The Climate Impact of Aviation: atmospheric science progress and uncertainties

David S. Lee

"*Towards Climate Optimized Aviation*"
First CAES European
Air and Space Conference:
Century Perspectives,
10th–13th Sept. 2007, Berlin

Manchester Metropolitan University

Manchester Metropolitan University

Overview

1. What is the background?
2. What are the remaining scientific uncertainties and the new and emerging issues?
3. Flight optimization?
4. Conclusions

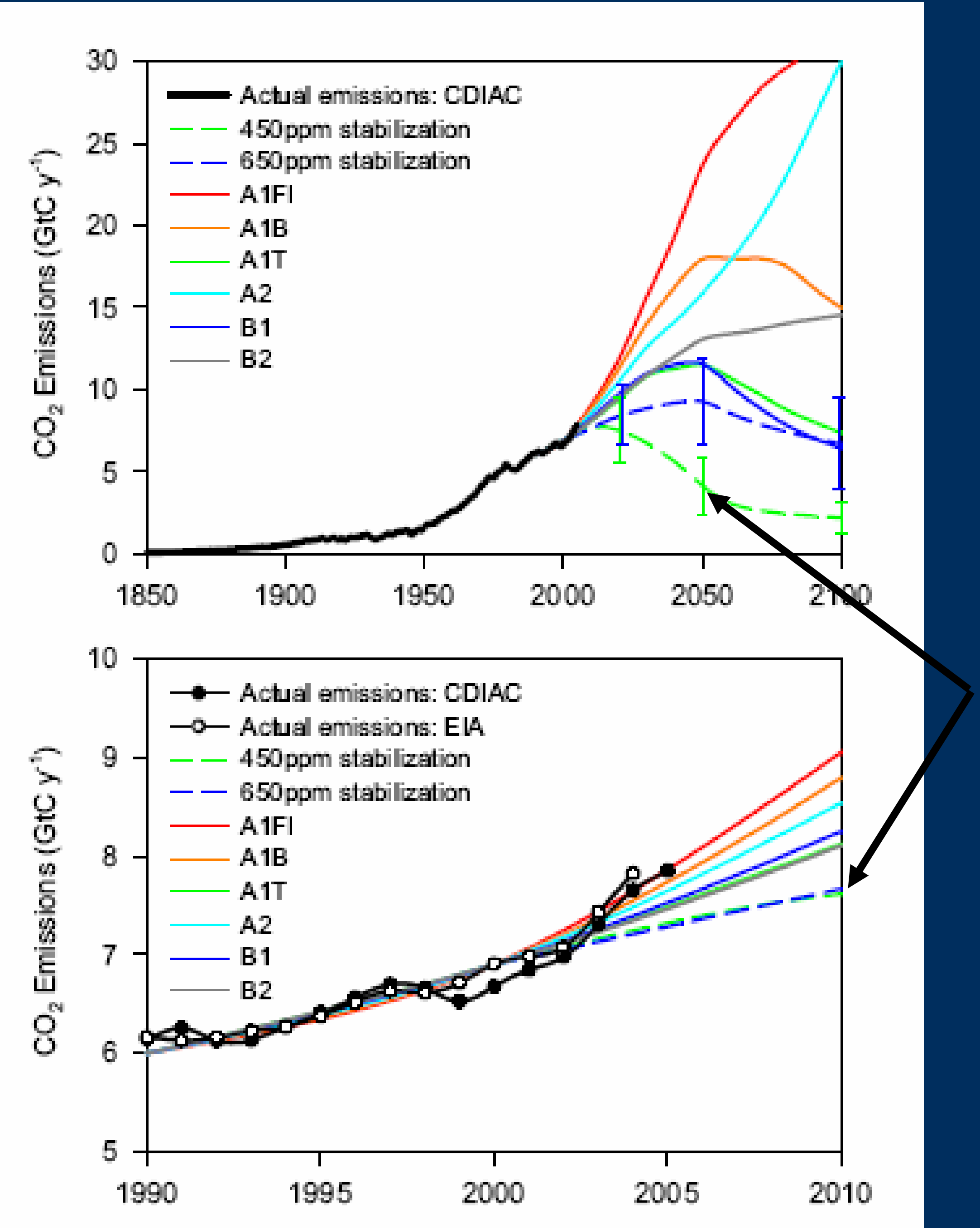

Section 1
The background
Manchester Metropolitan University

The background of aviation and climate issues

- General & global economic growth and development
- Resultant climate change (see U. Lohmann talk)
- Transport: a major growth challenge
- Aviation is a growing component of this (see U. Schumann talk) – and may be a large component if a climate stabilization pathway is followed (and not addressed)
- There are now much stronger policy interests in aviation giving rise to ‘emission equivalent’ questions

Manchester Metropolitan University

Overall growth of all emissions



Headline

Global growth rate of emissions of CO_2

1991 – 1999 1.1% yr^{-1}

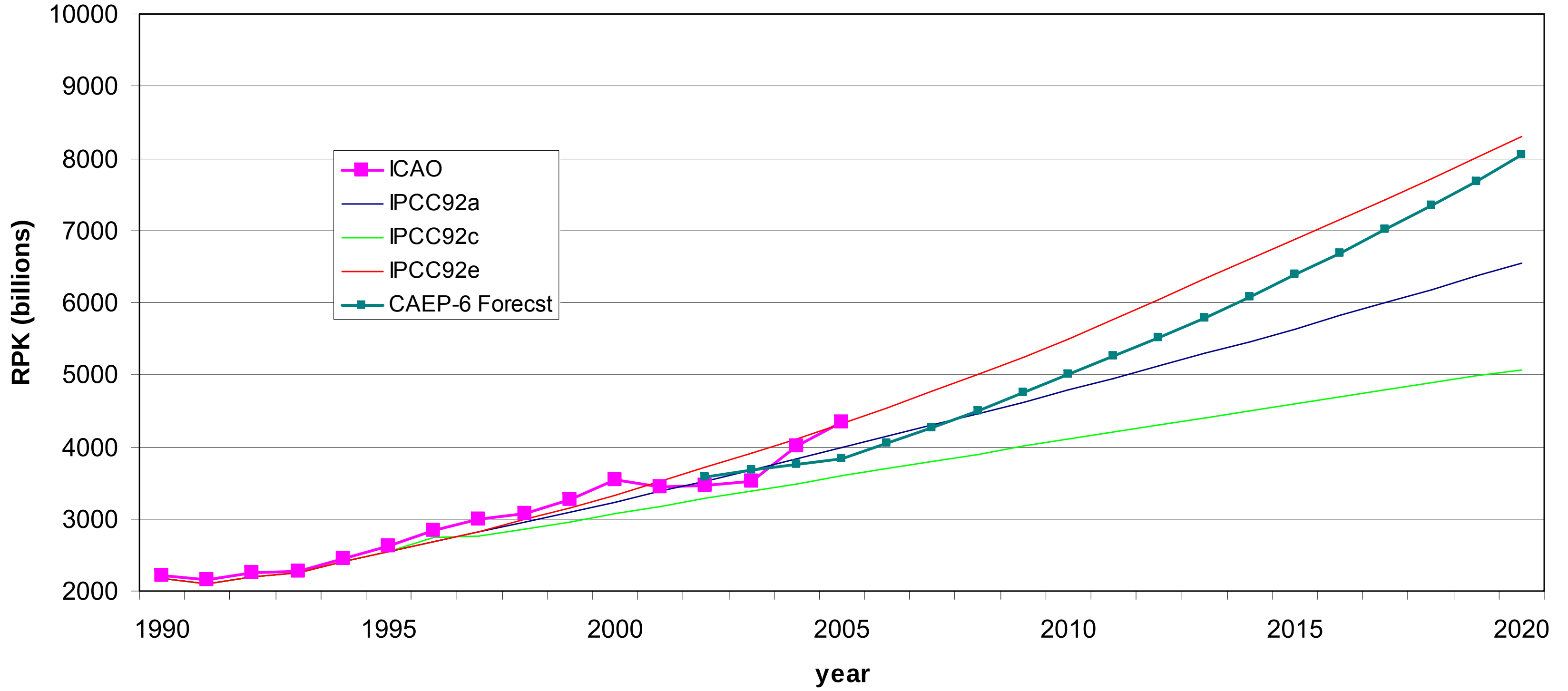
2000 – 2004 3.0% yr^{-1}

Note: Stabilization at 450 ppm CO_2 is probably required to achieve no more than 2degC global mean temperature increase

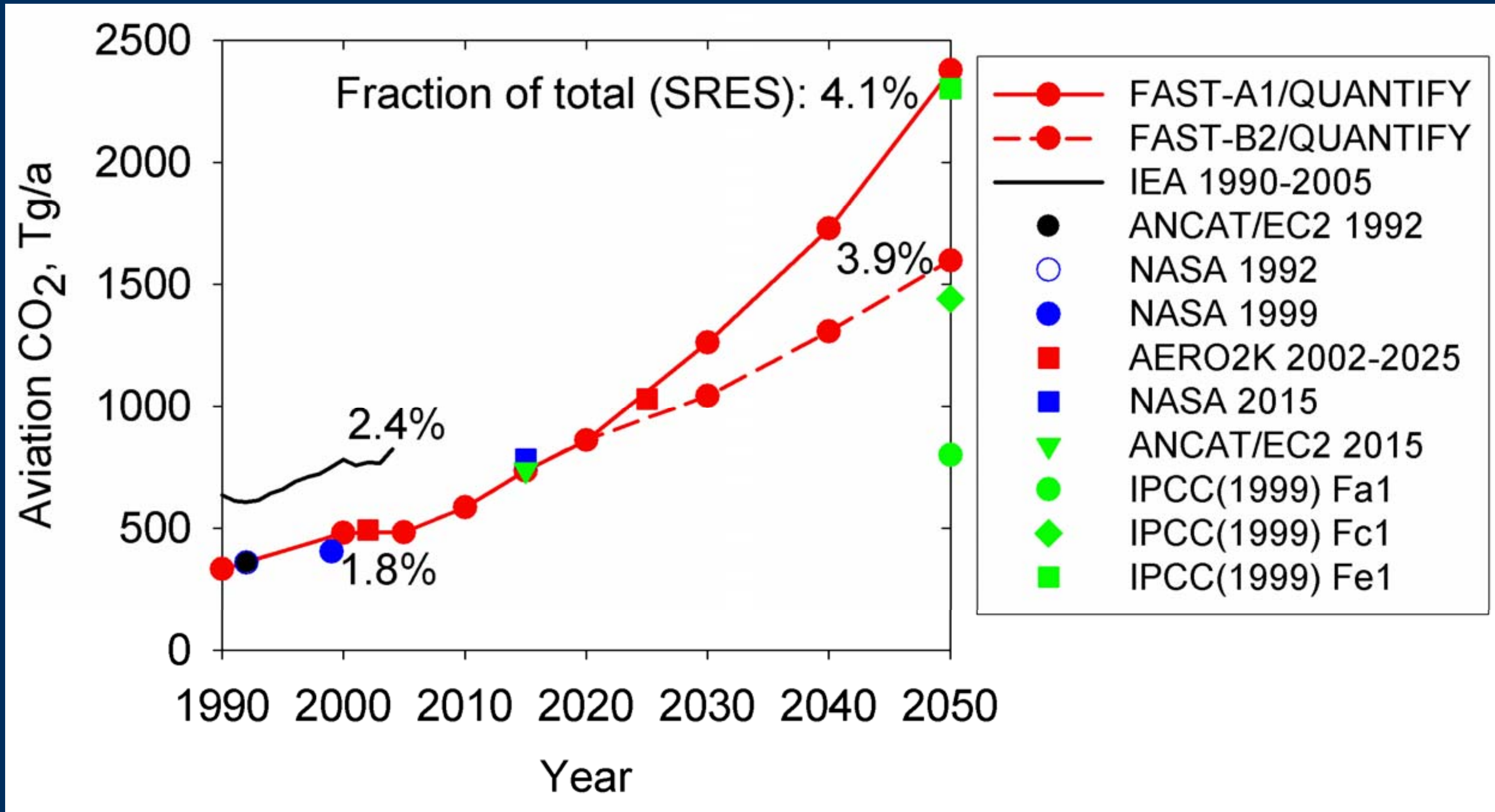
Raupach *et al*.
Global and regional drivers of accelerating CO_2 emissions.
Proc. Nat. Acad. Sci. May 22 2007

Manchester Metropolitan University

Recent development of air traffic (RPK)



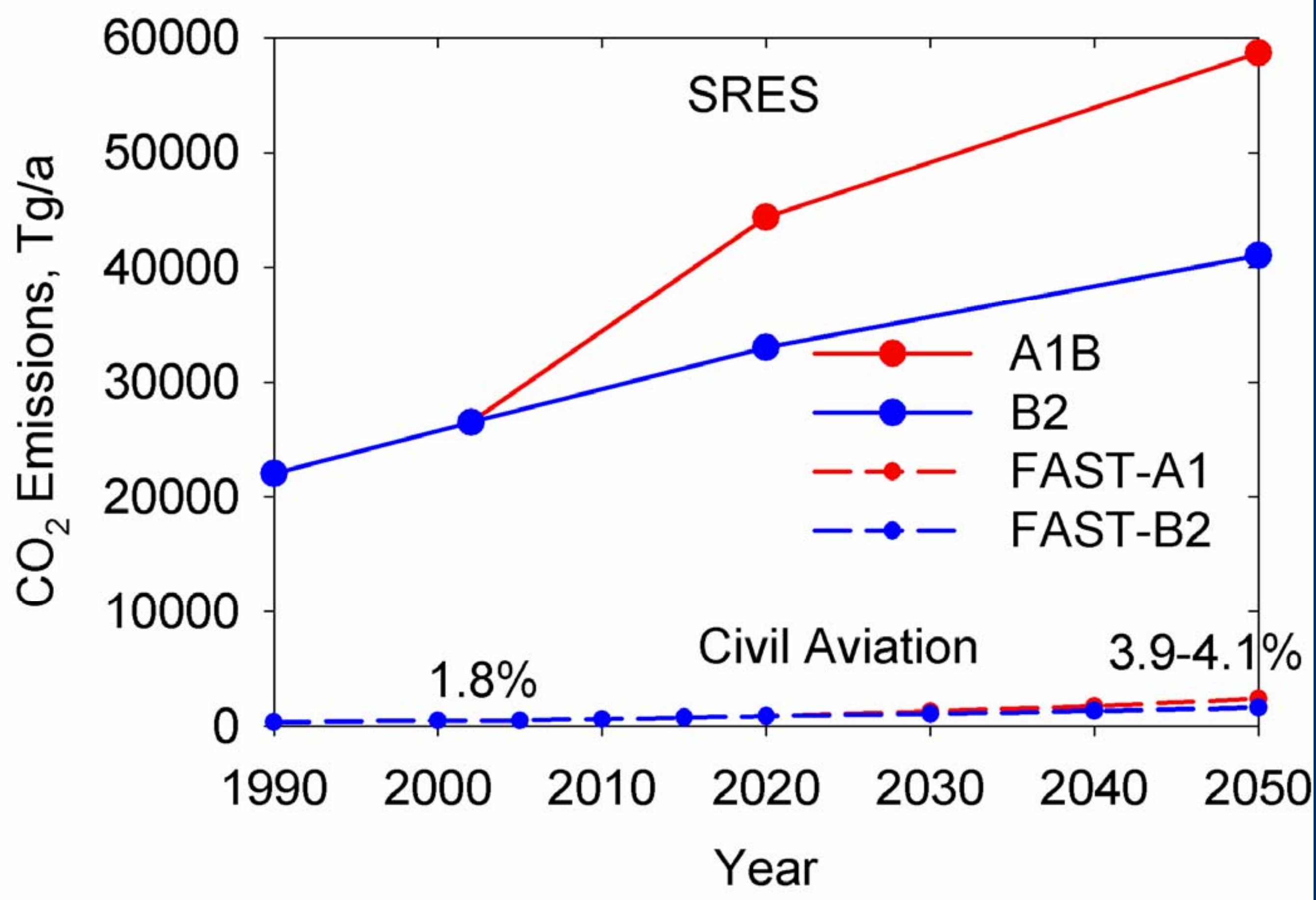
Current and projected aviation emissions of CO_2



Increase 2005 – 2050:
FAST-A1: factor 4.9
FAST-B2: factor 3.3

Data sources: Owen and Lee, 2006; IPCC 2007; Schumann, 2007

Manchester Metropolitan University



A1B: rapid economic growth, balance across all sources, fast intro. of new technologies, strong globalisation

B2: moderate economic growth, diverse technological change, more oriented towards environmental protection, focus on regional levels

Aviation projections in relation to total emissions

Manchester Metropolitan University

Section 2

What are the remaining scientific uncertainties and the new and emerging issues?

Manchester Metropolitan University

Areas of uncertainty

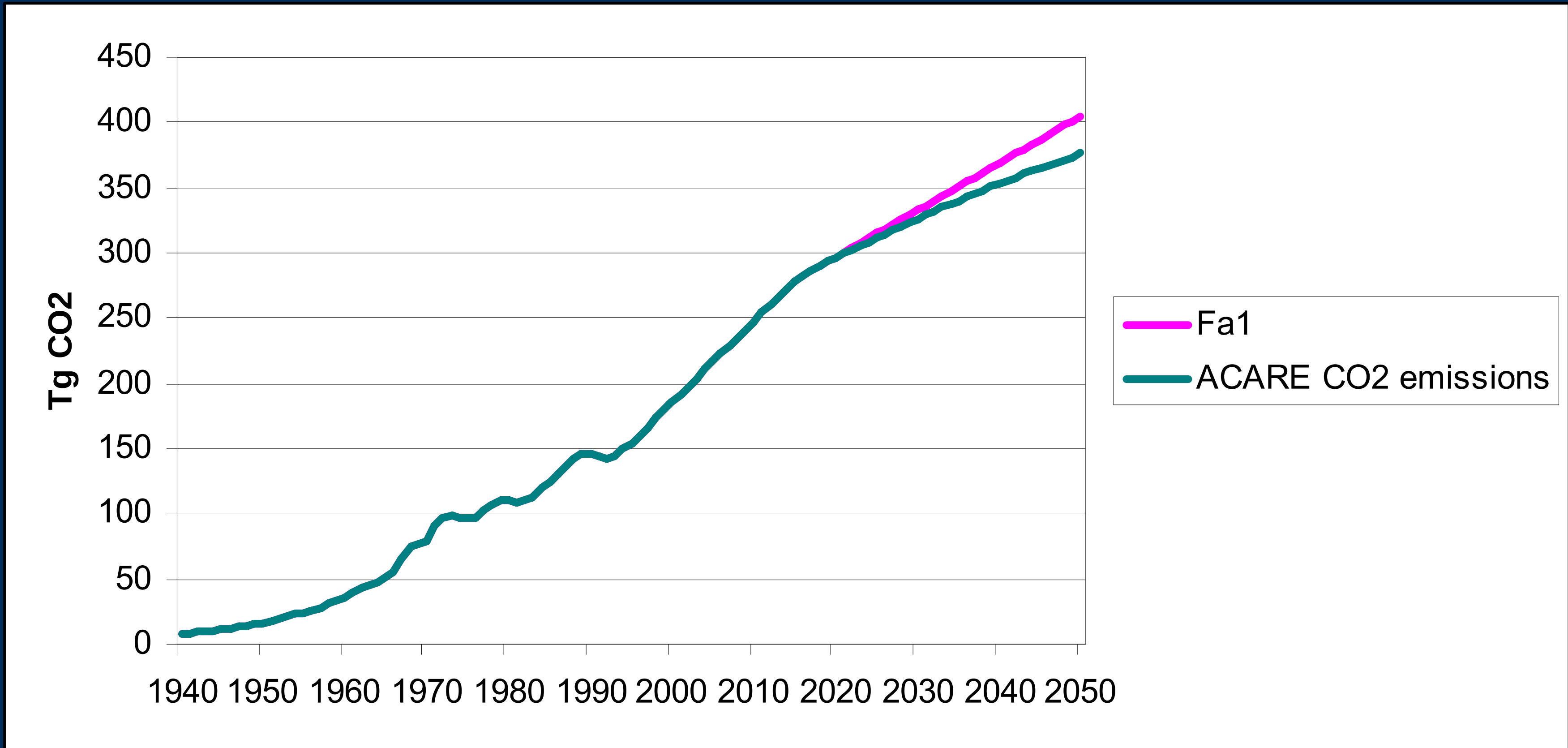
- Emissions projections (growth, technology)
- Contrail & contrail cirrus
- Policy metrics (emission equivalences)
- Climate response vs RF
  - *RF* vs Δ*T*
  - Efficacies
  - Regional/hemispheric forcings vs global forcings (e.g. O_3/CH_4)

Manchester Metropolitan University

Emissions projections, scenarios and underlying data

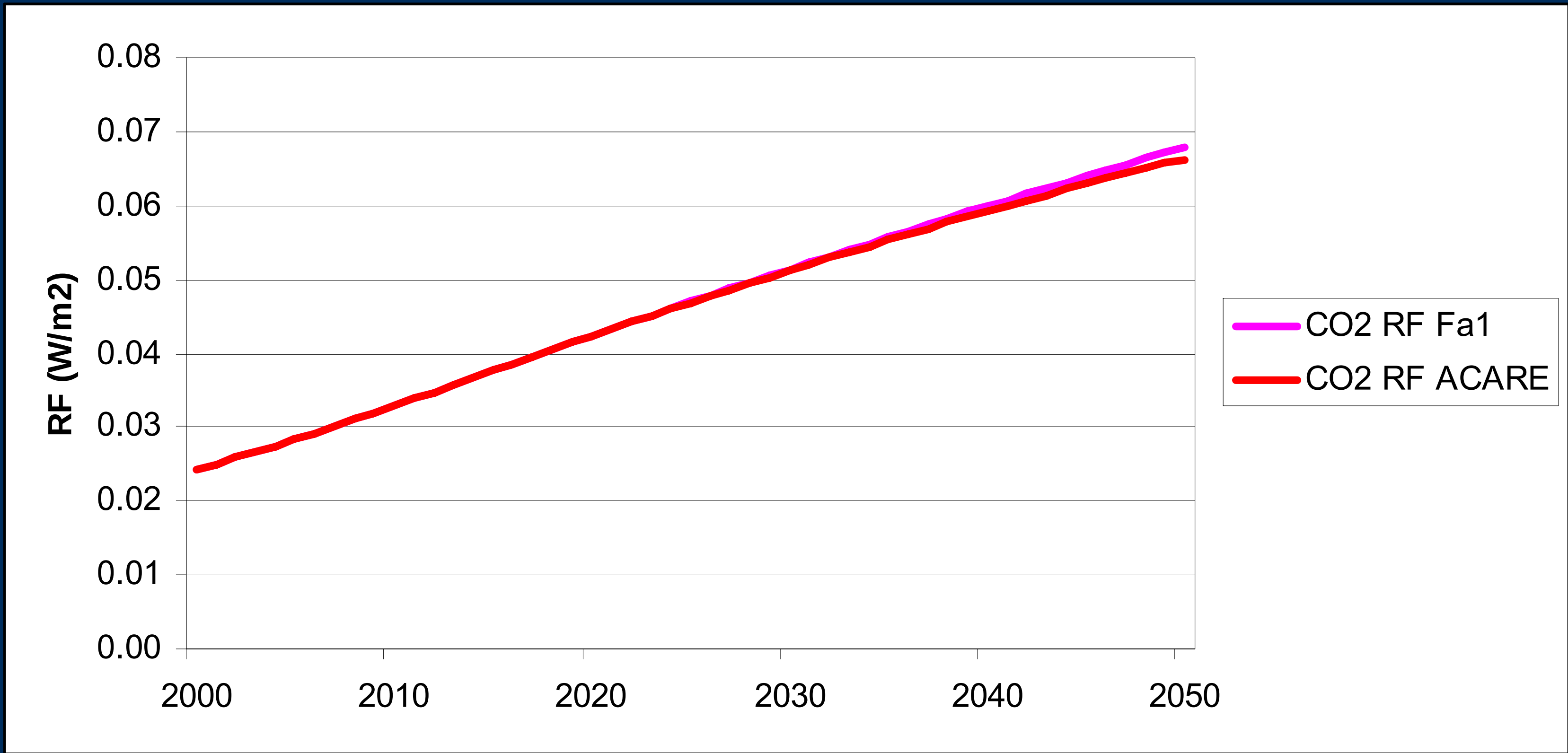
- Are current targets (ACARE) and goals sufficient?

Comparison of scenario Fa1 *cf* $ACARE_{30}$



Source: Owen and Lee, MMU

Radiative forcing from aviation CO_2, Fa1 *cf* 'ACARE$_{30}$' scenario



Source: Owen and Lee, MMU

Manchester Metropolitan University

Contrails and contrail cirrus

- Progress on refining contrail RF estimates (model and data estimates) (talk by U. Schumann) – major challenges remain
- Quantification of contrail-cirrus cloud coverage from observations remains difficult
- Quantification of ‘soot cirrus’, *triggering* cloud formation is an even greater challenge

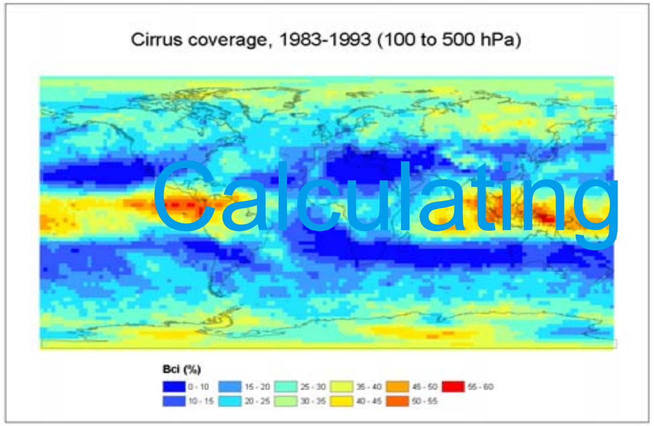
Manchester Metropolitan University

Contrail RF – still uncertainties on the coverage

- Recent estimates of RF give estimates ~5 to 10 mW/m^2
- Whilst one of the smaller aviation forcings, it remains key to potential contrail-cirrus forcing
- BUT severe limitations remain owing to few measurements:
  - by satellite – limitations of discrimination between visible and sub-visible contrails (optical thickness)
  - by ground observations (LIDAR) – limited long-term measurements and suitable sites

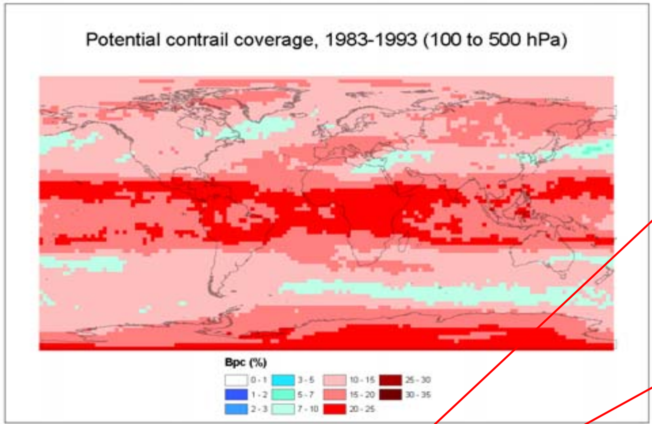
Manchester Metropolitan University

Calculating contrail coverage and RF

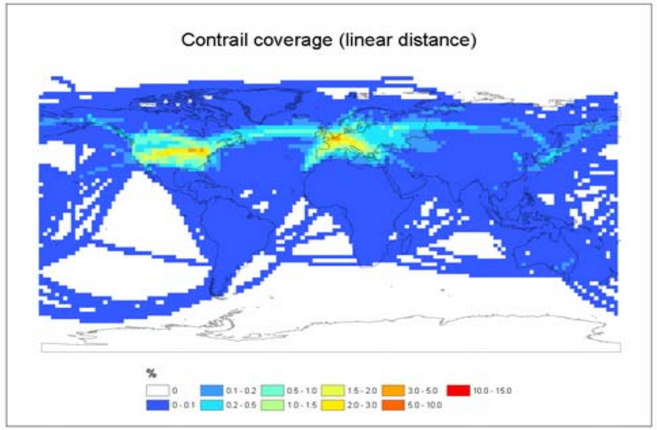


Cirrus cloud fraction

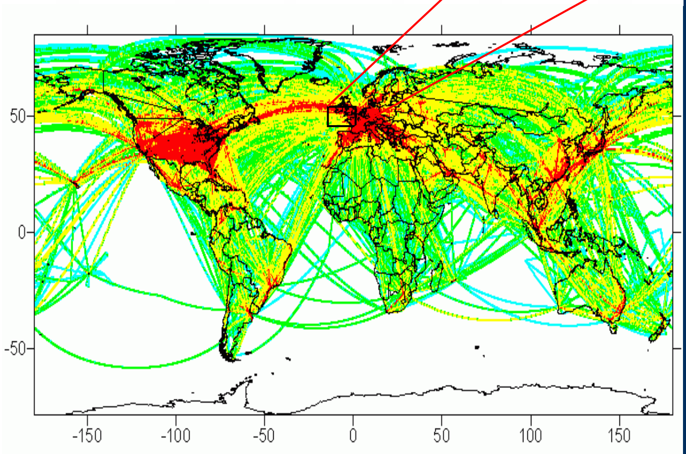
Contrail observations



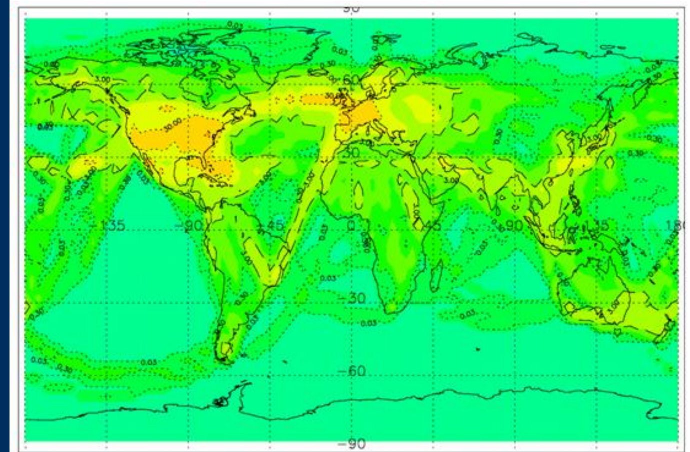
Potential contrail coverage



Contrail coverage



Air traffic density



Contrail RF

Technique based on Sausen et al. 1999 (DLR)

Contrail avoidance

There are several issues here:

- Linear contrails can largely be avoided (change altitude)
- Will avoidance have a proportional effect on contrail-cirrus?
- Is it worth it?
  - RF effects
  - operational/infrastructural costs
  - short term forcing vs long-term forcing from CO_2

Manchester Metropolitan University

Contrail/cirrus avoidance – conceptual scenarios

Linear Contrails ~10 mW/m² → **Contrail-cirrus 10 – 80 mW/m²** — Current understanding

'Smart flight avoidance'

Linear Contrails ~reduced RF → **Contrail-cirrus ~reduced RF** — Good outcome €??

Linear Contrails ~reduced RF → **Contrail-cirrus not proportionally affected RF** — Poor outcome €??

Linear Contrails ~reduced RF → **Contrail-cirrus *strong* reduction in RF** — Excellent outcome €??

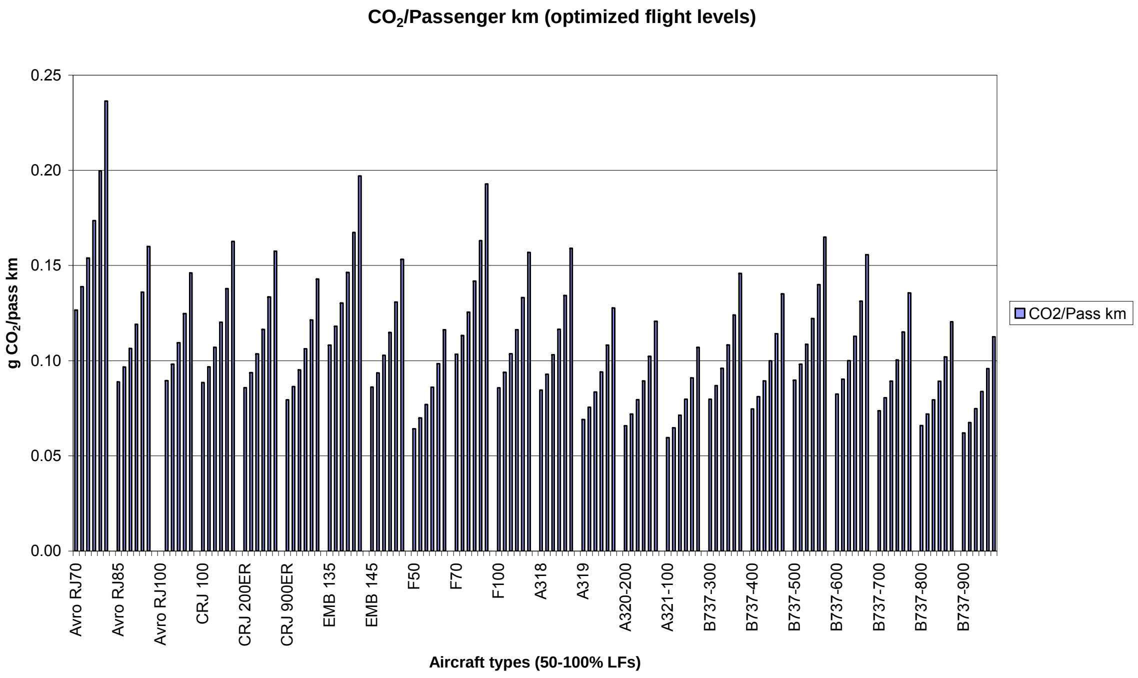
Manchester Metropolitan University

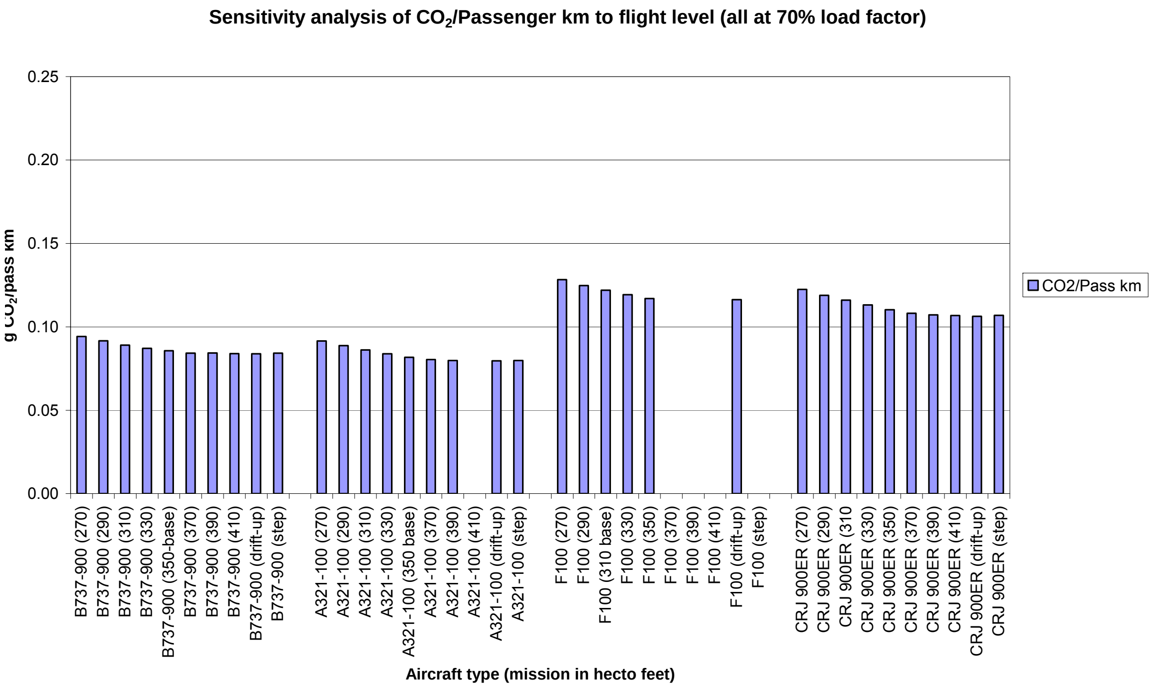
Contrail avoidance – CO_2 penalty?

- Parametric study (Fichter *et al*., 2005) shows increases in fuel usage of ~3, 4, 6% for changes in global fleet cruise altitudes of 2, 4, 6 kft
- Such changes would, in practice, not be necessary (Mannstein *et al*., 2005)
- Small changes in altitude have a smaller impact on fuel usage by one order of magnitude than load factor variation (50 – 100%) – g CO_2/pkm

Manchester Metropolitan University

Variation in g CO_2/pkm from load factor and cruise altitude





Manchester Metropolitan University

Science vs policy metrics

- Radiative forcing is an integral and therefore *backwards looking* – it tells you what the impact is ‘now’ as a result of history
- Radiative forcing does not reflect the ‘full’ effect as the *temperature response* is as yet not fully released because of thermal inertia of the climate system
- How do we use these as policy-oriented metrics for emissions equivalences?
- There is a need to educate policy-makers and stakeholders on the implications of their questions

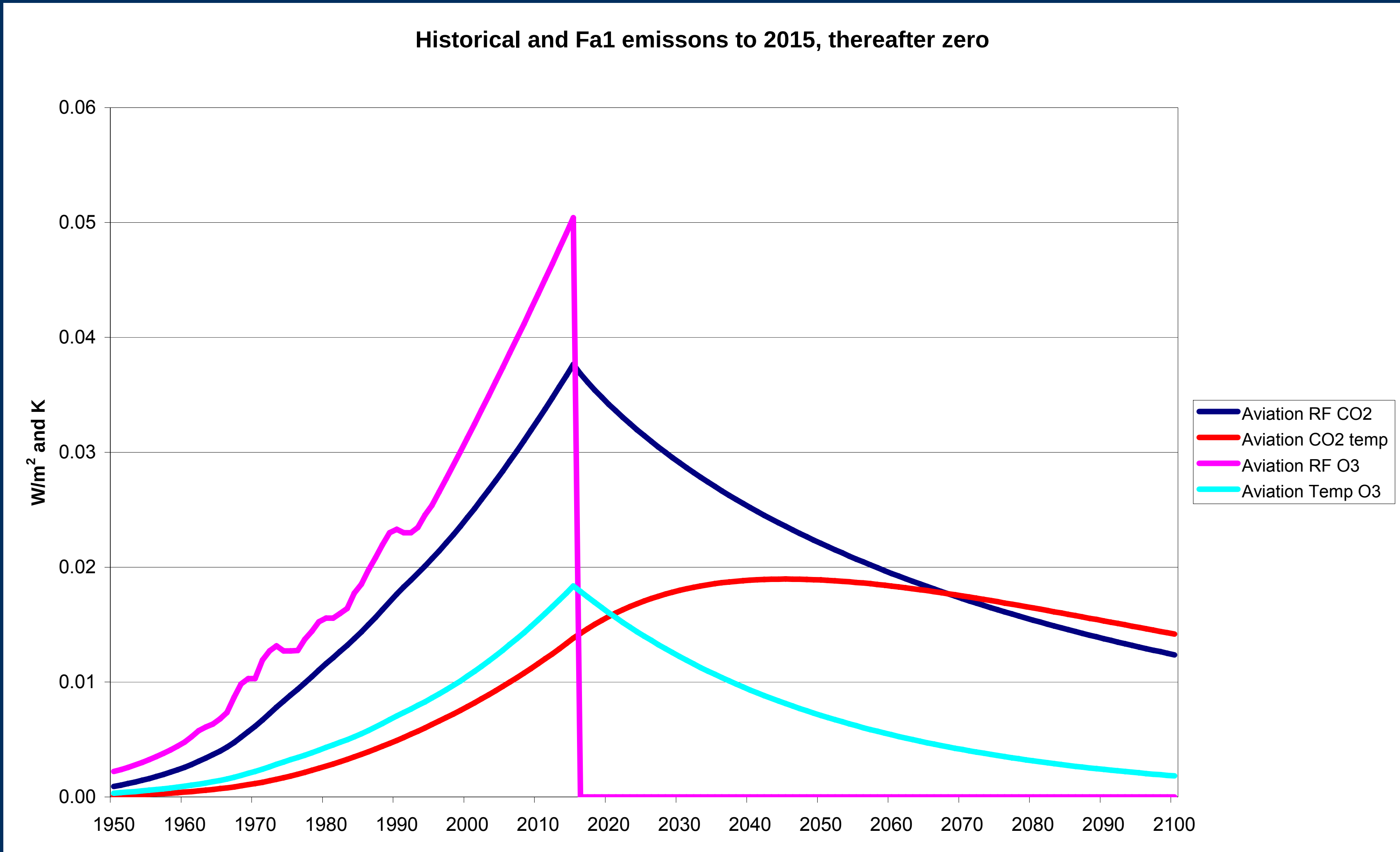
Manchester Metropolitan University

Metrics – purpose? Science, policy?

- RFI (ratio of total aviation forcings/CO_2 forcing) (IPCC, 1999)
  - a good fit-for-purpose comparative metric of a particular scenario of the ratio of total to CO_2 forcing
  - not suitable as an emission metric (backward looking, non-constant)
- Global Warming Potential
  - developed as an emission metric
  - has difficulties for short-lived species
  - may be possible to develop derivatives but will have a time-horizon
- Global temperature potential/temperature index (Shine *et al*., 2005; Wit et al., 2005)
  - closer to 'effect' and can potentially handle relationship to emissions
  - pulse, constant emissions, scenario?
  - needs further development but is likely to be tied to a time-horizon but is promising in order to develop an 'emissions multiplier'

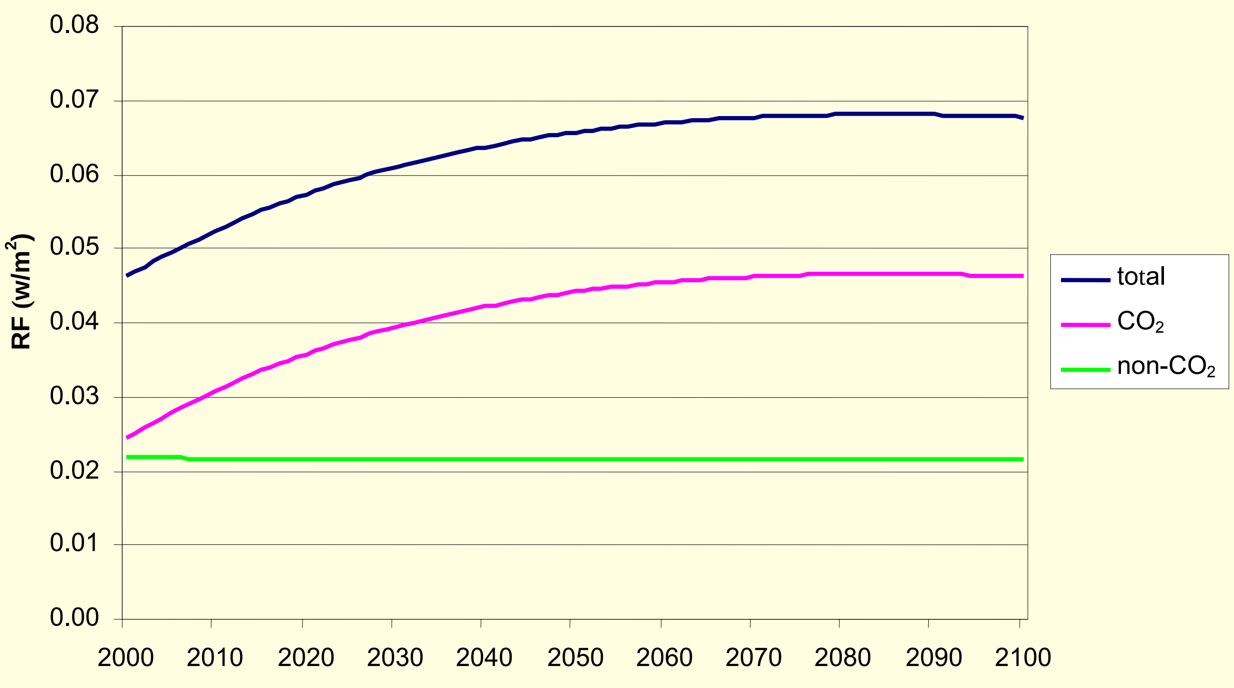
Manchester Metropolitan University

Radiative forcing and temperature response



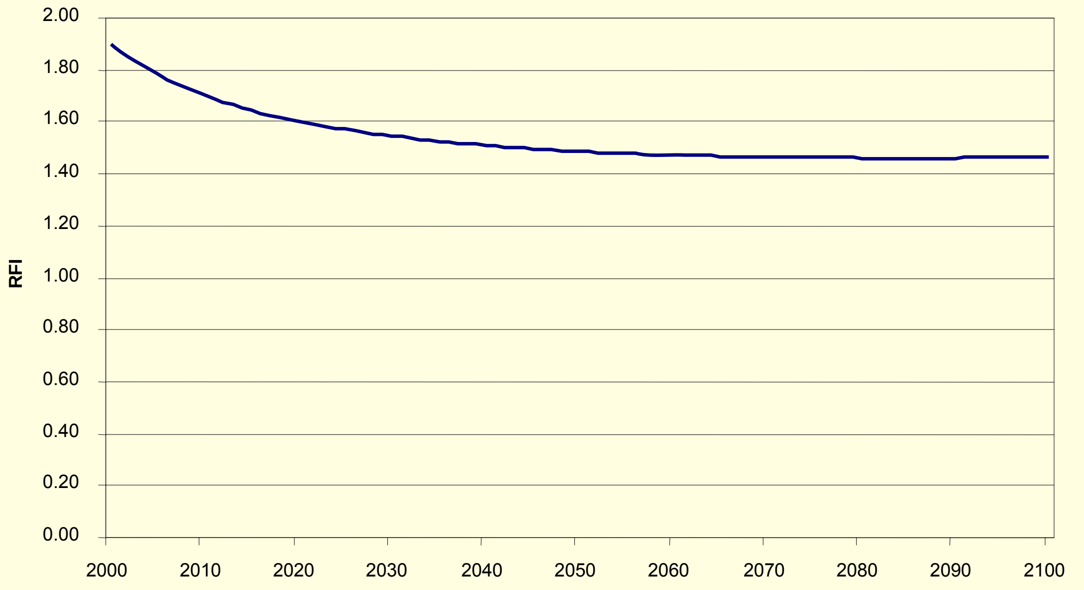
Source: Lim *et al*., 2007 (*model developed from that of Sausen and Schumann, 2000*)

Manchester Metropolitan University



Time evolved RFs

Constant emissions after 2000

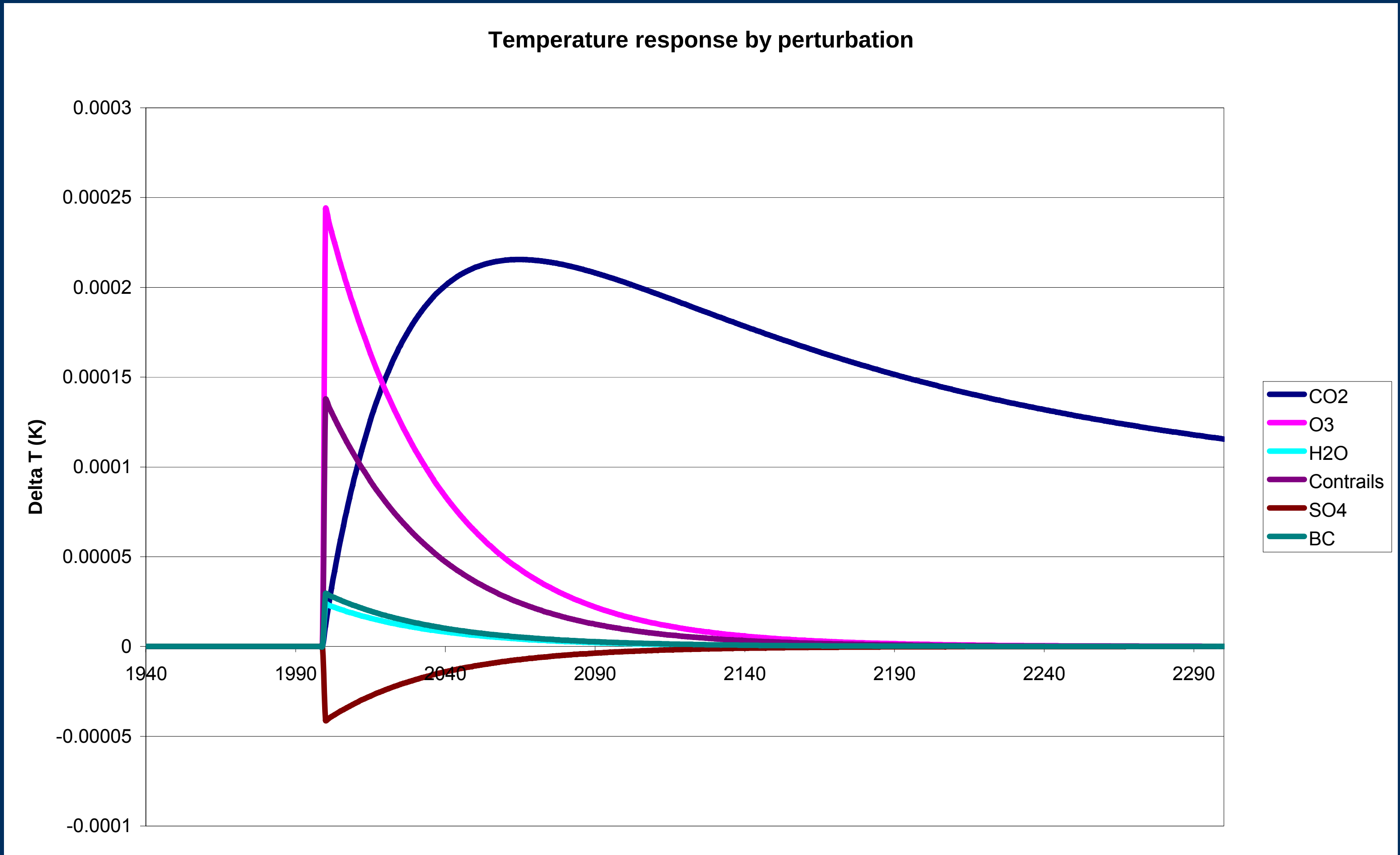


Time evolved RFI

Source: Wit *et al*. (2005)

Manchester Metropolitan University

Global fleet *temperature* pulse response



Source: Lee *et al*., 2007 (*model developed from that of Sausen and Schumann, 2000*)

Manchester Metropolitan University

Section 3

International Co-operation & UK Programmes

Manchester Metropolitan University

UK Programmes - Omega

- UK Knowledge transfer partnership: academia working with stakeholders covering noise, emissions (global and local) and market issues
- 9 university partners – covering the spectrum of the debate with internally recognized experts
- 2050 time horizon with short, medium and long term focused activities – studies and forum for dialogue with stakeholders
- Started 2007 to bring academic capability together: 18 studies initiated, more in preparation (ends Dec 2008)
- Identify and work on priority issues to help delivery agents: the industry and policy-makers

Manchester Metropolitan University

Omega – climate-related studies underway

- Assessing global temperature change: implications of projections of aviation growth
- Combining models of jet engine exhaust and climate impact to quantify trade-offs of changes in engine design and aircraft operation
- Adding contrails to the Met Office climate model
- RF effects of supersonic Bizjets

And expecting to initiate work shortly in the areas of

- Workshops on metrics and non-CO_2 impacts, work on scenarios and predictions

Manchester Metropolitan University

www.omega.mmu.ac.uk

Manchester Metropolitan University

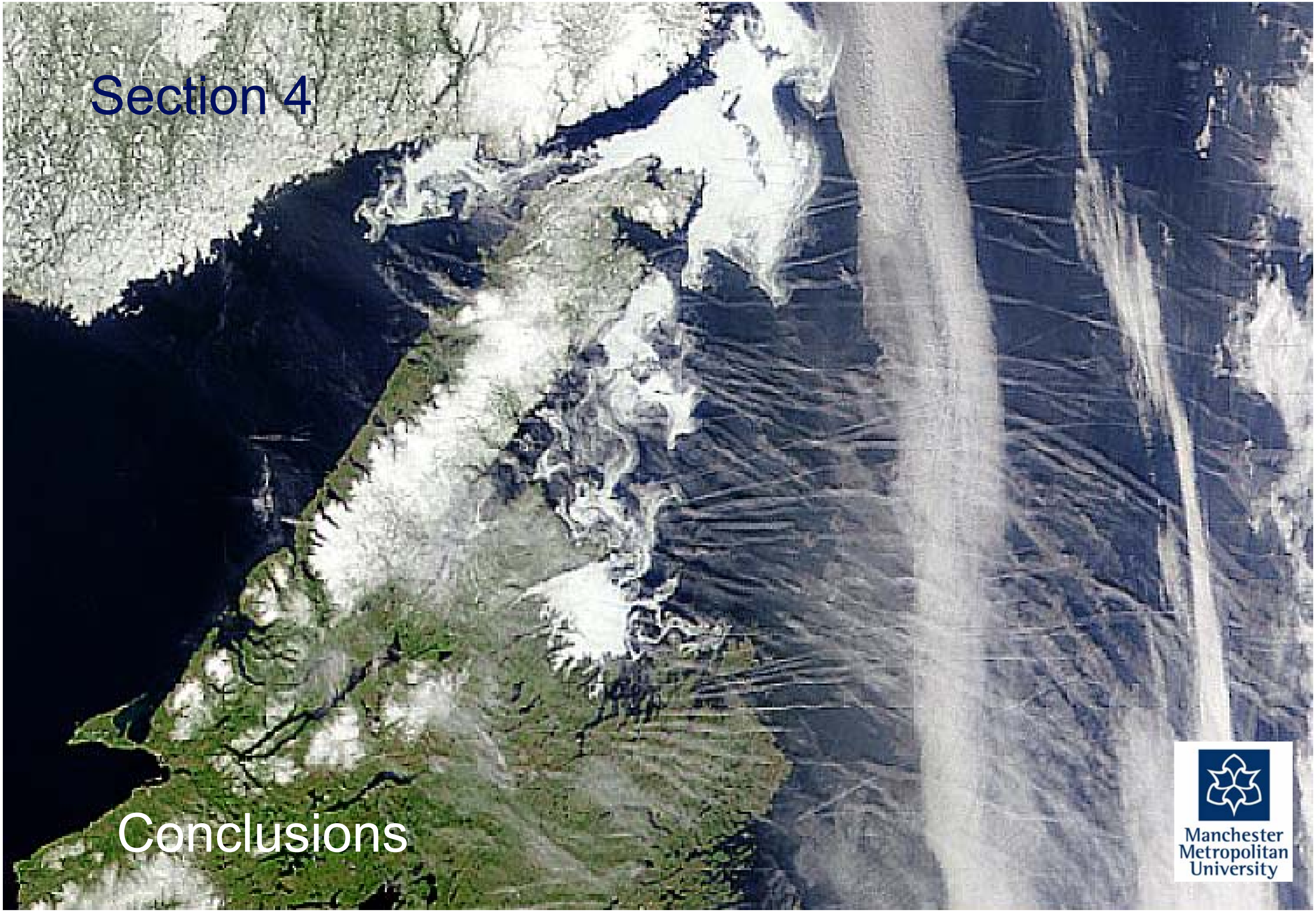
International co-operation and development of aviation-related climate science

- EU projects (Quantify*, ATTICA*)
- EU Networks of Excellence (ECATS*, ACCENT‡)
- National programme linkages (UK Omega)
- Academic partnerships (e.g. Visiting Professors MMU/DLR**)
- Conferences (A2C3 – 2001, AAC – 2003, TAC – 2006**)
- MoU networks and partnerships (e.g. ECATS* – US PARTNER)
- International organizations and assessments (WMO, IPCC)
- EU – US project involvements (Quantify*, ATTICA*)
- Policy arena (ICAO, WMO)

* Co-ordinated by DLR
** Joint MMU – DLR activities
‡ Coordinated by University of Bologna

Manchester Metropolitan University

Section 4



Conclusions

Conclusions – science

- Current climate situation summarized by U. Lohmann
- Aviation and climate situation summarized by U. Schumann
- Uncertainties remaining:
  - emissions and technology & policy responses
  - contrail RF still requires more measurements for validation
  - contrail-cirrus quantification a major challenge
  - policy-relevant metrics for comparing *emissions*
  - climate-optimized flight?
  - maybe, but there is more to do first
- Other important science aspects not touched on here

Manchester Metropolitan University


Thank you for your attention
Acknowledgements:
Dr Ling Lim, MMU
Ms Bethan Owen, MMU
Prof. M. Ponater, DLR
Prof. U. Schumann, DLR
EC Integrated Project
QUANTIFY
Network of Excellence
ECATS