E-CONTRAIL

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Advancing Contrail Detection Methods Over European Skies

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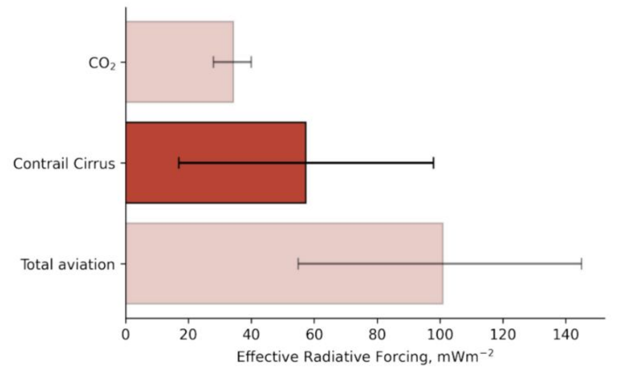
Abstract

Under particular atmospheric conditions, aircraft water vapor emissions can evolve into **enduring formations**, known as **contrails**, wherein they entrap the long-wave infrared radiation emitted by the Earth's surface modifying, consequently, the temperature structure within the lower atmosphere. This phenomenon, linked to **global warming**, underscores the need for studying **contrail environmental impacts**. Achieving this requires accurate methods to identify formation patterns and monitor size, splitting, and evolutionary dynamics of these features. The present study introduces a novel approach for achieving **contrail detection** in Multispectral Satellite Imagery based on linear structure considerations and temporal dynamic analysis. The assessment of experimental results relies on images acquired over **Europe** at specific instances when contrails were visible, leveraging the high temporal resolution provided by the geostationary satellite **Meteosat** Second Generation (MSG).

Motivation

★ Contrais are **artificial cirrus clouds** form by aircraft emissions and characterized by a distinctive linear shape.

★ In areas where **persistent contrails** form, called **Ice Supersaturated Regions** (ISSR), wind can cause them to spread and merge, creating a broader cloud coverage known as **Aviation-Induced Cloudiness** (AIC)



The proportion of total aviation ERF caused by Contrail Cirrus [1]

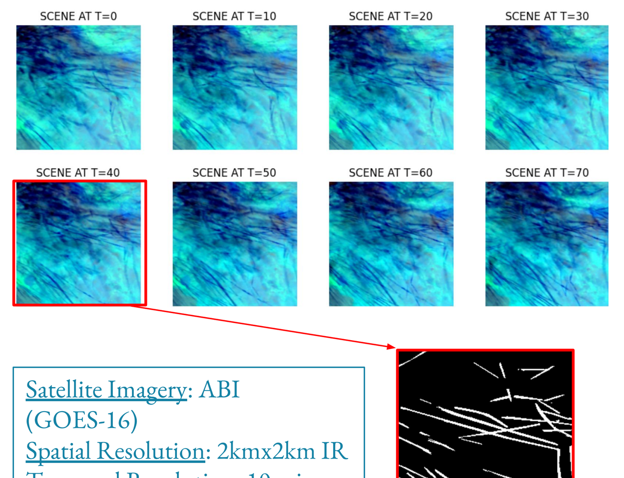
★ Persistent contrails are the **primary contributors** among aircraft emissions to **negative climate impact**, surpassing CO2 and NOx emissions.

★ **Contrail detection methods** are necessary for locating the ISSR and devising **aircraft rerouting** strategies to minimize persistent contrail formation.

★ **Contrail tracking methods** are essential for gaining a deeper **understanding** of contrail formation and evolution dynamics.

Data

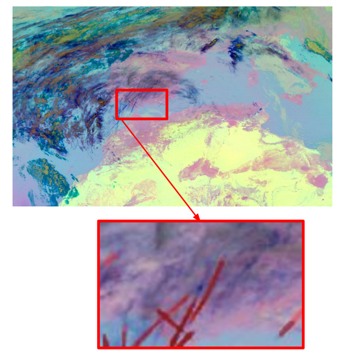
TRAINING DATASET: *OpenContrails [2]*



Satellite Imagery: ABI (GOES-16)
Spatial Resolution: 2kmx2km IR
Temporal Resolution: 10 min
Total number of scenes: 22,410
Duration of the scenes: 70 min (8 images)
Geographical coverage: America

TEST DATASET: *Ours*

We have created a dataset with MSG (Meteosat Second Generation) Images for initial tests until MTG (Meteosat Third Generation Images are released



Satellite Imagery: SEVERI (MSG3)
Spatial Resolution: 3kmx3km IR
Temporal Resolution: 15 min
Total number of scenes: 28
Duration of the scenes: 12 hours (49 images)
Geographical coverage: Middle Europe and North Africa

CONTRAIL VERIFICATION DATA SOURCES:

❑ ADS-B: Air traffic data
❑ ECMWF ERA5: Wind velocity and Humidity values

Methods

Preprocessing Procedures

FALSE-COLOR IMAGE SCHEME *(GOES-16 ABI BANDS)*

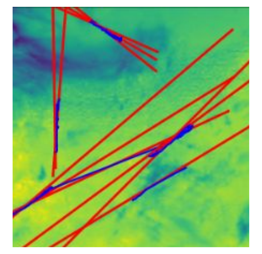
Ash RGB Recipe

Color	Band / Band Diff. (µm)	Min – Max, Gamma	Physically Relates to...	Small contribution to pixel indicates...	Large contribution to pixel indicates...
Red	12.3 – 10.3	-6.7 to 2.6 K 1	Optical depth / cloud thickness	Thin clouds	Thick clouds, ash plume
Green	11.2 – 8.4	-6.0 to 6.3 K 1	Particle phase/size	Large water or ice particles	Small water or ice particles, sulfur dioxide gas
Blue	10.3	243.6 - 302.4 K 1	Temperature of surface	Cold surface	Warm surface

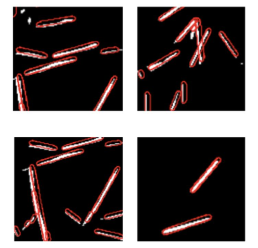
Ash Composite Brightness Temperature Channels [3]

CRIT *(Contrail Instance Retrieval Tool) - Ours*

1. LINEARIZATION



2. CONTOURING



The system utilizes two main procedures: (1) a Hough-based technique for extracting advected flight trajectories, and (2) a sequence of Morphological Operations aimed at segmenting each individual contrail instance from the binary mask.

Multi-Layer Spatio-Temporal Contrail Detection Ensemble

➔ **Single-Frame Model Fusion Layer:**

- **Models**: Two SoTA Instance Segmentation models, Mask-RCNN and YOLOv8, alongside the one of the top-performing single-model in the Google Contrail Competition [5], Unet with CoaT (*Co-scale Conv Attentional Image Transformers*) backbone, are trained for single-frame contrail detection independently.

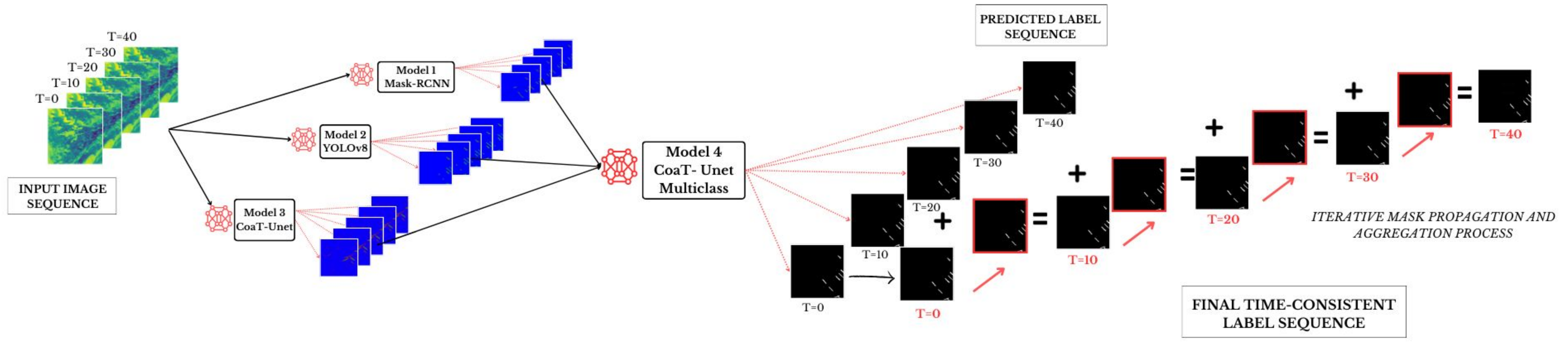
**Temporal consistency across the sequence is not guaranteed within this layer.*

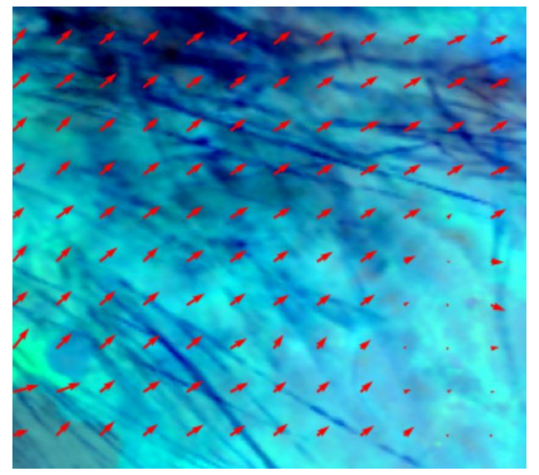
➔ **Label Refinement Layer:**

- **Model**: In this phase, a new Coat-Unet is deployed. Unlike preceding models, this is trained to perform a multiclass segmentation task. The goal is to make the model learn the existing differences within the image between the true contrails and the false positive detections found in the previous step.
- **Informed predictions**: The final masks from the previous layer are incorporated as extra input for this model. This enables the model to concentrate on the classification task to refine the labeling process.

➔ **Temporal Consolidation Layer:**

- **Motion vectors:** The wind velocity vectors between frames are estimated solving the Optical Flow equations with Lucas-Kanade method, enabling to calculate contrail displacement between frames.
- **Mask propagation:** Predicted masks are propagated in time using the optical vector field. At each time step, the predicted mask is merged with the mask propagated from the previous time step, facilitating the identification of newly formed contrails while maintaining temporal consistency throughout the detection sequence.

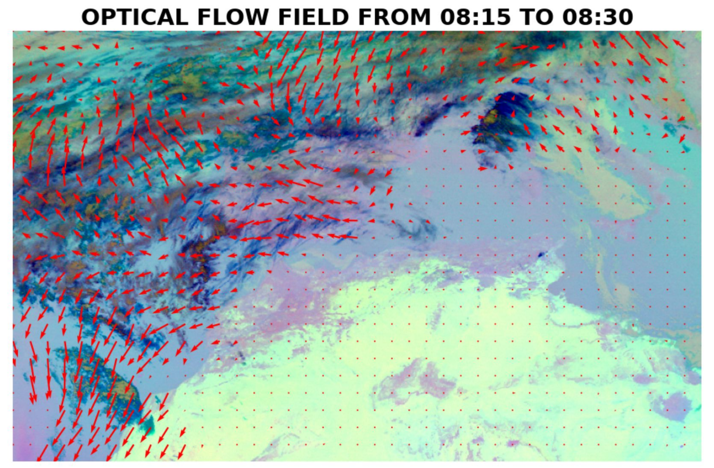




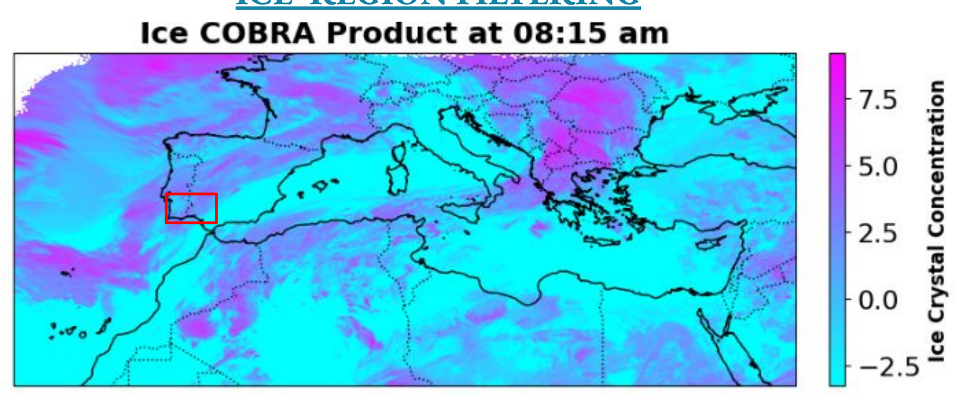
THE MOTION VECTORS BETWEEN TWO CONSECUTIVE FRAMES

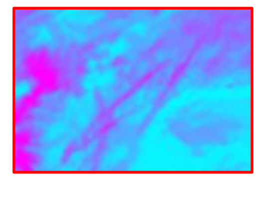
Experimental Scenario in Europe

★ **Date**: 26th of January 2024
★ **Temporal window**: 00:00 - 12:00
★ **Spatial Coverage**: *latitude: [24,49] , longitude: [-59,39]*



ICE REGION FILTERING





COBRA (Covariance-Based Retrieval Algorithm) is a Multispectral Algorithm that we have employed to compute the spectral signature of ice in each scene.

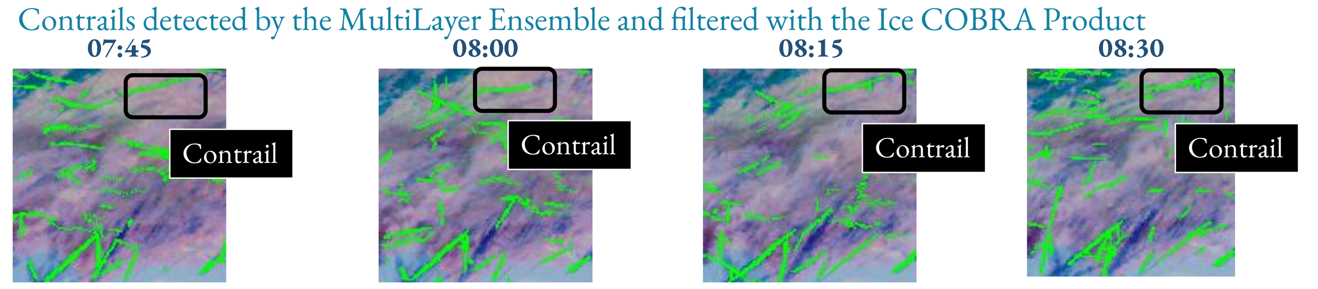
In order to the minimize the false positives, contrails detected by the model with low spatial gradient magnitude in the Ice COBRA product have been discarded.

CONTRAIL TRACKING QUALITATIVE RESULTS

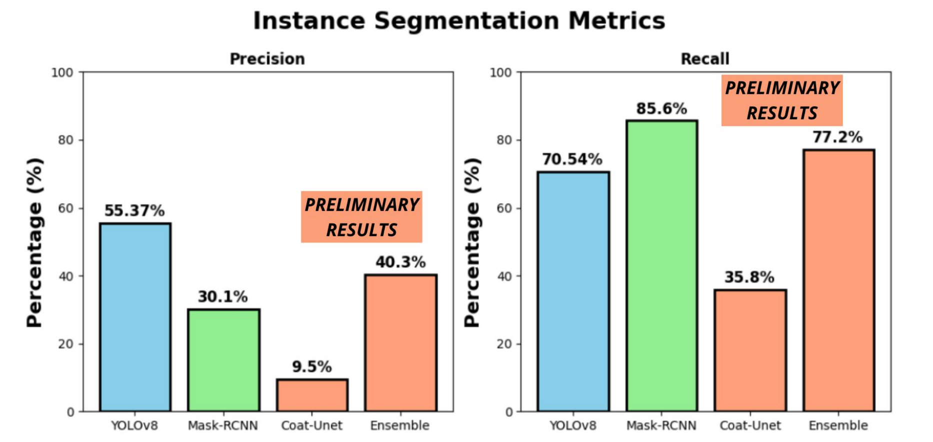
South of Spain 26/01/2024

Contrails detected by the YOLOv8 Model

Contrails detected by the MultiLayer Ensemble and filtered with the Ice COBRA Product



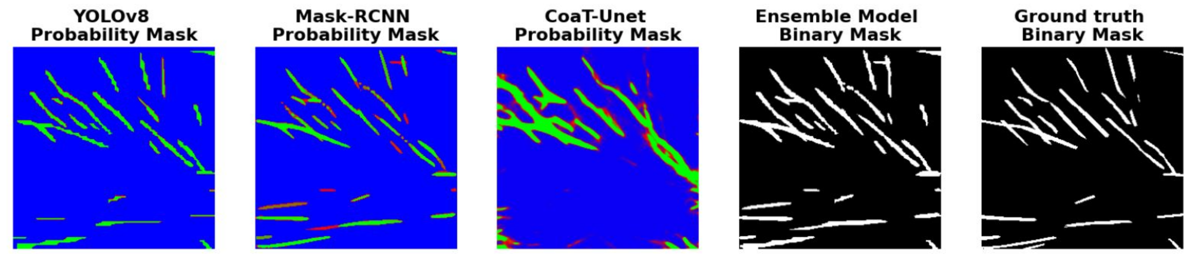
Model Results



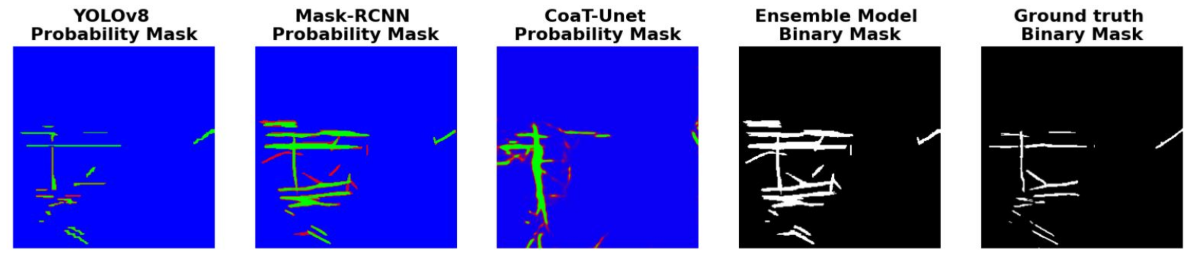
**The optimal performance levels for both the Coat-Unet Model and the final Multi-Layer Ensemble have not yet been attained and are anticipated to be achieved in the near future.*

Segmentation Performance Examples:

UTM (Universal Transverse Mercator) Image Coordinates: *[4195883.0, -2047.418579, 614459.6875, 1877.985962]*
Timestamp: *05/03/2020 12:40:00*



UTM (Universal Transverse Mercator) Image Coordinates: *[4692273.5, -2042.555176, 528789.0625 , 1884.564697]*
Timestamp: *09/04/2019 14:00:00*



Conclusions and Future work

➔ From our experiments we found **Instance Segmentation models** exhibit superior capability in the task of detecting individual contrails and therefore can be more suitable for tracking.

➔ **Ensemble methods** have demonstrated in numerous studies to outperform single-model detections. Our future work will be focused on finish the ongoing experiments and testing alternative ensembling techniques.

➔ **Temporal consistency** can be ensured by utilizing the optical flow field. In upcoming investigations, we aim to incorporate this approach into earlier stages of the model to refine the training process and enhance the final masks.

➔ The current results from MSG data are satisfactory, but we anticipate better outcomes with **MTG (Meteosat Third Generation)**, due to its higher resolution, once it's made available.

➔ Future work will utilize **COBRA products** alongside ash RGB images for training.

References

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[3] "GOES Ash RGB Quick Guide," 2017. [Online]. Available: https://rammb.cira.colostate.edu/training/visit/quick_guides/GOES_Ash_RGB.pdf..

[4] H. Brenot, M. Soler, I. Ortiz Abuja, P. de Buyl, R. Vinuesa, and E-CONTRAIL team, "The Covariance-Based Retrieval Algorithm for contrails detection using geostationary imagers," 4th ECATS conference, Delft, Netherlands, 24-26 Oct. 2023.

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