Pollution-Climate Interactions during the 20th Century

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Koch, D., A spreading drop plume model for Venus.
J. Geophys. Res., 1994.

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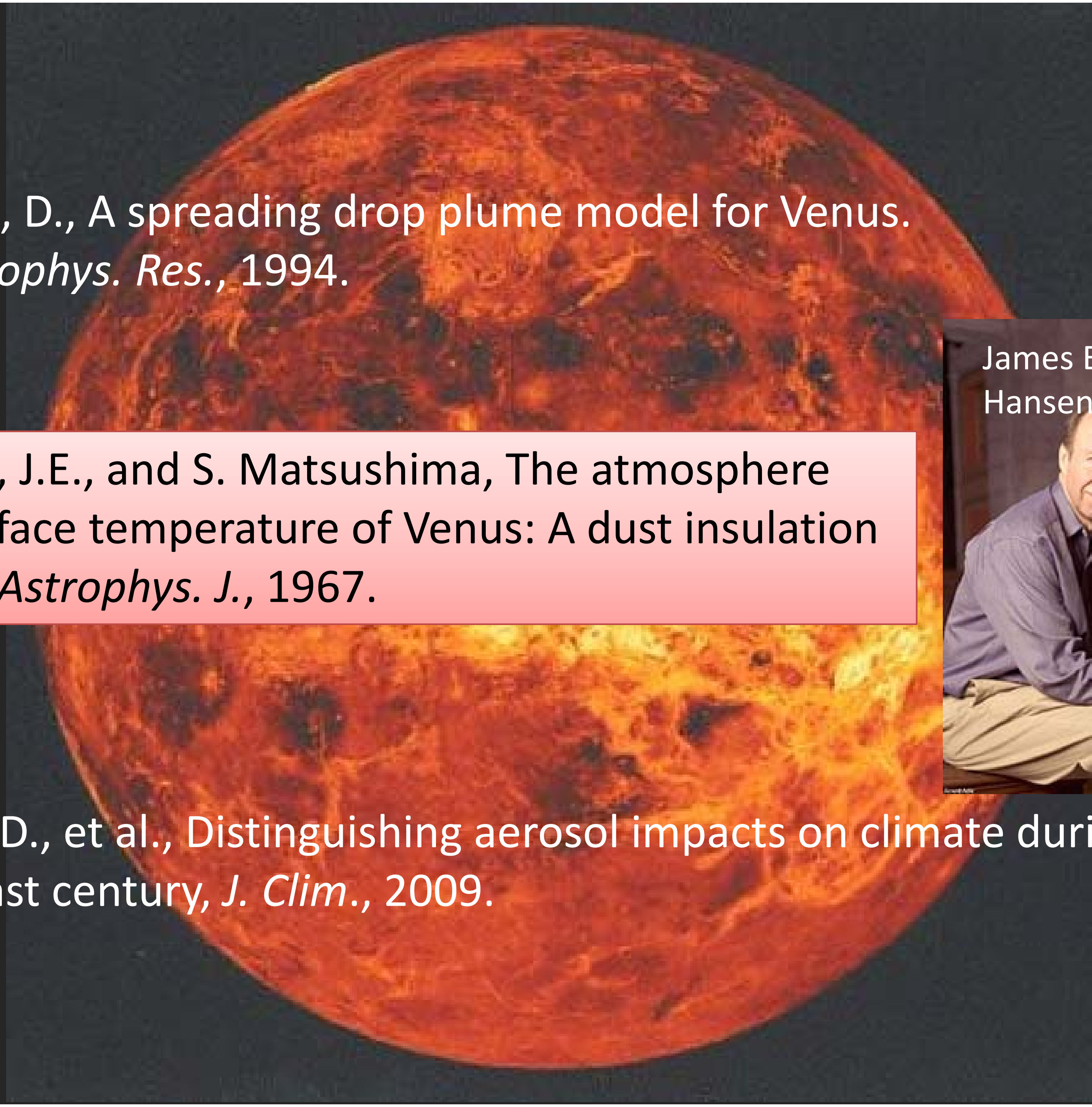
Koch, D., et al., Distinguishing aerosol impacts on climate during the past century, *J. Clim.*, 2009.

Koch, D., A spreading drop plume model for Venus. *J. Geophys. Res.*, 1994.

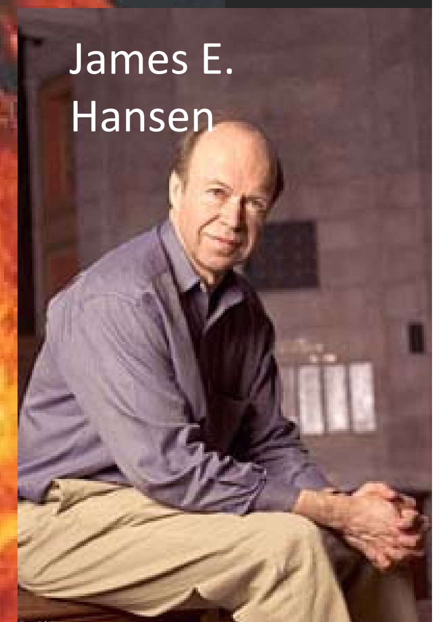
Koch, D.M., and M.E. Mann, Spatial and temporal variability of 7Be surface concentrations. *Tellus, 1996*.

Koch, D., et al., Distinguishing aerosol impacts on climate during the past century, *J. Clim.*, 2009.



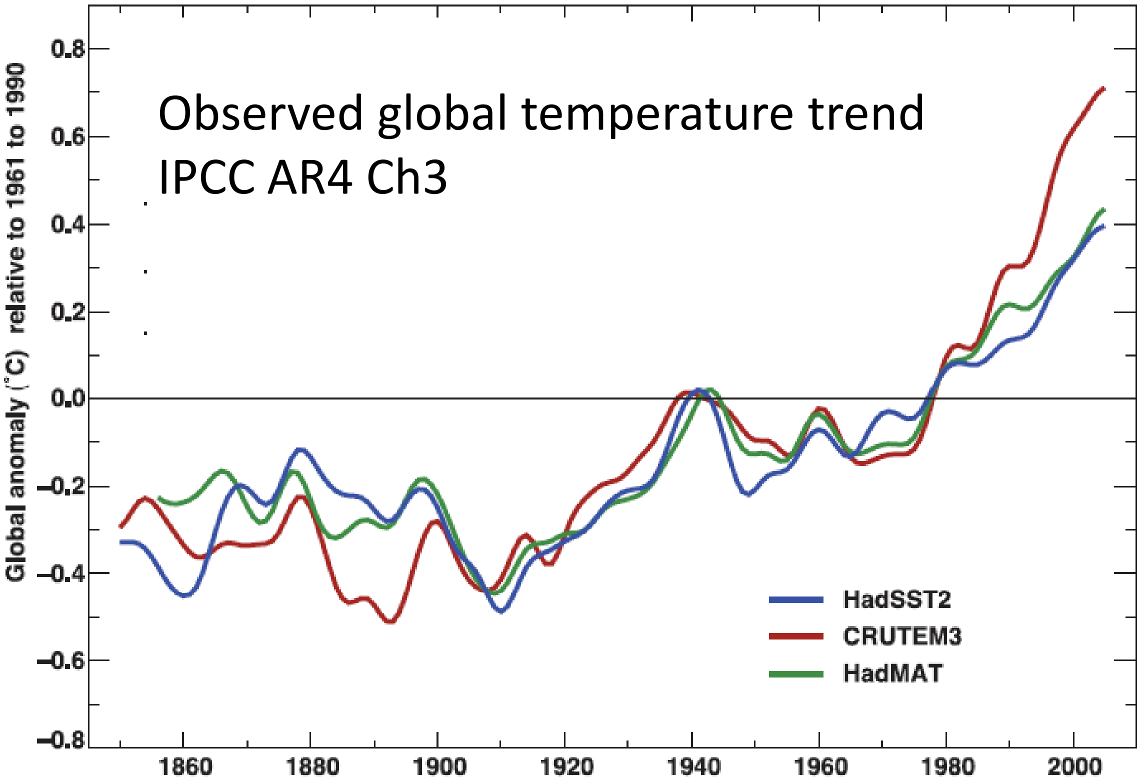
Koch, D., A spreading drop plume model for Venus. *J. Geophys. Res.*, 1994.

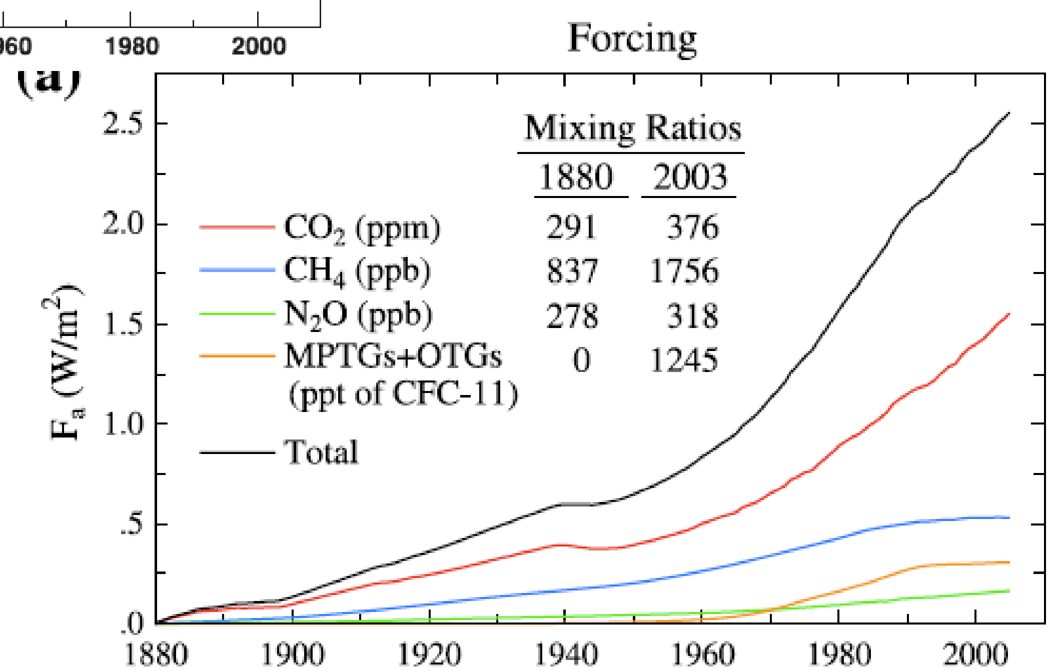
Hansen, J.E., and S. Matsushima, The atmosphere and surface temperature of Venus: A dust insulation model. *Astrophys. J.*, 1967.



Koch, D., et al., Distinguishing aerosol impacts on climate during the past century, *J. Clim.*, 2009.

20^{th} century Surface Air Temperature Long-lived GHG changes

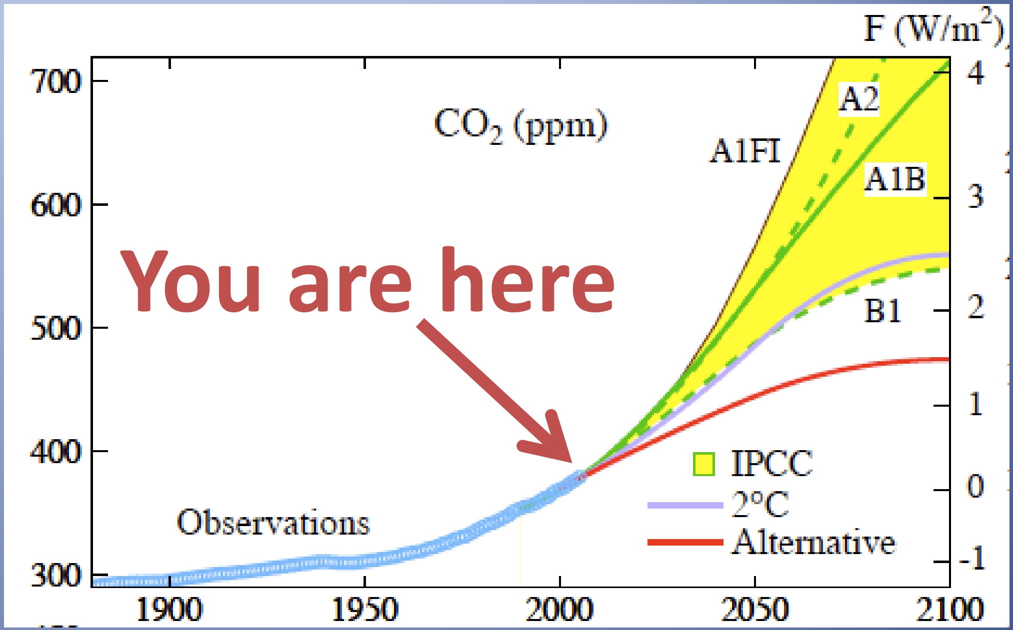


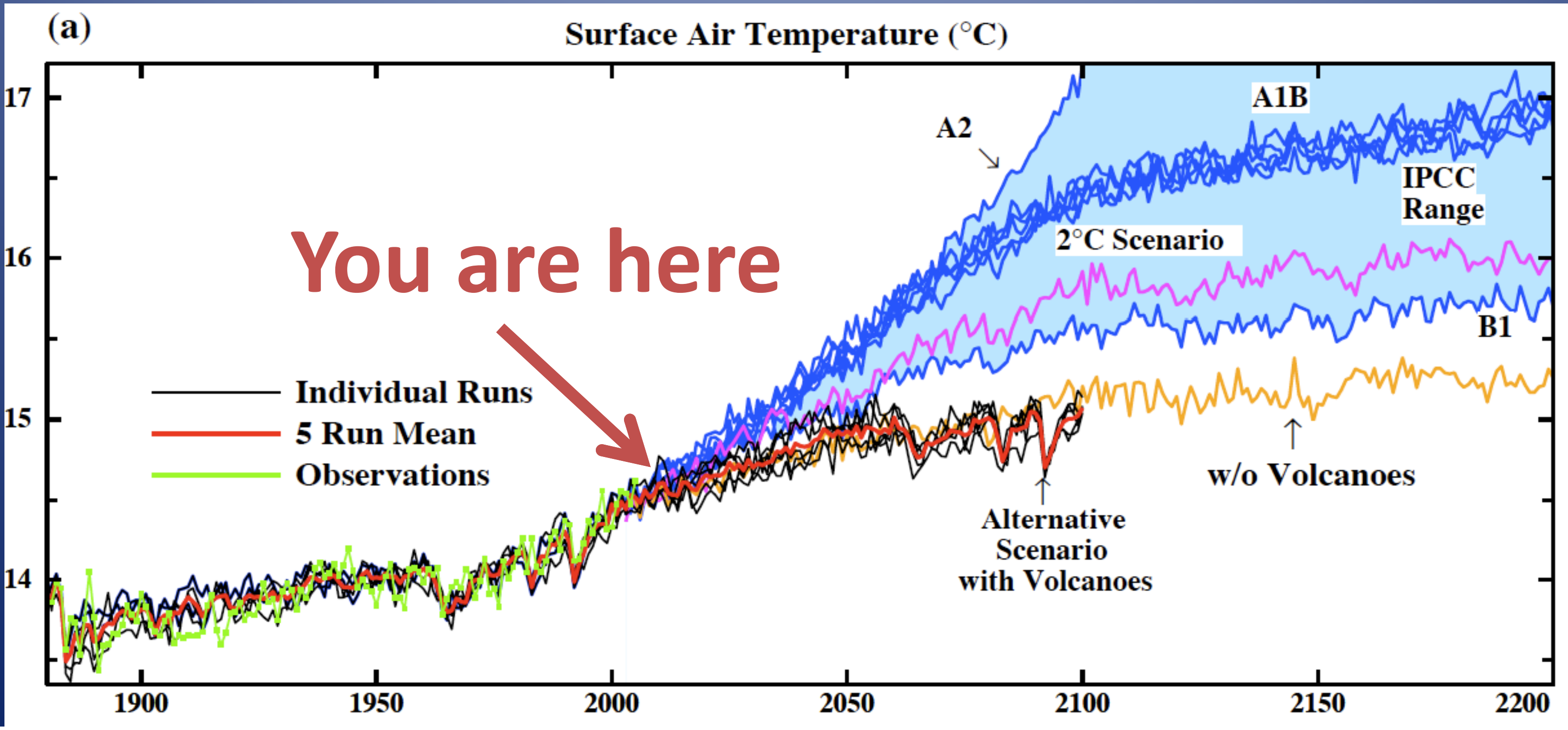


Hansen and Sato, 2004

Where might we be headed?

Climate models needed…

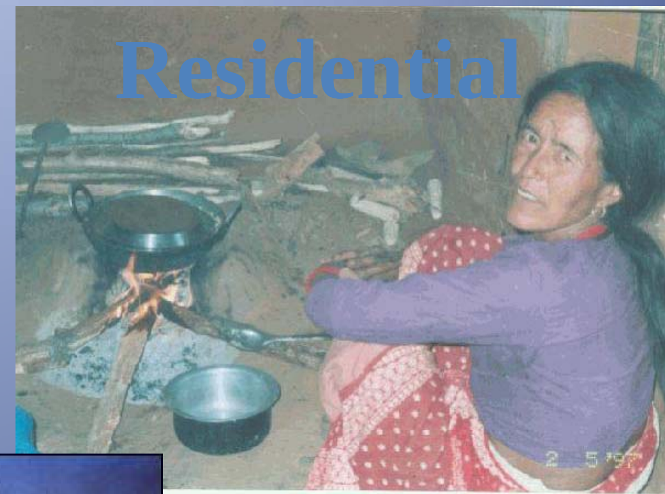




But climate models are uncertain…

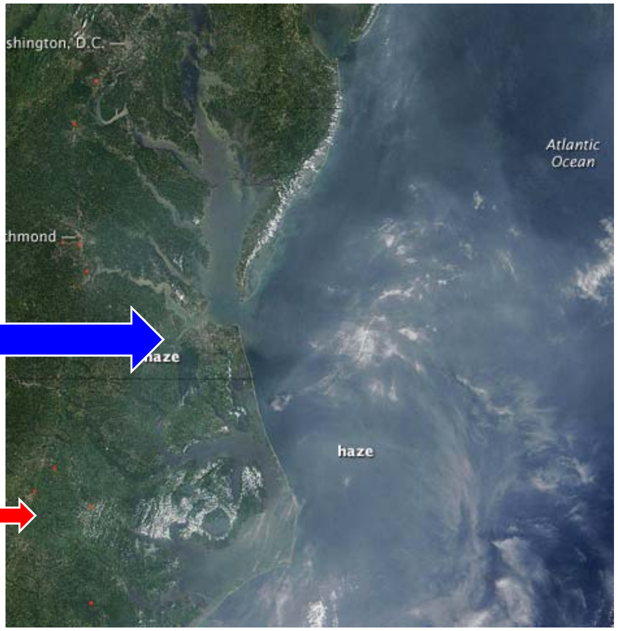
1. **Climate sensitivity**: warming amount per forcing change
2. **Cloud response**: Cloud cover change due to warming
3. **Ocean CO_2 and heat uptake** have delayed warming
4. **Aerosols have cooled/warmed, affected clouds and probably affected climate sensitivity**

Aerosol Sources; Air Quality Impacts



Aerosol Climate Effects

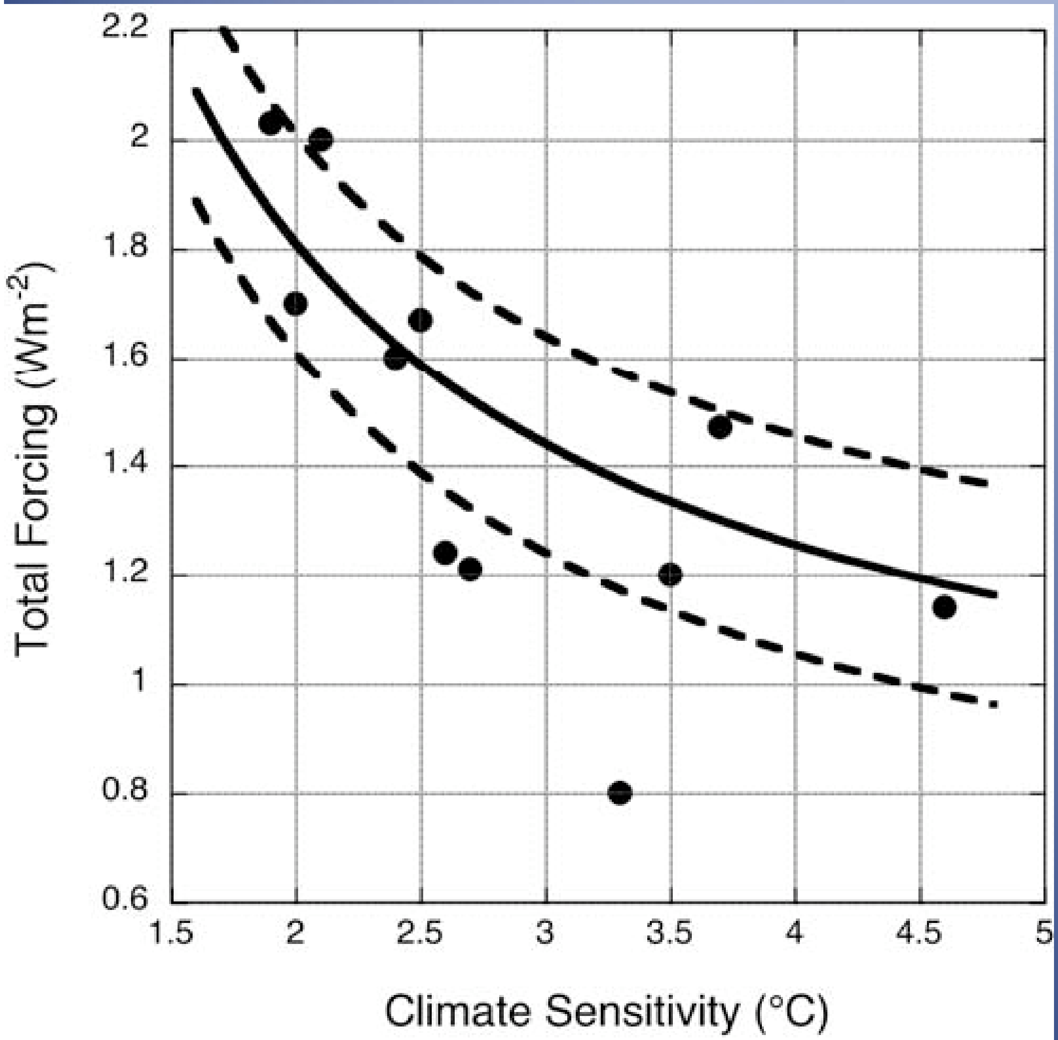
1. **Direct effect:** scatter and absorb incoming solar radiation. Sulfate, nitrate, organic carbon scatter. Black carbon (BC) also absorbs. (Ozone also warming)



2. **Indirect cloud effect:** Aerosol pollution makes clouds brighter and longer-lived. Cooling.

3. **BC-snow-darkening effect:** BC deposited on snow promotes melting. Warming

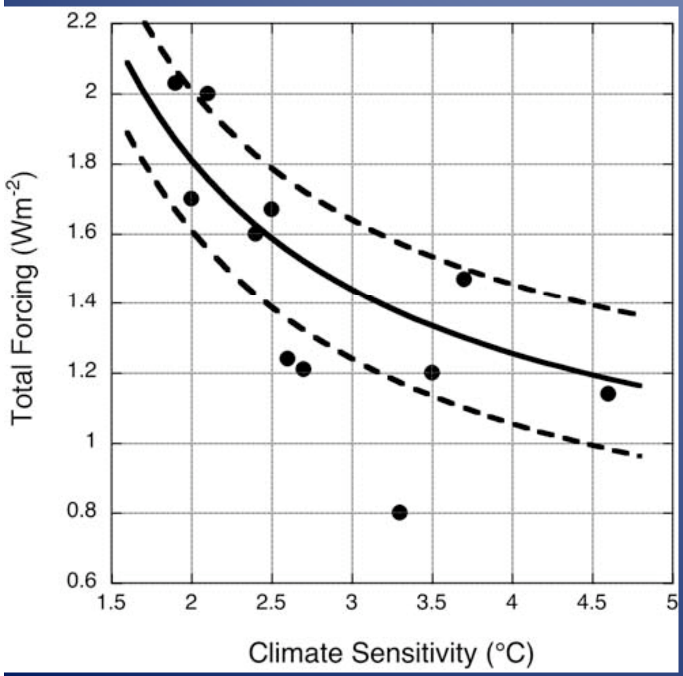
Model sensitivity

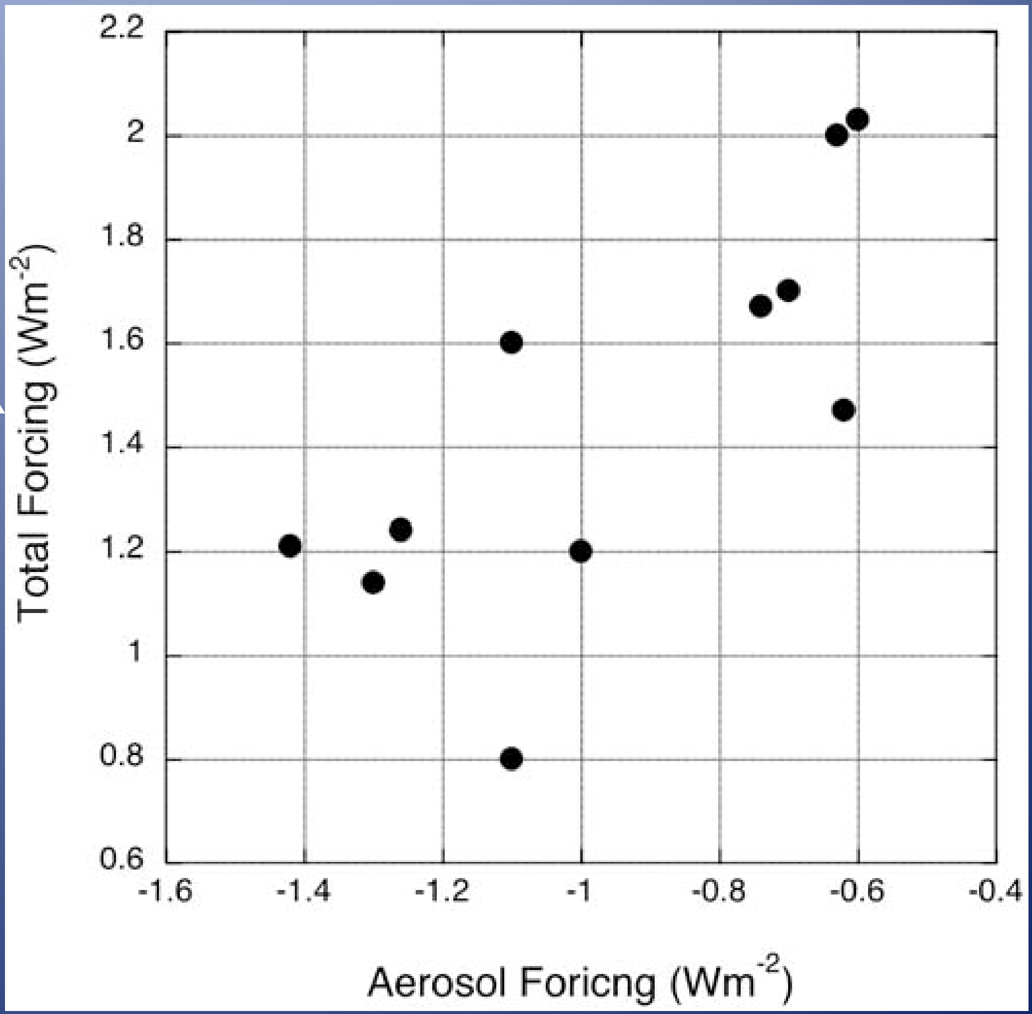


- Kiehl (2007) showed that AR4 climate models have smaller forcing if climate more sensitive…

Model sensitivity

- And most of the forcing difference is from aerosols

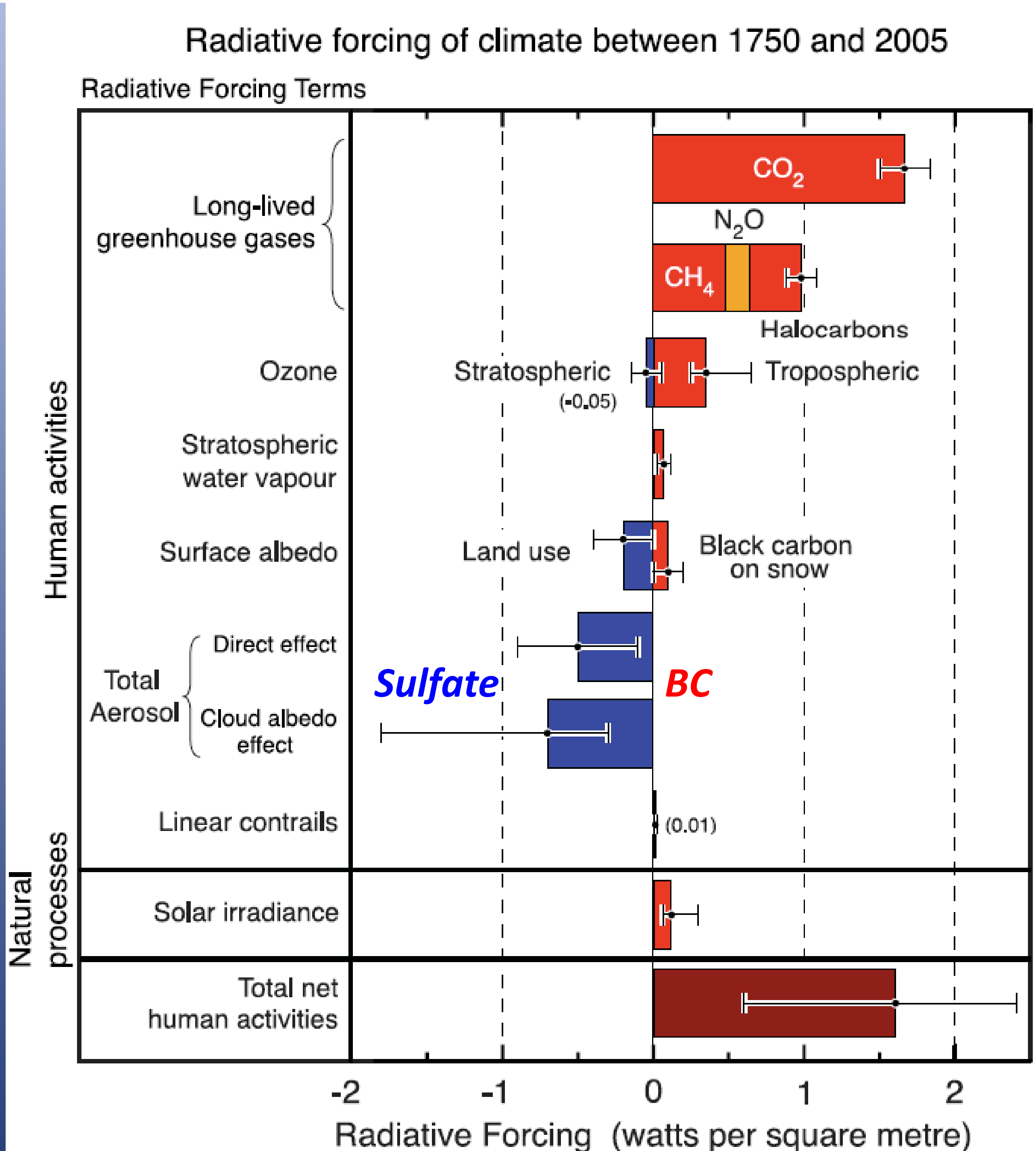




Global, Centennial View!!!

But aerosols vary temporally and spatially as regions industrialize and then address air quality.

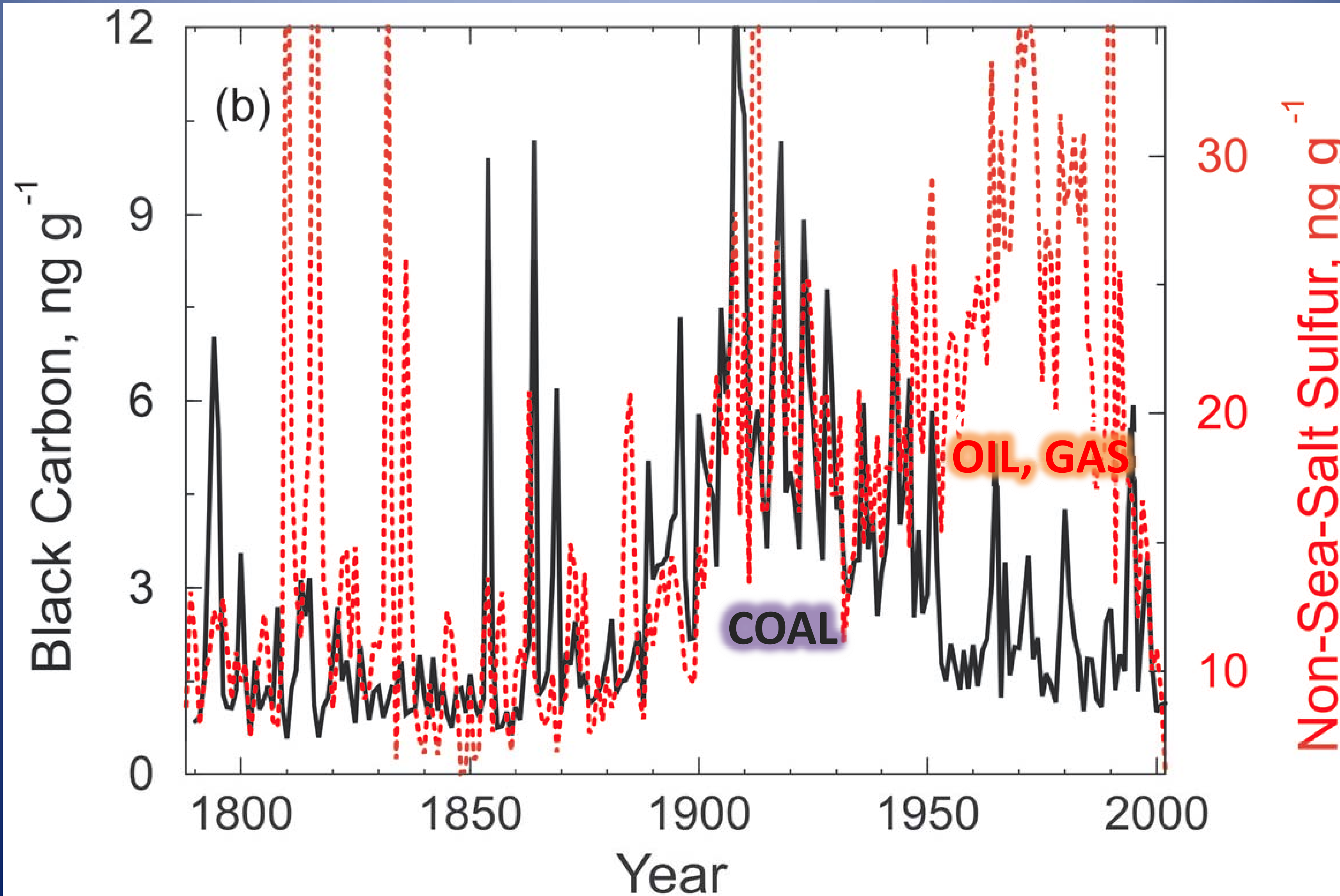
IPCC AR4 Ch2



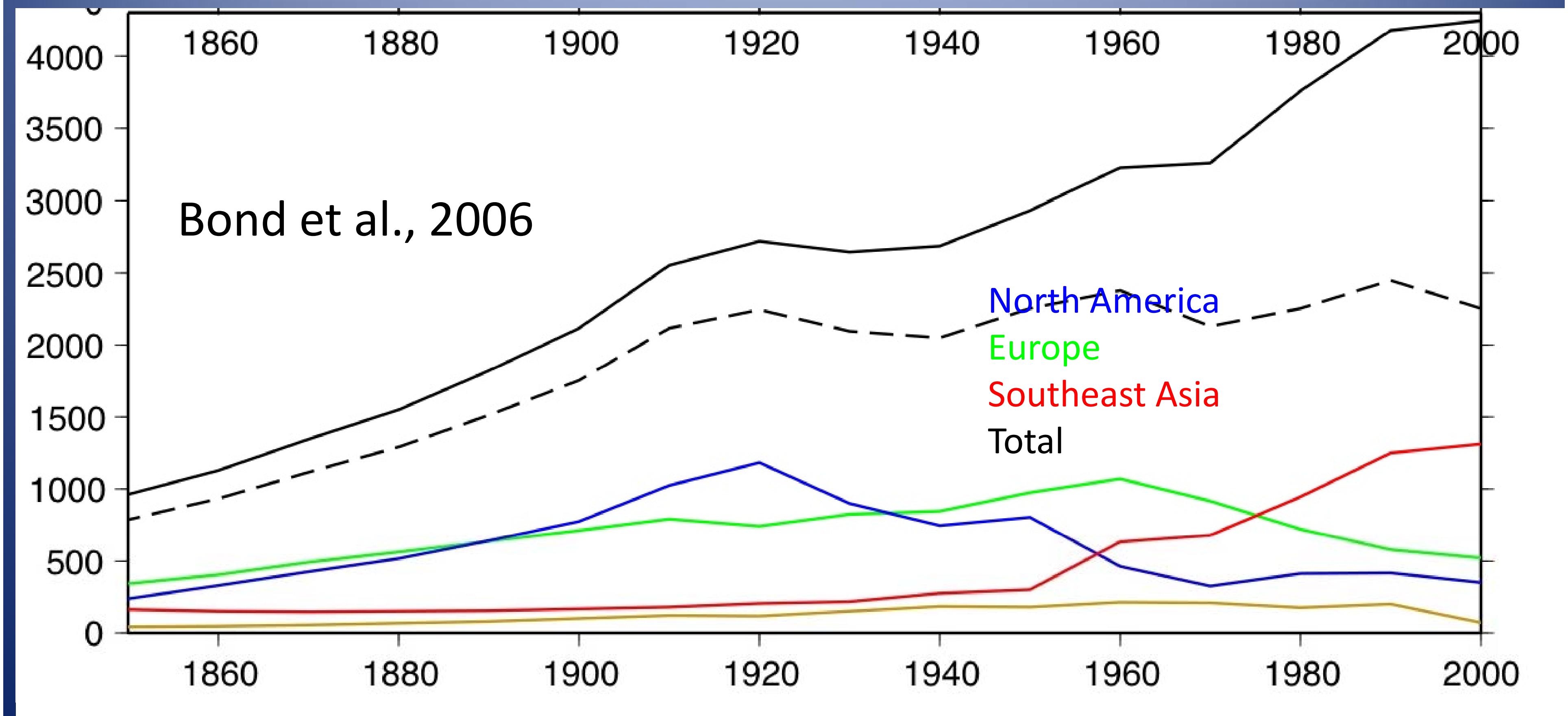
Greenland ice core records

McConnell et al., 2007

North American pollution changes



Black carbon fossil-, bio-fuel emission inventory

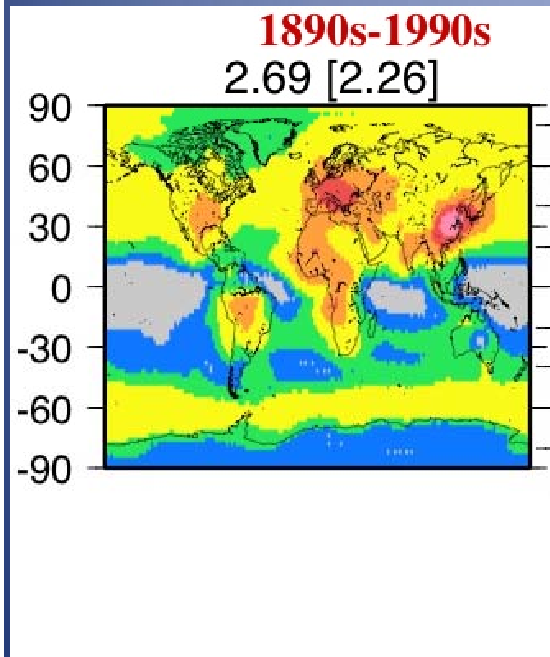


Our coupled chemistry-climate experiments

- Transient climate experiments, from 1890 to 2000.
- GISS GCM coupled to deep ocean, with aerosols-ozone-chemistry are FULLY INTERACTIVE with the climate.
- Aerosol-cloud indirect and BC-snow-albedo effects are fully interactive. (This is actually very tricky… the indirect effect in a transient model with a deep ocean has a powerful cooling effect beginning mid-century.)
- We do multiple experiments to isolate aerosol effects.
- We performed "pollution reduction" experiments.

Aerosol Optical Depth changes

Century



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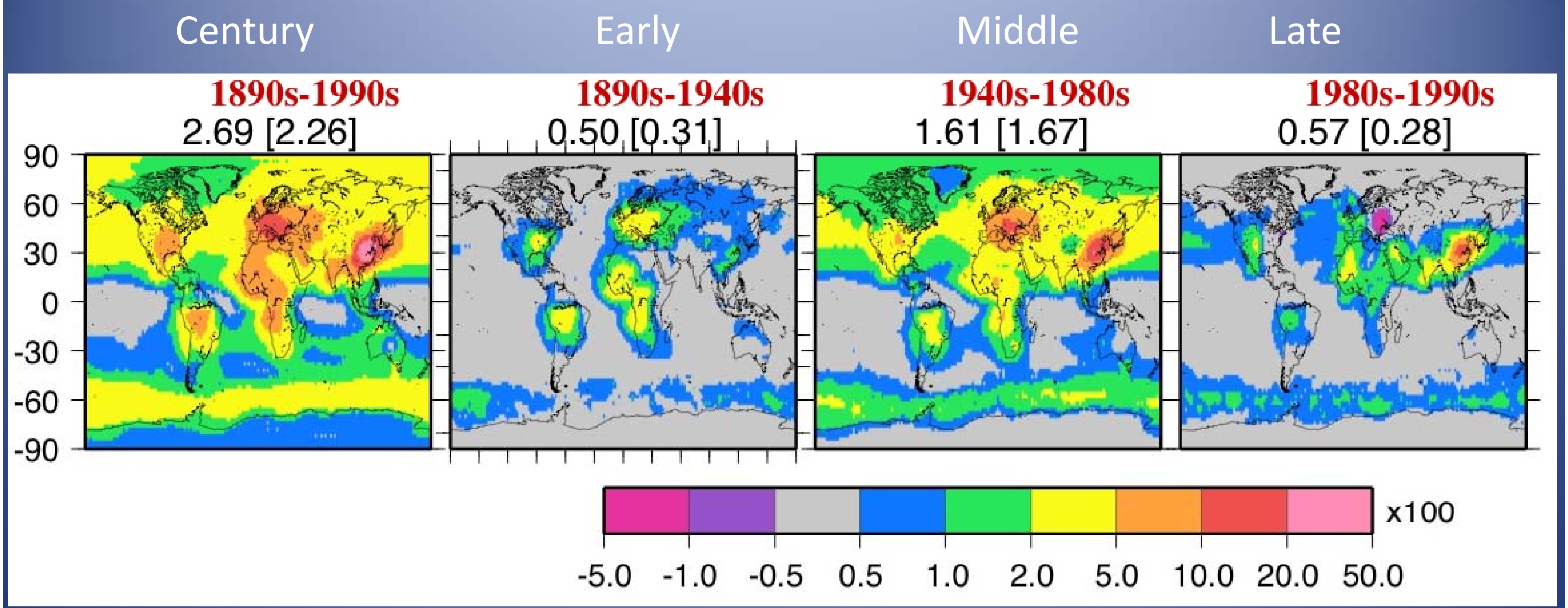
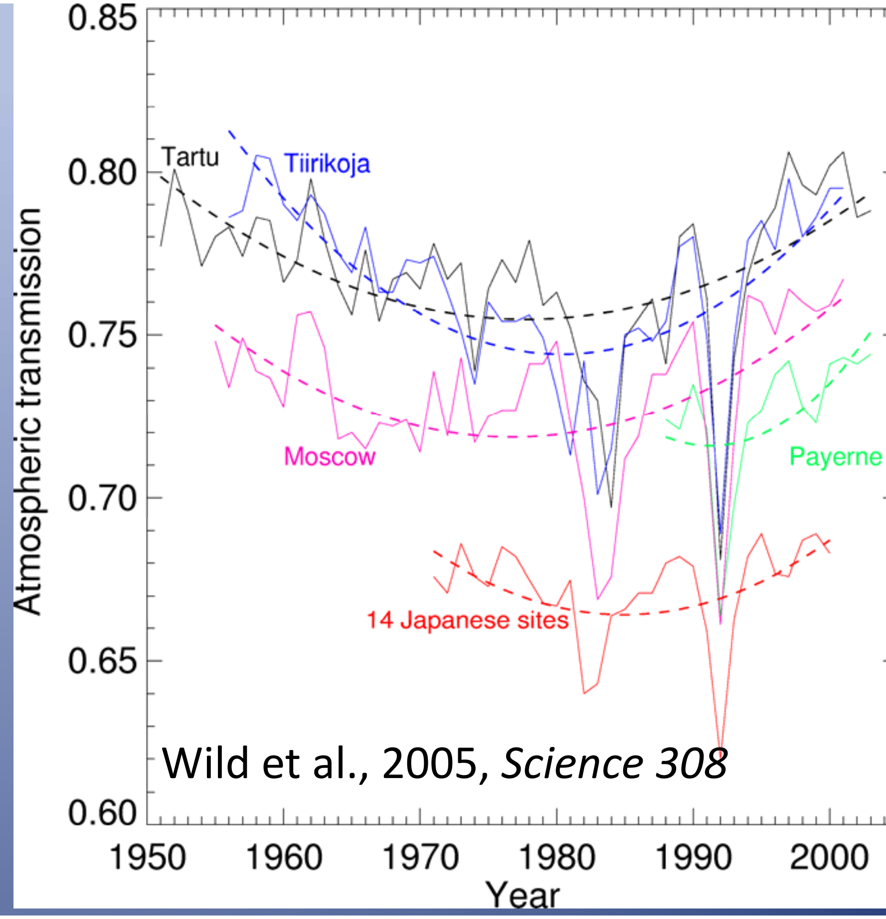
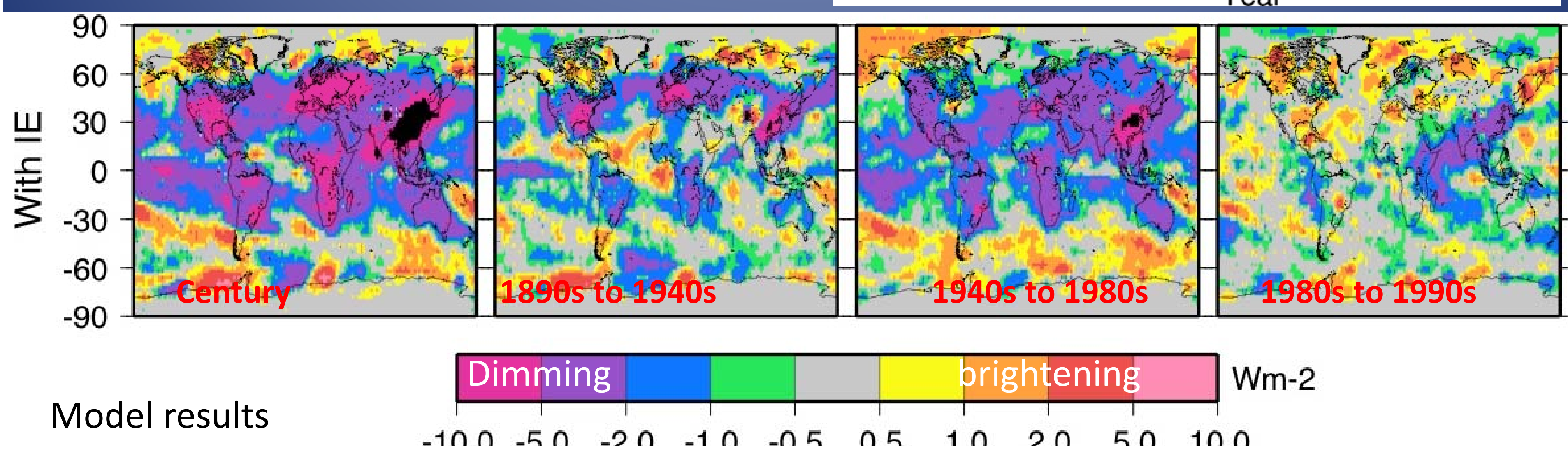
Aerosol Optical Depth changes



Surface radiation changes
“Dimming/brightening”

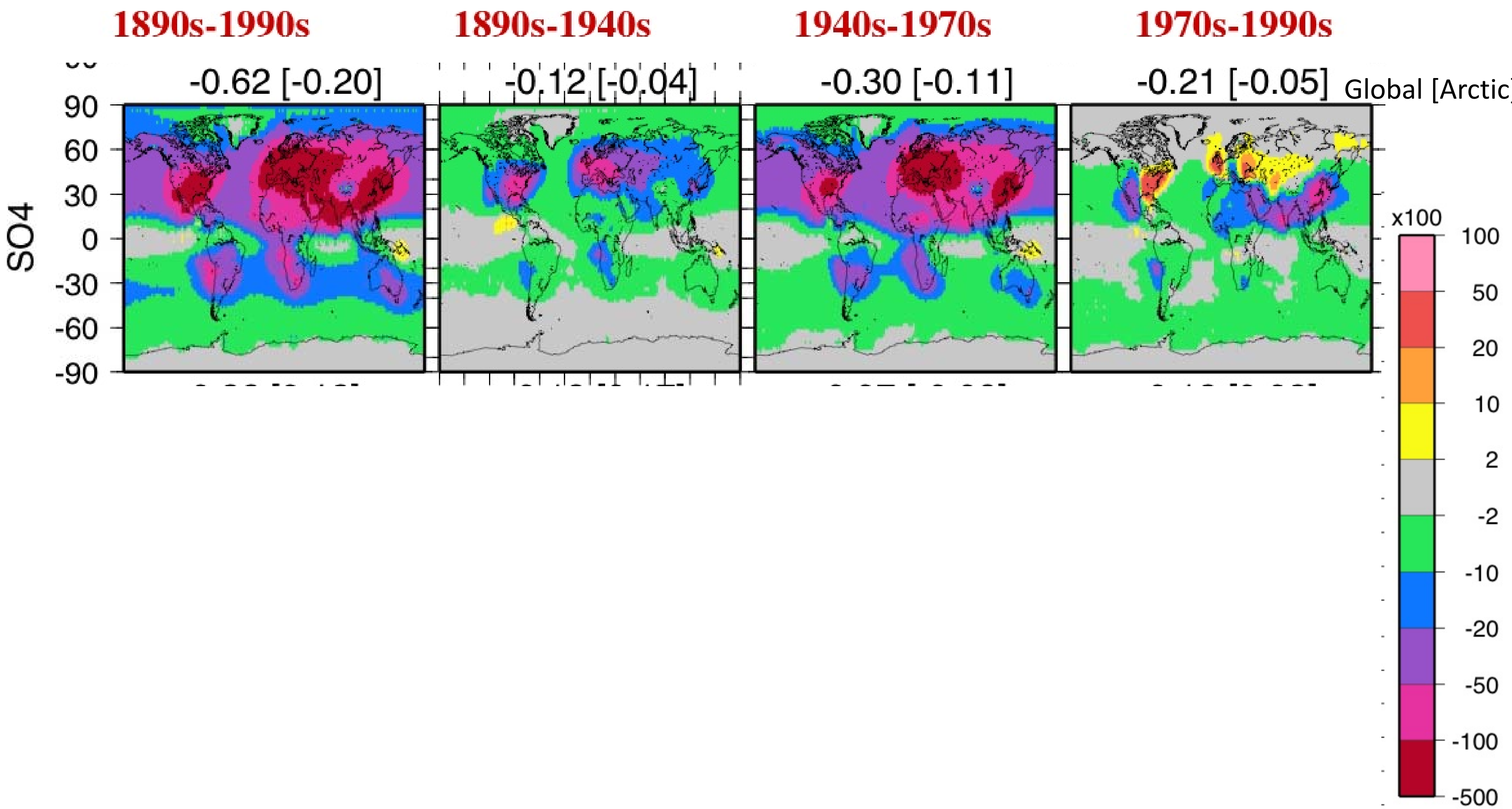
Observed



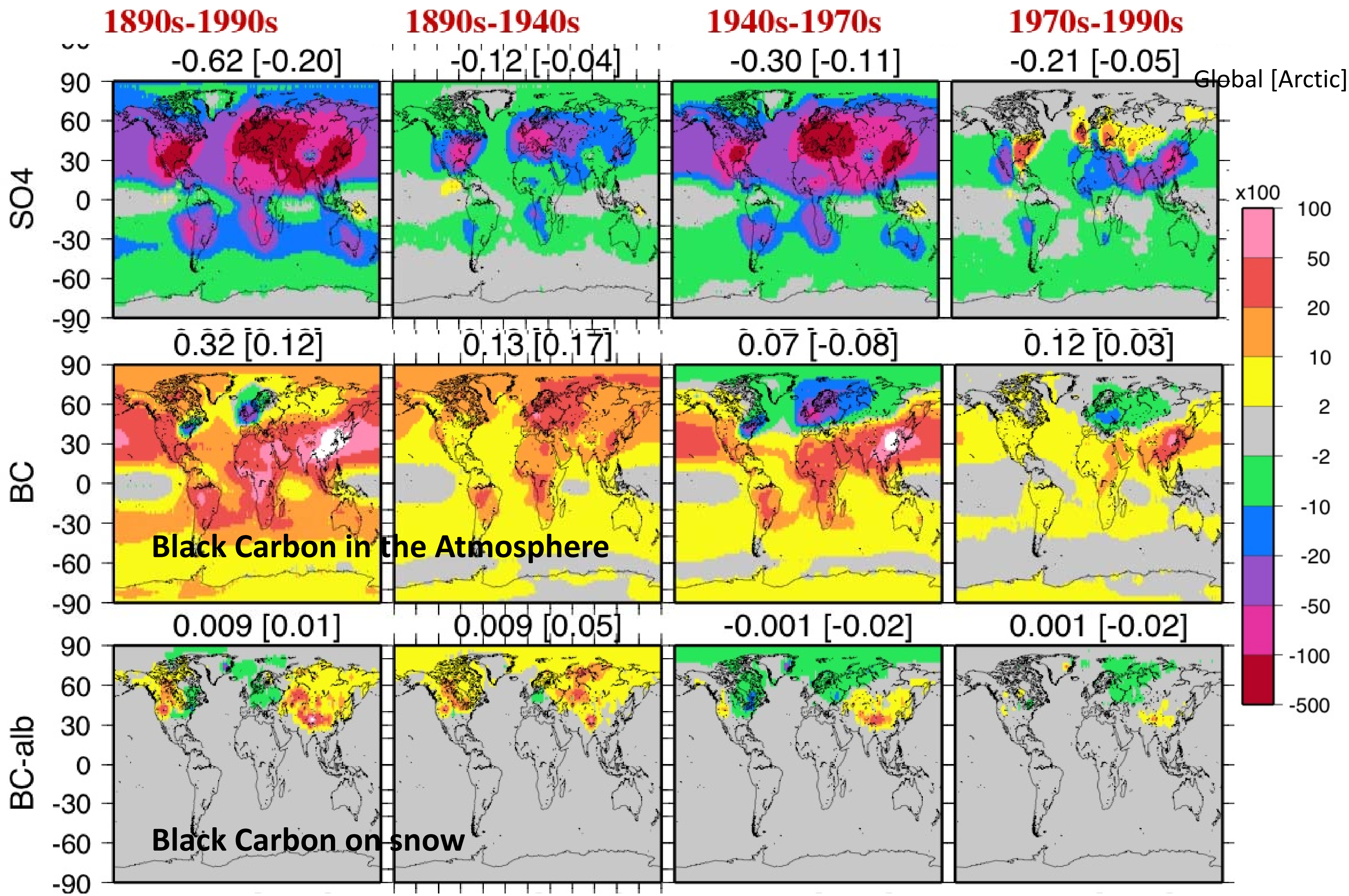


Model results

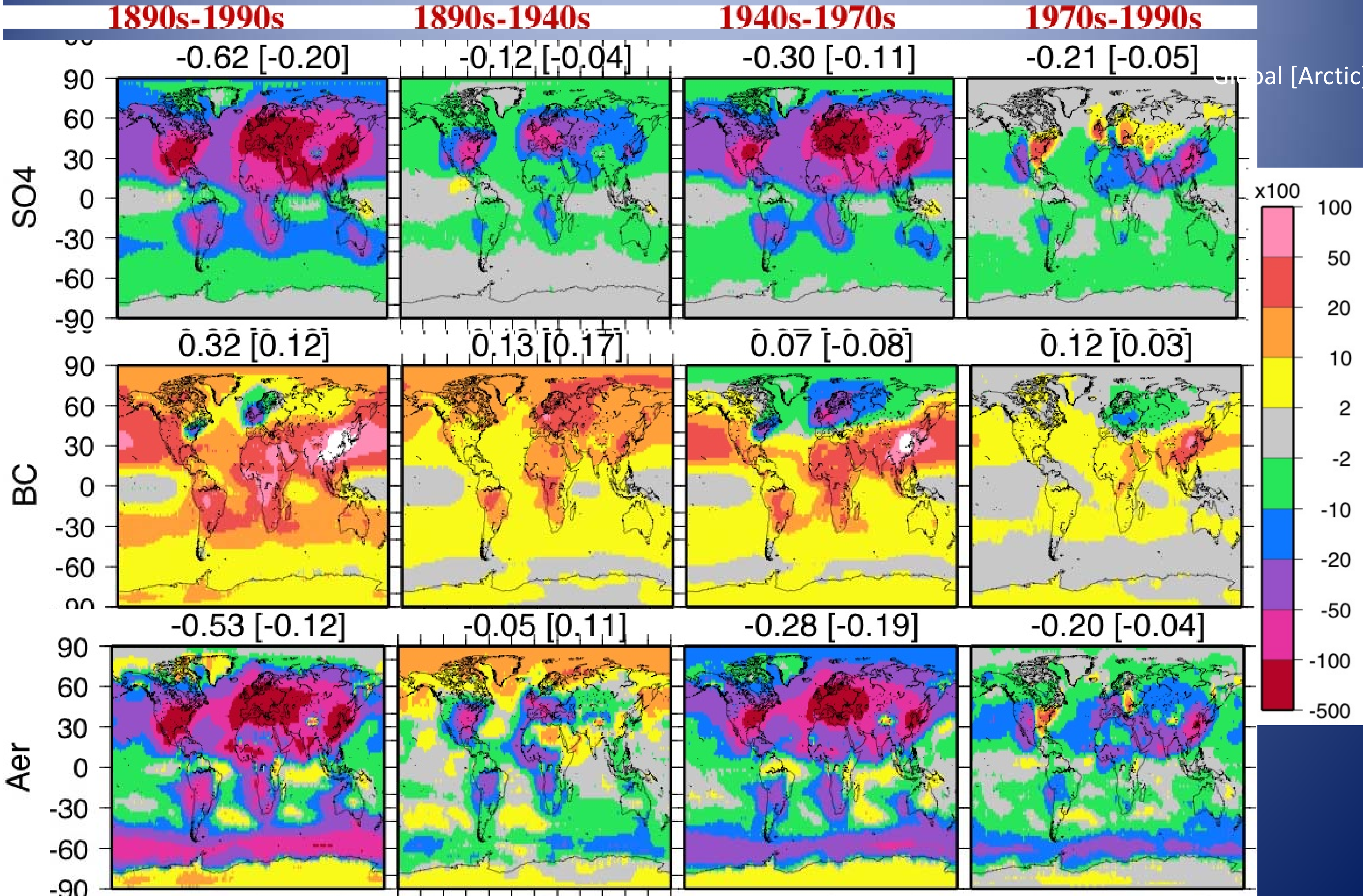
SULFATE top-of-atmosphere forcing changes



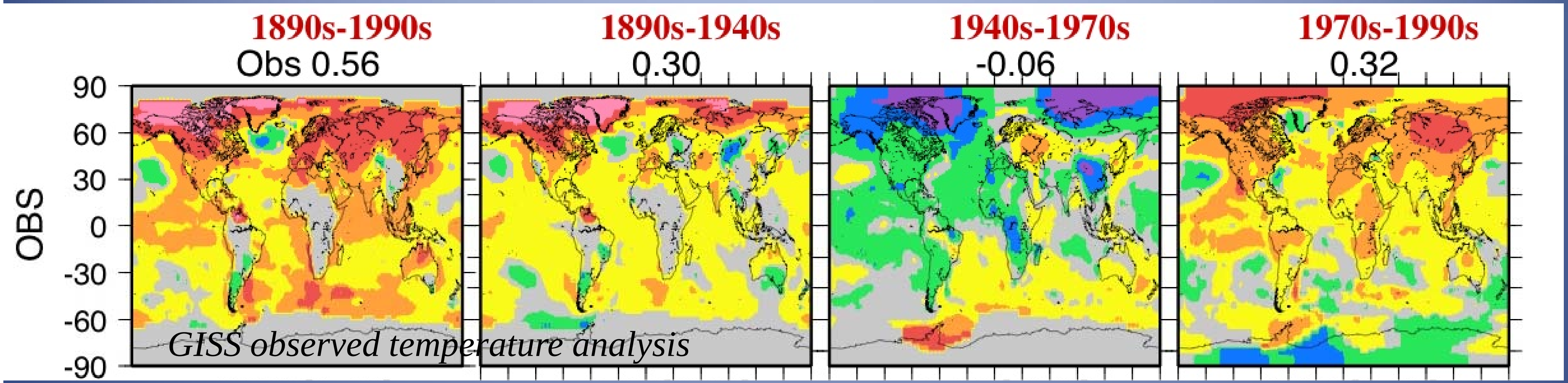
Sulfate vs Black Carbon TOA forcing changes



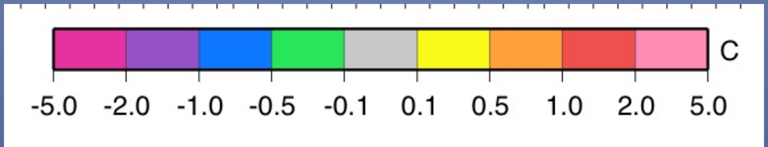
TOA forcing changes



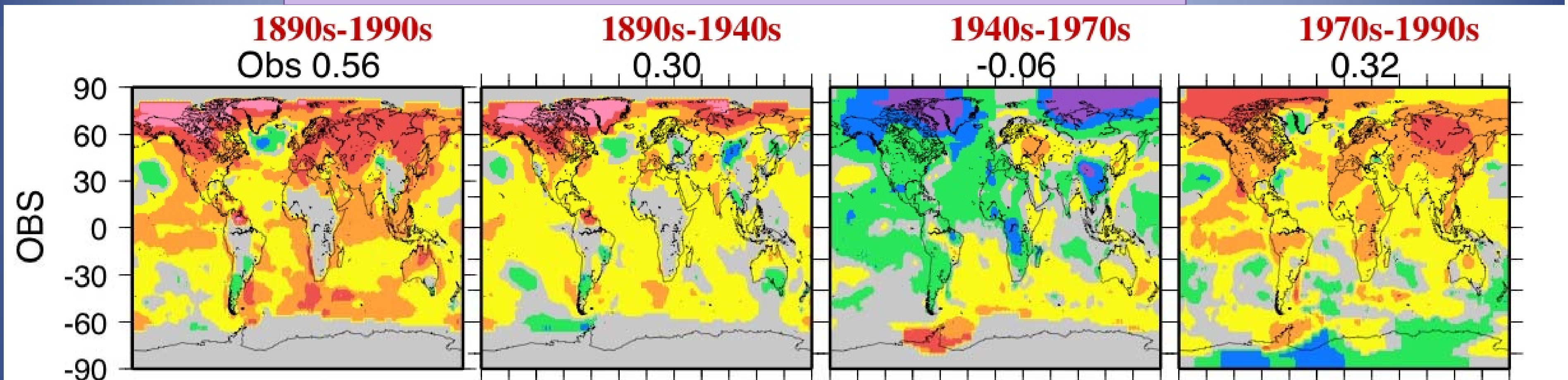
Observed Surface Air Temperature (SAT) changes



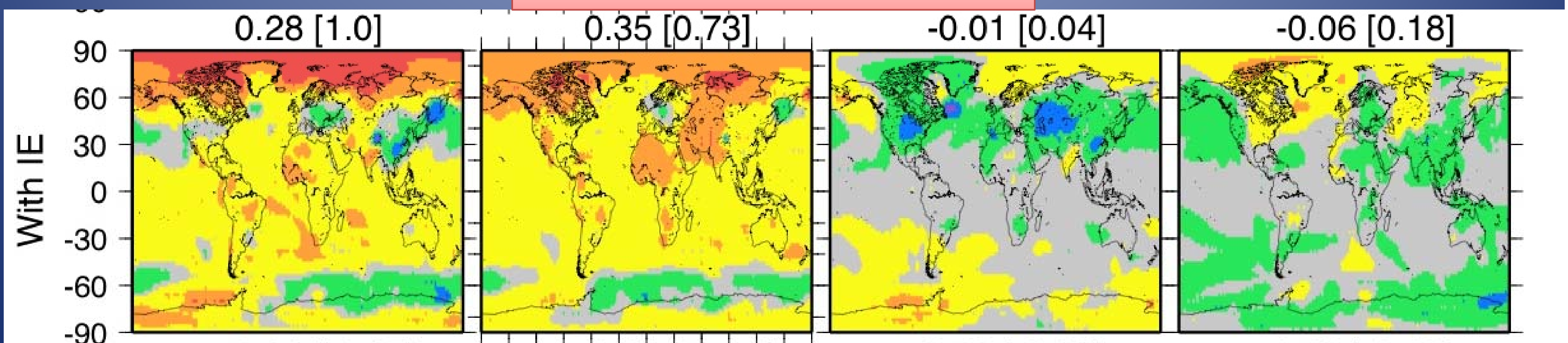
Δ century warmer neutral warmer

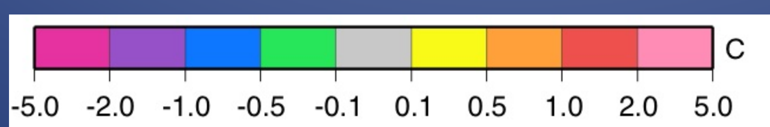


Observed Surface Air Temperature changes



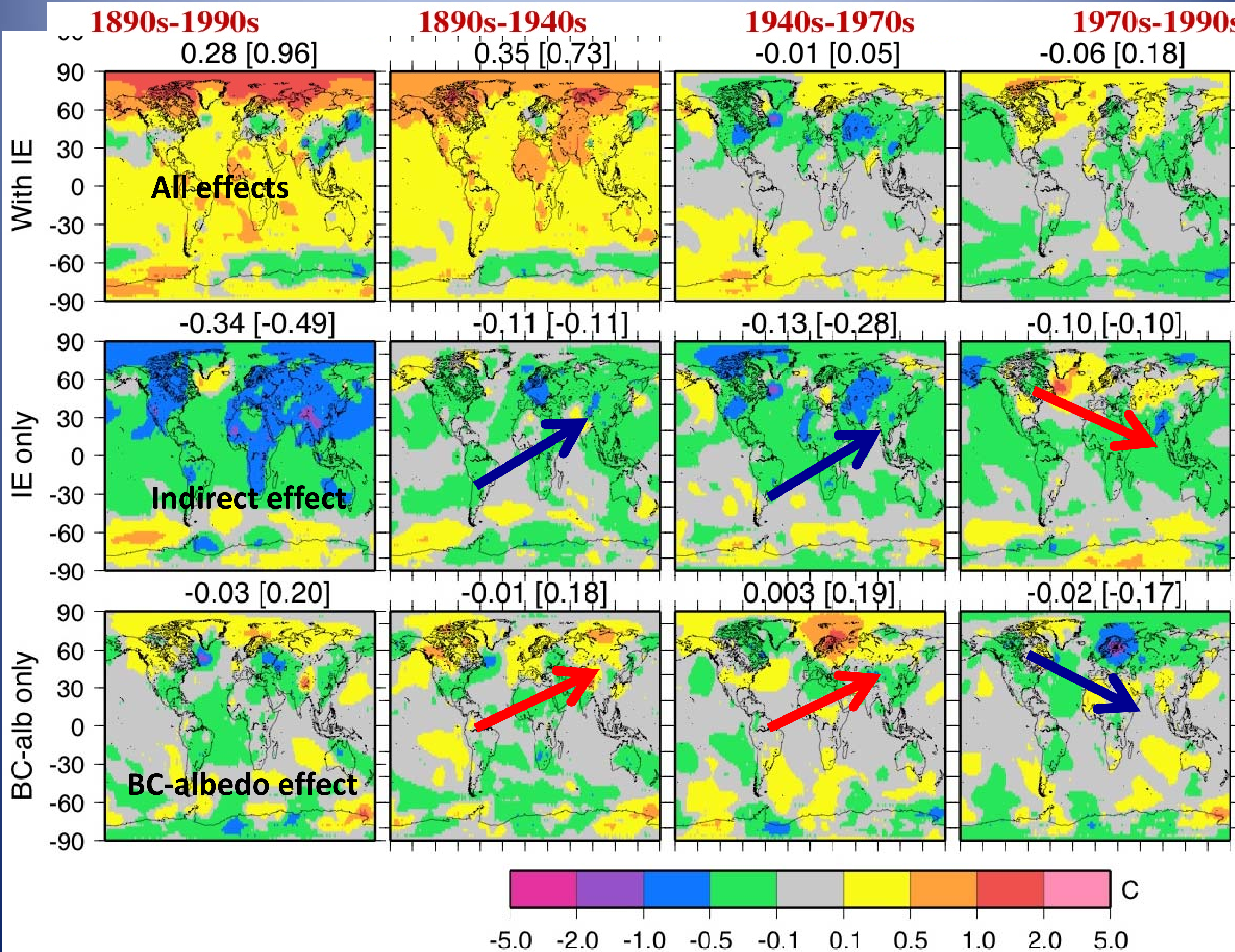
Modeled SAT changes





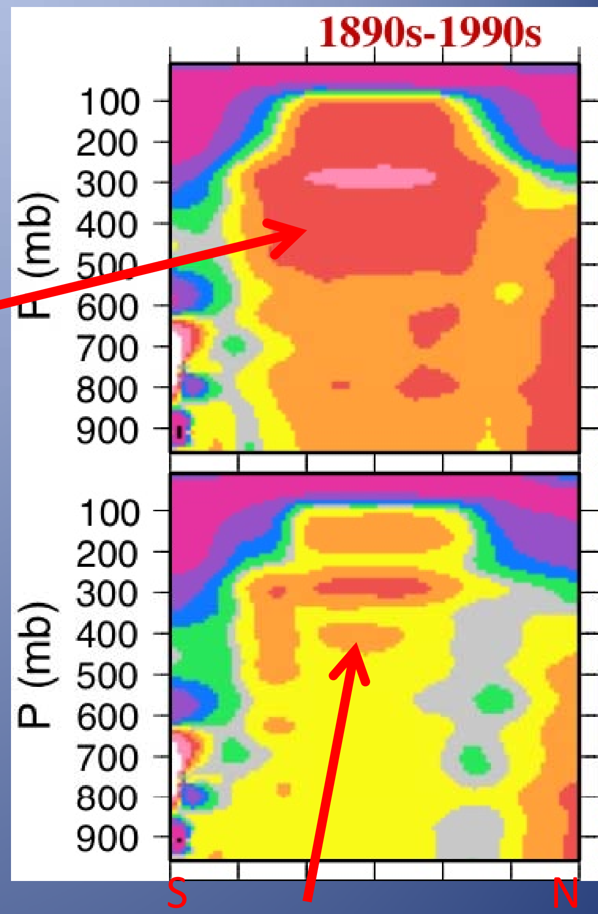
Indirect effect is too cooling near the end of the century

Aerosol effects on Surface Air Temperature (SAT) changes

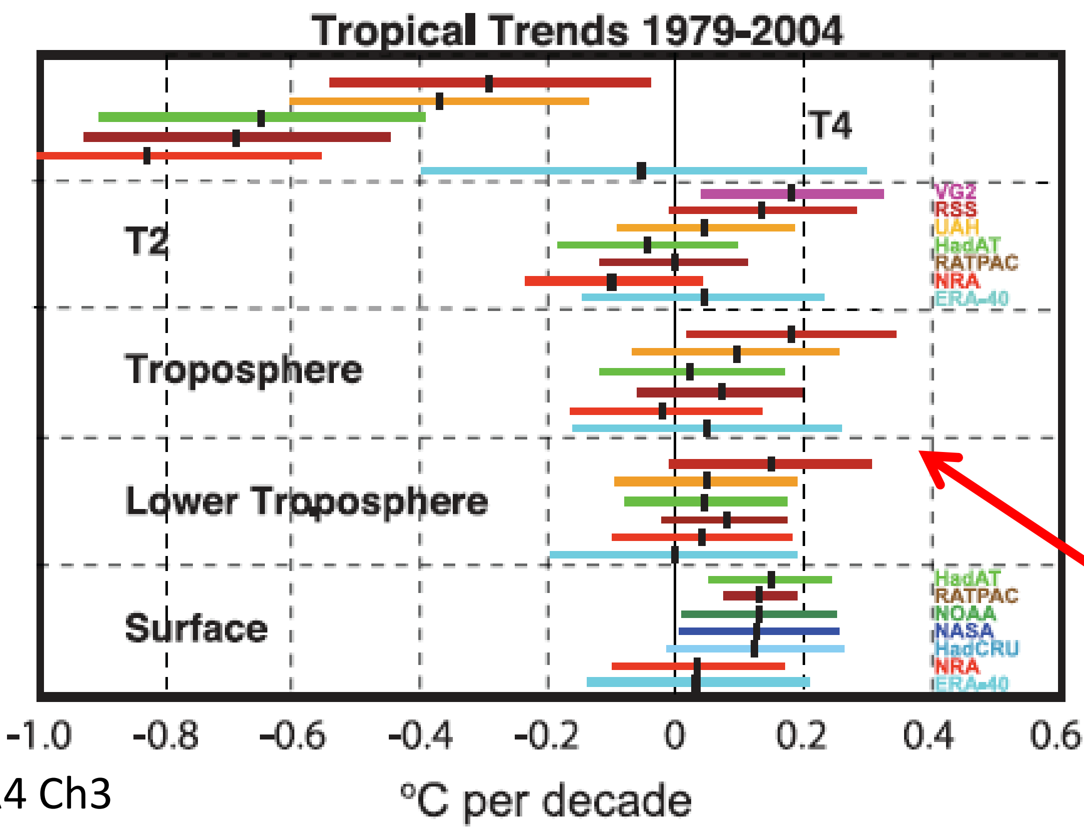


Indirect Effect helps the tropical vertical ΔT

Without the indirect effect, tropical upper troposphere warms too much, like AR4 models



With indirect effect warming is uniform, as observed



AR4 Ch3

Radiosonde, satellite data indicate uniform warming with altitude in the tropics for end of century.

Should we reduce Black Carbon pollution to cool climate?

ARCTIC COUNCIL

TROMSØ DECLARATION

On the occasion of the Sixth Ministerial Meeting of

The Arctic Council

The 29th of April, 2009, Tromsø, Norway

Note the role that shorter-lived climate forcers such as black carbon, methane and tropospheric ozone precursors may play in Arctic climate change, and **recognize** that reductions of emissions have the potential to slow the rate of Arctic snow, sea ice and sheet ice melting in the near-term, A policy-relevant summary of black carbon climate science and appropriate emission control strategies

icct

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Black Carbon e-Bulletin

UNEP

Volume 1, Number 2 | September 2009

PROJECT SURYA

Mitigation of Global and Regional Climate Change

Buying the planet time by reducing black carbon, methane and ozone

(Part I)

Black Carbon

A Review and Policy Recommendations

Authors

Karen Bice, Andrew Eil, Bilal Habib,
Pamela Heijmans, Robert Kopp, Juan Nogues,
Frank Norcross, Maragaret Sweitzer-Hamilton, Alex Whitworth

Project Advisor

Denise Mauzerall, Associate Professor of Public and International Affairs, Woodrow Wilson School

PRINCETON UNIVERSITY
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of Public & International Affairs

“Mitigation” Studies 1970-2000

Starting in 1970, branch 3 cases and compare with standard run.

Cooling experiments:

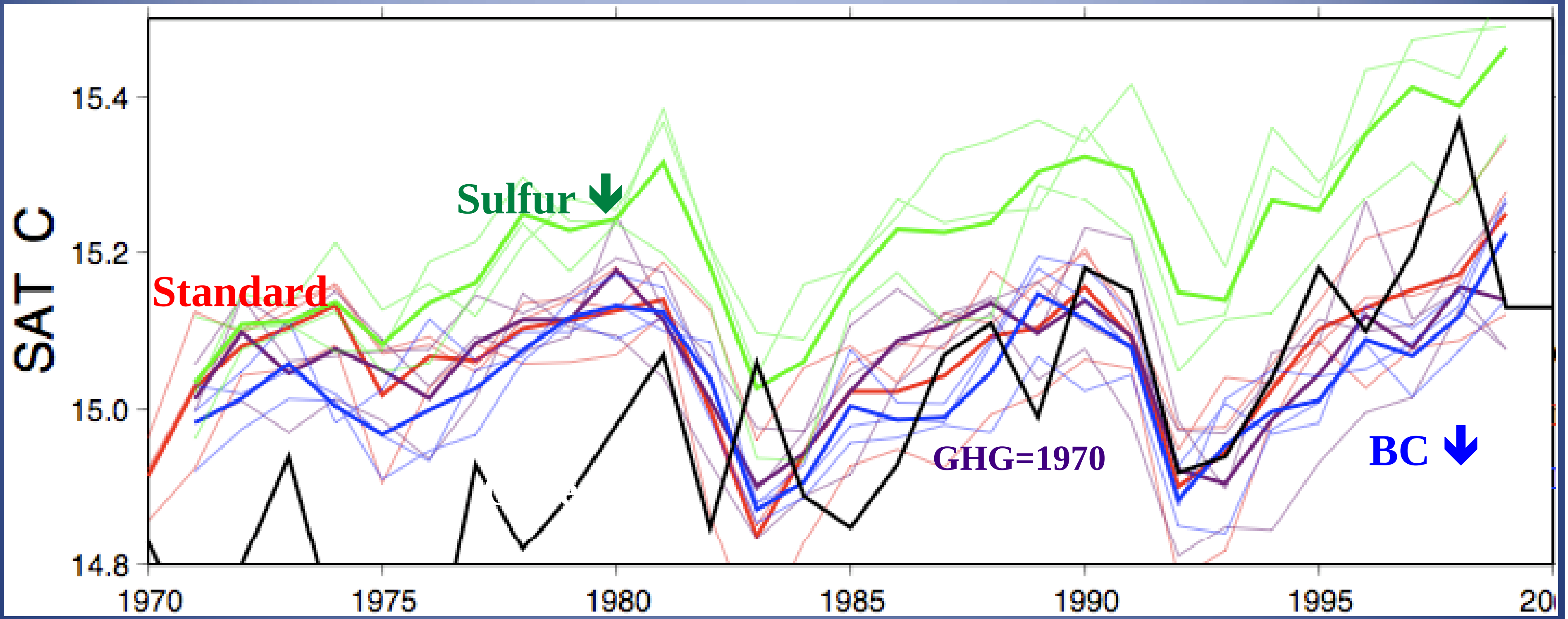
1. **Pollution BC = 0** (-0.3 W/m2)

2. **Long-lived GHGs at 1970 levels** (-1 W/m2)

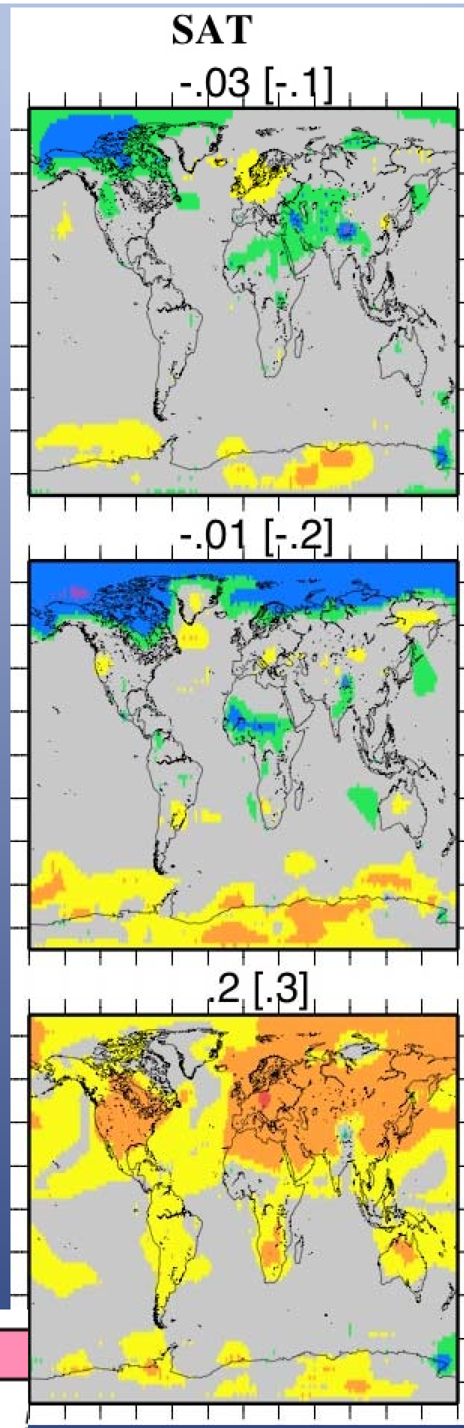
Warming Experiment:

3. **Pollution sulfur = 0** (+0.4 W/m2)

Global Surface Air Temperature Trend



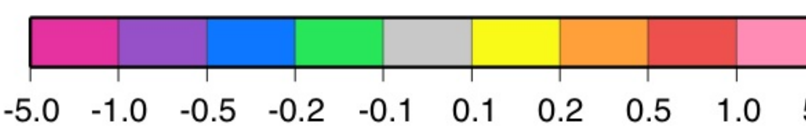
Temperature changes for mitigation experiments



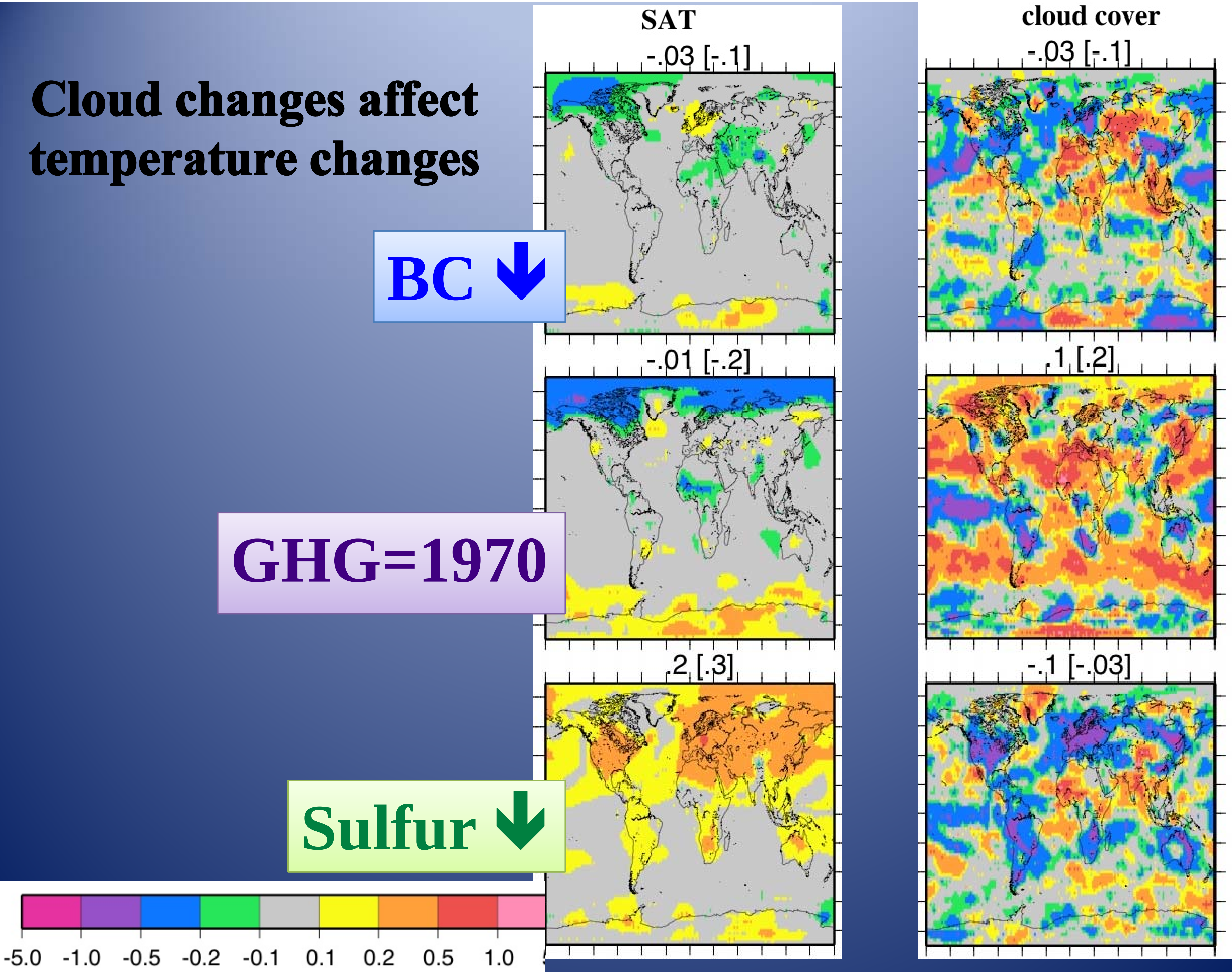
BC ↓

GHG=1970

Sulfur ↓



Cloud changes affect temperature changes

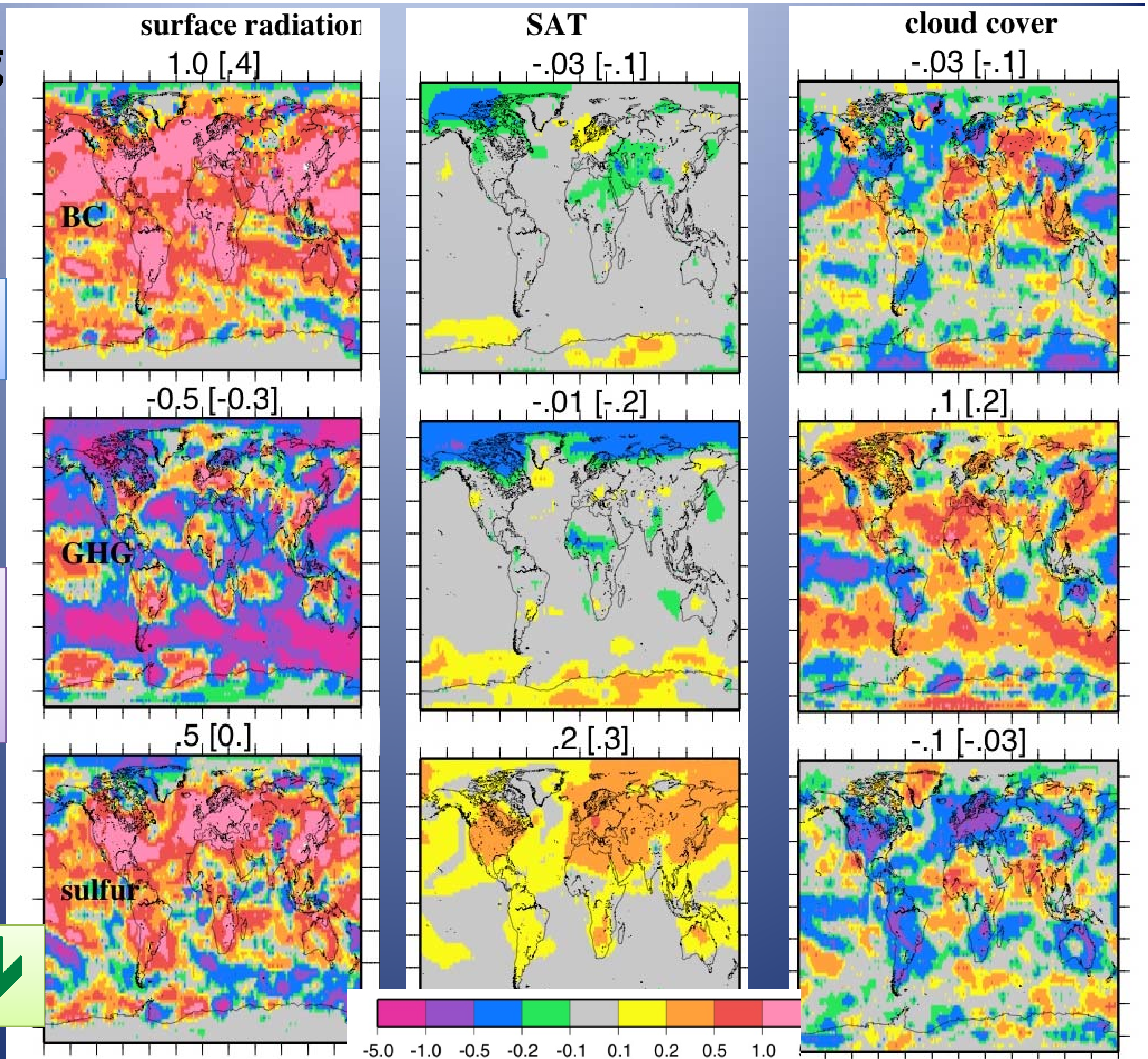


Unmasking !

BC ↓

GHG= 1970

Sulfur ↓

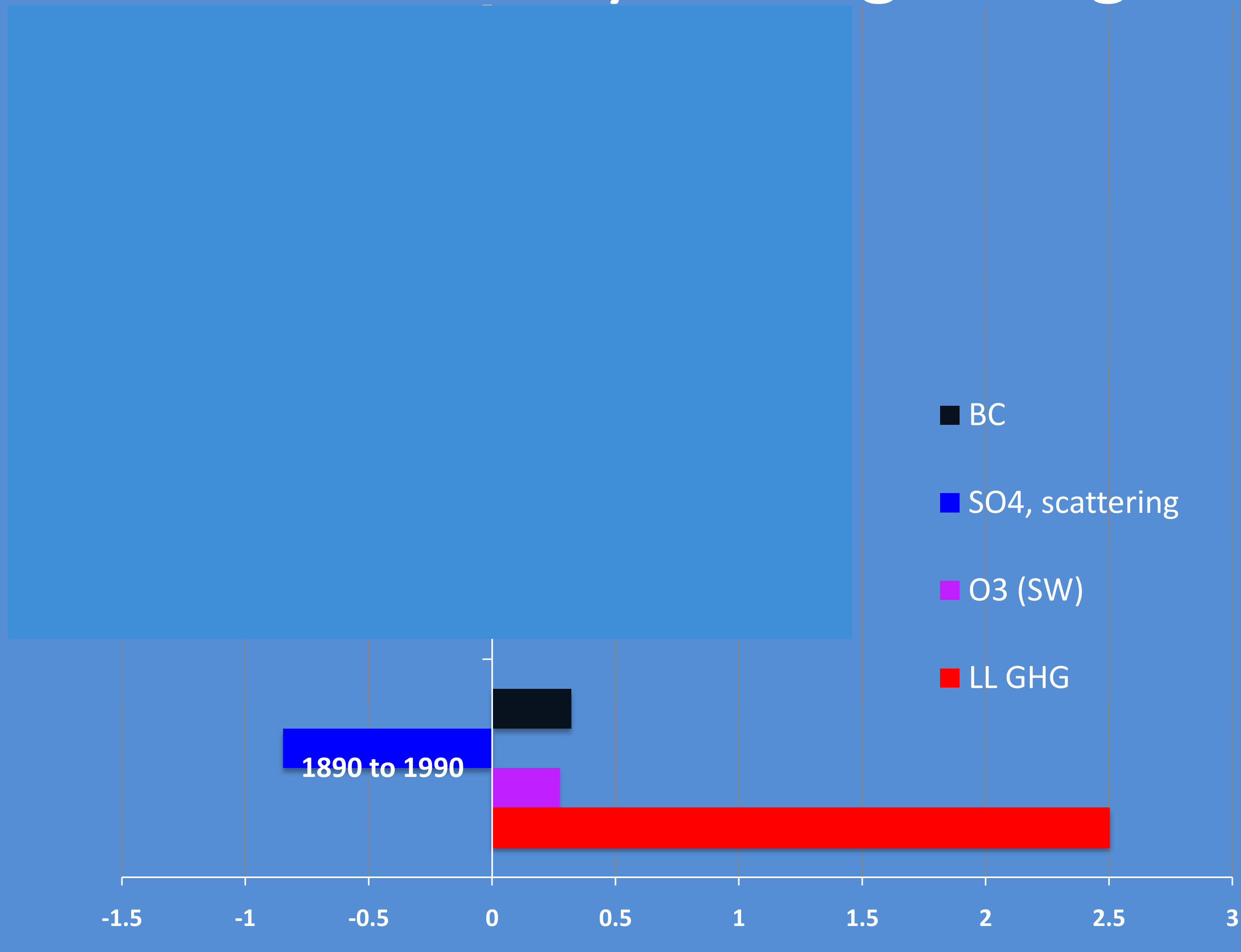


Conclusions

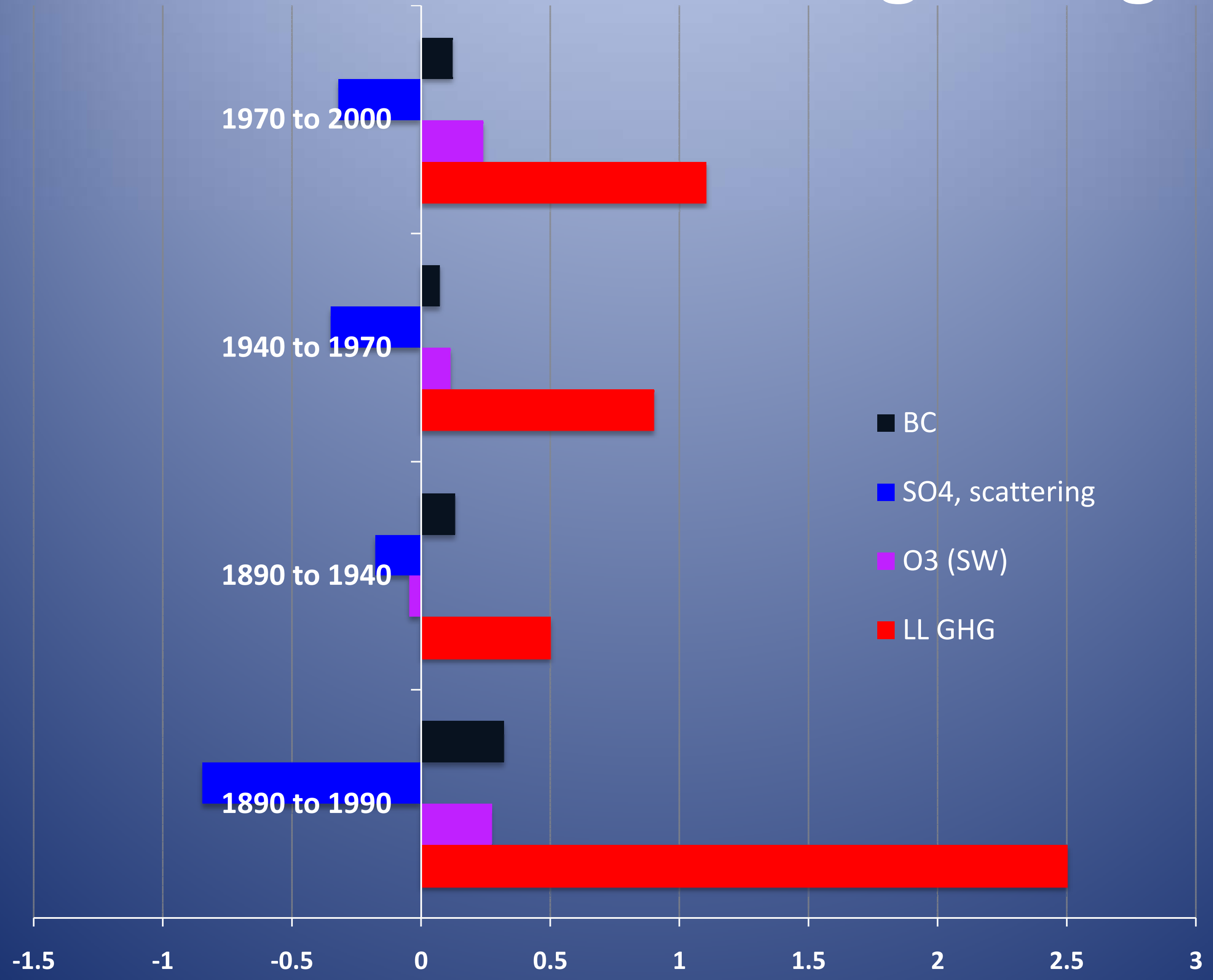
1. Aerosols during the 20th century climate:
   a) 1900-1950: Coal burning from Europe/North America ➔ Black Carbon, warmed and contributed to increased Arctic ice/snow melt.
   b) 1950-1980: Oil/gas from Europe/North America ➔ Sulfate ➔ dimming and reduced climate warming
   c) 1980-2000: Air quality/acid rain concerns ➔ Reductions in European/North American pollution ➔ brightening and warming. Developing (low latitude) regions continue to pollute.

2. IN OUR MODEL, BC reduction is less effective cooling strategy than GHG reductions because of cloud responses. Climate/hydrologic responses (not just radiative forcing) need careful consideration in mitigation strategies!

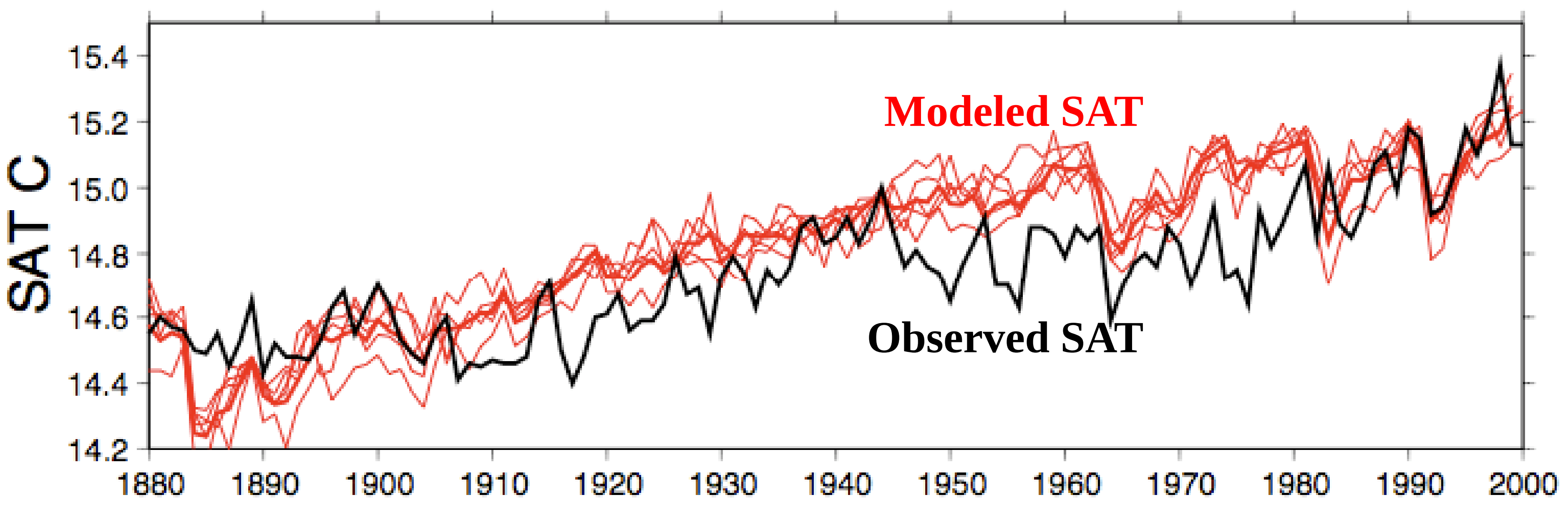
20th century forcing changes



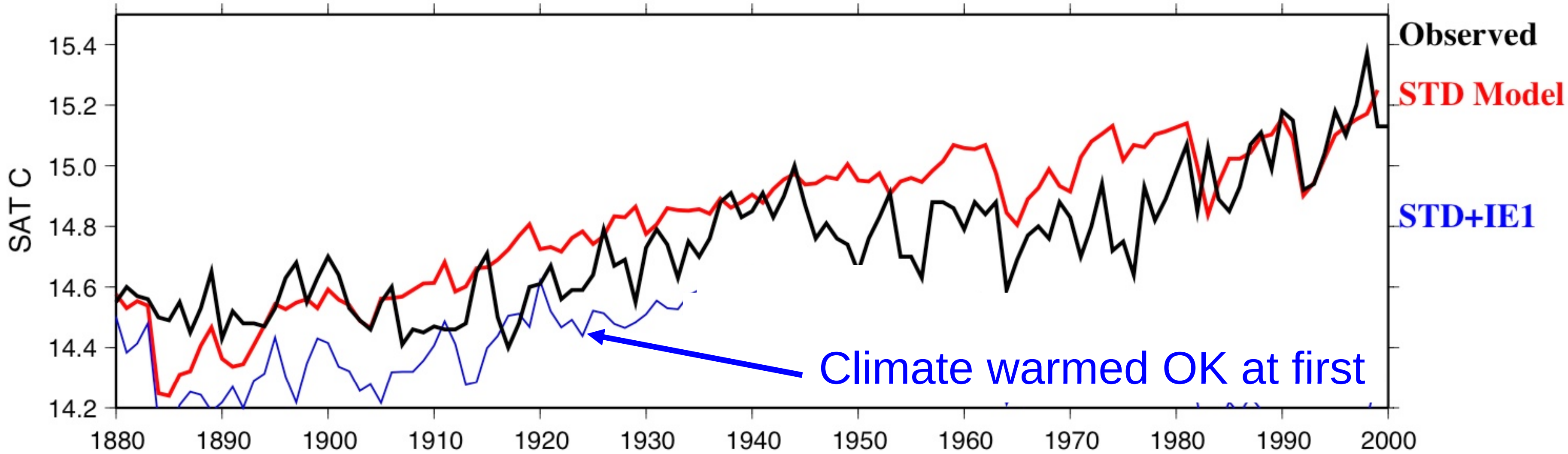
Another view of forcing changes



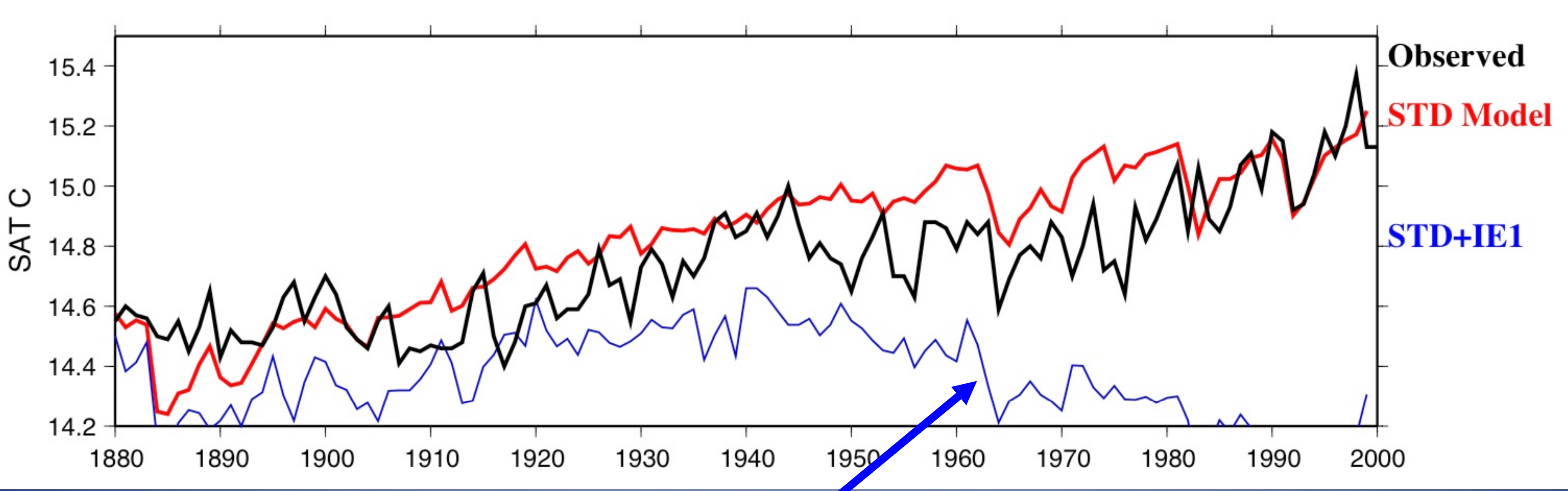
Surface Air Temperature (SAT) trend without indirect effect



SAT trend with the indirect effect

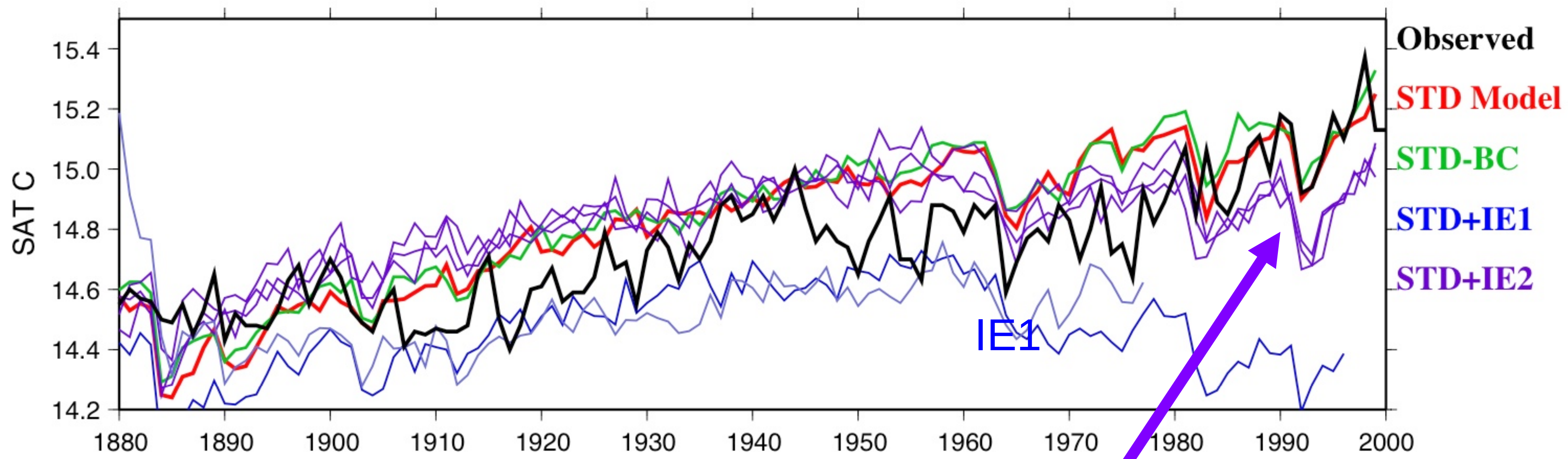


SAT trend with the indirect effect



Then climate went COLD!!!!

Trend in Surface Air Temperature



We weakened the indirect effect.
Other models are having a similar experience as they prepare for AR5.
These climate experiments are an excellent challenge for the indirect effect, the most uncertain and maybe most important aerosol effect.