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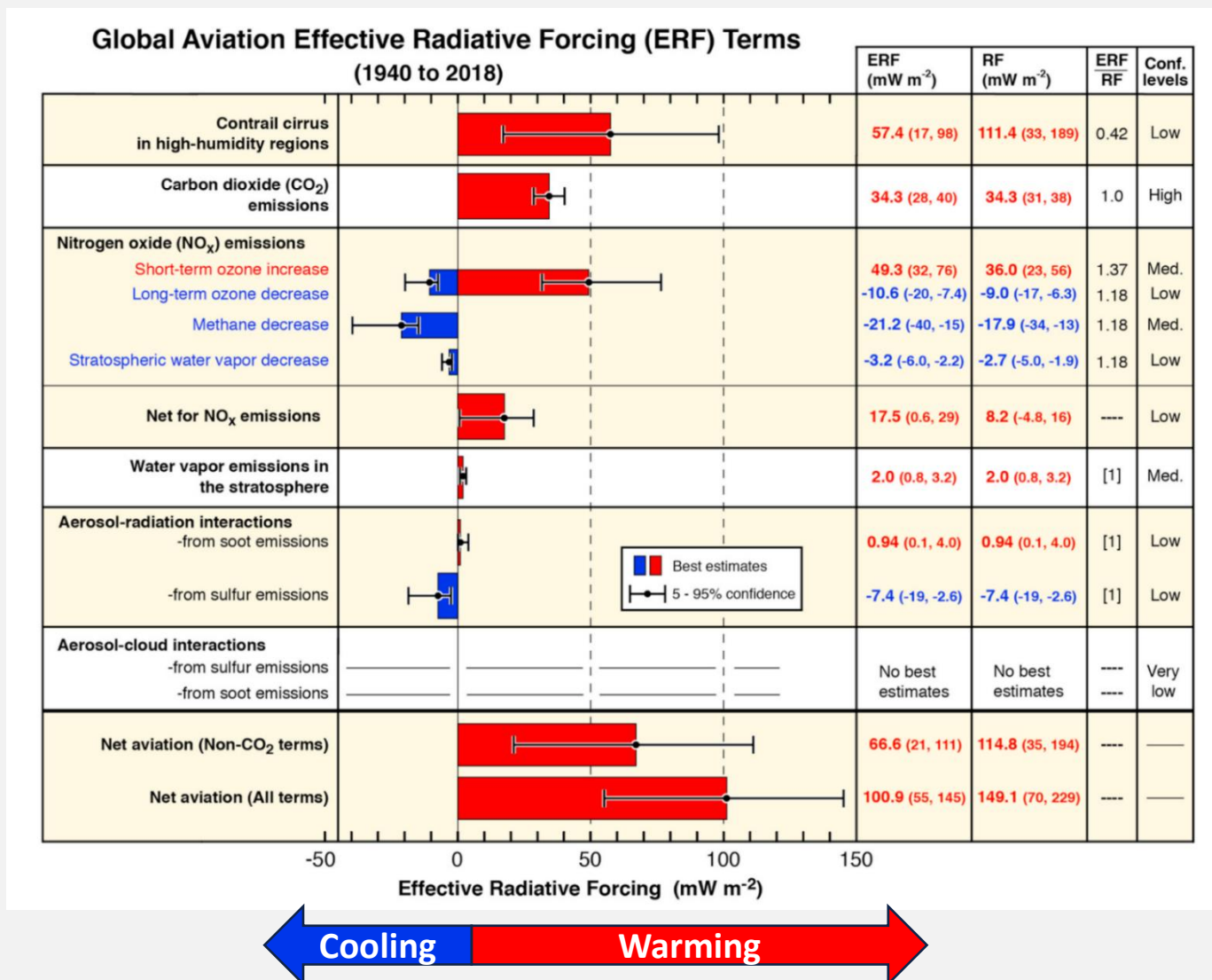
Contrail-to-Flight Attribution Using Ground Visible Cameras

SESAR Innovation Days 2025

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Overview of CO₂ and Non-CO₂ Effects of Aviation



❑ The **climate forcing** of non-CO₂ emissions could be similar in magnitude to that of CO₂ emissions.

❑ The main non-CO₂ effects are from **condensation trails and NO_x**

❑ Further work is needed to **improve scientific understanding** and reduce uncertainty in estimates.

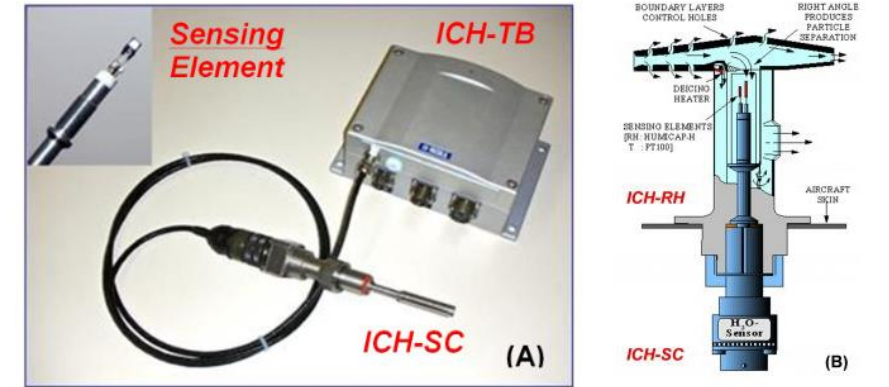
The Observational Approach

❑ Methods based on observations could play a significant role:

- To test and **validate physical approaches**
- To monitor and **confirm actual contrail occurrences**

❑ **Observational means** include :

- In-Situ measurements (IAGOS, MOZAIC, ...)
- **Geostationary satellites** (GOES, MTG, HIMAWARA)
- Low orbit satellites (LANDSAT)
- **Ground Camera systems**
- LIDARs (satellites and ground-based)



Source: <https://www.iagos.org/>

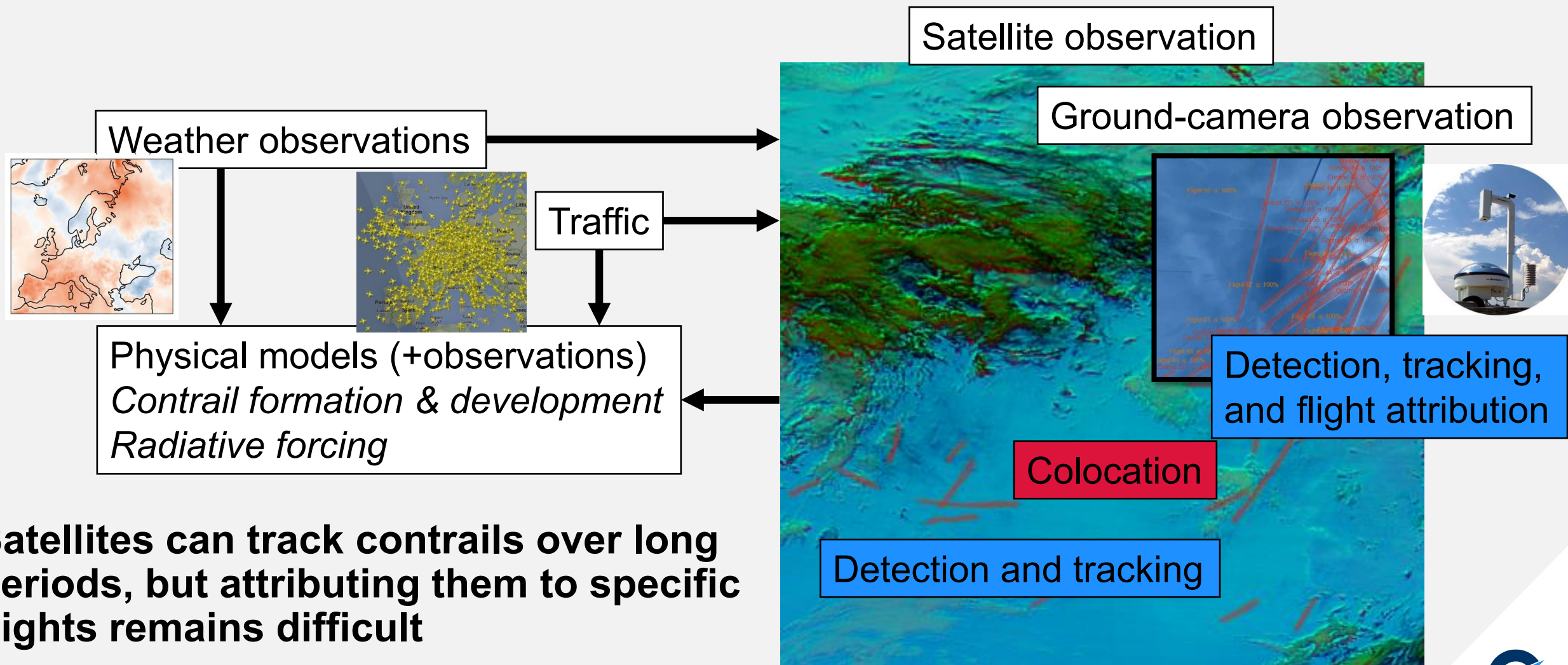


Source: Reuniwatt/Eurocontrol



Source: Reuniwatt/Eurocontrol

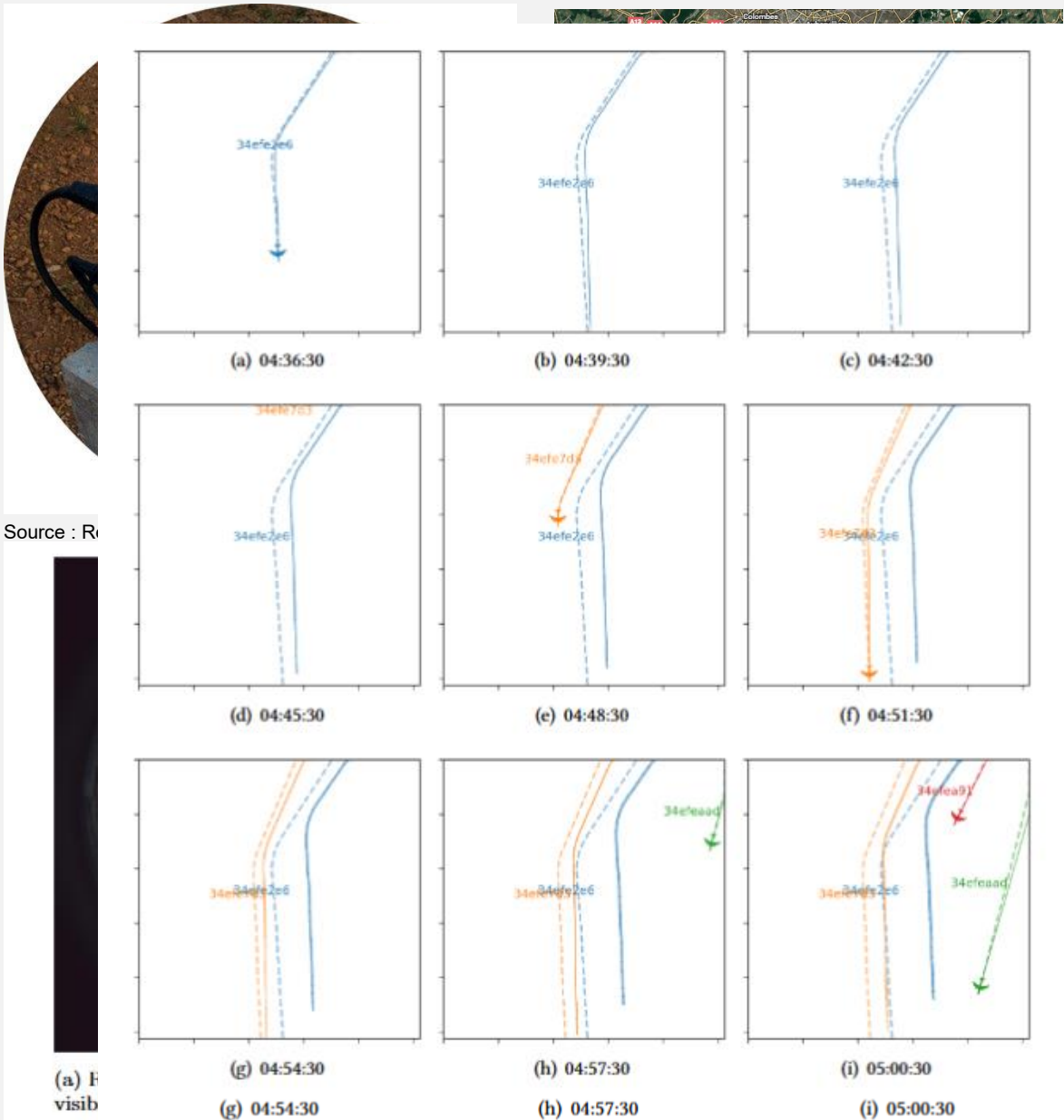
Satellite vs Ground-Based Camera Observations



GVCCS: A Dataset for Contrail Identification and Tracking on Visible All-Sky Cameras

- ❑ Camera coverage : 75 km
- ❑ Labelled images are organized in **sequences/videos of 1 or 2 hours** of consecutive images
- ❑ Labelled contrails are **tracked with a consistent identifier** across consecutive images
- ❑ **Ground truth** (human labels) are provided for the **matching task** (attribution to actual **ADS-B flights**)
- ❑ Contrails are modelled as **multi-polygons** (to account for fragmentation or **obscuration from low-altitude clouds**)

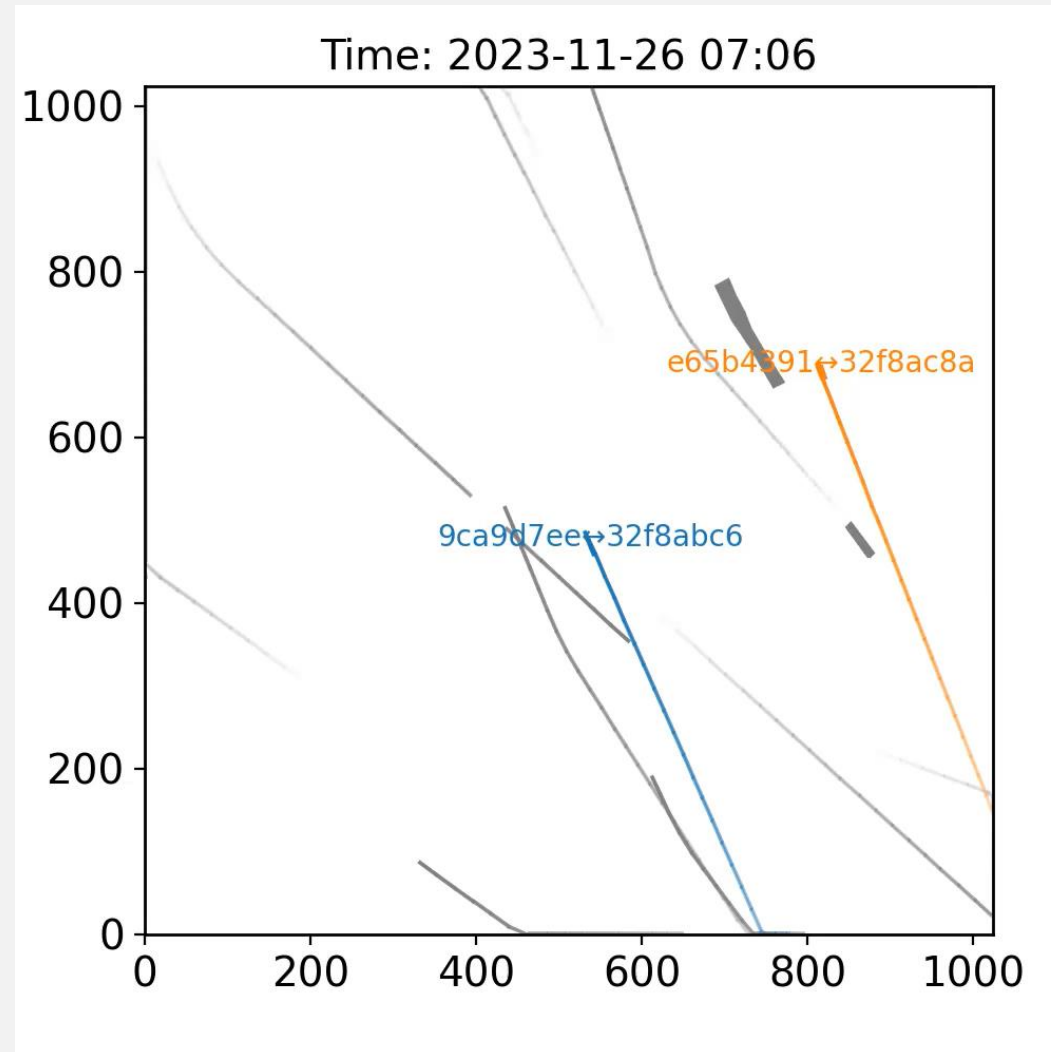
Metric	Value
Total sequences (labelled)	122
Total images	23,581
Average sequence duration in minutes	96.6
Images per sequence (min / max / mean)	41 / 600 / 193.3
Total annotated contrail instances	4660
Total unique flight IDs assigned	3346
Total polygons annotated	176,234
Contrail duration in minutes (min / max / mean)	0.5 / 142.5 / 14.6
Polygons per contrail (min / max / mean)	1 / 589 / 37.8
Polygons per frame per contrail (min / max / mean)	1 / 4.5 / 1.2



Source : Dalmou et al., 2025
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Contrails Attribution

- ❑ GVCSS dataset enables **the optimization of algorithmic attribution systems**.
- ❑ We provide **an open-source Python framework** with generic and **parameterizable attribution methods**
- ❑ Different geometric descriptions of contrails (skeletons, polygons...)
 - Different distances (nearest, Manhattan ...)
 - Possibility to consider several consecutive images for the attribution
 - Different allocation methods (greedy, Hungarian...)
- ❑ The results of the optimal attribution are good
 - The **attribution** problem is **easier for ground cameras** than for geostationary satellites
 - The results are quite **robust** with respect to the **attribution method**



Source : Eurocontrol

Abstract Algorithm (see the paper)

- ❑ For each observed contrail:

 - For each theoretical contrail:

 - Keep segments with similar *formation time*
 - Compute the distance between geometries
 - Update the aggregated distance for the pair
 - If aggregated distance is above a threshold, replace by $+\infty$

- ❑ Convert distances into probabilities

- ❑ Replace all probabilities below a threshold by 0

- ❑ Assign the theoretical contrail with the highest probability above zero

Concrete Implementation (see the paper)

- ❑ Theoretical contrails are computed with a dry advection model. They are multi-polygons
- ❑ Observed contrails are transformed to lines using skeletonization
- ❑ We use the maximum distance from any point on the observed line to the nearest point within the theoretical multi-polygon
- ❑ The aggregated distance is computed using an exponentially weighted moving average (EWMA)
- ❑ Distances are converted into probabilities using `softmax`

Contrail Classification

❑ For **Predicted** contrails:

- **Attributed:** the algorithm attributed the contrail to a flight
- **Unattributed:** otherwise

❑ For **Theoretical** contrails:

- **New:** the human labellers attributed the contrail to a flight
- **Old:** otherwise

Contrail Classification

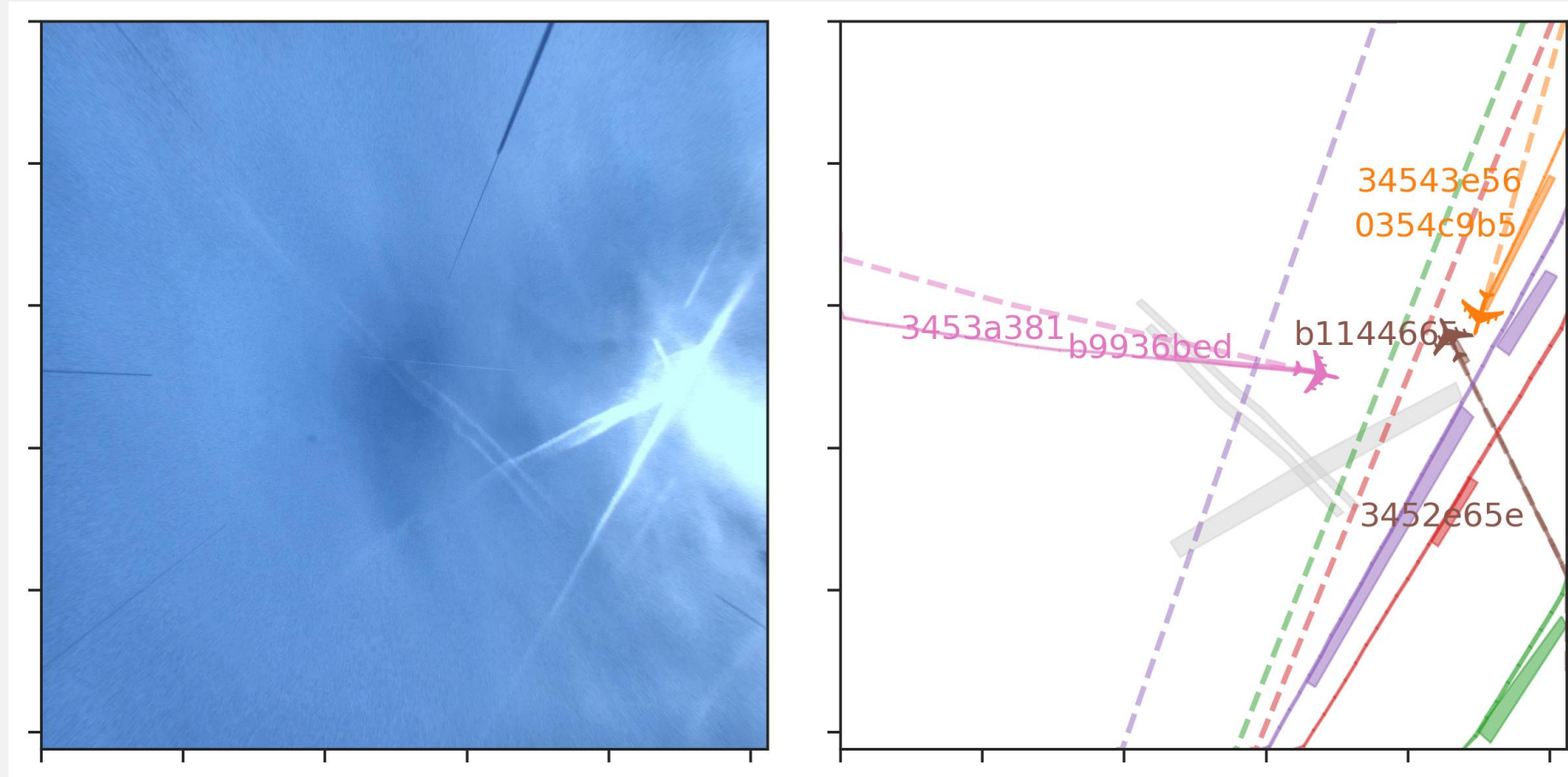
❑ For **Attributed** contrails:

- **Correct Attribution:** the contrail was attributed to the correct flight
- **Wrong Attribution:** the contrail was attributed to an incorrect flight
- **False Attribution:** the contrail was actually old

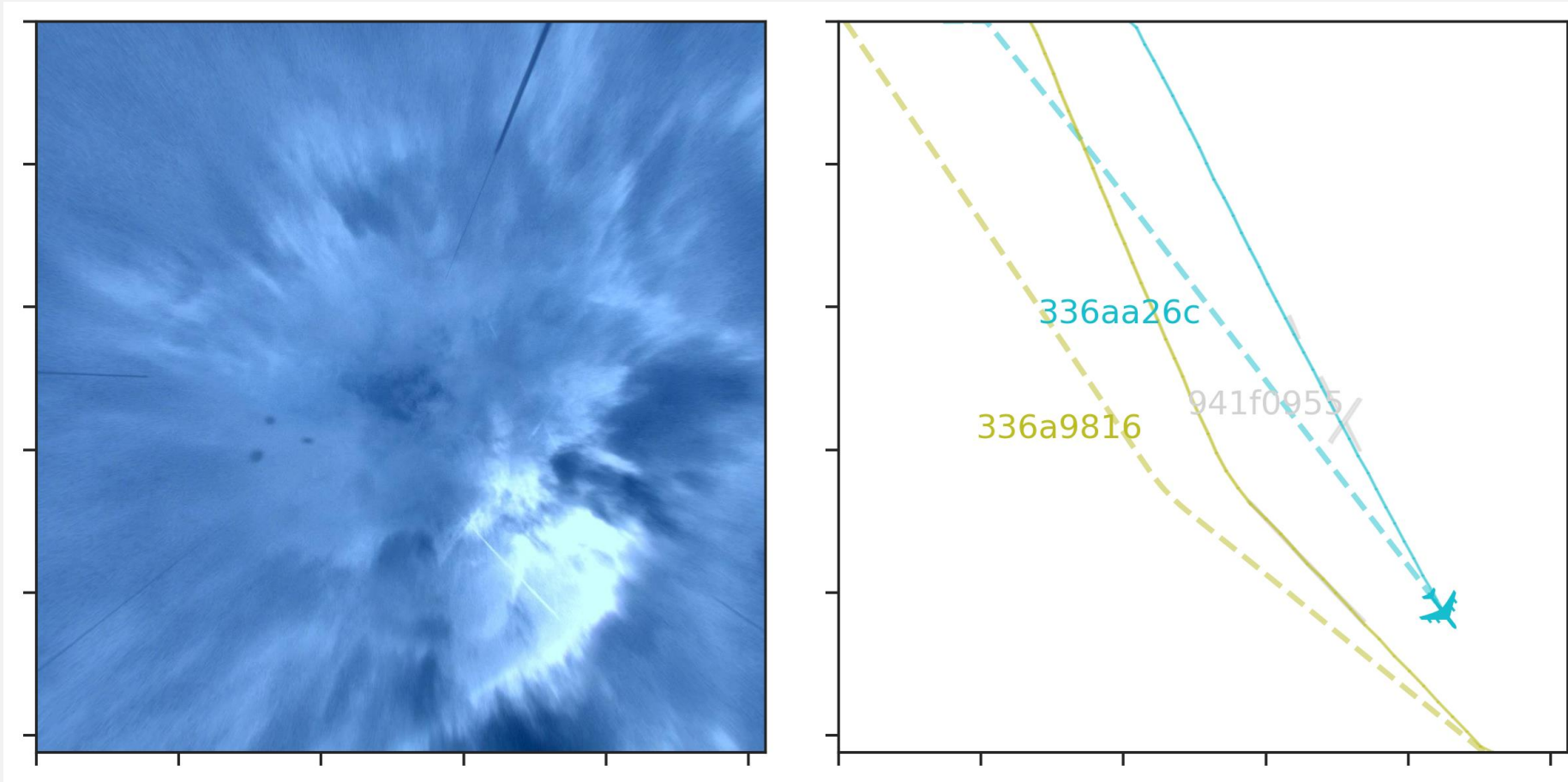
❑ For **Unattributed** contrails:

- **Correct Omission:** the contrail was indeed old
- **Missed Attribution:** the contrail was new but was not attributed

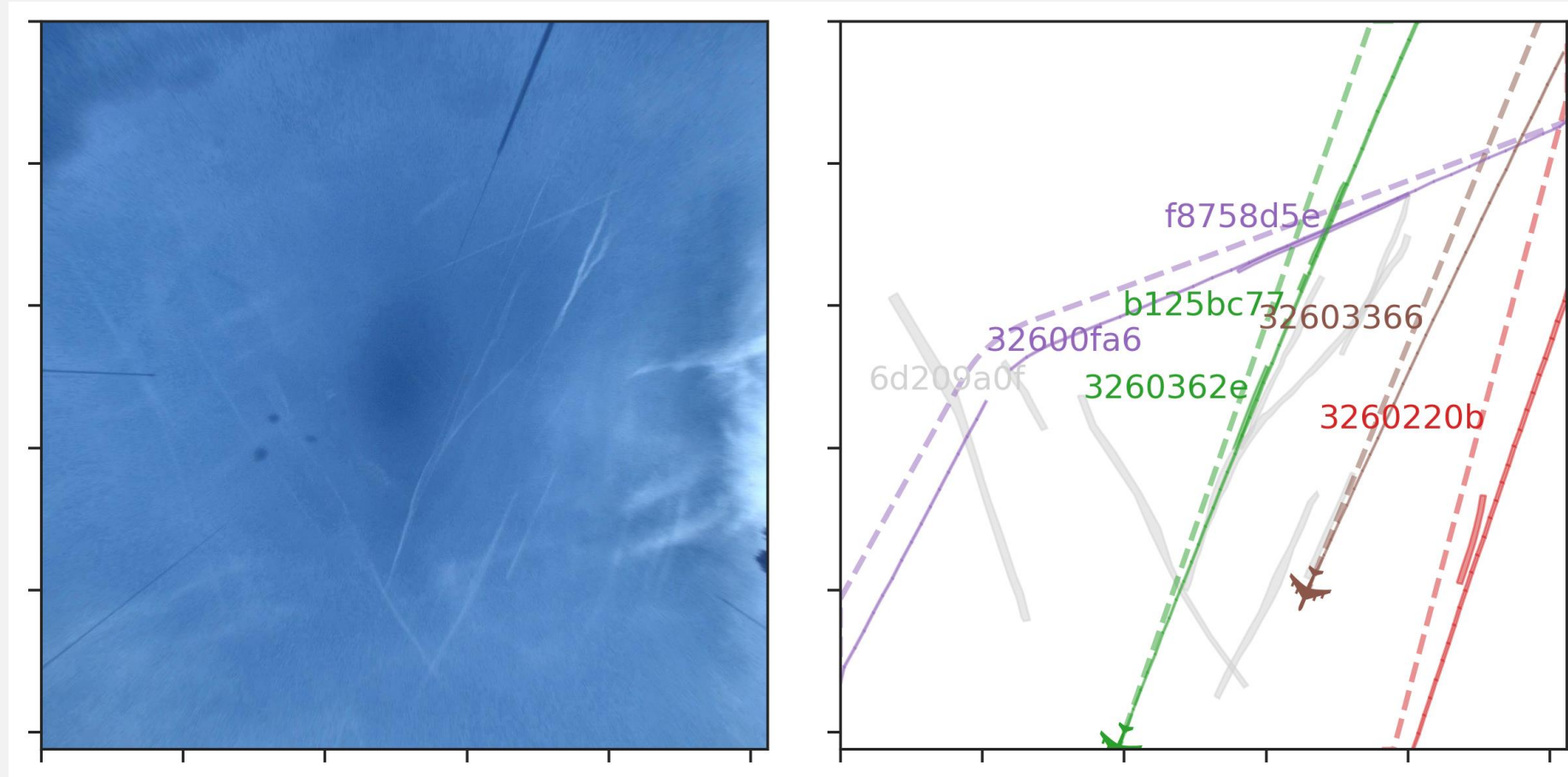
Example – Correct Attribution



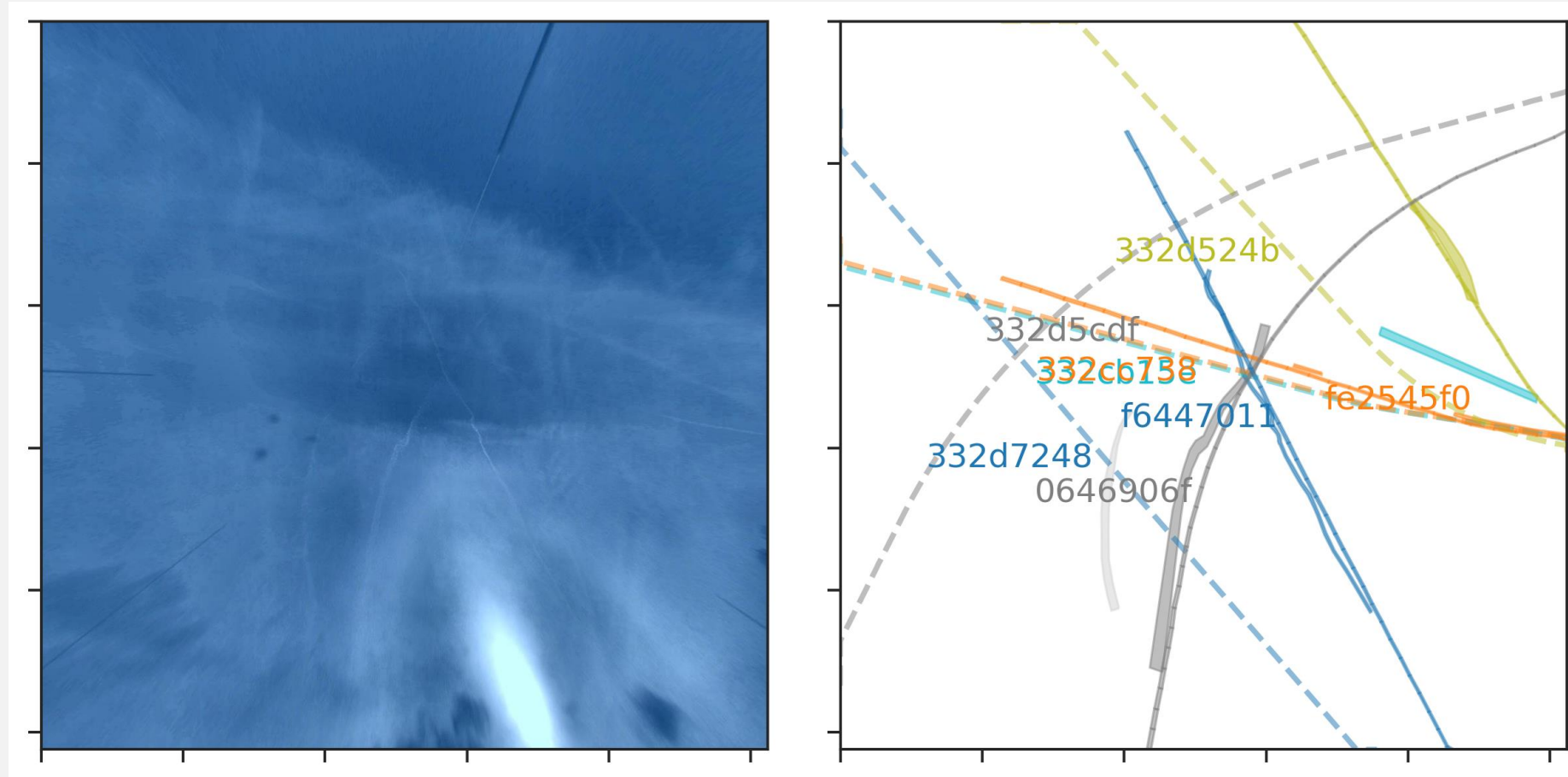
Example – False Attribution



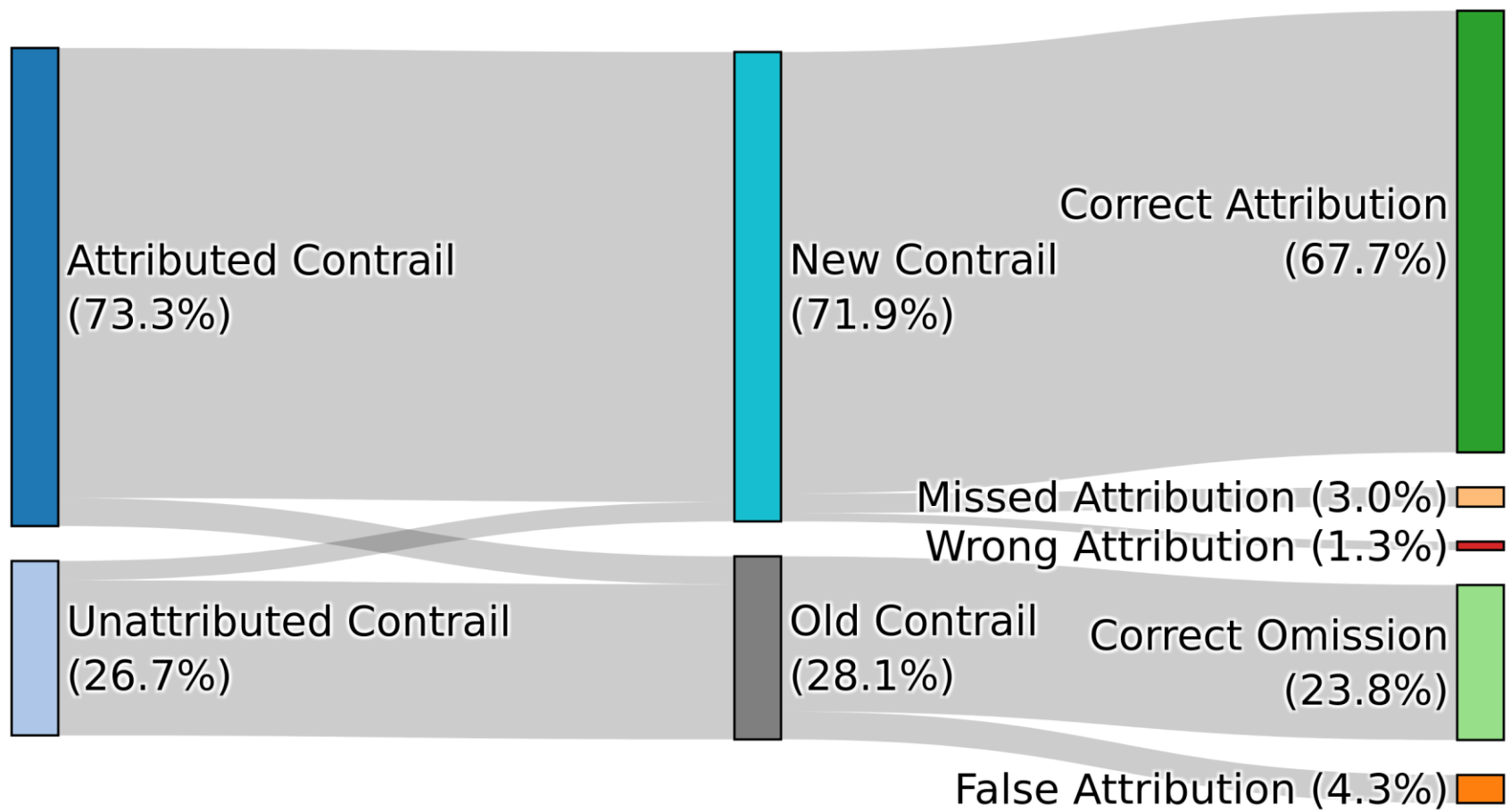
Example – Correct Omission



Example – Missed Attribution

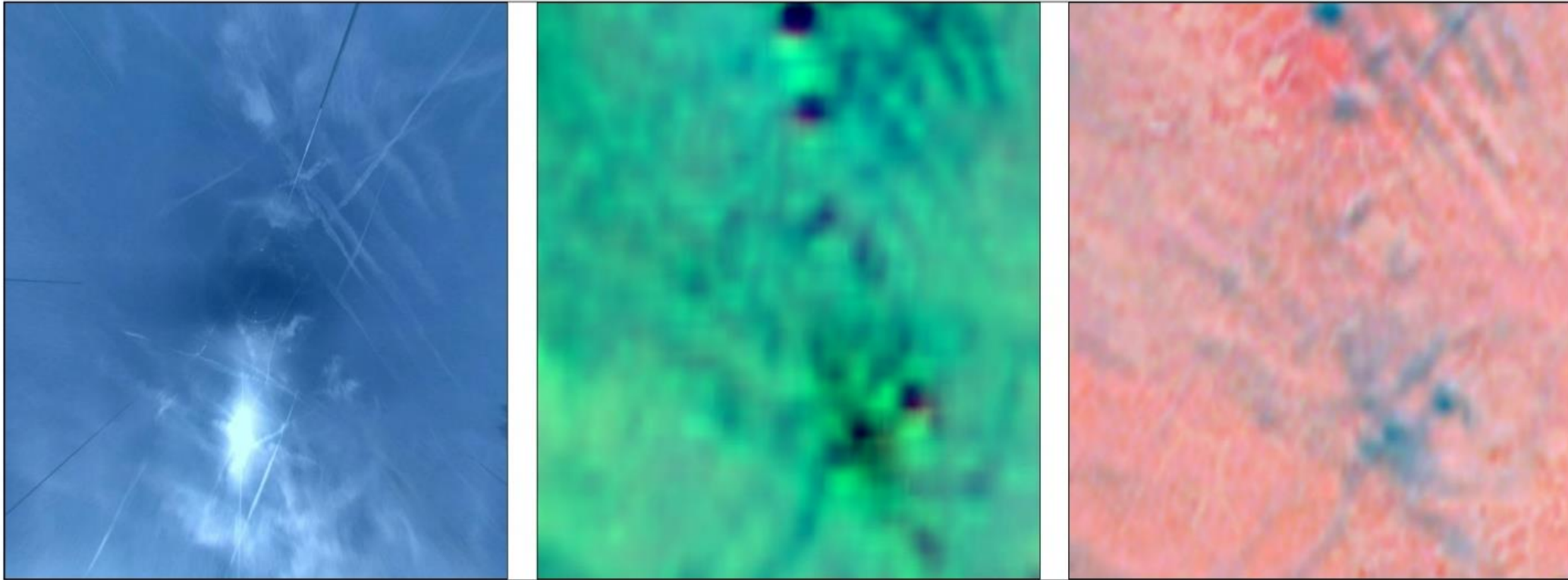


Results



Future Work: Collocation with Geostationary Satellite

- ❑ We are working on the **collocation** of **ground camera** images with **geostationary** satellites (MTG)
- ❑ This could help to **improve/optimize the attribution task on the satellite**
- ❑ Would allow to **build long sequences of observed contrails** that form and are attributed using the ground camera and tracked with the satellite





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Thank you!

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