Strong present-day aerosol cooling implies a hot future

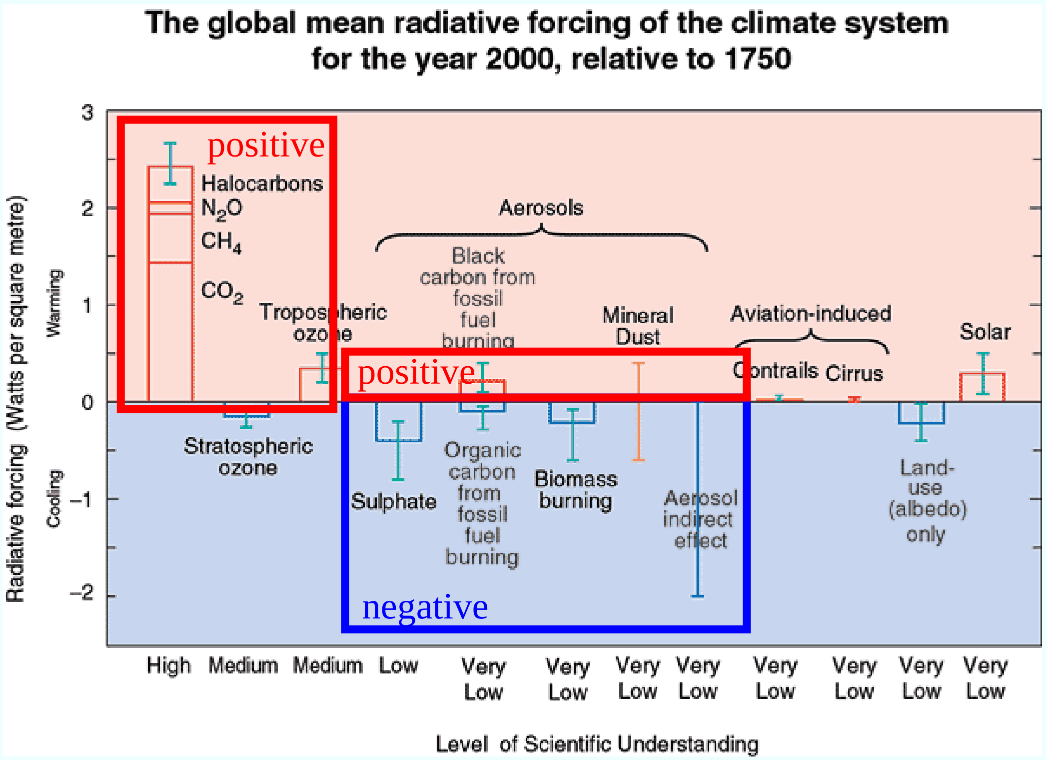
Meinrat Andreae, Chris Jones, Peter Cox

Nature, June 2005

Presentation by Kremena Darmenova

Objectives

Motivation: Many scientific studies (including the IPCC report) concluded that humans are causing significant climate change (global warming), however there is still considerable debate regarding how much and fast the Earth will warm.



Goal: Investigate how the present day aerosol loads affect future climate change by assessing the uncertainty in climate sensitivity due to uncertainties in the aerosol forcing.

Climate sensitivity

- Climate sensitivity is an averaged measure of how the system responds to a specific forcing change and may be used to compare model responses, calibrate simple climate models, and to scale temperature changes in other circumstances.
- The size and impacts of anthropogenically induced climate change strongly depend on the climate sensitivity.
- Climate sensitivity is often expressed as the temperature change at the surface after the Earth's climate system has reached a new equilibrium for doubled CO_2 in the atmosphere.

How to estimate climate sensitivity?

The heat balance equation

Global mean temperature change

Heat capacity 1.1±0.5 $GJm^{-2}K^{-1}$

$$c\frac{d(\Delta T)}{dt} = \Delta Q - \lambda \Delta T$$

Feedback factor

Heat storage term

Climate forcing $[W/m^2]$ (natural + anthropogenic)

After the climate system reaches equilibrium:

$$c\frac{d(\Delta T)}{dt} = 0$$

$$\Delta T_{2\times CO_2} = \Delta Q_{2\times CO_2} / \lambda$$

Large range of uncertainties $[\Delta Q, \lambda]$

Study	Method	$\Delta T_{2\times CO_2}$
IPCC 90, 96, 01	GCM estimate	1.5 to 4.5 K
Murphy et al. 2004	GCM estimate	-2 to 11 K

Climate sensitivity vs aerosol cooling

1) $\Delta T_{2\times CO_2} = \Delta Q_{2\times CO_2} / \lambda$

2) $\lambda = \dfrac{\Delta Q - c\dfrac{d(\Delta T)}{dt}}{\Delta T}$

3) $\Delta Q_{2\times CO_2} = 3.7\,W/m^2$

$\Downarrow$

$$\Delta T_{2\times CO_2} = 3.7\frac{\Delta T}{\Delta Q - c\dfrac{d(\Delta T)}{dt}}$$

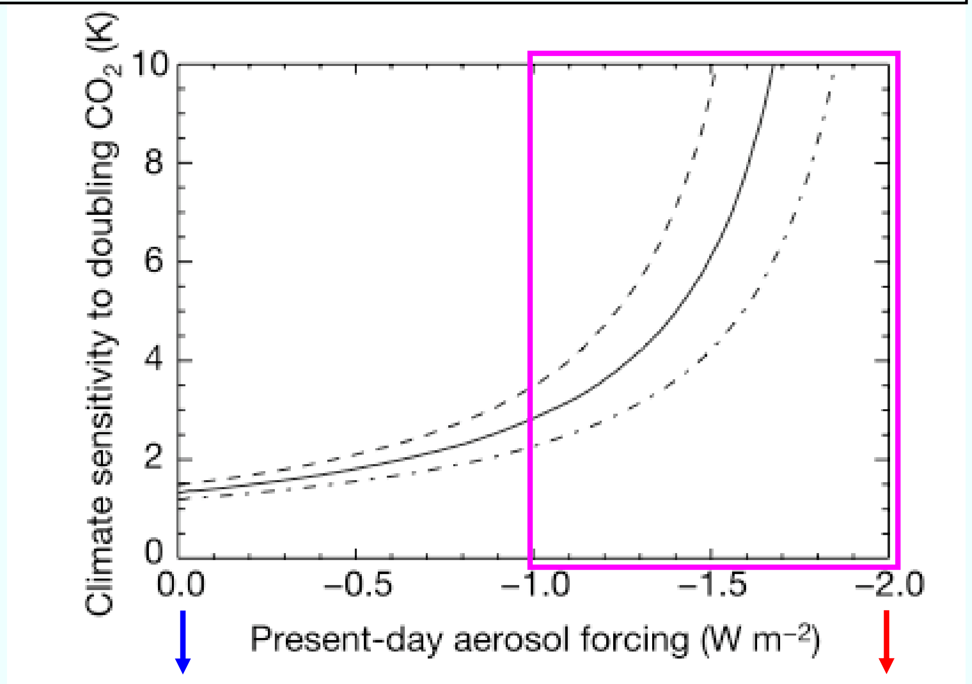
$\Downarrow$

$$\Delta Q_{GHG} + \Delta Q_{AER}$$

1) Observed global warming:
(Folland et al. 2001)
0.4 K from 1940 to 2000

2) $\Delta Q_{GHG} = +2.4 \pm 0.3\,W/m^2$

Climate sensitivity required to explain the observed 1940-2000 warming as a function of the strength of aerosol cooling.



Weak aerosol cooling → Low climate sensitivity

Strong aerosol cooling → High climate sensitivity

Present aerosol forcing and future aerosol scenarios

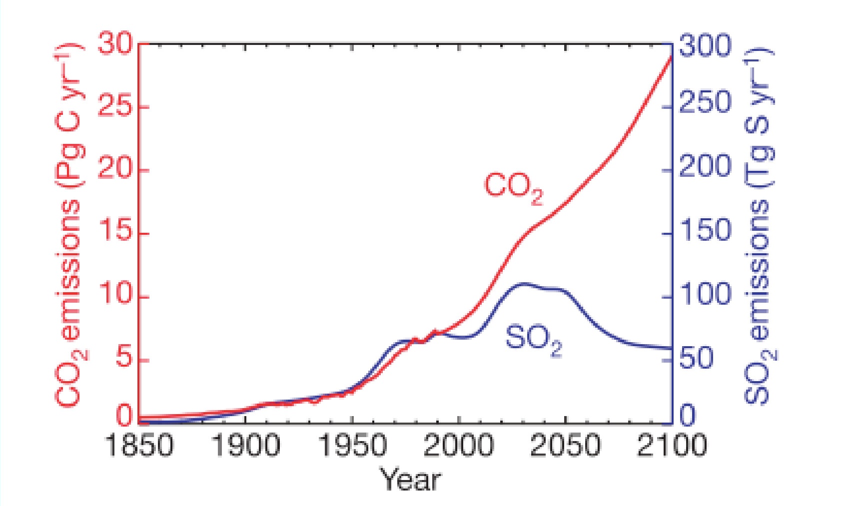
Present

Study	Species	Forcing
Anderson et al. 2003	aerosols	0 to -4.4 Wm^{-2}
IPCC 2001	GHG	+2.4 Wm^{-2}

Range of uncertainty in the total forcing:

+2.4 Wm^{-2} to -2 Wm^{-2}

Future



- Increasing warming from GHG
- Decreasing cooling from aerosols
- Positive feedbacks from the carbon cycle (T↑ causes accelerated release of soil carbon)

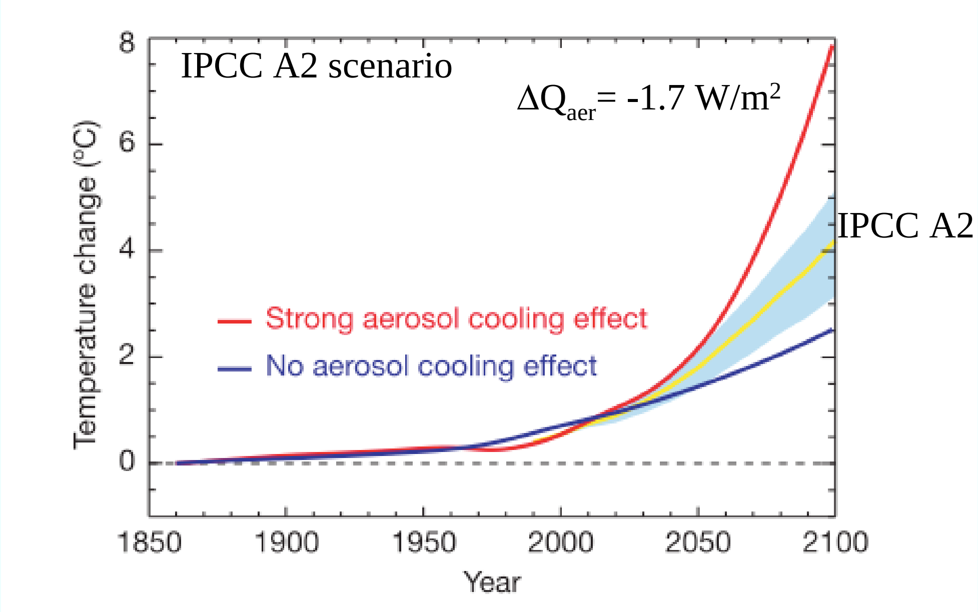
Hot future?

Simulations with a climate-carbon cycle model

- A simple climate-carbon cycle model was used to calculate the temperature change for the period 1850-2100.
- The model updates the global temperature using $\Delta T_{2\times CO_2} = 3.7 \frac{\Delta T}{\Delta Q - c\frac{d(\Delta T)}{dt}}$ and accounts for carbon cycle feedbacks.
- The model was run for several IPCC emission scenarios for a range of aerosol forcings.
- Two observational constraints were applied so the model was able to reproduce:
    - The observed global warming from 1940-2000.
    - CO_2 increase from 1940-2000.

Future projections

Temperature change for the period 1850 to 2100.



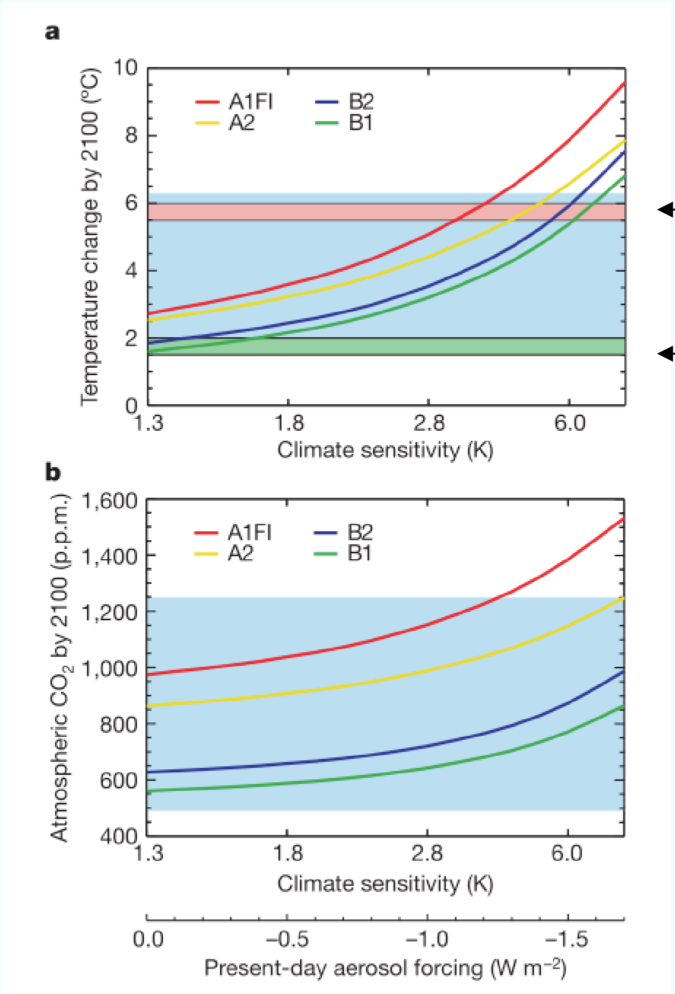
Two extreme cases:

1. Strong present-day aerosol cooling consistent with forward studies of aerosol effects on climate but with a climate sensitivity not constrained by observations
2. No aerosol cooling effect

- A2 scenario represents very heterogeneous world based on self-reliance and preservation of local identities.
- A large uncertainty range of temperature increase is observed depending on the strength of the historical aerosol forcing.
- Strong aerosol cooling effect results in high climate sensitivity. ΔQ_{aer}= -1.7 W/m^2 corresponds to climate sensitivity of 10 K which seems to be extremely high but it was also confirmed by paleoclimate studies.

Future projections

Modeled temperature change and CO_2 increase by 2100 under different development scenarios.



Temperature change between ice ages and interglacials

Threshold of dangerous anthropogenic interferences

- The temperature increases with more than 6º C for the the central estimate of the aerosol forcing (-1.5 W/m^2).
- Such enormous increase would be comparable to the temperature change from the previous ice age to the present.
- Part of the reason for this extraordinary sensitivity of future projections to the historical aerosol forcing is due to the impact of of the carbon cycle feedback on projected CO_2 levels.

Conclusions and future work

- Aerosols cool the Earth and reduce the effect of the greenhouse warming.
- Decreasing emission of aerosols and their short lifetime will result in a decrease of their cooling effect, leaving us vulnerable to greater climate change and greater uncertainty.
- Thus, strong present-day aerosol cooling implies a hot future.

Future research directions:

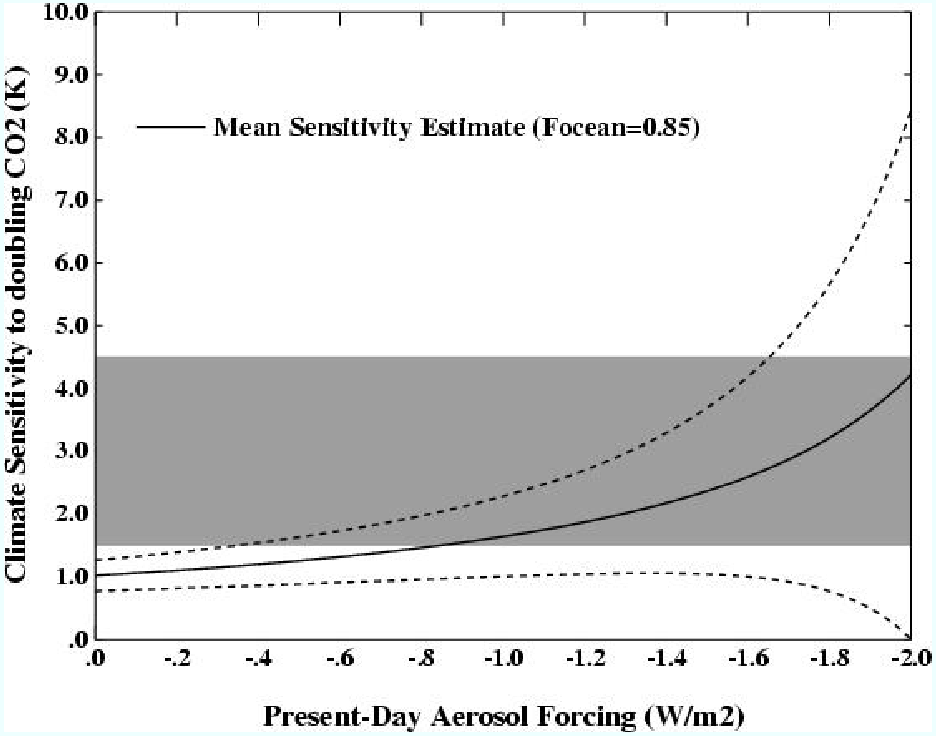
- In-situ studies that investigate the response of cloud microphysics and dynamics to enhanced aerosol concentrations
- The effect of aerosols on cloud properties and abundance must be studied using remote sensing data
- Parameterizations of cloud processes and feedbacks in GCMs must be improved
- Uncertainties in feedbacks that are strongly dependent on climate sensitivity, such as carbon cycle feedback, must be reduced.

Drawbacks

- Other sources of uncertainties in the estimated radiative forcing exist (ozone, land use, etc.). These factors reduce the direct influence that the aerosol forcing alone should have on climate sensitivity.
- This study assumes that the sulfate aerosol forcing will decrease. More coal-fired power plants are built in the US, China, India and elsewhere. Most if not all of these plants will not take advantage of newly developed but expensive clean coal technology to reduce sulfate emissions. Also human population is increasing so the energy demand is not decreasing any time soon.
- There are several indications that the cooling influence of aerosols is overestimated. To see what the real influence is of aerosols, one need to look at their influence on regional temperatures where there is a large decrease or increase of SO_2 (and other aerosol) emissions. In particular look at Europe (a 60 % decline in the period 1980-1998) and Southeast Asia, where there is a strong increase in the last decades.

A comment by Gavin Schmidt, NASA GSFC

Re-calculated climate sensitivity, including the ozone, land-use and solar forcings and their uncertainties along with the aerosol forcing estimates, and using the ocean heat content changes from Hansen et al. 2005.



- The net aerosol forcing is indeed an important determinant of the uncertainty, it is not overwhelming.
- Indeed, a broad range of net present-day aerosol forcings of (-0.5 to over -2.0) could still compatible with the IPCC estimates for climate sensitivity.
- This is a quite different conclusion to that drawn by Andreae et al. paper.

Climate sensitivity is indeed uncertain, but the classic IPCC range is still a good “likely” estimate.