Satellite-Based Quantification of Contrail Radiative Forcing over Europe

Irene Ortiz[1], Ermioni Dimitropoulou[2], Pierre de Buyl[2], Nicolas Clerbaux[2], Javier García-Heras[1], Amin Jafarimoghaddam[1], Hugues Brenot[3], Jeroen van Gent[3], Klaus Sievers[4], Evelyn Otero[5], Parthiban Loganathan[5], Manuel Soler[1]

[1] University Carlos III of Madrid
[2] Royal Meteorological Institute of Belgium
[3] Royal Belgian Institute of Space Aeronomy
[4] Klaus Sievers Services
[5]KTH Royal Institute of Technology

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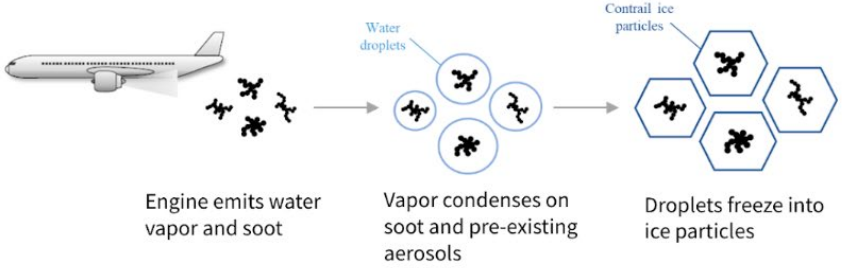
SESAR Innovation Days 2024
12 - 15 November 2024. Rome

Non-C02 Aviation Effects

Condensation trails (Contrails) trails form when water vapor emitted by aircraft engines freezes producing a visible trail behind the aircraft



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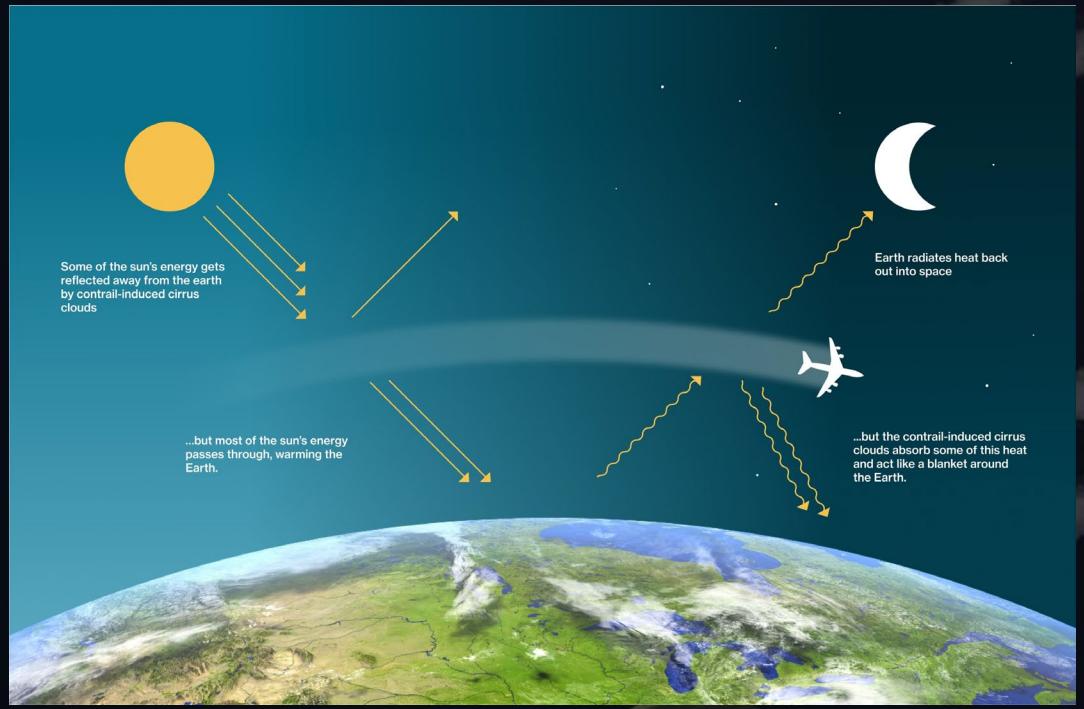
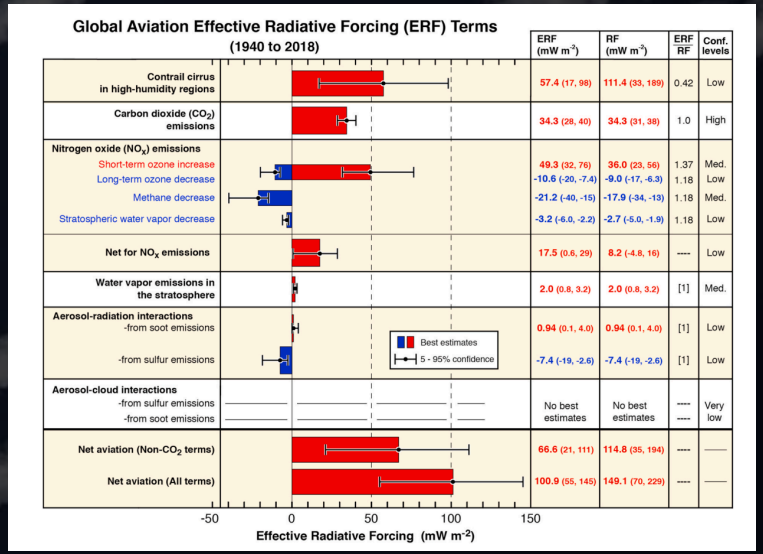
Non-C02 Aviation Effects

Contrail radiative effects lead to alterations in the temperature of the atmosphere



Lee et at., 2021



Precisely quantifying these radiative effects is essential for understanding the climate impacts of aviation.

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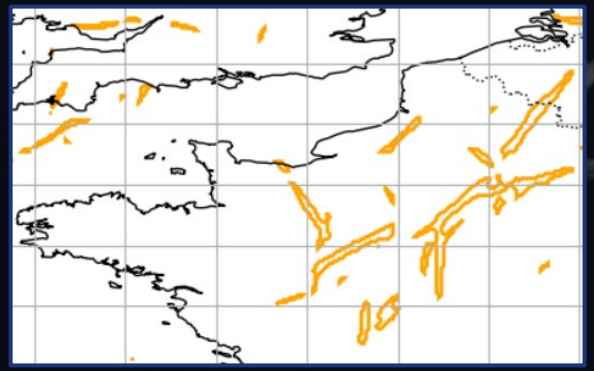
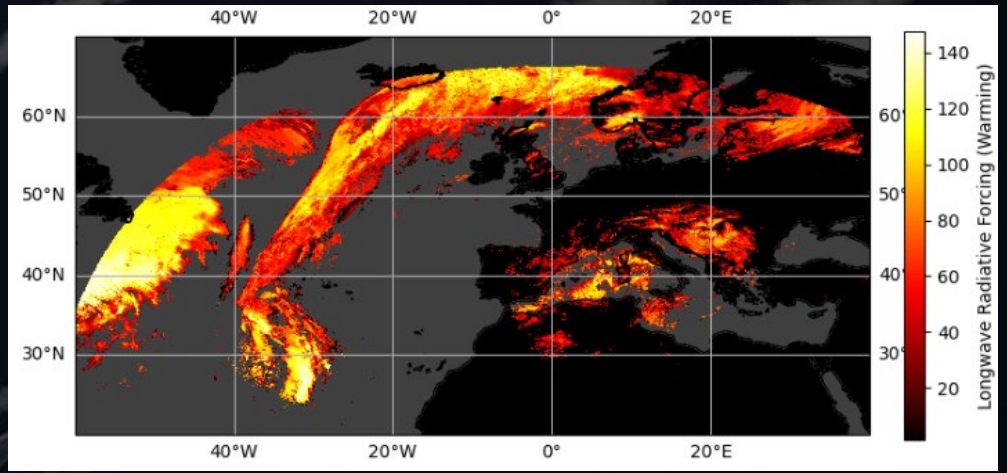
How do we quantify Contrail Impacts?

Contrail Detection → Radiative Forcing Calculation





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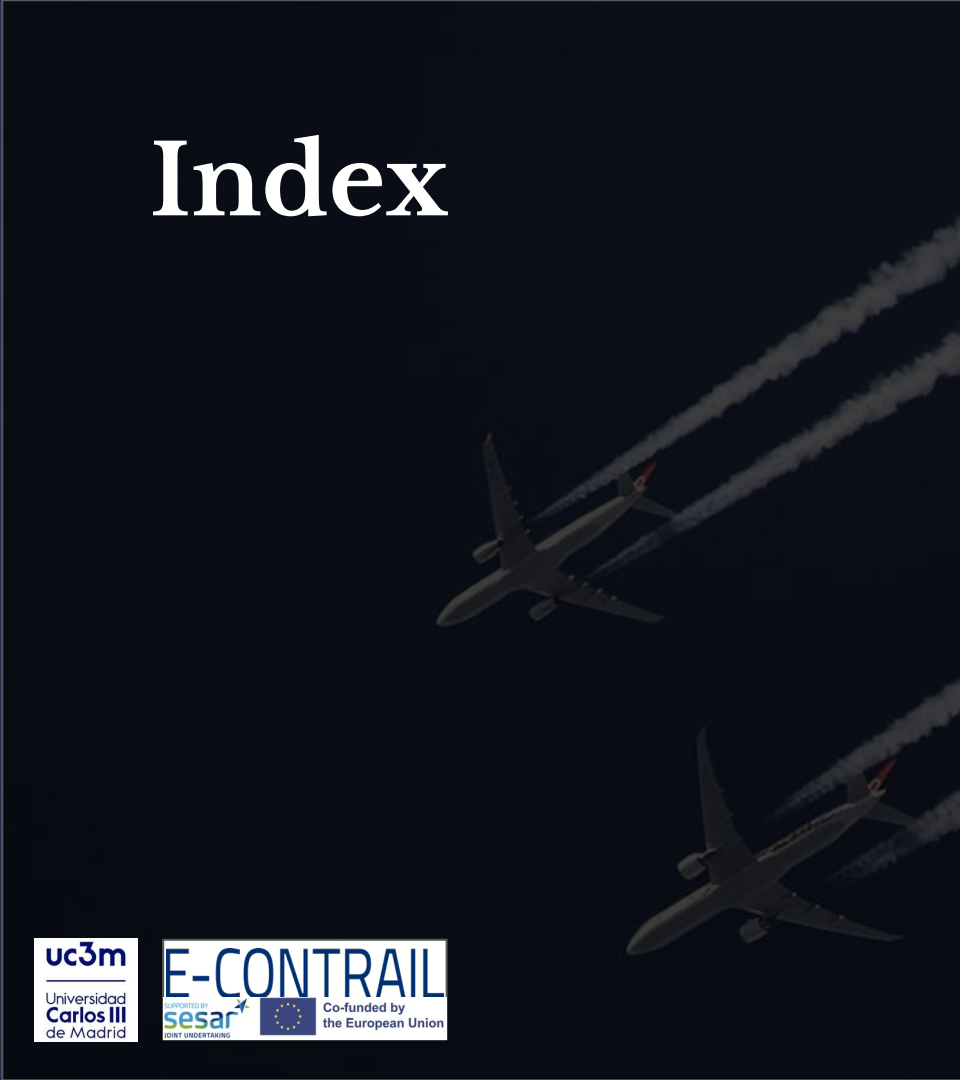

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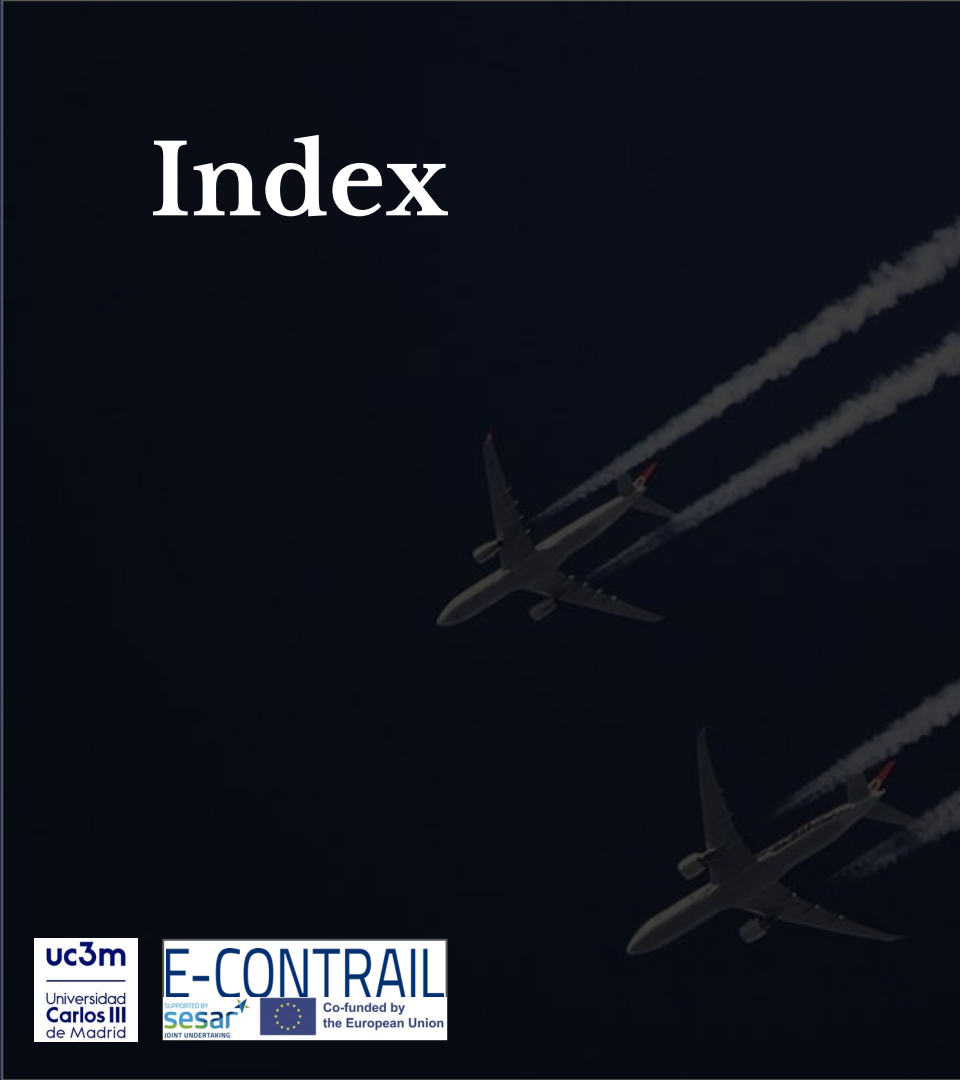

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1. Contrail Detection

Contrail Detection using AI

- Allows for larger - scale analysis
- Strongly depends on data availability

State of the Art on Contrail Detection

Before 2021

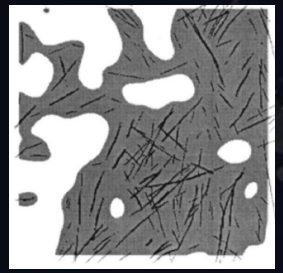
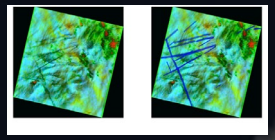
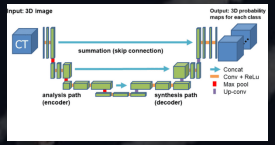


Image Processing Algorithms and first Neural Networks

Mannstein et at., 2012

2021 - 2023

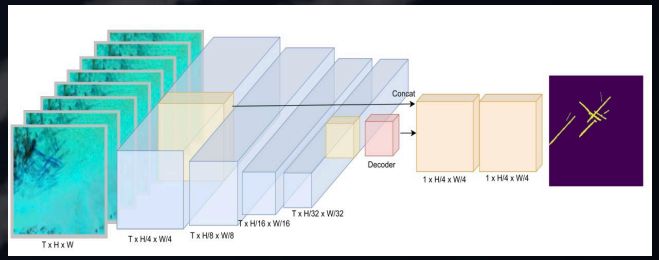




More advanced Networks but still not enough labelled data

McCloskey. et al, 2021

2023 & 2024



Advanced Networks and a large labelled dataset available

Ng. et al, 2023

Open Problems:

- European Data
- Performance Metrics
- Instance Segmentation
- Associated RF

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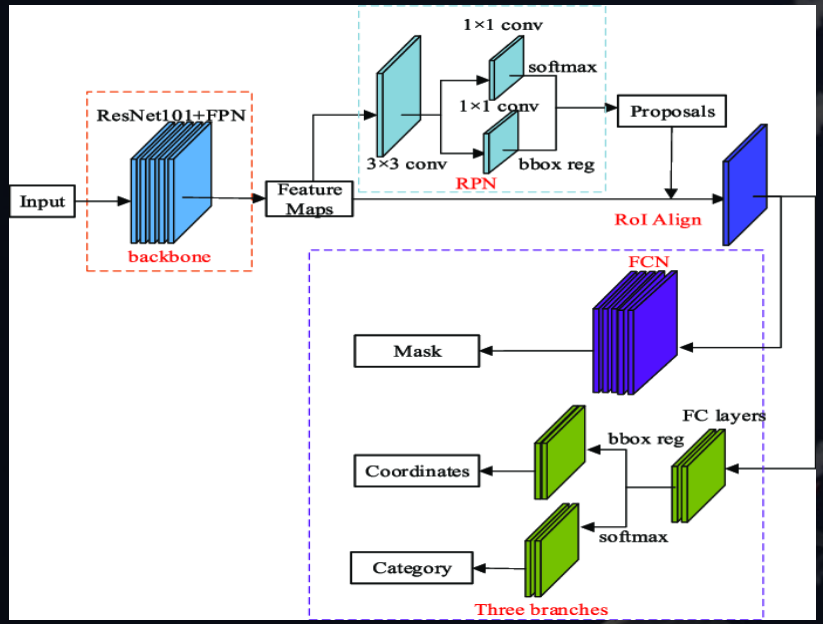
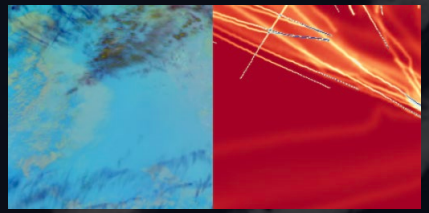
1. Contrail Detection

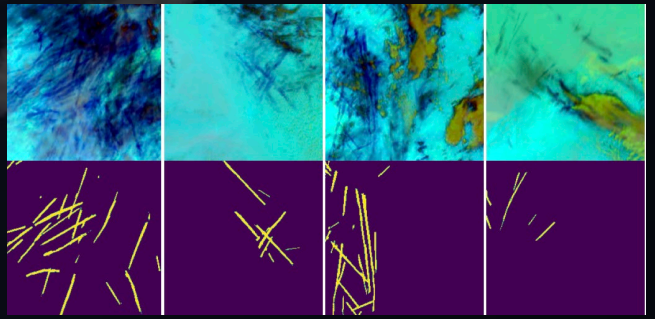
Method: Automize the detection of contrails over large amounts of data using Neural Networks



Training Data:

GOES-16 Ash RGB images obtained from the OpenContrails Google Dataset (Ng. et al, 2023)





Still lacks a labelled dataset in Europe

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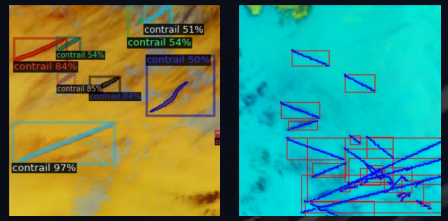
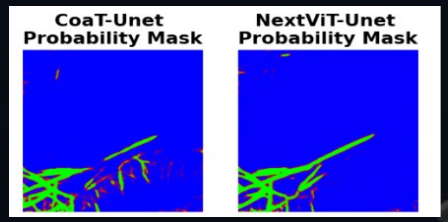
1. Contrail Detection

Models Trained:

- Instance segmentation (MaskRCNN & YOLO11x)



- Semantic segmentation (CoaT & NeXtViT)



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1. Contrail Detection

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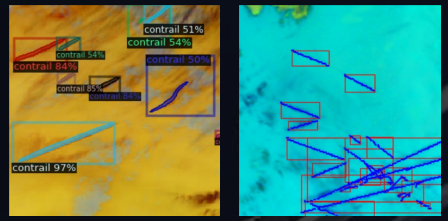

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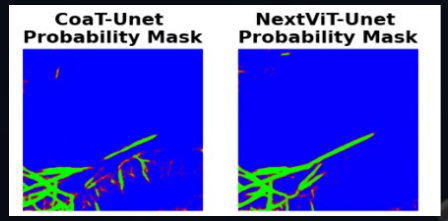
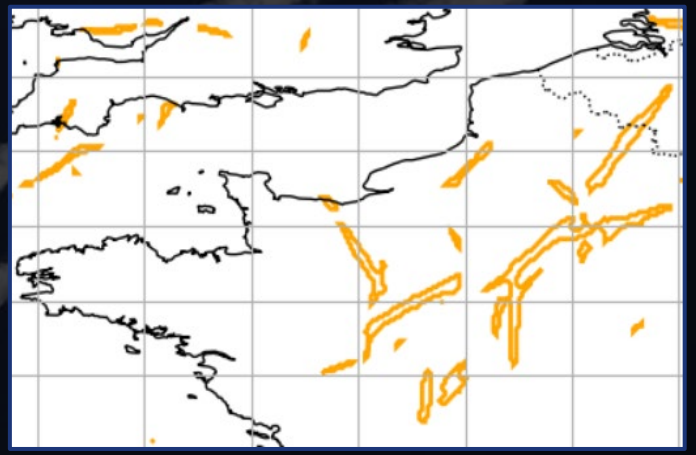


Detections on SEVIRI (Meteosat Second Generation):

- Interpolation to 2km resolution (preprocessing)
- Sliding window detections
- Polygon conversion (postprocessing)



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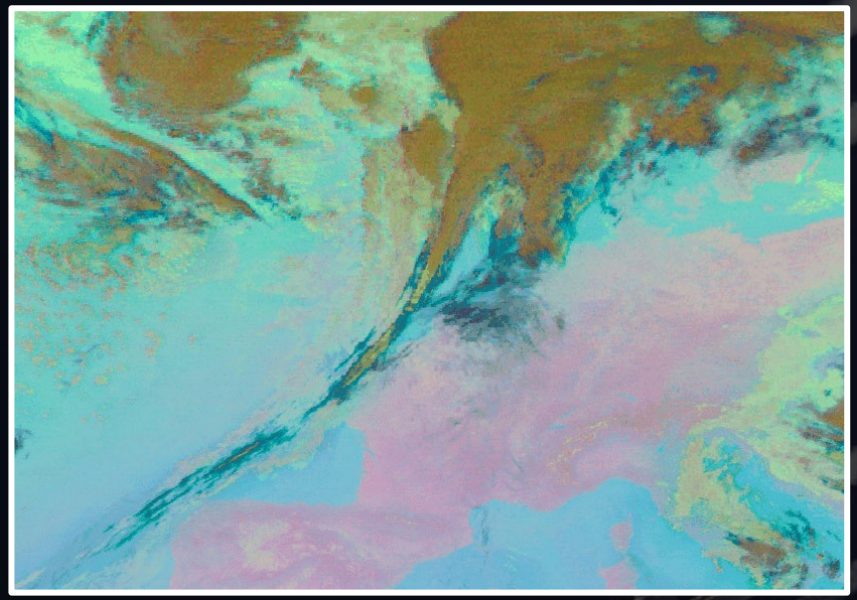
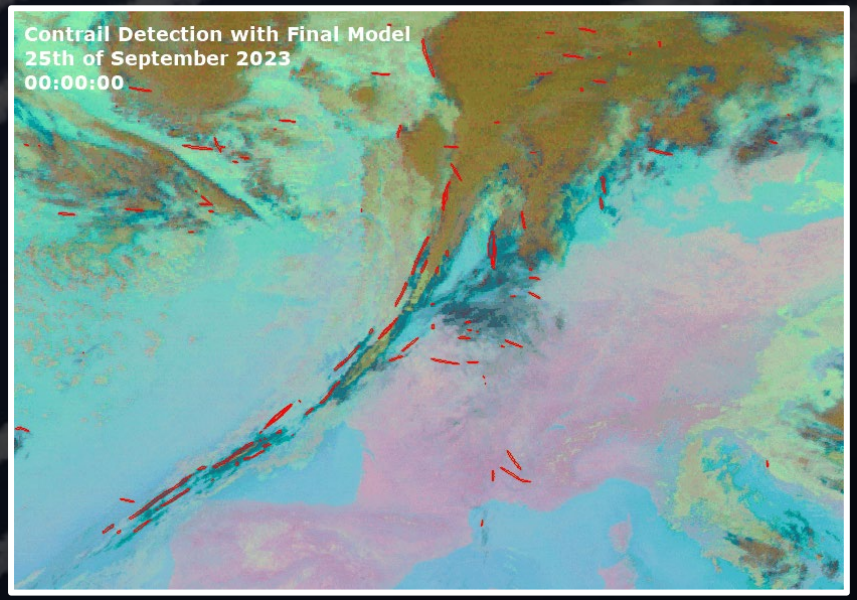
1. Contrail Detection

Visual example of performance on MSG: Contrails Detected on the 25th of September of 2023 from 00:00 to 10:00 over France and neighbouring regions





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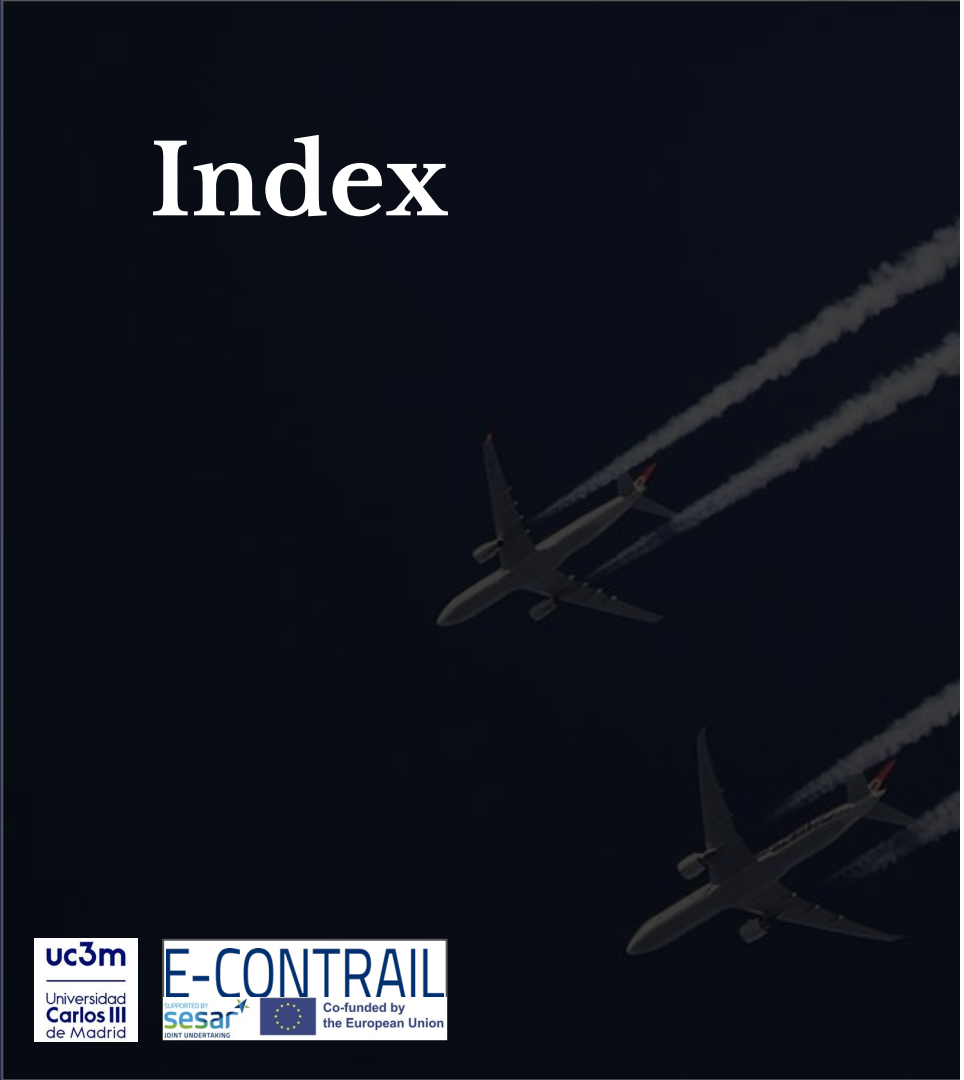

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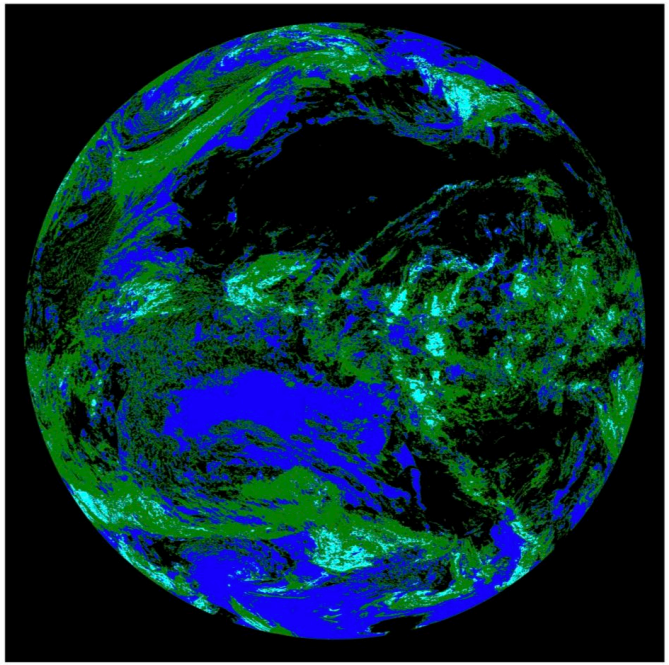
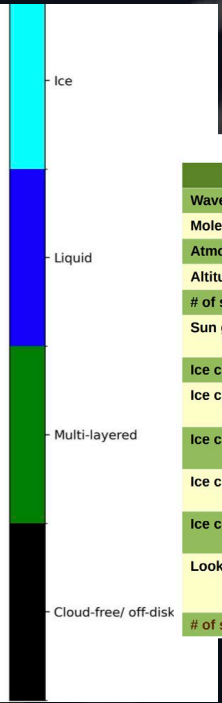
2. Radiative Forcing Calculations

Cloud Property Retrievals

Cloud Optical Thickness, Cloud Phase, Cloud Effective Radius & Cloud Top Pressure retrieved with Optimal Cloud Analysis (OCA)

→ **Calculation of RF using libRadtran Radiative Transfer Model**





Category no.1/ Ice cloud above ocean surface

	Solar	Thermal
Wavelength range	250 nm – 5000 nm	2500 nm – 98000 nm
Molecular absorption param.	(default)	Fine (except LUT3, which is medium)
Atmospheric profile	U.S. Standard	U.S. Standard
Altitude	TOA and BOA	TOA and BOA
# of streams	16	16
Sun geometry	SZA= 0° to 80° [step 5°] **Total: 17 values**	
Ice cloud properties	Yang et al., 2013	Yang et al., 2013
Ice crystal shapes	Moderately rough aggregates of 8-element columns	Moderately rough aggregates of 8-element columns
Ice cloud optical thickness	0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 1, 2, 3, 5, 10, 30 **Total: 13 values**	0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 1, 2, 3, 5, 10, 30 **Total: 13 values**
Ice cloud effective radius	5, 10, 15, 20, 40, 60, 80 μm **Total: 7 values**	5, 10, 15, 20, 40, 60, 80 μm **Total: 7 values**
Ice cloud height	10 km **Total: 1 value**	6 to 13 km [step 1km] **Total: 8 values**
Look Up Tables CAT1	Cox and Munch BRDF Wind speed = 5 m/s	Sea Surface Temperature (SST) 273 to 303 K [step 5 K] **Total: 7 values**
# of simulations	**1.547**	**5.096**

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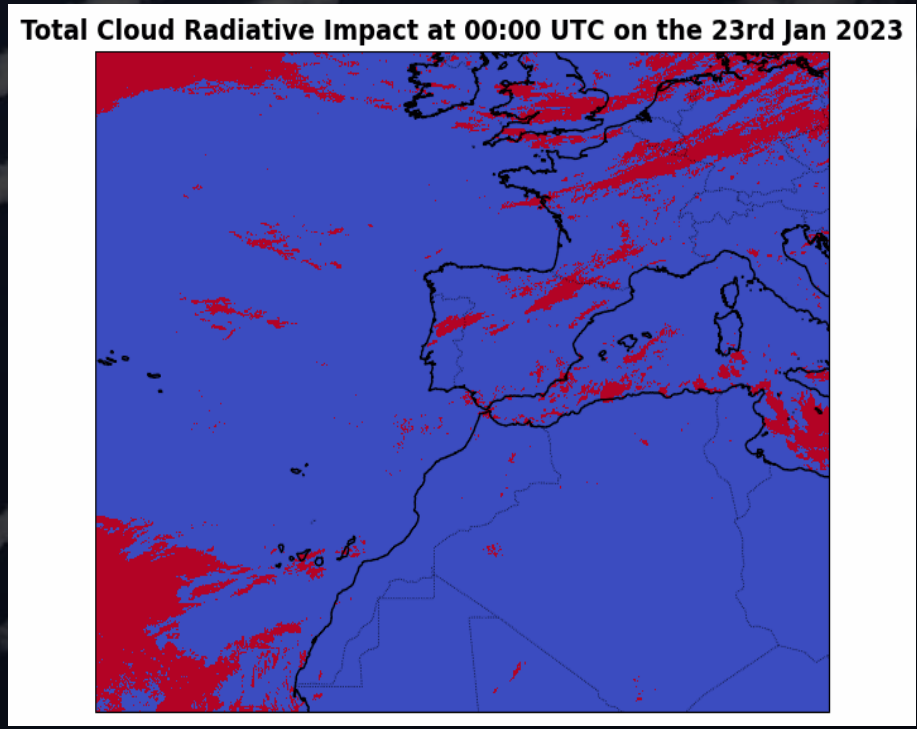
2. Radiative Forcing Calculations

Calculation of solar and thermal fluxes

Parameter interpolation over the LUTs



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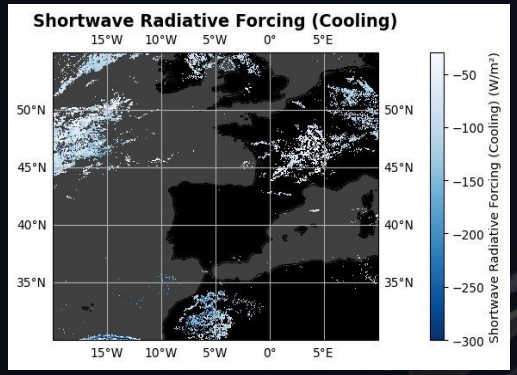
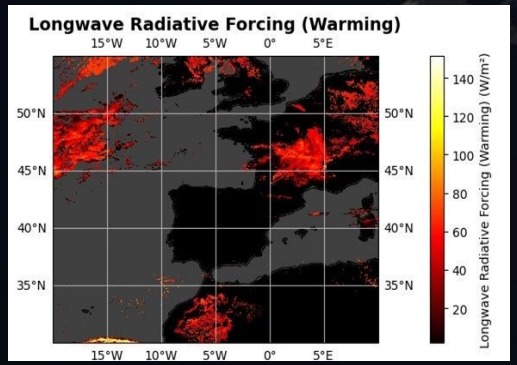
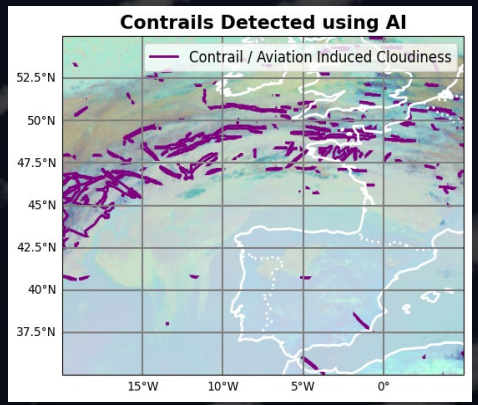
2. Radiative Forcing Calculations

Total Cloud RF estimations

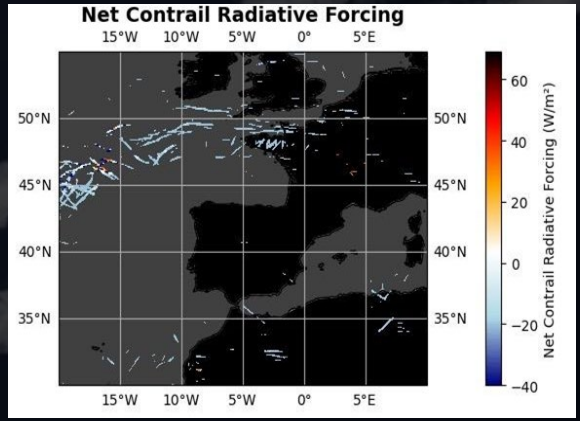




Contrails detected using AI



Final Contrail RF estimations



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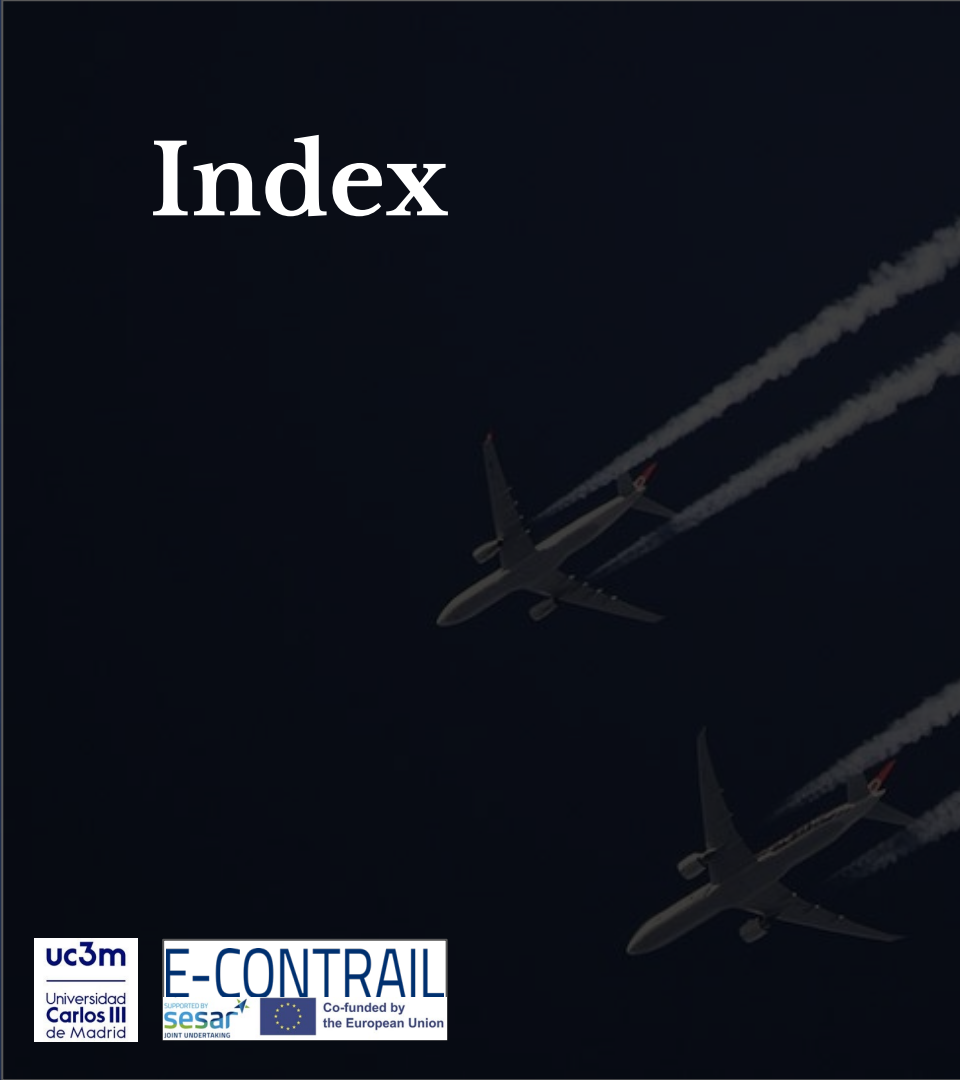
Index



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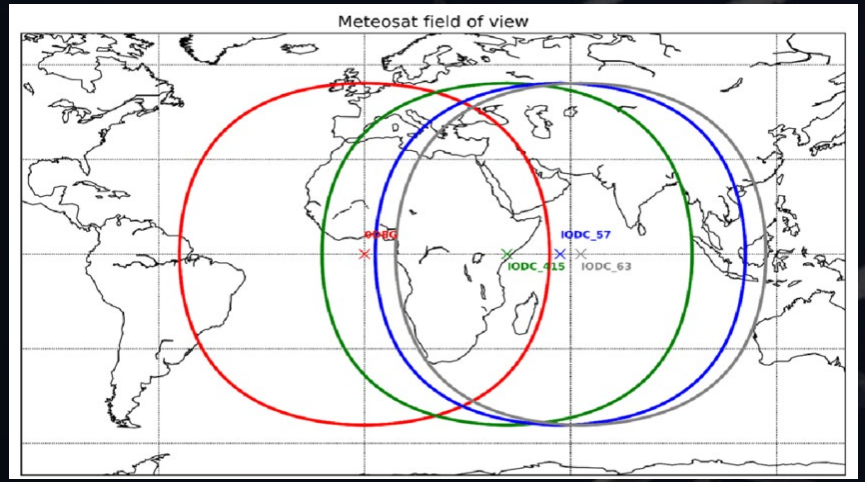
3. Experiment Definition

Time period

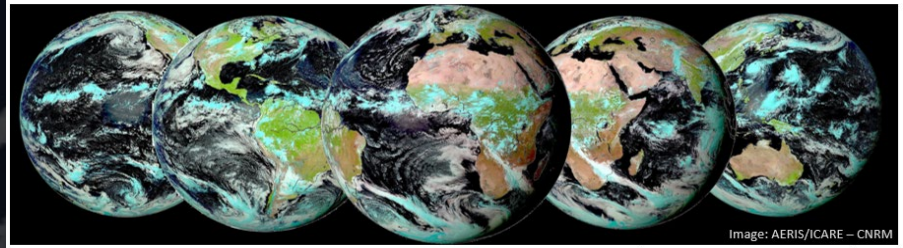
Geographical extent



Data Source

MSG (SEVIRI) Spectral Bands: 8IR & 3VIS

Colour (ash/dust RGB)	GOES-E / ABI	GOES-W / ABI	MSG-11 / SEVIRI	MSG-8 / SEVIRI	HIMAWARI-8 / AHI
RED lin. combo. [channel in µm]	[12.3]^{rad} – [10.3]^{rad}	[12.3]^{rad} – [10.3]^{rad}	[12.0]^{rad} – [10.8]^{rad}	[12.0]^{rad} – [10.8]^{rad}	[12.4]^{rad} – [10.4]^{rad}
GREEN lin. combo. [ch. in µm]	[11.2]^{rad} – [8.4]^{rad}	[11.2]^{rad} – [8.4]^{rad}	[10.8]^{rad} – [8.7]^{rad}	[10.8]^{rad} – [8.7]^{rad}	[10.4]^{rad} – [8.6]^{rad}
Blue lin. combo. [ch. in µm]	[10.3]^{rad}	[10.3]^{rad}	[10.8]^{rad}	[10.8]^{rad}	[10.4]^{rad}



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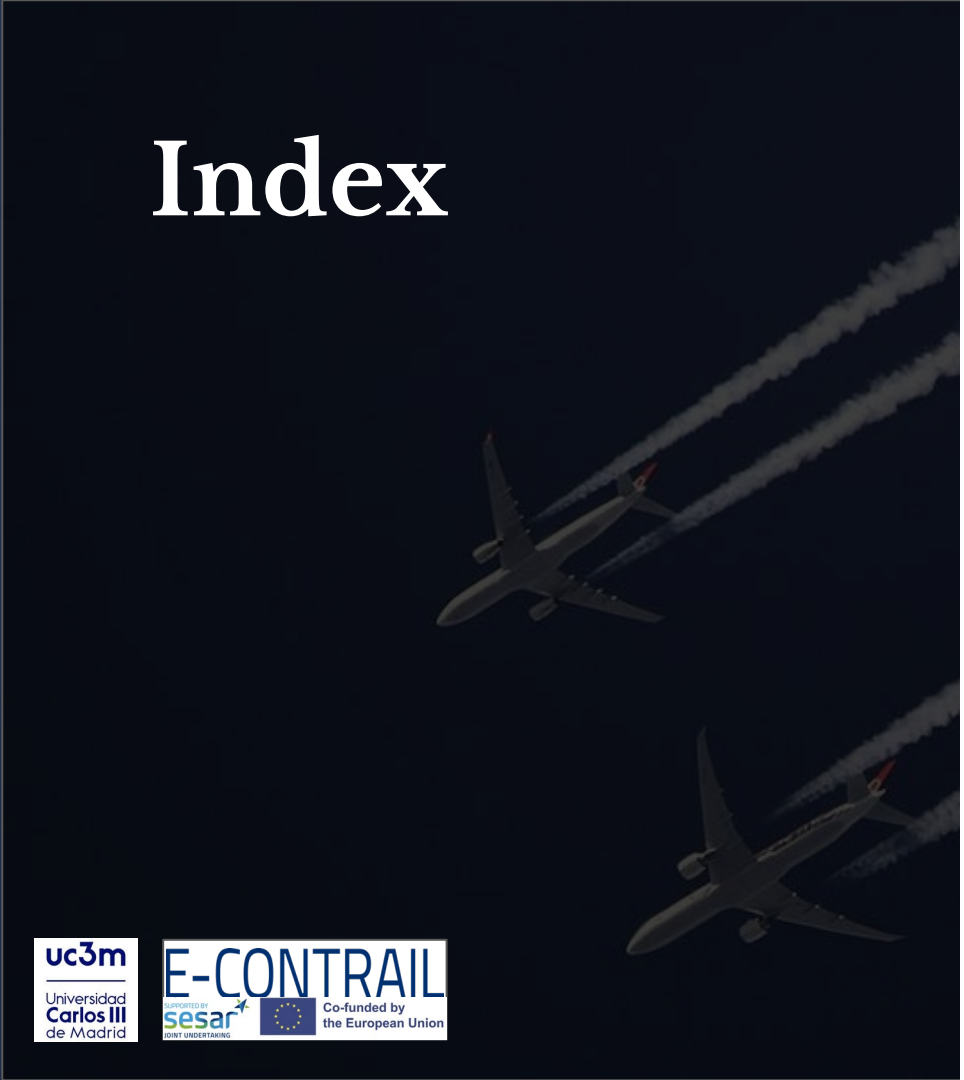

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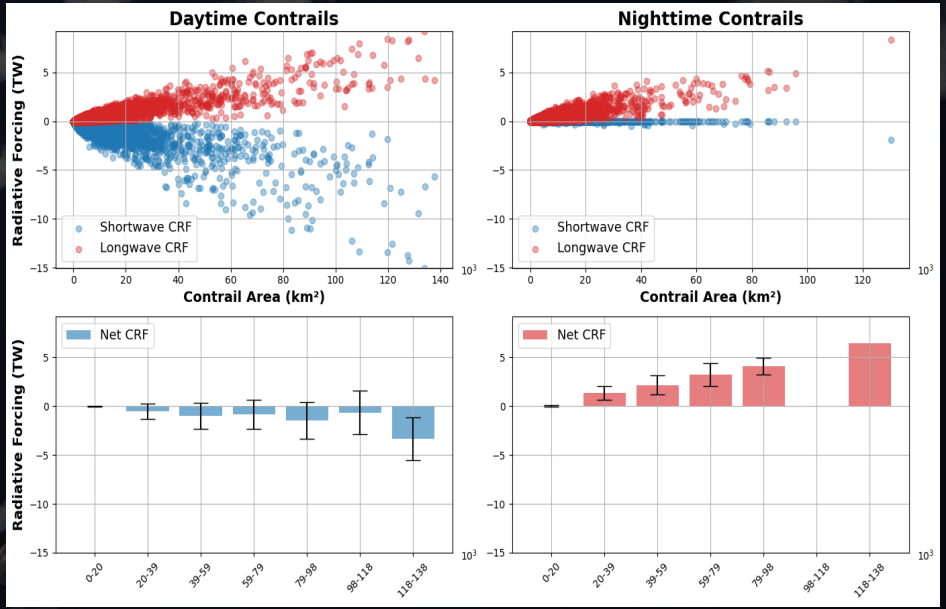
4. Results

Diurnal Patterns

In January, daytime contrails show cumulative CRF values at minimums of -8 TW, while nighttime contrails show positive values and up to 6 TW.

The overall daily impact of the detected contrails is warming due to a larger amount of nighttime contrails, which make up 62% of the total.



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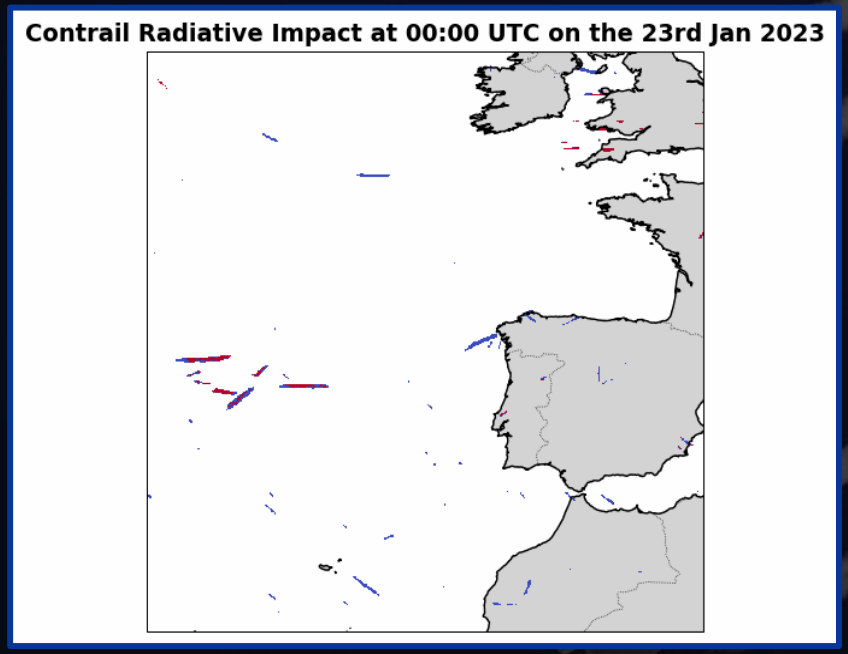
4. Results



The comparison between 2023 and 2024 Data shows:

- A **41.03%** rise in contrail coverage between the two weeks evaluated
- A **128.7%** increase in CRF values, suggesting an increased warming from the additional number of contrails
- A 19.02% increase in total cloud RF, in which CRF only represents ~1%.

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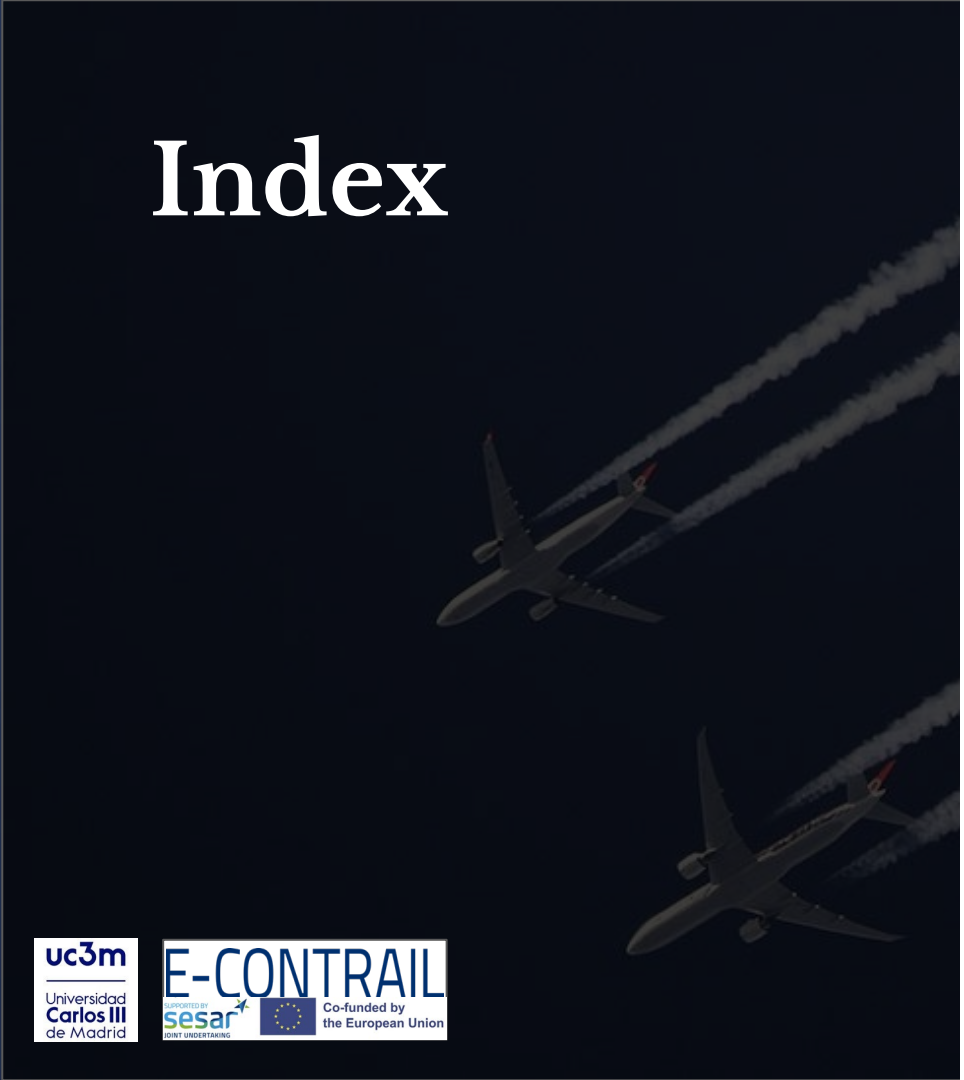

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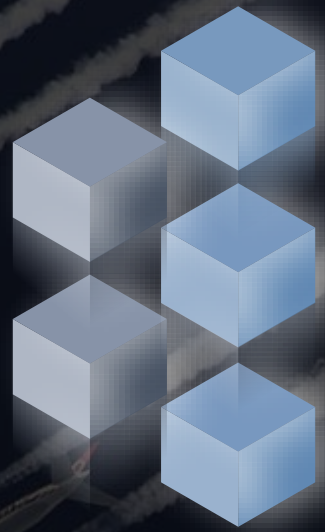
5. Conclusions

Main takeaways:

The methods presented here enable comprehensive large-scale analysis

Further research into the observed trends and over larger time periods is needed



Preliminary Results:

The detected contrails show an overall warming effect throughout the day

Potential increase in contrail cover and warming from 2023 to 2024

The increase in contrail radiative forcing only represents a 1% of the total

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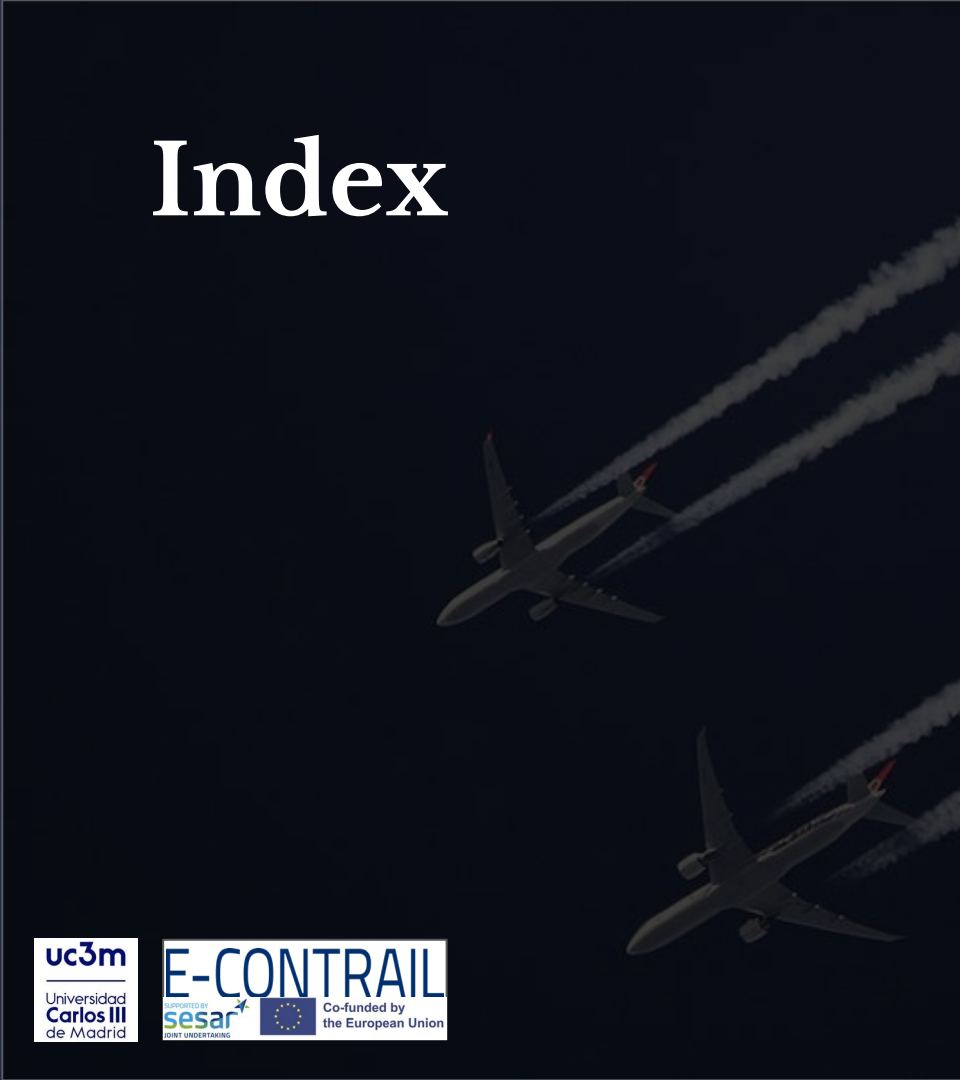

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6. Next Steps

1. Validate Detections

Use a set of labeled data for validating of the model.

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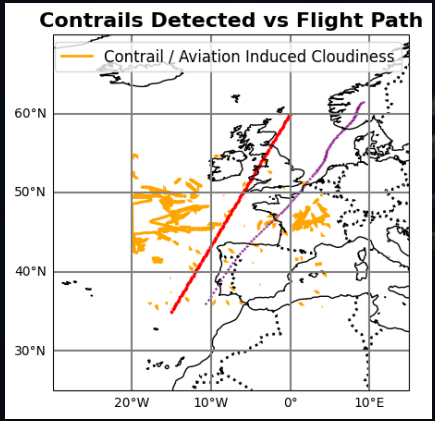
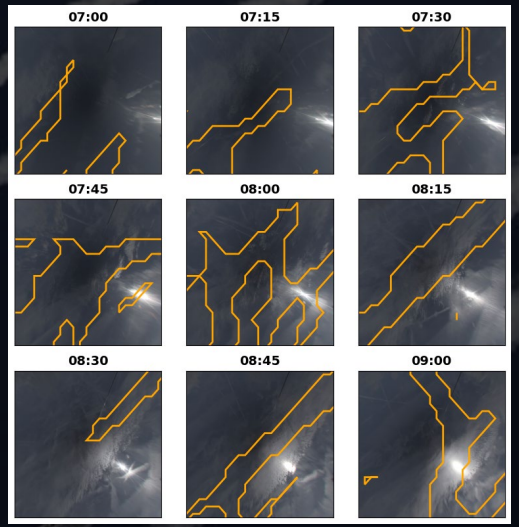
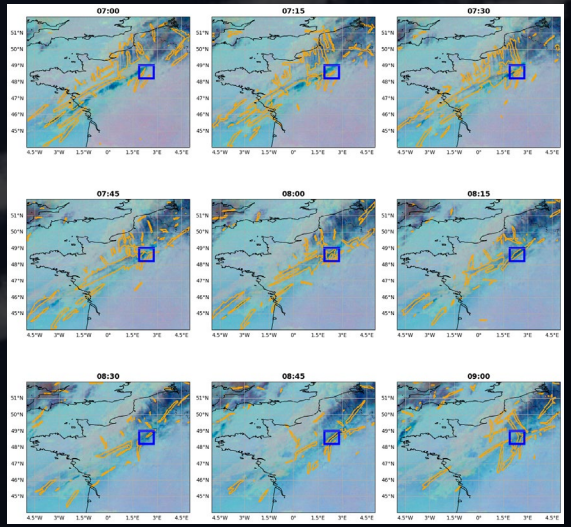
Validation of the Contrails Detected using AI

Validation using ADS-B and weather data



Validation with Ground Camera images





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6. Next Steps

2. Validate RF Calculations
Quantify the errors in the LW and SW RF calculated values.

1. Validate Detections
Use a set of labeled data for validating of the model.

3. Perform an extended experiment
Repeat the study over an extended time period to account for seasonal variations and incorporate additional data.

4. Move from MSG to MTG Data
Take advantage of the higher spatiotemporal resolution of the new FCI onboard MTG Satellites.

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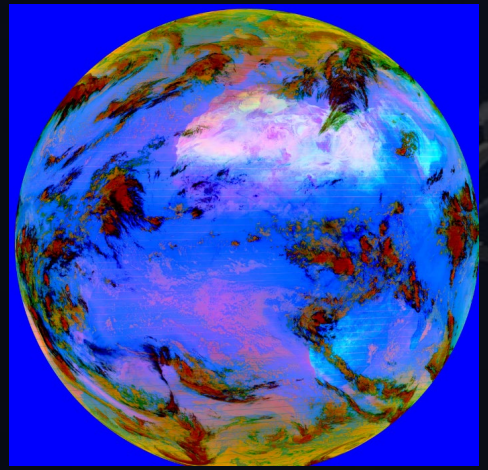
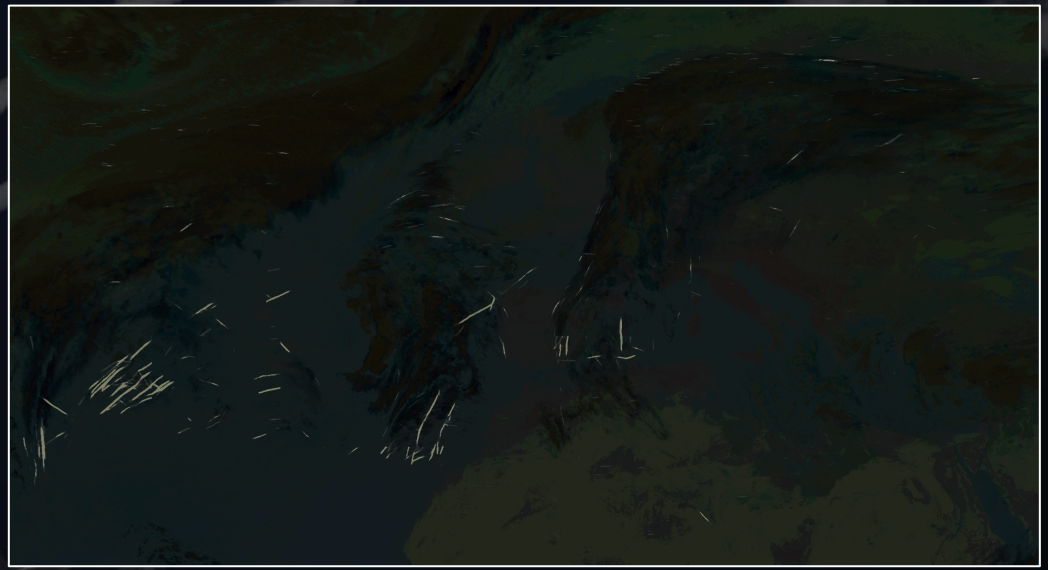
Move from MSG to MTG Data

First MTG FCI Images available in 2024



Contrails Detected on MTG with AI

Results shown for the 10th of October 2024 over the whole field of view of MTG satellites



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6. Next Steps

2. Validate RF Calculations
Quantify the errors in the LW and SW RF calculated values.

1. Validate Detections
Use a set of labeled data for validating of the model.

3. Perform an extended experiment
Repeat the study over an extended time period to account for seasonal variations and incorporate additional data.

4. Move from MSG to MTG Data
Take advantage of the higher spatiotemporal resolution of the new FCI onboard MTG Satellites.

4. Share the RF LUTs and Trained Models
Make available to the community the use of these methods for assessing contrail climate impacts

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Thank you for your attention

Contact information:

irortiza@ing.uc3m.es
www.linkedin.com/in/irene-ortiz-abuja

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