Forecasting conditions for contrail development

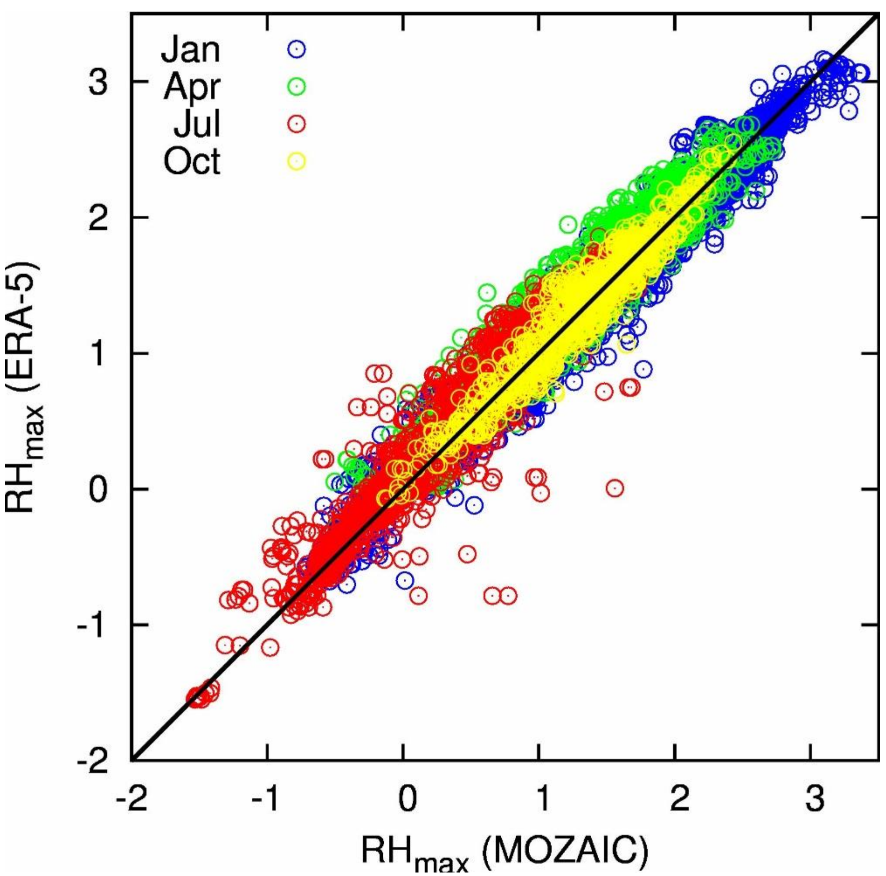
Klaus Gierens, DLR Oberpfaffenhofen

with contributions from L. Wilhelm, P. Peter, et al.

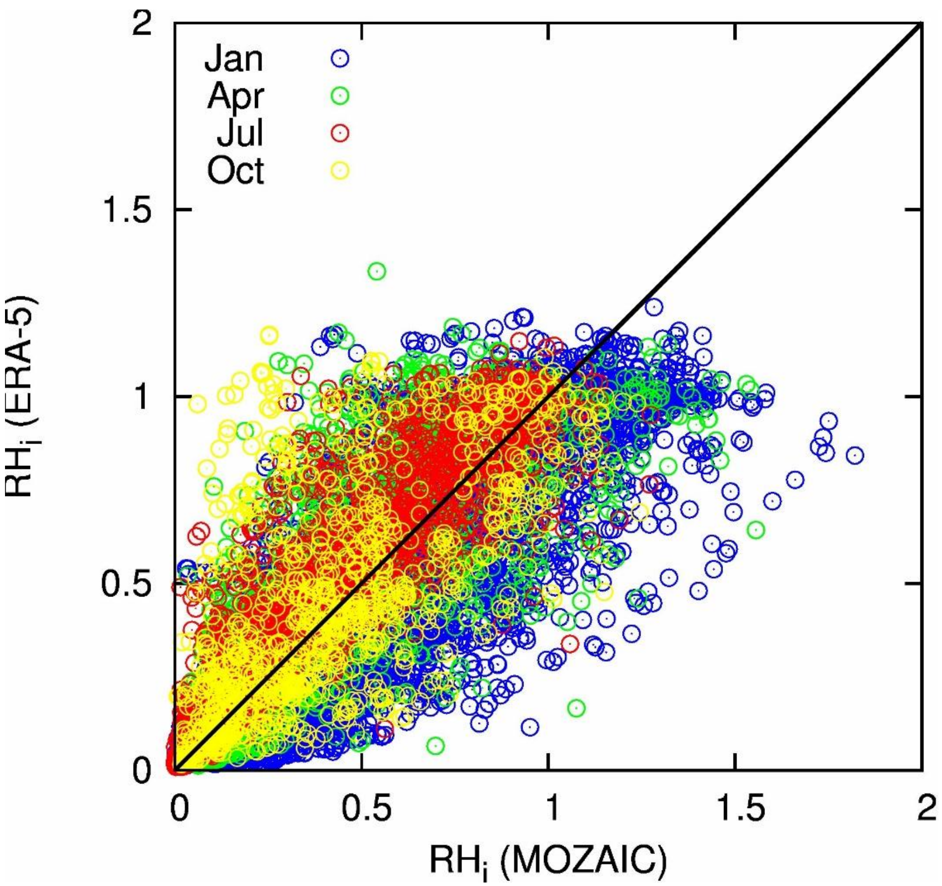
This work has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreements No 875036 and 101056885

Forecasting persistent contrails – a challenging problem

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

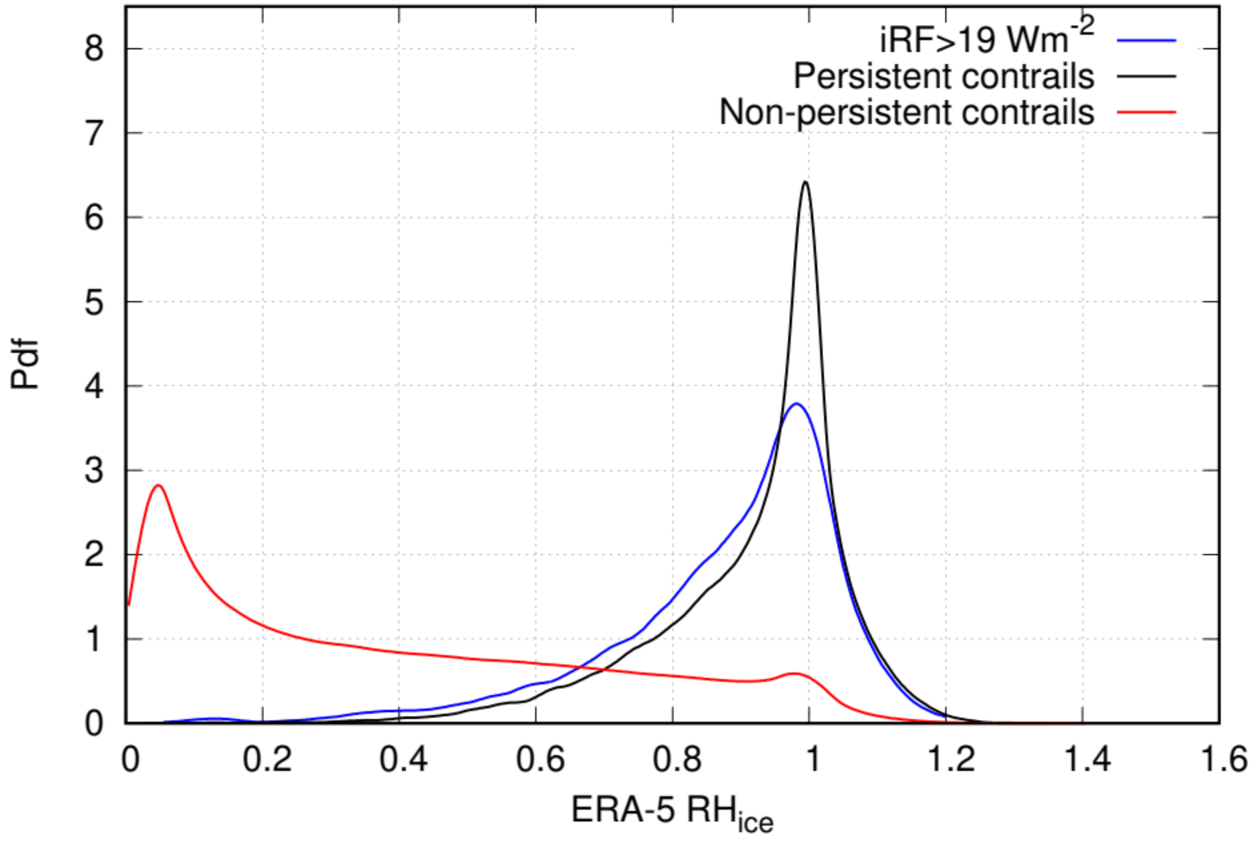


Contrail persistence criterion (RH_i>1)



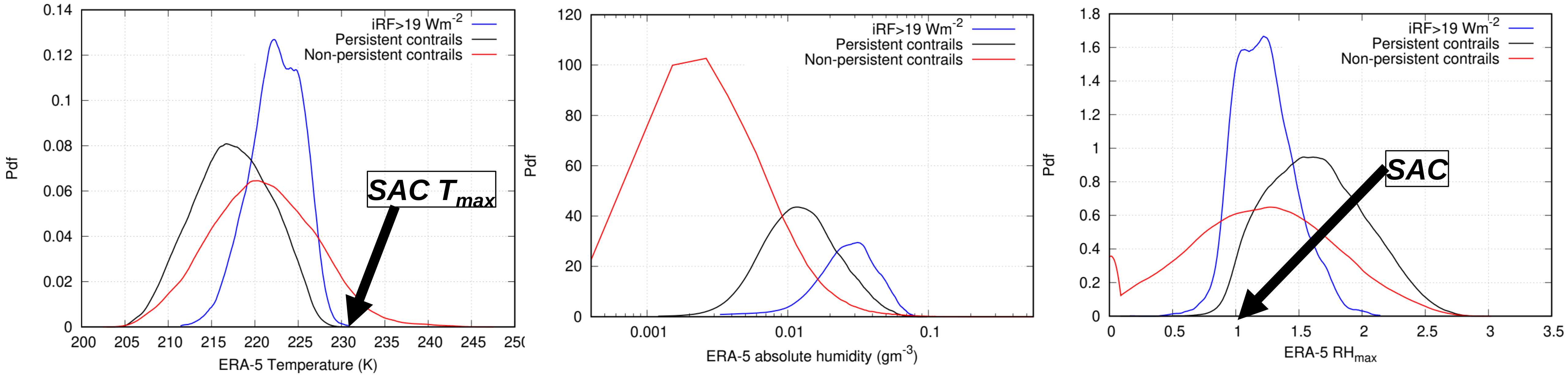
Forecasting persistent contrails – a challenging problem

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



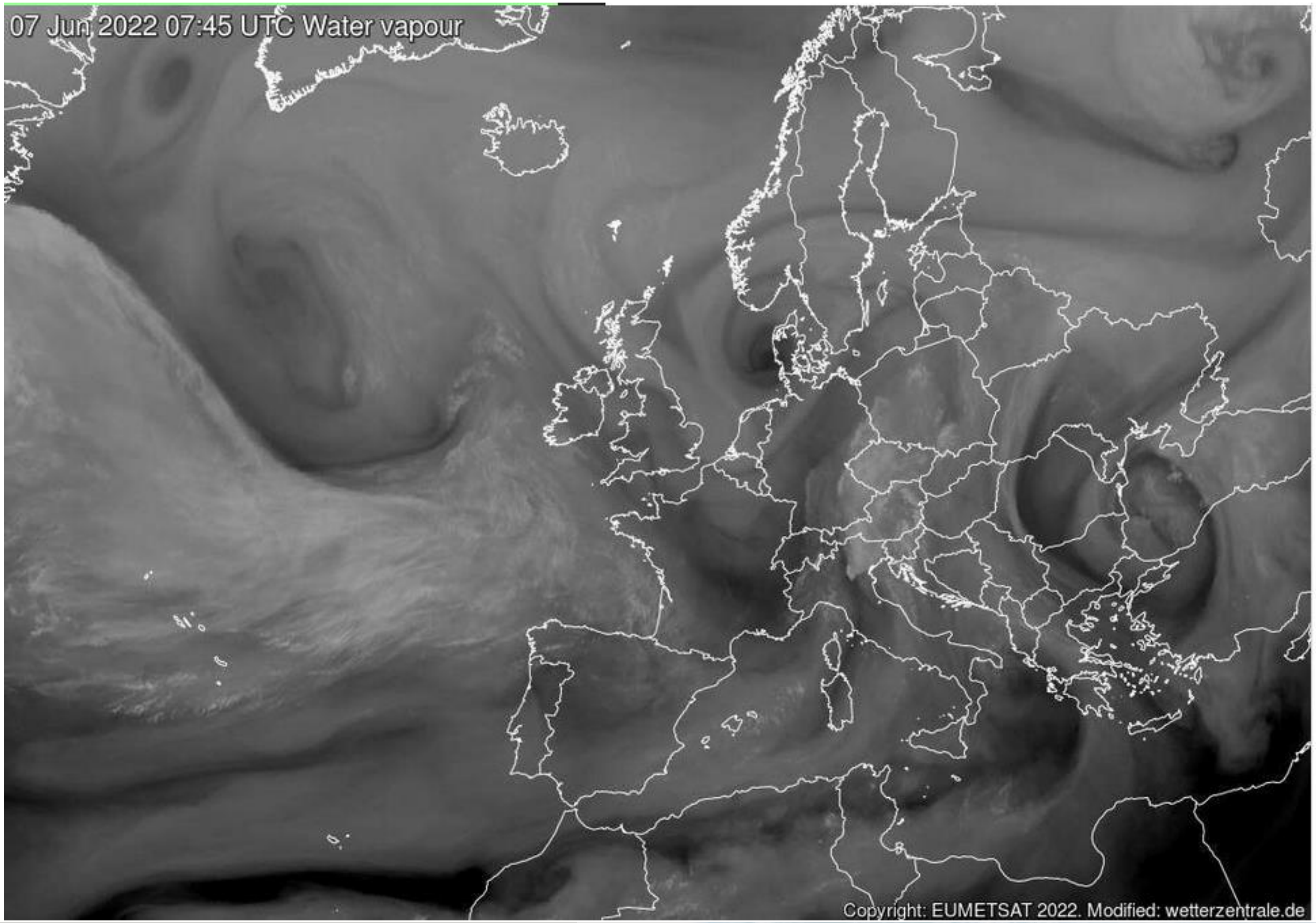
Red: No contrails or at least no persistence possible (acc. to MOZAIC data)
Black: Persistent contrails possible (acc. to MOZAIC data)
Blue: Persistent contrails with strong instantaneous RF possible (acc. to MOZAIC data)

Thermodynamic conditions (temperature and humidity)



Red: No contrails or at least no persistence possible (acc. to MOZAIC data)
Black: Persistent contrails possible (acc. to MOZAIC data)
Blue: Persistent contrails with strong instantaneous RF possible (acc. to MOZAIC data)

What makes prediction of ice supersaturation so difficult? Strong variability of water vapour



Water vapour participates in dynamic, thermodynamic, chemical and aerosol processes on a multitude of spatial and time scales.

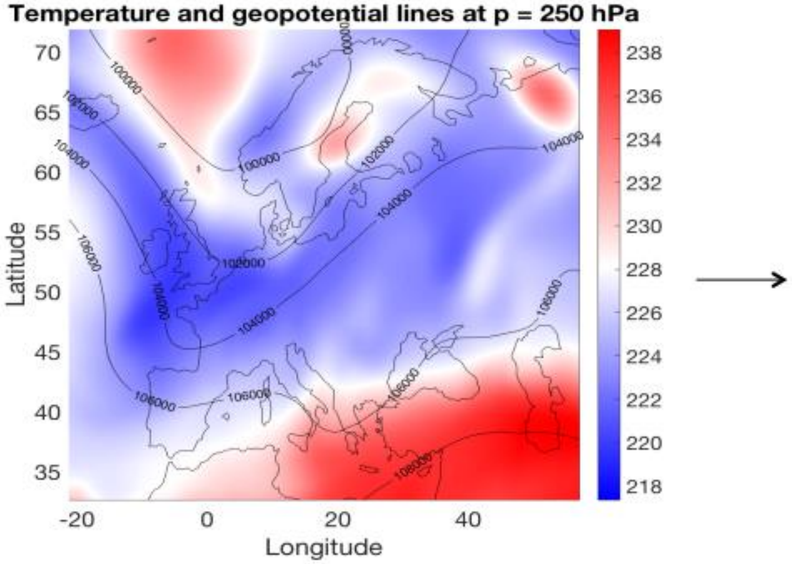
This causes strong variability and sharp gradients in the water vapour field of the upper troposphere.

Extremal, non-equilibrium states like ice-supersaturation are much more sensitive to changing conditions than are „normal“ states.

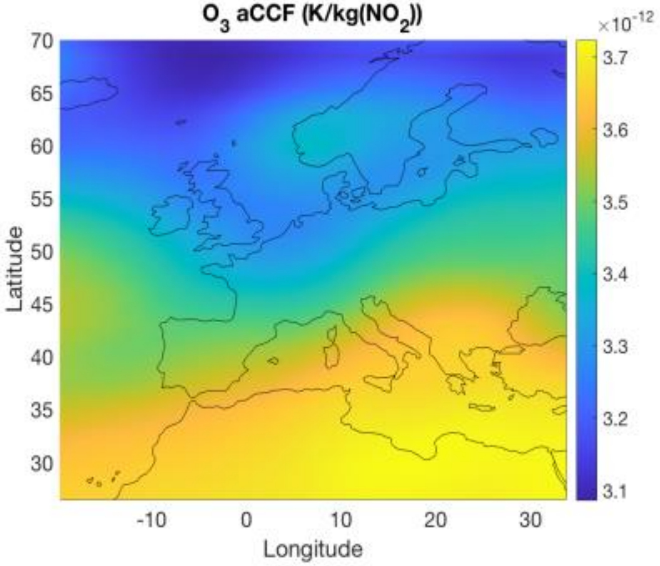
Other constituents and variables have smooth fields

In contrast, gaseous emissions (CO2, NOx) participate only in chemical processes; their aCCFs are smooth and follow roughly the large-scale circulation patterns.

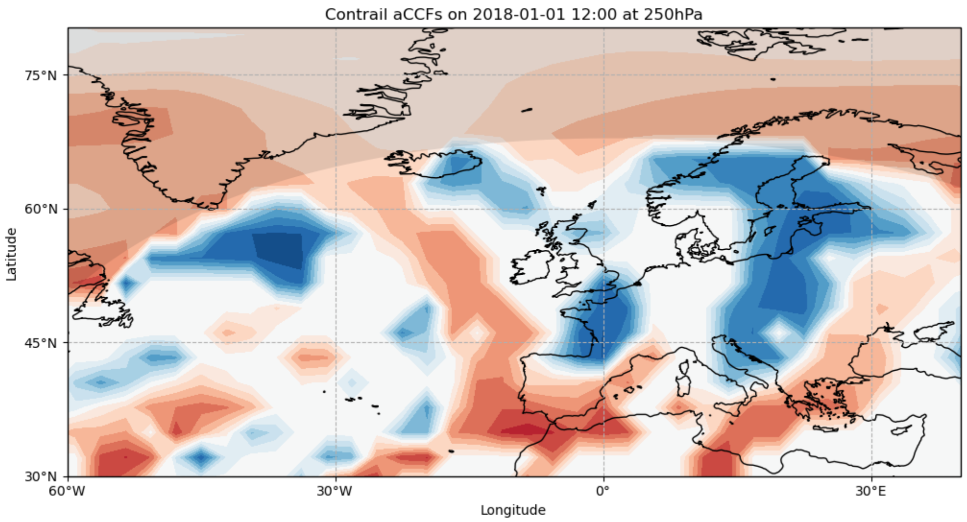
Temperature fields as well are much smoother than the water vapour field.



Weather situation (T, Φ)



Climate impact of NOx on O_3



Contrail aCCF at a certain time

Figures from Rao et al., 2021, and P. Peter

Lagrangian simulations of spatially close contrails

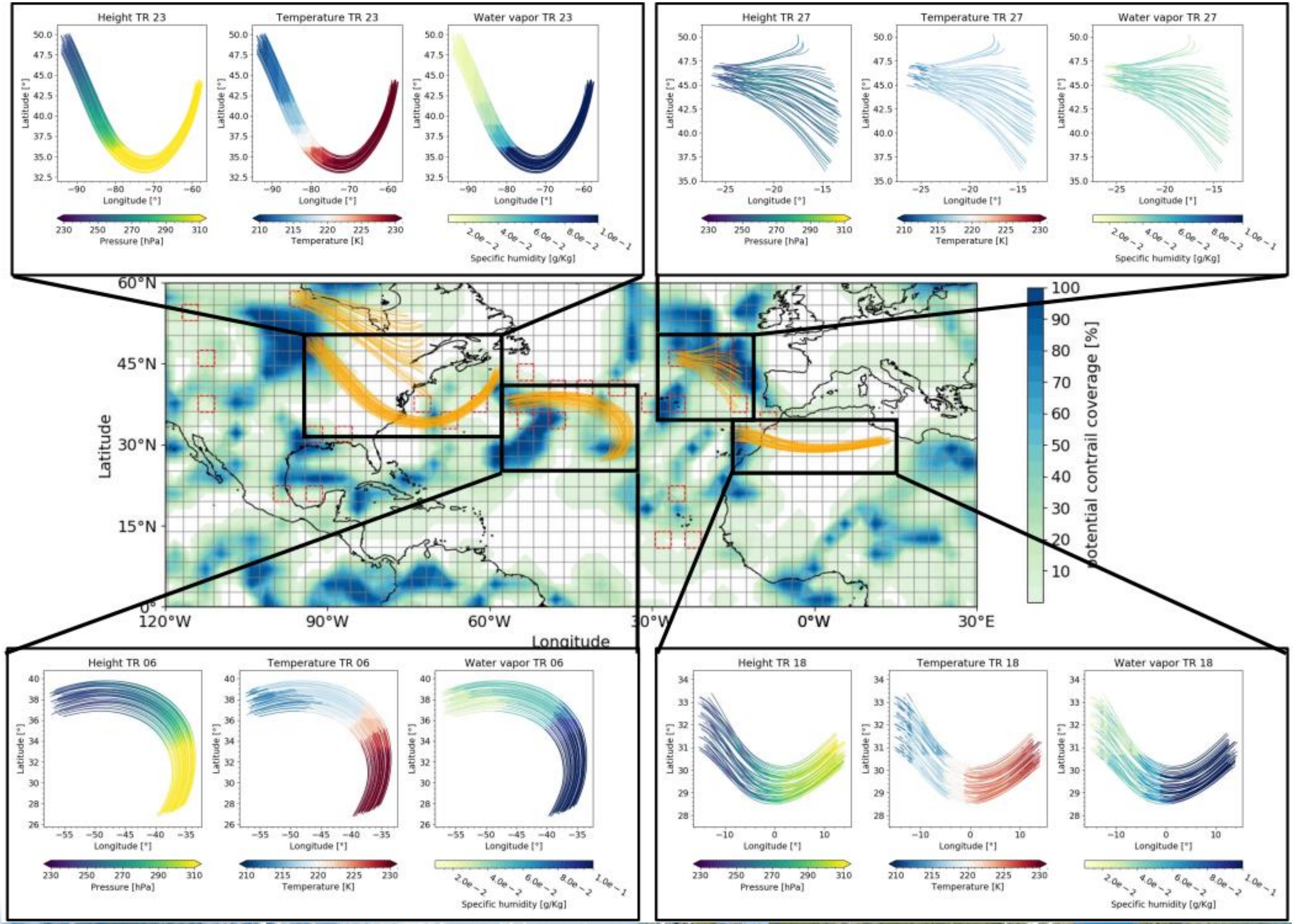
ECHAM5-ATTILA L41

Water vapor pulse emissions are released on the start point of 50 trajectories and life cycle of contrails is investigated

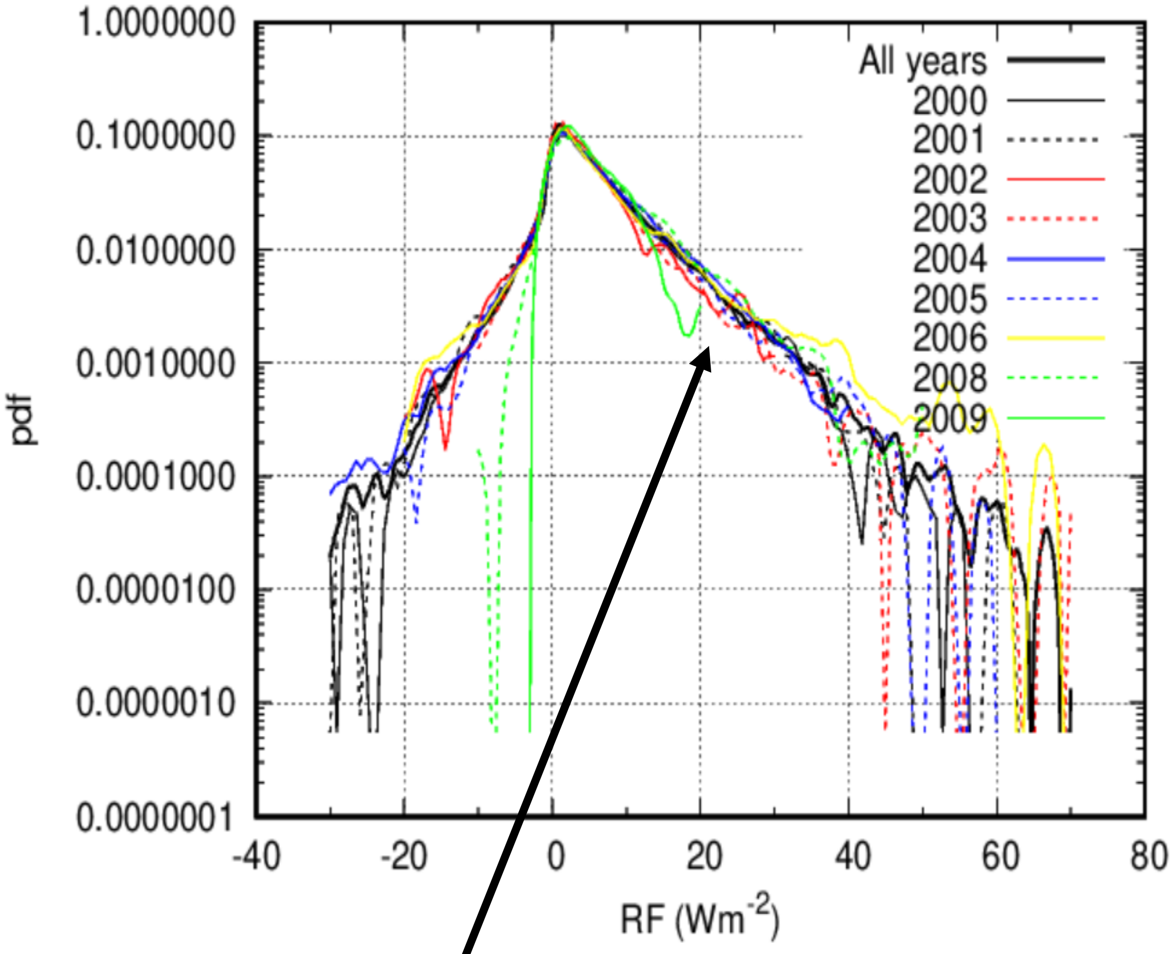
Note the different possibilities:

Some-times the 50 contrails behave similarly, but sometimes there is a wide diversity in position and properties

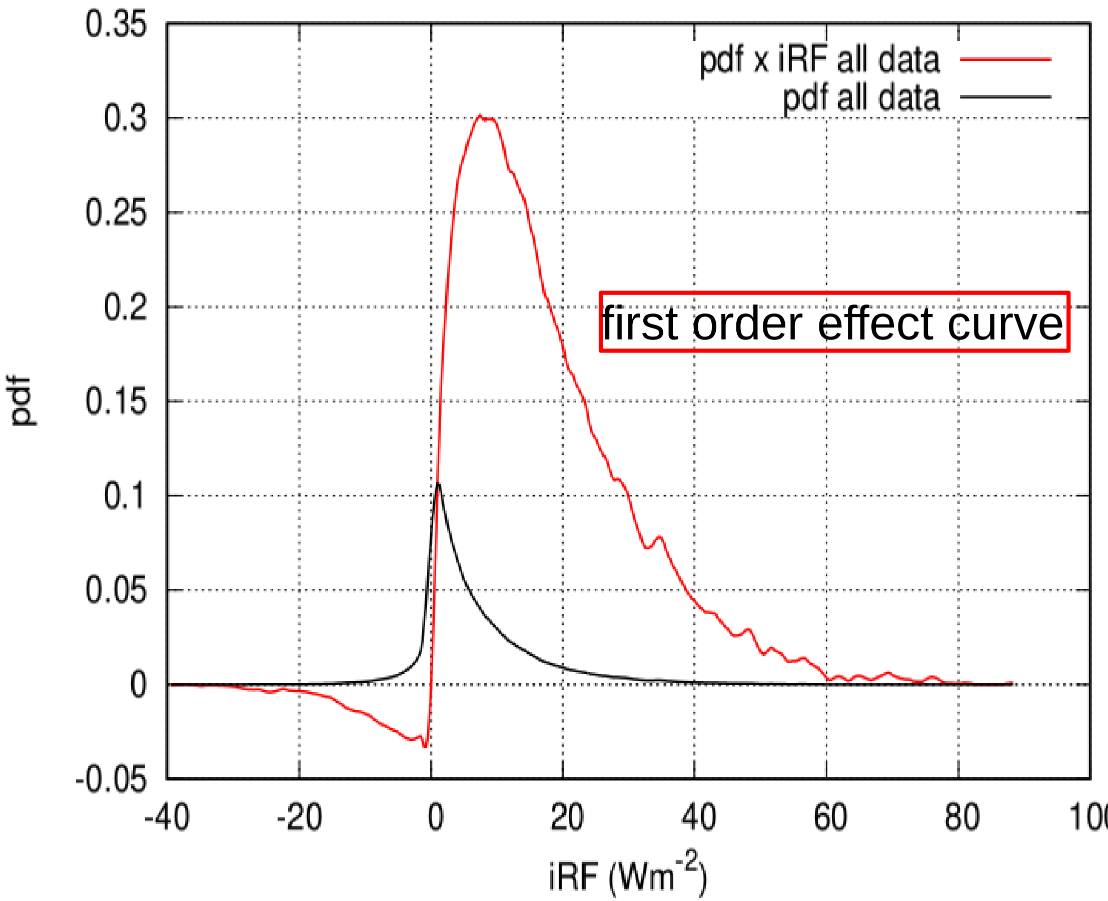
P. Peter, phd-work



Huge variability in instantaneous (individual) radiative forcing



exponential distribution



Figures from Wilhelm et al. 2021

How can the forecast of persistent contrails be improved?

We need much more regularly-obtained humidity data for the upper troposphere (flight levels)

- Only few aircraft equipped with WV sensors in the framework of the AMDAR system
- Main purpose is to provide vertical soundings during ascent and descent, no measurement during cruise
- Needs new technical developments
- Should be free of costs for weather offices (win-win situation)

https://flyht.com/weather-sensors/wvss-ii/

Cruise level RH data assimilation and improved cirrus representation

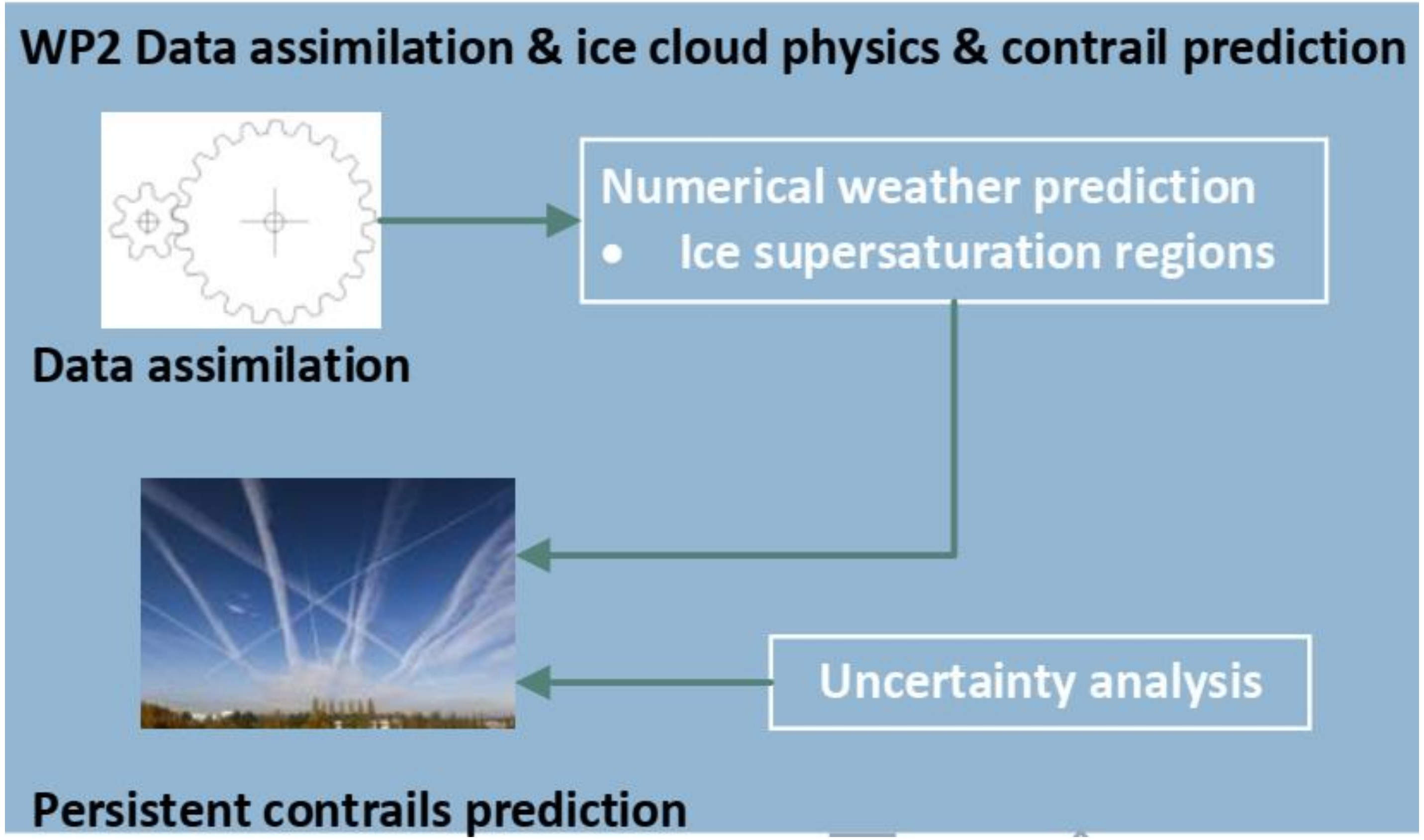
BeCoM project work package

Data assimilation of cruise level humidity data (various sources)

Improved cirrus physics that better represents the interaction between cirrus clouds and their parent ice supersaturated regions

Validation and uncertainty analysis

Project just started, will run until May 2026



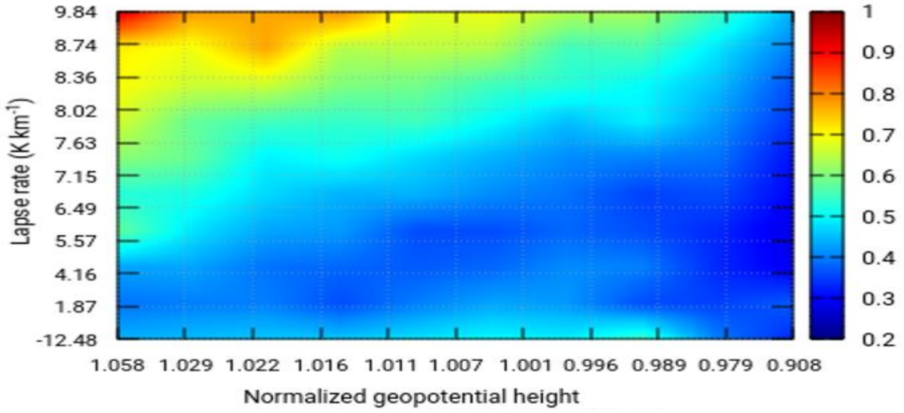
Dynamical proxies

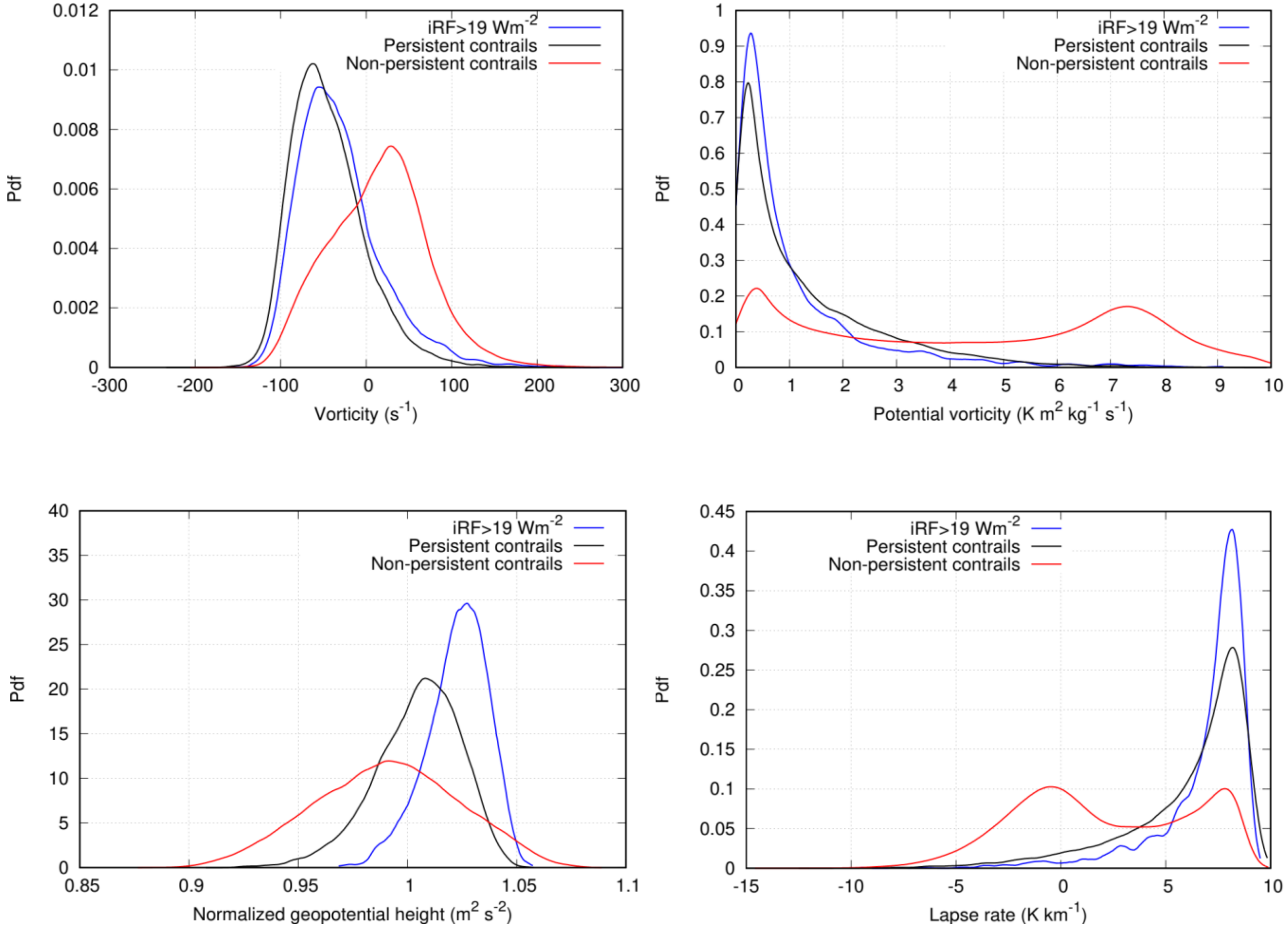
The dynamical fields

- Relative vorticity
- Potential vorticity
- Normalized geopotential
- Lapse rate

have distinctly differing conditional probability distributions.

Combining their values can inform contrail persistence prediction.





Summary and future work

PART 1:

- Although weather models simulate quite reasonable thermodynamic fields, forecasting contrail persistence on the spot is currently not reliable. It works better for regional and time-period based predictions.

PART 2:

- WV is involved in many processes and thus much more variable than other chemical compounds or the temperature field, for instance. While CCFs of other emissions are smooth, those for contrails are patchy.
- Sometimes, contrail formed close to each other display wide variety of evolution (butterfly effect)
- Background conditions (weather, radiation) induce a huge variability of individual forcing values.

PART 3:

- Regular measurements in sufficient quantities of relative humidty at cruise levels are urgently needed.
- These need to be assimilated into NWP models. Cirrus representations in NWP models need improvements.
- Dynamical proxies can be used in modern statistical methods to provide probabilistic contrail forecasts.