The Science of Short-lived Climate Forcers

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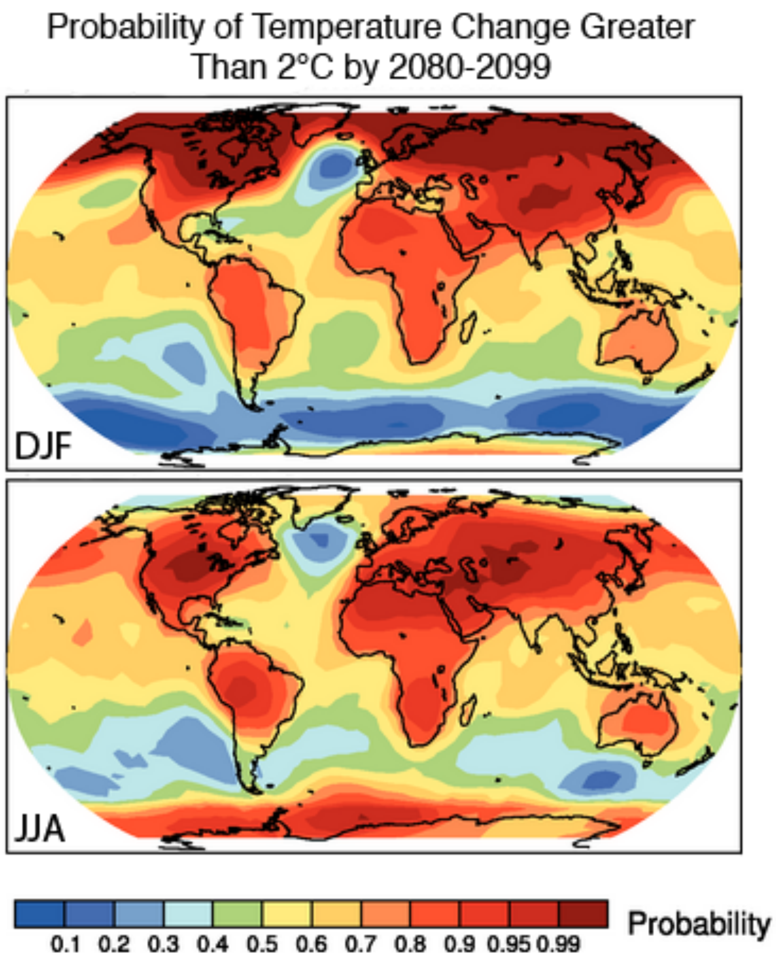
Photo Courtesy of Cameron McNaughton

September 22, 2010

Two Concurrent Problems: Air Quality and Climate Change

Long-term Climate Modification

Health Effects, Visibility Degradation, and Acid Deposition



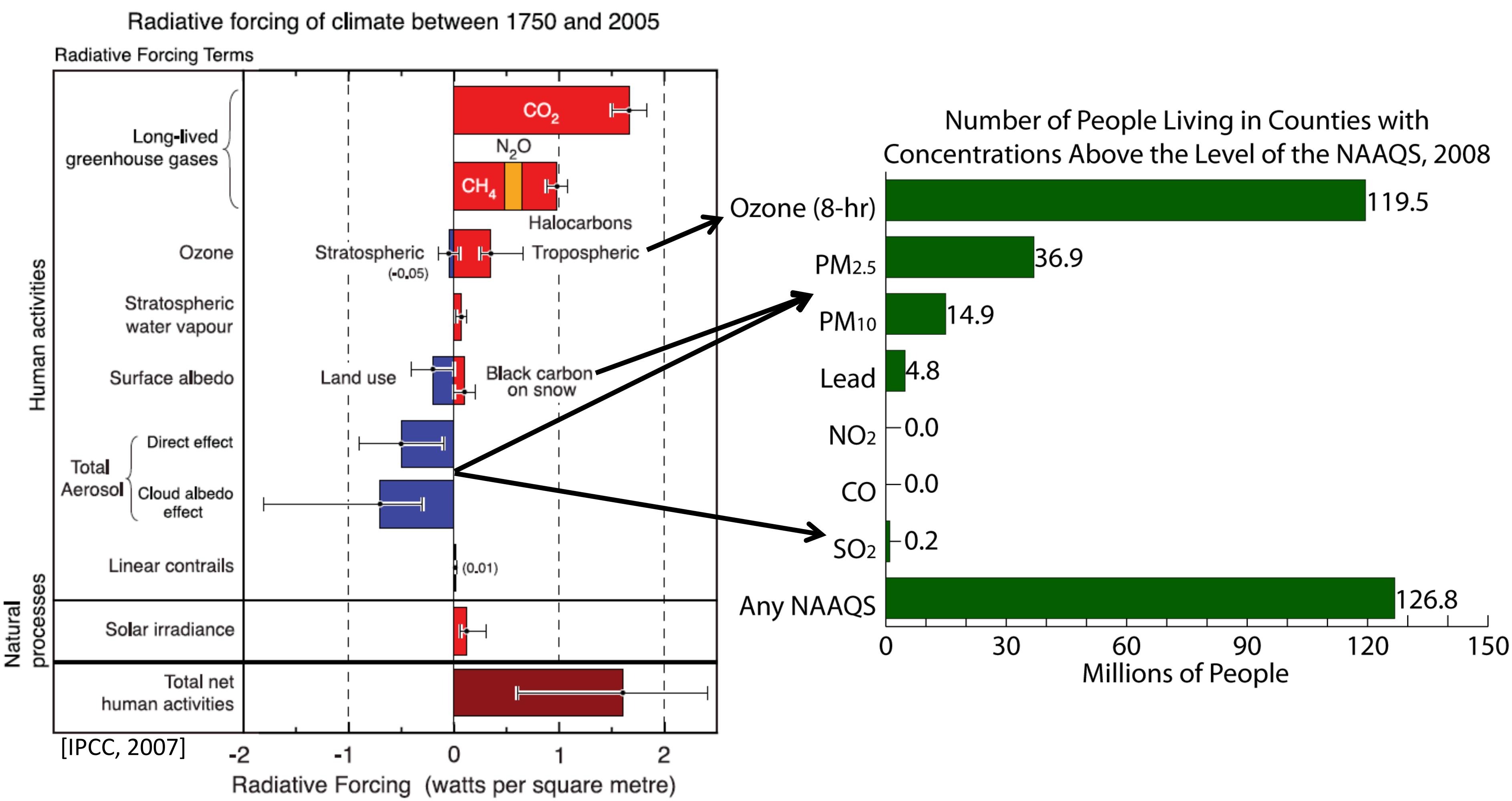
[Meehl et al., 2007]

Boston May 31, 2010

Germany

Grand Canyon

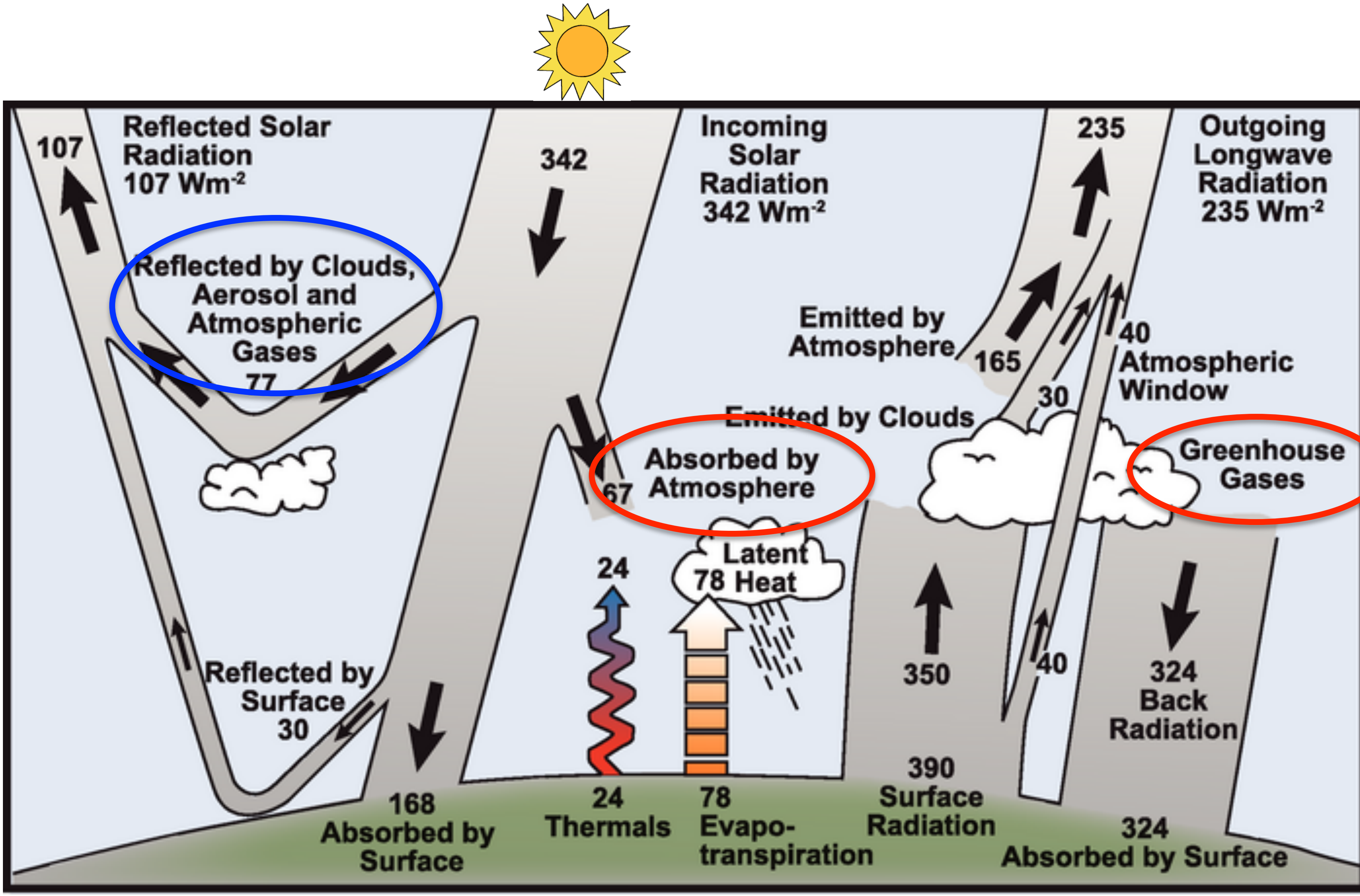
Two *Related* Problems: Air Quality and Climate Change



The problems are related: short-lived air pollutants affect climate

GOAL: Reduce air pollution while simultaneously mitigating climate change

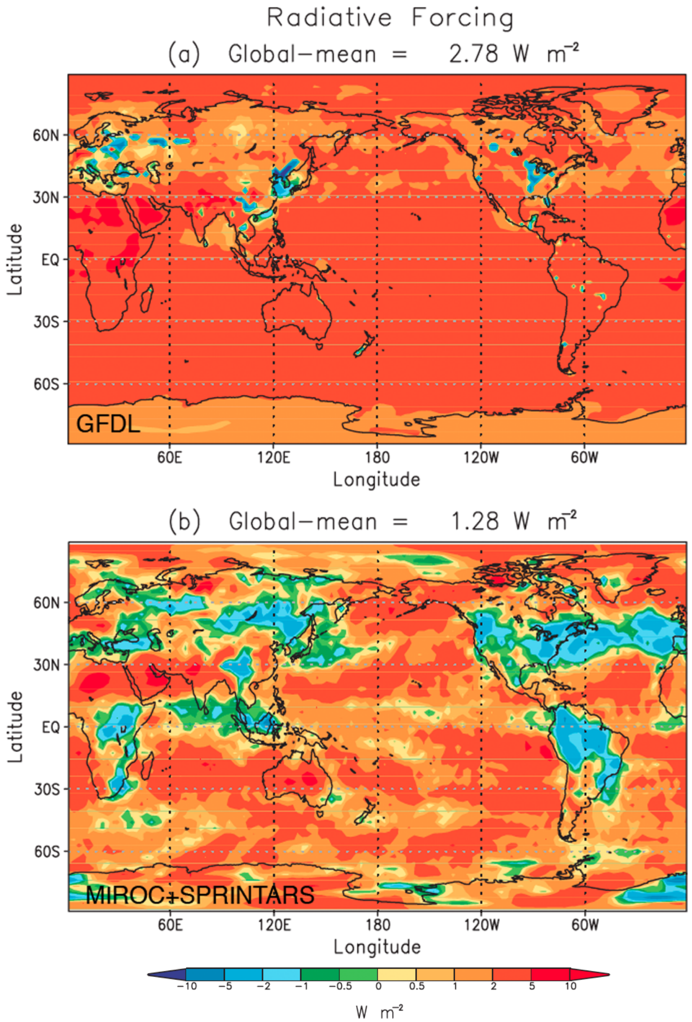
Short-lived Pollutants and Global Energy Balance

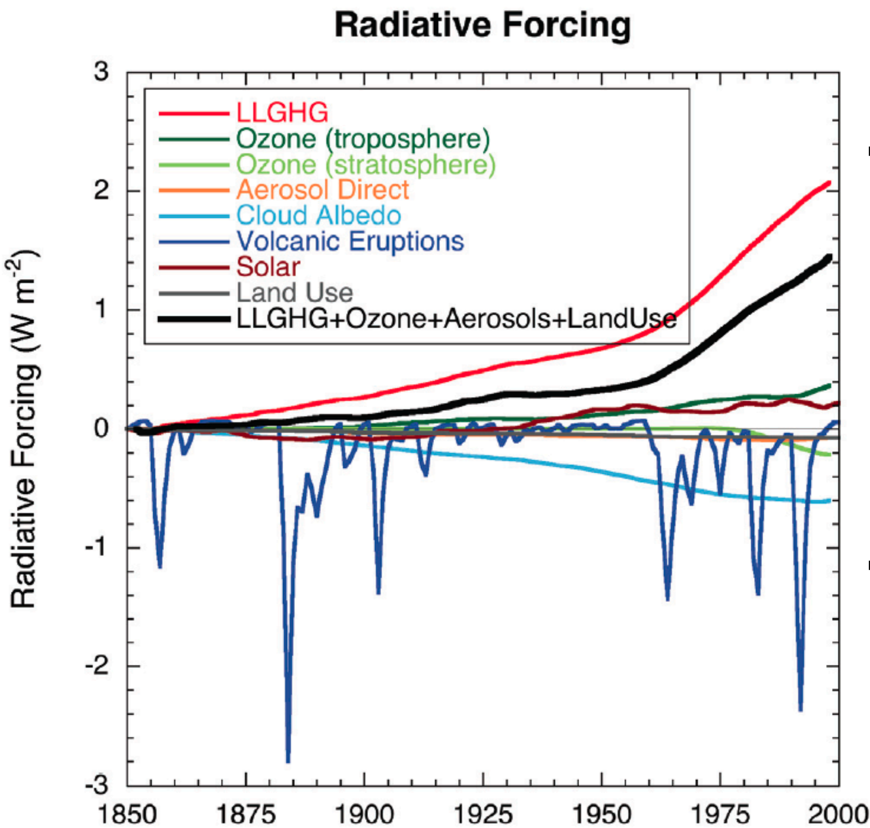


[Le Treut et al., 2007]

Radiative Forcing

"The change in net (down minus up) irradiance (solar plus longwave; in W m^{-2}) at the tropopause…" – IPCC AR4



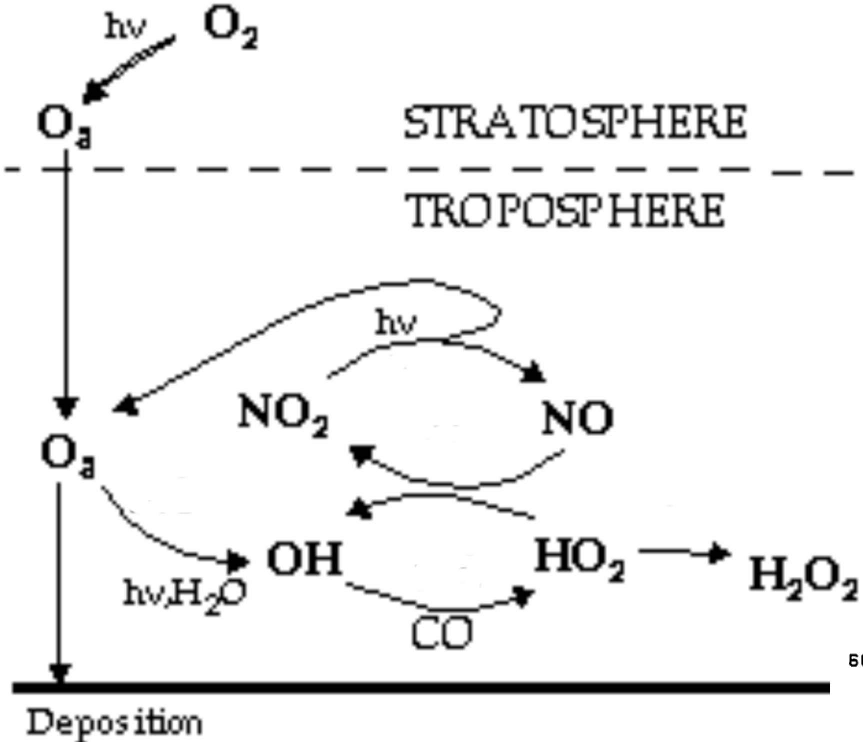


[Forster et al., 2007]

Radiative forcing must be in reference to a different amount of a chemical (either 0 or pre-industrial levels).

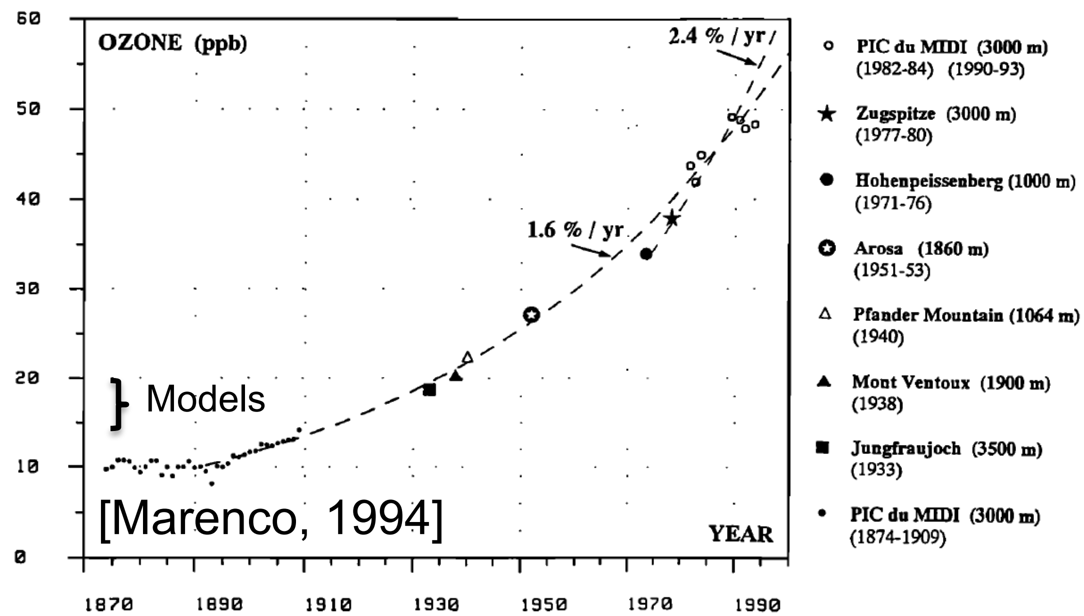
Radiative forcing from long-lived (a.k.a. well-mixed) greenhouse gases (CO_2) is well known. Model mismatches in total forcing arise from different treatments of short-lived species (ozone, aerosols).

Tropospheric Ozone



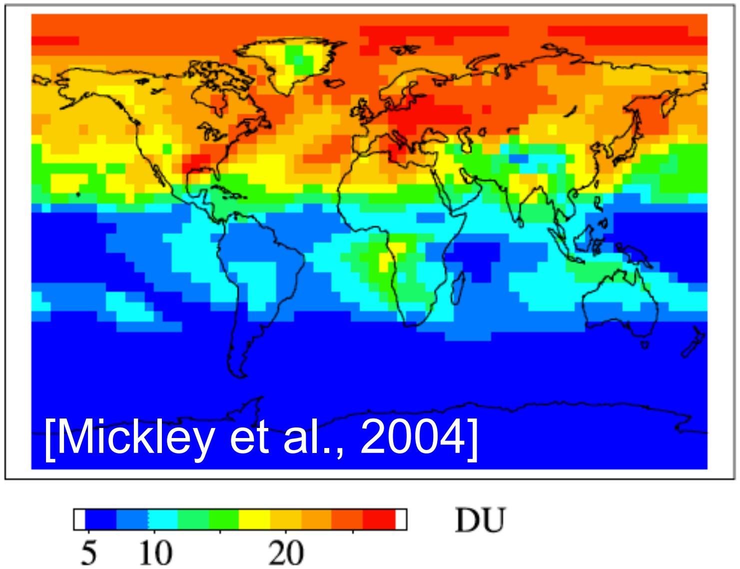
Ozone is formed in the atmosphere through photochemical cycling of NO_x and HO_x. We know the precursors of ozone, NO_x, CO, and methane have all increased significantly since pre-industrial times.

Models have a difficult time reproducing the lower values of ozone. This influences estimates of the anthropogenic enhancement of ozone, but we know ozone has significantly increased in the troposphere.

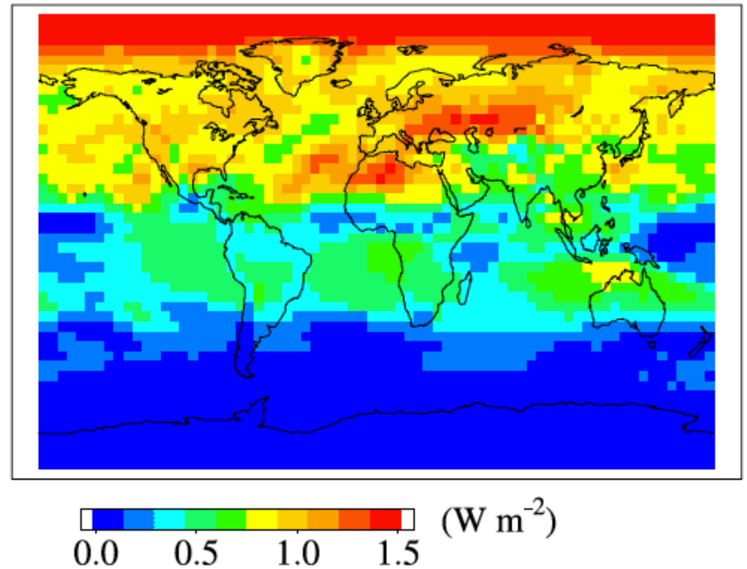


Tropospheric Ozone – Radiative Forcing

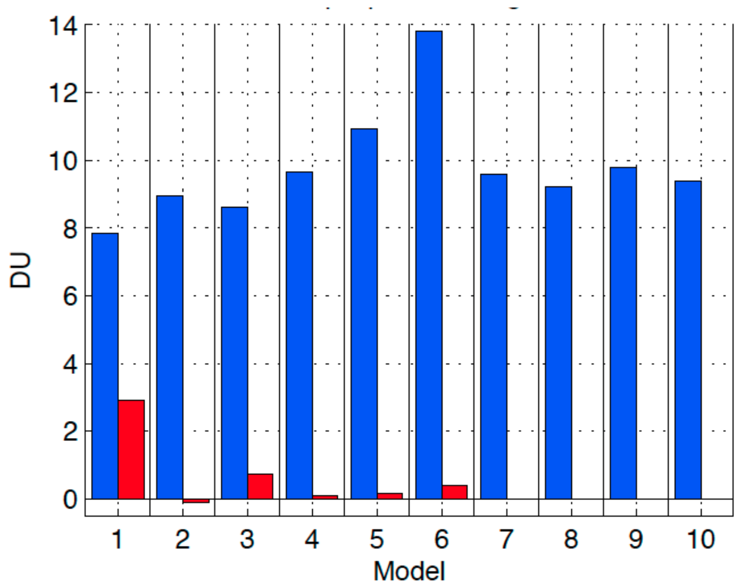
Change in Tropospheric Ozone Since 1850



Change in Ozone Radiative Forcing Since 1850



Change in Tropospheric O_3 Since PI



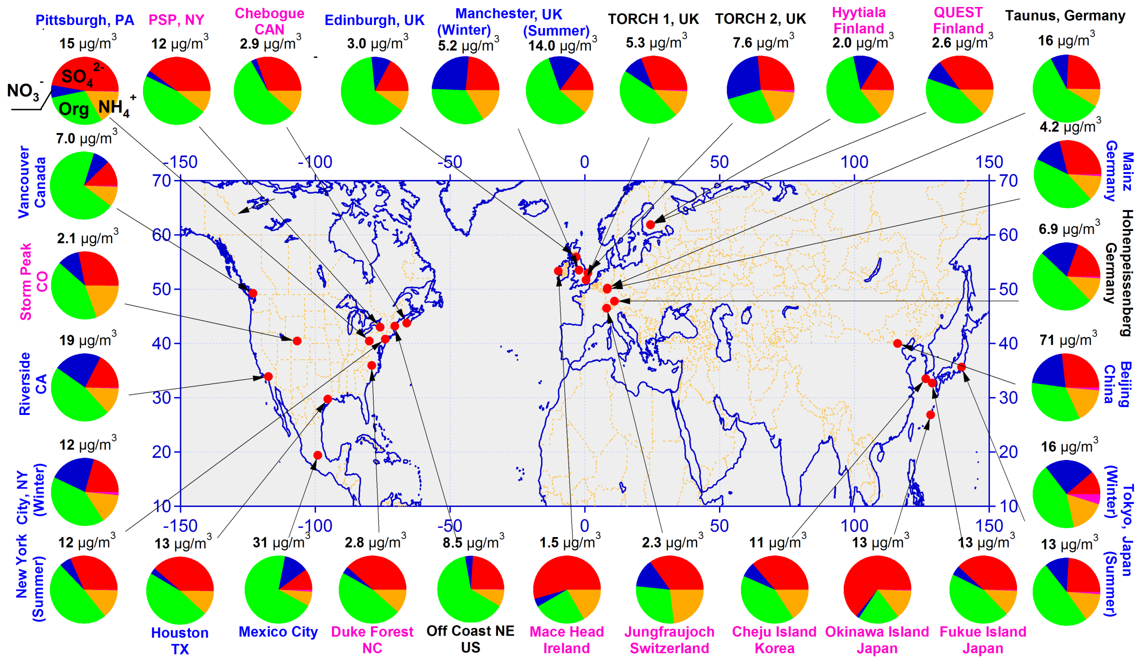
[Gauss et al., 2006]

Ozone is a greenhouse gas and perturbs the longwave radiative balance. Tropospheric ozone is most effective as a greenhouse gas in the upper troposphere, providing a positive radiative forcing

Ozone Radiative Forcing = 0.35 W m^{-2}

Aerosols

Aerosol Composition



Zhang, Jimenez et al., *GRL*, 34, L13801, 2007

Aerosol (particulate matter) concentrations have been significantly enhanced since pre-industrial times. Pre-industrial amounts of sulfate and black carbon were very small, while a large fraction of organic carbon occurs naturally.

The distribution of aerosols is very heterogeneous (differs by location) due to their short lifetime and varied regional sources.

Main Sources:

SO_2 – Power

BC – Transport/Biomass

NH_3 – Agriculture

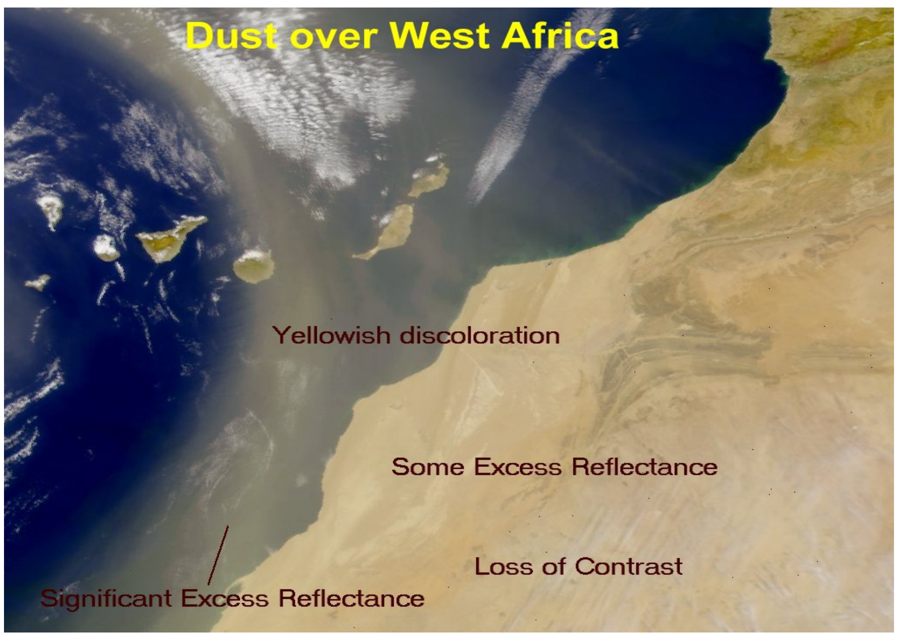
	Emissions	Burden	Lifetime
Sulfate	179 Tg SO_4	1.99 Tg SO_4	4.1 days
Black Carbon(BC)	11 Tg C	0.24 Tg C	7.1 days
Organic Carbon	97 Tg C	1.70 Tg C	6.5 days

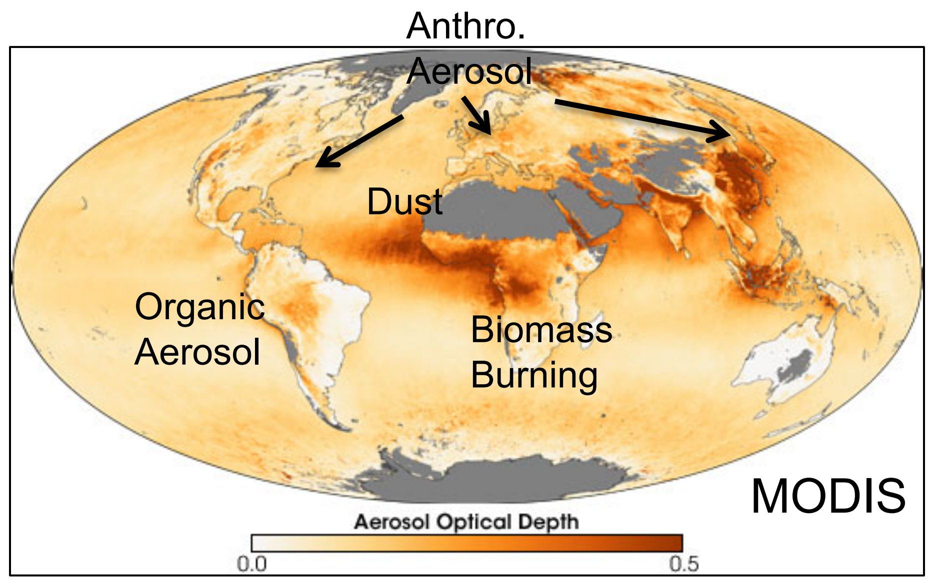
Aerosol Direct Effect

The aerosol direct effect accounts for *scattering* and *absorption* of solar radiation. This is the same process that reduces surface visibility.

Scattering + Absorption = Extinction

A measure of the total extinction is the aerosol optical depth (AOD, a.k.a. aerosol optical thickness, AOT).

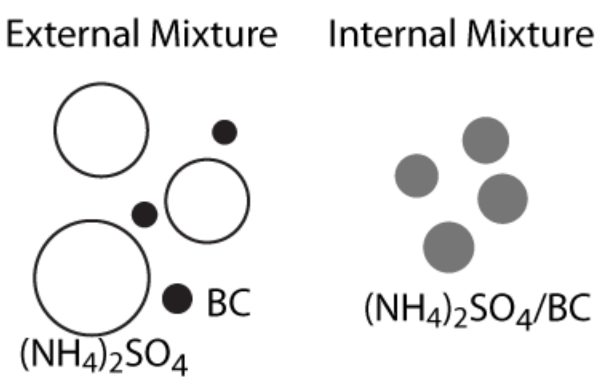


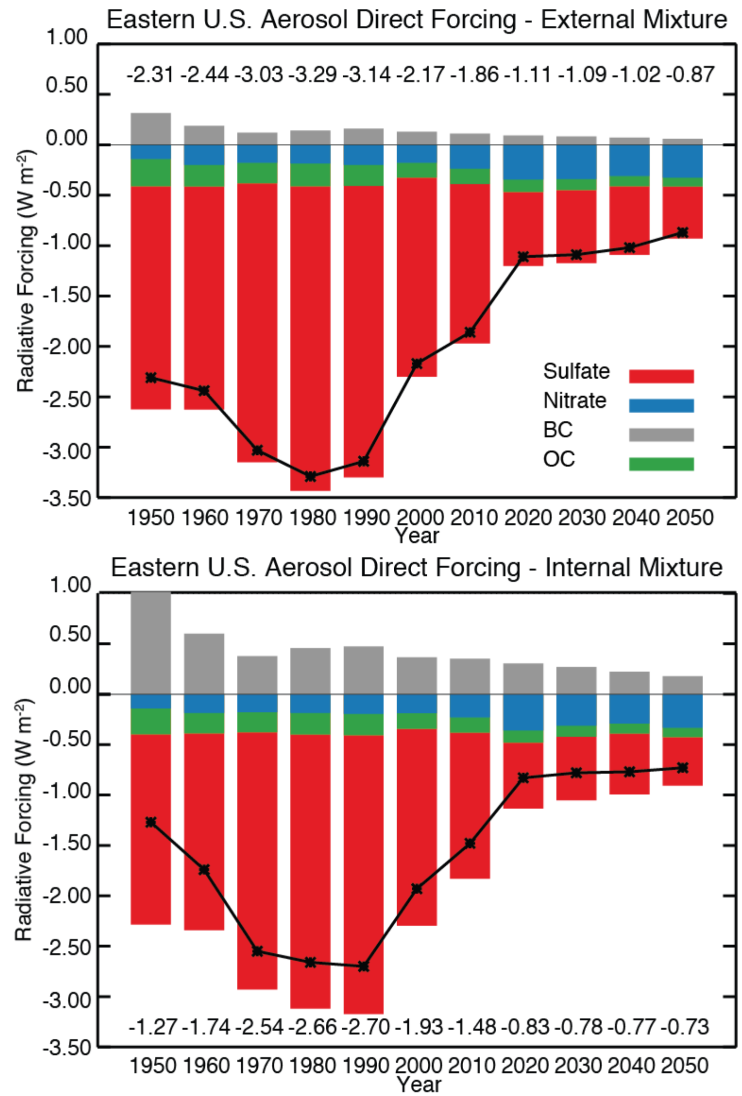


Aerosol Direct Effect – Effect of Black Carbon Coating

The traditional way to calculate radiative forcing is to assume each aerosol particle is one chemical (sulfate, OC, BC all in separate particles). Aerosols of this type are called an external mixture.

In reality, aerosol particles are composed of many different chemicals. When black carbon is mixed within an aerosol particle, it's absorption is greatly enhanced since it has a larger cross-sectional area. Aerosols of this type are called an internal mixture.





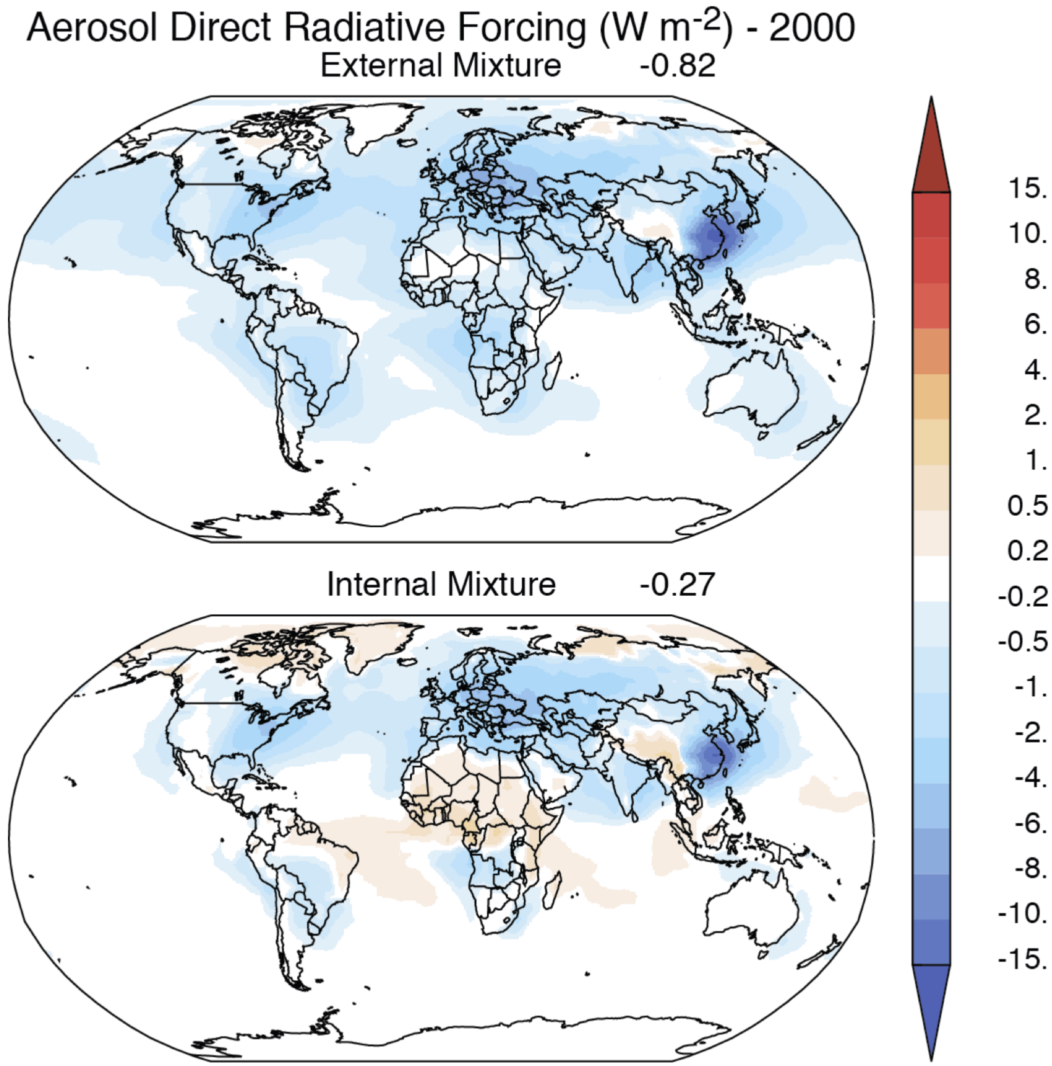
[Leibensperger et al., in prep.]

Black Carbon = Primarily Absorbing (warming)
Sulfate/Nitrate/OC = Primarily Scattering (cooling)

Aerosol Direct Effect – Global Mean Radiative Forcing

The net radiative forcing of aerosols is negative. IPCC AR4 assigns a median global radiative forcing of -0.5 ± 0.4 W m^{-2}. The large error arises from biases between model and observational estimates. The latest estimates (since AR4) bring satellites and models to about -0.3 W m^{-2}.

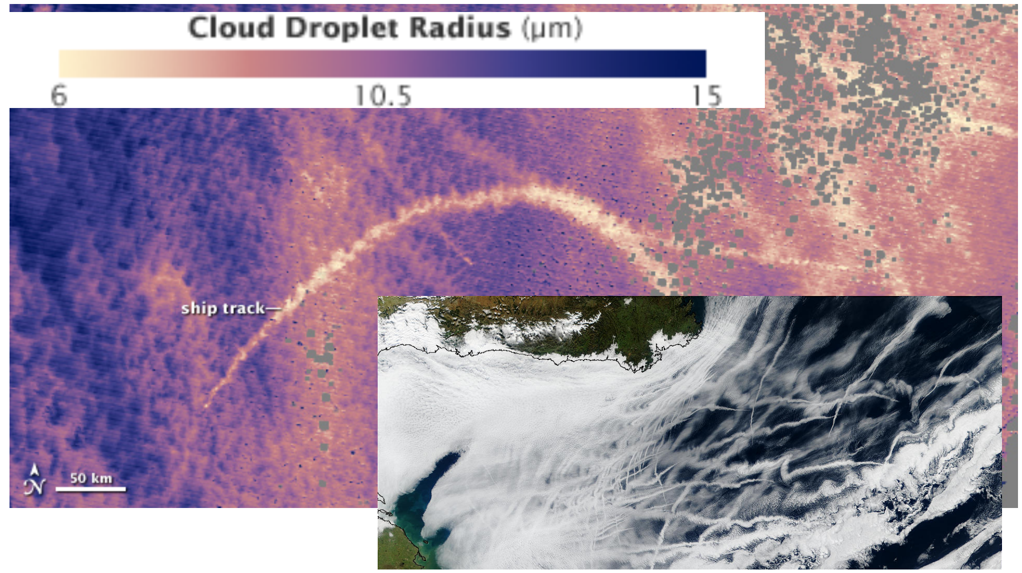
Aerosol direct radiative forcing is concentrated over source regions and can have magnitudes greater than -10 W m^{-2}. As a result, aerosols affect regional climate in addition to global climate.

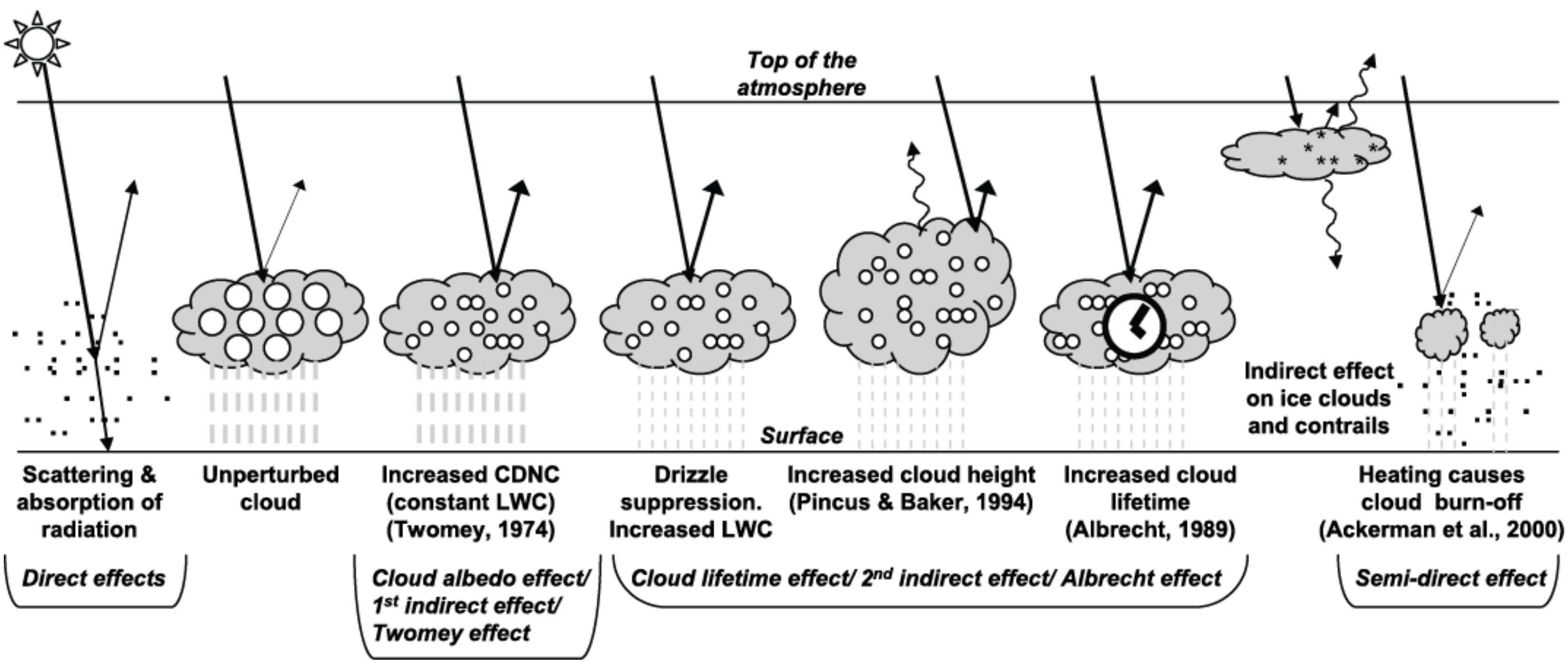


[Leibensperger et al., in prep.]

Aerosol Indirect Effects (Cloud Albedo and Lifetime Effects)

Aerosols can act as cloud condensation nuclei (CCN) or cloud seeds. For a given amount of liquid water, more cloud droplets means the droplets must be smaller. These smaller droplets cause clouds to become brighter (1st indirect effect). Smaller cloud droplets slow precipitation and increase the lifetime of clouds (2nd indirect effect).

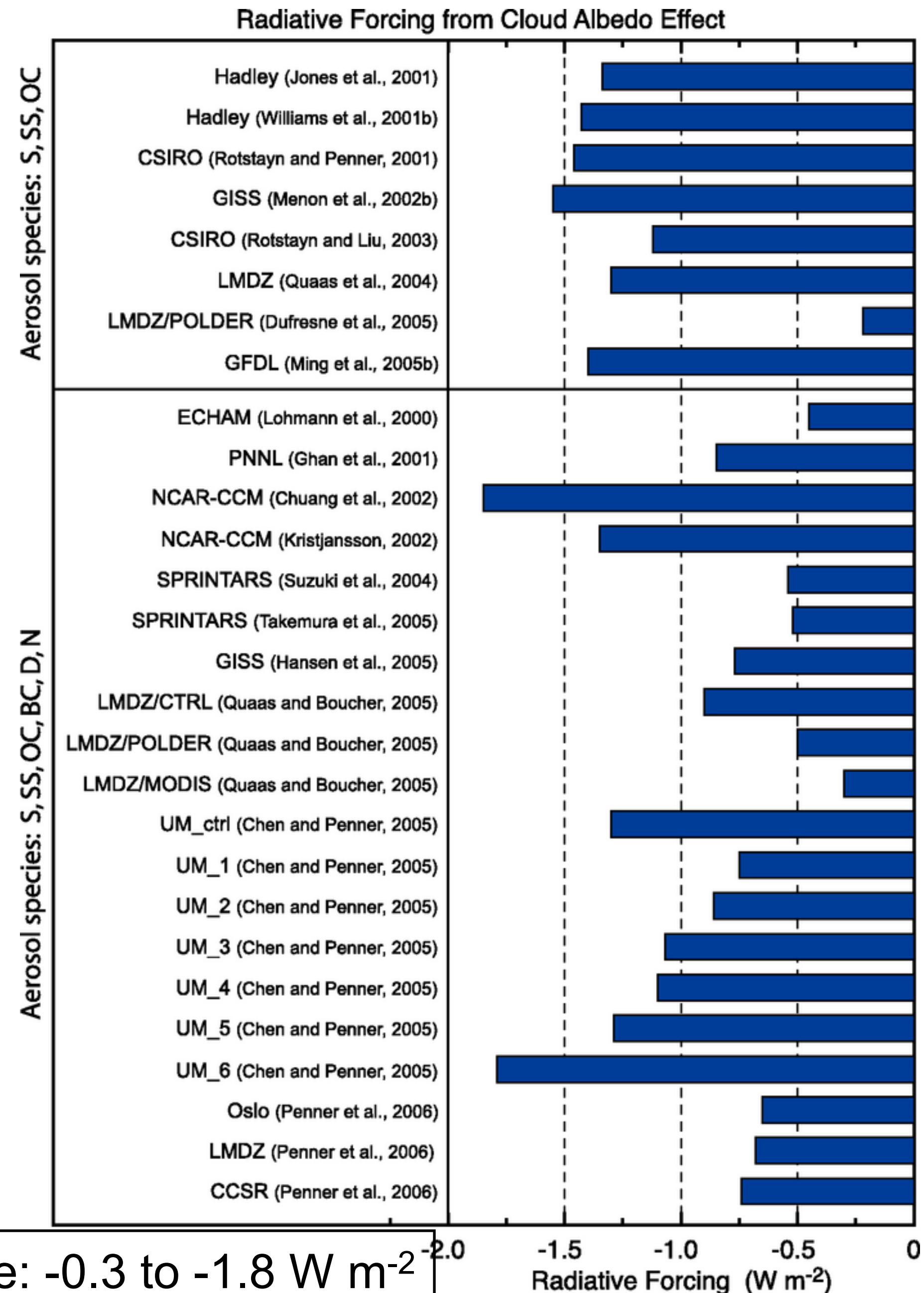




Aerosol Indirect Effects – Global Mean Radiative Forcing

The aerosol indirect effects are the most uncertain anthropogenic radiative forcing. Multi-model median for the cloud albedo effect is -0.7 W m^{-2}, but has a wide range of uncertainty. The radiative forcing from the cloud albedo effect is very likely negative.

IPCC AR4 did not officially assign a value for the cloud lifetime effect, but it is generally thought to be roughly the same magnitude as the cloud albedo effect and very likely negative.

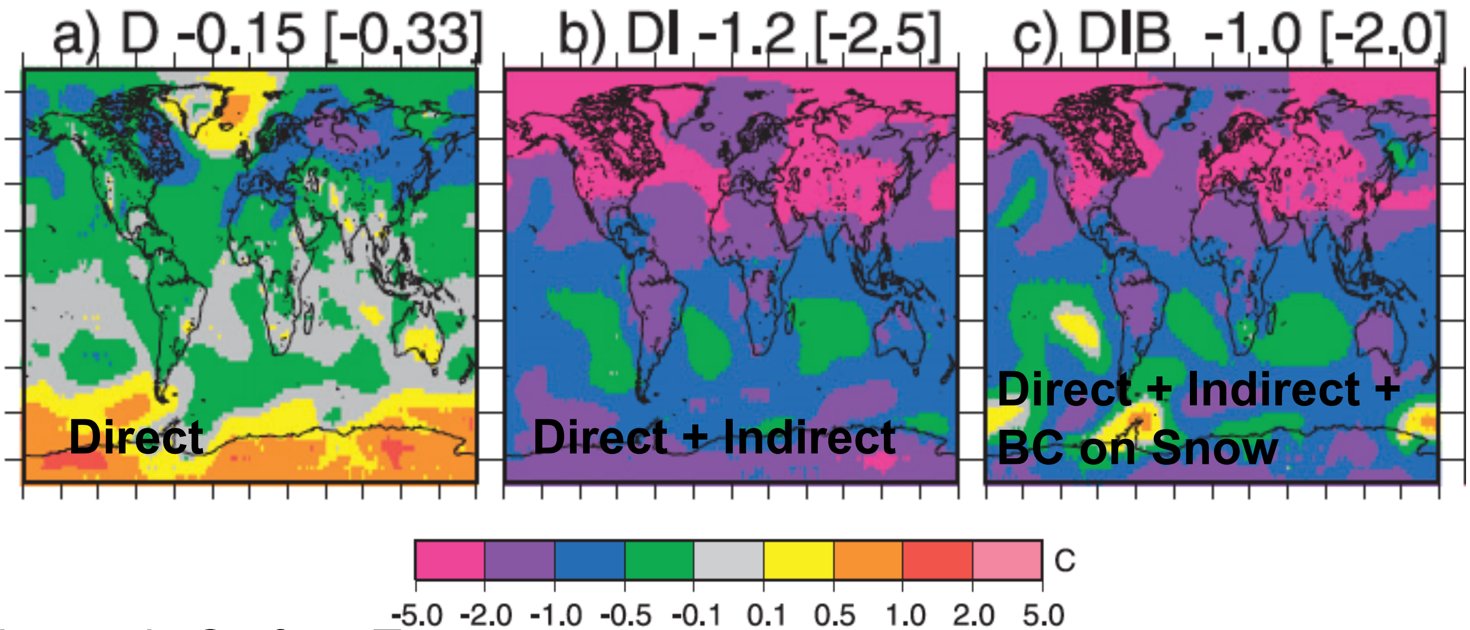


[Forster et al., 2007]

Estimate: -0.3 to -1.8 W m^{-2}

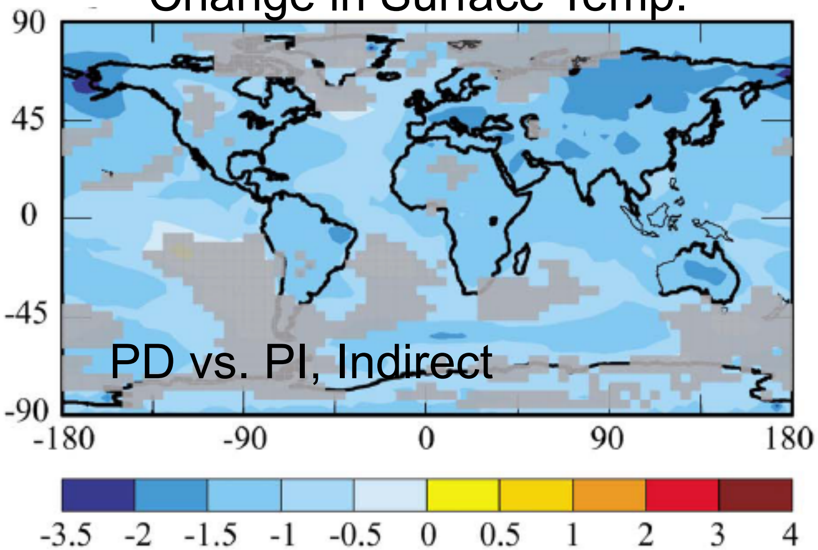
Climate Response to Aerosol Forcing

PD vs. PI



[Koch et al., 2009]

Change in Surface Temp.

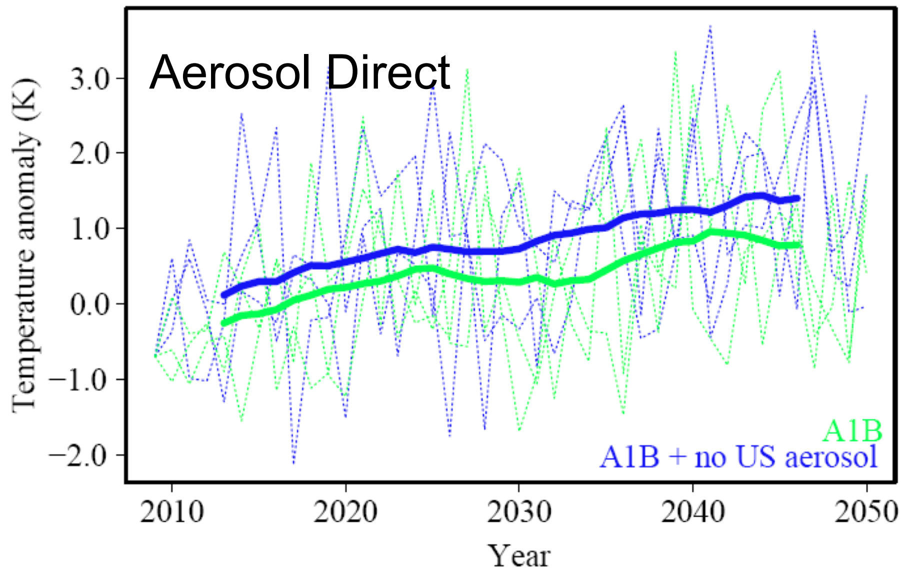


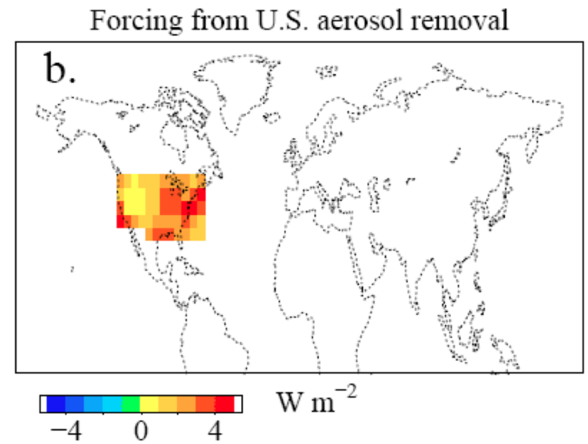
[Chen et al., 2010]

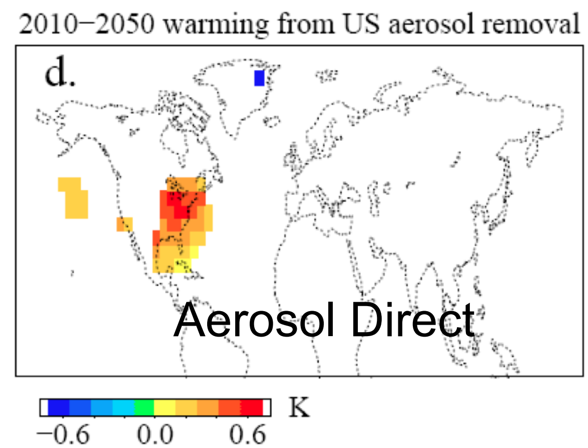
Aerosols:

- Cool the surface through reduced solar radiation ("global dimming")
- Warm the atmosphere (BC)
- Slow down the hydrological cycle by reducing evaporation (ADE+AIE) and delaying precipitation (AIE)
- Decrease cloudiness (BC)
- Increase cloudiness (AIE)

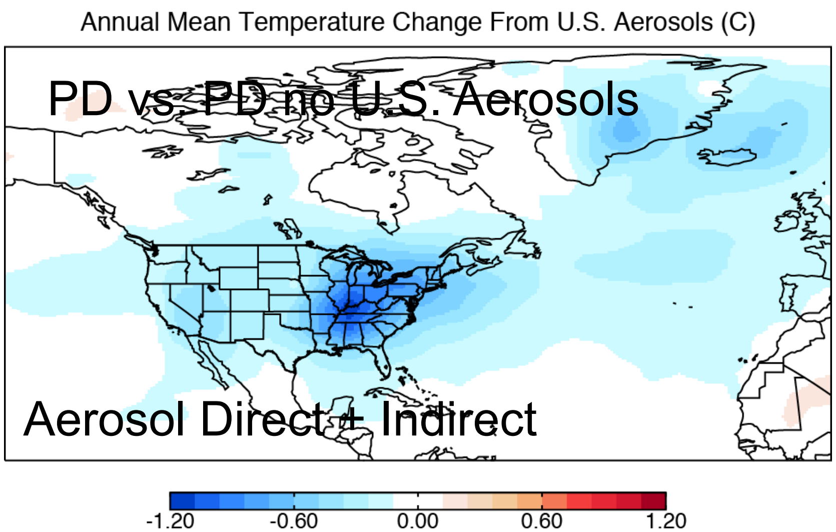
Climate Response to Regional Aerosol Forcing







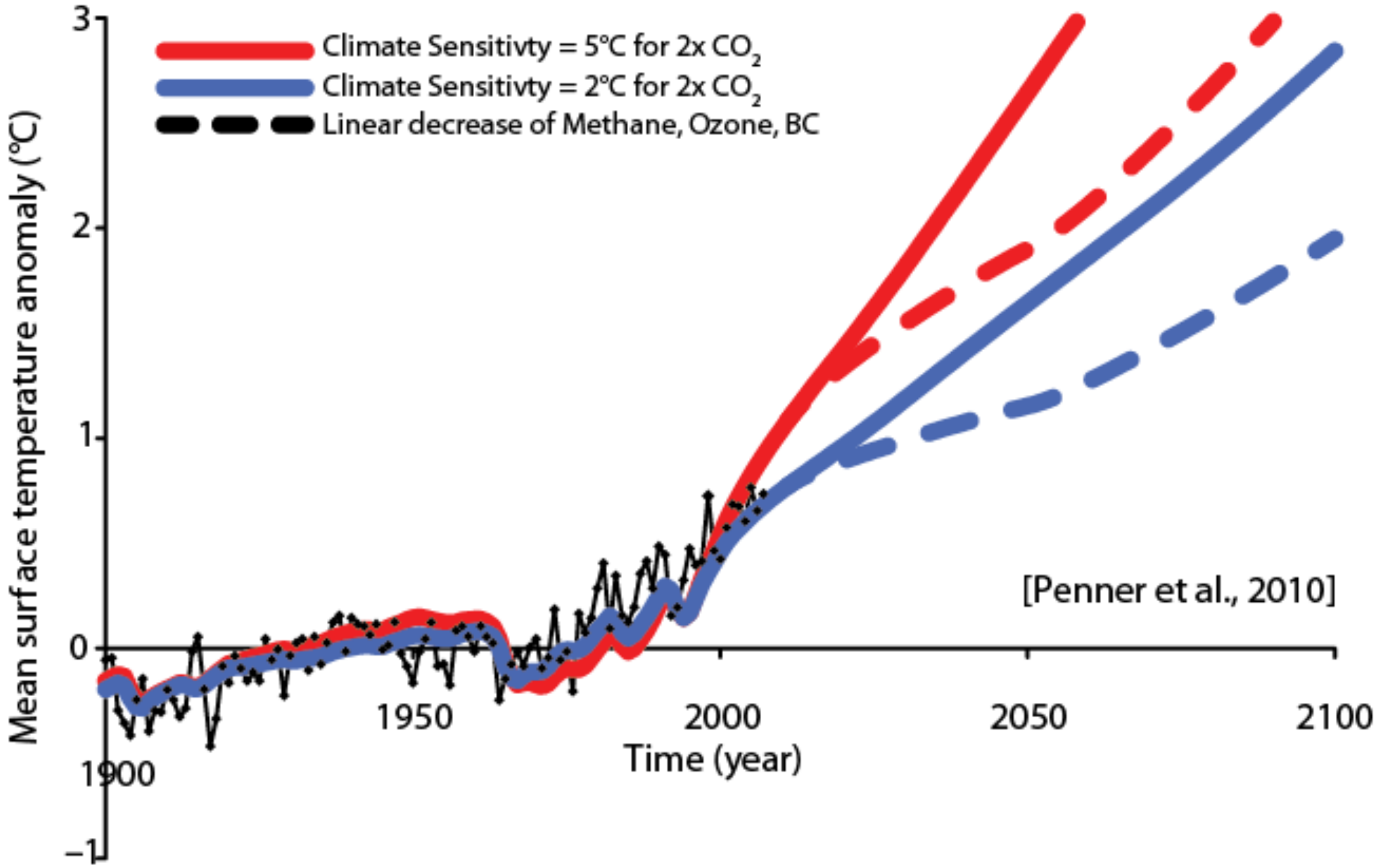
[Mickley et al., submitted]



[Leibensperger et al., in prep.]

Aerosols and their radiative forcing are not evenly distributed. Is the climate response regional or global?

Climate Response: Short-Lived Species Can Make a Difference!

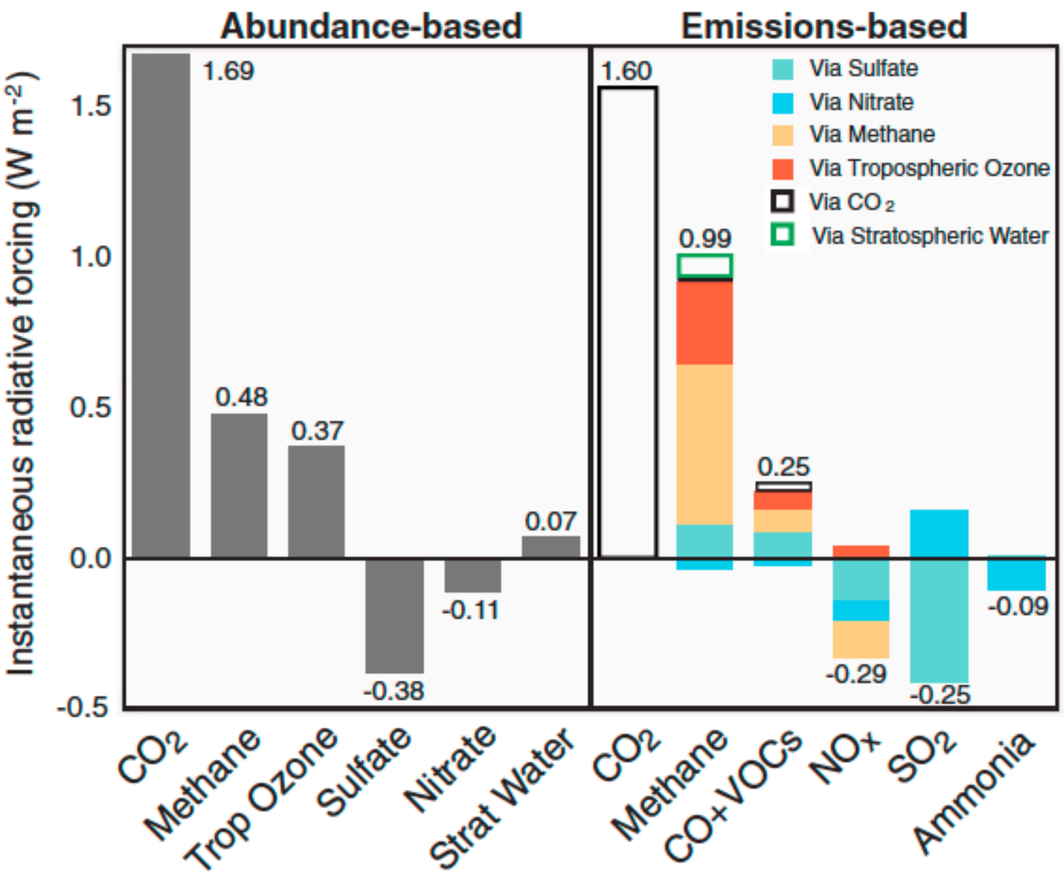


A linear reduction of methane, ozone and BC starting in 2010 leads to more than 0.5°C cooling by 2050 (dashed vs. solid lines).

Reductions of SLCFs with a positive radiative forcing “delays” full realization of CO_2 warming.

Attribution of Radiative Forcing

"Obvious" SLCF targets due to their positive RF and effects on AQ: ozone and black carbon ……. BUT:



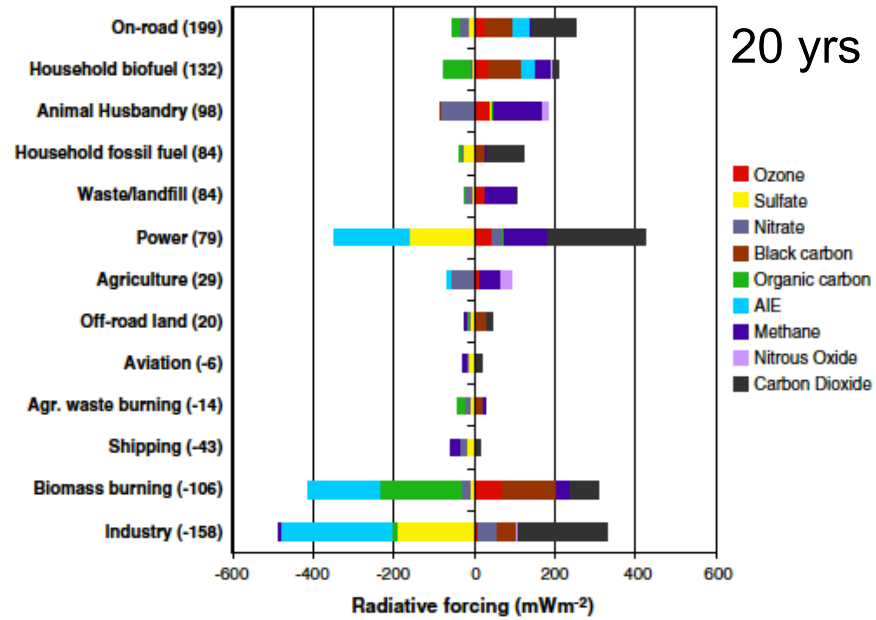
[Shindell et al., 2009]

Aerosol and gas-phase chemistry are connected. Changes in the emissions of NO_x to improve ozone air quality affects not only ozone, but also methane and sulfate/ nitrate aerosols. These changes occur through perturbations to oxidant chemistry (concentration of OH radical).

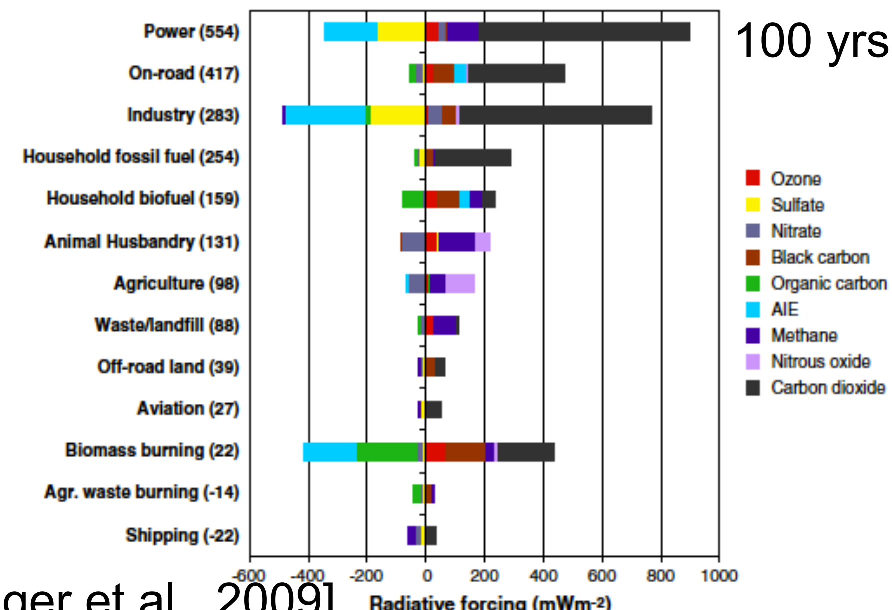
Reductions of NO_x will reduce aerosol forcing and increase methane forcing. It is thus important to fully consider all possible outcomes from a given emission reduction!

Moving Past the Species Point of View

Many researchers have focused on the radiative forcing (direct and indirect) from different chemical species (sulfate, ozone, BC). More recently, research has shifted to sector based accounting, which is potentially more policy relevant.



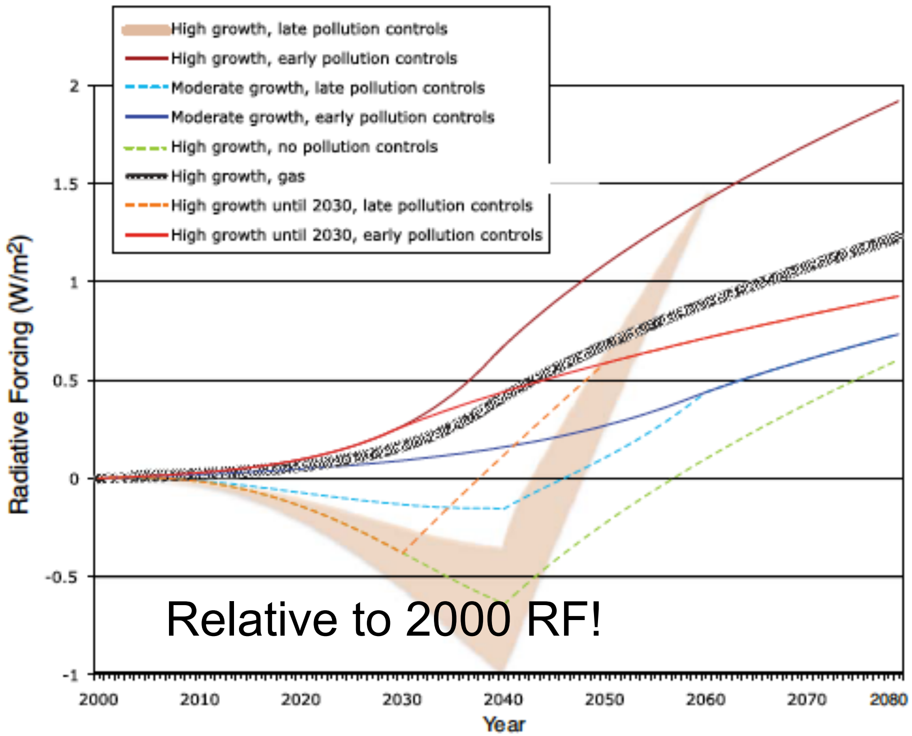
Activities have a different net radiative forcing depending on the time horizon under examination. The radiative forcing of SLCF is at full value almost instantaneously, while CO_2 forcing is initially small, but grows over the long lifetime of CO_2.

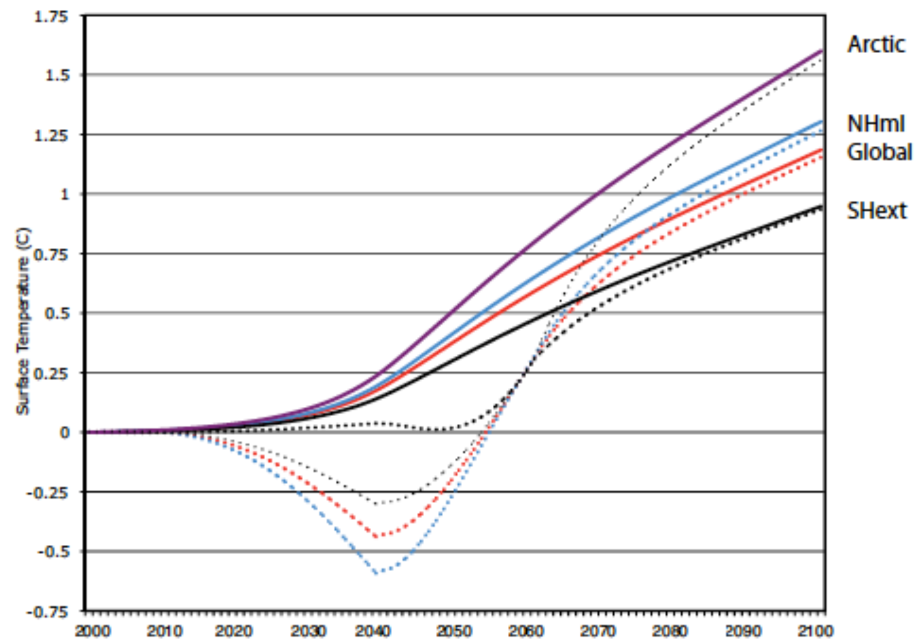


[Unger et al., 2009]

Example: The Net Radiative Forcing from a Power Plant

[Shindell et al., 2010]



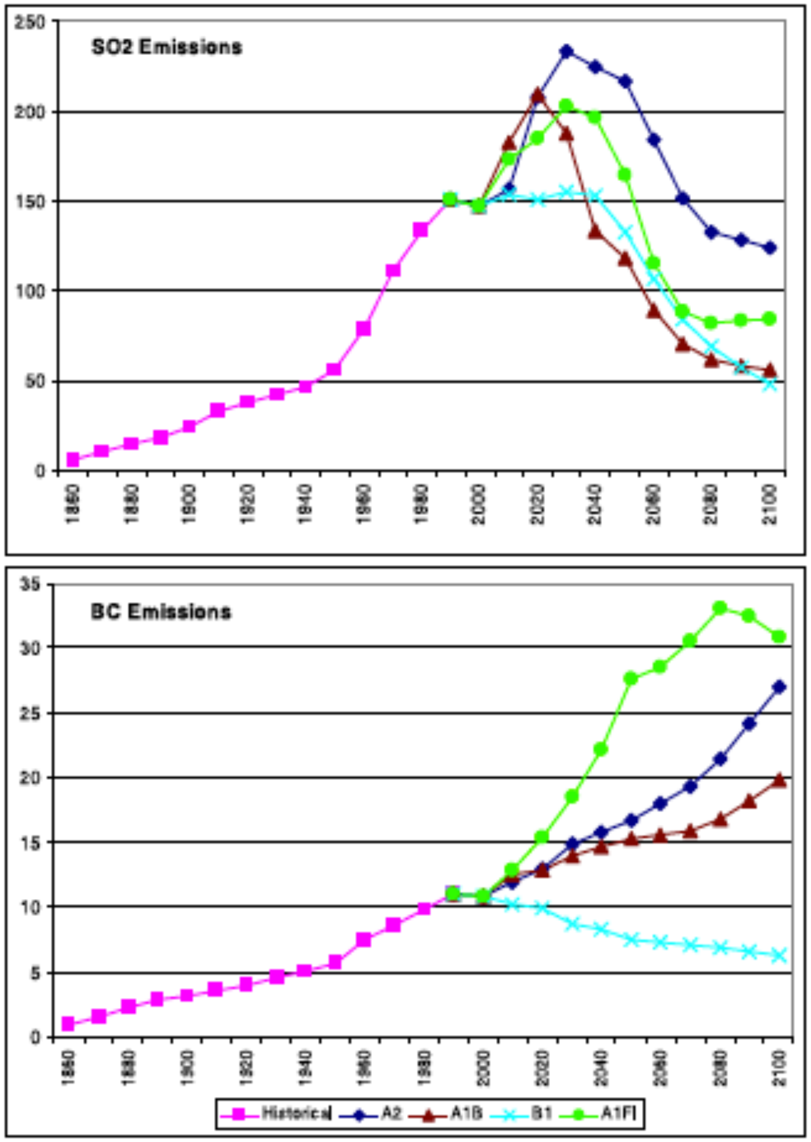


Initially, a new power plant with minimal regulations has a net negative radiative forcing due to aerosol effects. After about 25-30 years, CO_2 that has accrued in the atmosphere overwhelms the aerosol forcing.

A power plant with strict regulations will have positive forcing right away.

Uncertainties/Future Research Needs

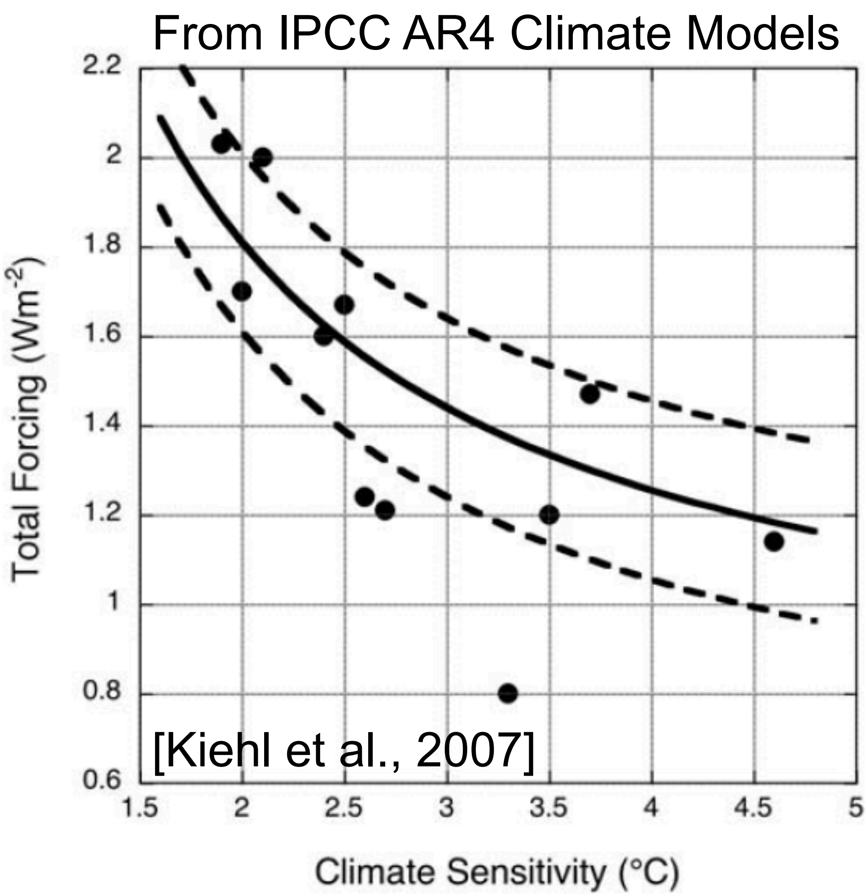
Global Emissions



[Horowitz et al., 2006]

1. Emissions (especially BC)
2. Mixing state of aerosols (external vs. internal)
3. Additional satellite-model assessment of aerosol direct and indirect effects
4. Increased focus on radiative forcing from emission sectors, is it possible to only remove warming SLCFs?
5. Does BC have a net positive or negative forcing when including the aerosol indirect effect?!?
6. Connecting local to regional to global climate change from SLCF. In other words, does SLCF policy only have to focus on local climate change?

Short-Lived Climate Forcers and Climate Sensitivity

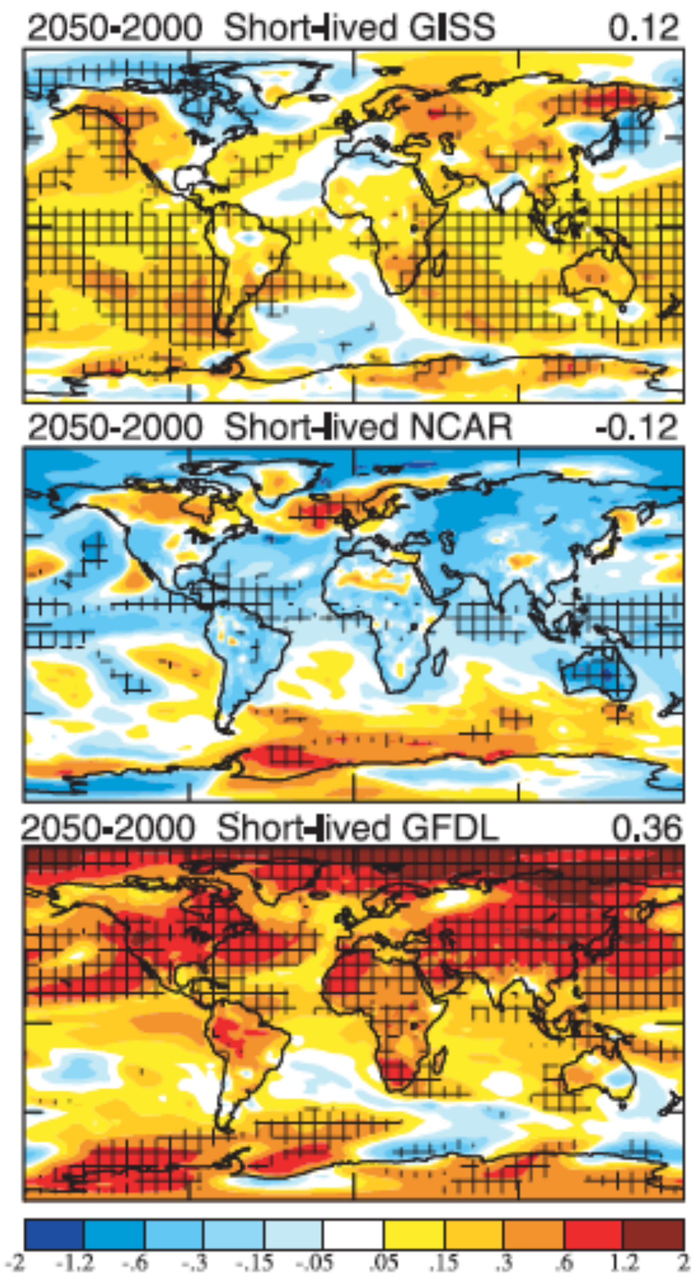


Climate sensitivity is a measure of how sensitive the climate system is to a given radiative forcing. This is typically displayed as the temperature change for doubling CO_2.

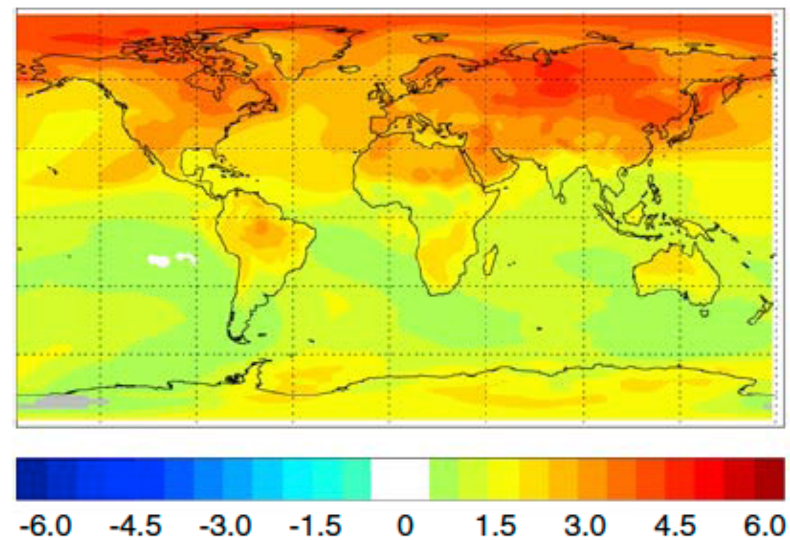
If most climate models can successfully simulate the 20th century, why do they have differing projections of the 21st century?

Because each model has a different climate sensitivity. Climate sensitivities based on the 20th century must consider the effects of short-lived species, which are less certain than CO_2 abundances. We need a better understanding of SLCFs to improve climate predictions!

Climate Predictions: Sensitive to SLCF



[Shindell, 2008]



[Kloster et al., 2009]

All models to the left assume same emissions scenario.

Model above uses a different emissions scenario.

Contact Information

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