Persistent Contrails
Can we predict them?

ADNS X71PR2504669

COMMERCIAL AIRCRAFT

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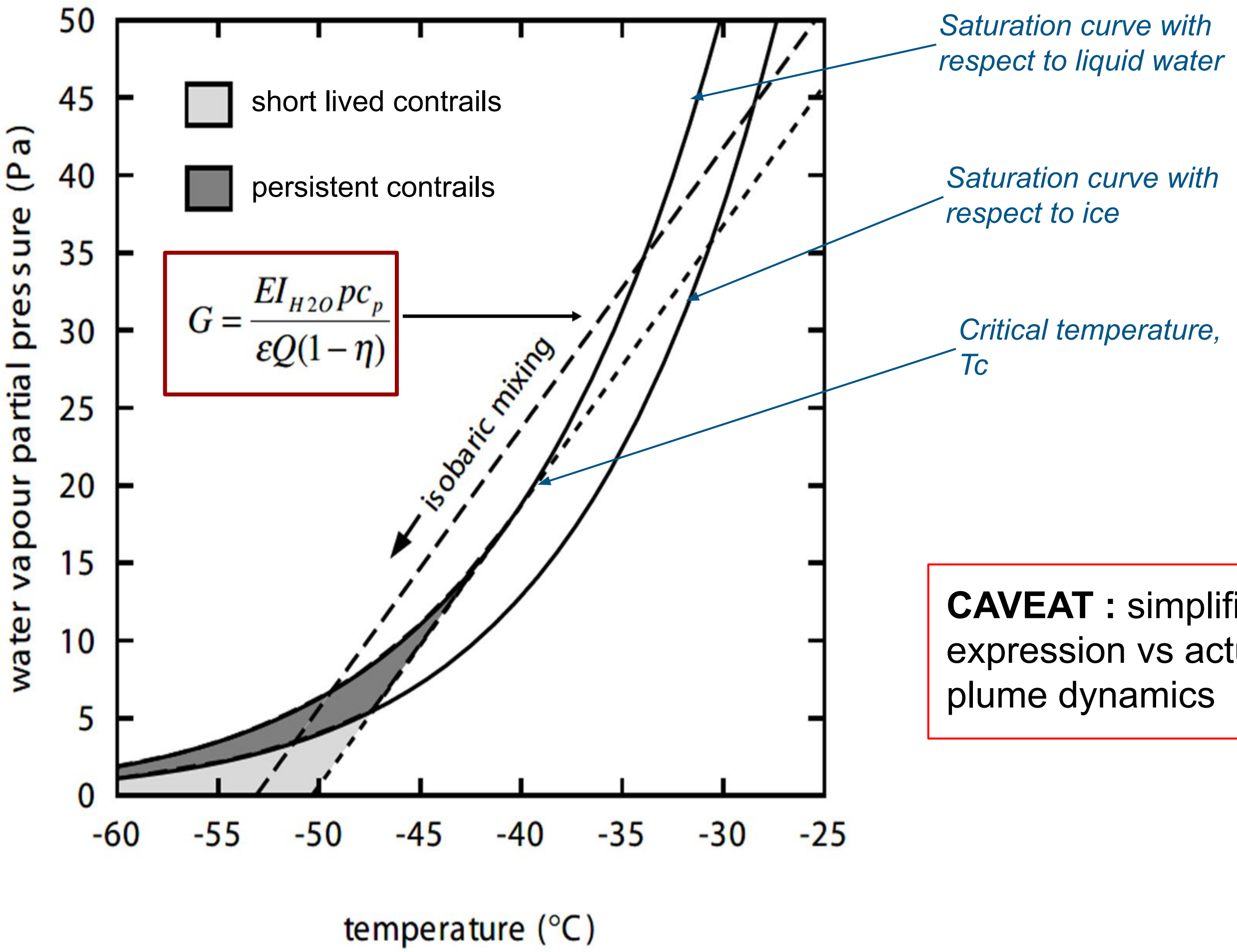
Contents

Contrail formation and persistence

Schmidt-Appleman Criterion (SAC) is typically used to determine whether a contrail will form.
G represents the isobaric mixing between the aircraft exhaust air and the atmospheric air.



CAVEAT : simplified expression vs actual plume dynamics

G depends on the following parameters:

- local atmospheric pressure, temperature and humidity
- fuel energy content (Q)
- fuel water vapour emissions index (EI(H_2O), mass of H_2O emitted per kg of fuel burnt)
- engine overall efficiency (η)

Persistence requires the contrail to be formed in an Ice Supersaturation Region (ISSR).
This is an atmospheric area where the relative humidity with respect to ice is > 100%.

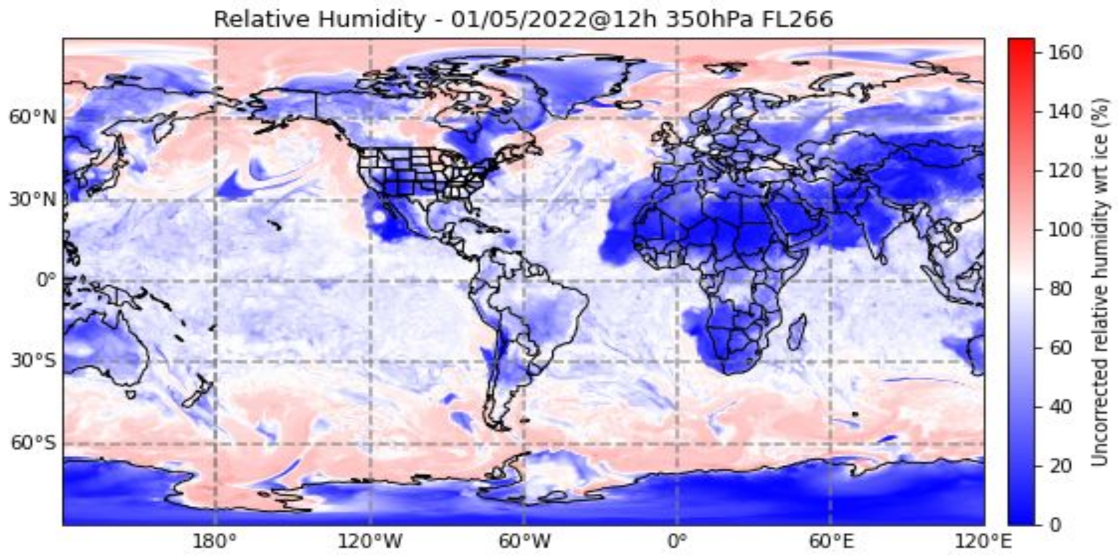
Among contrails, only persistent contrails and in particular contrail cirrus contribute to the overall climate impact from aviation

Ice supersaturated regions from ECMWF ERA5 dataset

ERA5 reanalysis data:
(Courtesy of Copernicus Climate Change and Atmosphere Monitoring Services)

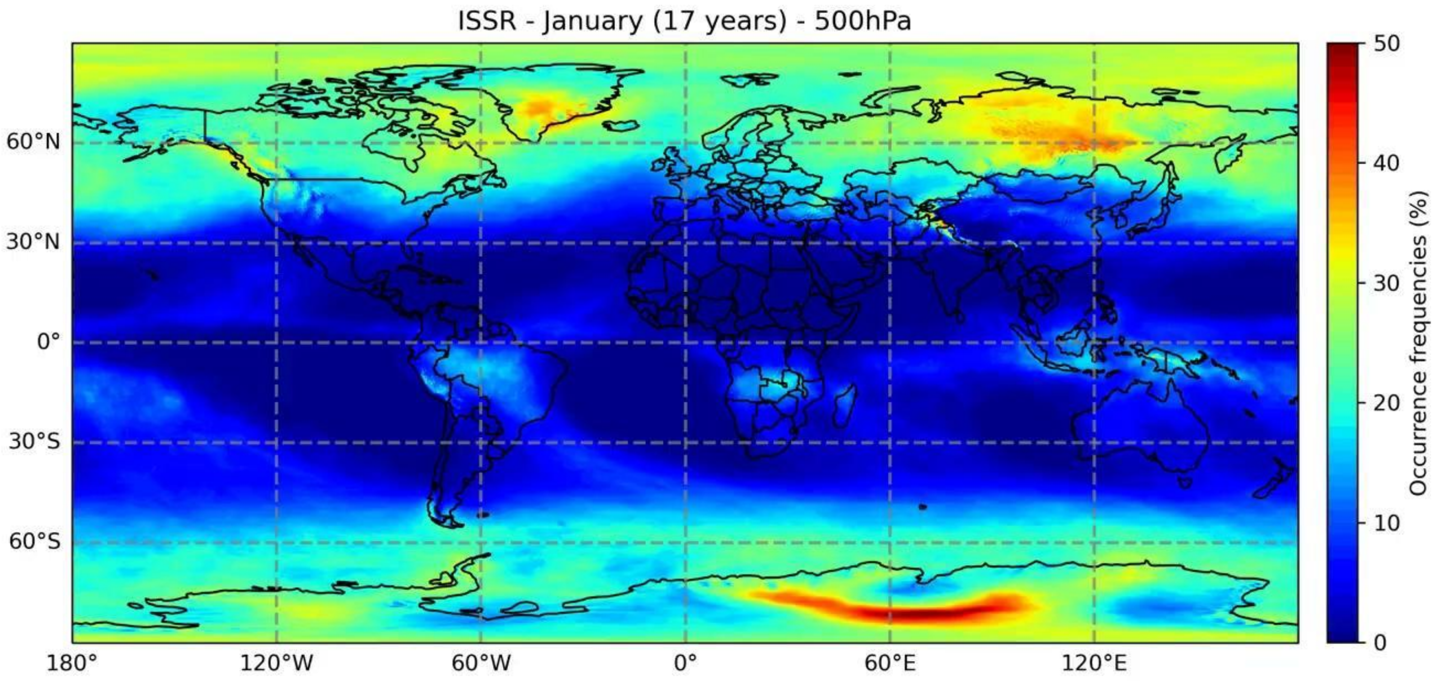
- 17 years ECMWF ERA5 reanalysis data:
  - 2007 - 2023
- Spatial resolution:
  - 0.25° x 0.25°
- Temporal resolution:
  - 1h
- Vertical resolution:
  - 11 pressure levels
  - 500 - 125 hPa
  - FL183 - FL480

- ERA5 data: RH = RH_{ice} & RH_{liq} from -23°C to 0°C
  - Interpolate using SH, T
  - Use Sonntag for calculating RH_{ice} & RH_{liq}
- Teoh et al correction for North Atlantic applied



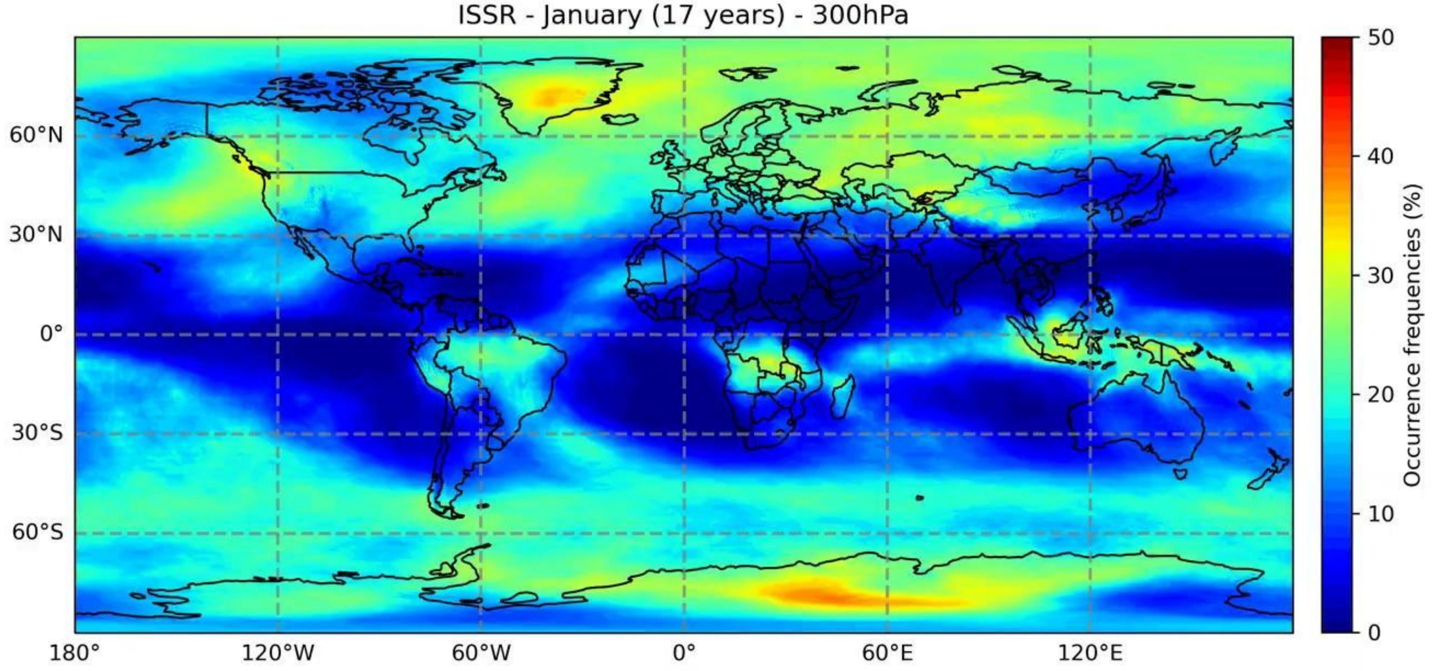
Statistics of ice supersaturation regions (ISSR) at altitudes

Using 14 years of ECMWF ERA5 reanalysis data 2010 - 2023

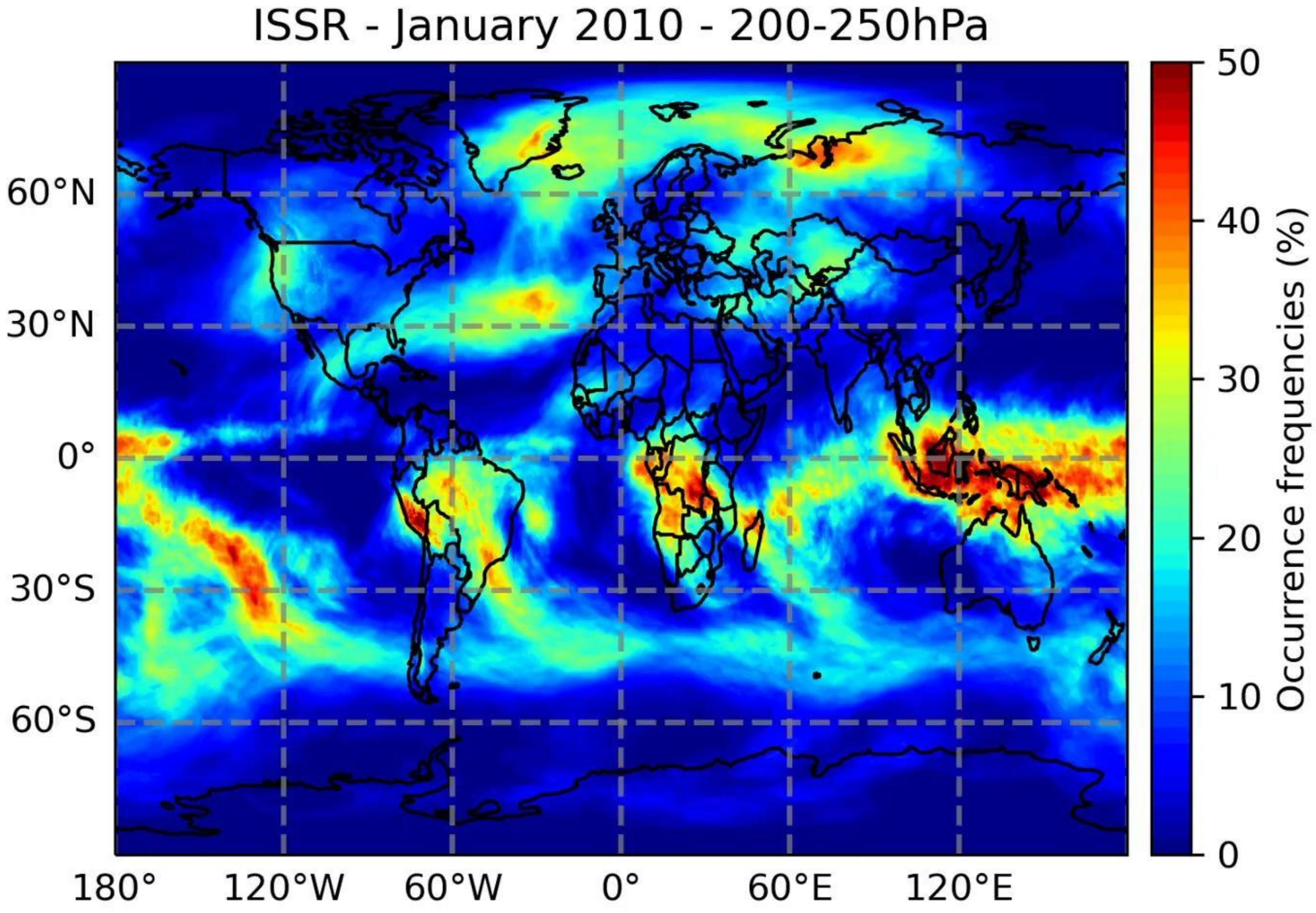


Monthly statistics of ice supersaturation regions (ISSR)

Using 17 years of ECMWF ERA5 reanalysis data 2007 - 2023



Yearly statistics of ice supersaturation regions (ISSR)

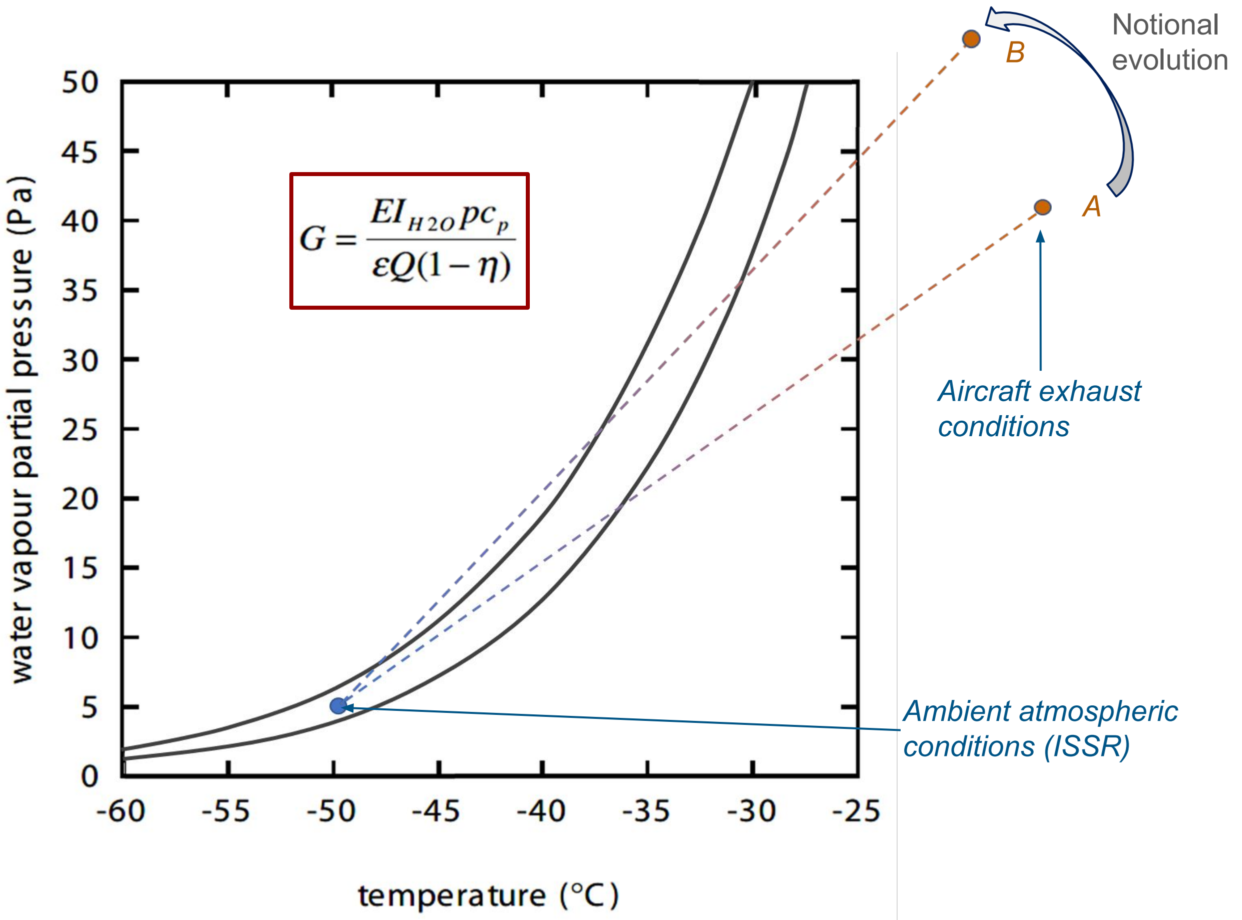


Contrail formation and persistence

Influence of more efficient engines and/or change in fuel composition (e.g. SAF use)

Schmidt-Appleman Criterion (SAC) with the G slope corresponding to the mixing between the aircraft exhaust air and the atmospheric air, which depends on:

- local atmospheric pressure, temperature and humidity
- fuel energy content (Q)
- fuel water vapour emissions index (EI(H_2O), mass of H_2O emitted per kg of fuel burnt)
- engine overall efficiency (η)



➩ such changes can induce the **formation of new contrails or longer contrails** along the flight path, **which will also be persistent if in ISSRs**

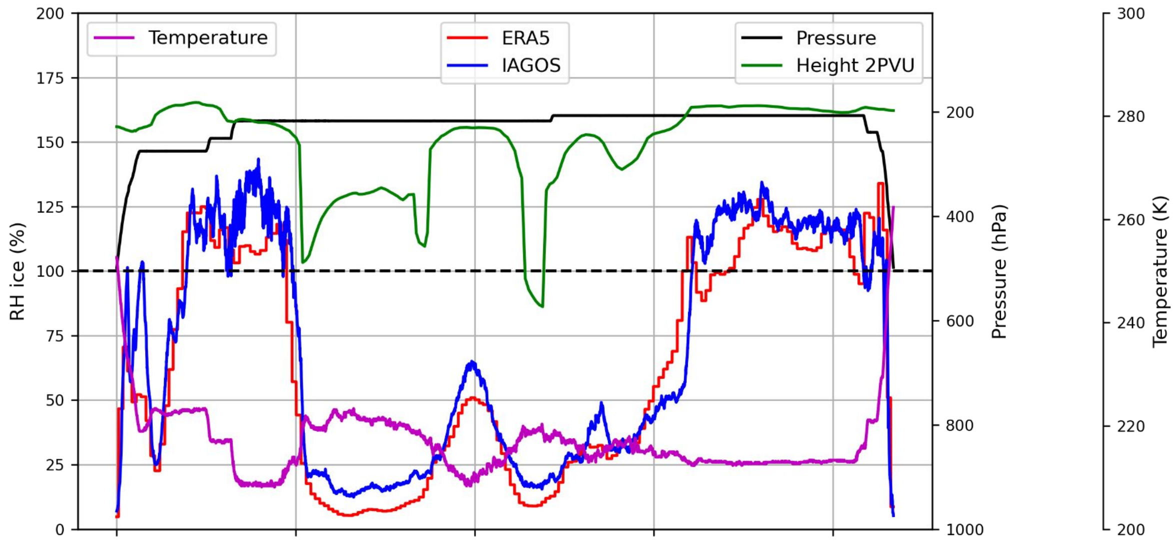
Ice supersaturated regions from ECMWF ERA5 dataset

ERA5 reanalysis data + Teoh et al correction:
(Courtesy of Copernicus Climate Change and Atmosphere Monitoring Services)

IAGOS flight data: (Courtesy of IAGOS)

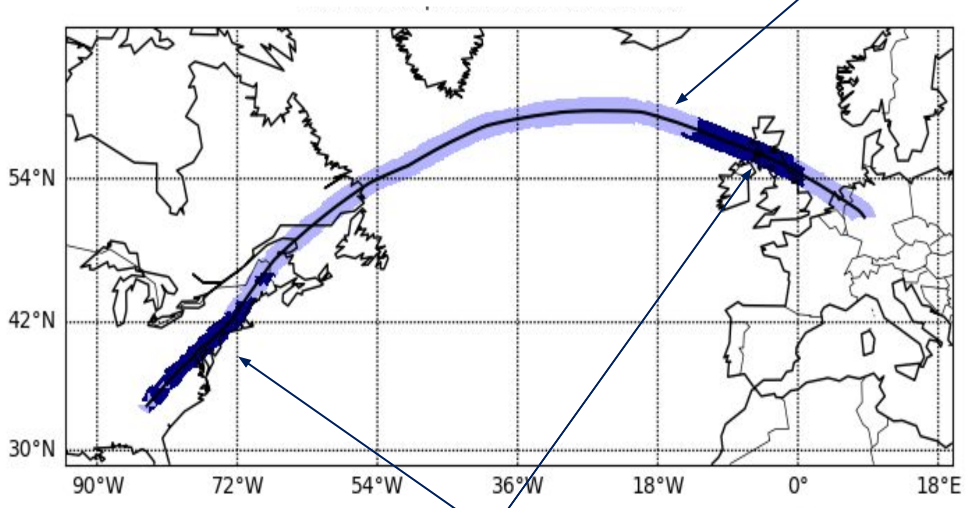
- ~35 000 flights
- 2010 - 2023

❖ **RH flag = 0 (Good)**

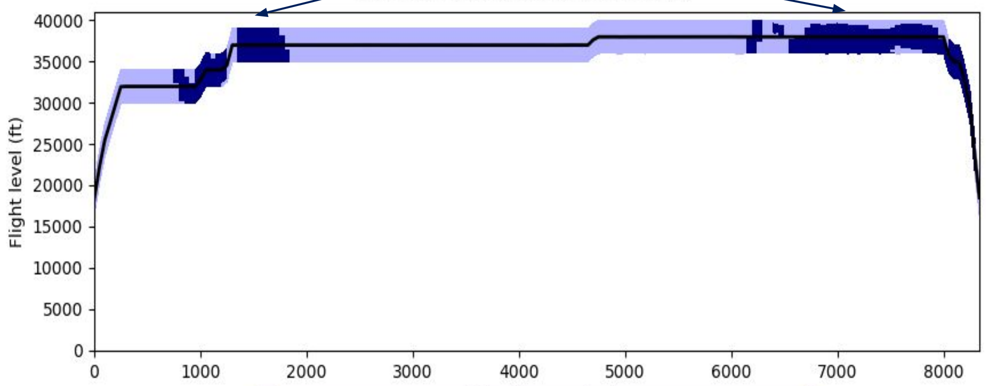


Flight Frankfurt to Atlanta, 27th December 2019

4D simulated weather area along the trajectory



ISSRs



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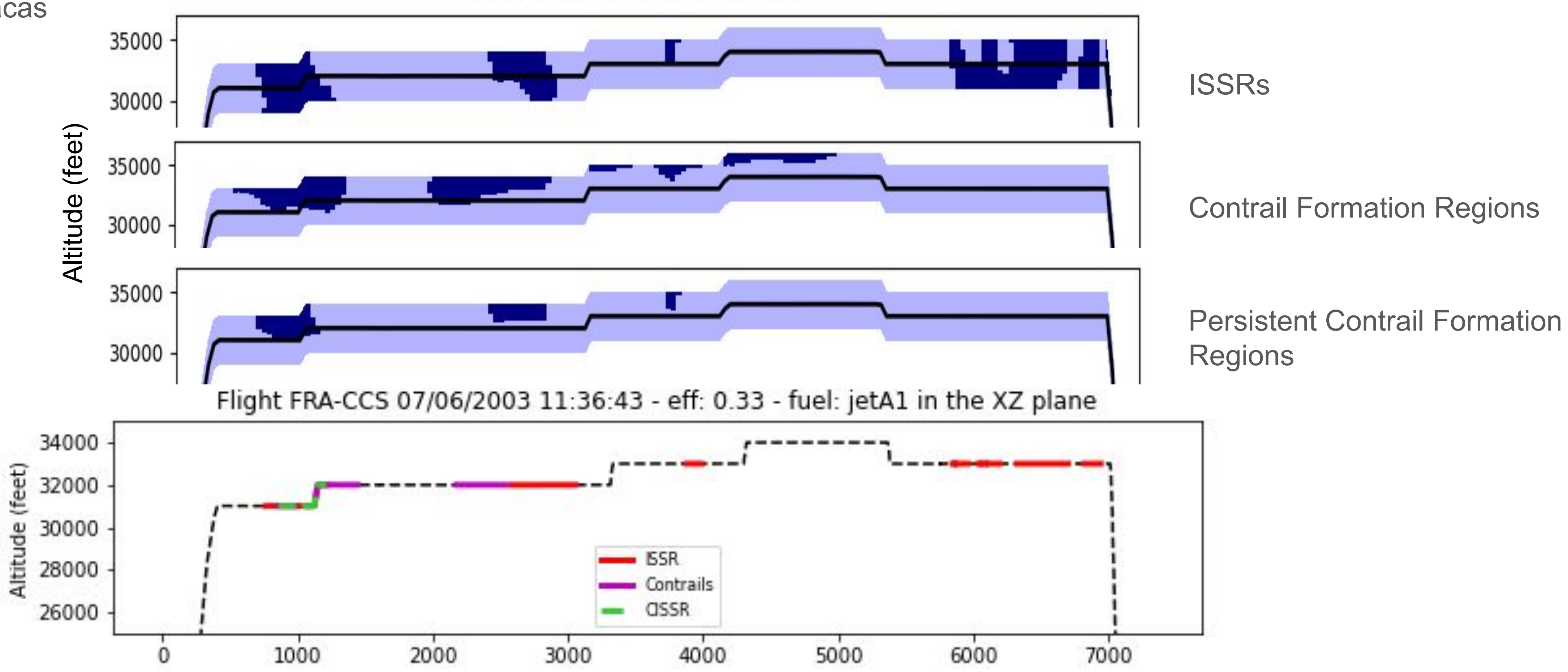
ISSR, Contrail formation and Persistent Contrail formation regions

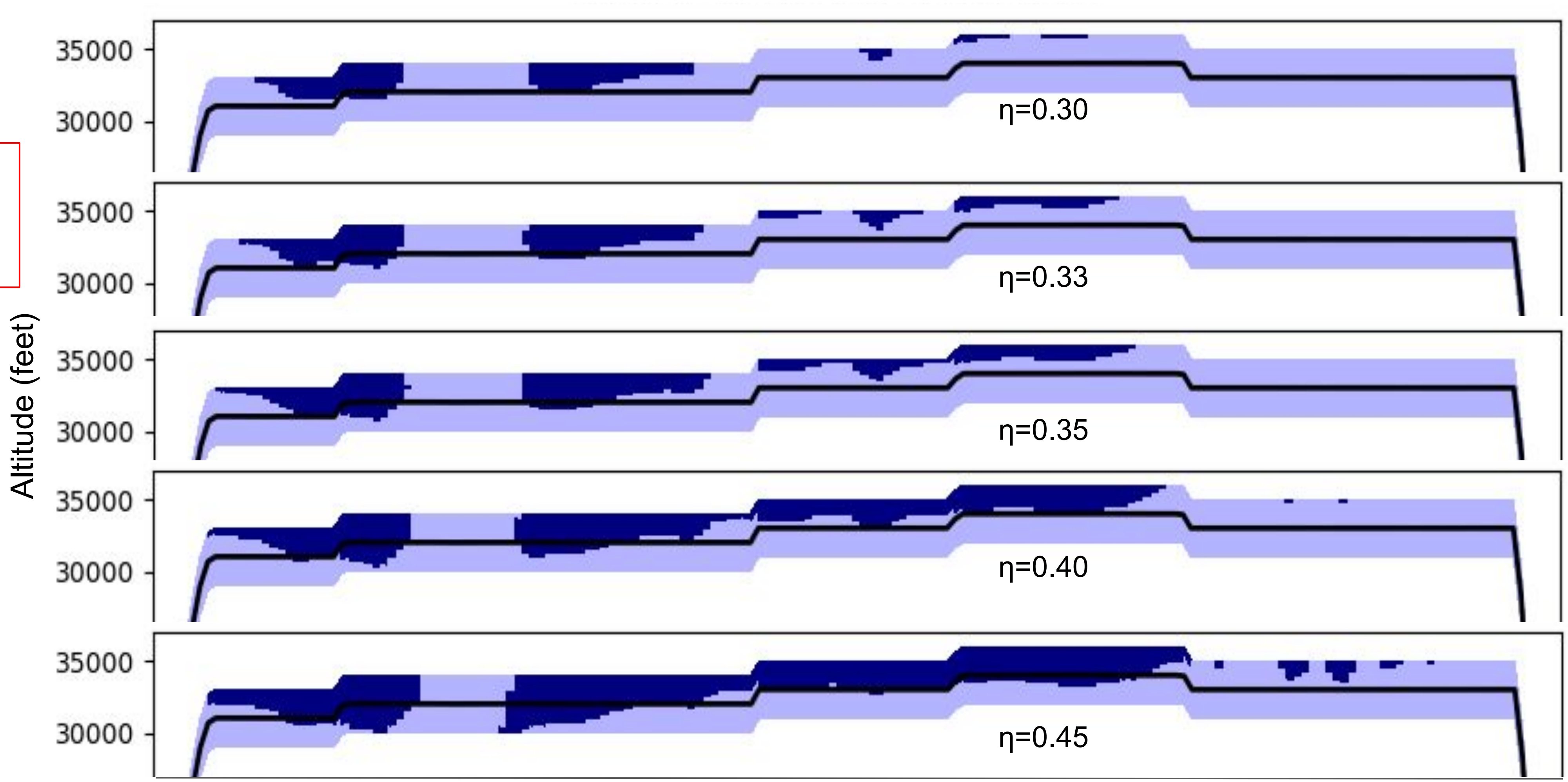
IAGOS flight from Frankfurt to Caracas



Contrail formation regions with a variation in engine overall efficiency

IAGOS flight from Frankfurt to Caracas

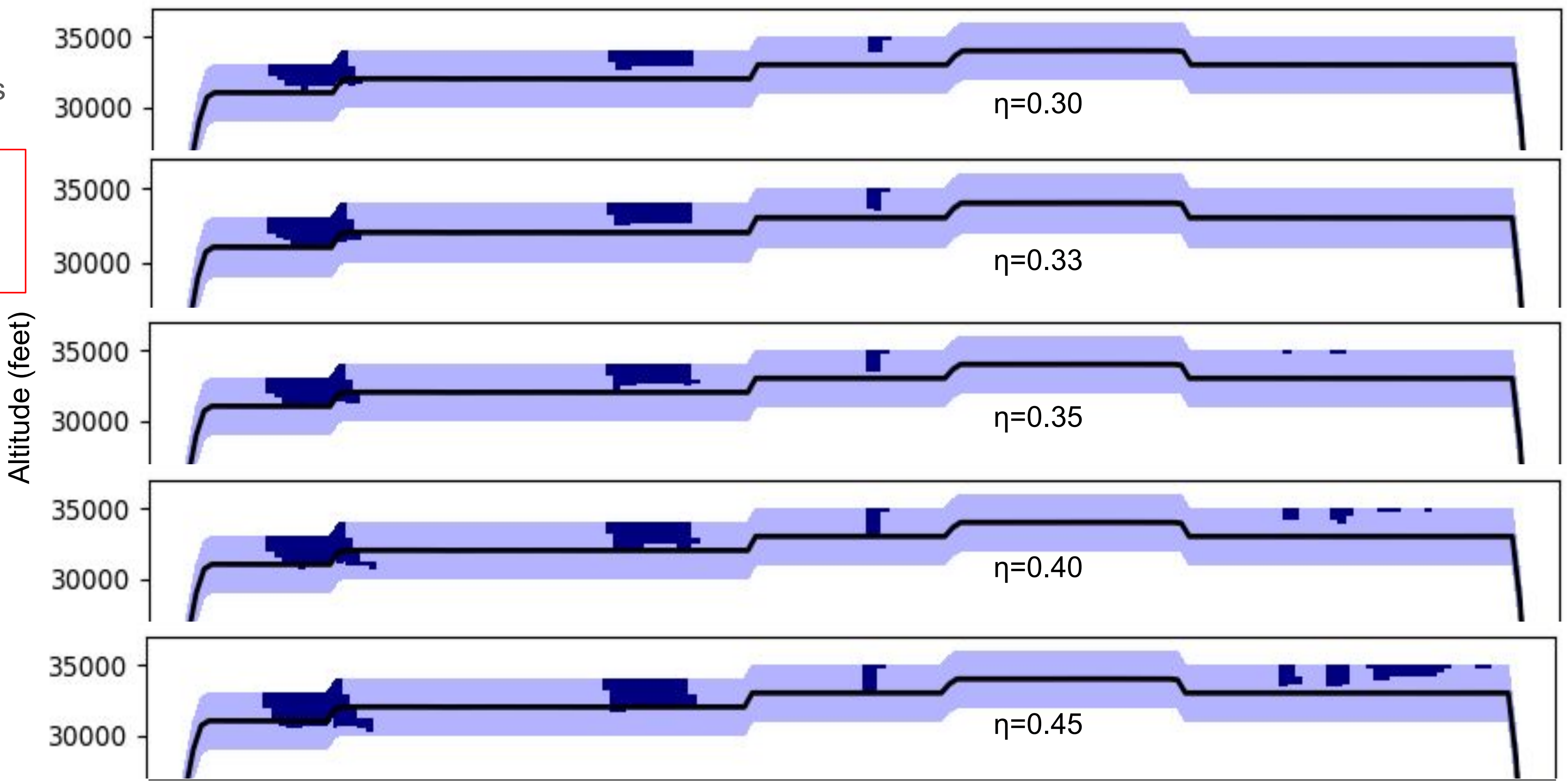
Note: Theoretical study assuming the same flight profile.



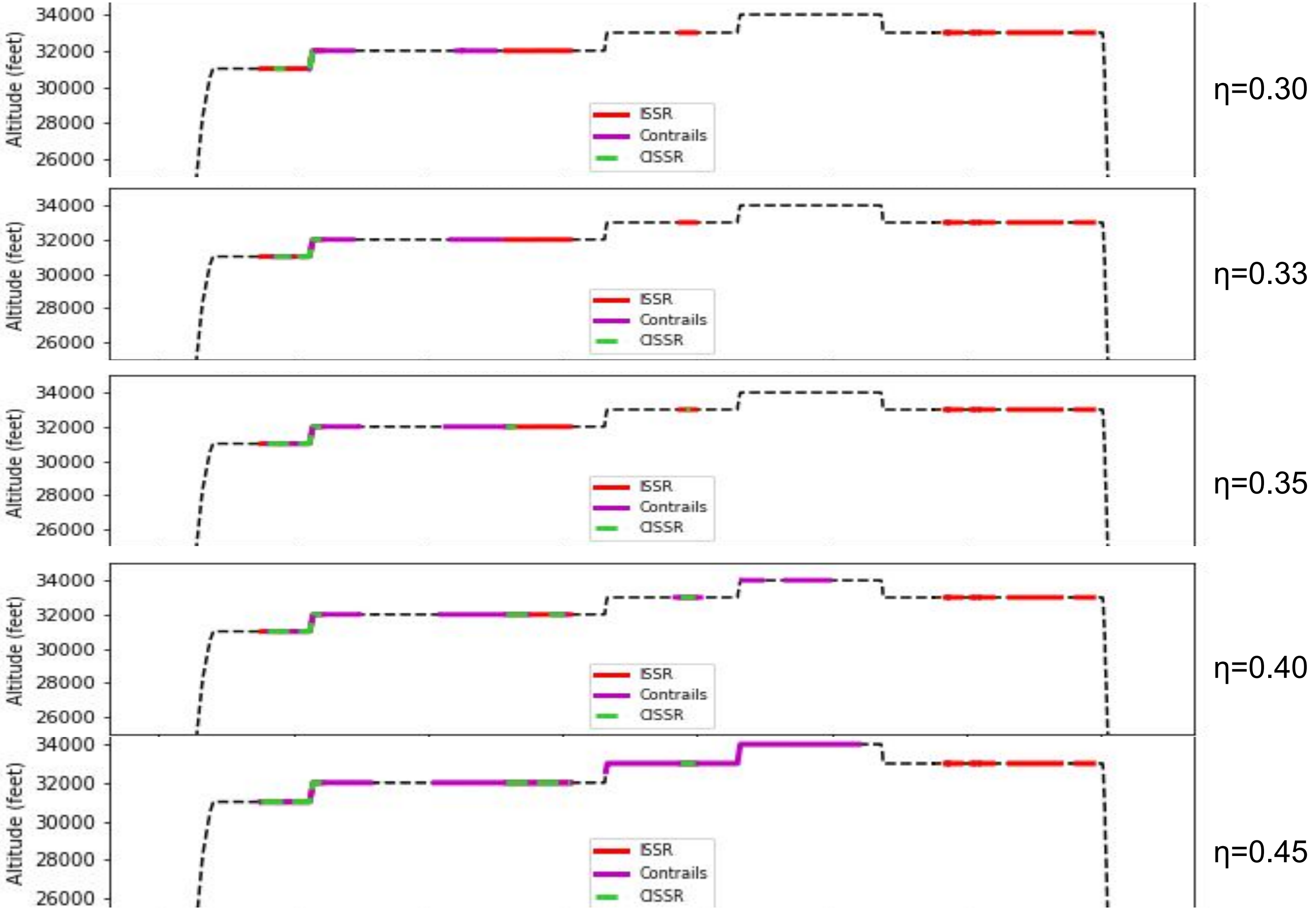
Persistent contrail formation regions with a variation in engine overall efficiency

IAGOS flight from Frankfurt to Caracas

Note: Theoretical study assuming the same flight profile.



Persistent contrail formation regions with a variation in engine overall efficiency



In **this** example an increase in engine overall efficiency → increases:

- Contrail formation
- Persistent contrails **IF** in ISSR

In general this is true **only** when the conditions are close to the critical temperature.

Although the probability of persistent contrails may increase, it does not mean the contrail impact will increase as other factors play a role.

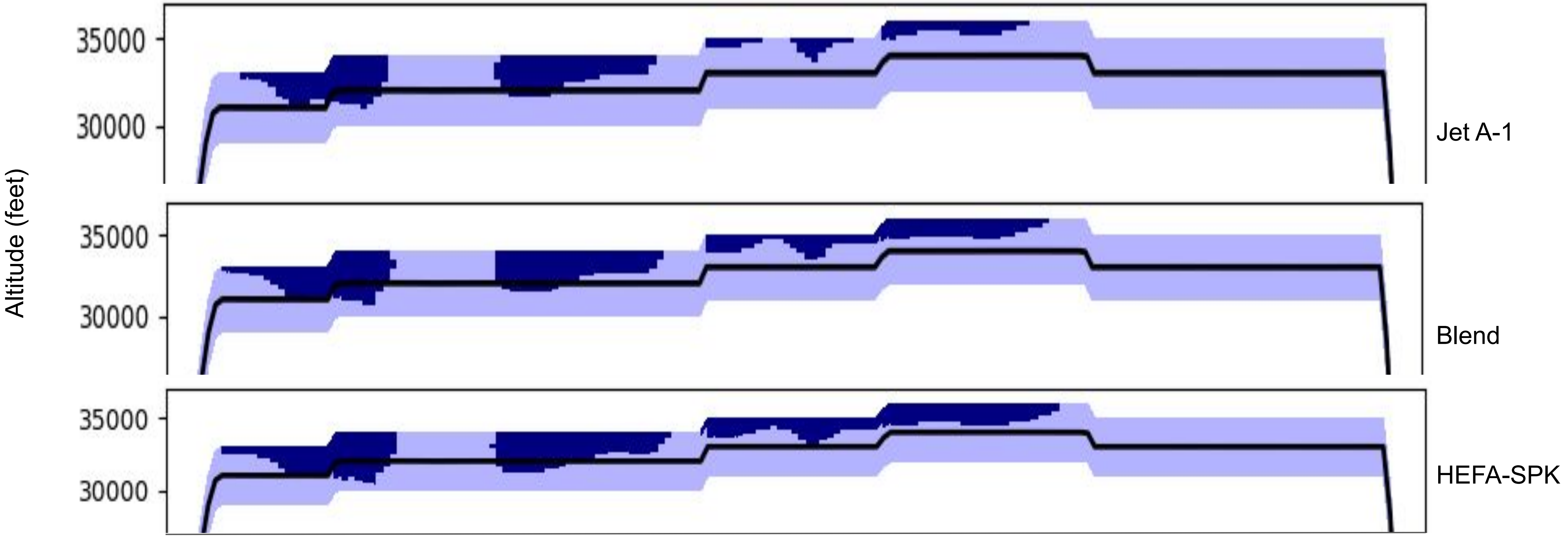
IAGOS flight from Frankfurt to Caracas

Airbus Amber

EU_EC_NotListed

Contrail formation regions with different fuels

IAGOS flight from
Frankfurt to Caracas



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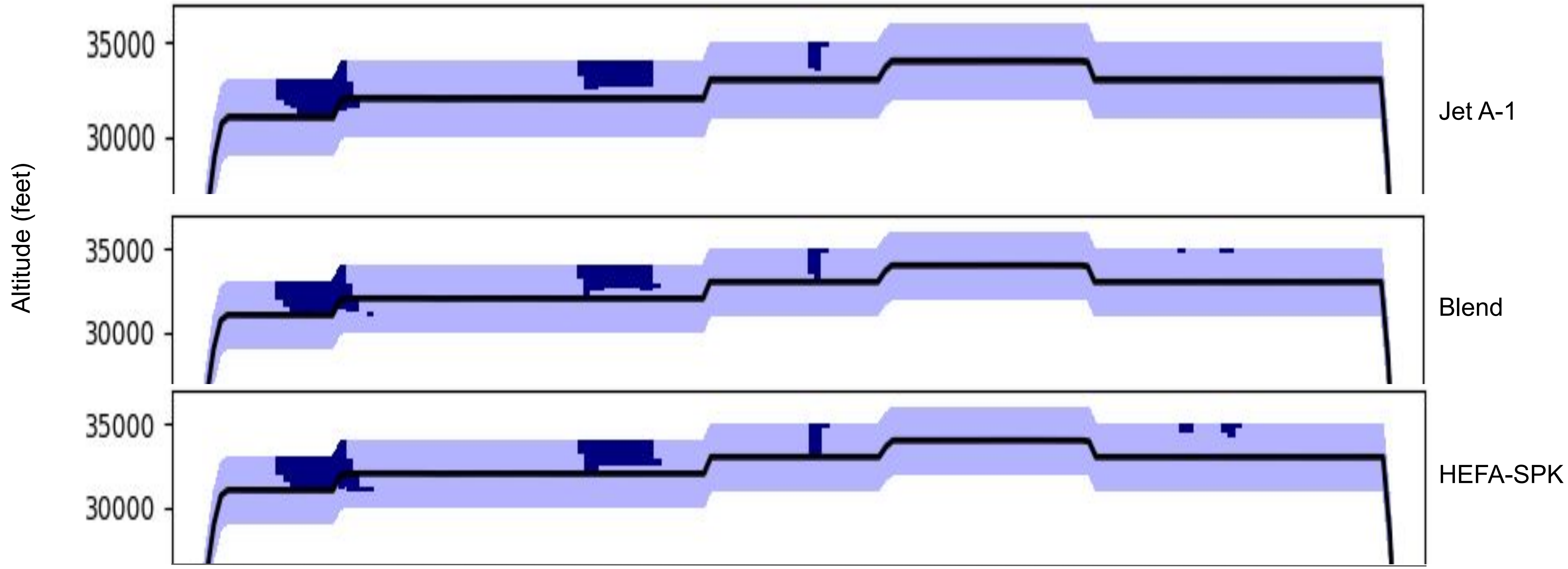
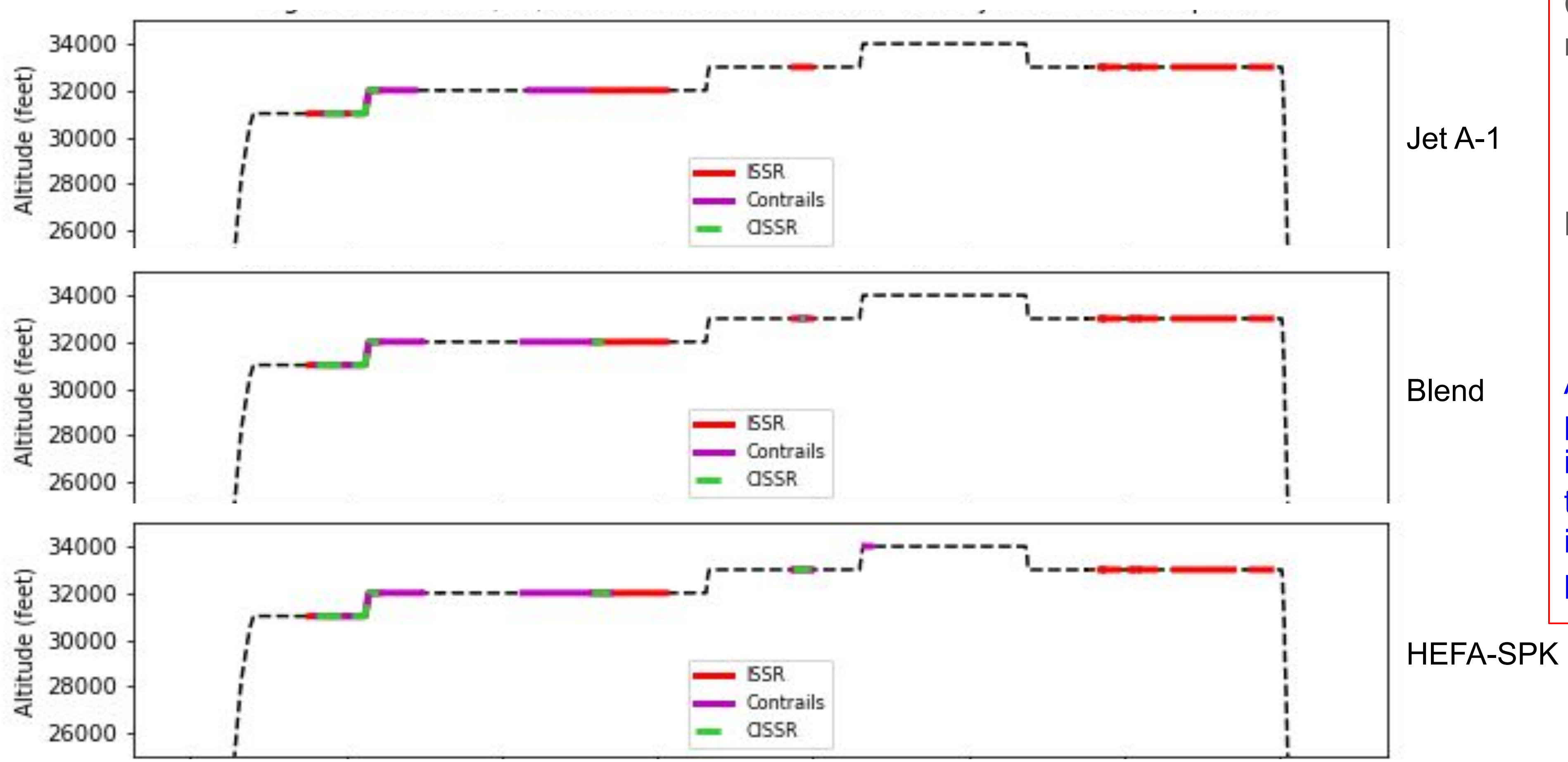
Persistent contrail formation regions with different fuels

IAGOS flight from
Frankfurt to Caracas



Persistent contrail formation regions with different fuels

IAGOS flight from
Frankfurt to Caracas



Change in fuel composition may lead to increases in:

- Contrails formation
- Persistent contrails **IF** in ISSR

BUT

- Contrail properties are different!

Although the probability of persistent contrails may increase, it does not mean the contrail impact will increase as other factors play a role.

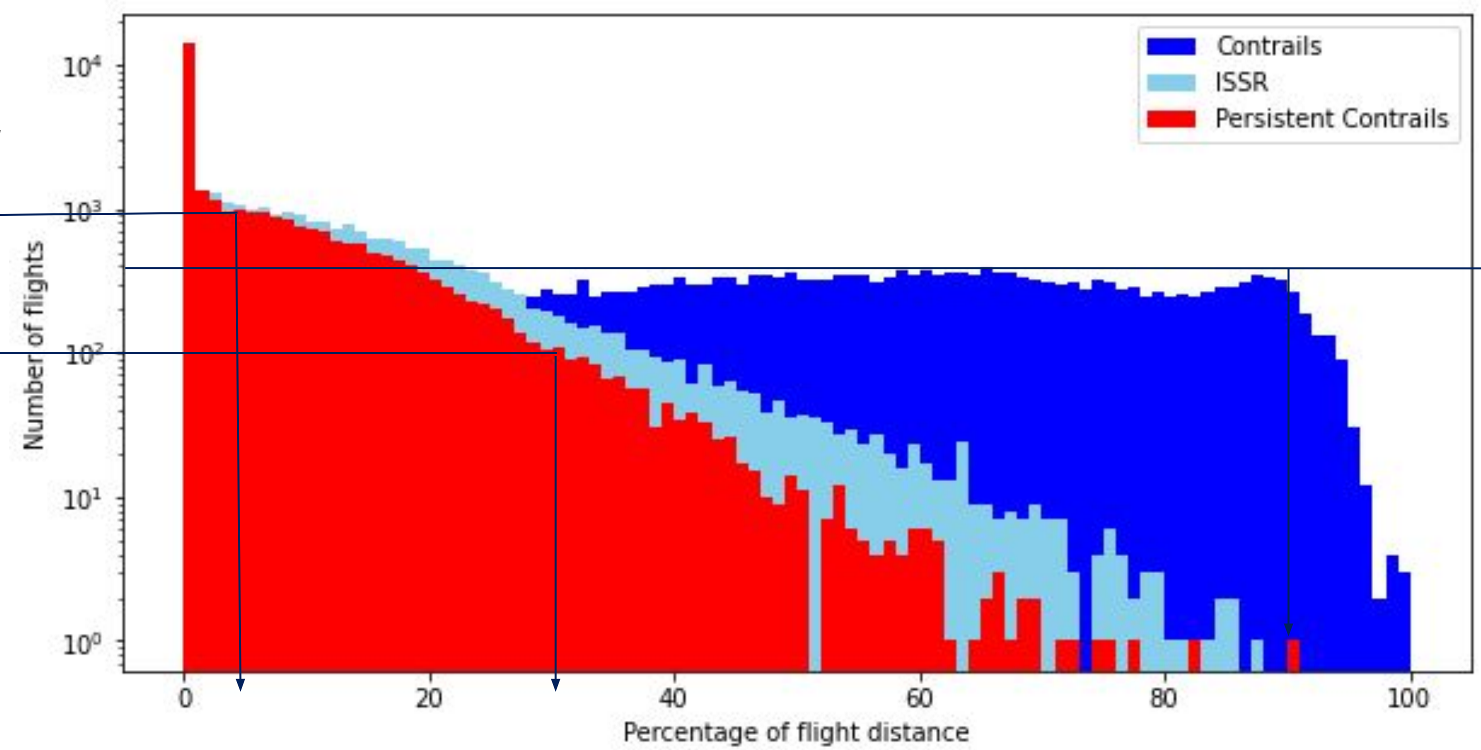
Statistics from IAGOS flight trajectories 2010 - 2023 - First Results!

Conditions of simulation: data measured along 35000 flights, using an assumed fixed engine efficiency and fuel composition of a typical Jet A-1
Percentage of flights registering ISSR, Contrails and Persistent Contrails along the trajectory using interpolated ERA5 data

	ISSR	Contrails	Persistent Contrails
% of flights	73%	79%	59%

3% of flights with 3% of the flight distance with persistent contrails

0.3% flights with 30% of persistent contrail



Log plot!

1% of flights with 90% contrails and 0.002% of flights with 90% persistent contrails

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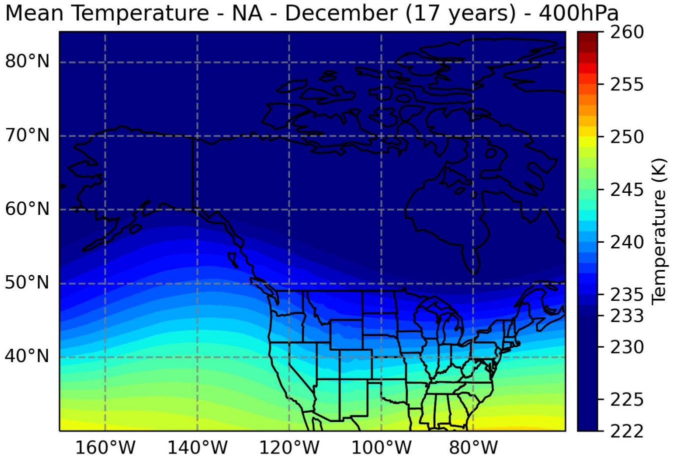
In practise…

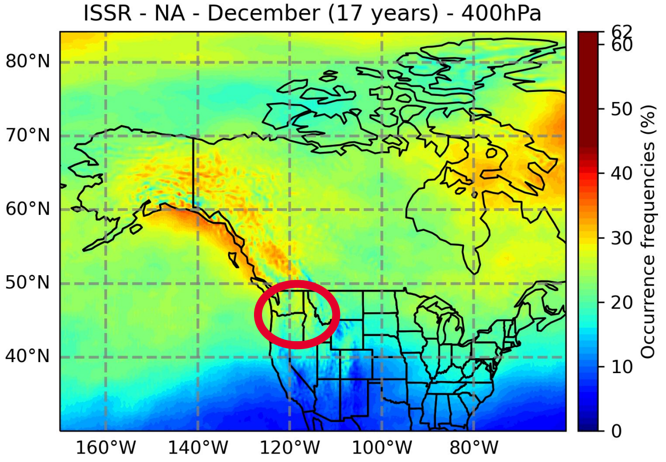
Test flights to produce and measure contrails:

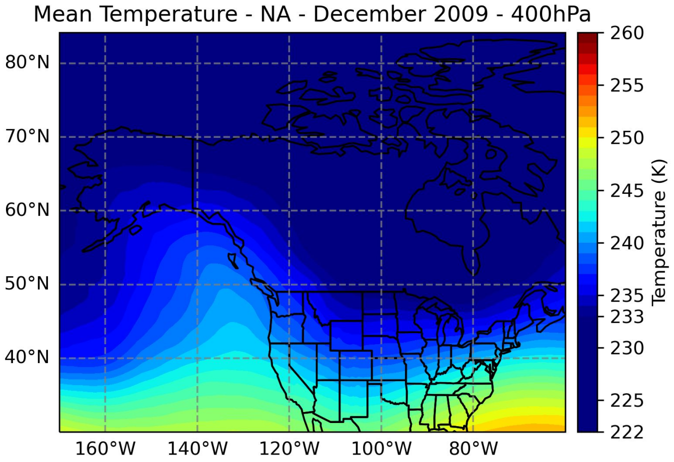
- Using statistical weather data to plan where to carry out the campaign
- Using forecast data to plan the test flights
- Using historical forecast data to compare with the forecasts used
- Interpolation of forecast and reanalysis data along the flight trajectory
- Comparison with the in-flight measurements

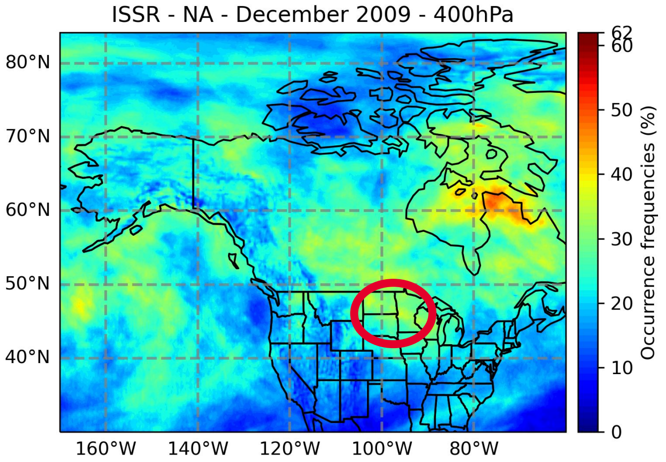
Use of ISSR statistics for flight test preparation

Using ECMWF ERA5 reanalysis data 2007 - 2023

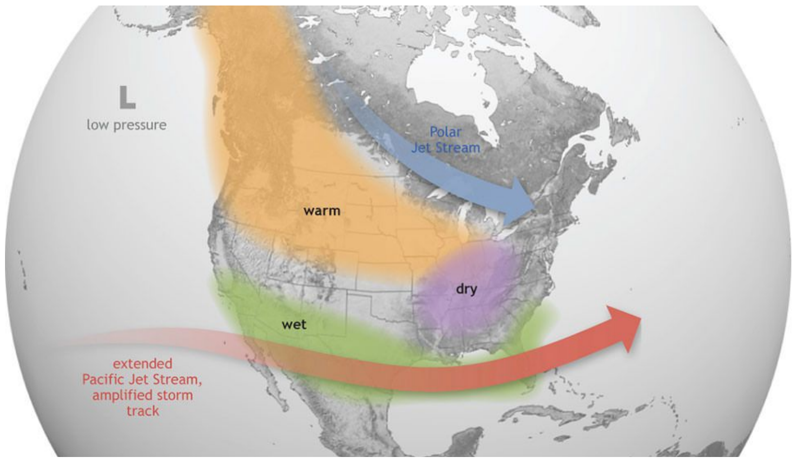








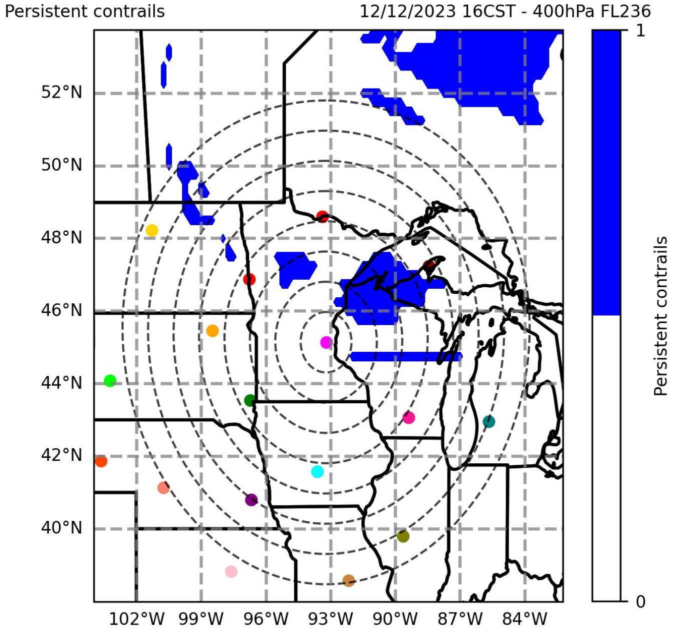
2023 El Niño identified in June



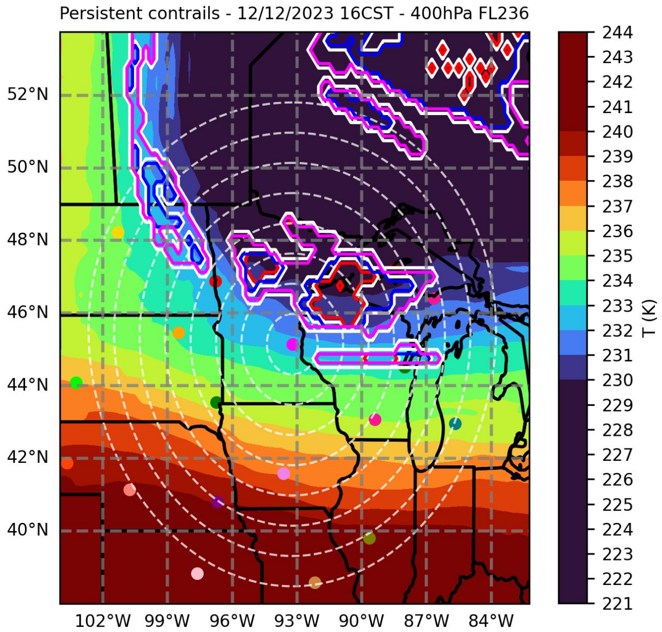
Courtesy of the National Oceanic and Atmospheric Administration (NOAA)

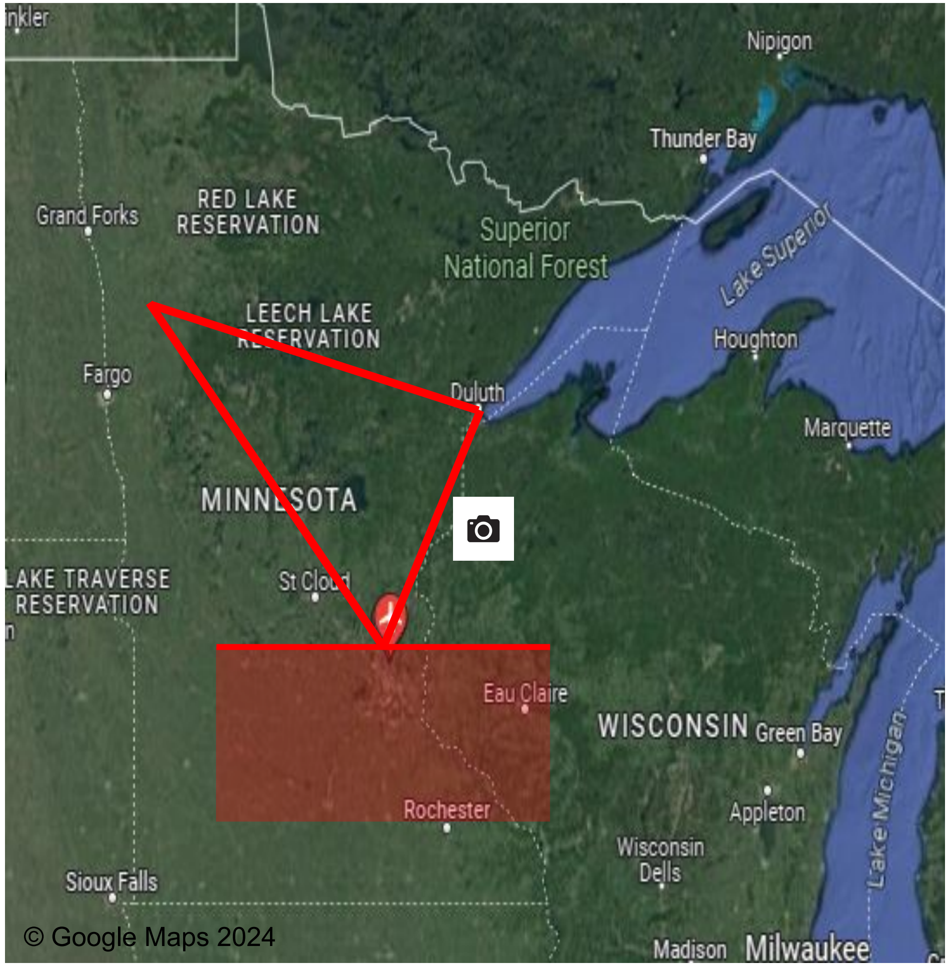
Strong El Niño predicted in October
Last Strong El Niño 2009

Persistent Contrail Prediction for flight tests



100% RHi
90% RHi
75% RHi





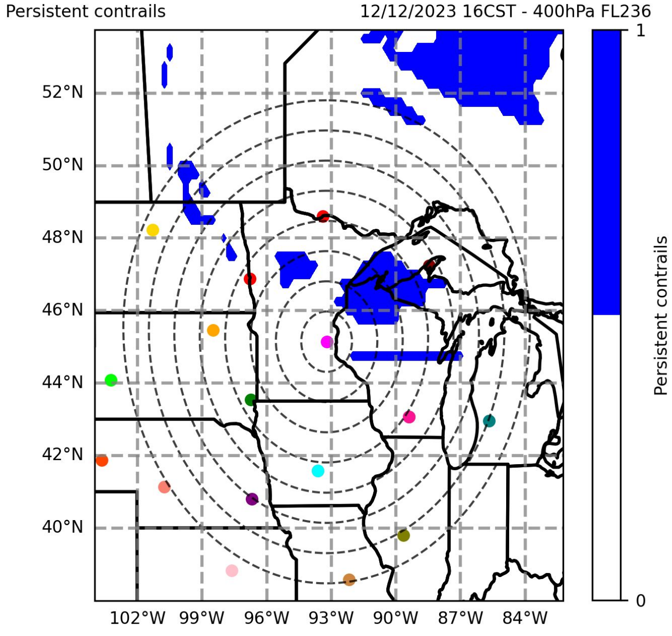
Using NOAA GFS weather forecast data

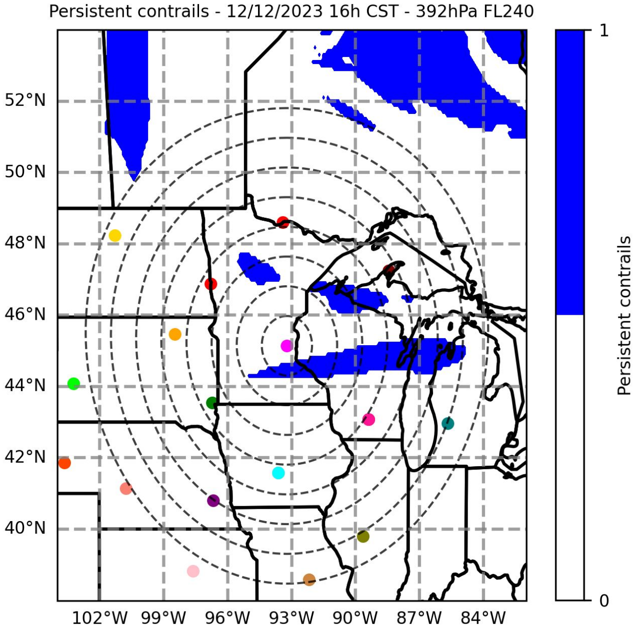
Weather prediction for flight tests - results

Thanks to Jean Cammas, Florian Thorey & Max Bailey

Comparison of forecasts from different meteorological sources

Differences in the predictions from GFS and IFS forecasts





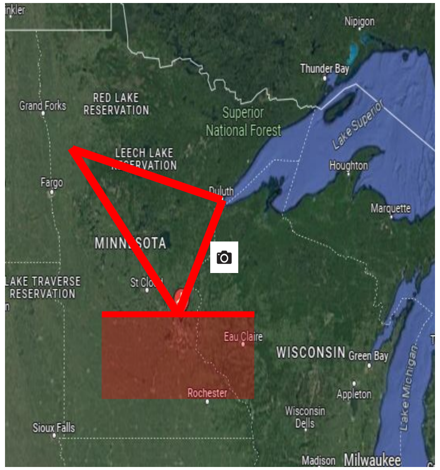
GFS 0.25° x 0.25°

NOAA GFS weather forecast data

IFS 0.1° x 0.1°

ECMWF archived IFS-HRES data

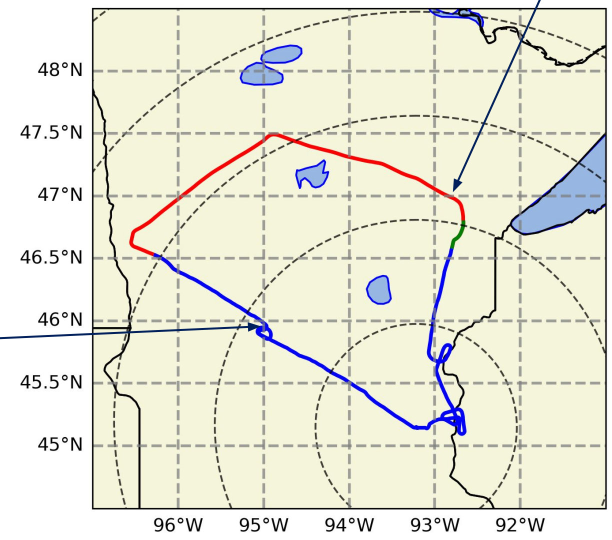
Thanks to Pierre Crispel & Matthieu Plu of Météo France for preparation and provision of data in the framework of the CICONIA project.



© Google Maps 2024

Flight trajectory

Chaser plane departs



Chaser plane arrives

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Forecast versus measurements

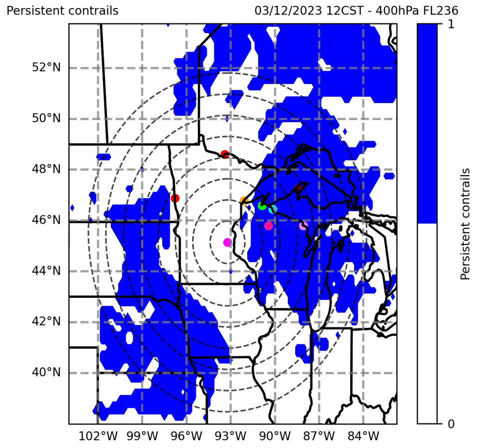
3 flights of interest:

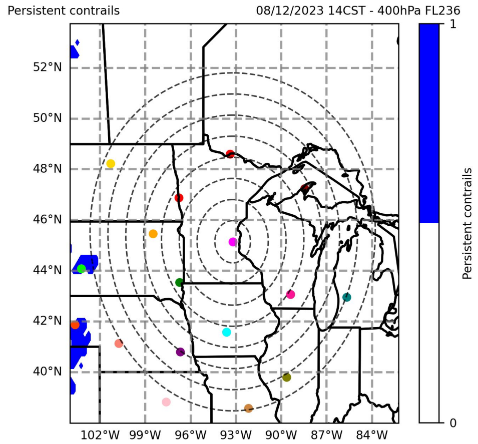
03/12
- persistent contrail area forecast with GFS
- cloud cover minimal
- contrails formed and persistent enough for measurements

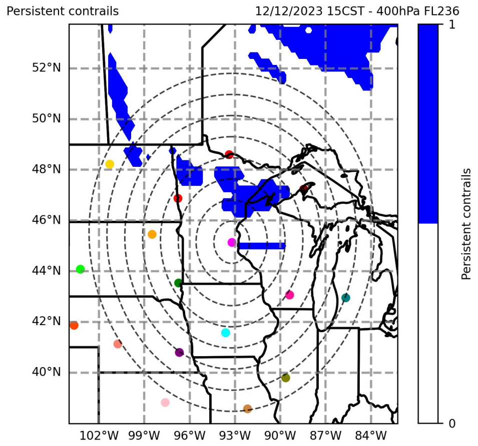
08/12
- no persistent contrail area forecast with GFS
- cloud cover near the region of highest relative humidity
- no contrails observed

12/12
- persistent contrail area forecast with GFS
- cloud cover minimal
- contrails formed over a large region
- persistent enough for measurements and photos

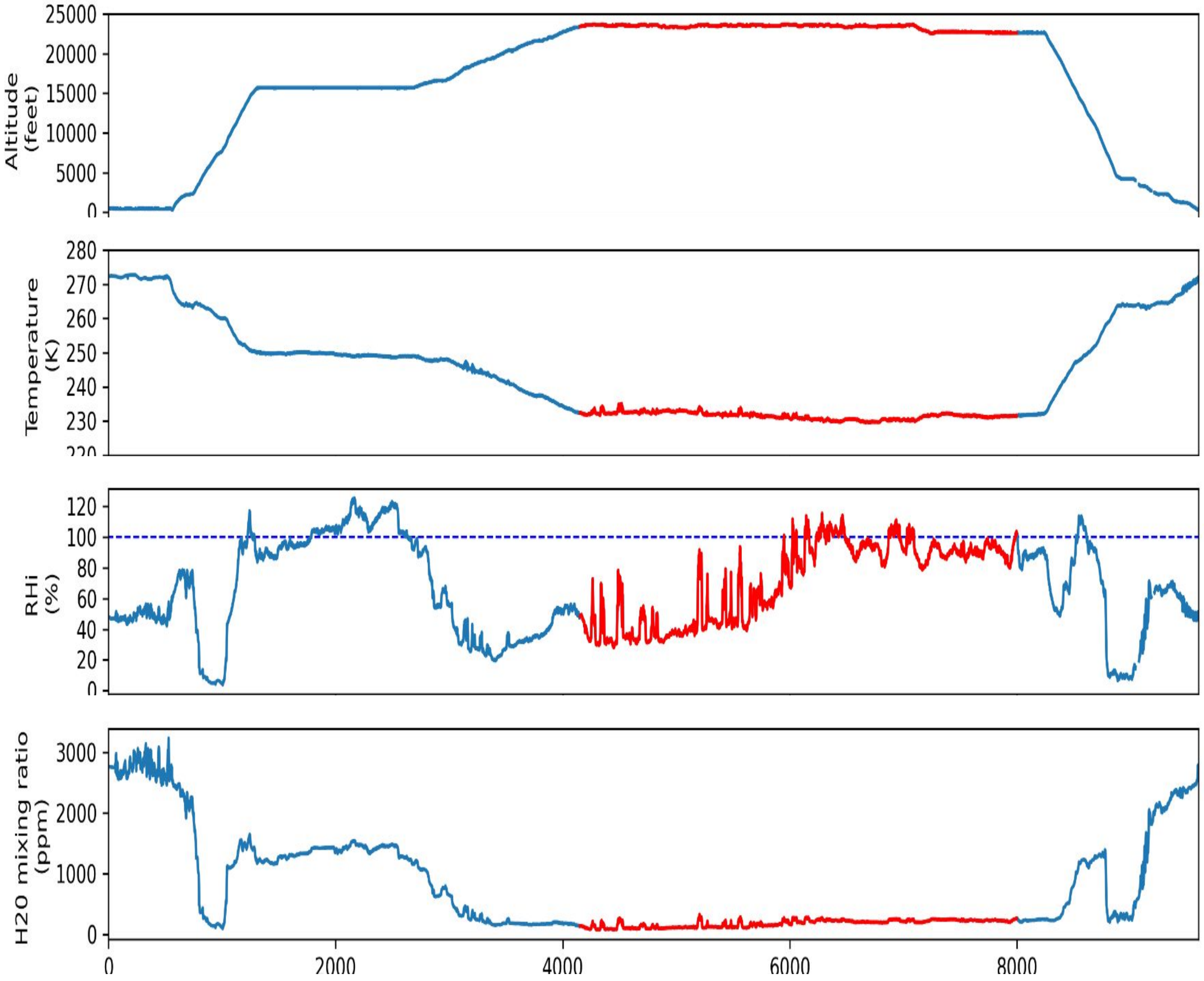
→ comparison of forecast with measurements





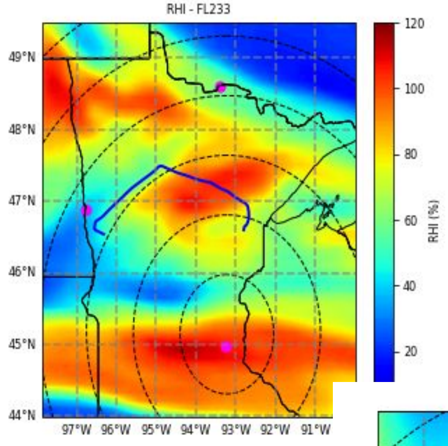


Flight 12/12/2023 - measurements

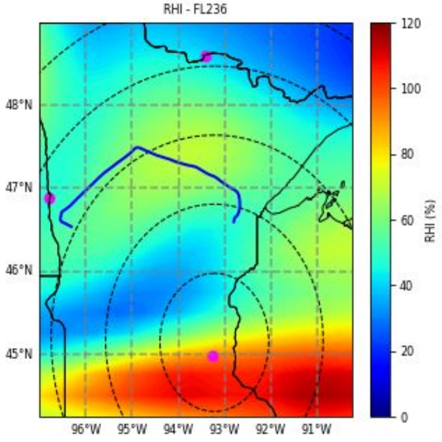


Contrails observed

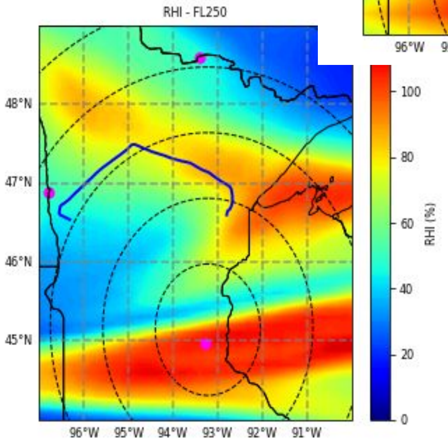
GFS



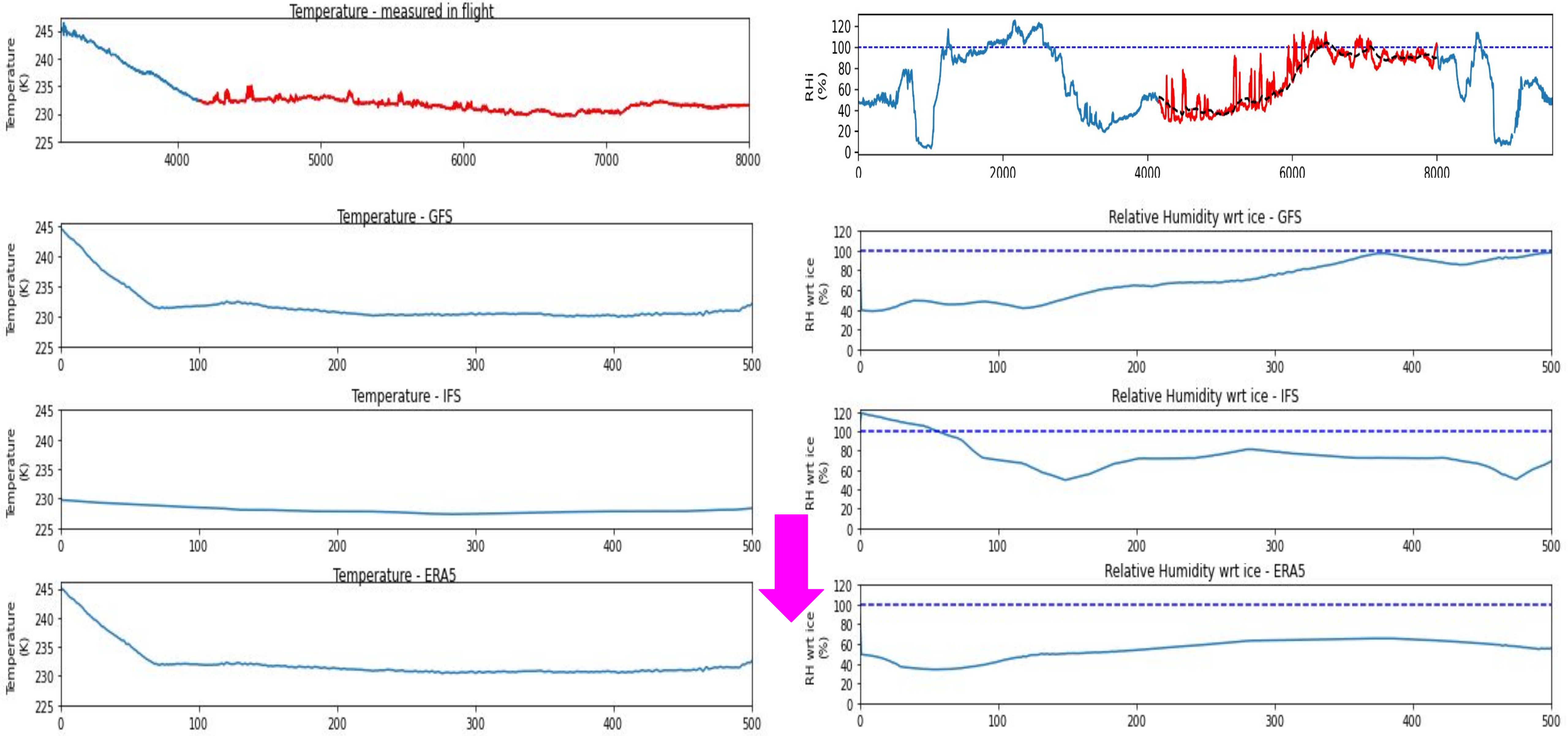
IFS



ERA5



Flight 12/12/2023 measurements compared to forecast



Conclusion & Recommendations

We can identify to a certain extent ISSRs & persistent contrails regions

- Large forecast-to-forecast variations in humidity predictions
- Very large variations in humidity due to altitude, region, season & time of the day
- AND, engine overall efficiency…
- AND, fuel composition…

When close to the critical temperature

- We can use available weather forecasts to estimate where persistent contrails will be formed
    - Dependant on the points above + expertise
    - BUT, a **good forecast is imperative!** However, there are large uncertainties to manage

Recommendations:

- **More frequent & improved forecasts** are a requirement for F/T campaigns and even more for operational mitigation options
- **Data collection and analyses** (aircraft sensors, ground & satellite imaging and sensing, …) to feed models and to validate the forecasts
- Require a **forecast just before take-off** (large hourly variations in the predictions)

Thank you