# How Well Can Persistent Contrails Be Predicted?

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# Background and Motivation

Lee et al., 2020:

“Non-CO2 terms sum to yield a net positive (warming) ERF that accounts for more than half (66%) of the aviation net ERF in 2018.”

“Despite the large ERF/RF adjustment, this [i.e. contrail’s] ERF term is the largest for global aviation in 2018…”

Teoh et al., 2020:

Only 2.2% … of flights contribute to 80% of the contrail EF in this region [Japanese airspace]. A small-scale strategy of selectively diverting 1.7% of the fleet could reduce the contrail EF by up to 59.3% …, with only a 0.014% … increase in total fuel consumption and CO2 emissions.

If one knew beforehand which flight tracks would produce the strongest warming contrails, one could reroute these flight parts to avoid Big Hits, with minor or even no increase of fuel consumption.

This strategy needs, however, a reliable forecast of strong persistent contrails.

Three steps: Contrail formation (Schmidt-Appleman criterion) $\rightarrow$ contrail persistence (ice supersaturation) $\rightarrow$ strong positive individual radiative forcing.

Here we study how reliable the ECMWF model forecasts contrail formation and persistence conditions.

# Data

Forecast data: ERA-5 from Copernicus Data Service

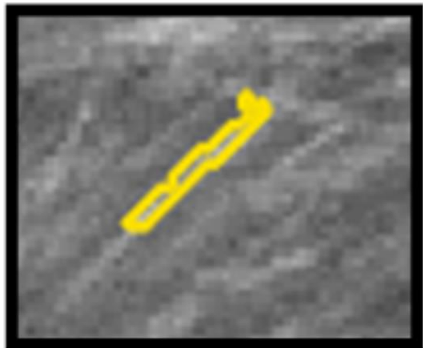
- Pressure levels: 200/225/250/300 hPa
- Dynamics (w, div, vorticity, PV, geopot.) and thermodynamics (T, RH, IWC) data
- Radiation flux densities at TOA
- January, April, July and October 2014
- 1°× 1° resolution for comparison with IAGOS/MOZAIC, ¼°× ¼° for case studies, 1 hour temp. res.

Passenger aircraft data from IAGOS/MOZAIC (statistical analysis)

- Temperature and relative humidity
- Flight position (longitude, latitude, pressure altitude)
- Quality labels

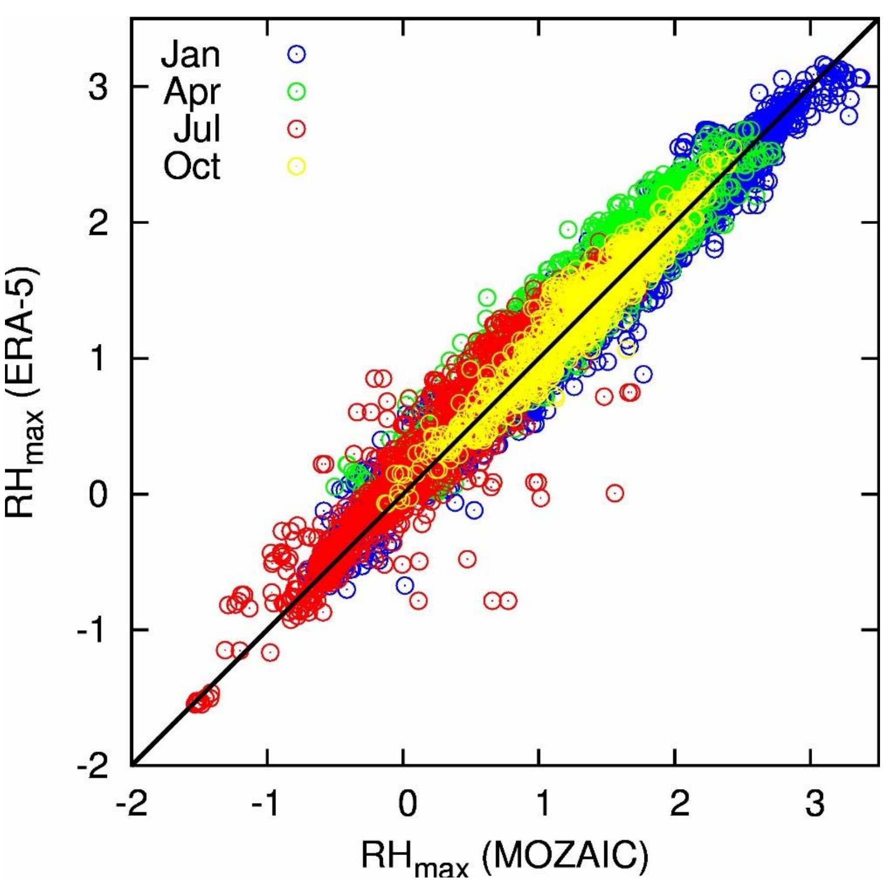
Satellite based contrail data set ACTA for case studies

- Two cases for which ACTA shows large positive values of RF

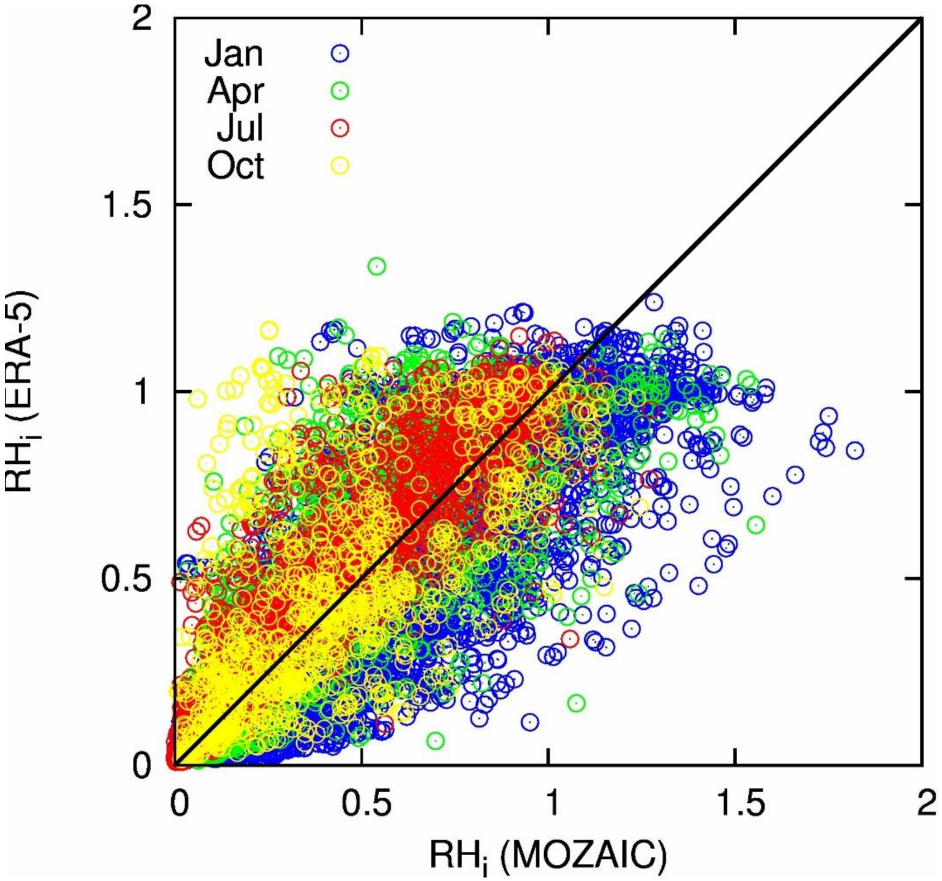


# ERA-5 vs IAGOS/MOZAIC (Statistical analysis)

Schmidt-Appleman criterion ($RH_{max}$>1)




Contrail persistence criterion ($RH_i$>1)



# Summarising the comparison: Equitable Threat Score

ETS = (a − r)/(a + b + c − r) with r = (a + b)(a + c)/(a + b + c + d)

| month | $N$ | Y/Y | Y/N | N/Y | N/N | ETS |
|---|---|---|---|---|---|---|
| | | | SAC | | | |
| 01 | 4706 | 3599 | 32 | 117 | 958 | 0.85 |
| 04 | 2224 | 1726 | 8 | 103 | 387 | 0.73 |
| 07 | 2552 | 679 | 13 | 319 | 1541 | 0.55 |
| 10 | 1092 | 838 | 8 | 28 | 218 | 0.82 |
| | | | ice-supersaturation | | | |
| 01 | 4706 | 34 | 157 | 199 | 4316 | 0.25 |
| 04 | 2224 | 32 | 91 | 103 | 1998 | 0.11 |
| 07 | 2552 | 9 | 35 | 102 | 2406 | 0.05 |
| 10 | 1092 | 8 | 38 | 45 | 1001 | 0.06 |

a = # Y/Y
b = # Y/N
c = # N/Y
d = # N/N

ETS = 1: optimal
ETS = 0: random
ETS < 0. contradictory res.

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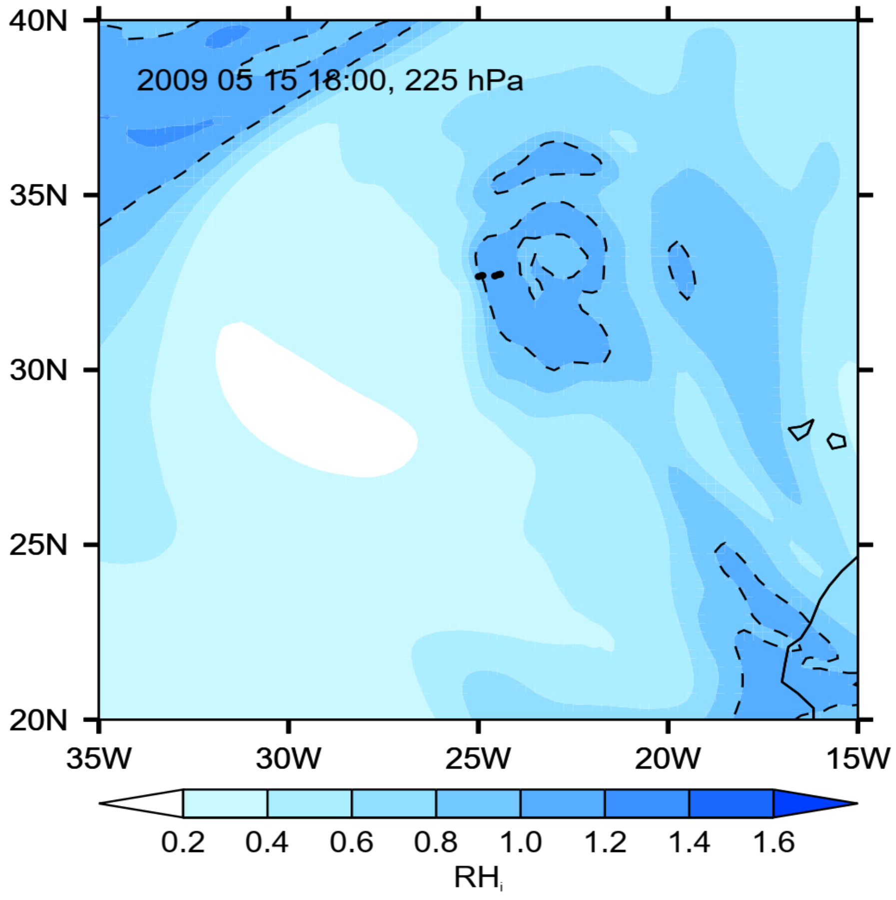
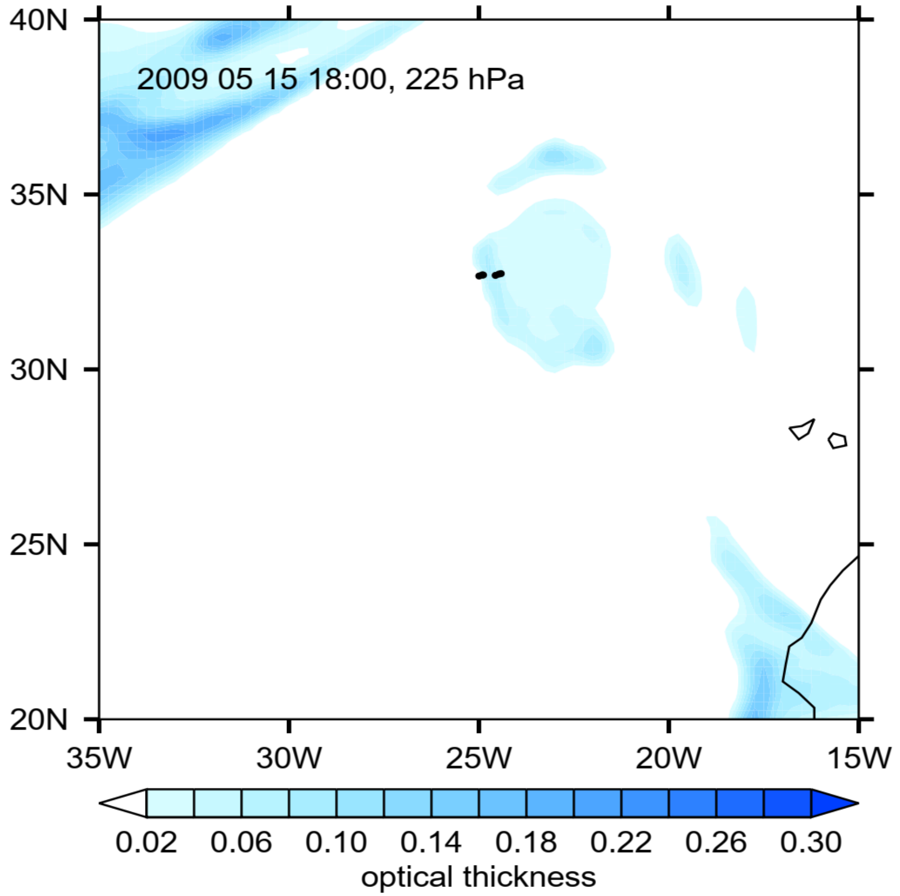
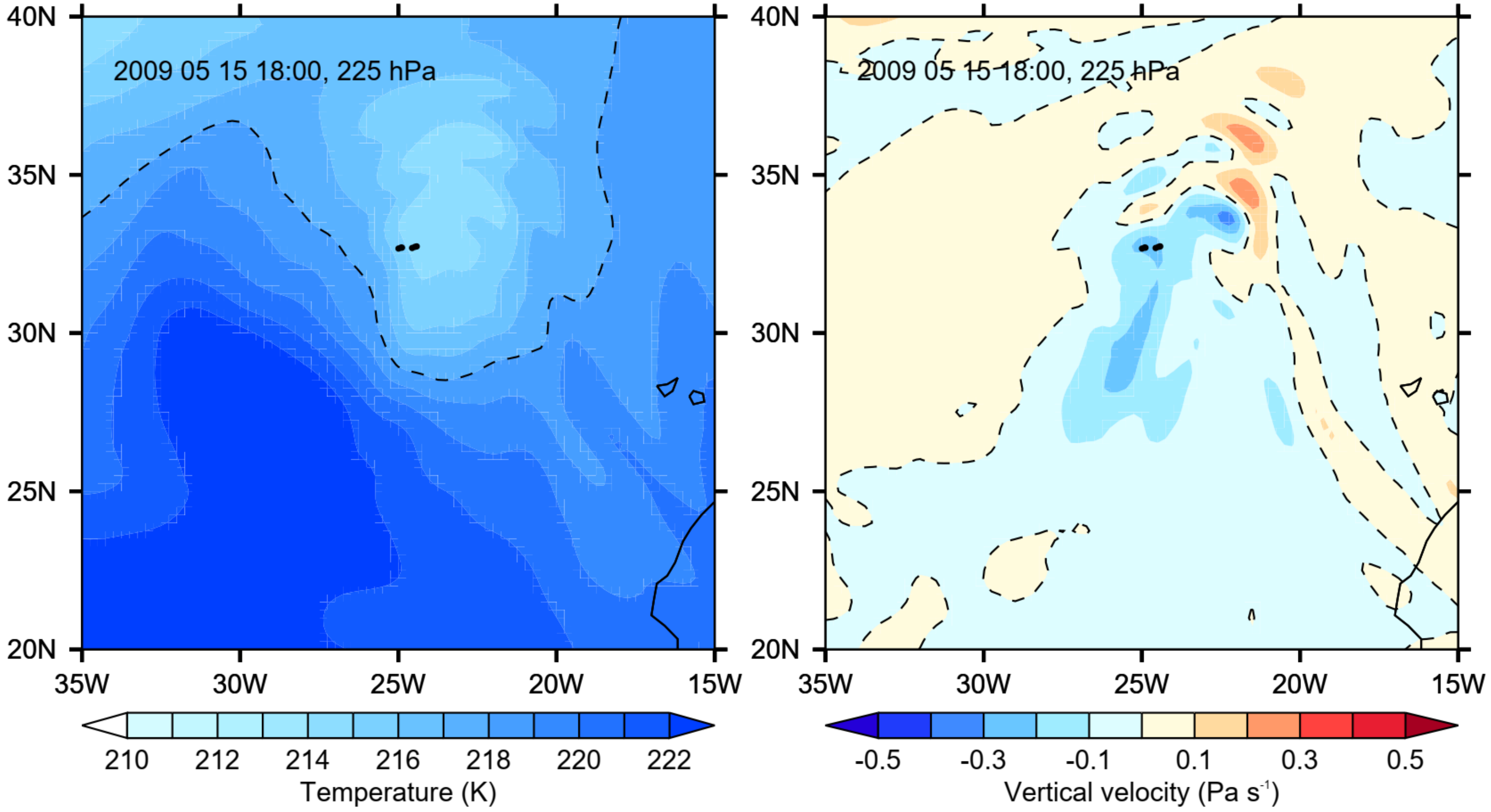
# Case study: 15 May 2009, between 1740 and 1830 UTC 25°W, 33°N, ca. 12 km altitude, iRF > 50 W $m^{-2}$, $\tau \approx$ 0.6-0.7



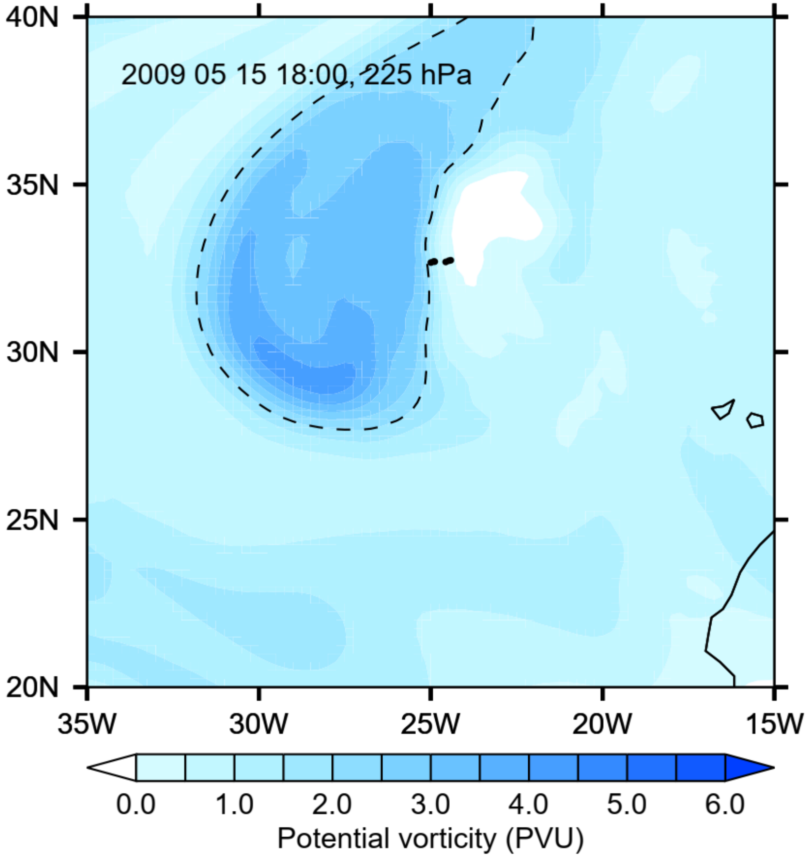

ERA-5
just a bit ice-supersaturation
⇒ too low optical thickness
⇒ too low iRF

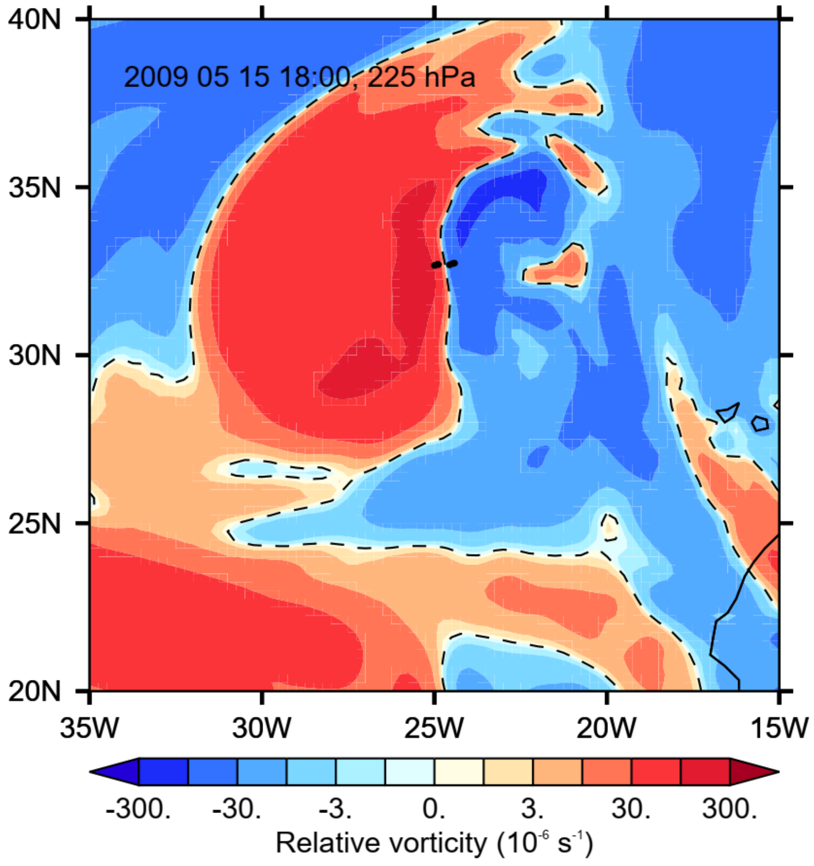
# Case study, contd.




ERA-5
temperature minimum
gentle uplift

# Case study, contd.




ERA-5
dynamical properties
divergence and
relative vorticity
typical for ISSRs
but not for non-ISSRs.

Big Hit occurs right at the lower boundary of the extra-tropical transition layer.

# Summary and Conclusions

- Targeted avoidance of strongly warming contrails ➔ minor rerouting and minor fuel penalty
- Requires reliable forecast of
    - Contrail formation (Schmidt-Appleman criterion)
    - Contrail persistence (ice-supersaturation criterion)
    - Contrail optical thickness and radiation effect

- Statistical comparison ERA-5 vs MOZAIC/IAGOS and case study ERA-5 vs. ACTA

- Prediction of contrail formation is not bad (seasonally variable) but can be improved
- Prediction of ice supersaturation at the right place and time is more or less random

- One ACTA case was not met at all, the other had a weak persistent contrail at the right place and time, with dynamic properties that are more typical for ISSRs than for subsaturated air.

Numerical weather prediction must be improved to implement this avoidance strategy!

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