Towards an aviation weather forecast for green operations

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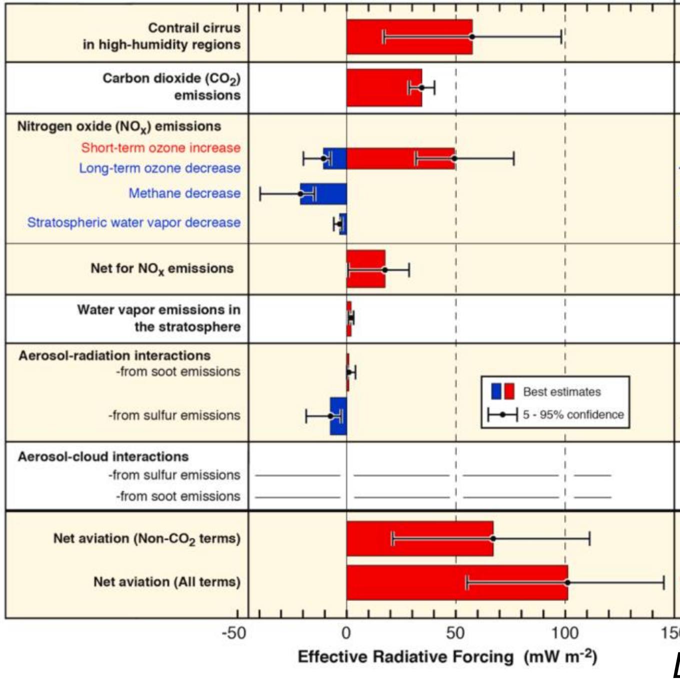
Climate impact of aviation: CO_2 and non-CO_2 effects

Global Aviation Effective Radiative Forcing (ERF) Terms (1940 to 2018)



Term	ERF ($mW\,m^{-2}$)	RF ($mW\,m^{-2}$)	ERF/RF	Conf. levels
Contrail cirrus in high-humidity regions	57.4 (17, 98)	111.4 (33, 189)	0.42	Low
Carbon dioxide (CO_2) emissions	34.3 (28, 40)	34.3 (31, 38)	1.0	High
Nitrogen oxide (NO_x) emissions: Short-term ozone increase	49.3 (32, 76)	36.0 (23, 56)	1.37	Med.
Long-term ozone decrease	-10.6 (-20, -7.4)	-9.0 (-17, -6.3)	1.18	Low
Methane decrease	-21.2 (-40, -15)	-17.9 (-34, -13)	1.18	Med.
Stratospheric water vapor decrease	-3.2 (-6.0, -2.2)	-2.7 (-5.0, -1.9)	1.18	Low
Net for NO_x emissions	17.5 (0.6, 29)	8.2 (-4.8, 16)	----	Low
Water vapor emissions in the stratosphere	2.0 (0.8, 3.2)	2.0 (0.8, 3.2)	[1]	Med.
Aerosol-radiation interactions -from soot emissions	0.94 (0.1, 4.0)	0.94 (0.1, 4.0)	[1]	Low
-from sulfur emissions	-7.4 (-19, -2.6)	-7.4 (-19, -2.6)	[1]	Low
Aerosol-cloud interactions -from sulfur emissions	No best estimates	No best estimates	----	Very low
-from soot emissions			----	
Net aviation (Non-CO_2 terms)	66.6 (21, 111)	114.8 (35, 194)	----	——
Net aviation (All terms)	100.9 (55, 145)	149.1 (70, 229)	----	——

Lee et al., 2021

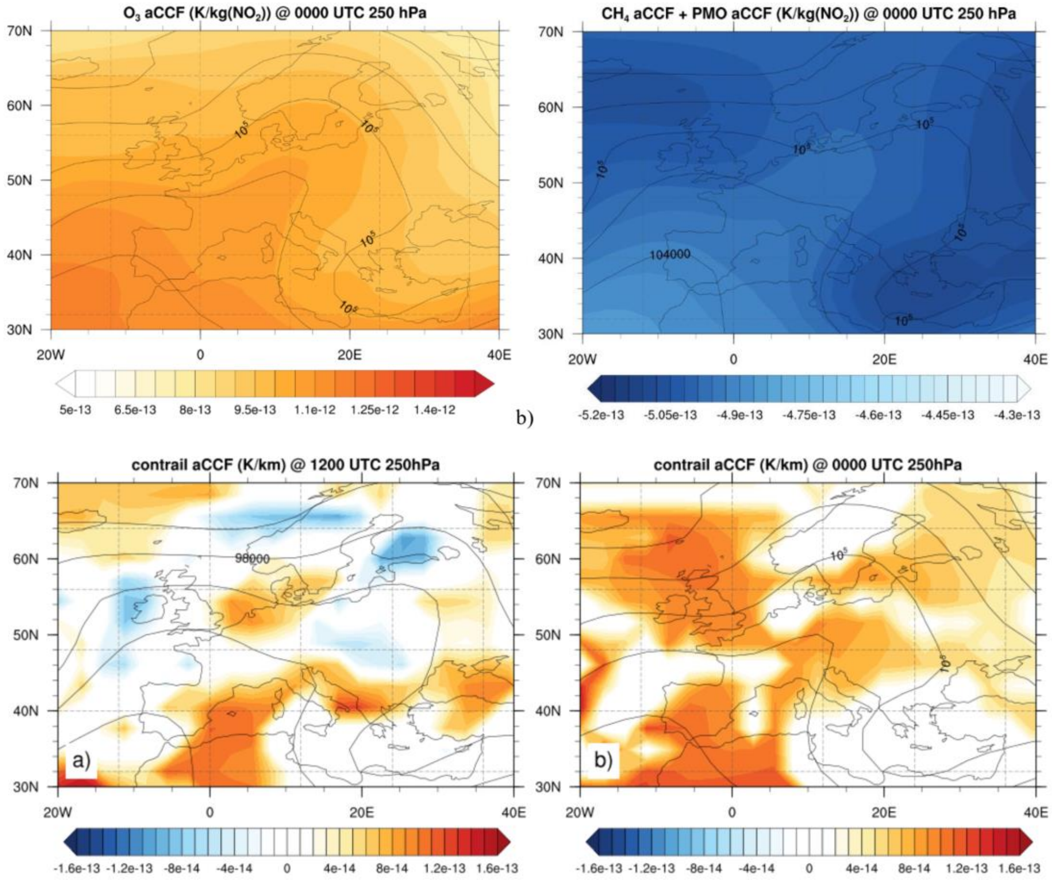
- The non-CO_2 effects contribute at least 2/3 to the total aviation ERF.
- Non-CO_2 effects also occur if alternative fuels are used, in particular H_2.
- The magnitude of the non-CO_2 effects depends on location and time of the emissions.

$\Delta T = \lambda$ ERF (Effective Radiative Forcing)

Forecast of individual climate effects (NO_x and its chemical effects, contrails): algorithmic climate change functions (aCCFs)

aCCFs describe the climate effect of an individual unit emission in a certain choosable metric. They depend on the meteorological conditions at the time and place of emission. Currently there exisit aCCFs calculated for Europe and the Northern Atlantic for NO_x, water vapour and contrails.
While the chemical effects have smooth aCCFs, contrail aCCFs are patchy and highly structured.

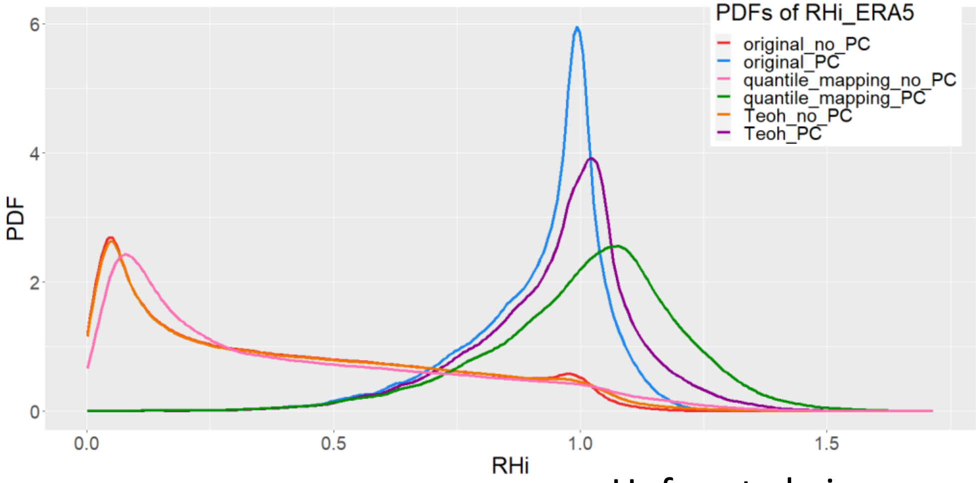
Figures from Yun et al., GMD, 2023.



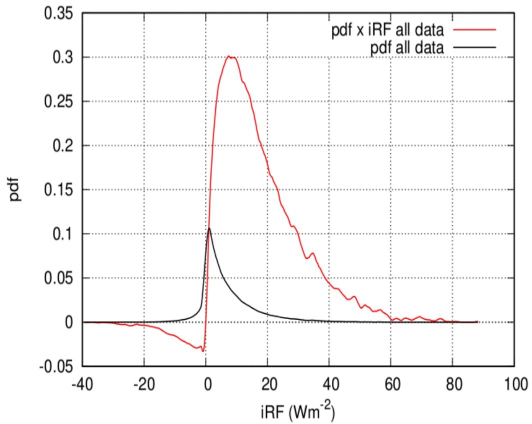
Forecast of persistent contrails and their individual climate effect

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



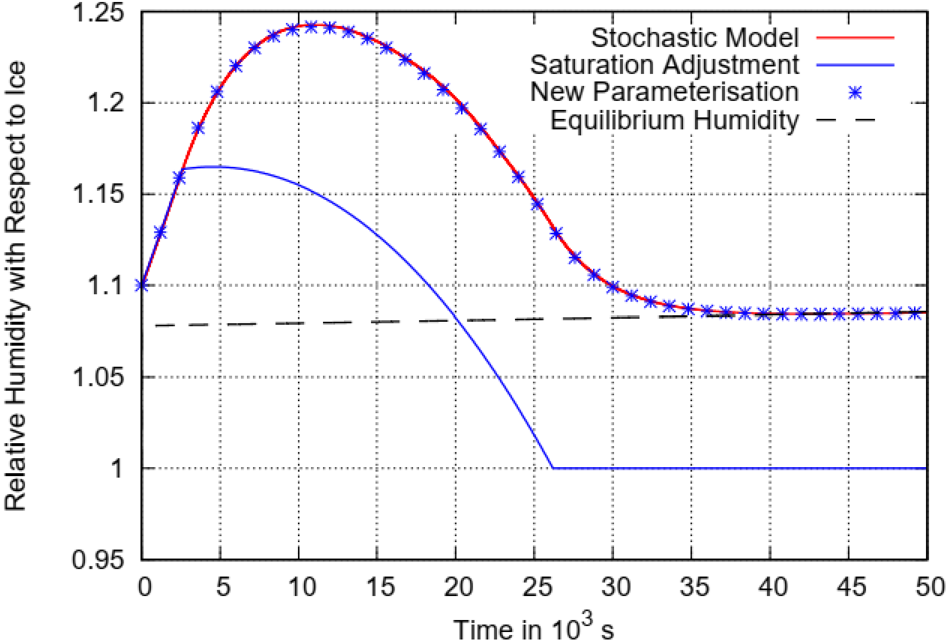
Hofer et al., in prep.

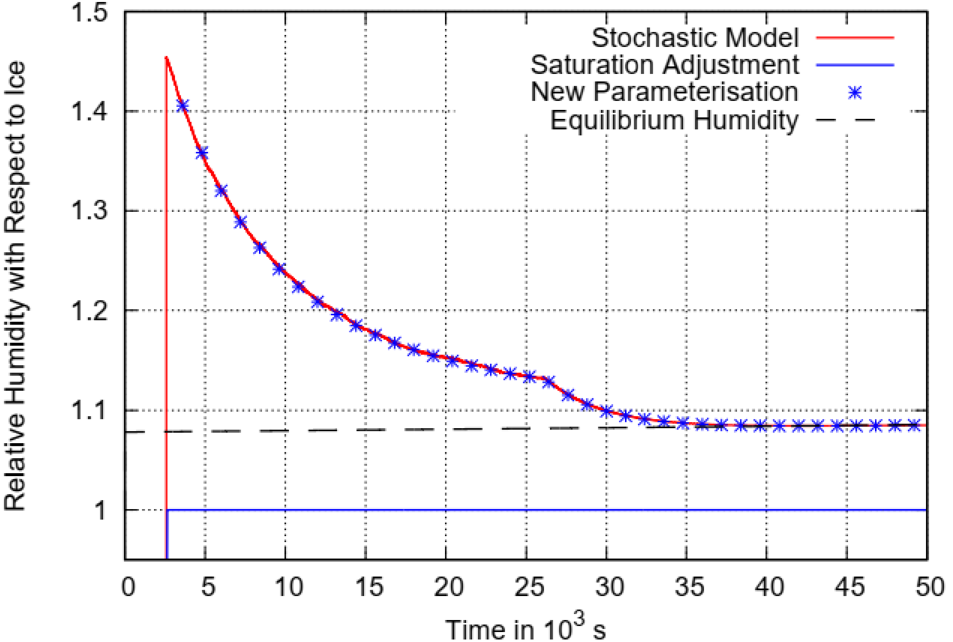


Wilhelm et al., 2021

Current developments in EU-projects ACACIA and BeCoM

- Forecast of ice supersaturated regions using dynamical proxies (regression and neural networks)
- New cirrus parameterisations for numerical weather prediction models
  - one-moment model (abandon saturation adjustment)
  - two-moment model (DWD)





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 cimate-aware flight-planning.
- Chemical effects are currently treated using socalled algorithmic Climate Change Functions, which provide an *expected* individual climate effect of a unit mass of emissions.
- 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 sat. data for validation.