



# The Assessment of Aviation Cloudiness in IPCC Climate Change 2007 - The Physical Science Basis

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  - linear contrails
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# Intergovernmental Panel on Climate Change (IPCC)



*“... to assess scientific, technical and socio- economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation.”*

- > Policy neutral but policy relevant*
- > Consensus within an international group of scientists*
- > Multiple expert and government reviews*

## Climate Change 2007: The Physical Science Basis Contribution of Working Group I to the IPCC Fourth Assessment Report

Dahe Qin (**China**) and Susan Solomon (**USA**), Co-Chairs

### **Chapter 2: Changes in Atmospheric Constituents and in Radiative Forcing**

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# Aviation contrails and contrail cirrus



## Persistent linear contrails:

- > thin-cirrus (ice) clouds formed primarily from ambient water vapor
- > Require sufficiently cold ambient temperatures (**high relative humidity**) and water vapor emissions
- > Require ambient or aviation aerosol **particles** to form
- > Formation conditions can be **accurately** predicted for individual aircraft (*Schmidt-Appleman criterion*)

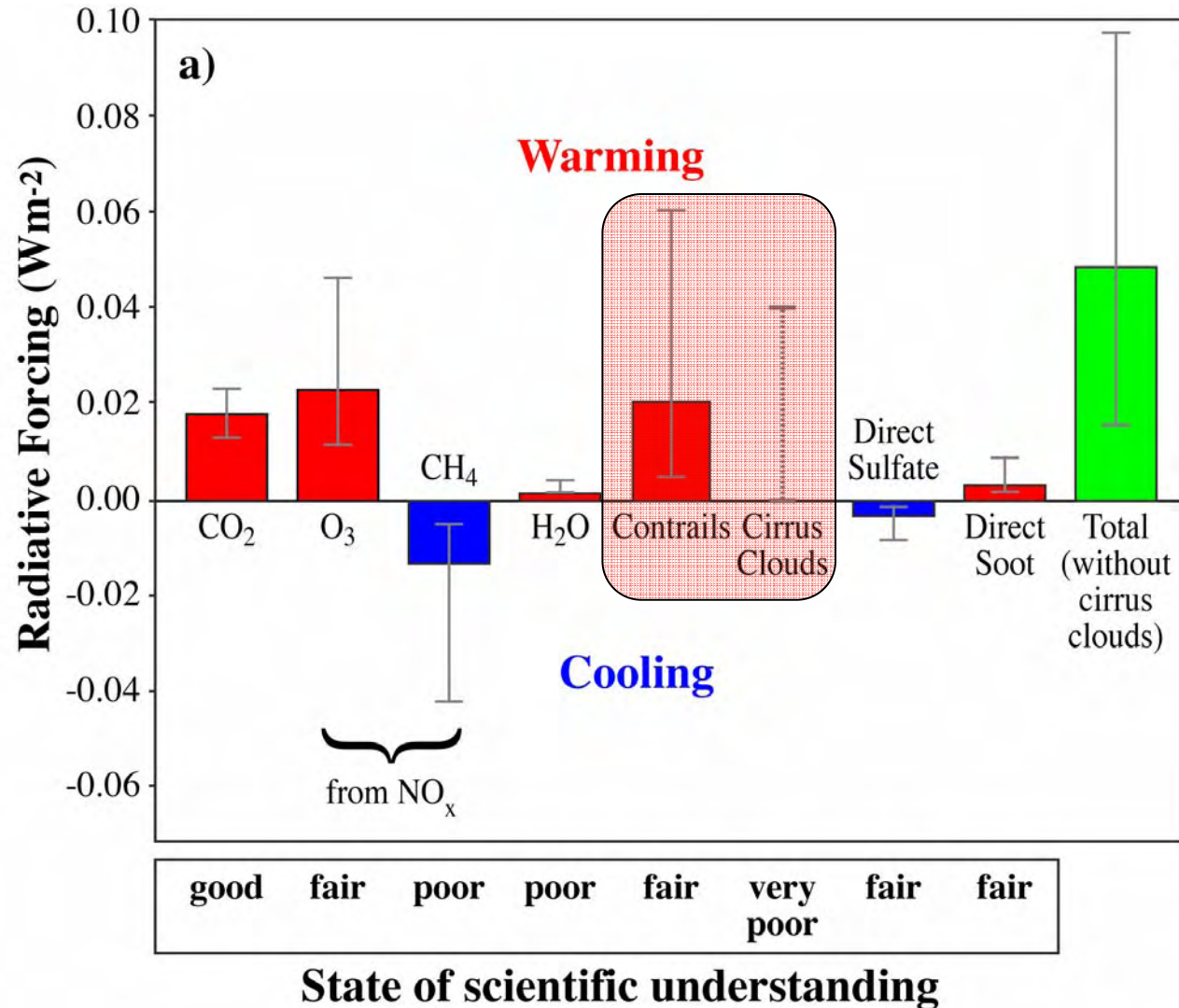
## Contrail (induced) cirrus cloudiness:

- > Evolves/spreads from persistent linear contrails into more extensive cirrus cloud cover

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- > Contrails and contrail cirrus increase **radiative forcing** which leads to **climate warming**



# IPCC (1999): Radiative forcing from aircraft in 1992

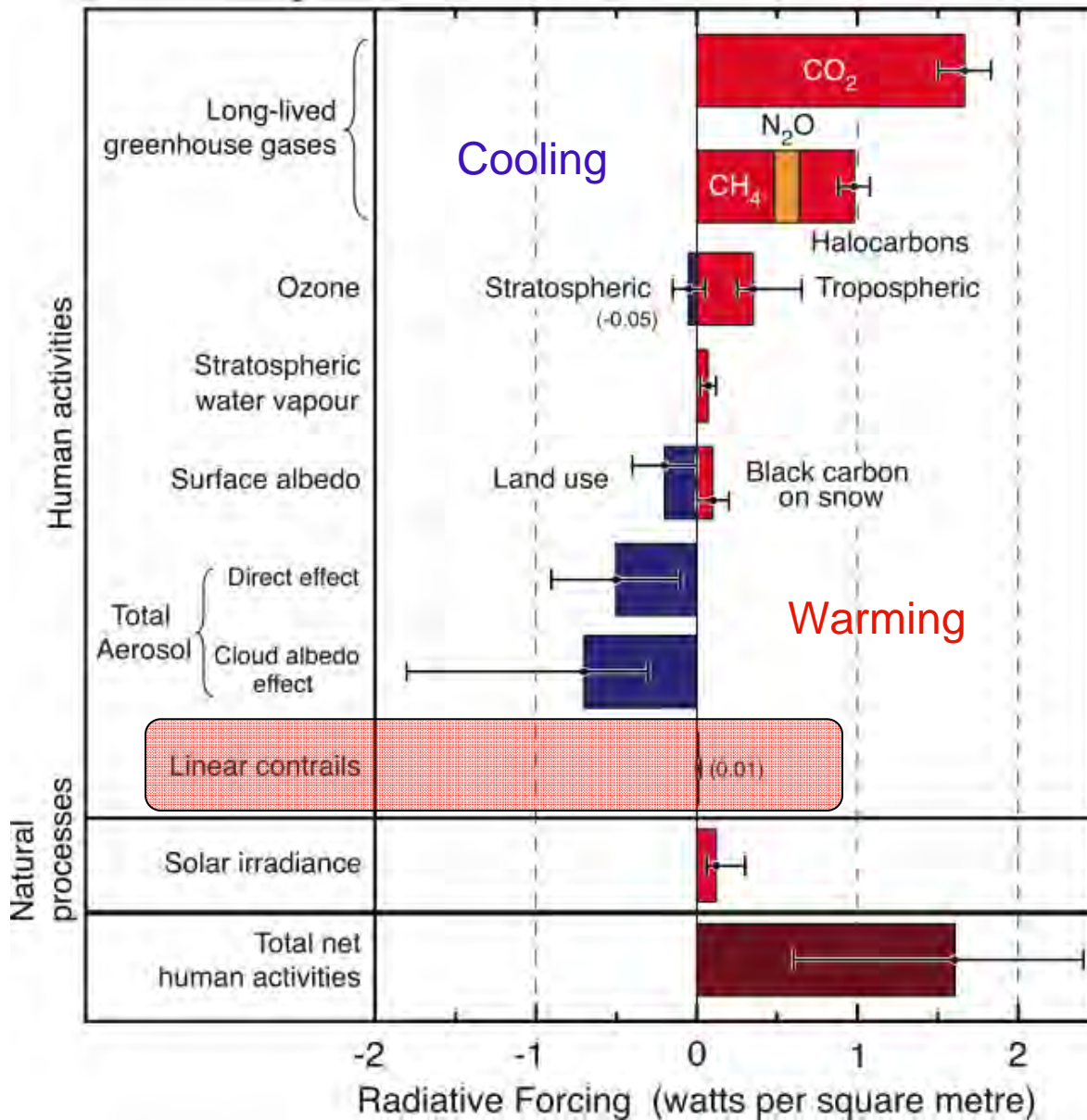


Progress from 1999-2007:

- Improved studies with global models and satellite datasets
- EU TRADEOFF Project evaluation of aviation effects

# Human and natural terms in climate forcing from IPCC 2007

(1750 - 2005)



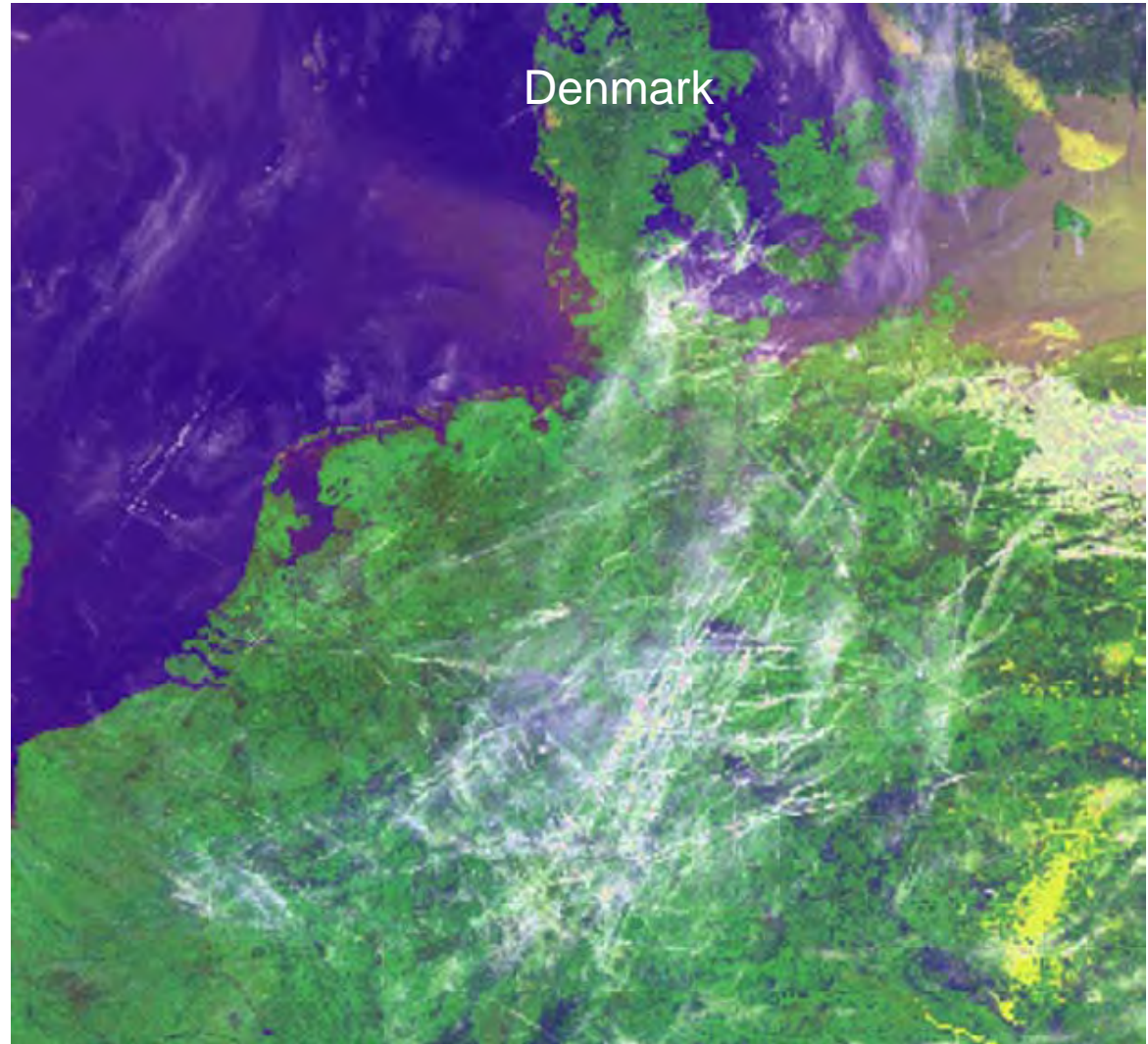
Unique to aviation:  
 - linear contrails  
 - additional cirrus cloudiness

Linear contrails:  
 0.01 W/m<sup>2</sup>

Total human activities:  
 1.6 W/m<sup>2</sup>

## Persistent linear contrails

Contrails represent  
**visible** evidence of  
climate forcing



Contrails over Europe on 4 May 1995 based on  
NOAA-12 AVHRR satellite data.

IPCC Aviation & Global Atmosphere, 1999.

# Persistent linear contrails



Linear contrail **formation** depends on:

- engine and aircraft parameters
- high relative humidity in the exhaust plume and surrounding atmosphere

*Well understood*

Linear contrail **geographic cover** depends on:

- contrail formation conditions
- air traffic and traffic patterns
- relative humidity distribution in the atmosphere

*Less well understood*

Linear contrail **climate impact** (radiative forcing):

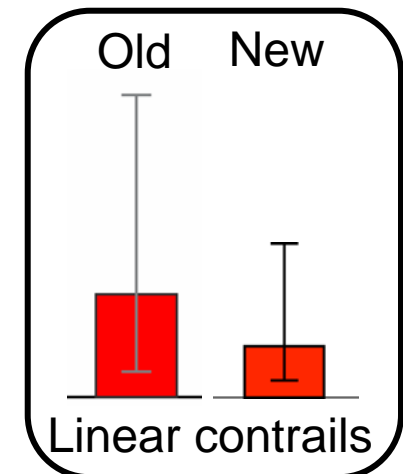
- contrail cover
- contrail optical properties

*Less well understood*

Linear contrail radiative forcing estimates:

- 1992 subsonic fleet 0.02 W/m<sup>2</sup> (0.005 - 0.06) (IPCC, 1999)
- 2005 subsonic fleet **0.01 W/m<sup>2</sup> (0.003 - 0.03 W/m<sup>2</sup>)\*\***

**\*\*** Downward adjustment due to refined estimates of contrail cover and cloud optical properties



# Contrail (induced) cirrus cloudiness



Suburban Washington, DC



Persistent contrails spread to form **additional cirrus** in high relative humidity regions

US Environmental Protection Agency (EPA), Aircraft Contrails Factsheet  
<http://www.epa.gov/otaq/regs/nonroad/aviation/contrails.pdf>



# Contrail (induced) cirrus cloudiness



Induced cirrus **formation and cover** depends on:

- linear contrail formation } *Well understood*
- wind shear conditions
- high relative humidity in the atmosphere } *Less well understood*

Induced cirrus **climate impact** (radiative forcing) depends on:

- additional cirrus cover
- cirrus optical properties } *Less well understood*

***Caveat:** Some fraction of induced cirrus indistinguishable from background cirrus clouds*

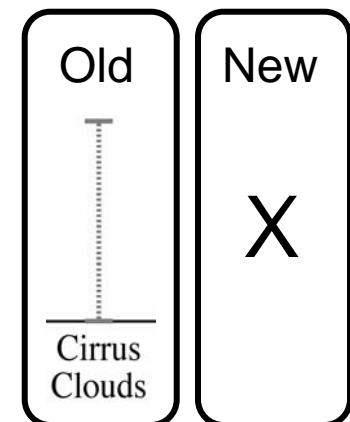
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Old estimate (IPCC, 1999):

- for 1992 subsonic fleet: **0 to 0.04 W/m<sup>2</sup>**
- **no best estimate** of contrail cirrus

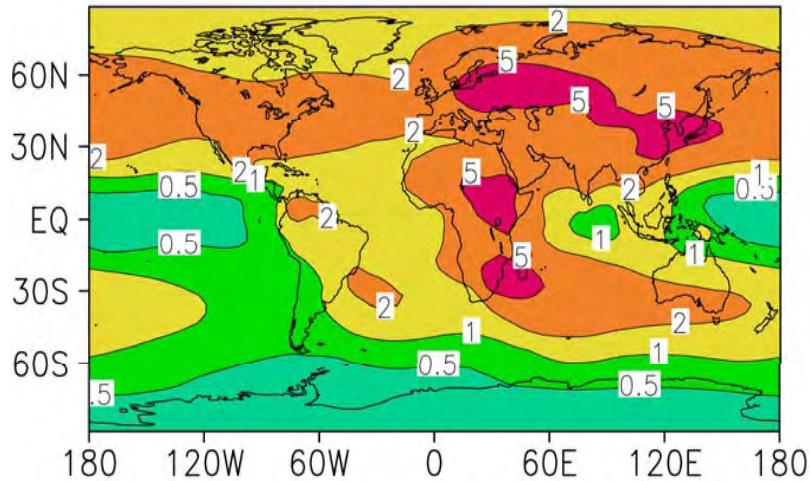
New estimates:

- **no best estimate** of contrail cirrus
- ratio of contrail cirrus to linear contrail cover in 2005: **1.8 - 10**
- total aviation cloudiness in 2005: **0.030 W/m<sup>2</sup>** (0.01 - 0.08 W/m<sup>2</sup>)

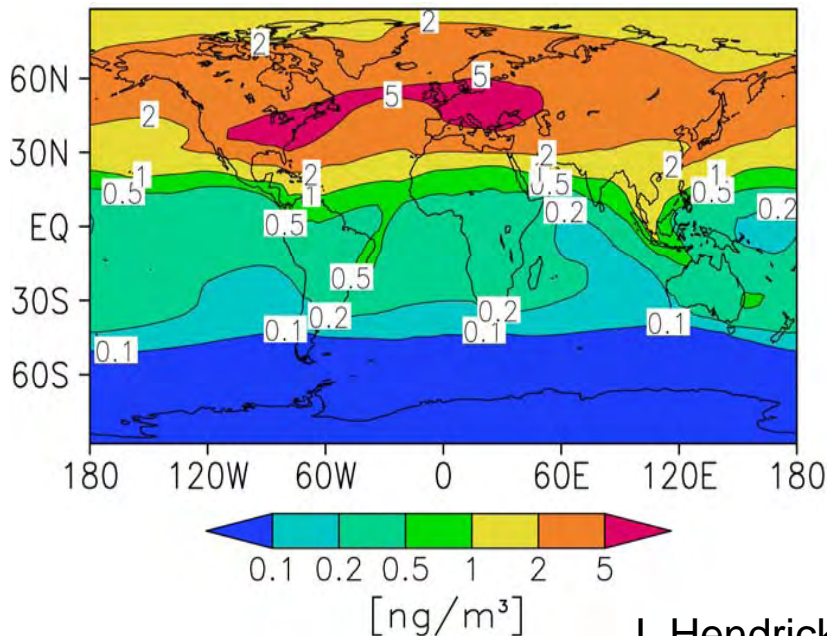


# Aviation sulfate and black carbon (soot) aerosols

## Black carbon mass from all sources



## 100 x Black carbon mass from aviation



> **Accumulation** of aviation aerosol mass calculated with atmospheric models, emission indices, and traffic scenarios

> Aviation source is small in **mass** units in comparison to other natural and human sources: **small** direct climate forcings

> Aviation source of black carbon is large in the increase of the **number** of particles:

- potential cloud effects are important but currently **unknown**

# Conclusions



- > **IPCC** international assessment process has contributed to the evaluation of aviation effects.
- > Increased cirrus cloudiness (contrails and contrail cirrus) is a **fixture** of global aviation operations.
- > Linear contrails add **0.01 W/m<sup>2</sup>** (0.03 - 0.3) to climate forcing from human activities (revised downward from IPCC, 1999).
- > Contrail cirrus is an additional component but currently has **no best estimate**.
- > Aviation aerosol (soot) influence on background cloudiness is potentially important but has **not been quantified**.

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*Thank you for your attention.*

# Persistent linear contrails

