

Collaborative Learning For Intelligent Meteorological Aviation

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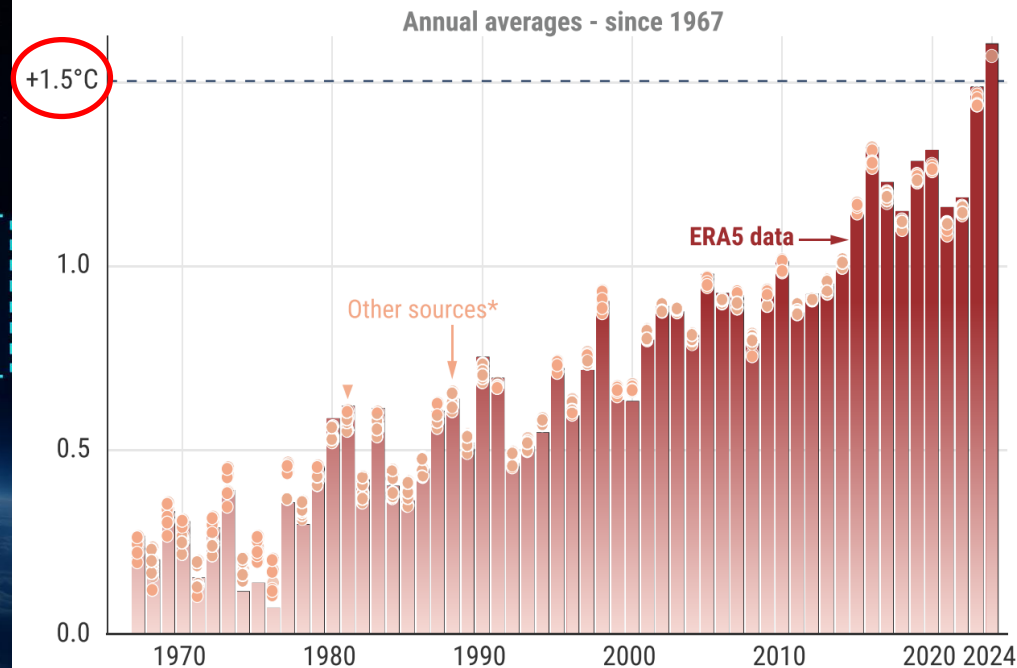
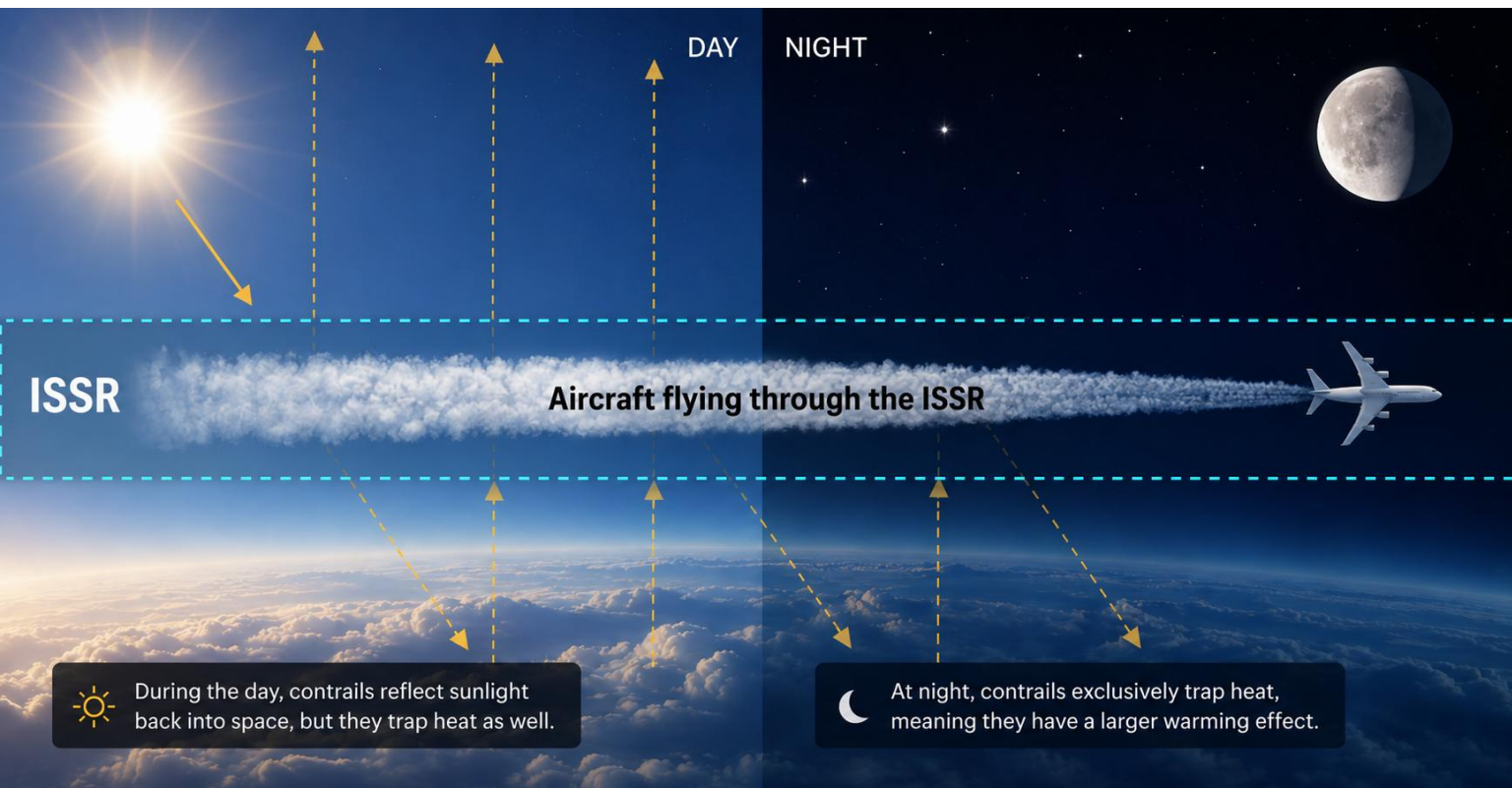
PhD Aerospace Engineering UC3M
Doctoral Meetings 2026
2nd and 3rd June 2026

The main motivation of this study is:

- To predict where **contrails form and persist**, a problem that remains **highly uncertain**.

One of the biggest contributor in climate impact is **contrail**. Also In 2024, the global average temperature **exceeded 1.5°C** above pre-industrial levels for the first time:

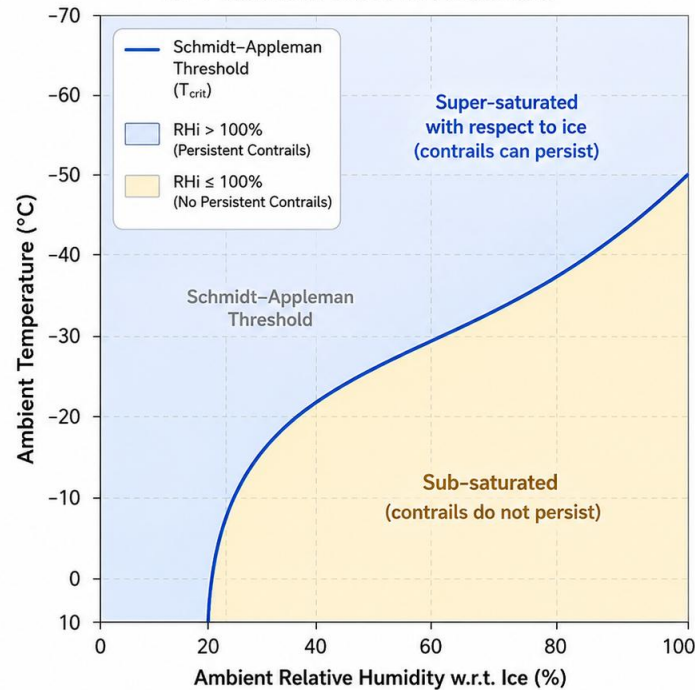
- To use collaborative AI to predict **contrail outbreaks** and estimate their **climate impact**.
- To help aircraft **avoid flying** regions where persistent contrails are likely to form.



An **ISSR** occurs:

- Ambient air is supersaturated with **respect to ice**.
- Relative humidity with respect to ice (RH_i) > 100%.

Schmidt–Appleman Criterion for Persistent Contrail Formation



Note: Above the Schmidt–Appleman threshold (blue region), contrails are likely to persist. Below the threshold (yellow region), contrails are unlikely to persist.



Physical Basis

Contrails form when the ambient relative humidity with respect to ice (RH_i) exceeds 100%.



Global Occurrence

Occurs worldwide, but with strong regional and seasonal variability.



Operational Relevance

Key challenge for avoidance strategies and climate-aware flight planning.

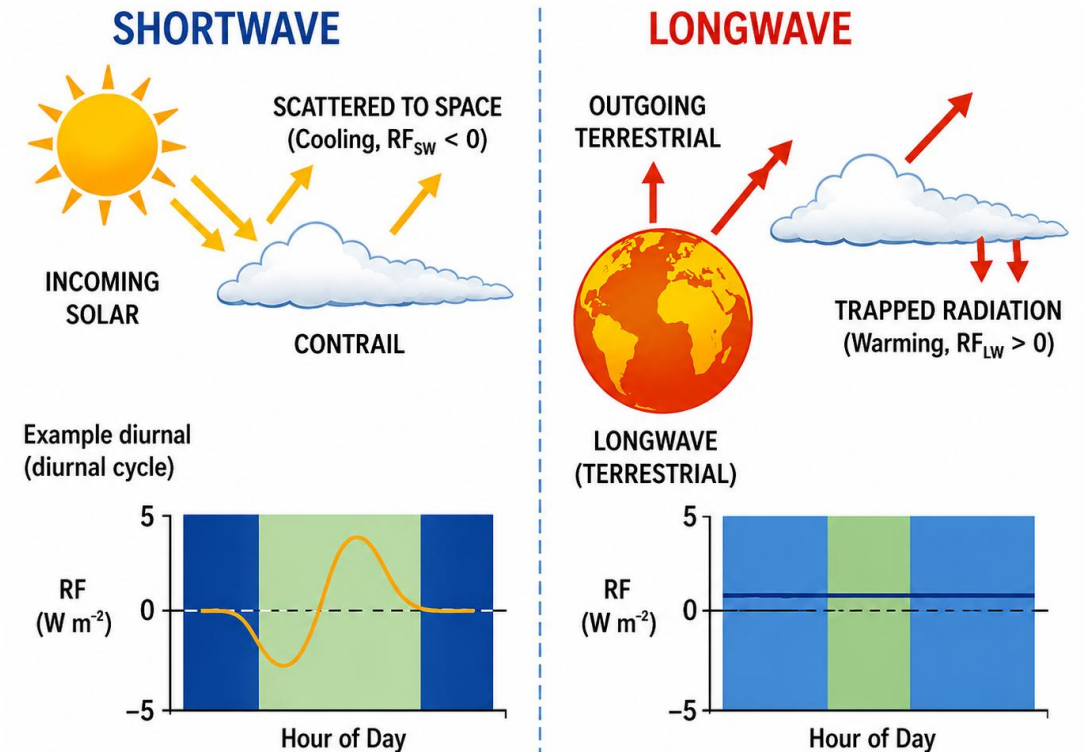
Where Persistent Contrails Form



ISSR typically found in mid- to high-latitude flight corridors.

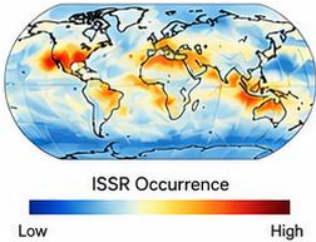
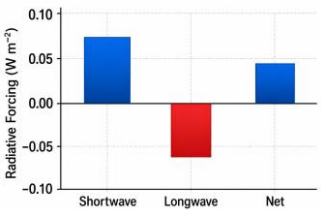
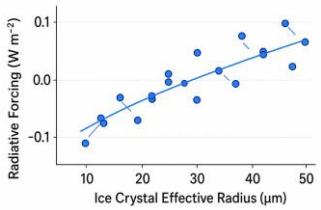
Radiative Forcing is:

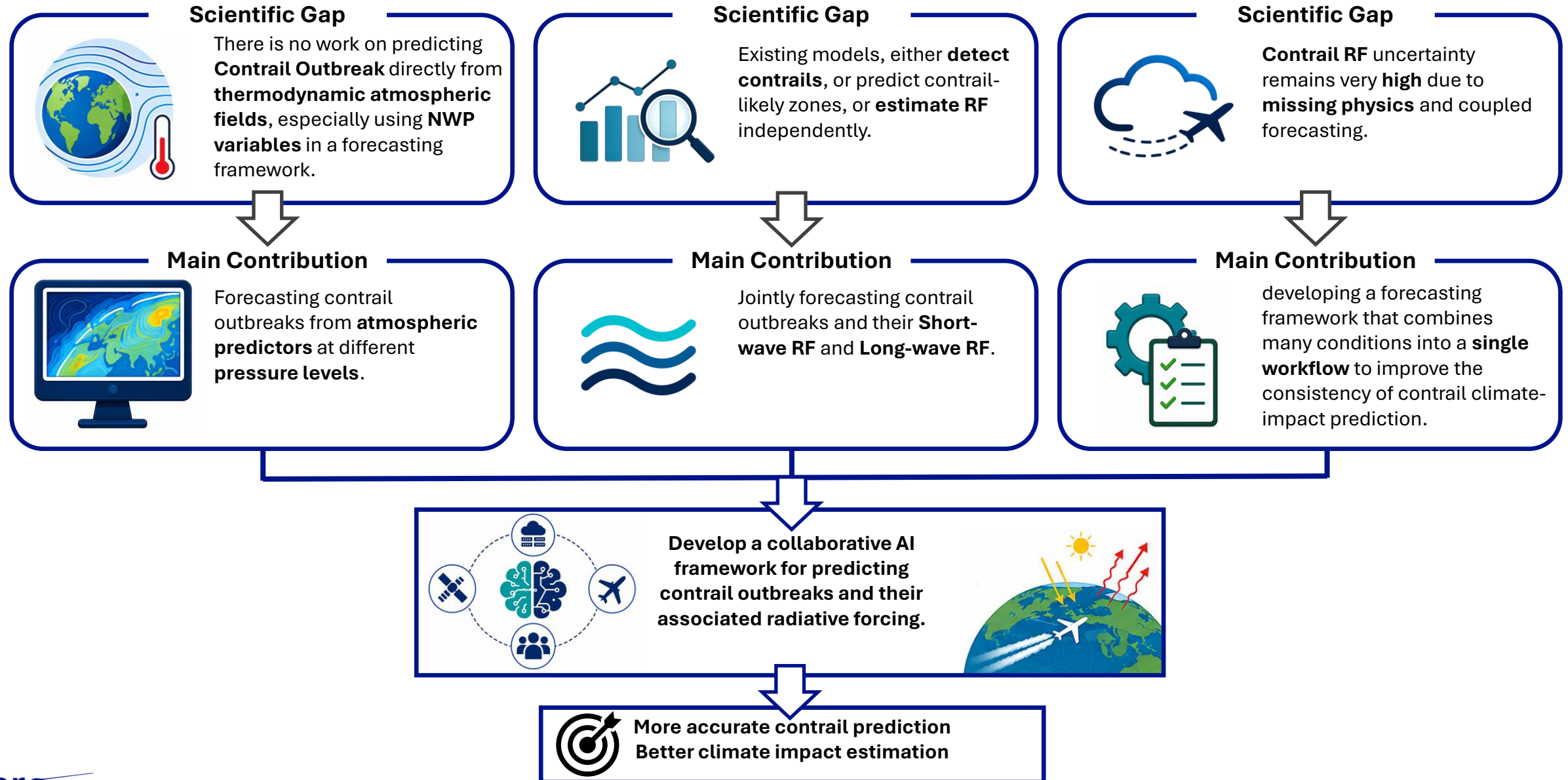
- change in the net radiant energy flux at the top of the **atmosphere** or **tropopause**.
- caused by a particular factor such as **contrails**, clouds, and etc.

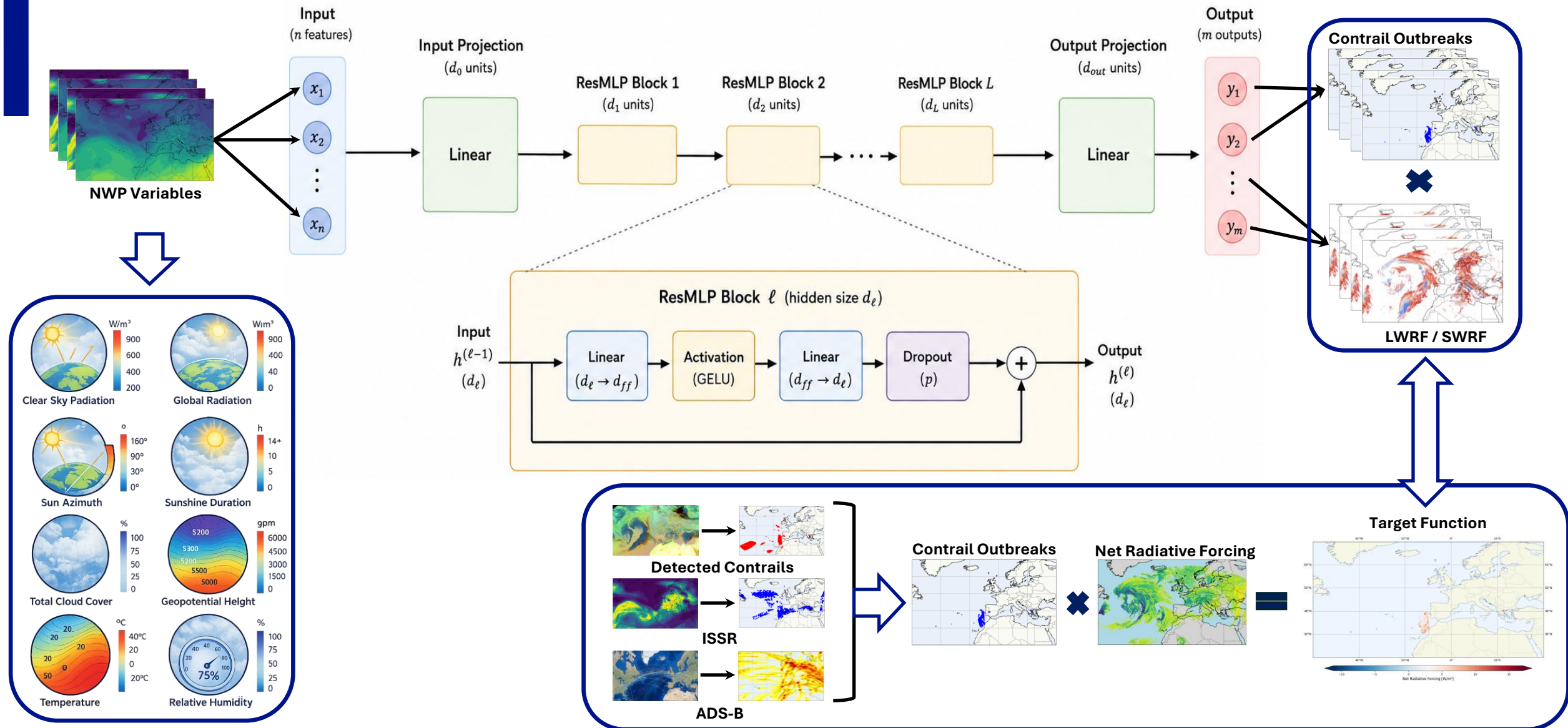


$$\text{Net Radiative Forcing (RF}_{net}) = RF_{SW} + RF_{LW}$$

STATE OF THE ART (ISSR & RF)

Study / Reference	Key Focus / Methodology	Main Contribution	Limitations
 Burkhardt, U., & Kärcher, B. <i>Global climate impact of contrail cirrus (2023).</i>	 Numerical weather prediction (NWP) using ECMWF atmospheric humidity and temperature fields.	 Improved representation of ISSR occurrence and persistence in global contrail-climate simulations, highlighting the importance of accurate upper-tropospheric humidity forecasts.	 ISSR prediction remains highly sensitive to humidity uncertainty in NWP models.
 Geraedts, S., et al. <i>A scalable system to measure contrail formation on a per-flight basis (2024).</i>	 AI-based prediction framework integrating weather forecasts and flight trajectories.	 Developed scalable operational prediction of ISSR occurrence for individual flight segments using atmospheric data and automated validation.	 ISSR prediction accuracy depends strongly on forecast humidity resolution.
 Wang, M., et al. <i>Observations of microphysical properties and radiative effects of a contrail cirrus outbreak over the North Atlantic (2023).</i>	 Observational study of contrail cirrus RF.	 Quantified warming contribution of persistent contrails under real atmospheric conditions.	 Focused on a single contrail outbreak event over the North Atlantic, limiting global generalization.
 Wolf, K., et al. <i>Sensitivity of cirrus and contrail radiative effect on cloud microphysical and environmental parameters (2024).</i>	 Sensitivity analysis of contrail RF.	 Demonstrated strong dependence of RF on ice crystal size and atmospheric humidity.	 Relied heavily on idealized radiative transfer simulations rather than direct observations.





Main dataset:

2023-01-01 to 2023-12-31

Training: 80%

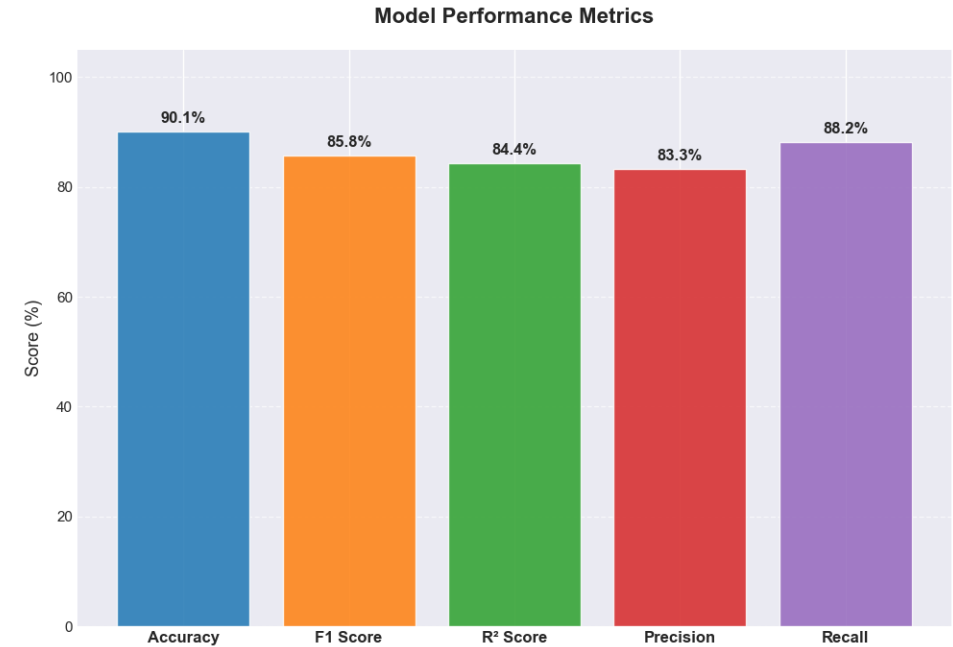
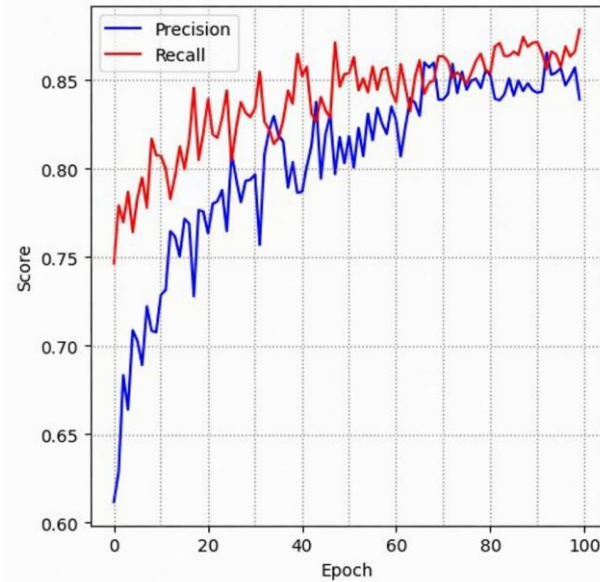
Validation: 20%

Pressure levels:

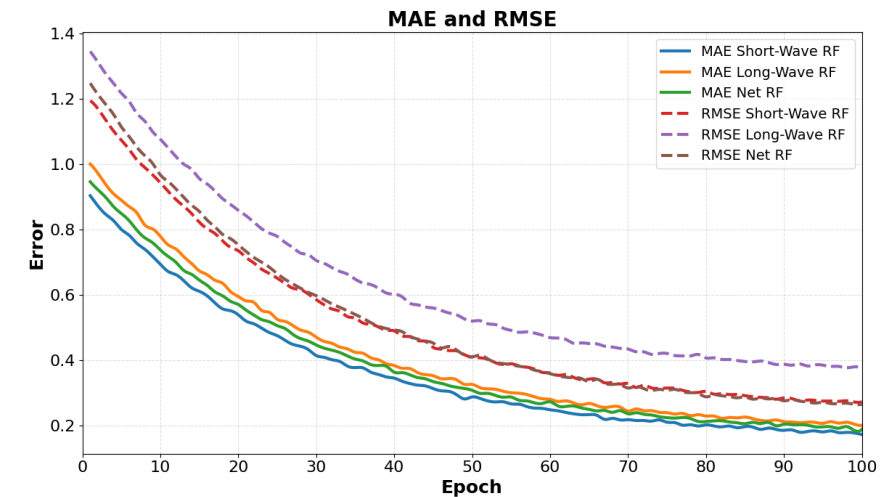
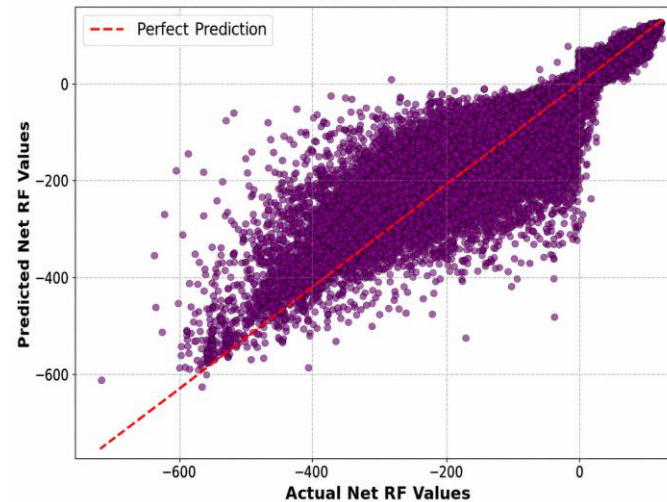
200hPa

250hPa

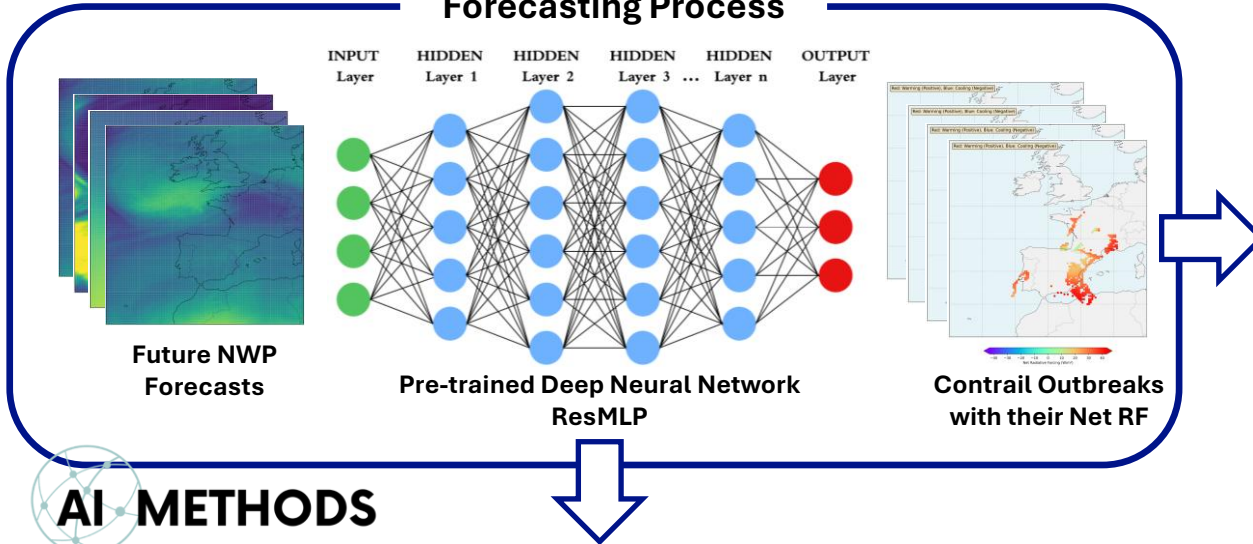
300hPa



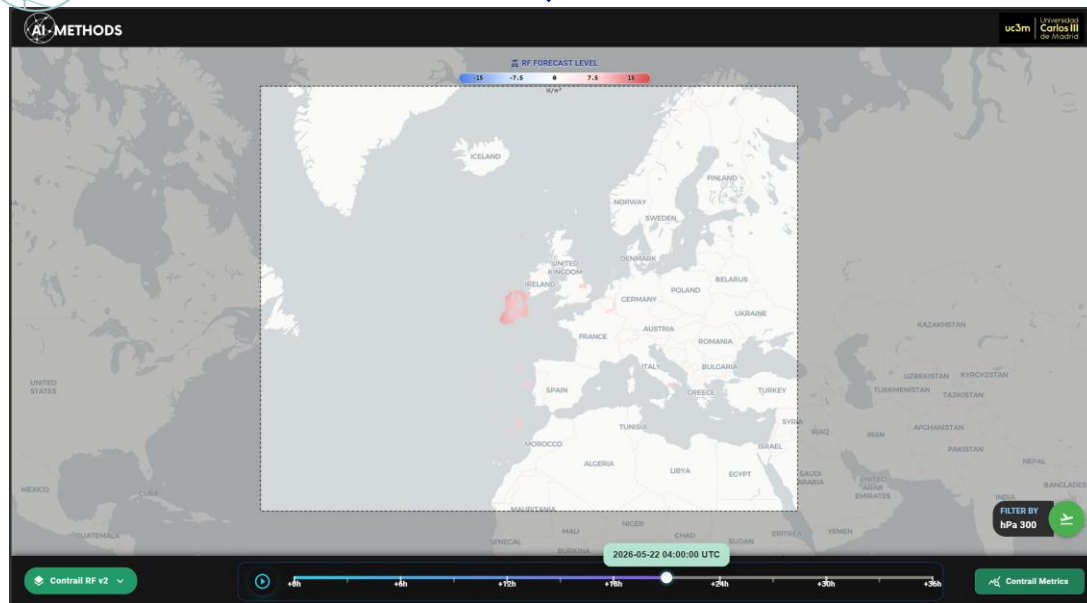
Net RF Predictions vs Actual (Correlation = 0.951)



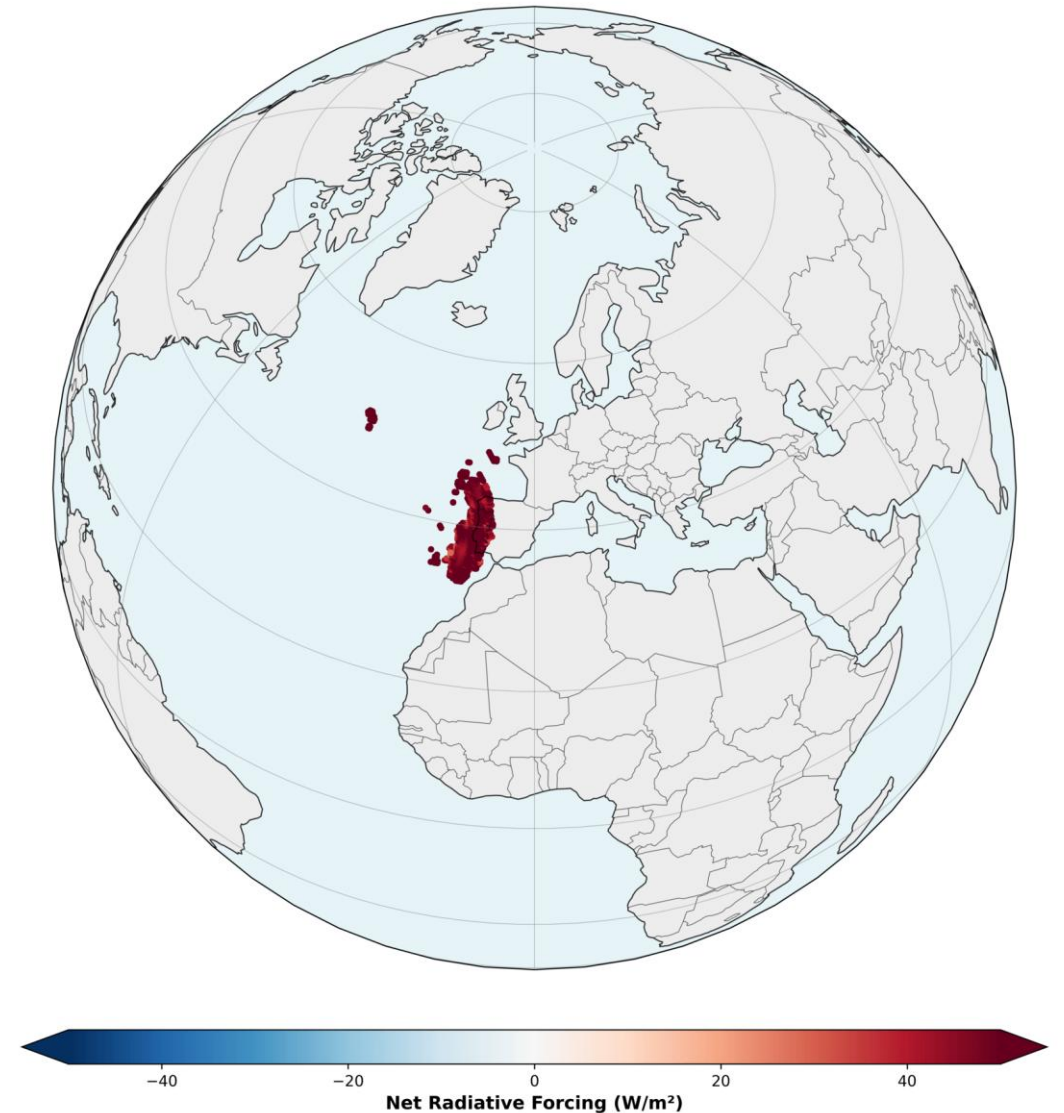
Forecasting Process



AI METHODS

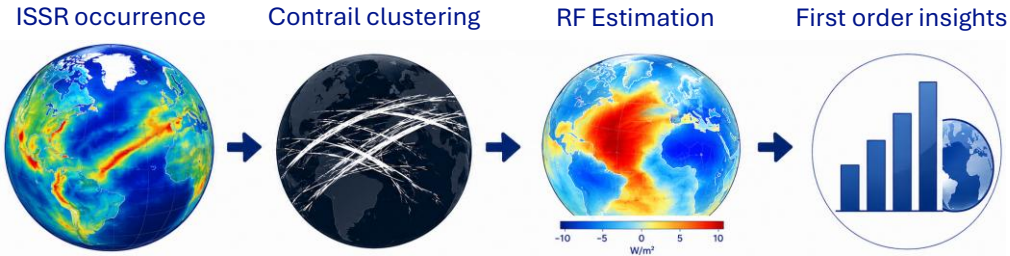


Contrail Outbreaks with Net Radiative Forcing 2023-10-16 00:00 UTC - Orthographic Projection

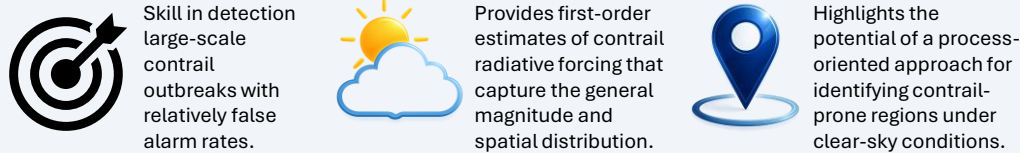


CONCLUSION

A forecasting framework that couples **ISSR occurrence** with **contrail clustering** and estimates **Radiative Forcing**.



HIGHLIGHTS



KEY LIMITATIONS

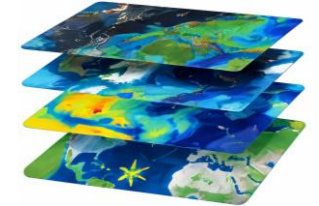


FUTURE DIRECTIONS

Evolving from foundational model to a more **comprehensive** and **physically consistent** framework.



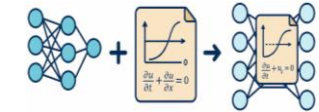
Higher-resolution meteorological inputs:
Integrate a higher resolution data to better resolve atmospheric structures and improve detection and forcing estimates.



Improve microphysical parameterization:
Incorporate advanced microphysical schemes to better represent contrail formation and evolution.



Physical constraints and variability:
Incorporate advanced microphysical schemes to better represent contrail formation and evolution.



Extend to cloudy scenes:
Develop methods to extend detection and forcing estimates to cloudy scenes.





We presented a prototype of the model in **ECATS 2025** conference as a poster.



Attended to **external** and **internal** workshops:



IATA-RAeS Workshop 2026 (9 & 10 March) –

Contrail Management: progressing towards risk-informed decision making (online).



5th ECMWF-ESA Machine Learning Workshop 2026

(13 to 17 April) (online).



Exchange Workshops of the PhD program in

Aerospace Engineering (in person).



We submitted a conference paper to **IWAC 2026** conference (17 to 19 November).



We submitted the first Journal paper to **IEEE Transactions on Geoscience and Remote Sensing (TGRS)**.



Thanks a lot for your attention!
Questions?

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