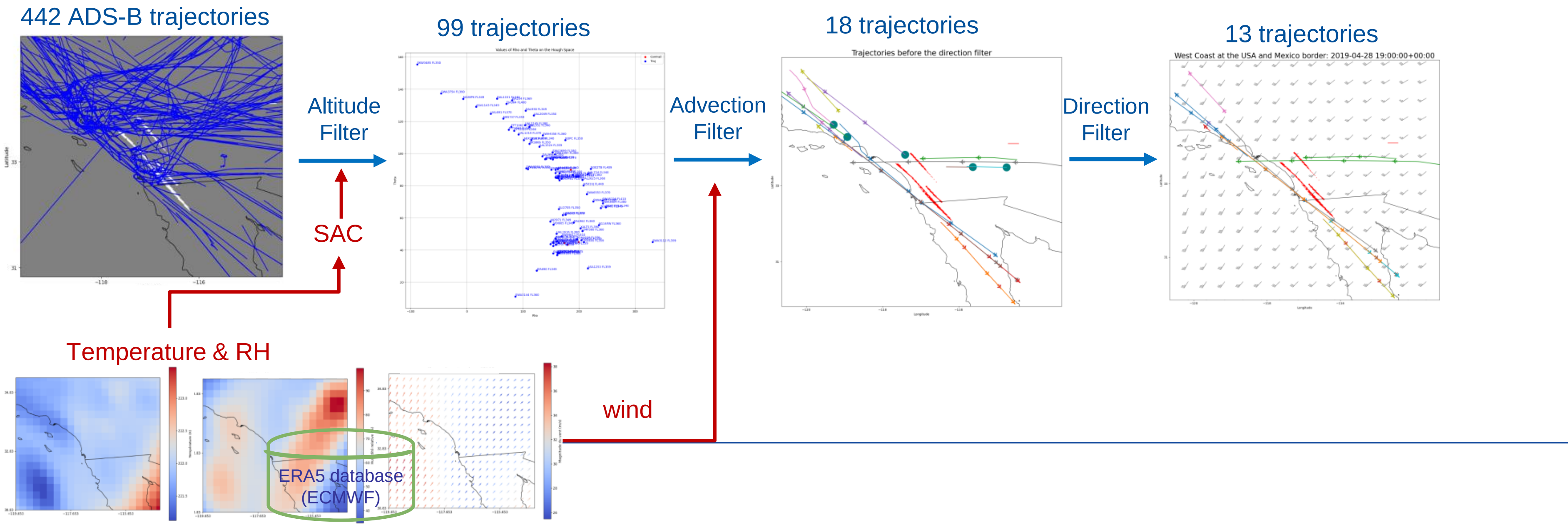
- ADS-B data from OpenSky Network
- 442 trajectories
  - 40 min before the satellite image
- Assumptions
  - contrails & trajectories are the same altitude
  - not far from each other



Contrails and flights matching

Satellite

- Successive filters to eliminate flights:
  - **Altitude filter**: SAC applied to select the altitude at which contrails can form
  - **Advection filter**: maximal displacement of the contrail according to the wind (eliminate flights that are too far from the contrail)
  - **Direction filter**: eliminate the aircraft flying toward the contrail

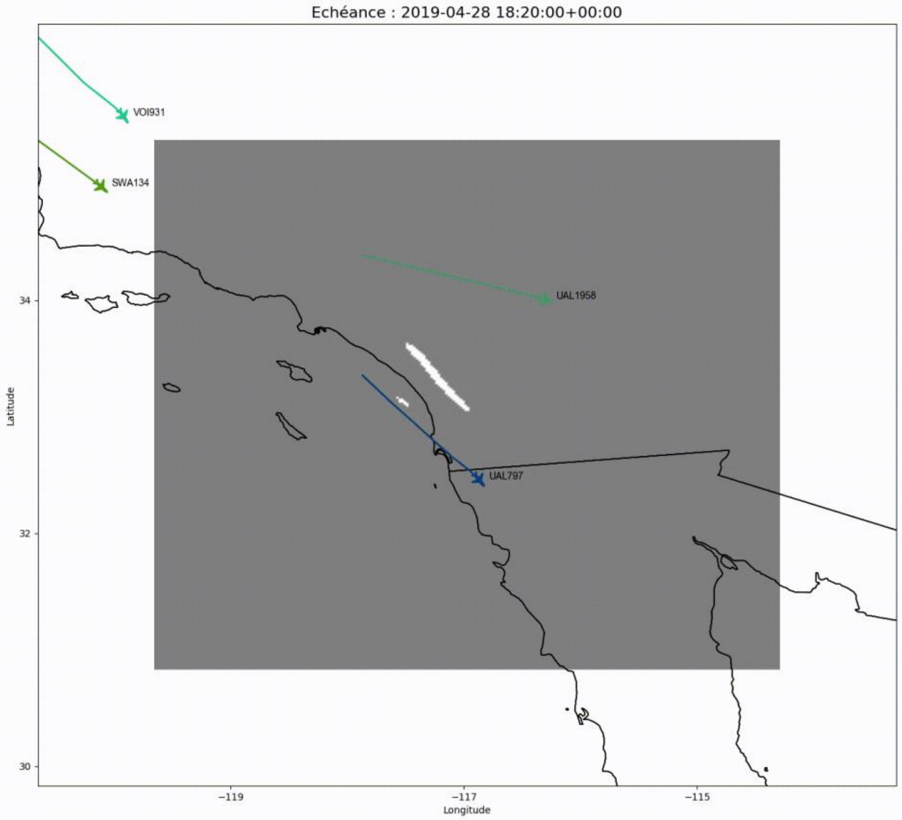


Contrails and flights matching

Satellite

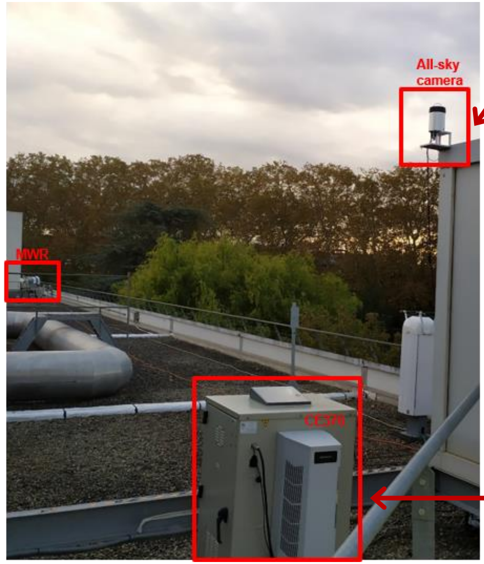
- Contrail advection from 18:20 to 19:30
- Image every 10 min

- Not possible to get reliable association



Contrails automatic detection

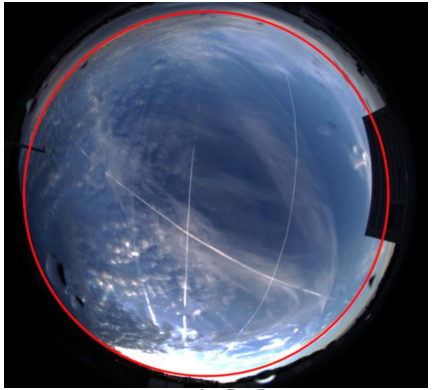
Ground camera

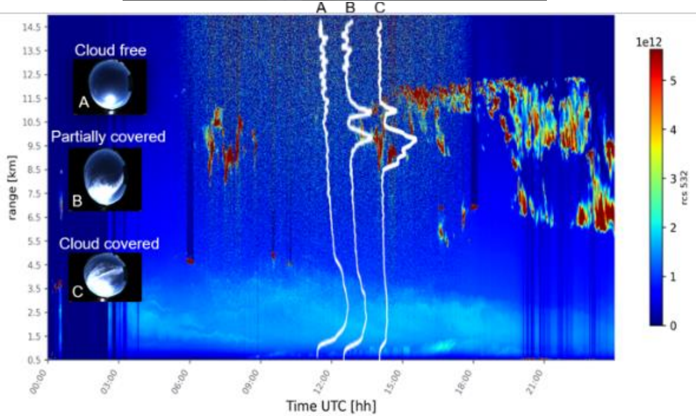


All-sky camera
30s time step

Lidar

Colocation



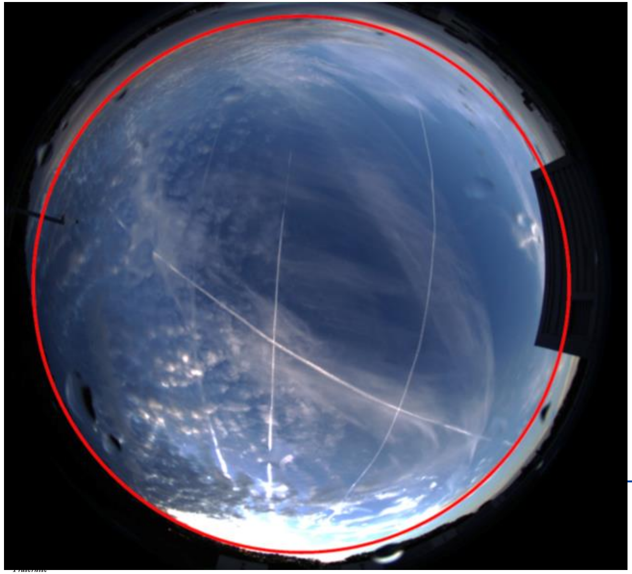


Contrails automatic detection

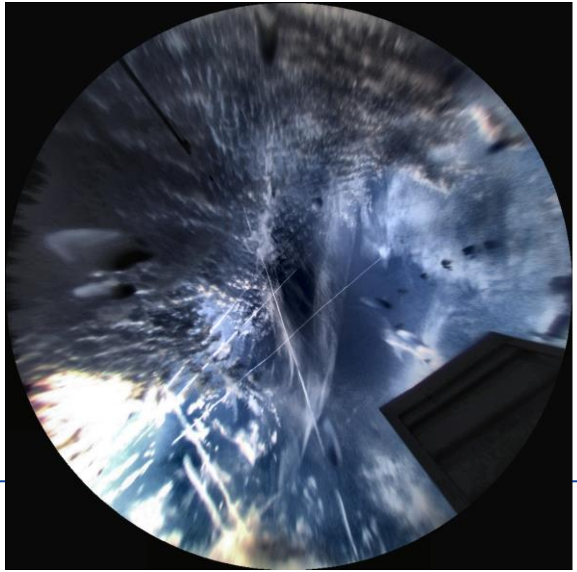
Ground camera

- Dataset
  - 30 seconds time step images, 1 min LIDAR data
  - 400 human labelled images

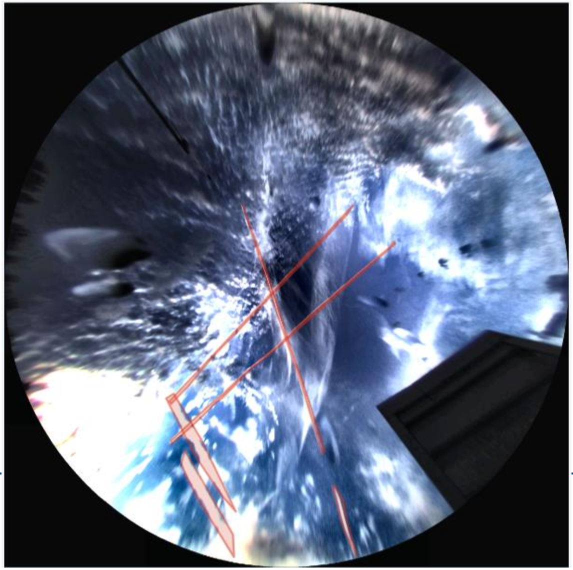
Raw images, θ<80°



Projection on a cartesian plan



Labelling

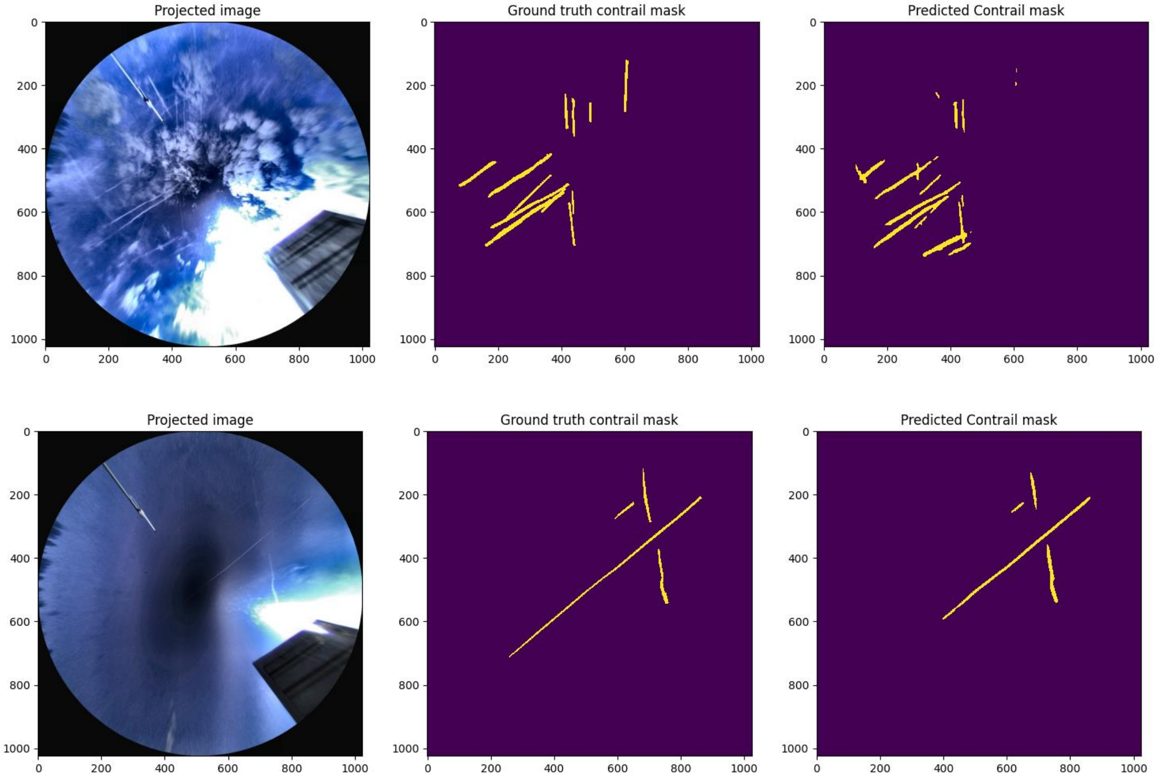


Contrails automatic detection

Ground camera

- Deep Learning results based on Onera dataset

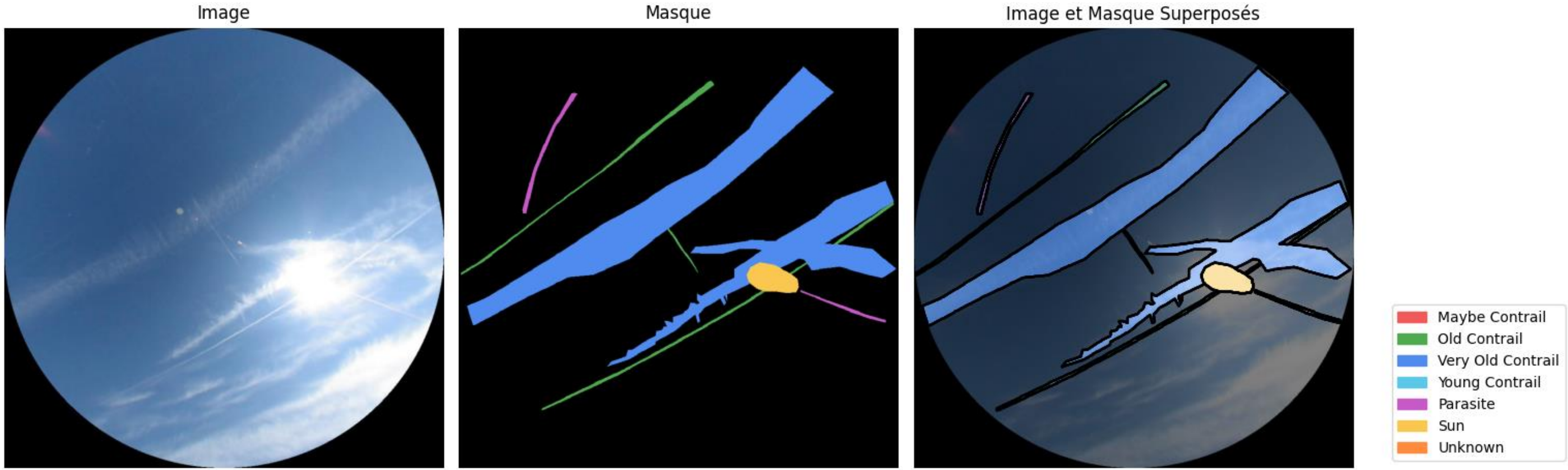
Projected image | Labelled mask | Predicted contrails



Contrails automatic detection

Ground camera

- Complementary training on IPSL database (Gourgue et al., 2025)
  - 7 labelling classes
  - 1600 labelled images

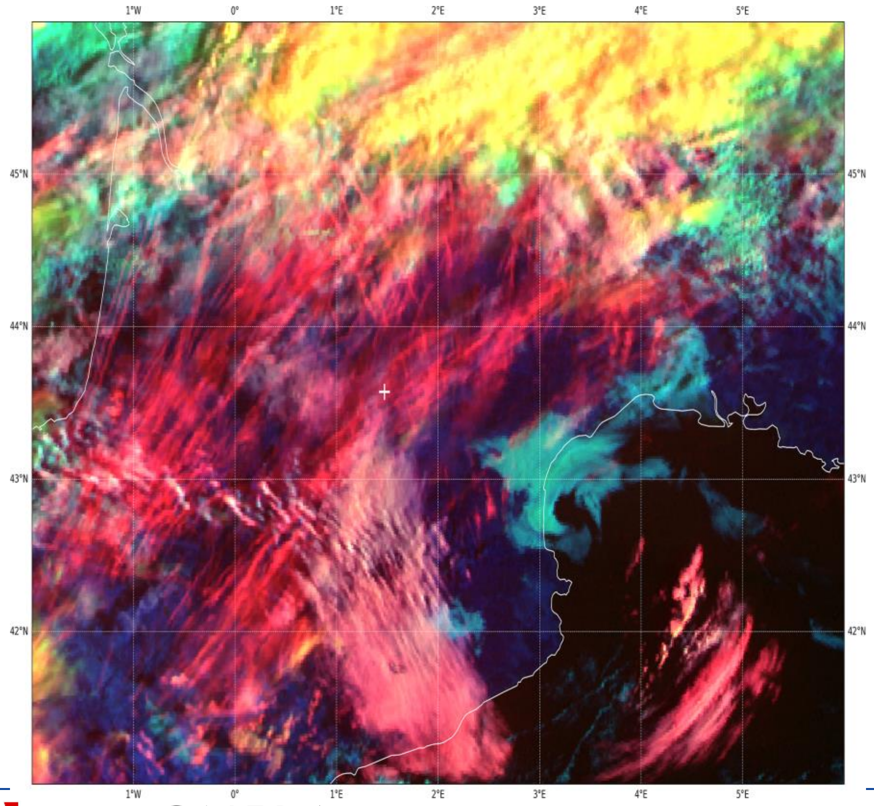


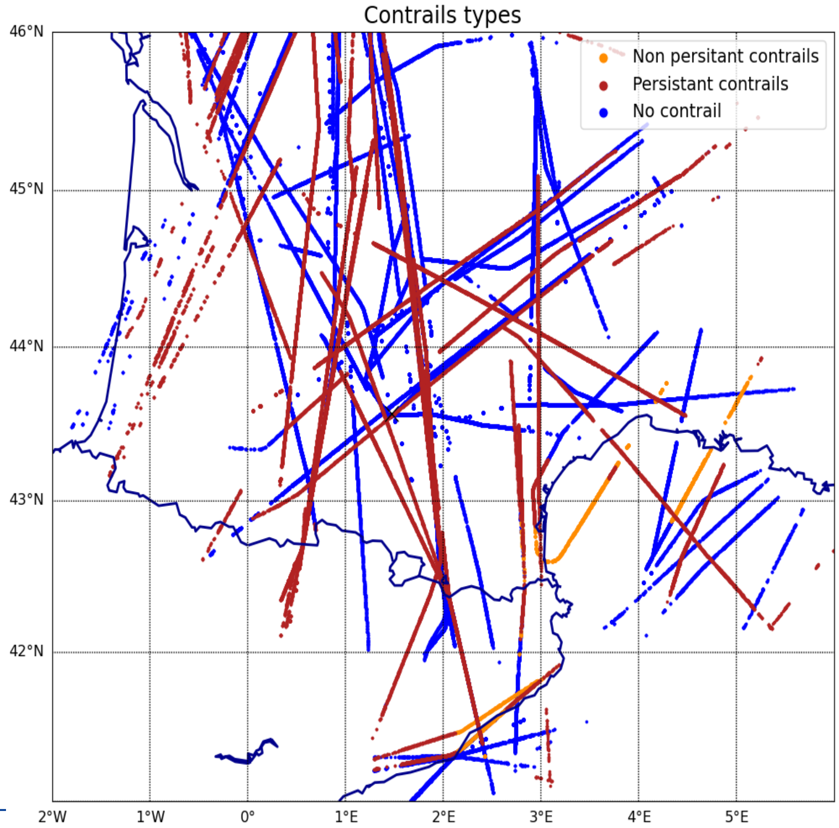
Contrails prediction and aircraft association

- Objectives
  - Real observations
    - Satellite images
    - Ground cameras
  - Comparison with simulation results (inverse simulation, SAC)
    - Persistent and non-persistent contrails with ERA5 temperature and humidity

Contrails prediction and aircraft association

Simulation – satellite images





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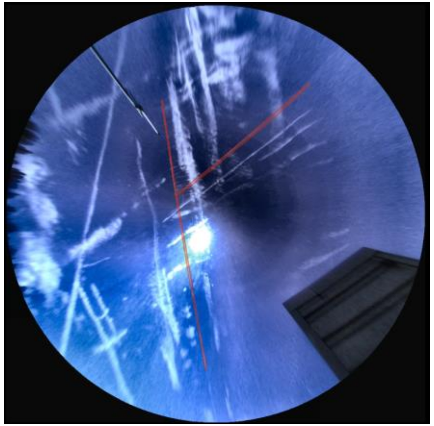
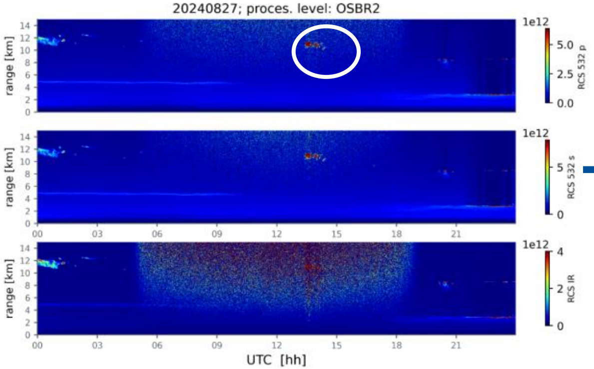
Contrails prediction and aircraft association

Simulation – ground images and LIDAR

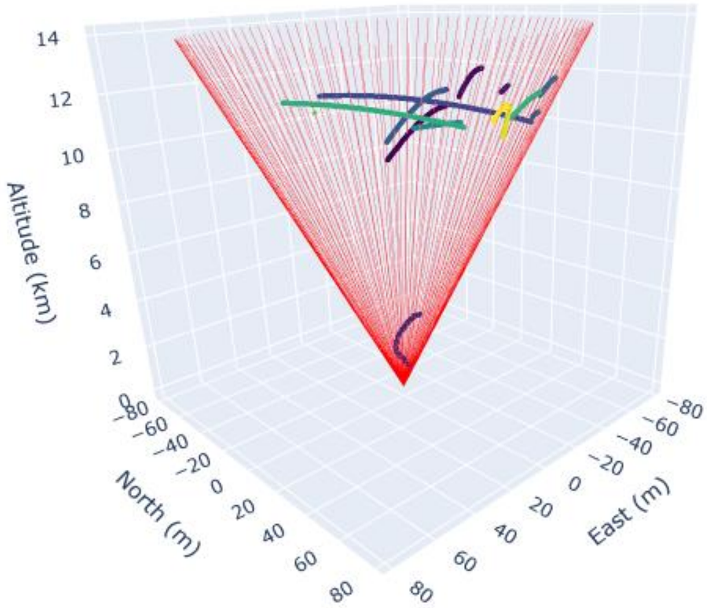
1. Detection with AI in cam images



2. LIDAR observations for altitude



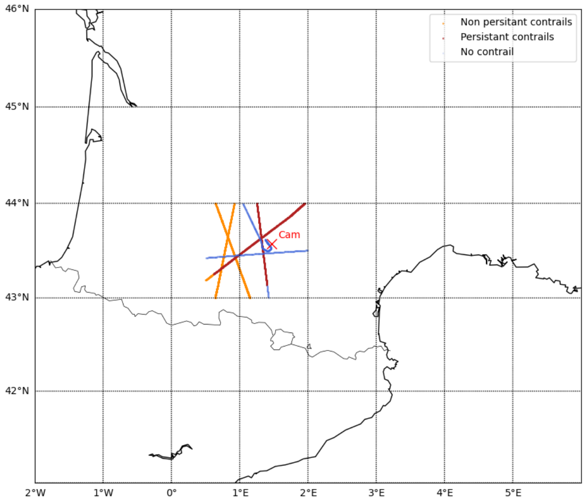
3. ADS-B data in the camera's cone vision



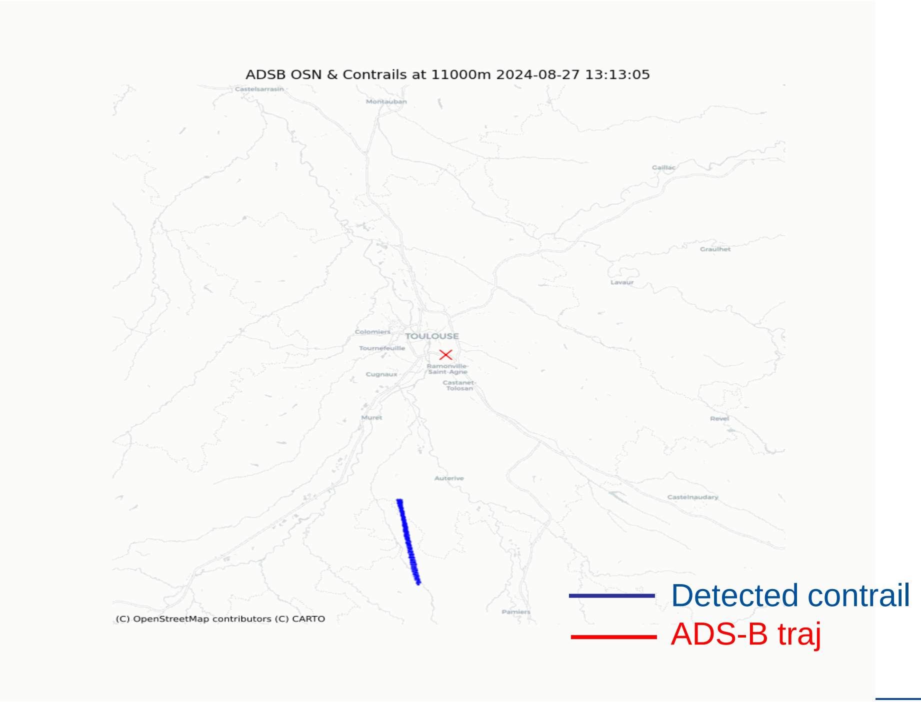
Contrails prediction and aircraft association

Simulation – ground images and LIDAR

3. ATMLab simulations



4. ADS-B data with Lidar altitude



Conclusion and perspectives

Conclusion

- ATMLab: robust and versatile tool for aviation environmental impact assessment
  - Consistent and accurate simulation results for both CO_2 and non-CO_2 effects
  - Improvements still needed

Perspectives

- Emissions
  - Enhance mass initialisation
  - Yearly emissions calculations
    - FlightRadar24 traffic for 2024
    - Inverse simulation
- Contrails
  - Enhance automatic contrails detection and aircraft matching
- Climate impact assessment

Acknowledgements

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Any question?