The contrail mitigation potential of aircraft formation flight derived from high-resolution simulations

S. Unterstrasser

Short Introduction

- Learn from migratory birds; flying in a V-formation saves energy [*Lissaman and Shollenberger, 1970; Weimerskirch et al., 2001]*
- In a formation of two aircraft, the follower aircraft can save up to 20% fuel by flying in the upwash region of the leader aircraft *[Beukenberg & Hummel, 1990; Blake & Multhopp, 1998; Nangia & Palmer, 2007]*
- Fuel benefits directly translate into reduced a $C0_2$ footprint; 5 - 10% reduction are expected.
- Moreover, the contrail climate effect could be substantially reduced.

Why?

Basic facts

- Contrails are produced in air colder than around 225K. They are persistent if the air is moist enough.

- Contrails and their ice crystals grow by uptake of atmospheric water vapour. The contribution of the initial water vapour emission to the total contrail ice mass becomes negligible.
  => Saturation effects are expected when contrails are produced in close proximity.

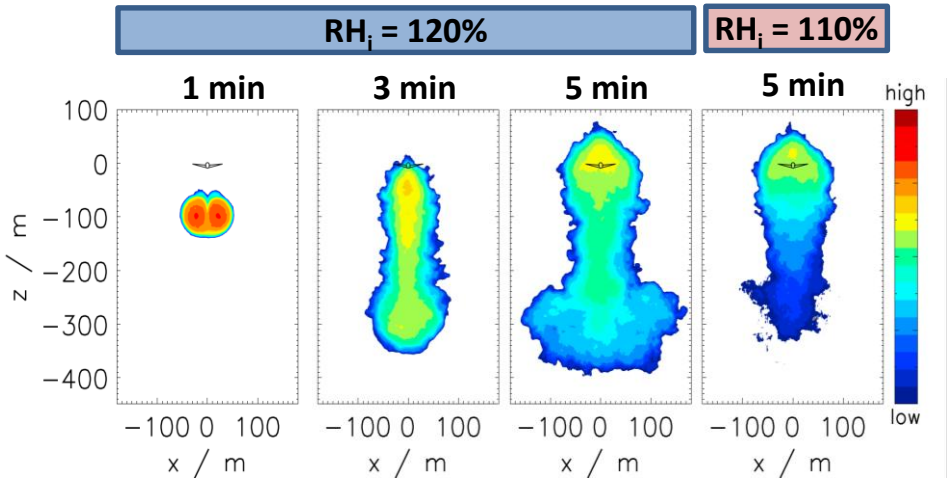
- Basic thought experiment:
  - Two aircraft fly independently of each other and produce two separate contrails.
  - In a formation, those two aircraft produce a single contrail.
  - If this single contrail has properties similar to those of the two separate contrails
    => the climate impact is roughly halved.

Do contrails behind a two aircraft formation differ from those behind a single aircraft?

High-resolution contrail simulations

Use large-eddy simulation (LES) model EULAG [*Smolarkiewicz et al , 2014*] in combination with ice microphysics code LCM [*Sölch & Kärcher, 2010*]

Early contrail evolution
Interaction with wake vortices



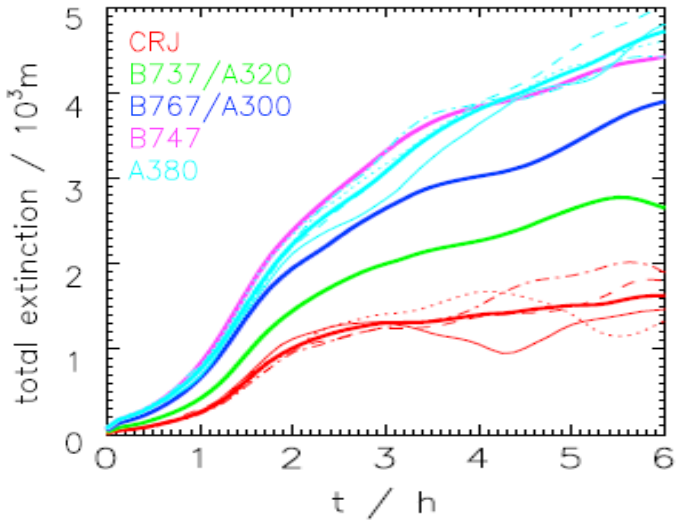
[Unterstrasser, 2014]

Important early phenomena:

- ➢Vertical expansion
- ➢Ice crystal loss

Early contrail properties have long-lasting impact on contrail-cirrus properties

Impact of aircraft type on contrail cirrus properties



[Unterstrasser & Görsch, 2014]

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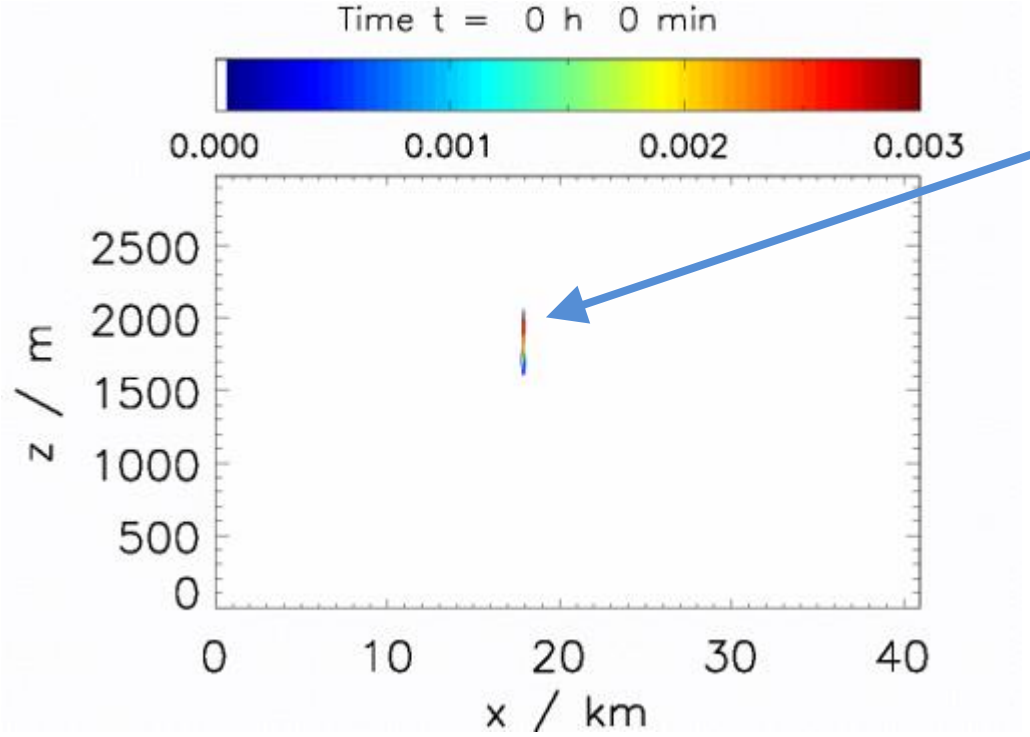

Cross-section of 5 min old contrail

3 km deep layer of the upper troposphere

Prescribe specific atmospheric scenario

[Unterstrasser et al, 2017a,b]

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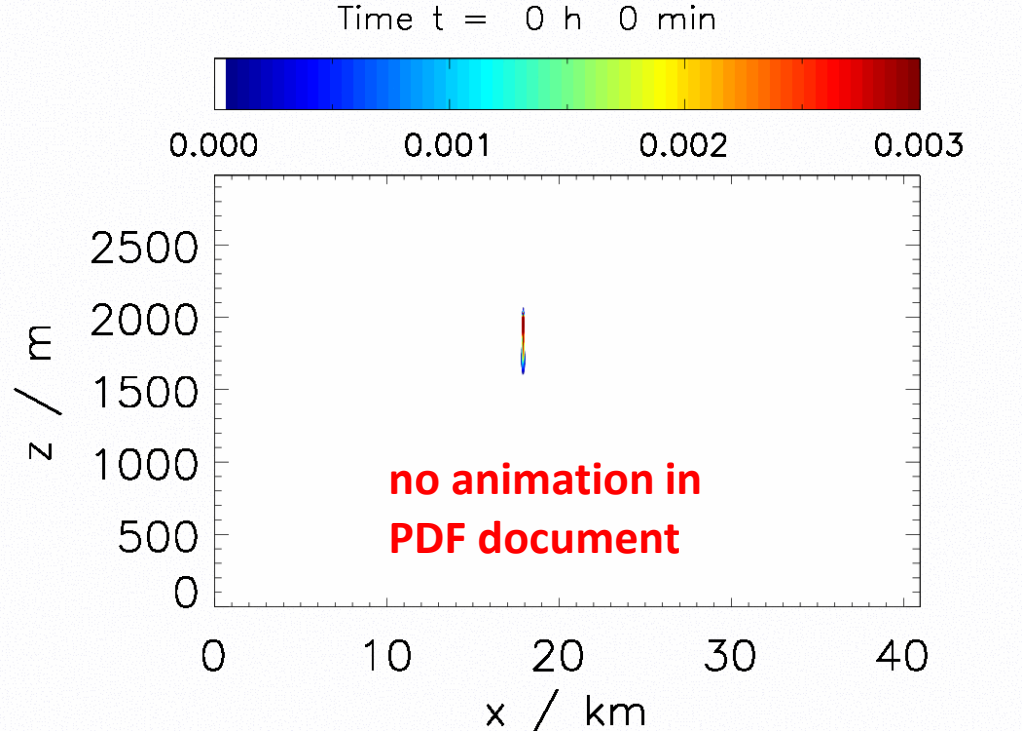


[Unterstrasser et al, 2017a,b]

3 km deep layer of the upper troposphere

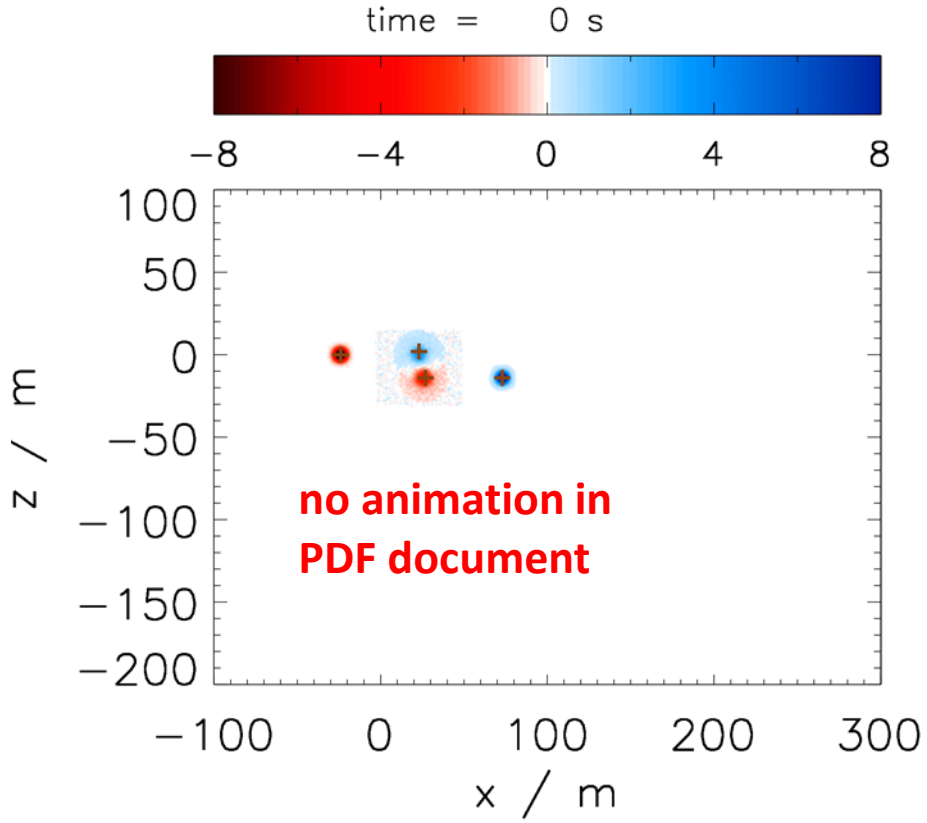
Prescribe specific atmospheric scenario

Simulate contrail spreading

Compute total extinction E and total ice mass I, which serve as proxy metrics for contrail radiative forcing.

Young contrails behind formations and behind single aircraft

Early contrail evolution governed by complex four vortex system



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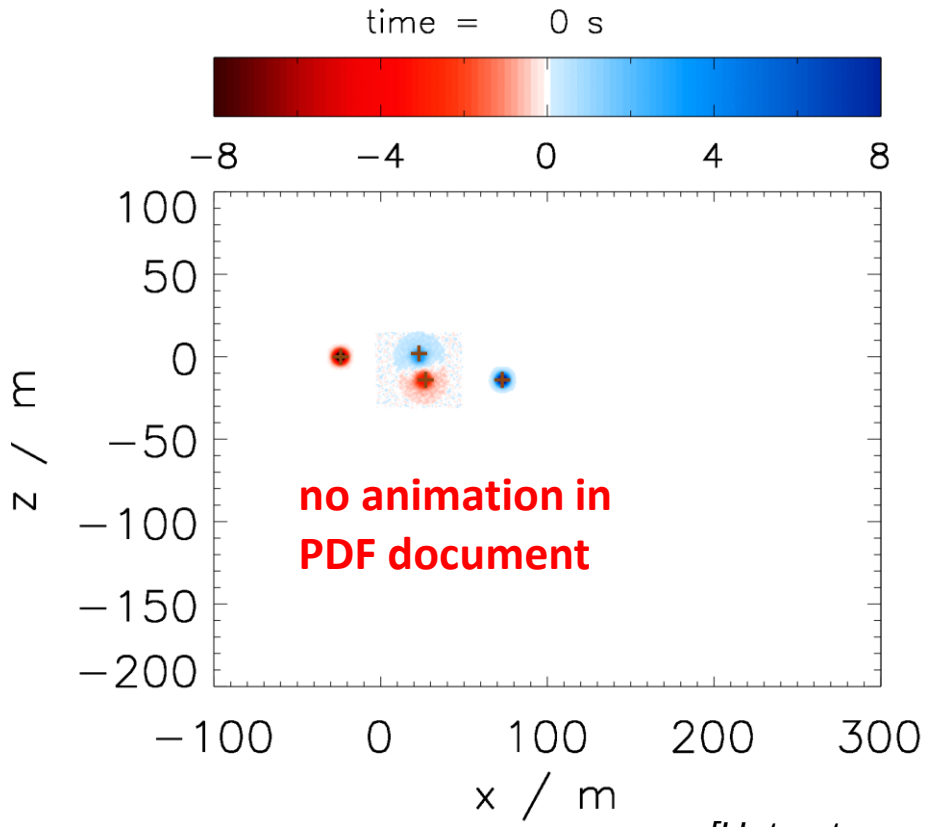
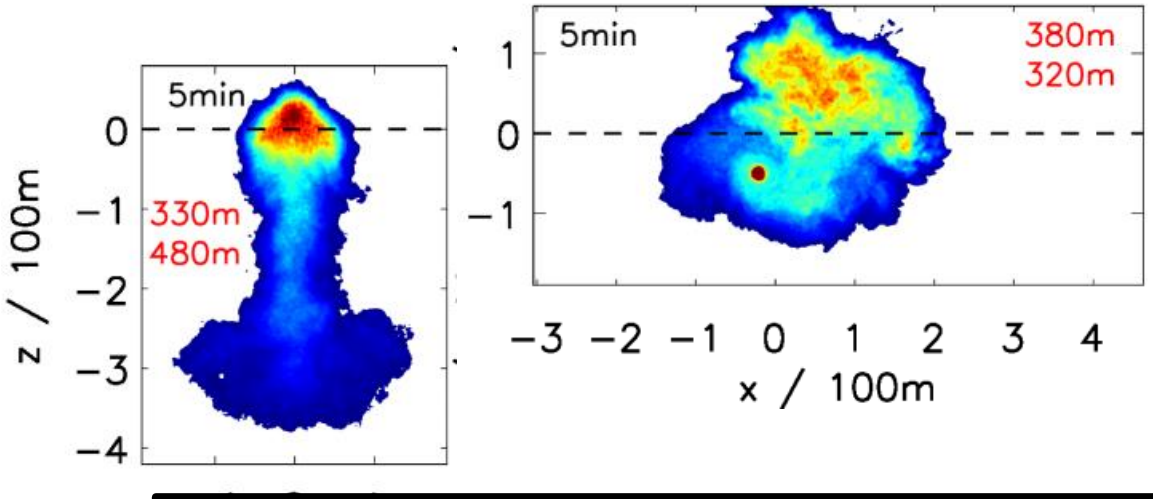


[Unterstrasser & Stephan, 2020]

Contrail cross-section after 5 minutes

Single AC **Two AC formation**

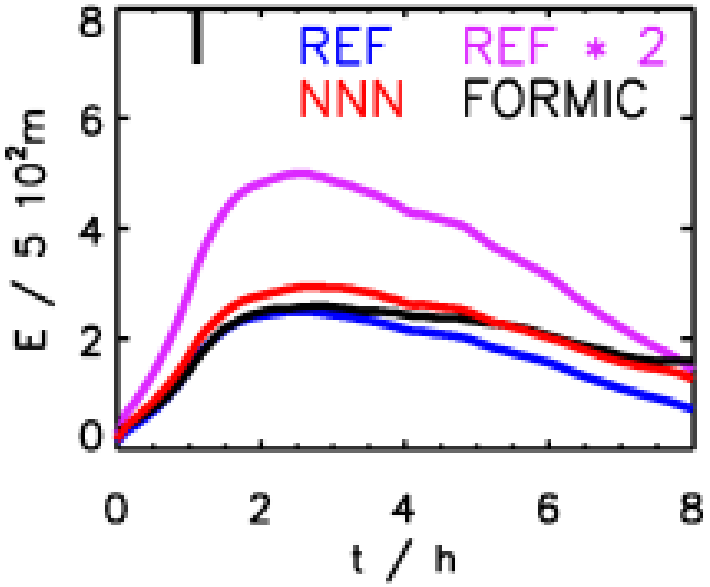


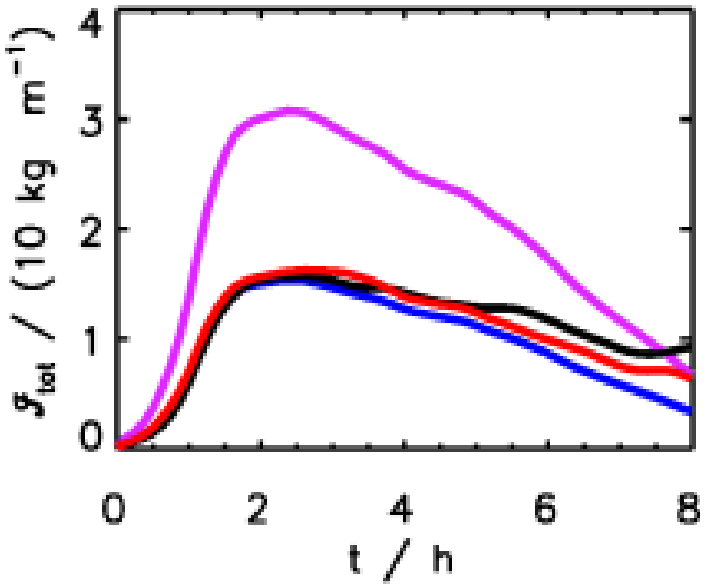
Young “formation” contrails are less deep, but broader than “single AC” contrails.
Moreover, they contain 3 to 5 times more ice crystals

Differences in contrail-cirrus evolution

Time evolution of total quantities
for one specific atmospheric scenario

REF = single aircraft case
FORMIC = two aircraft formation case
REF * 2 = two independent aircraft





Comparison of “**FORMIC**” with ”**REF * 2**” shows strong saturation effects

Use lifetime-integrated values for further comparison. Normalize “**FORMIC**”-values by “**REF * 2**”-values

Saturation effect

RH_i = 110% / 120%

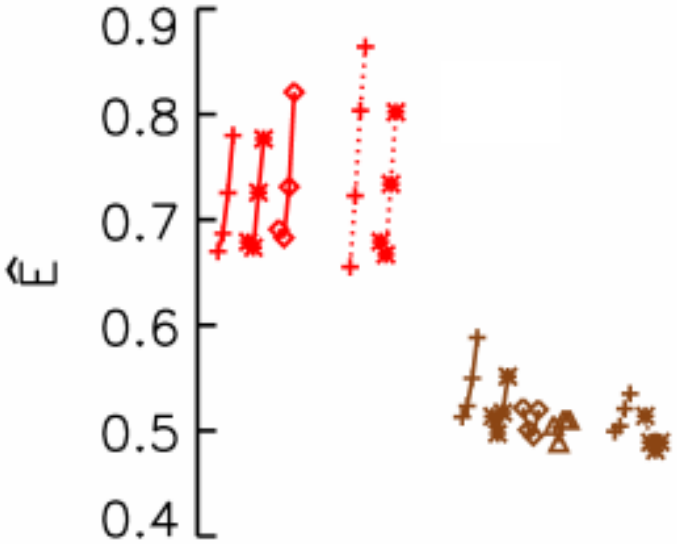
ΔT = 2K ——— 4K ·····

+ w05 ✱ w02 ◇ w01 △ s6

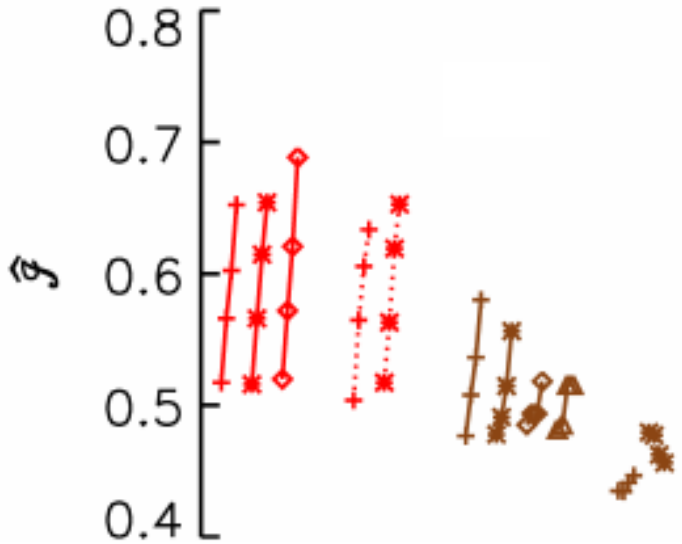
Normalized (“**FORMIC**”/ “**REF *2**”) and lifetime-integrated values evaluate the contrail reduction by formation flight.

A value of 0.6, e. g., means that the contrail effect is reduced by 40%

Total extinction



Total ice mass



Reduction in contrail strength (in terms of total extinction and total ice mass) by 20% to 55% due to formation flight.

[To be submitted to ECATS special issue @ Aerospace]

Summary

Reduction in contrail strength
(in terms of total extinction and total ice mass)
by 20% to 55% due to formation flight.

Feed those numbers into a global model and
combine it with emission inventories for formation flight=>
obtain a first global estimate of
formation flight mitigation potential
(further FORMIC talks by
K. Dahlmann and T. Marks tomorrow)

Contrails were compared for a representative set of atmospheric scenarios. Yet, the present study does not account for effects of changing flight altitudes or geographical distributions of flight routes.

Questions?

This work contributed to the project FORMIC (Formation Flight Impact on Climate) funded by BmWi

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