Contrails Spreading into Cirrus

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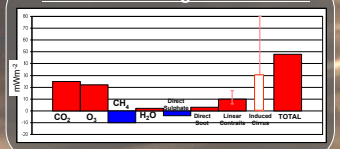
1 Background

- Condensation trails (Brewer, 1946) or Contrails (Appleman, 1953) are visible line clouds that form behind aircraft flying in sufficiently cold air due to water vapour emissions
- Generate changes in regional and global cloud cover and optical depth
- Reduce the amount of SW radiation reaching the Earth (albedo effect)
- Reduce the amount of LW radiation leaving from Earth to space (greenhouse effect)
- Possible effects on air composition and hydrological cycle

$RF_{Contrails} > 0$

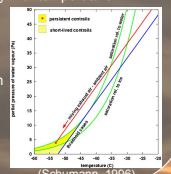
2 Radiative Forcing from Aviation



3 Contrail formation

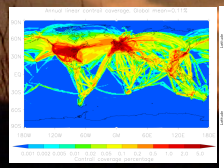
- Contrail formation is expected thermodynamically due to the increase in RH that occurs in the engine plume
- Result of the heat and water vapour mixing between the warm and moist exhaust and the cool ambient air
- Consequence of the non-linear increase of saturation humidity with temperature

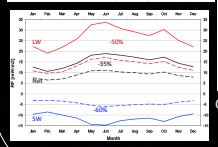
- With T below a threshold, humidity may reach liquid saturation in the plume
- Liquid water droplets form by condensation on soot and volatile particles
- Contrails persist if the air is supersaturated with respect to ice

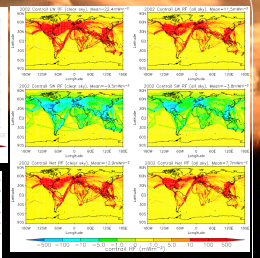


(Schumann, 1996)

4 Linear contrail parameterisation







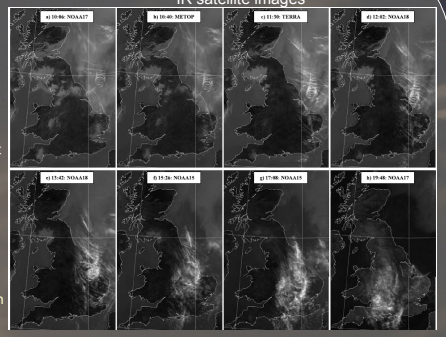
Global annual mean 2002 estimates:
- contrail cover : 0.11%
- contrail RF: 7.7 mW/m²

(Rap et al., JGR, 2010)

5 20 March 2009 case

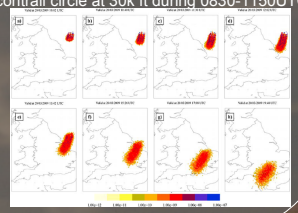
- A distinct coil-shaped contrail evolving into cirrus (CCC) that is thought to have originated from manoeuvres performed by an Airborne Warning and Control System (AWACS) aircraft was observed in satellite imagery
- First orbit started around 0830UTC and contrail formation from the aircraft ceased around 1150UTC
- The Met Office NAME model shows that the origin of the cirrus over the UK appears to be from persistent contrail even when the CCC becomes indistinct in the observations
- Contrail persisted for more than 18h, at peak covering >50,000 km²

IR satellite images



- RF estimated at +15Wm⁻² for a 24h period (+10Wm⁻² during daylight and +30Wm⁻² during night-time hours)
- This single event represents about 7% of the diurnally averaged global mean persistent contrail forcing (0.02% of the annual global mean RF from persistent contrails)
- RF/(km flown) for this event is 5000 greater than the mean of the entire civil fleet. Contrail-induced cirrus could exert a disproportionately high RF and hence warming of the climate system.

Results from NAME model initiating a contrail circle at 30k ft during 0830-1150UTC



(Haywood et al., JGR, 2010)

6 COSIC flights

UK FAAM Bae-146 research aircraft

Aim

- To produce contrails that spread into cirrus clouds
- To sample them with a range of in-situ and remote sensing instrumentation

Flights

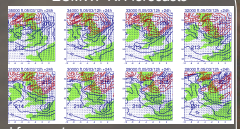
- B516 – 5 March 2010
- B517 – 9 March 2010
- B587 – 19 March 2011

7 Flight B516

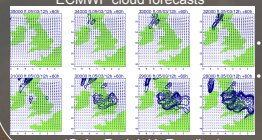
Aim

- Ideally fly in an area with:
  - high supersaturation
  - no natural clouds

ECMWF RH forecasts



ECMWF cloud forecasts

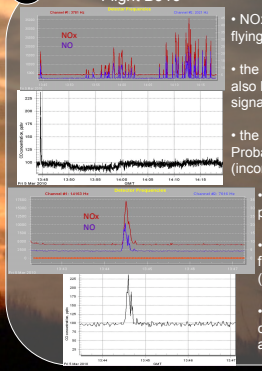


- Take off: 10:46 UTC
- Land: 15:31 UTC

(Gaby Radel, U. Reading)

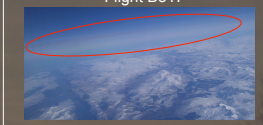
8 Measurements

Flight B516



- NOx signature confirms when flying through a contrail
- the contrail sampled at 13:44 also has CO in its chemical signature
- the 13:44 contrail: not ours. Probably from an older (incomplete combustion) aircraft
- NO and CO traces match perfectly
- NOx and CO analysers sample from different air sampling pipes (port and starboard respectively)
- Thus, the measured CO in this contrail is not an instrumental artefact

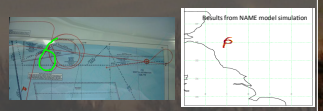
Flight B517

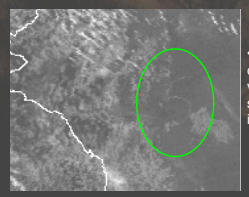


- Difficult in-situ sampling of own contrail during orbits
- Persistence much better over land; contrails not visible in satellite images (snow on the ground)
- Good series of 9 tight orbits (4-5 min/orbit) at 32k ft

- good amount of in-situ measurements

Flight B587





- Own contrail visible on satellite images

9 COSIC flights summary

- Very challenging objectives:
  - accurate forecast of supersaturated, cloud free regions
  - make persistent contrail
  - sample own contrail
  - observe contrail in satellite images
- Learned on the job
- Objectives achieved, although not at the same time
  - good in-situ measurement: B517, ~B516
  - observe own contrails in satellite images: B587, ~B516

10 Conclusions

- Individual contrail spreading events can cause very large radiative perturbations over large regions
- These events happen relatively infrequently over the UK

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