Mitigating Climate Impact of Aviation by Minimizing Aircraft Contrails

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Summary of 2 papers +
Outlook

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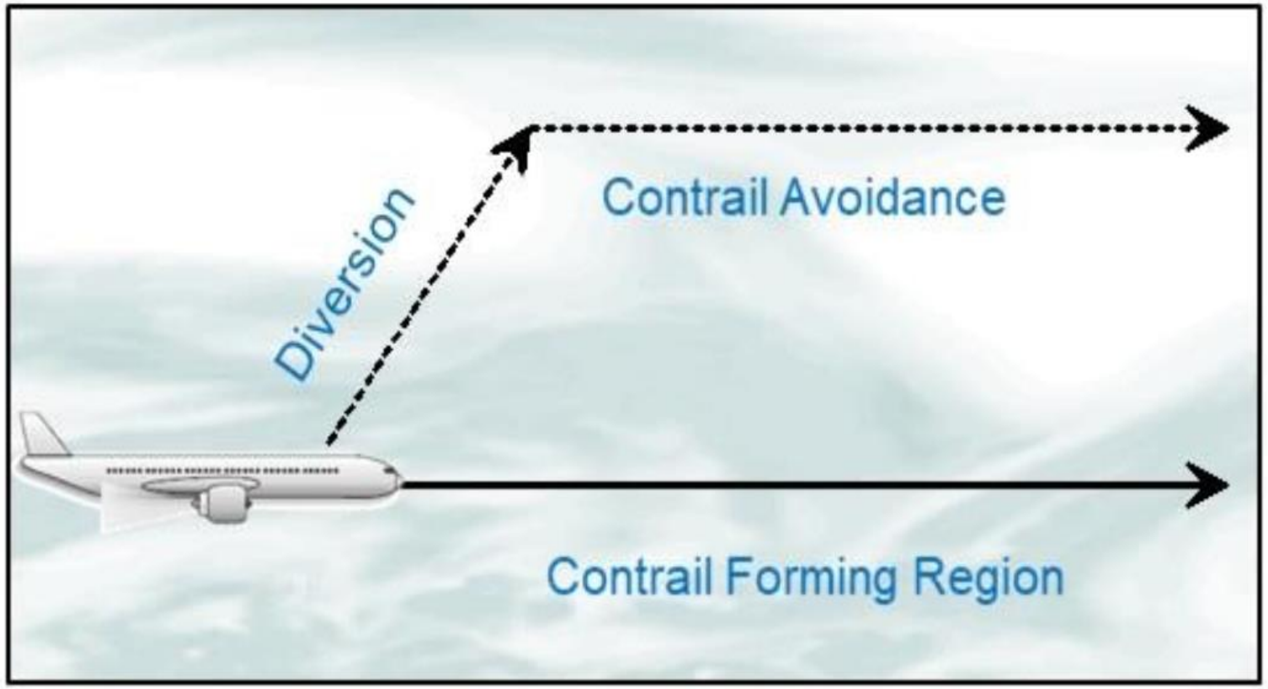
Mitigation by Contrail Avoidance?

Contrail cirrus introduces significant climate forcing at rather short time scales that could be avoided by small changes in flight routing (vertically and laterally)

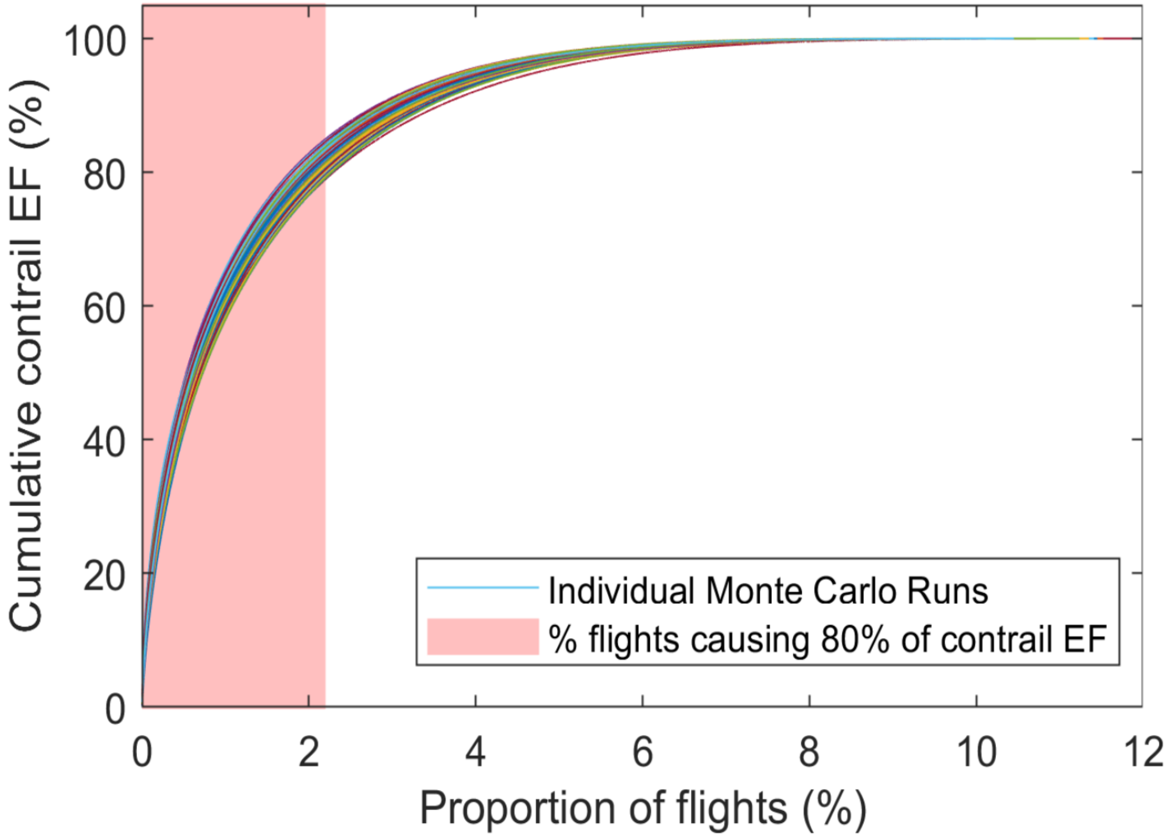


Idea floating around since 1990, 1994, 2002, 2005, 2017 (DLR Cologne Conference, Sausen, Williams, Mannstein, Grewe et al.)

Requires:
Traffic (e.g., Japan)
Performance (BADA3 or Poll&S (2020))
Soot emissions (EI of soot number)
Contrail cirrus model (ECMWF+CoCiP)
Metric, e.g. Energy Forcing and AGTP
Uncertainty analysis (Monte Carlo)
Validation

Teoh, Schumann, Majumdar and Stettler, 2020:
Env. Sci. Techn., **54**, 2941–2950, doi: 10.1021/acs.est.9b05608.

Mitigation by Contrail Avoidance? - avoiding warming contrails



$$\mathrm{EF_{contrail}[J]} = \int_0^t \int_L \mathrm{RF}'(t,s)W(t,s)\,ds\,dt$$

$$\mathrm{EF_{CO_2}\ [J]} = \int_0^{\mathrm{TH}} \mathrm{RF_{CO_2}d}t \times \mathrm{S_{Earth}}$$
$$= [\mathrm{AGWP_{CO_2,TH}}] \times \mathrm{TFC} \times \mathrm{EI_{CO_2}} \times \mathrm{S_{Earth}}$$

Together they are used to compute the
Absolute Global Temperature Potential (AGTP)

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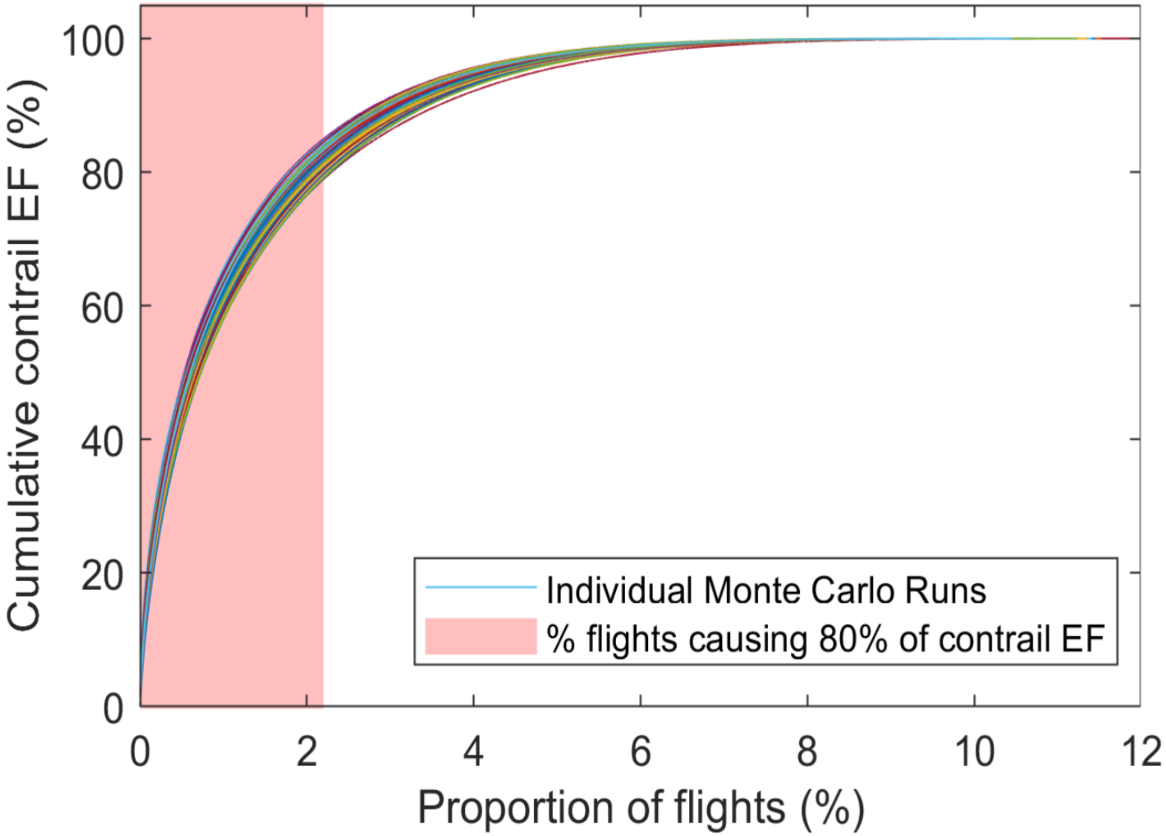

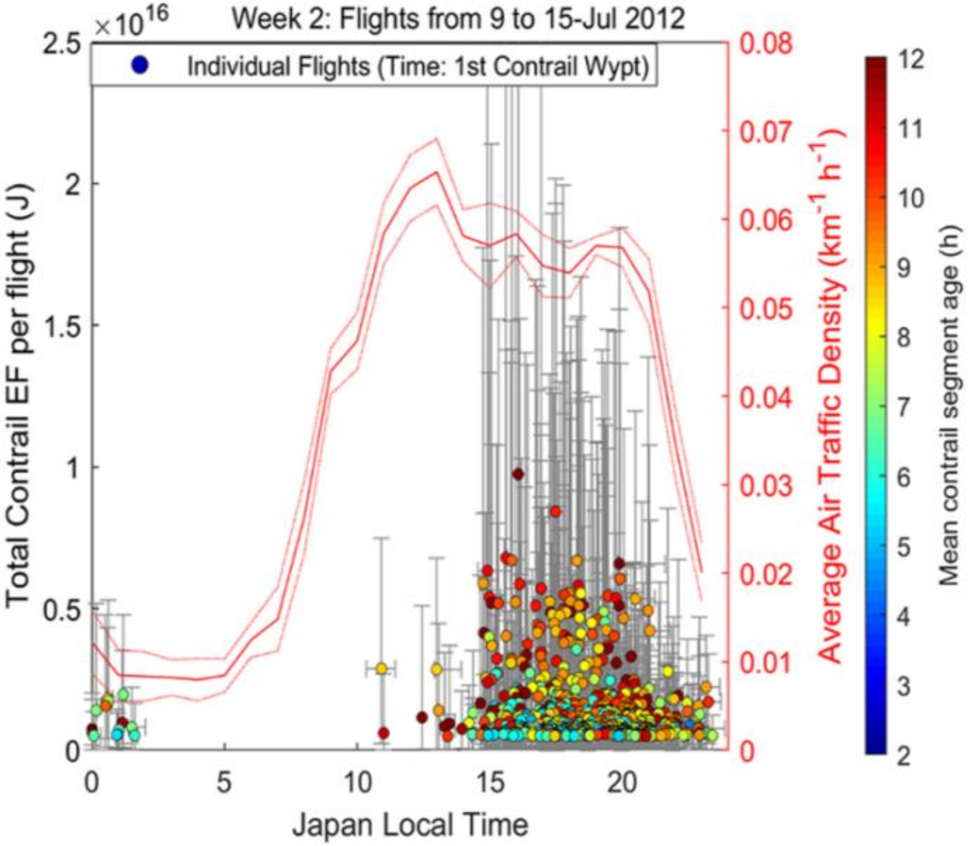

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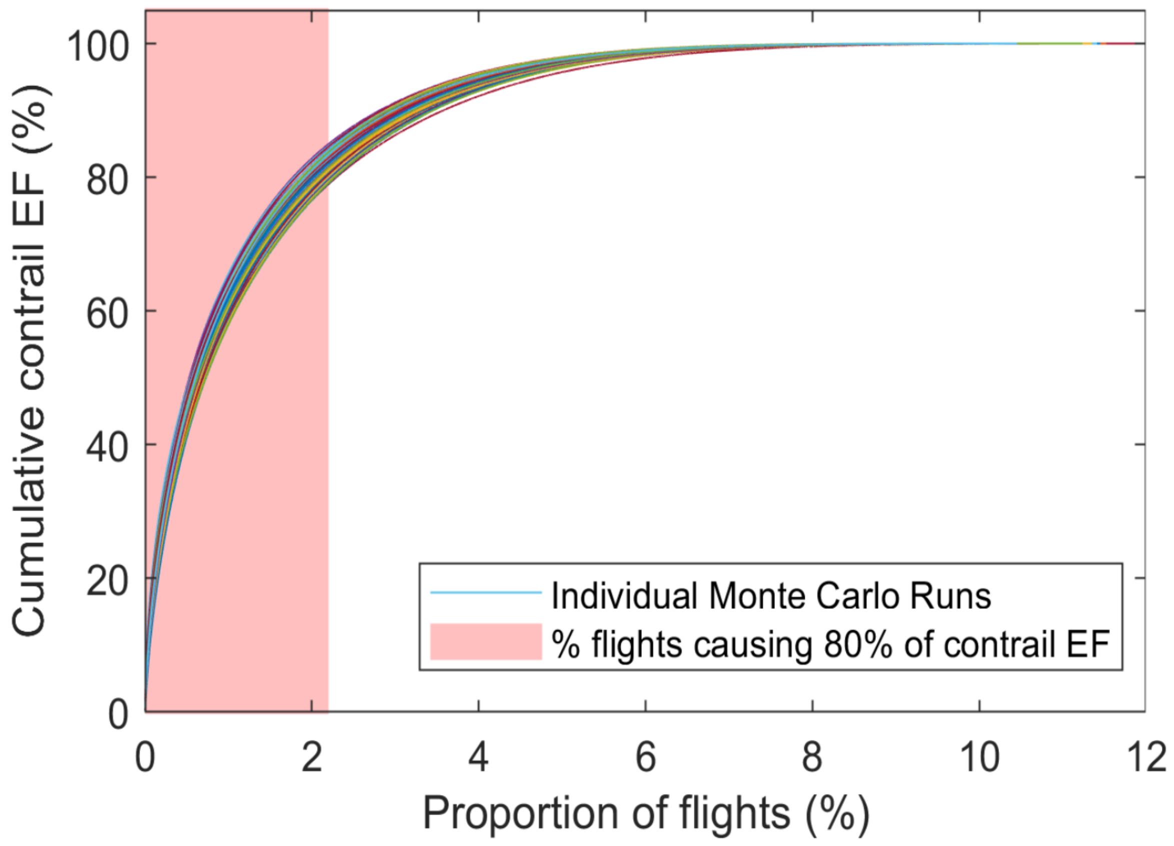
Mitigation by Contrail Avoidance? - avoiding warming contrails



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Only 2.2% [2.0, 2.5%] of flights contribute to 80% of the contrail EF in this region.

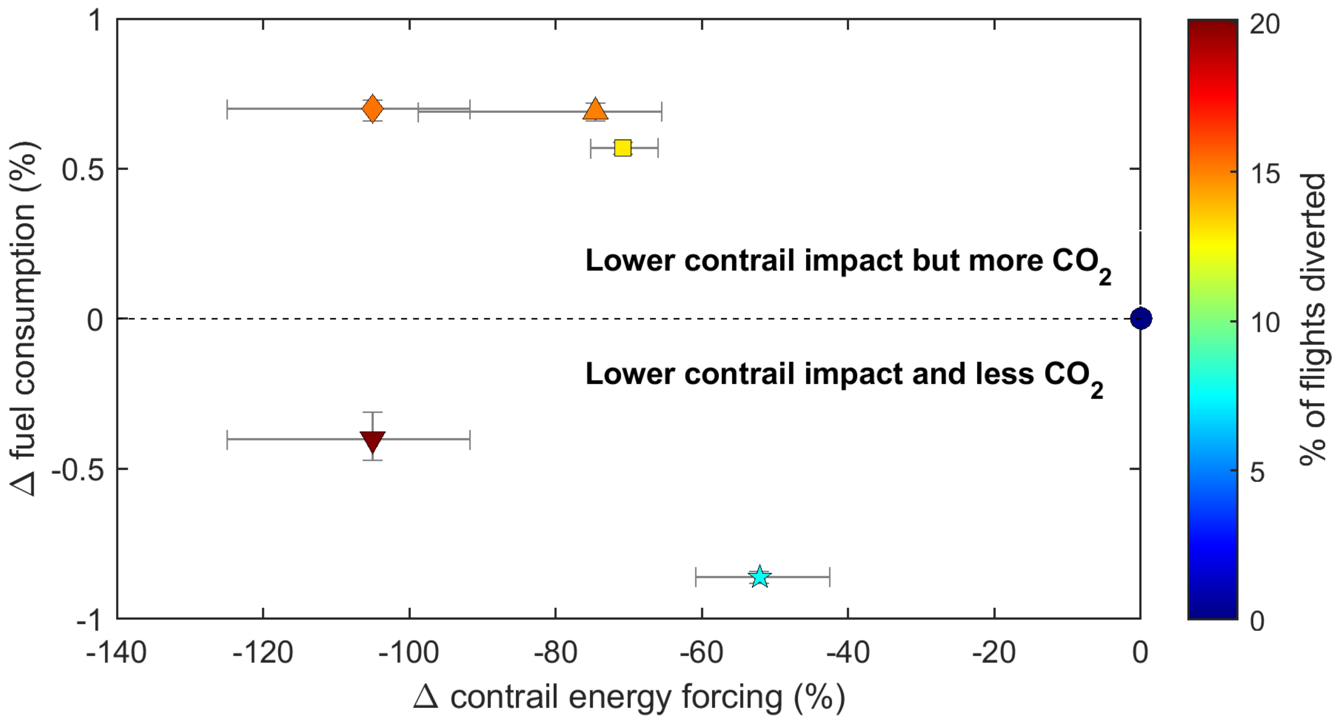
A small-scale strategy (in contrast to fleet-wide diversion) of selectively diverting 1.7% of the fleet with largest EF and minimum ATM disturbance could reduce the contrail EF by up to 59.3% [52.4, 65.6%],
with only a 0.014% [0.010, 0.017%] increase in total fuel consumption and CO_2 emissions.

Low BC soot emissions from new engine combustor technology could achieve a 68.8% [45.2, 82.1%] reduction in the contrail EF.

Still, any increase in CO_2 emissions causes the risk of long-term climate damage when the model overestimates the contrail EF

Beyond Contrail Avoidance: Minimise Contrail Climate Forcing

Contrail avoidance strategies may be suboptimal because most contrails have a short lifetime, and some have a cooling effect.



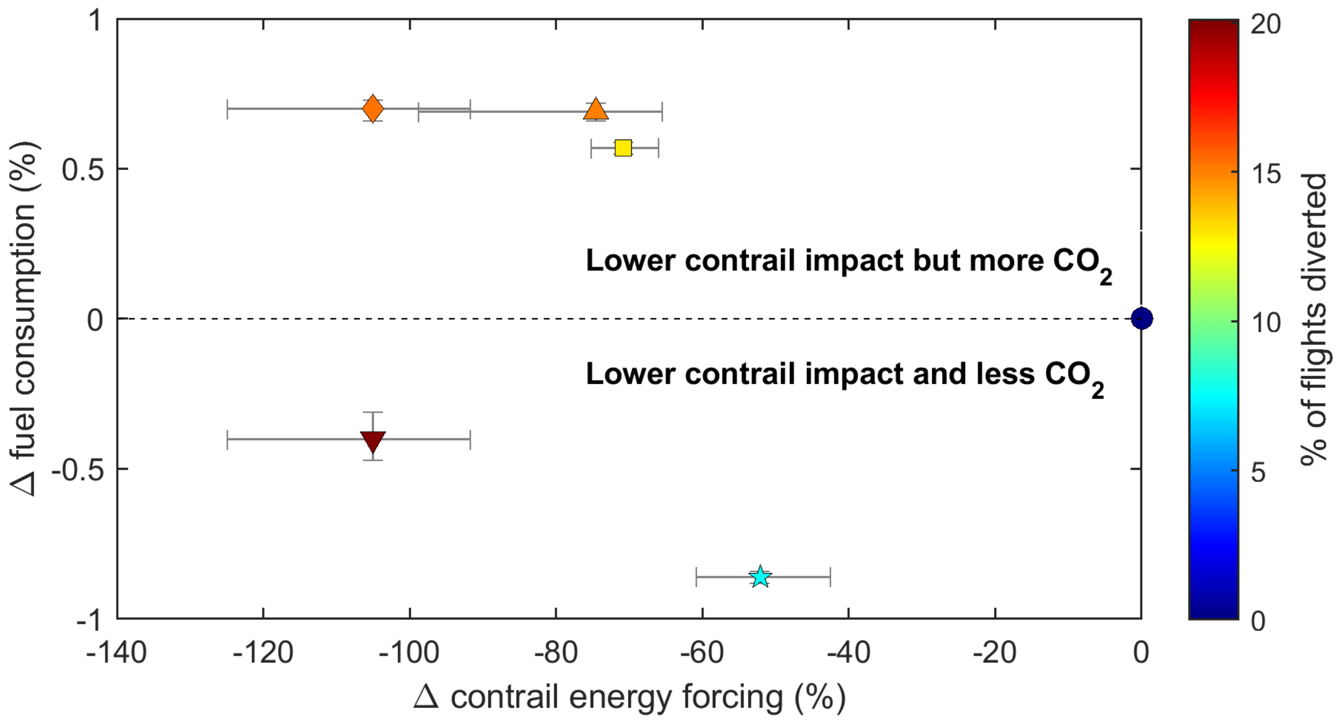
Teoh, Schumann and Stettler, 2020:
Aerospace, **7,** (9) 121, doi: 10.3390/aerospace7090121.
Special Issue 3rd ECATS Conference

Instead, a strategy that reroutes 15.3% of flights to avoid long-lived warming contrails, while allowing for cooling contrails, reduces the contrail energy forcing ($EF_{contrail}$) by 105% [91.8, 125%] with a total fuel penalty of 0.70% [0.66, 0.73%].

A minimum EF_{total} strategy (contrails + CO_2), diverting 20.1% of flights, reduces the $EF_{contrail}$ by the same magnitude but also reduces the total fuel consumption by 0.40% [0.31, 0.47%].

(optimal FL and maximum tail winds)

Minimise Contrail Climate Forcing with low ATM disturbance, significantly and rapidly



For the diversion strategies explored, between 9% and 14% of diversions lead to a loss of separation standards between flights, demonstrating a modest scale of ATM impacts.

These results show that small changes in flight altitudes are an opportunity for aviation to significantly and rapidly reduce its effect on the climate.

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Open issues

- Model validation

- Validation of cooling/warming SW/LW RF ratio

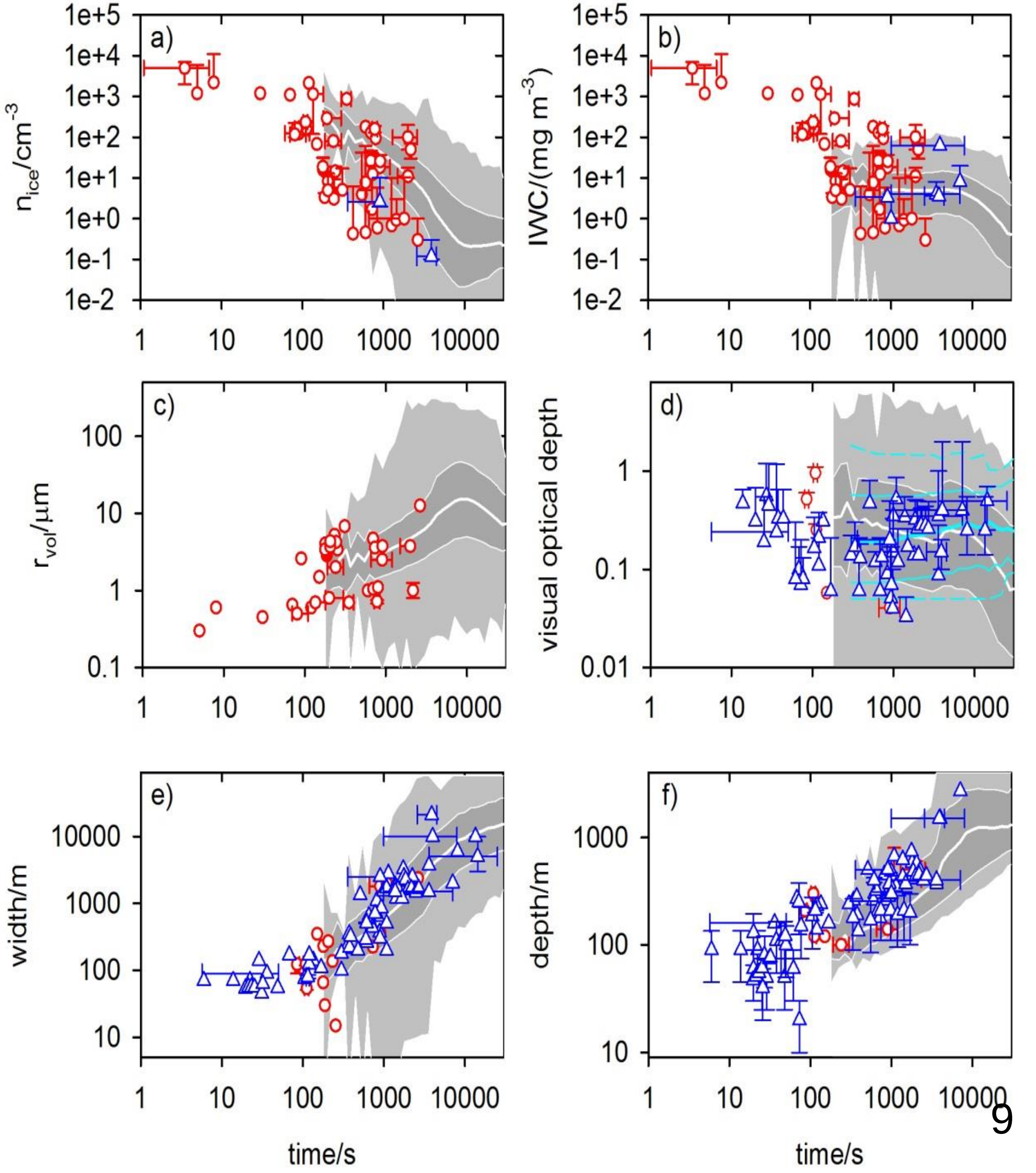
- Aviation-induces RF at longer than diurnal time scales, including soot, NOx and other emission effects

- Chances from COVID-19 traffic reduction in 2020 compared to previous years

Previous Progress on Model Validation for individual contrails

- Comparison of model results with data collected from 40 years of insitu and remote sensing measurements

Model (CoCiP+CAM):
Data from Schumann, Penner et al. (2015)
White curves with grey shading: 0, 10, 50, 90, 100% percentiles
In-situ measurements:
Knollenberg 1972; Baumgardner and Cooper 1994; Poellot et al. 1999; Schröder et al. 2000; Gao et al. 2006; Febvre et al. 2009; Heymsfield et al. 2010; Voigt et al. 2011; Jones et al. 2012; Jeßberger et al. 2013; Schumann et al. 2013a; Kaufmann et al. 2014.
Remote sensing observations:
Hoshizaki et al. 1975; Baumann et al. 1993; Freudenthaler et al. 1995, 1996; Minnis et al. 1998; Spinhirne et al. 1998; Sussmann and Gierens 1999; Duda et al. 2004; Atlas et al. 2006; Atlas and Wang 2010; Schumann et al. 2013b.
Remote sensing of life cycle:
(Meteosat, ACTA, Vazquez-Navarro et al., 2015), percentiles of optical depth data.
(Schumann and Heymsfield , 2017; Schumann et al., 2017)

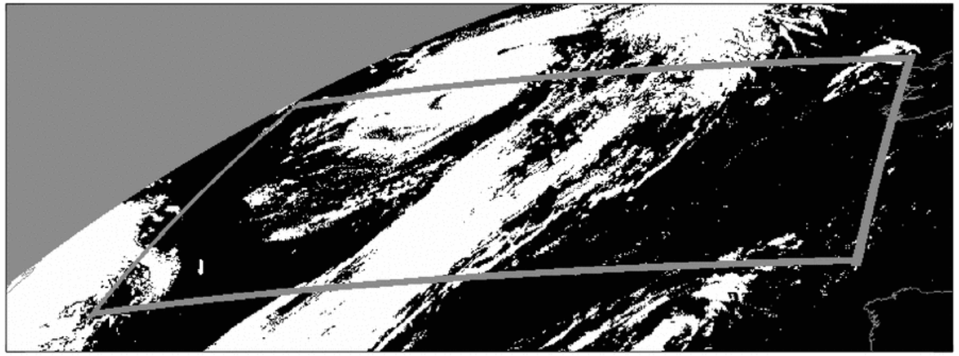


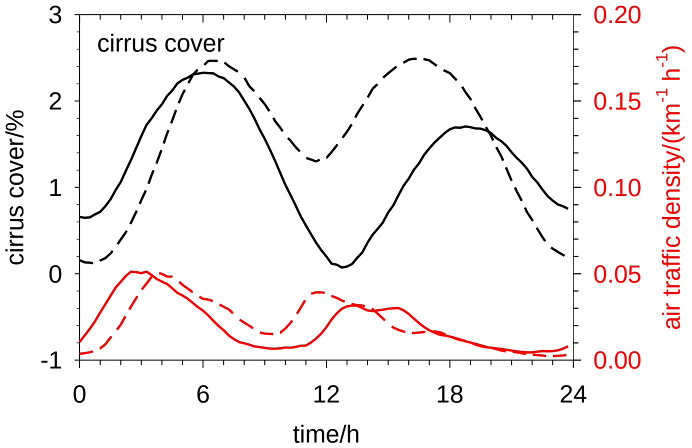
Previous Progress on Model Validation by Aviation-induced Cirrus and LW RF

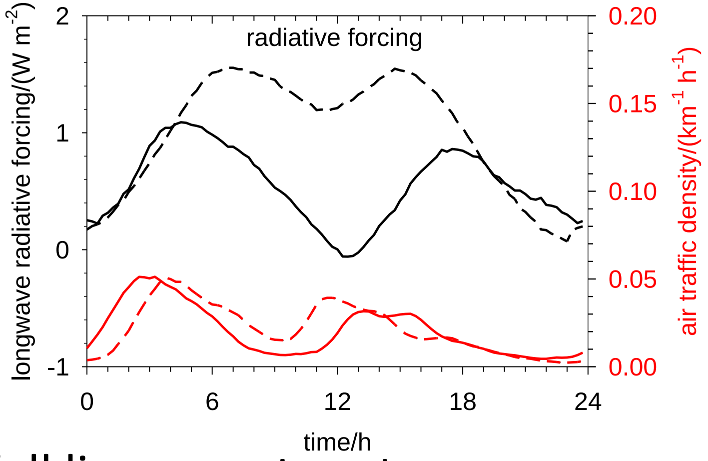
- E.g. by observing cirrus cover and outgoing longwave radiation with Meteosat data
- and comparison with ECMWF/CoCiP model results
- for the North Atlantic domain with aviation fingerprint in diurnal cycle and its east-west dependence
- 8 years of data
- Successful: cirrus cover change and LW RF

Air traffic density in km / (km² h), 25.04.2004, 00:00 UTC

MeCiDA cirrus classification, 25.04.2004, 00:00 UTC





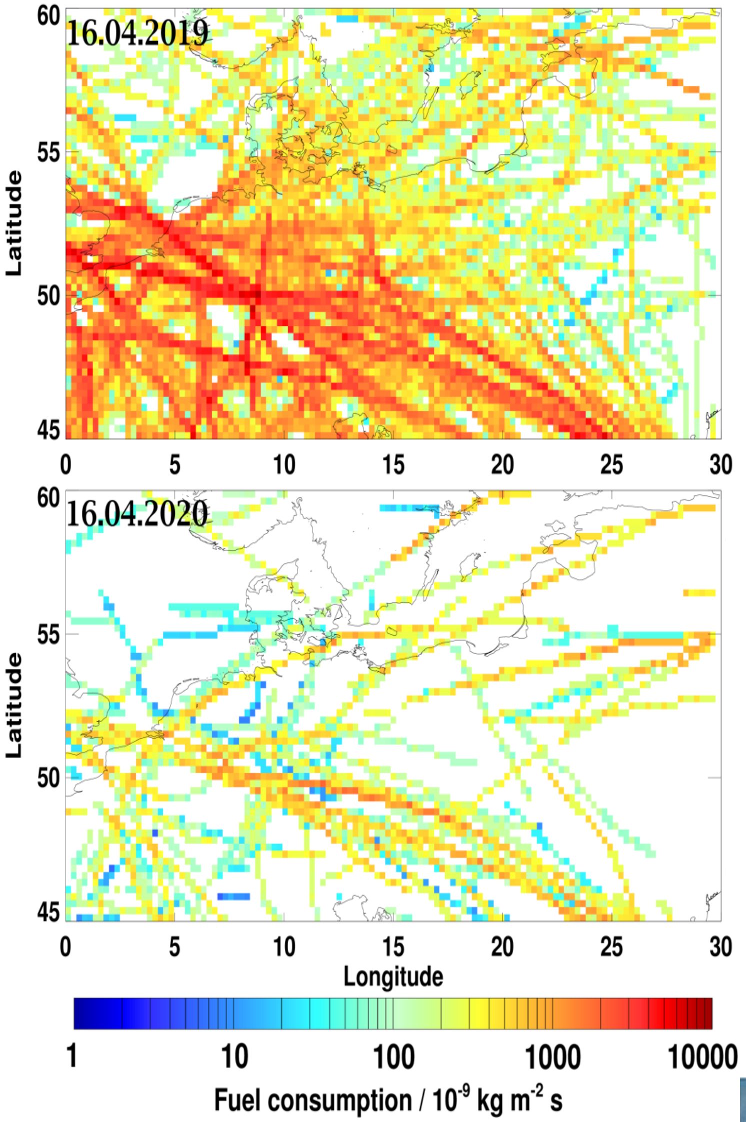


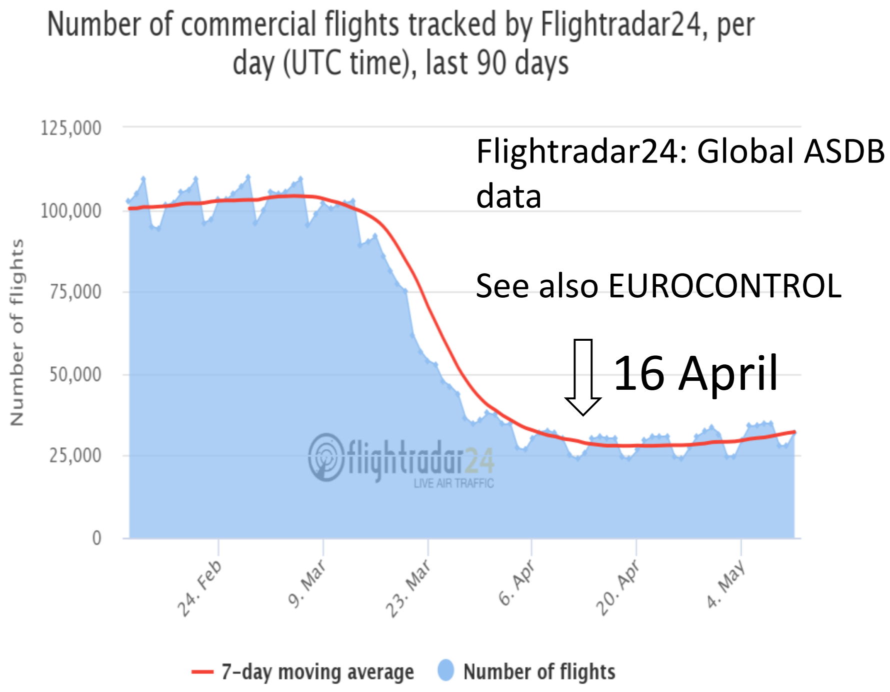
full lines: west part
dashed lines: east part

Graf et al. (2012); Schumann and Graf (2013)

COVID-19: Chance to find long-term aviation effects in observations

Traffic data from EUROCONTROL
Fuel consumption computed with BADA or PS





Traffic 16 April 2020	Percentage of 2019
Number of aircraft in flight	14 %
Flight distance	12 %
Fuel consumption	19 %

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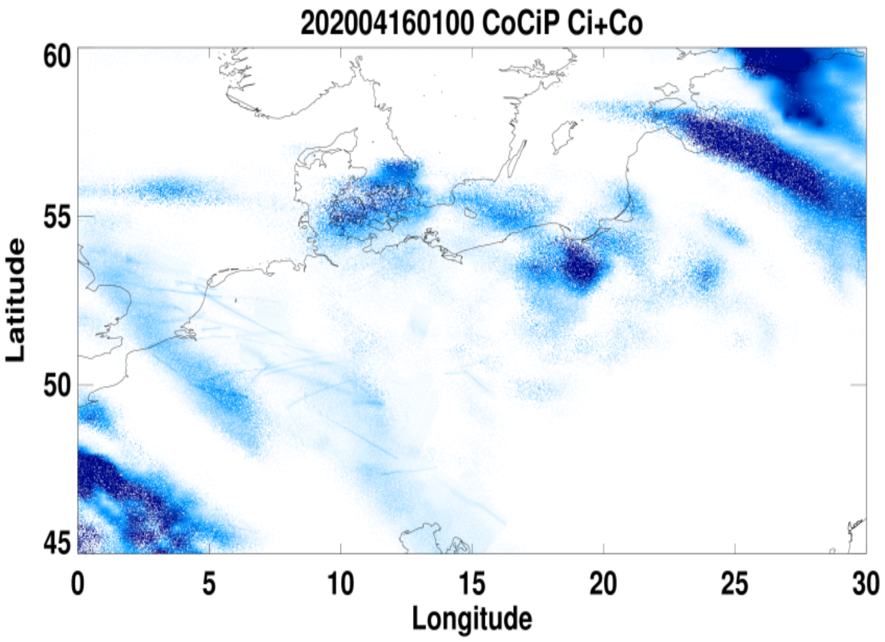
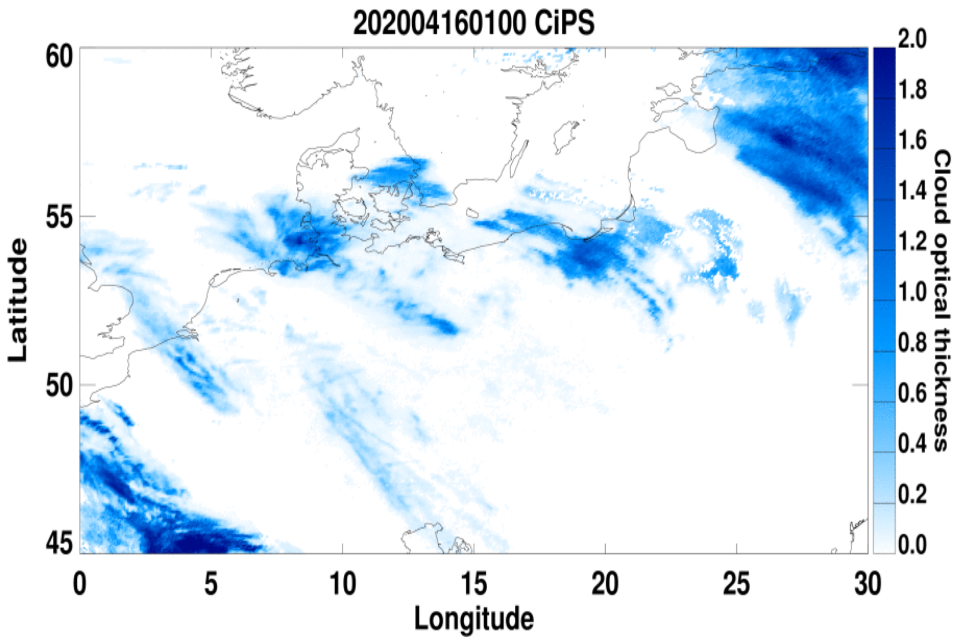
Contrail Cirrus Optical Thickness 16 April 2020

CoCiP cirrus with contrails from ECMWF-IFS data (Schumann, GMD, 2012)

CiPS (Cirrus Properties from SEVIRI): Neural network for SEVIRI trained with CALIPSO (Strandgren, Bugliaro, et al., AMT, 2017a, b)





Also available: TOA Irradiances (OLR and RSR), allowing to check LW+SW RF over a year

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- Progress achieved: Small-scale strategies are effective in converting traffic with warming contrails into traffic with cooling contrails at minimum or even negative change in fuel consumption (CO_2 emissions)

- Soot model made available, and model sensitivity to input data quantified

- Validation: The validity of the contrail model has been demonstrated previously
  by comparison to insitu and remote sensing data for individual contrails and
  for diurnal cycle of cirrus /longwave radiation changes in the North Atlantic

- COVID-19 offers the chances for further validation, including SW RF and annual time scale

- Still open: climate surface impact:
  Search for relationships between thin cirrus and surface temperature
  Requires extended models