Forecasting ice supersaturation and persistent contrails

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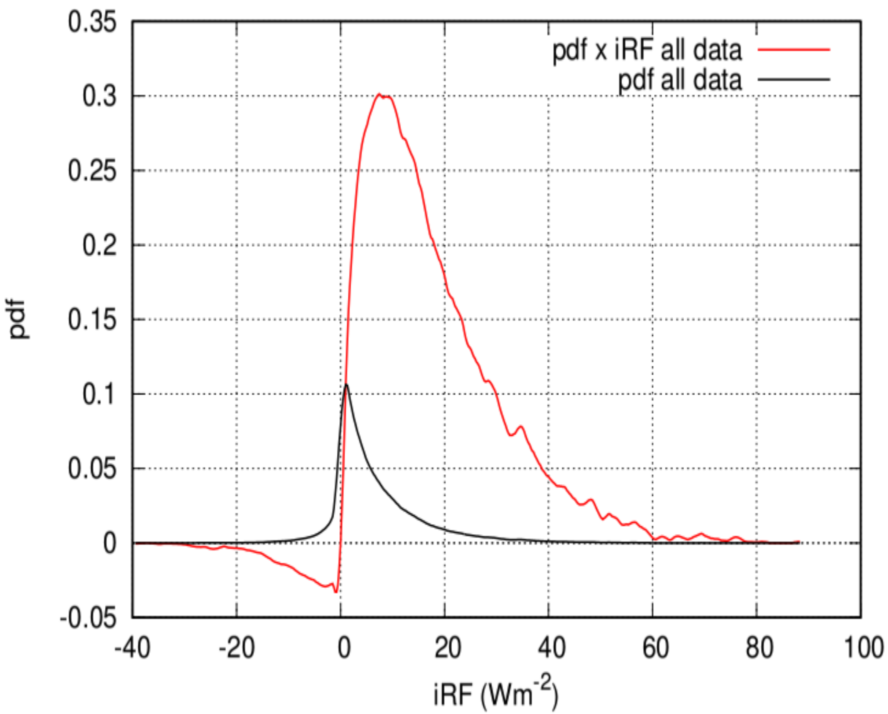
Forecast of persistent contrails and their individual climate effect

Necessary steps for avoiding contrails:

1. Predict the formation of contrails with a reasonable skill
   - ⇨ Schmidt-Appleman criterion
2. Predict the formation of **persistent** contrails with a skill that is sufficient for deviating air traffic
   - ⇨ Predict the occurrence of ice super-saturated regions (ISSRs)
3. Predict the RF (ERF, ATR, ...) associated with individual contrails with a skill that is sufficient for deviating air traffic

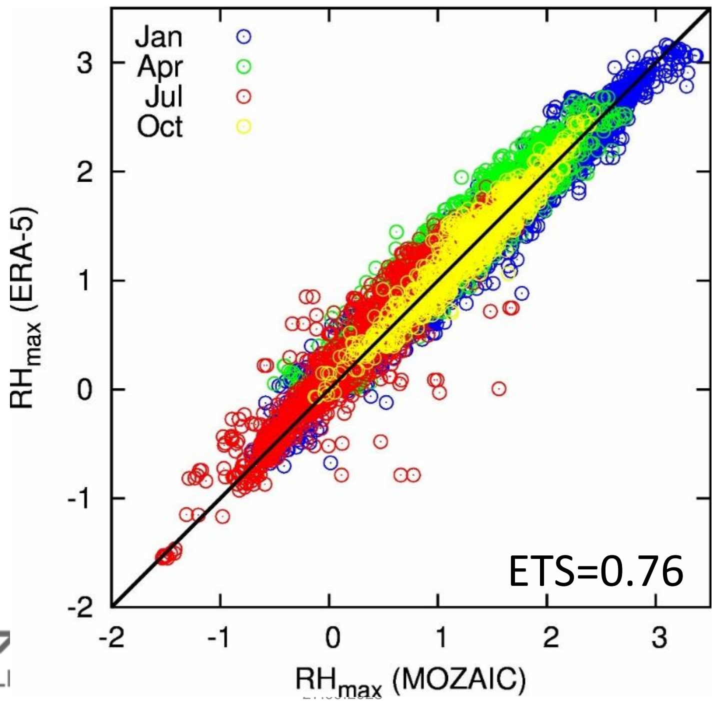


Wilhelm et al., 2021

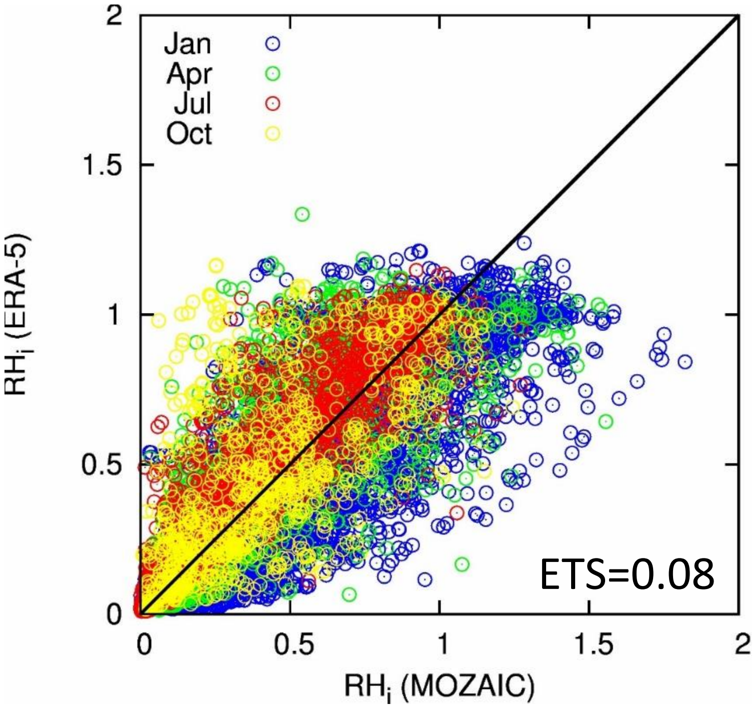
How well can persistent contrails be predicted?

Gierens, Matthes and Rohs, 2020: Analysis of 4 months of IAGOS data

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



Contrail persistence criterion ($RH_i>1$)

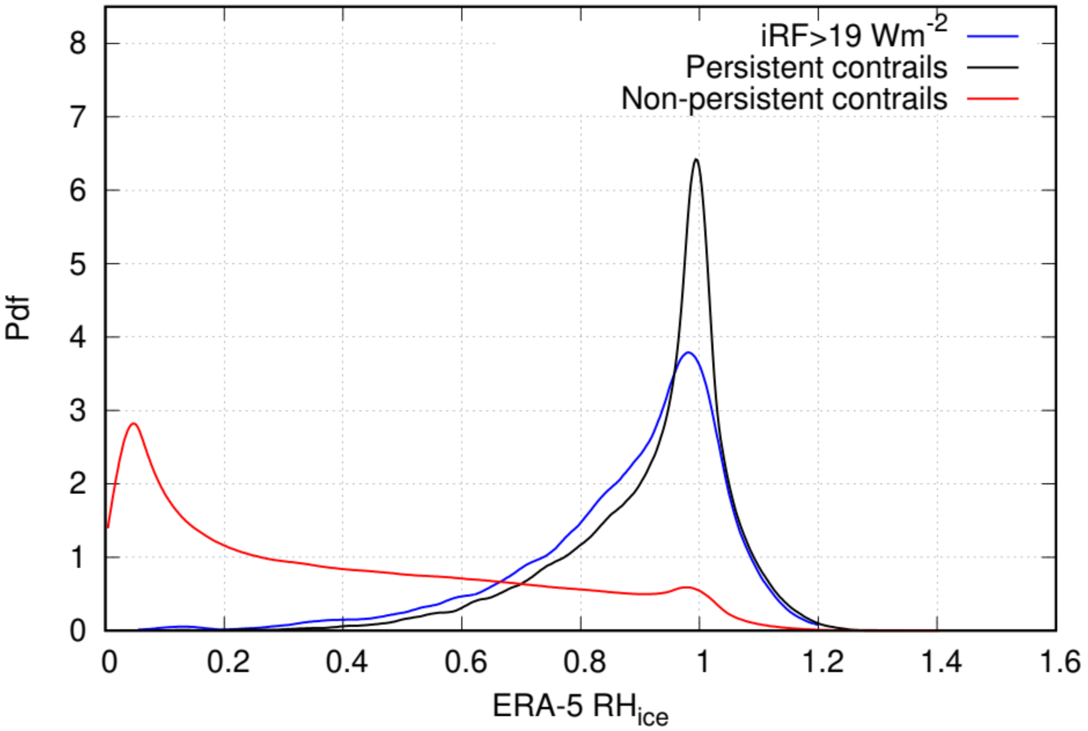


Part 1: Test of dynamical proxies

Conditional distributions of RHi

Wilhelm, Gierens, and Rohs, 2021: Analysis of 10 years of IAGOS data

Many quite dry cases in ERA-5 where IAGOS measurements show ice supersaturation and SAC fulfilled

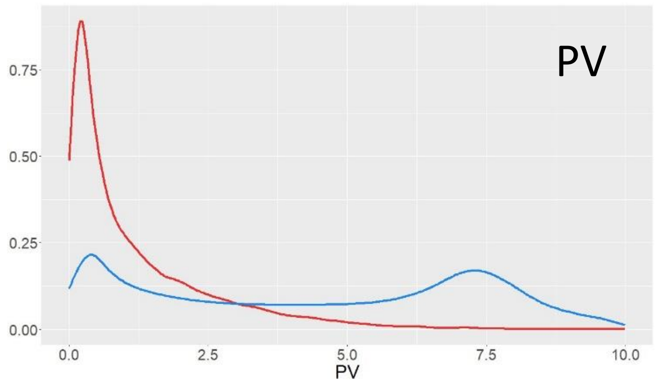


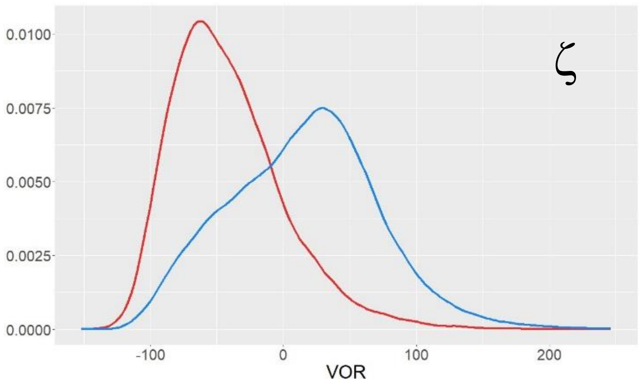
Red: No contrails or at least no persistence possible (acc. to IAGOS data)

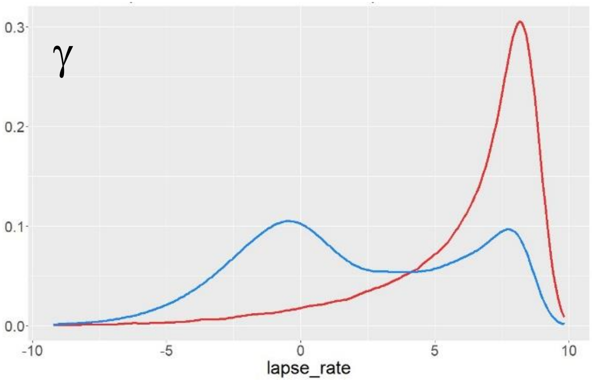
Black: Persistent contrails possible (acc. to IAGOS data)

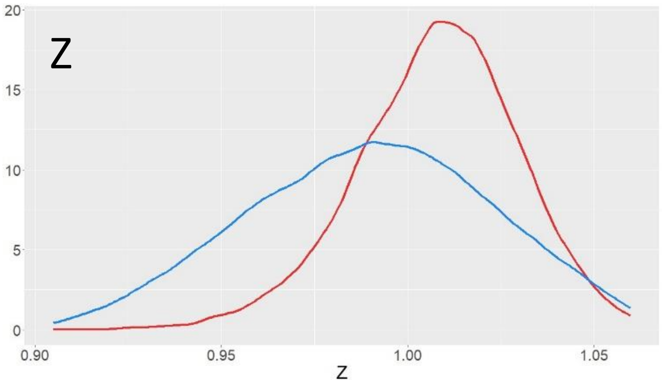
Blue: Persistent contrails with strong instantaneous RF possible (acc. to IAGOS)

Dynamical proxies: Relation between ISS and PV, ζ, γ, Z
Distinct conditional distributions









red: ISS,
blue: no ISS

Log-likelihood ratios are too small!

Use dynamical proxies in a Bayesian learning procedure:

$$\log(\Omega|x) = \log\Lambda + \log\Pi$$

with

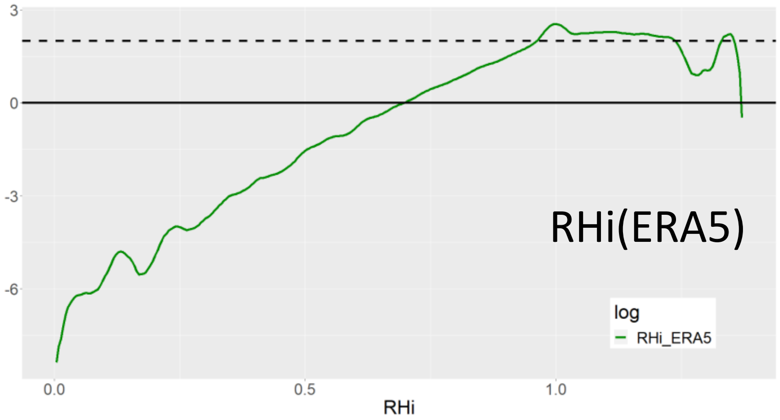
$$(\Omega|x) = P(ISS|x)/P(\overline{ISS}|x)$$

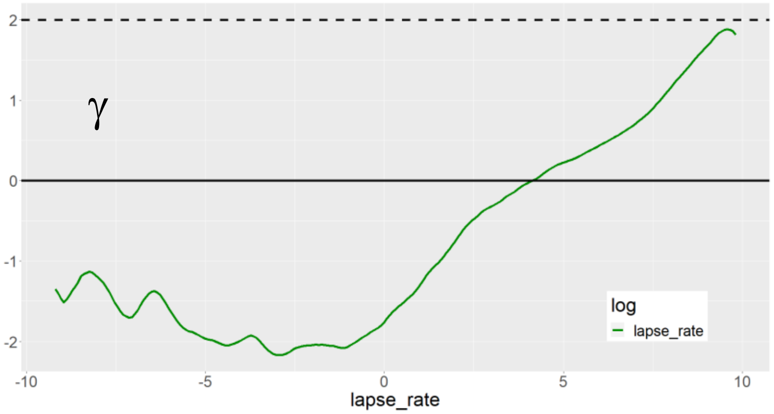
$$\Lambda = f_X(x|ISS)/f_X(x|\overline{ISS})$$

$$\Pi = P(ISS)/P(\overline{ISS}), \log\Pi \approx -2$$

Unfortunately too small log-likelihood ratios (almost always < 2).

Thus the probability for ISS does hardly raise above 1/2.

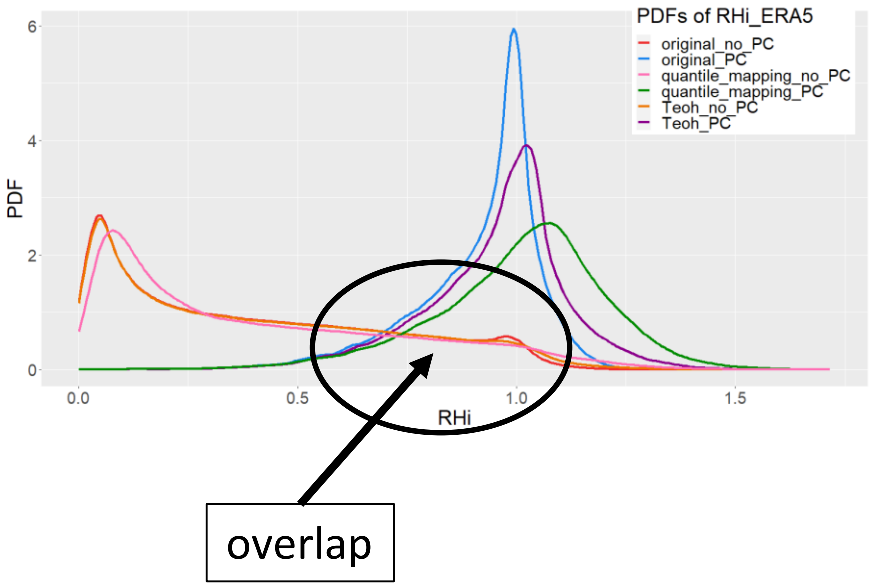




Regression using generalised additive models (GAMs)

GAM: $\log(\Omega|x) = \beta_0 + \sum f_i(X_i)$

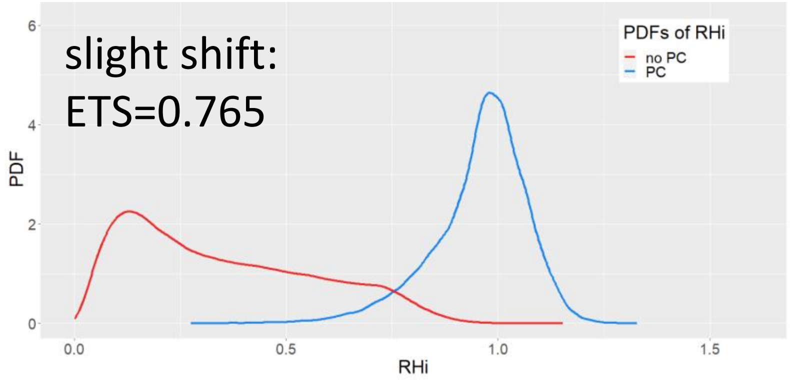
- inclusion of RHi(ERA5) is essential
- ETS values do not get larger than about 0.38
- inclusion of proxies does not raise ETS significantly
- a priori correction of RHi does not help
- better results are prohibited by the large overlap btw. the cond. pdfs

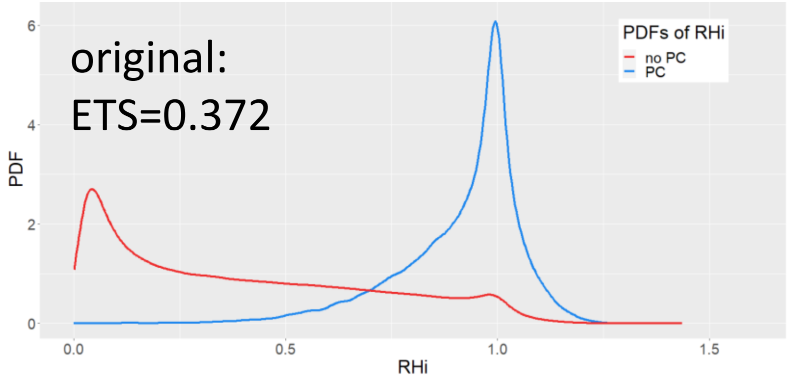


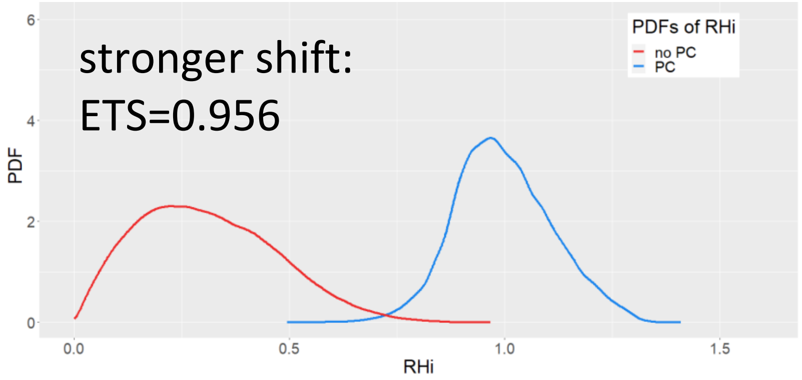
Test of the GAM with artificial pdfs (RHi) with reduced overlap

Reducing the overlap of the conditional pdfs raises the ETS of the GAM substantially.

This points to the problem that needs to be overcome in NWP.





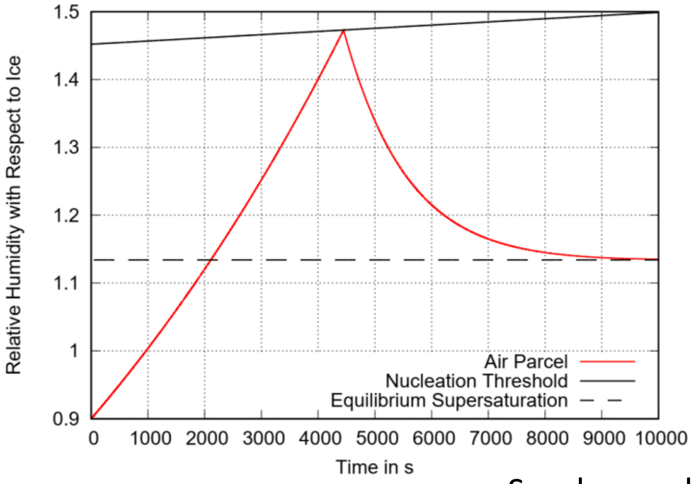


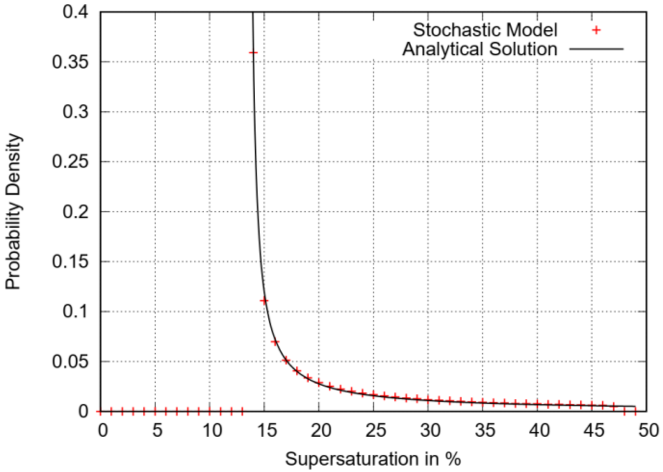
Hofer et al., in prep.

Part 2: New concept of a one-moment ice cloud scheme for NWP models

New One-Moment Scheme avoiding saturation adjustment

- New scheme assumes sub-grid variability in the humidity field
- Whenever the humidity threshold for homogeneous nucleation is passed locally within a grid box, the resulting cloud fraction is predicted
- Exponential decay of specific humidity assumed in the cloudy part of the grid box instead of instantaneous conversion of all supersaturation to ice (saturation adjustment)

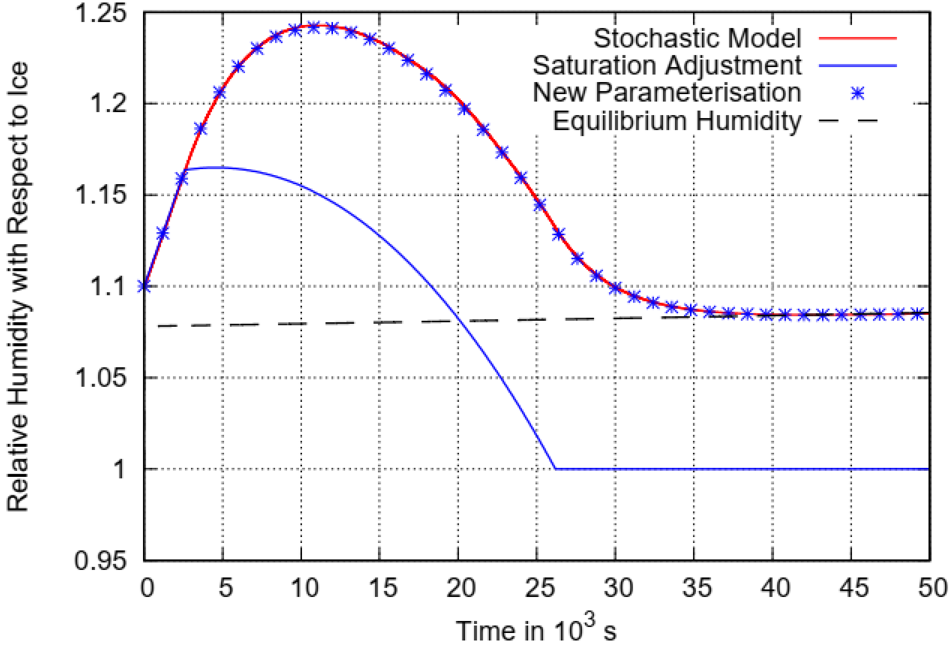




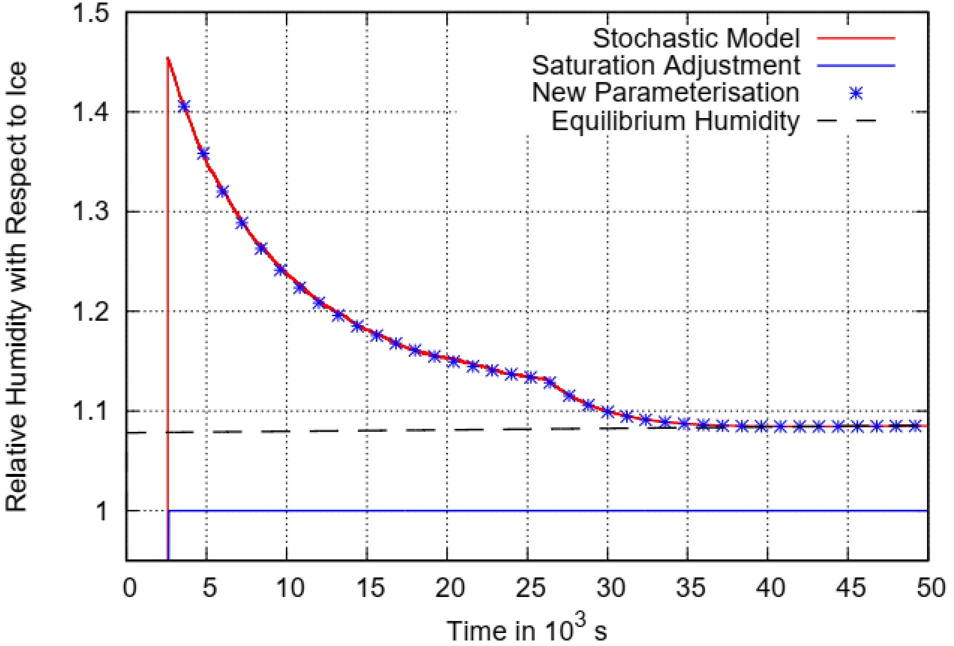
Sperber and Gierens, 2023, in press

New One-Moment Scheme avoiding saturation adjustment

Grid mean relative humidity



In-cloud mean relative humidity



⇒ Considerably larger supersaturation during cloud formation, but also in the aged cirrus cloud.

Summary and further research

- Aviation contributes to climate change (warming) through CO_2 emission and non-CO_2 effects. The latter are short-lived and strongly situation-dependent. This implies that they can be lowered by a climate-aware flight-planning.
- Strongly warming persistent contrails can be avoided if flights avoid ice supersaturated regions. The forecast of the latter is challenging.
- We need improved representations of ice-clouds and their supersaturated environment in NWP models.
- We need many more good humidity measurements at cruise level for data assimilation.
- We need better detection of contrails in satellite data for validation.