



# Contrail Research: The Critical Role of Observational Data & AI

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EUROCONTROL Sustainability Unit

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# TOPICS

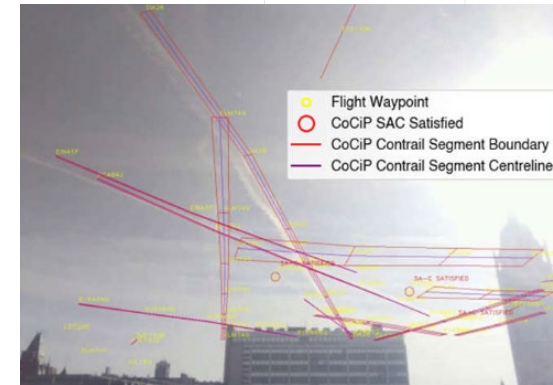
- 1. How can observational Data & AI contribute to contrail research?**
2. Focus on Ground Camera Systems
3. Sharing Datasets and Expertise for Contrail Science

# Three Fundamental Questions For Contrail Research

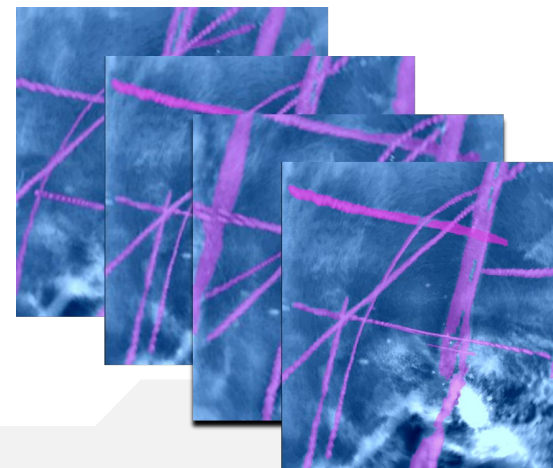
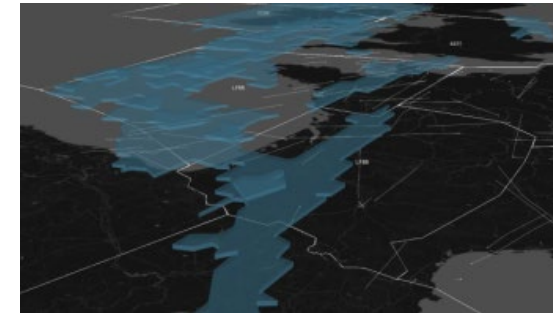
1. *Can we accurately determine whether a flight has produced contrails?*
2. *Can we predict the formation of contrails?*
3. *Can we monitor the evolution of contrails and assess their physical properties throughout their life cycle?*

How can **observational data and AI** provide valuable input to these questions?

What are the **current limitations**?



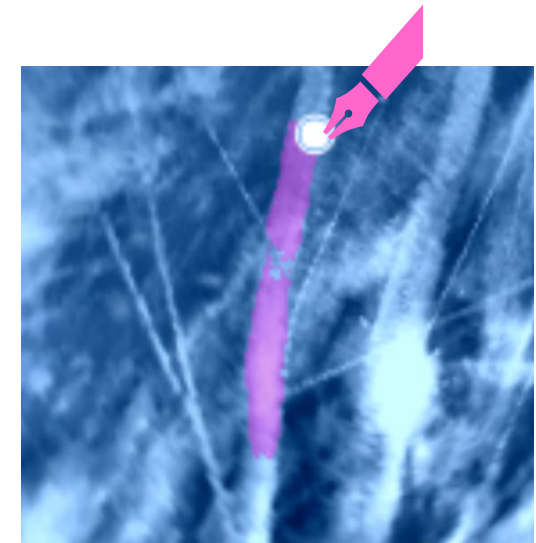
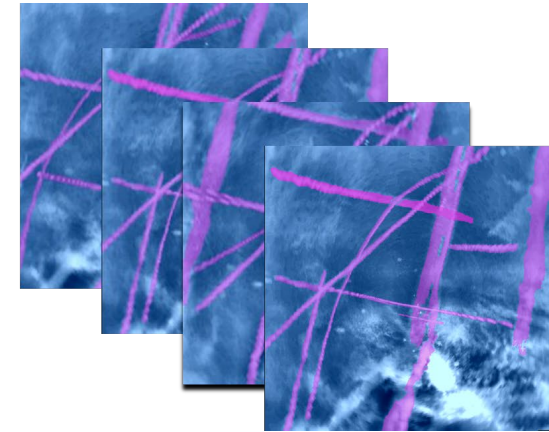
Source :Low et al., 2022



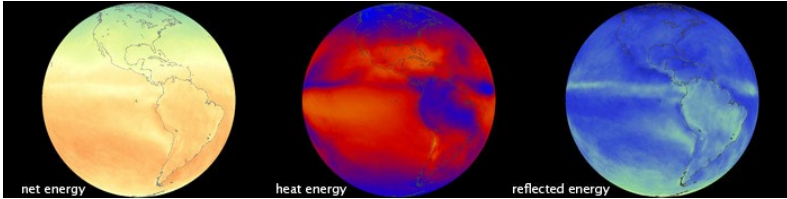
# AI Central Building Block for Contrail Research: Contrail Detection

- ❑ Artificial intelligence enables **large-scale pattern recognition** (almost) without expert knowledge:
  - ✓ For contrail science: **contrail detection on remote sensors**
- ❑ To build and validate such AI algorithms, **large datasets** of (usually) **human-labelled patterns** are required.
  - ✓ “Human Labelling Campaigns” are needed for Contrails detection

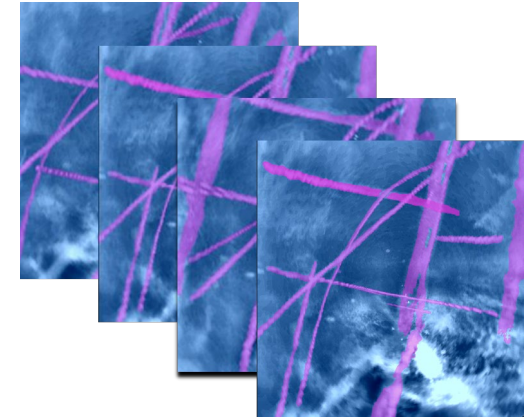
Contrail Detector



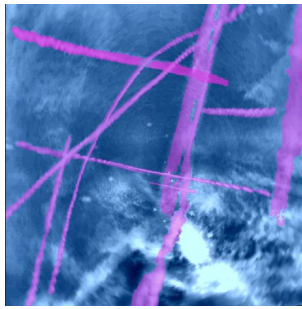
# Combining Information from Different Sensors



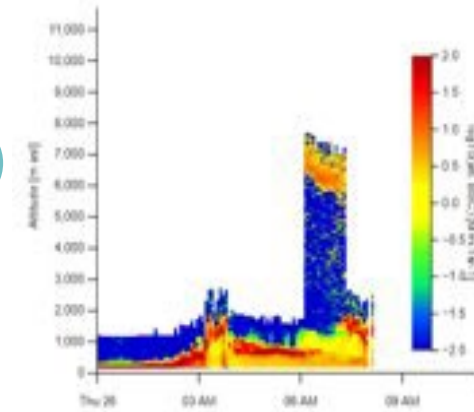
Study of long-term patterns (advanced computer vision)



Correlation with direct measurements of radiation to estimate radiative forcing (CERES)



Fusion with active sensors to study vertical physical properties (LIDAR ...)



Flight Matching and Contrail Monitoring (using ADS-B and weather data)



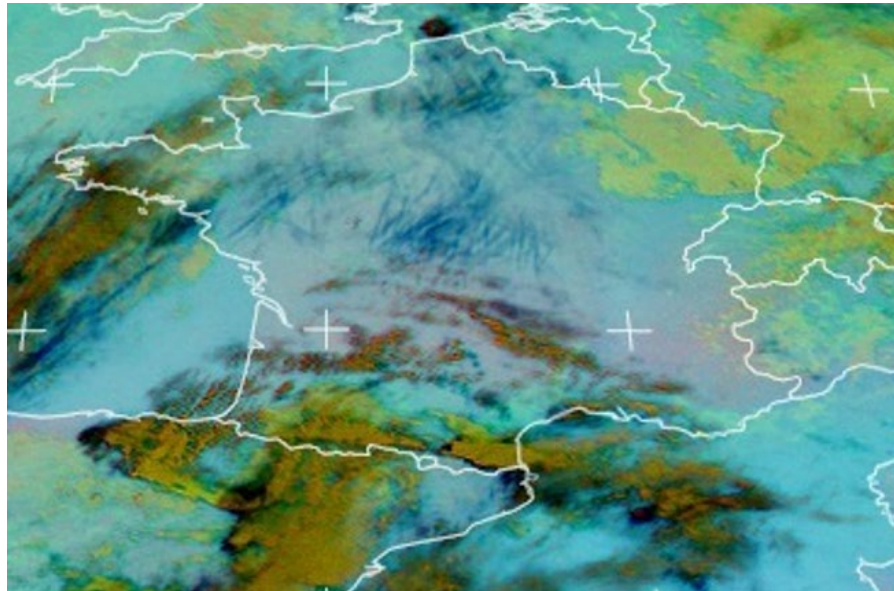
Contrail Prediction based on actual contrail observations



# Current Limitations of Contrail Detection

## Fundamental trade-off between accuracy and coverage

- ❑ Observations from low-orbit **satellites** or **ground-based cameras** can provide accurate contrail detection, but their **coverage is limited**
- ❑ **Geostationary satellites** have **limited resolution** (cannot detect young contrails) **but satellites remain the best observational tool for observing contrails on a global scale**



Data	Ground Images	Low orbit Images	Geostat Images
<b>Coverage</b>	Fixed, Local 50/80km large	Moving, Intermediate 150-200km	Fixed, Continental
<b>Frequency</b>	Every 15-30 sec	Every 3-5 days	Every 10 mins
<b>Resolution</b>	1 pixels ≈ 10-100m	1 pixels ≈ 30-100m	1 pixel ≈ 2-5km (GOES-MTG) 4-7km (MSG)

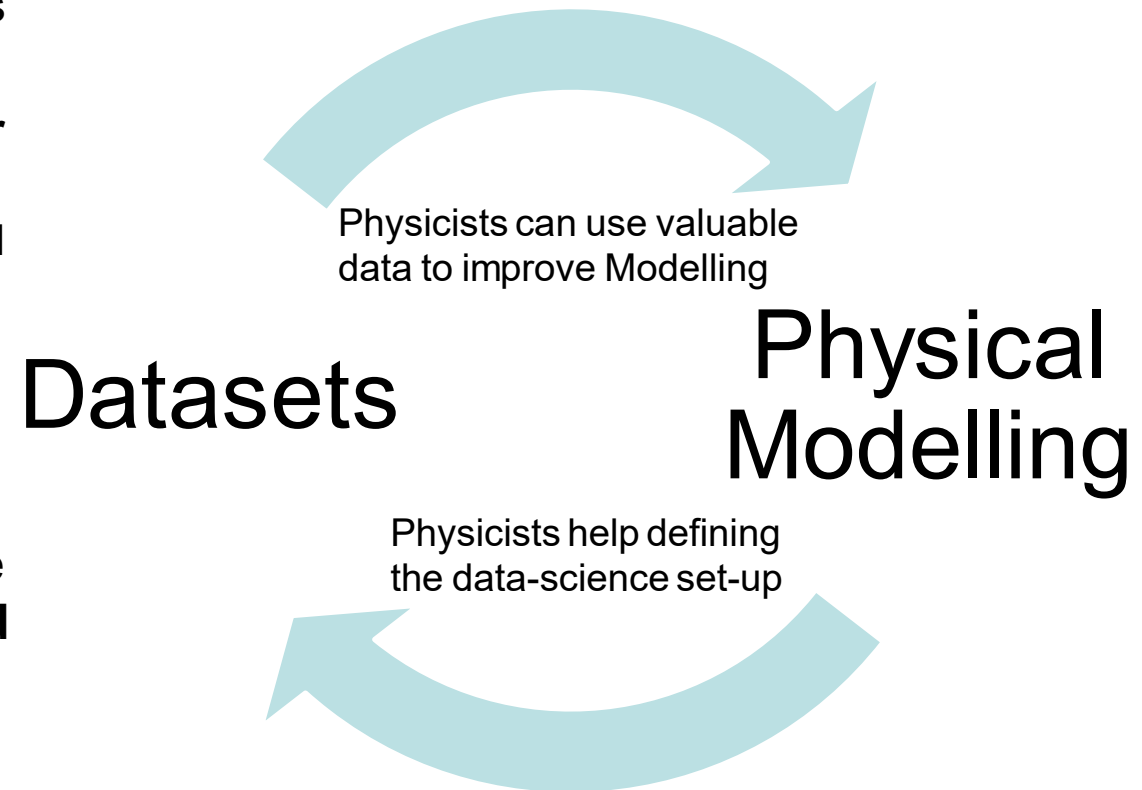


# The Need for Collaboration between Physics and Data Based Approaches

- ❑ Both Meteorological models and observational techniques have **inherent limitations**:
  - ✓ Atmospheric models are limited by the **accuracy of weather data**
  - ✓ Data Science approaches suffer from limited **coverage/precision**

Collaboration can lead to significant progress:

- ❑ Datasets from combined remote sensors will provide atmospheric physicists with **valuable data to test and validate physical models**
- ❑ **Hybrid approaches and/or physics-informed machine Learning** model can help mitigate the limitations of both approaches



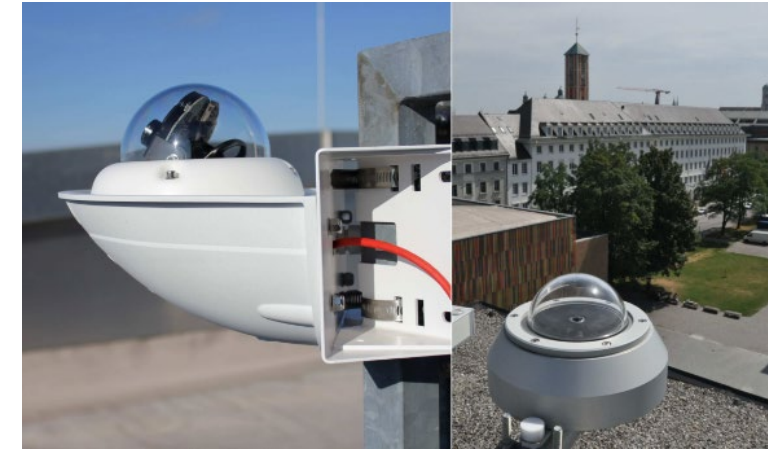
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# Example of Past and Present Research/Initiatives

## ❑ Contrails/Clouds detection and tracking

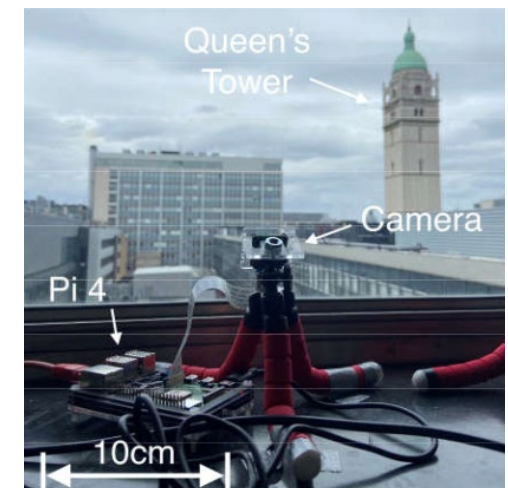
- ✓ *University of Minnesota*: Classification with visible all-sky images (Siddiqui et al., 2020)
- ✓ *University of Dortmund*: Night detection of clouds with visible all-sky cameras using starlight (Adam et al., 2016)
- ✓ *Lowell Observatory*: Cloud detection (Mommert, 2020)
- ✓ *Eurocontrol MUAC*: Tracking, matching and inclusion with ATM systems
- ✓ *DLR*:
  - ✓ Tracking, altitude estimation with two cameras, coverage estimation (Schumann et al., 2013)
  - ✓ Comparisons with satellites (Mannstein et al., 2009)
- ✓ *Eurocontrol ASU*: Segmentation with IR all-sky cameras



Source :Schumann et al., 2013

## ❑ Comparaison with Physical approaches

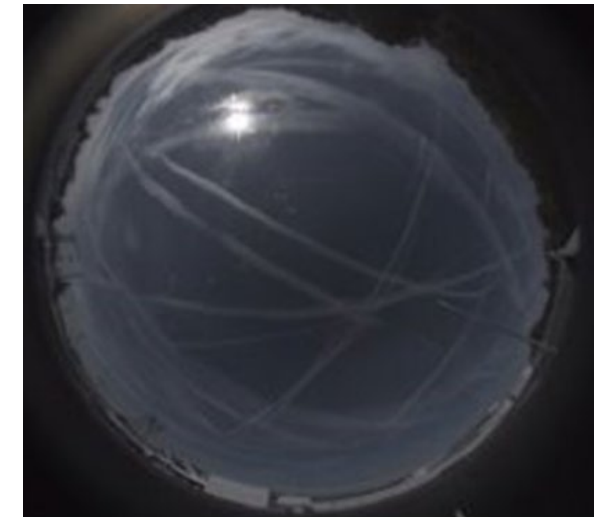
- ✓ *Imperial College*: Validation of physical models (Low et al., 2022)
- ✓ *University of Dresden*: Validation of physical models (Rosenow et al., 2023)



Source :Low et al., 2022

# Different types of Ground Cameras Systems

- ❑ **Wide angle vs hemispheric/all-sky cameras**
  - ✓ Structural difference in coverage/angle-of-view
  
- ❑ **Different spectral bands:**
  - ✓ Visible (0.4-0,8 microns)
  - ✓ Short wave infrared (0.8-3 microns)
  - ✓ Medium wave infrared (3-8 microns)
  - ✓ Long wave infrared (8-13 microns)
    - Useful for night monitoring and radiance measurements
  
- ❑ Differences in **resolution** (0.1 -> 20 MP, IR)
  
- ❑ Automatic vs manual calibration
  - ✓ Geometric calibration (pixels to zenith/azimuth, latitude/longitude/altitude)
  - ✓ Radiometric calibration (radiance to temperature) for IR cameras



# Ground Cameras at Eurocontrol Sustainability Unit

Eurocontrol is equipped with a camera system from *REUNIWATT*

- ❑ A **hemispheric camera** in the **visible range**:
  - ✓ Daytime contrails are **easy to identify (cooling effect)**
  - ✓ Hemispheric lens monitors contrails over long-time scales
  
- ❑ A **hemispheric camera** in the **long wave Infrared Range (thermal range)**:
  - ✓ Contrails are also observed **at night (Warming effect)**
  - ✓ Estimation of the effective radiative forcing ?
  
- ❑ Both cameras are automatically calibrated



Source :Reuniwatt

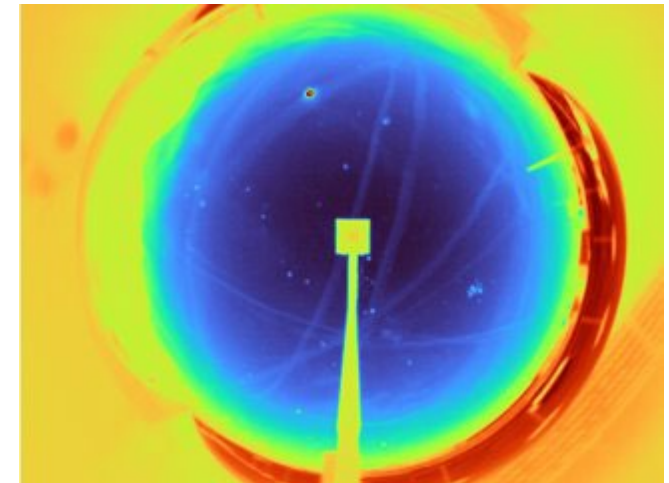


Source :Reuniwatt

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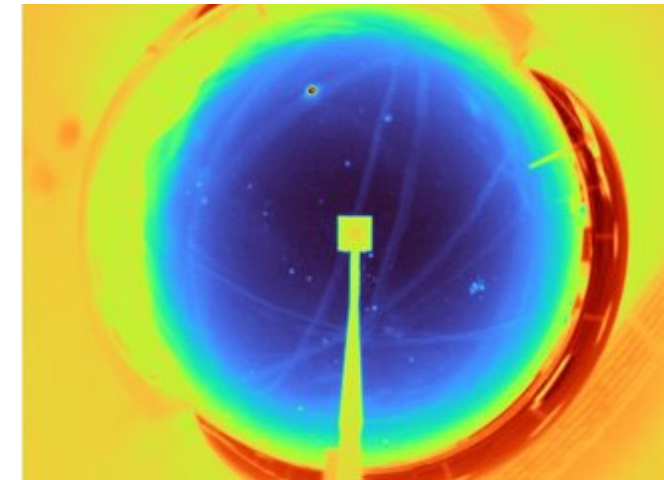
- ❑ A **hemispheric camera** in the **visible range**:
  - ✓ Daytime contrails are **easy to identify (cooling effect)**
  - ✓ Wide-angle fish-eye lens monitors contrails over long-time scales
  
- ❑ A **hemispheric camera** in the **long wave Infrared Range (thermal range)**:
  - ✓ Contrails are also observed **at night (Warming effect)**
  - ✓ Estimation of physical parameters ?
  
- ❑ Both cameras are automatically calibrated



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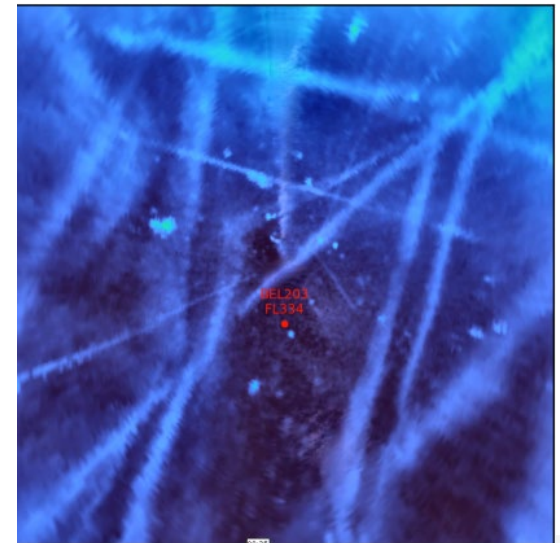
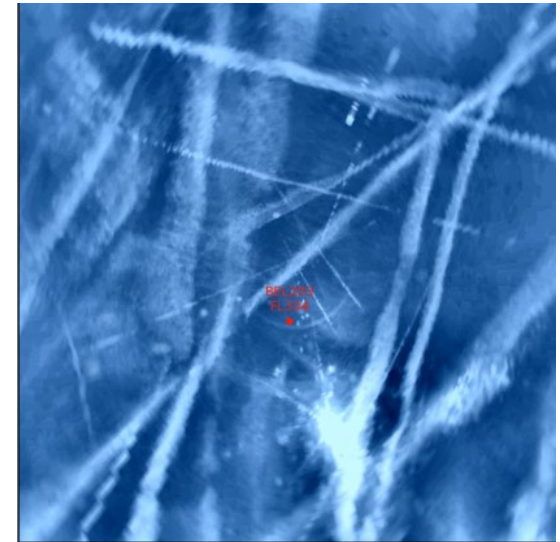
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# Efficient Preprocessing in the Visible and Thermal Range

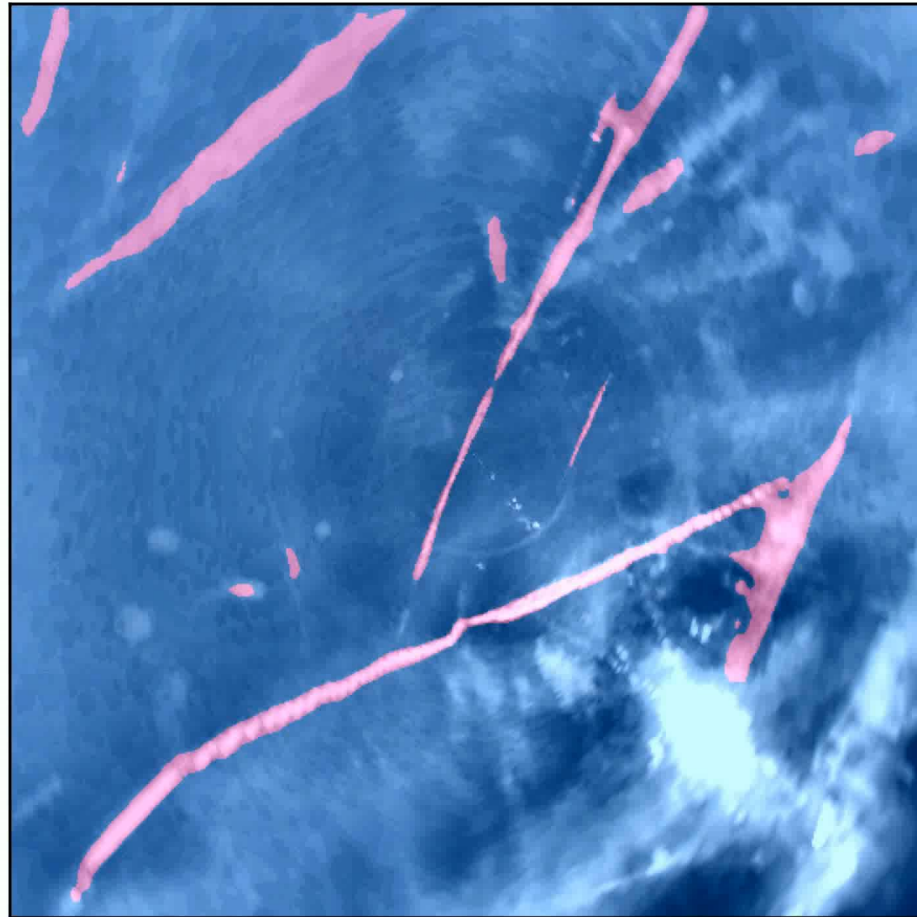
- ❑ Precise geometric calibration **simplifies the conversion to longitude and latitude**
- ❑ **High dynamic-range** of modern camera allows contrast to be enhanced in the most interesting regions
  - ✓ Sunlight illumination can be partially eliminated
- ❑ *Reuniwatt* IR cameras are equipped with algorithms that detect **uninteresting elements** in the image (sun, buildings, vegetation ...) which can then be **masked and completed by AI**
- ❑ Advanced pre-processing on IR Images targets the **distinct thermal range of contrails** and adjusts for **higher temperatures towards the horizon**.



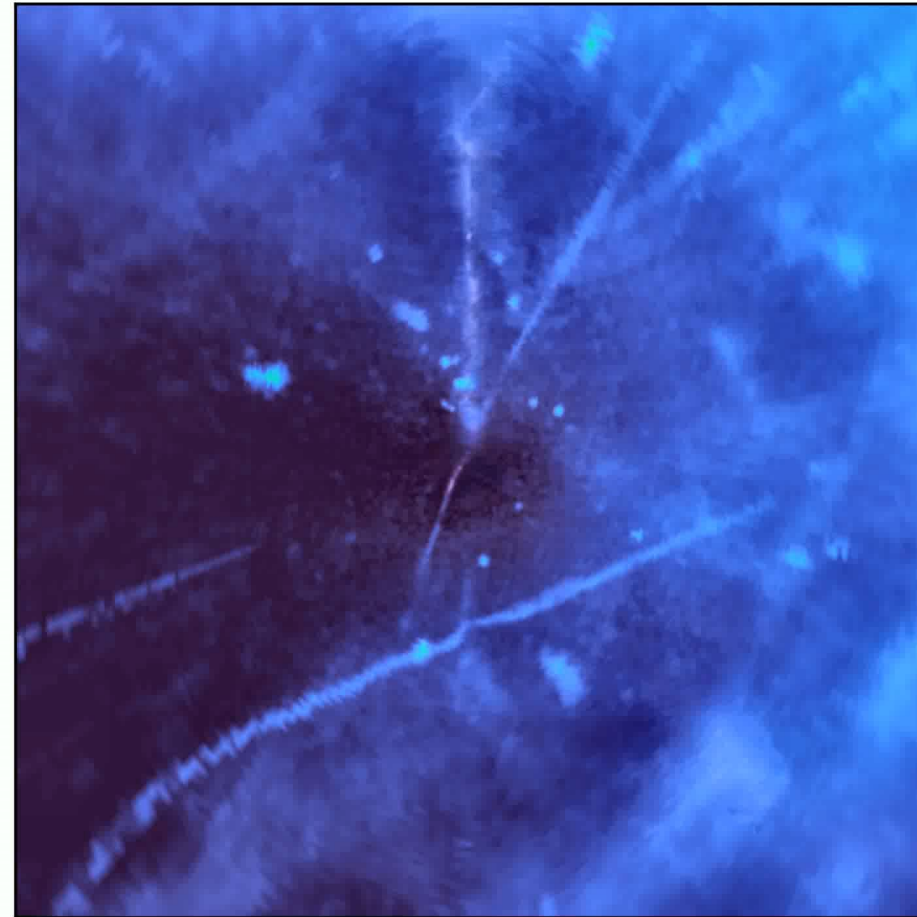


# Contrails Detection on Ground Cameras

Visible 20230925093000



Infrared 20230925093000





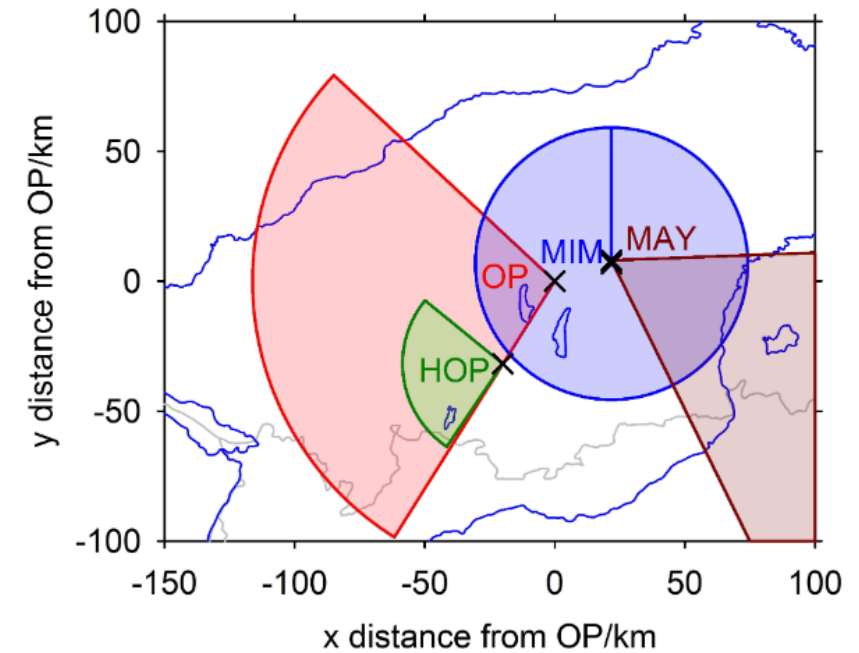
# Future Work and Questions to be answered

Fusion and comparison of **satellite and camera detection**

- ✓ Which contrails are missed by geostationary satellites ?
- ✓ Which contrails are missed by ground-based cameras ?

Which camera for a **camera network** ?

- ✓ Coverage?
- ✓ Resolution?
- ✓ Night monitoring?



Can a camera network really help to solve the **tracking problem** ?

Source :Schumann et al., 2013

Can **IR cameras** provide correlation with physical parameters?

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# ConrailNet: Sharing Datasets and Expertise for Conrail Science

- ✓ EUROCONTROL, along with Airbus and Thales, **calls for the creation of ConrailNet, a technical network aimed at consolidating European research efforts related to aviation contrails**
- ✓ Aim is to **create a common repository of contrail observation data**, which will be used to enhance the aviation industry's capabilities to reduce the climate impact of non-CO2 emissions such as contrails and nitrogen oxides (NOx)
- ✓ ConrailNet emphasizes the **importance of collaboration** between different stakeholders in aviation, including industry professionals, aircraft manufacturers, airlines, ANSPs, researchers, and students to collectively work **towards mitigating non-CO2 impacts on the climate**

# Conrail Science and AI: The Need for Datasets

- **ConrailNet will launch several labelling campaign on different datasets (MTG Satellite, Ground Cameras, Lidars ...)**
  - ✓ Such efforts have been achieved by Google & MIT for GOES16 & Landsat
  - ✓ A similar effort is needed in Europe
  
- ✓ **A common repository will be set up to provide labelled datasets to the scientific community**
  - ✓ Multiple datasets per use case/remote sensor will be made available to the community
  - ✓ Exact architectures, formats to be jointly defined

