NATURE CLIMATE CHANGE | NEWS AND VIEWS

Atmospheric science: Seeing through contrails

Olivier Boucher

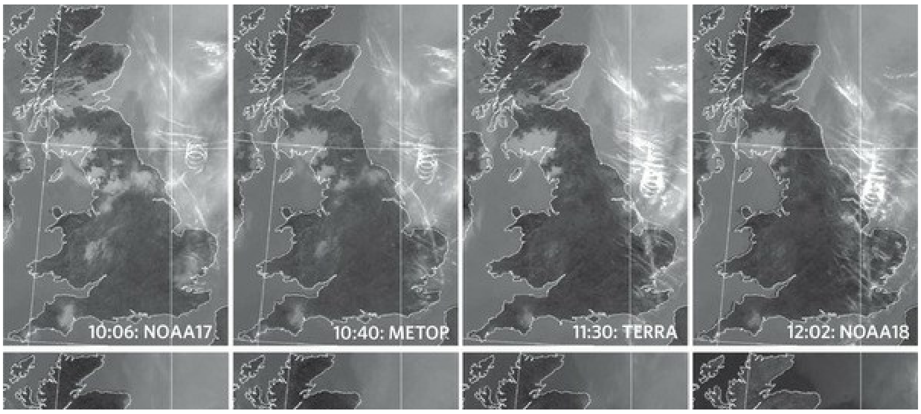
Nature Climate Change **1**, 24–25 (2011) | doi:10.1038/nclimate1078
Published online 29 March 2011

Contrails formed by aircraft can evolve into cirrus clouds indistinguishable from those formed naturally. These 'spreading contrails' may be causing more climate warming today than all the carbon dioxide emitted by aircraft since the start of aviation.

Aviation is at present responsible for about 3% of all fossil fuel carbon dioxide emissions, but an estimated 2–14% of anthropogenic climate forcing[1]. Furthermore, its contribution to climate forcing could triple by 2050, according to some scenarios[1]. As such, mitigating the impact of aviation on climate has become a subject of considerable public and political interest. The debate is complicated, however, by the fact that aviation's climate impact results from a number of different factors, as well as by the large uncertainty in the effect that some of these factors have on climate. Writing in *Nature Climate Change*, Burkhardt and Kärcher[3] present a global modelling study that quantifies the climate effect of 'spreading contrails' — the least well quantified of all the aviation-related climate-forcing agents.

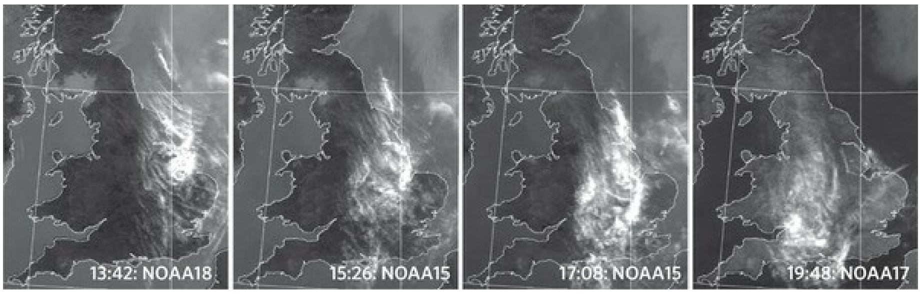
Aircraft-engine emissions are mostly composed of carbon dioxide, water vapour, nitrogen oxides, sulphur oxides and aerosol particles. As well as the direct effect that these emissions have on climate, aviation has an added impact induced by the formation of condensation trails (contrails) in the wake of the aircraft. These line-shaped trails are formed by the mixing of hot, moist air coming out of the engine with cold ambient air. When the atmosphere is supersaturated with respect to ice, the line-shaped contrails can spread to form cirrus cloud, which has a warming effect on climate. Although there are robust case studies of this spreading phenomenon using satellite observations[2] (Fig. 1), its relevance to the climate system remains unknown.

Figure 1: Satellite infrared images of contrails spreading into cirrus clouds over the UK.



Associated links
Article
Global radiative forcing from contrail cirrus
by Burkhardt and Kärcher

Most read
Vulnerability and adaptation of US shellfisheries to ocean acidification
Nature Climate Change | 23 February 2015
Quantifying the likelihood of a continued hiatus in global warming
Nature Climate Change | 23 February 2015
Assessing species vulnerability to climate



The young contrails, which appear as a spring shape and sharp lines in the first image, gradually spread into cirrus clouds, which appear as bright white areas in the lower images. The time of each image and the satellite used to take it are shown in the inset of each frame. Burkhardt and Kärcher[3] used a model that simulates this spreading process to assess the warming effects of contrails and the cirrus clouds that form from them. Their results indicate that so-called spreading contrails cause an order of magnitude more climate warming than the line-shaped contrails alone, and are the largest single climate-forcing agent associated with aviation. Image reproduced with permission from ref. 2, © 2009 AGU.

Full size image (148 KB)

Both ground- and satellite-based cloud observations have suggested a small but noticeable increase in cirrus cloud cover in regions of high air-traffic density relative to adjacent regions[4, 5, 6]. However, contrail spreading is not the only mechanism that could explain this increase. It has also been suggested that aircraft-emitted aerosols could serve as ice nuclei and facilitate the formation of cirrus cloud[7]. To understand the impact of aviation on climate, it is necessary to quantify the importance of these two mechanisms. This, however, is not a straightforward task.

In situ observations of aerosols and ice nuclei in the upper troposphere are still very scarce. There are also multiple confounding factors that make the observations difficult to interpret. For instance, when a line-shaped contrail spreads into a large cirrus cloud, it is virtually impossible to tell from observations alone whether a cirrus cloud would have formed naturally (that is, without having being triggered by the aircraft) at some point in time. Climate modelling does not have these difficulties, and thus offers a way of tackling this thorny problem.

Burkhardt and Kärcher[3] developed a process-based model of how contrails form, grow (through the depletion of water vapour in the surrounding air), spread and finally disappear (through mixing and fall-out of the ice crystals). By tracking the fate of contrail and natural cirrus separately, the authors can quantify the radiative forcing from spreading contrails (including young line-shaped contrails), which they estimate to be 38 mW m^{-2}. This can be compared with a radiative forcing of 4 mW m^{-2} from young contrails alone and 28 mW m^{-2} from aviation carbon dioxide. Interestingly, spreading-contrail cirrus clouds cause a reduction in natural cirrus, because they modify the water budget in the upper troposphere; however, this reduction in natural cirrus is relatively small (-7 mW m^{-2}).

Overall, and despite their short lifetime, contrails may have more radiative impact at any one time than all of the aviation-emitted carbon dioxide that has accumulated in the atmosphere since the beginning of commercial aviation. It is important to note, however, that the emitted carbon dioxide would continue to exert a warming influence for much longer than contrails, should all aircraft be grounded indefinitely. These results are intrinsically difficult to validate against observations, but the authors have performed a sensitivity study that shows their results are not significantly affected by the contrail spreading rate (±5 mW m^{-2}). This is a conservative estimate of the uncertainty and more work is needed to assess the robustness of the results.

These findings are important, because if the calculations of Burkhardt and Kärcher are correct, they provide a basis to develop mitigation strategies to reduce the impact of aviation on climate. For instance, it has been suggested that flight routes or flight altitudes could be planned and altered in real time to avoid parts of the atmosphere that are supersaturated with respect to ice[8, 9]. Even though this would help to reduce both young and spreading contrails, such a strategy is likely to lead to an increase in fuel consumption. It would be important to make sure that, given the large difference in atmospheric lifetime of carbon dioxide and contrails, the associated carbon dioxide penalty does not offset in the longer term the gain obtained by avoiding contrail formation[10].

The results by Burkhardt and Kärcher might also justify the development of a novel engine concept that seeks to condense a fraction of the water vapour in aircraft emissions in a cooling unit before it leaves the engine[11]. The condensed water could be vented in the form of large ice crystals or droplets that would fall quickly through the atmosphere. Reducing the content of water vapour in the engine exhaust would make contrail formation less likely.

Alternatively, one could make use of the finding that spreading contrails suppress the formation of natural cirrus clouds. It may be possible to accelerate the deposition of ambient water vapour onto the contrail ice crystals either by modifying the aircraft wake dynamics or the aerosol and cloud microphysics in the exhaust plume. If the lifetime of the contrail cirrus can be reduced several-fold for the same suppression of natural cirrus, there could be a net climate-cooling effect from contrail formation.

Although the work of Burkhardt and Kärcher[3] offers some exciting pointers as to how the impacts of aviation on the climate system might be reduced, the uncertainties remain large. Given the urgency of the issue, it is important that research on the climate impacts of contrails and on how contrails could be mitigated through technological advances or operational changes in the aviation industry are pursued in parallel.

References

References • **Author information**

1. Lee, D. S. *et al*. *Atmos. Environ.* **43**, 3520–3537 (2009).

   Show context — Article ISI ChemPort

2. Haywood, J. M. *et al*. *J. Geophys. Res.* **114**, D24201 (2009).

   Show context — Article

3. Burkhardt, U. & Kärcher, B. *Nature Clim. Change* **1**, 54–58 (2011).

   Show context — Article

4. Boucher, O. *Nature* **397**, 30–31 (1999).

   Show context — Article ISI ChemPort

5. Zerefos, C. S. *et al*. *Atmos. Chem. Phys.* **3**, 1633–1644 (2003).

   Show context — Article ISI ChemPort

6. Stubenrauch, C. J. & Schumann, U. *Geophys. Res. Lett.* **32**, L14813 (2005).

   Show context — Article

7. Hendricks, J. *et al*. *Geophys. Res. Lett.* **32**, L12814 (2005).

   Show context — Article ChemPort

8. Mannstein, H. *et al*. *Transport. Res. D* **10**, 421–426 (2005).

   Show context — Article ISI

9. Williams, V. *et al*. *Clim. Policy* **3**, 207–219 (2003).

   Show context

10. Forster, P. M. *et al*. *Atmos. Environ.* **40**, 1117–1121 (2006).

    Show context — Article ISI ChemPort

11. Noppel, F. & Singh, R. *J. Aircraft* **44**, 1721–1726 (2007).

    Show context — Article ISI

Download references

Author information

References • Author information

Affiliations

Olivier Boucher is at the Met Office Hadley Centre, Fitzroy Road, Exeter EX1 3PB, UK

Corresponding authors

Correspondence to: Olivier Boucher or Olivier Boucher

Nature Climate Change ISSN 1758-678X EISSN 1758-6798 This journal is printed on recycled paper Header image source: ESA/NASA