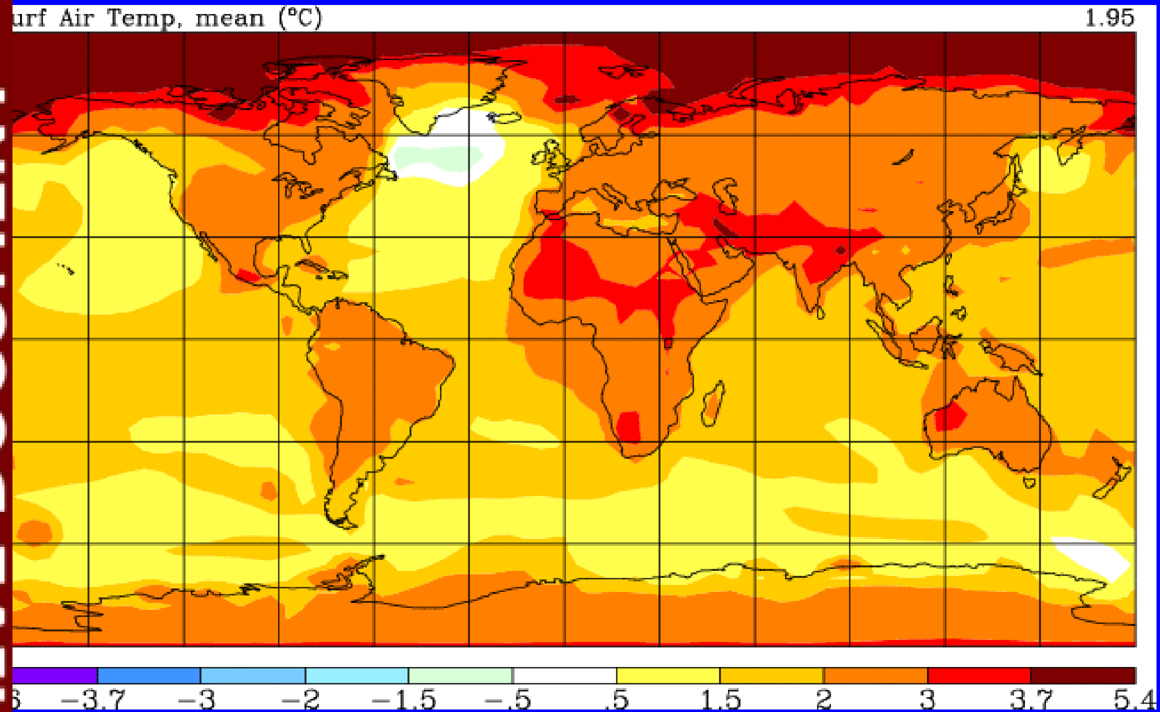
Climate Impacts of Short-lived Pollutants

Drew Shindell

Climate response to Short-lived forcers

- How do we think about climate impacts when short-lived species are involved?
- Forcing is a useful metric to characterize the multiple responses to forcing from long-lived greenhouse gases
- Climate response to short-lived species is far more sensitive to where and when pollutants are emitted

Climate response to Short-lived forcers



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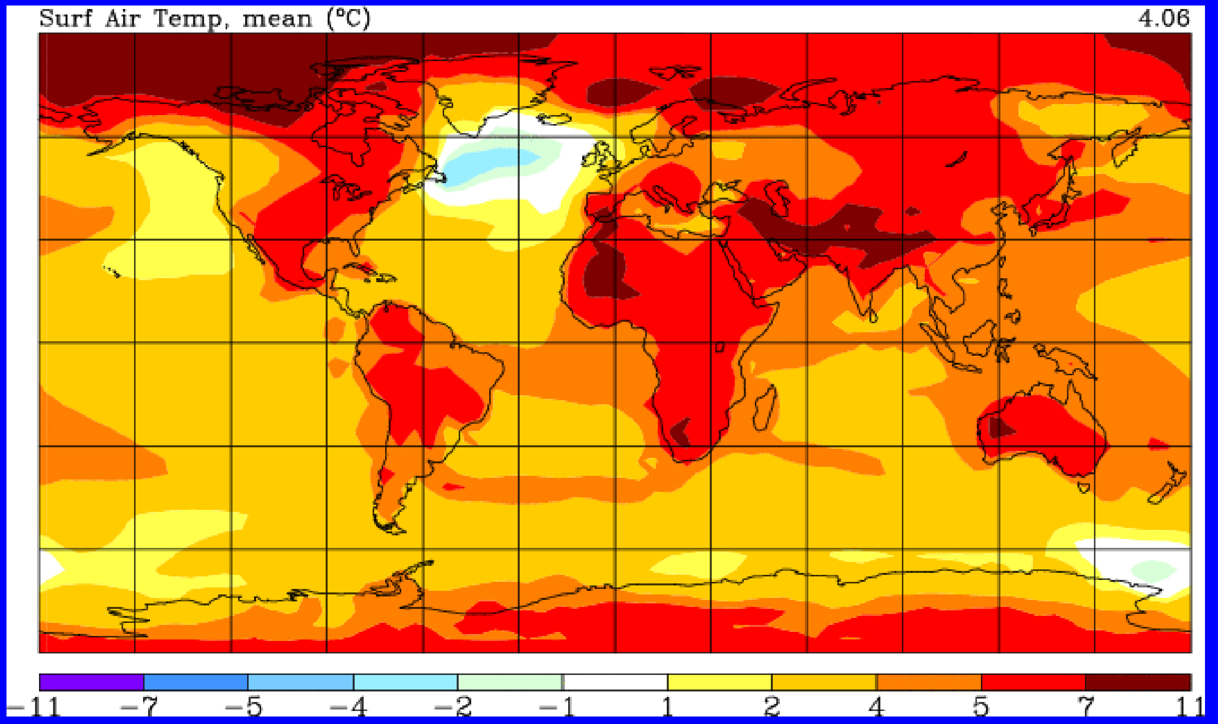
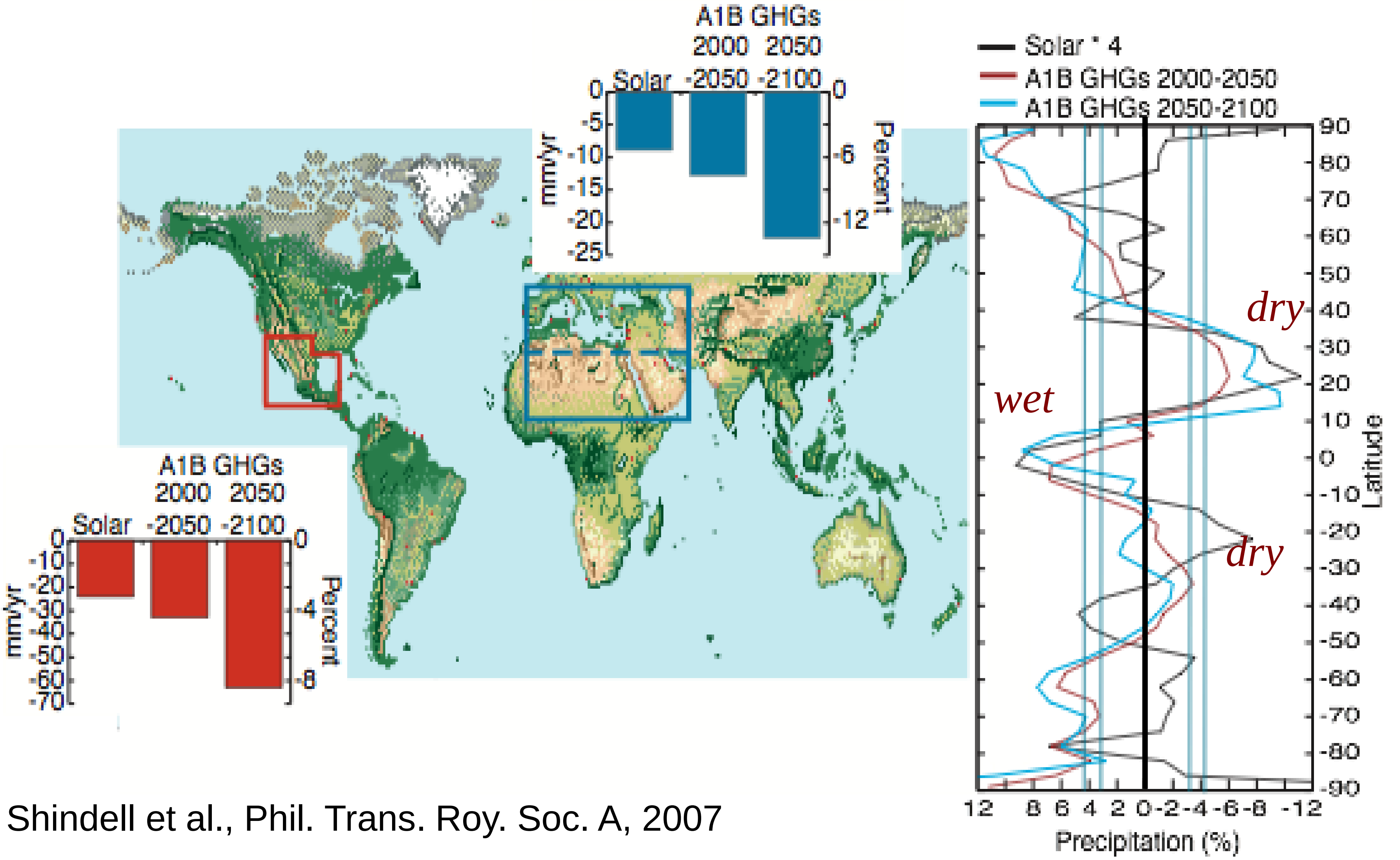


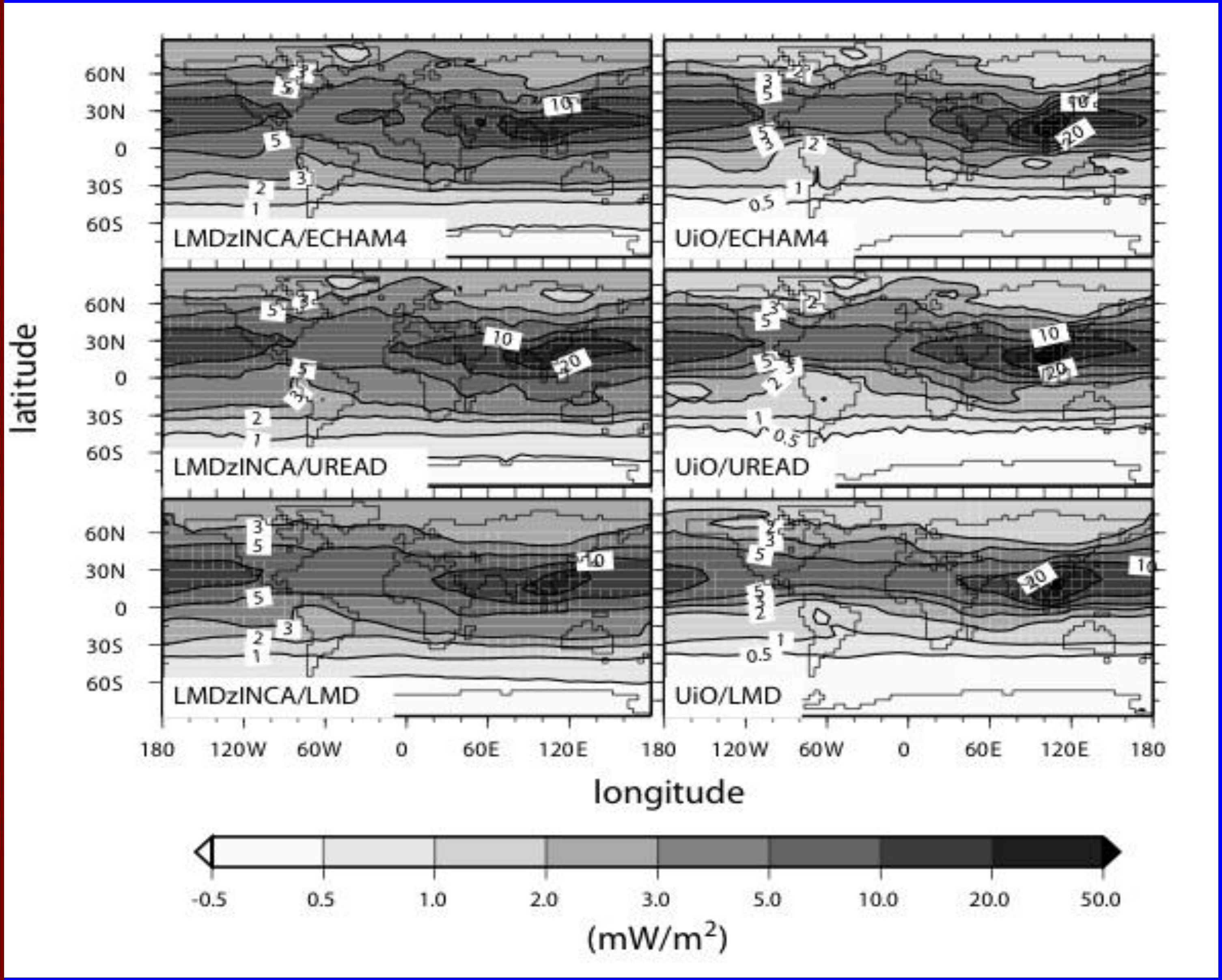
Climate response to Short-lived forcers



Shindell et al., Phil. Trans. Roy. Soc. A, 2007

Ozone Forcing:

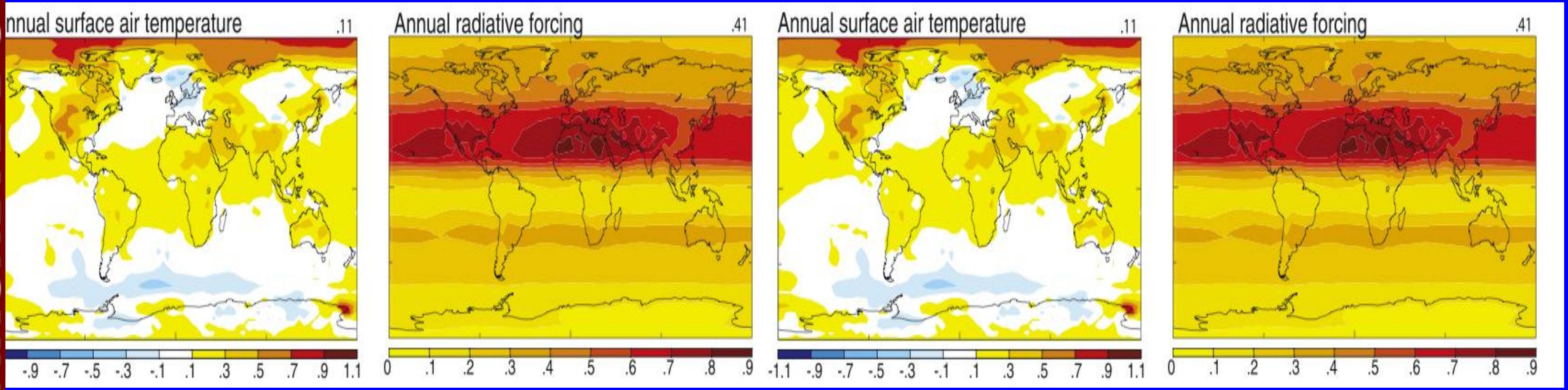
Not localized to emission region; robust!



- +1 TgN/yr NOx from Asia
- Ozone forcing using different CTMs (columns) & GCMs (rows)
- Berntsen et al., Tellus, 2005

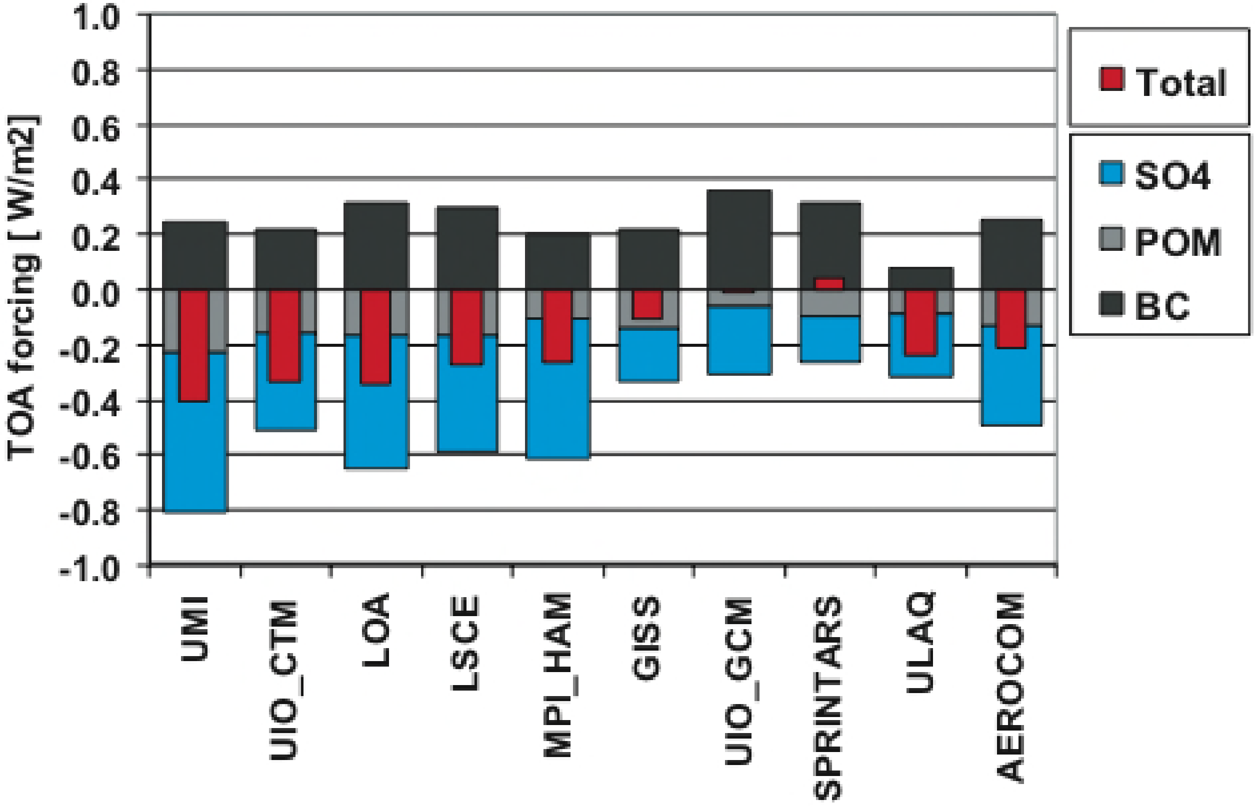
Ozone Forcing:

Not localized to emission region; robust!



Shindell et al, JGR, 2006

Aerosol Forcing



Mean clear-sky forcing -0.68 (range: -0.29 to -0.94)

Mean cloudy-sky forcing -0.02 (range: -0.16 to 0.34)

Mean clear-sky RF over land and ocean: -0.59 and -1.14

Satellite clear-sky RF over land and ocean: -1.10 and -1.80

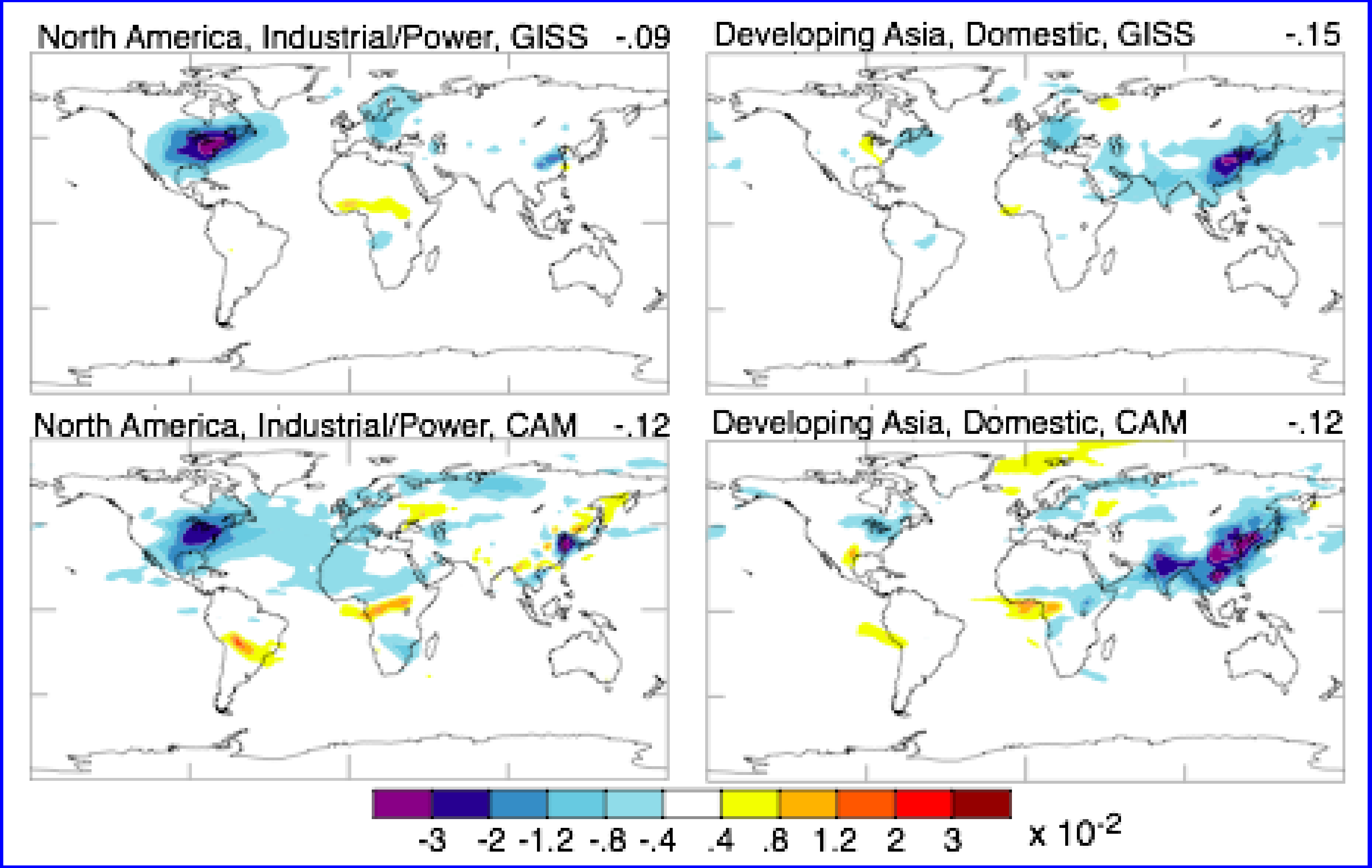
- Ramanathan & Charmichael (Nature Geoscience, 2008) give 0.9 W/m^2 TOA forcing, based on satellite & ground-based obs driven calculation

- Chung & Seinfeld give 0.60 W/m^2 for internally mixed (0.33 for externally)

Schulz et al, ACP, 2006

Aerosol Forcing

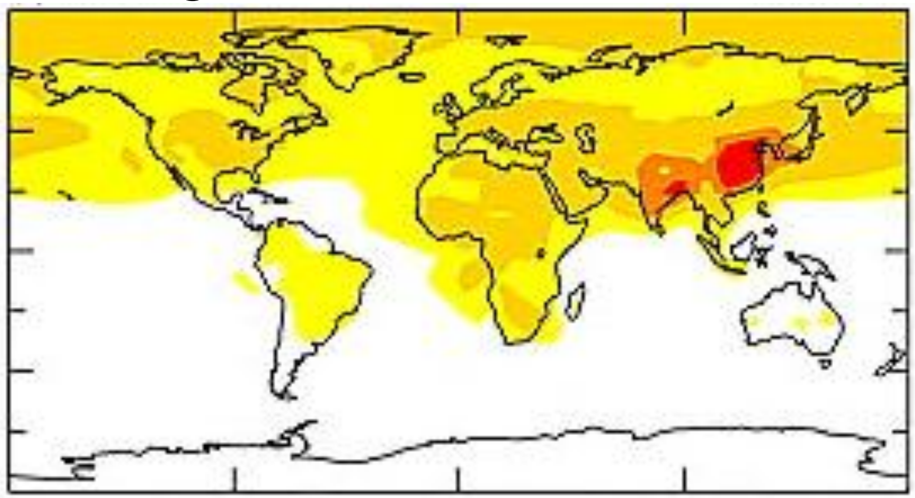
Continued



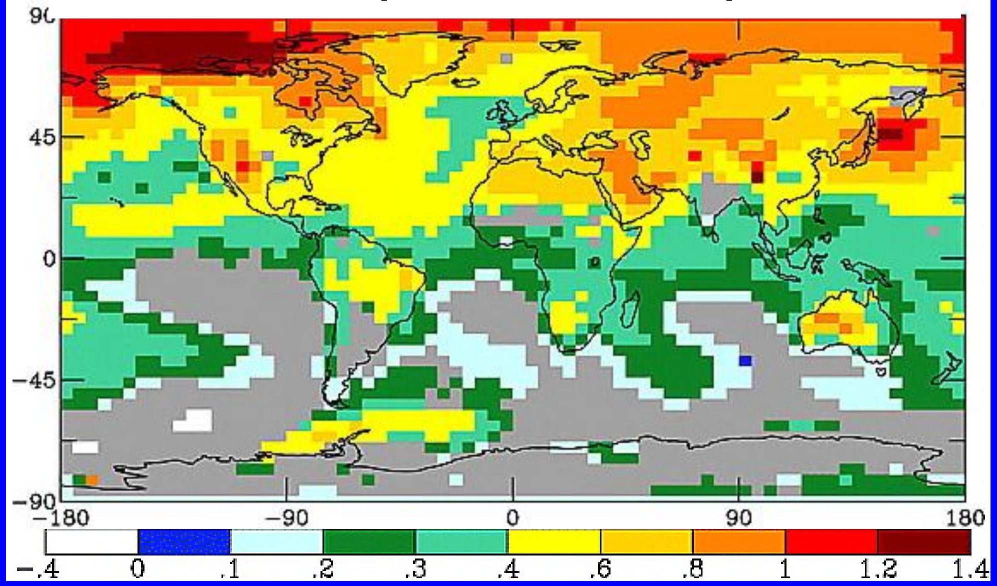
Shindell et al., ACP, 2008; CCSP3.2

Model results

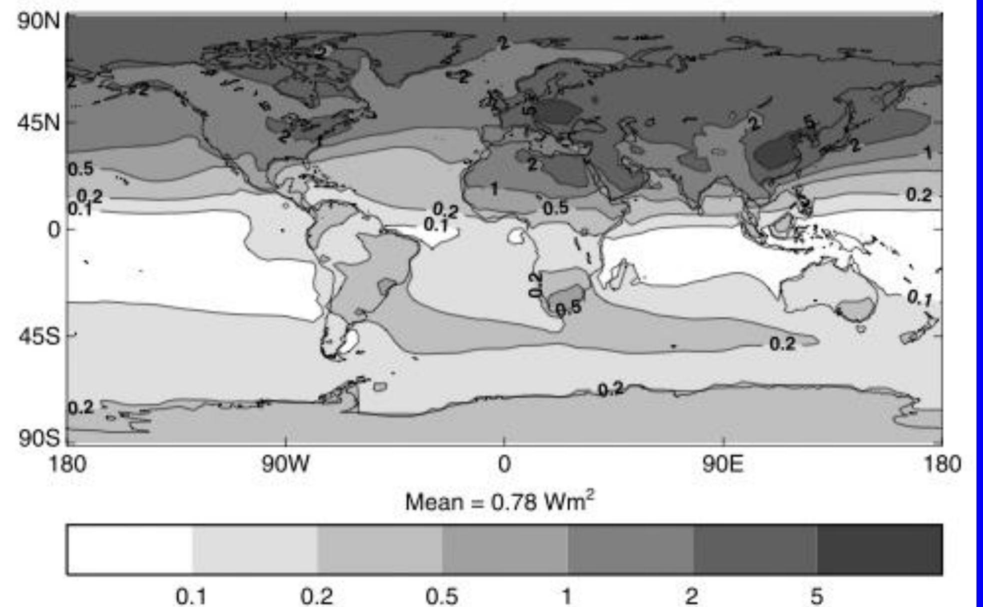
Forcing

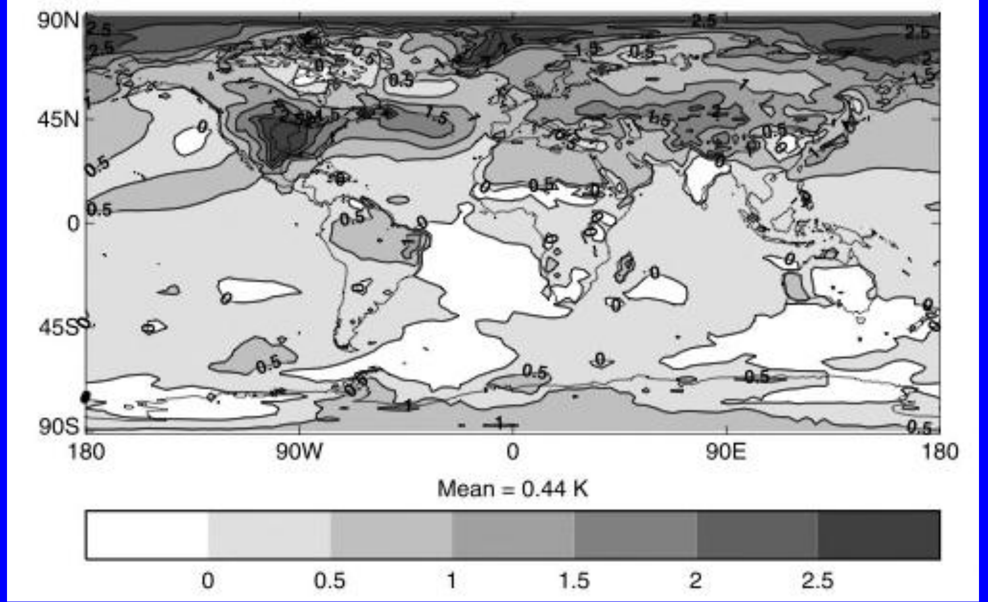


Surface temperature response



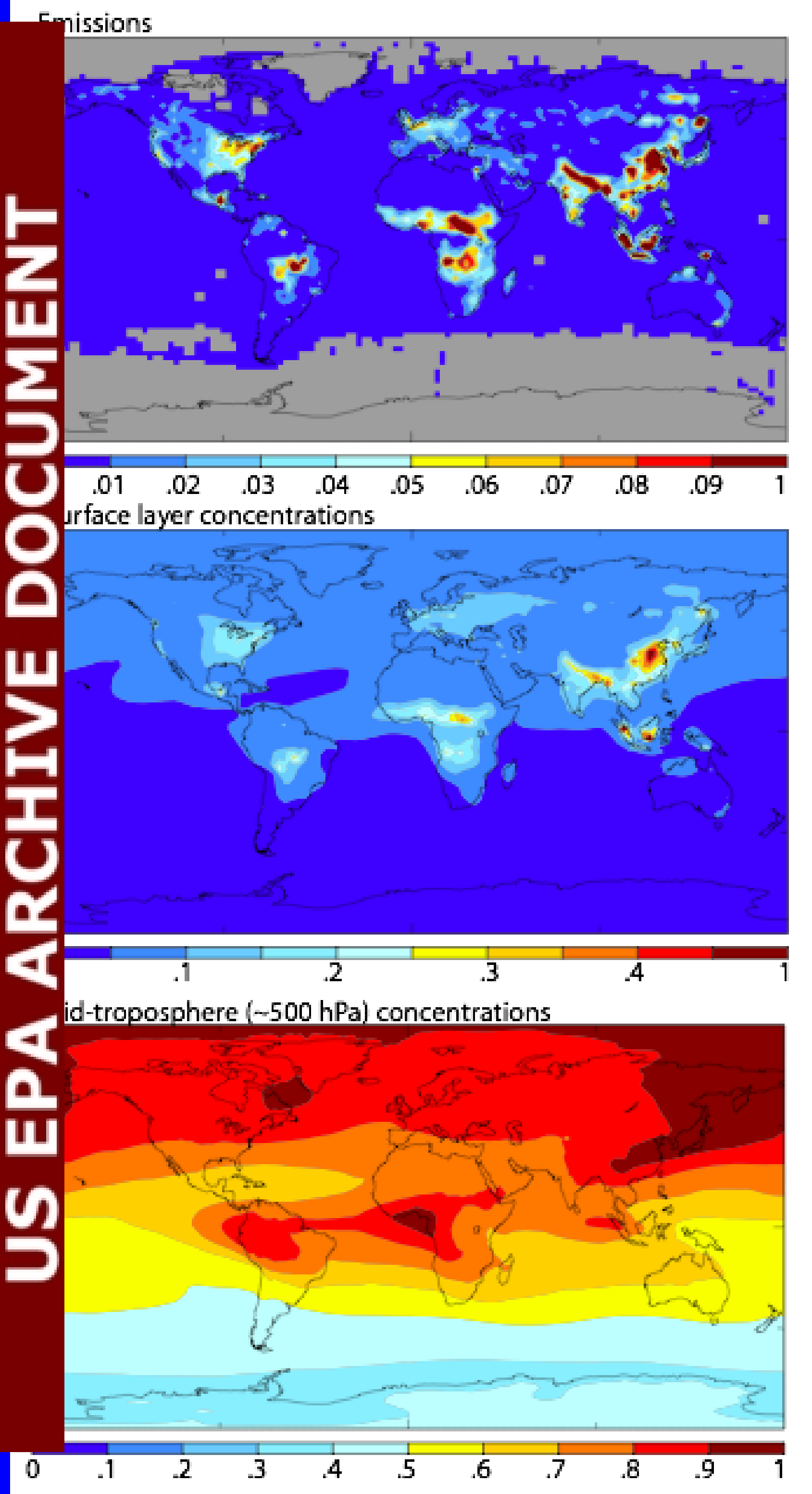
Chung & Seinfeld, JGR, 2005





Roberts & Jones, JGR, 2004

Forcing & Response length scales

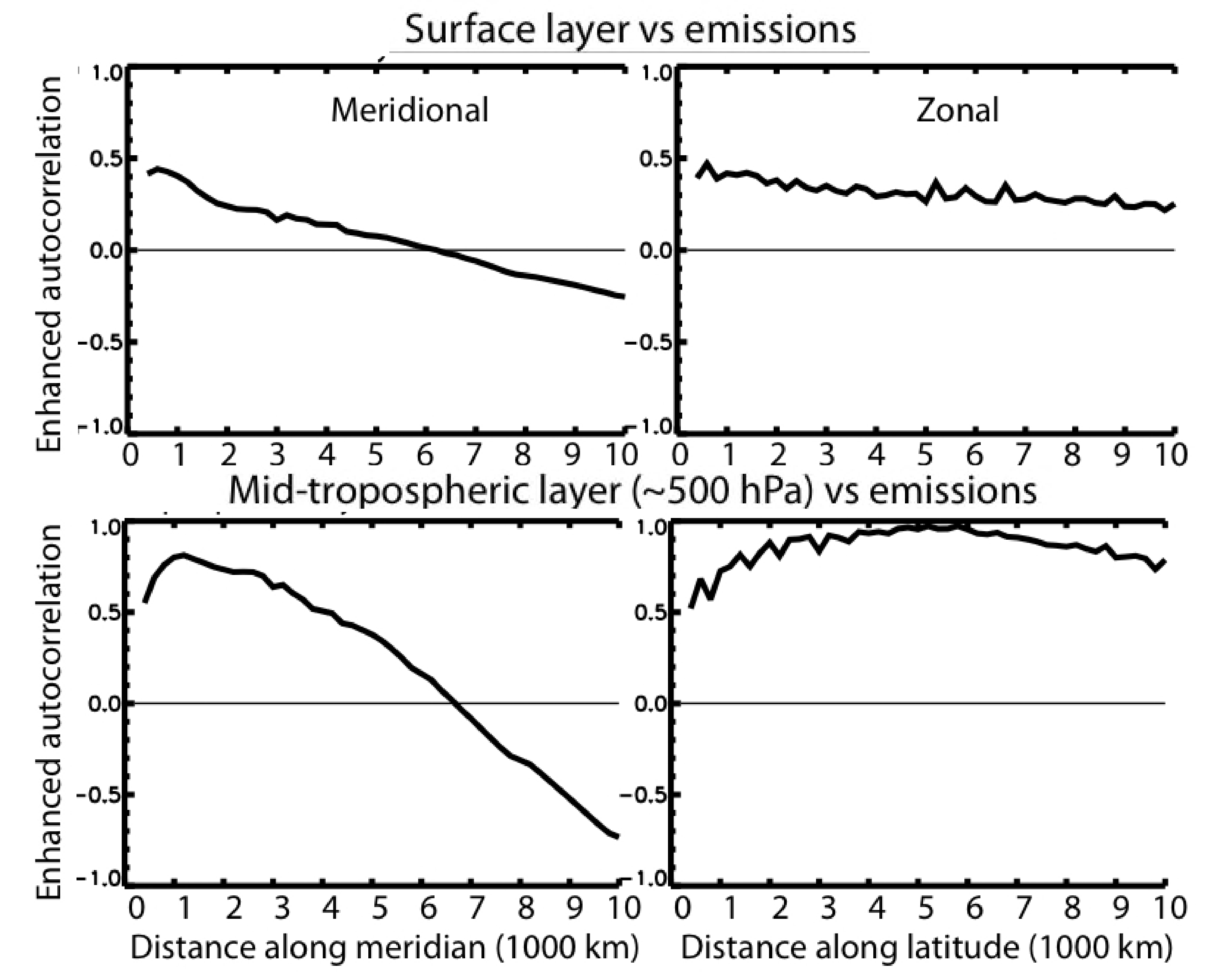


Emissions

Surface concentrations

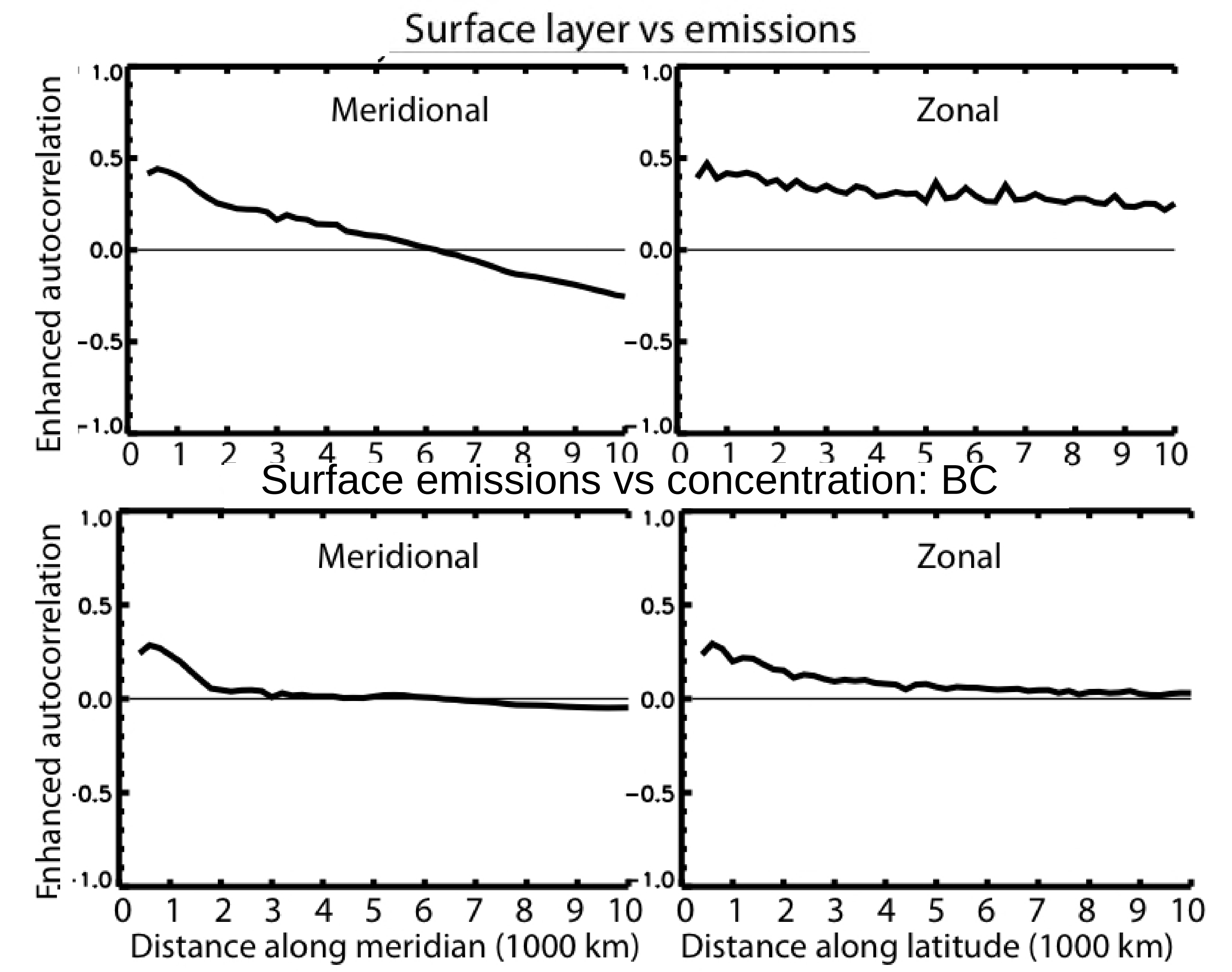
Mid-troposphere concentrations

Forcing & Response length scales



Shindell, Schulz, Takemura, Ming et al, in review

Forcing & Response length scales



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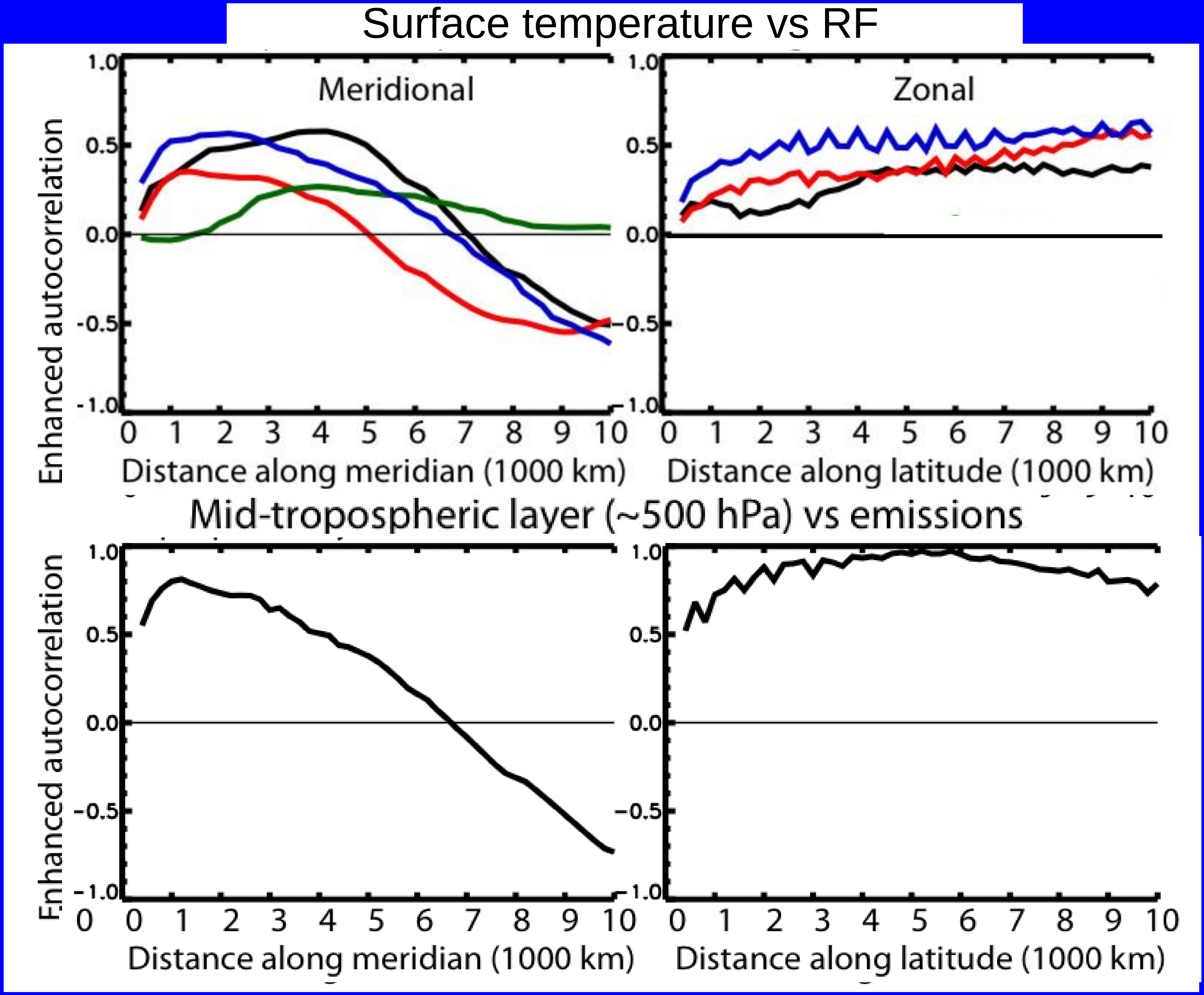
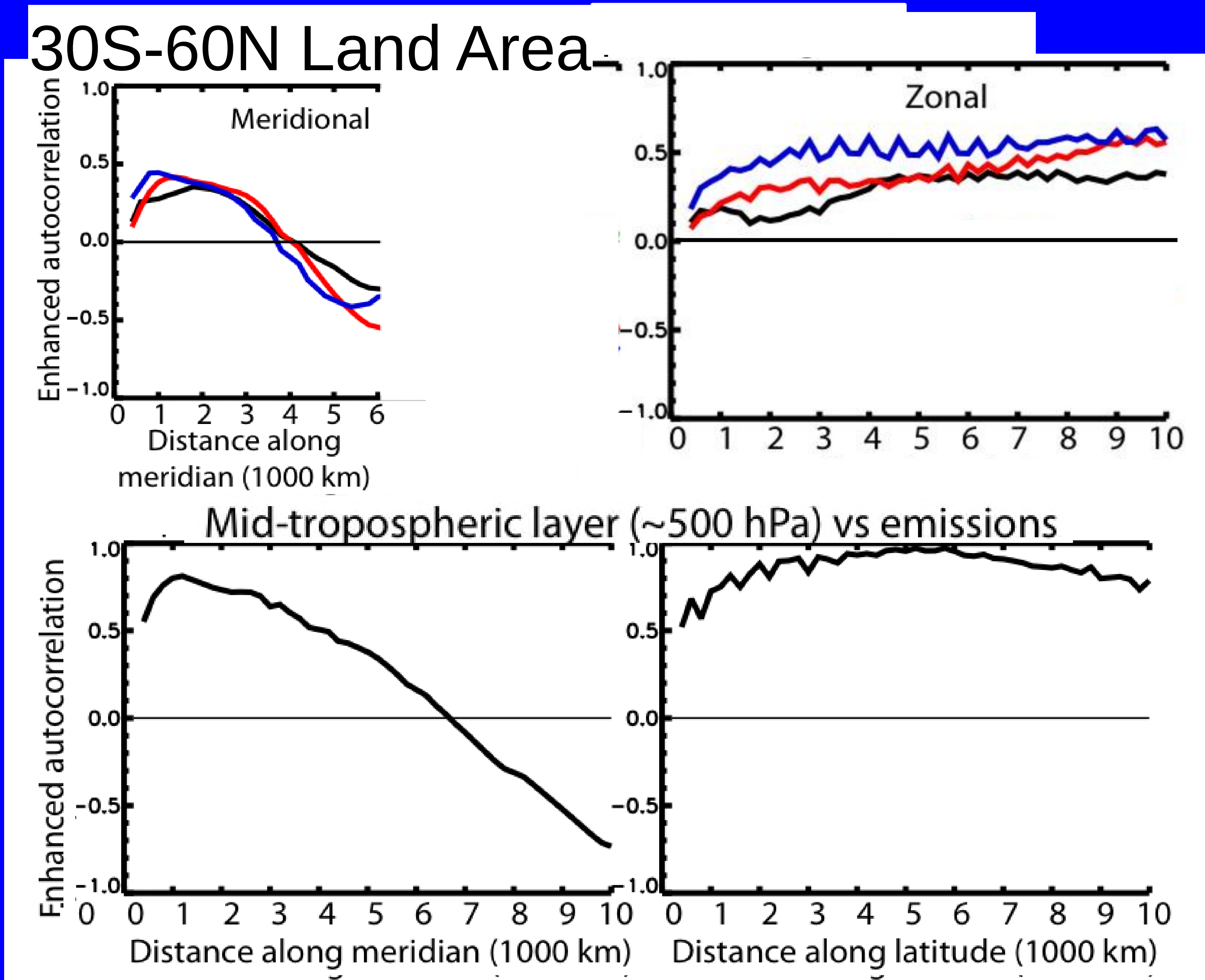
Forcing & Response length scales



Shindell, Schulz, Takemura, Ming et al, in review

Forcing & Response length scales

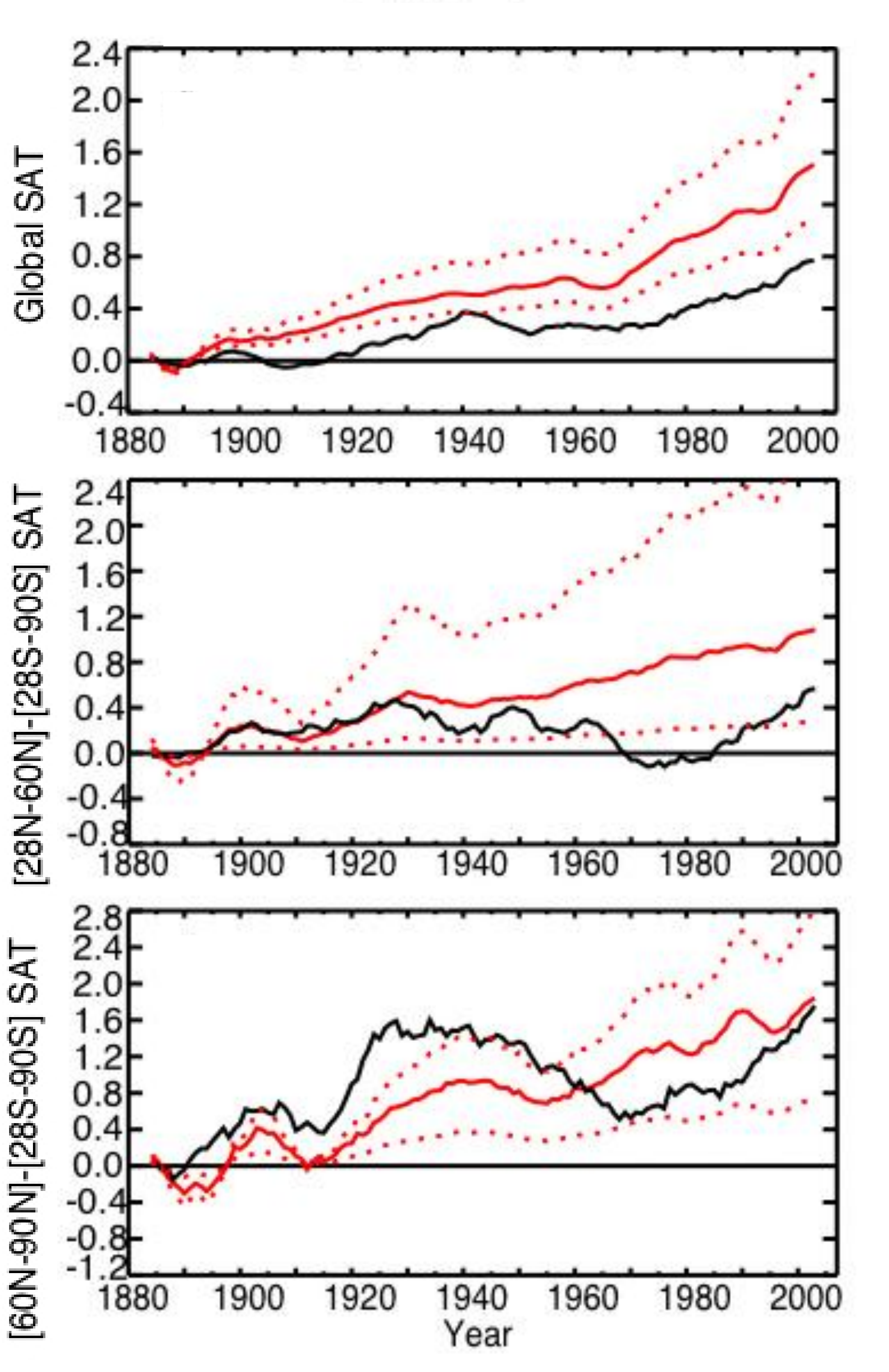


Shindell, Schulz, Takemura, Ming et al, in review

Response to regional forcing

- Climate forcing from methane changes mostly clear
- Climate forcing from ozone precursor changes fairly clear
- Climate forcing from aerosol precursor changes less clear
- Effect of regional forcing on temperature getting clearer; namely, localized out to ~30 degrees in latitude (tropics/extratropics), impact can extend far beyond highly polluted areas in longitude
- Also know that GLOBAL climate response enhanced ~40-50% for NH extratropical forcing (feedbacks)

Using Observed Patterns

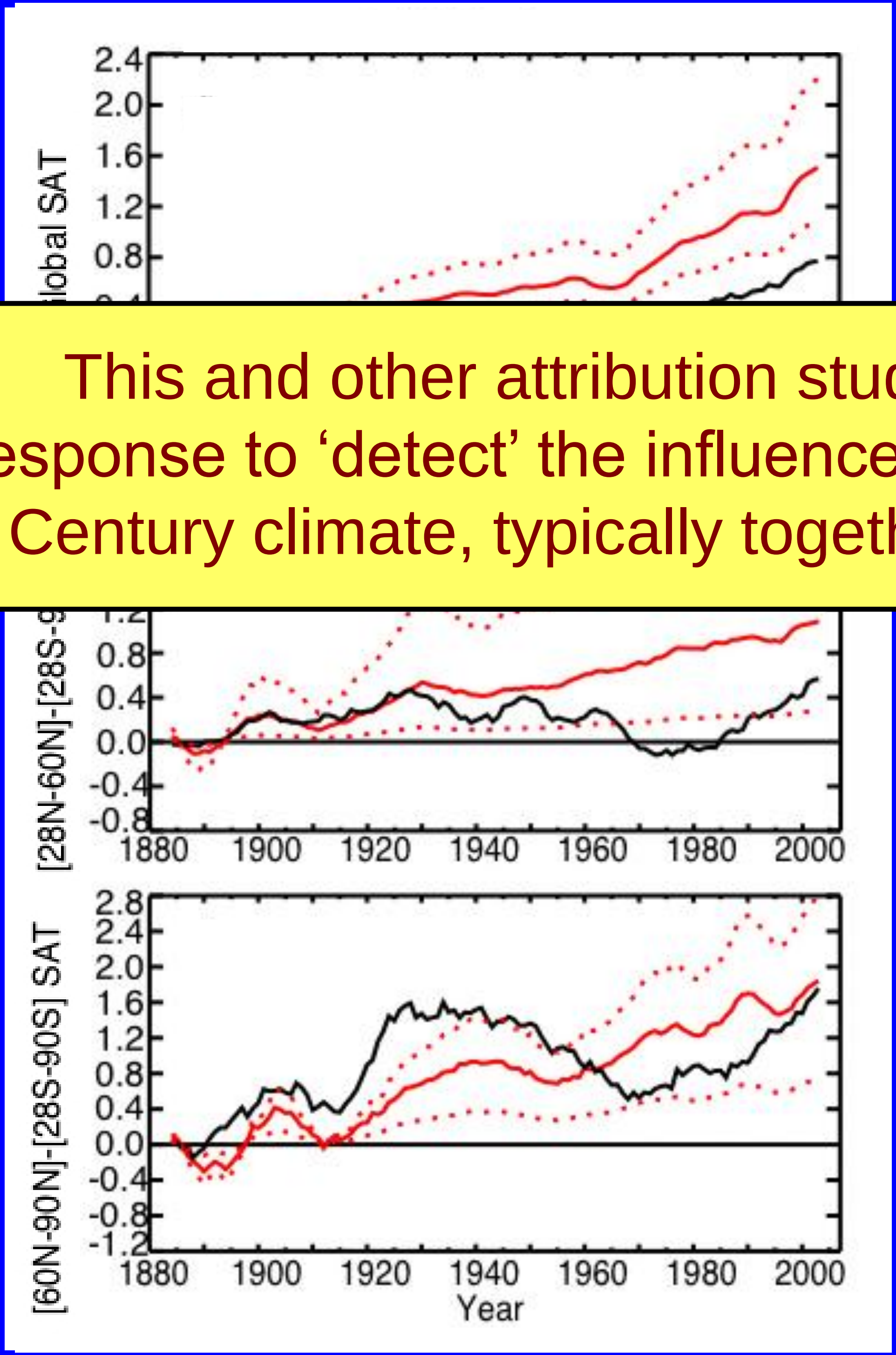


•Black Line: Observed temperatures

•Red Line: CMIP3 mean and range of model responses to greenhouse gas, natural, and ozone forcing (no aerosols)

Shindell & Faluvegi, Nature Geoscience, 2009

Using Observed Patterns

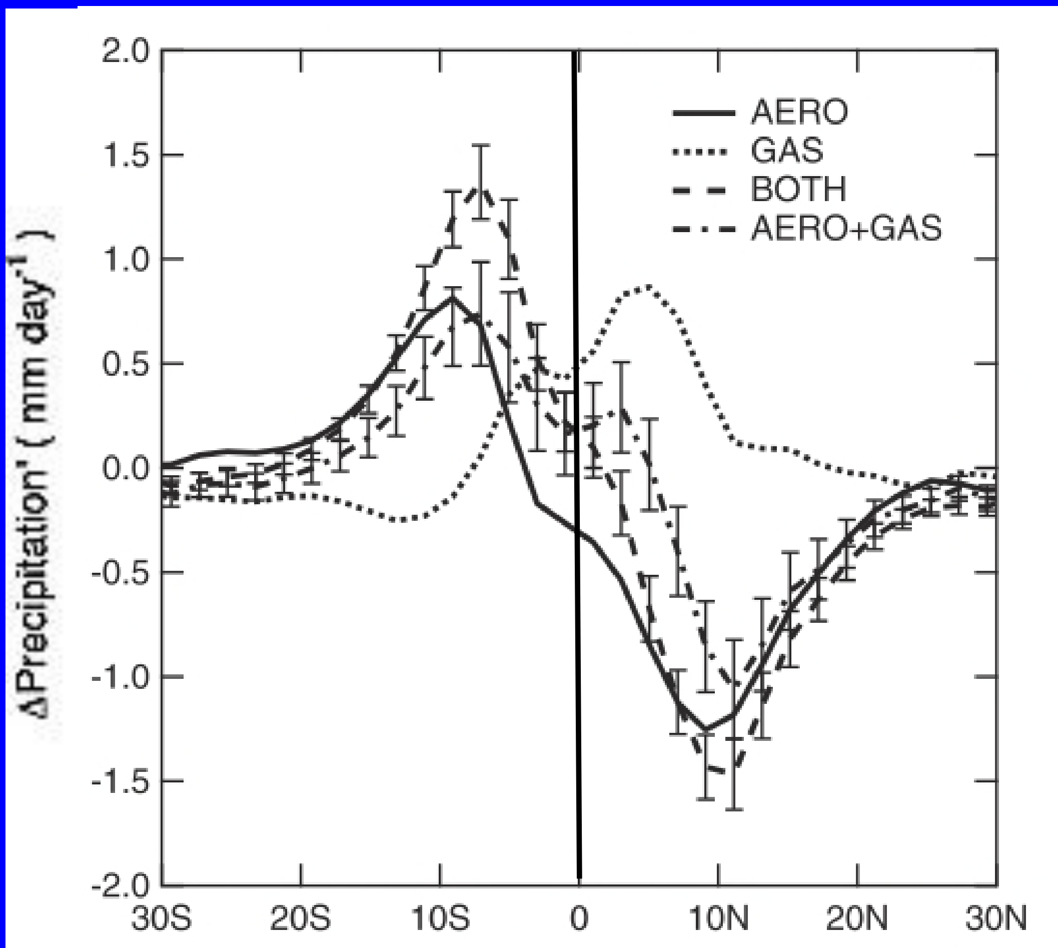


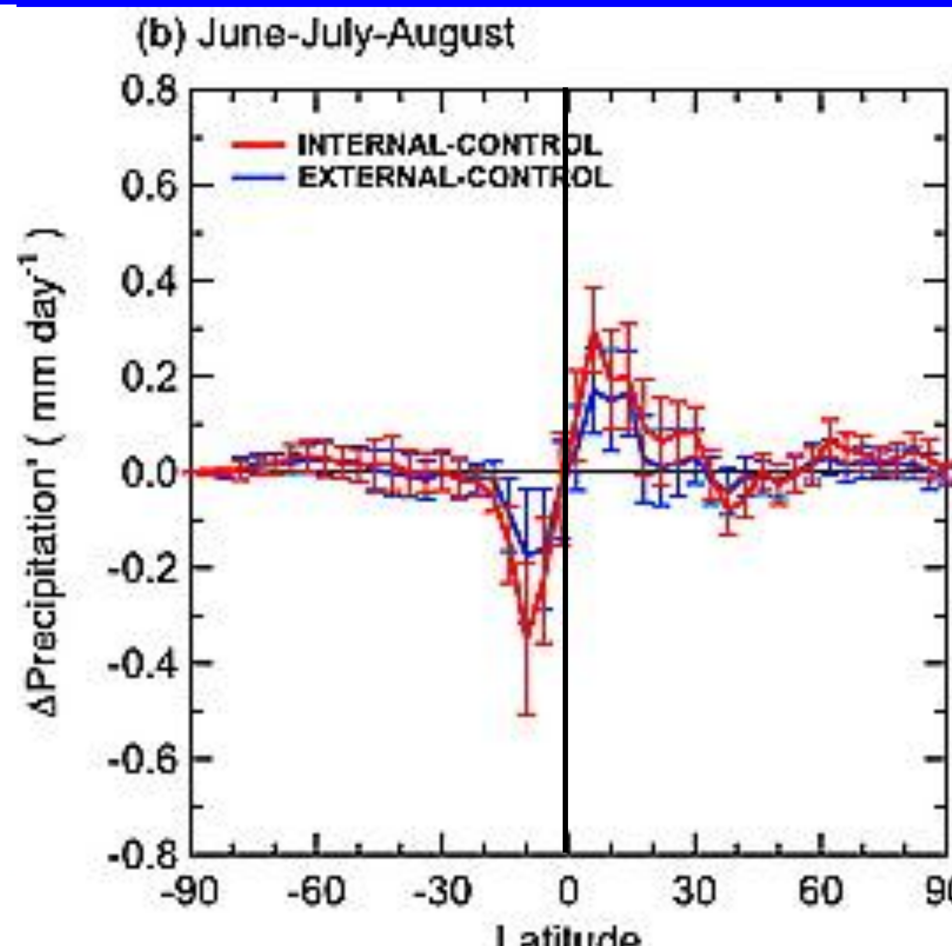
This and other attribution studies have used the pattern of response to ‘detect’ the influence of sulphate and BC/OC on 20th Century climate, typically together as patterns are degenerate

range of model responses to greenhouse gas, natural, and ozone forcing (no aerosols)

Shindell & Faluvegi, Nature Geoscience, 2009

Effect of aerosols on precipitation





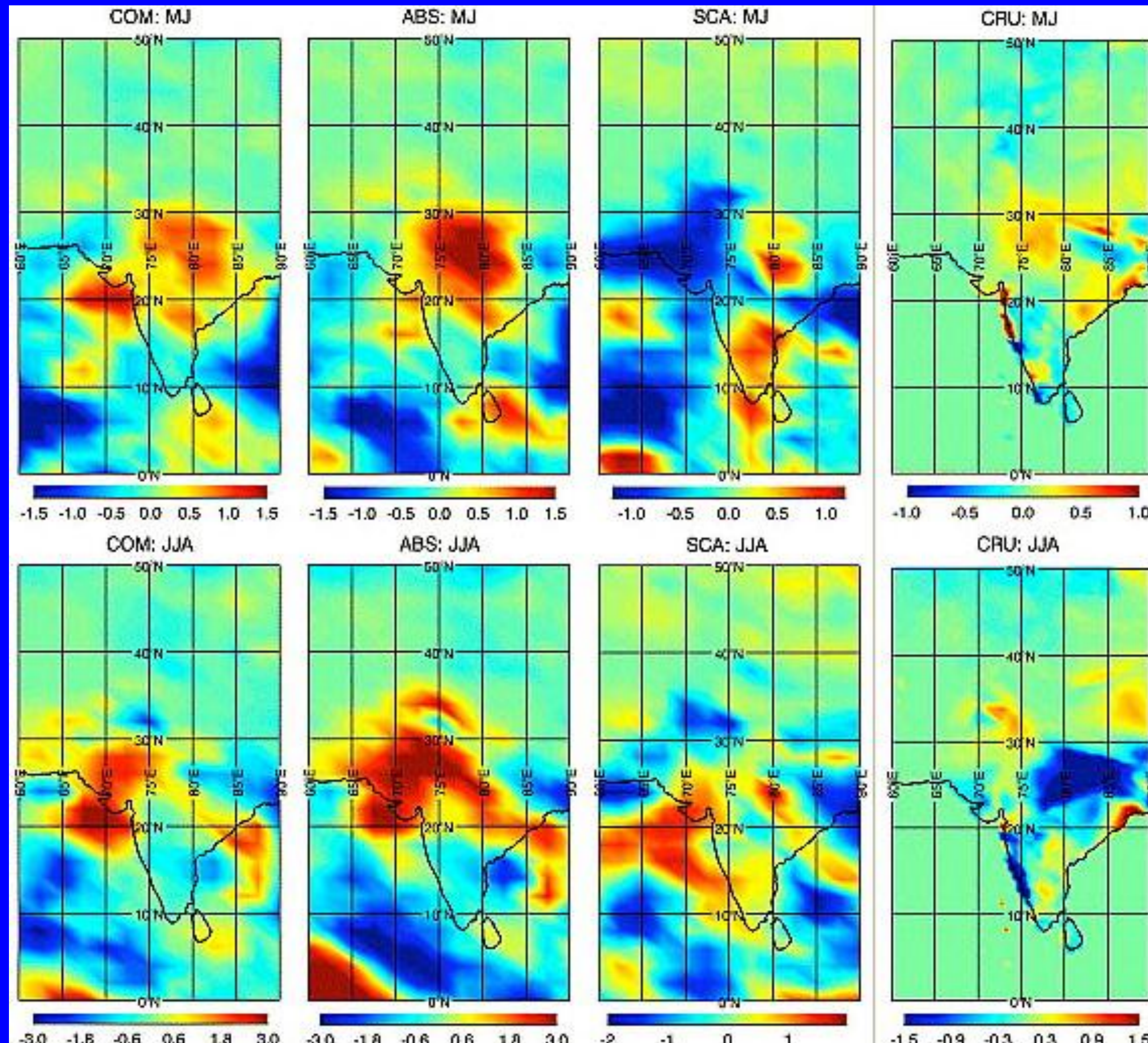
All aerosols, Annual avg

BC aerosols, Jun-Aug

Ming & Ramaswamy, J Clim, 2009

Chung & Seinfeld, JGR, 2005

Effect of BC on monsoon precipitation



Combined Absorbing Scattering Observed
~1950-2000

Wang et al, GRL, 2009

Effect of BC on monsoon precipitation

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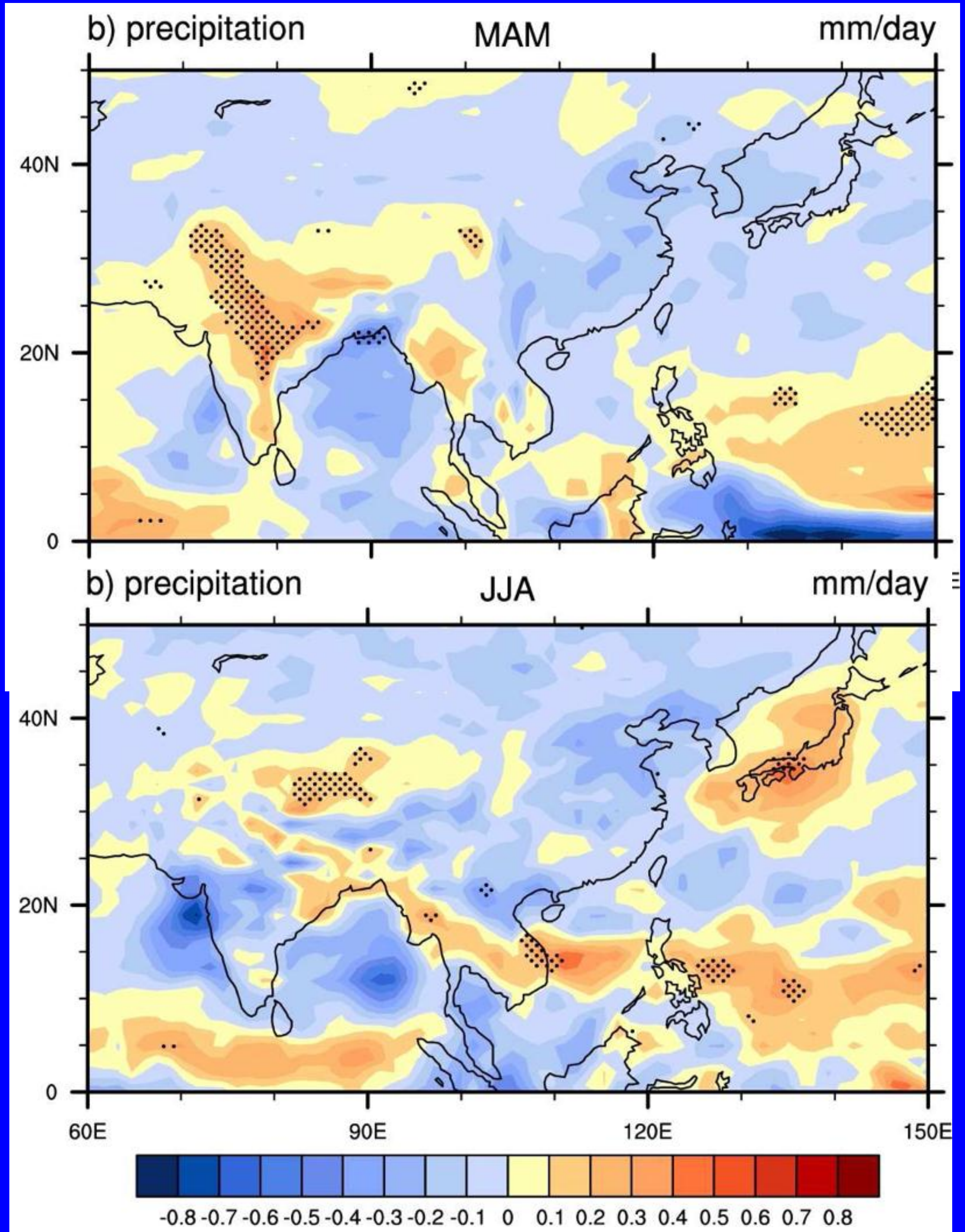

Meehl et al., J Clim, 2008

Wang et al, GRL, 2009

Effect of BC on monsoon precipitation

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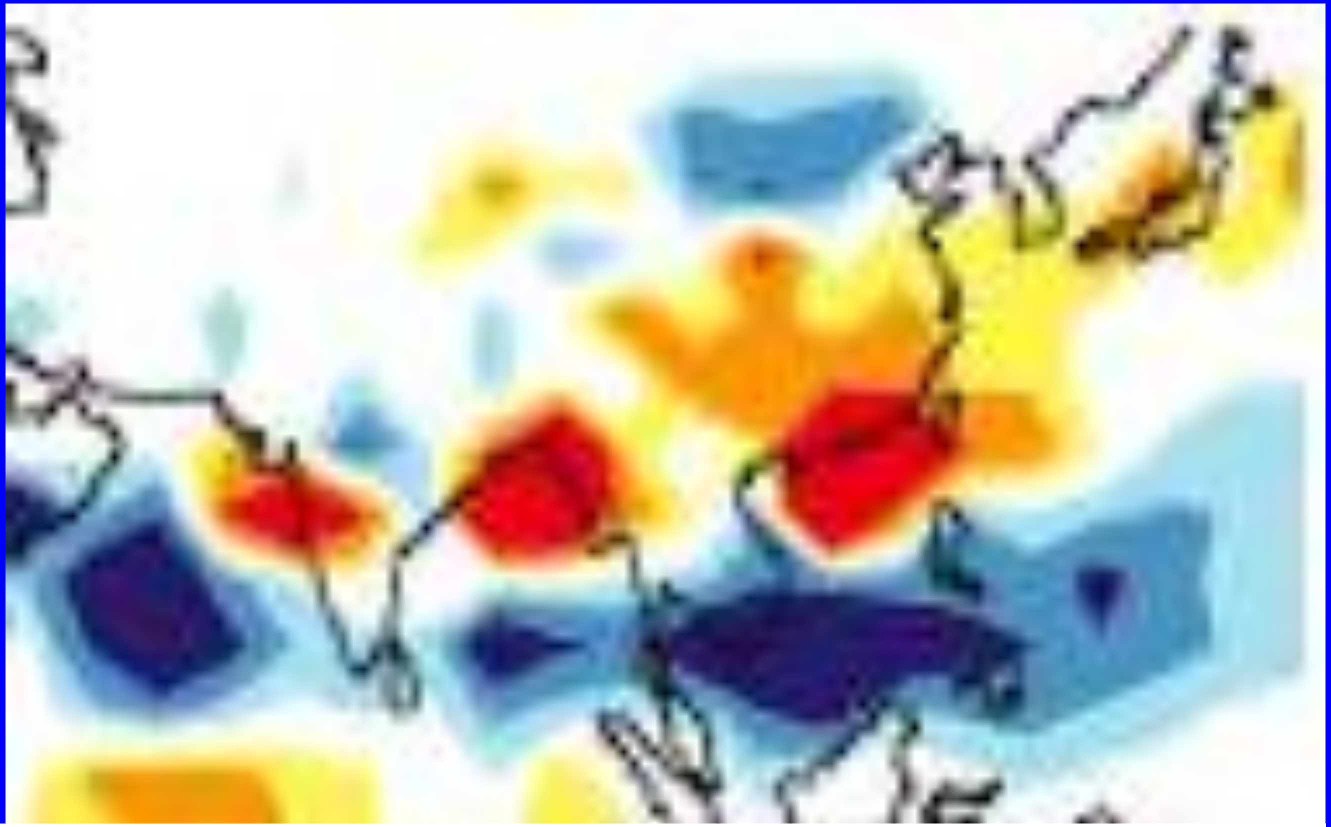


Menon et al., Science, 2002

Wang et al, GRL, 2009

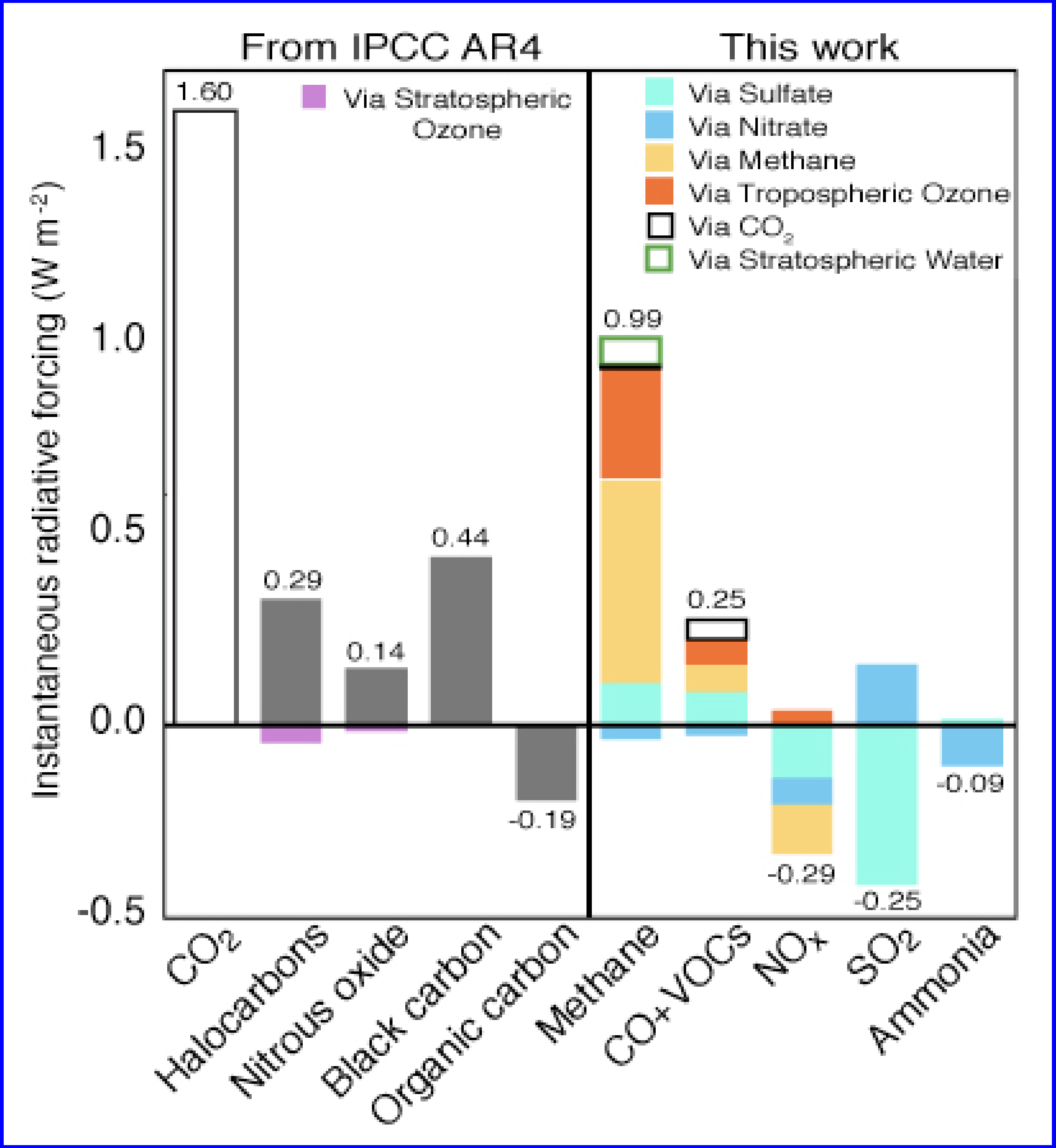
Dealing with uncertainty

- Although substantial uncertainties remain in current understanding, we can provide reasonable estimates of temperature change at large scales for a given forcing.

- Precipitation is harder (evaluation against observations), but also the impacts of any changes are more generally negative.

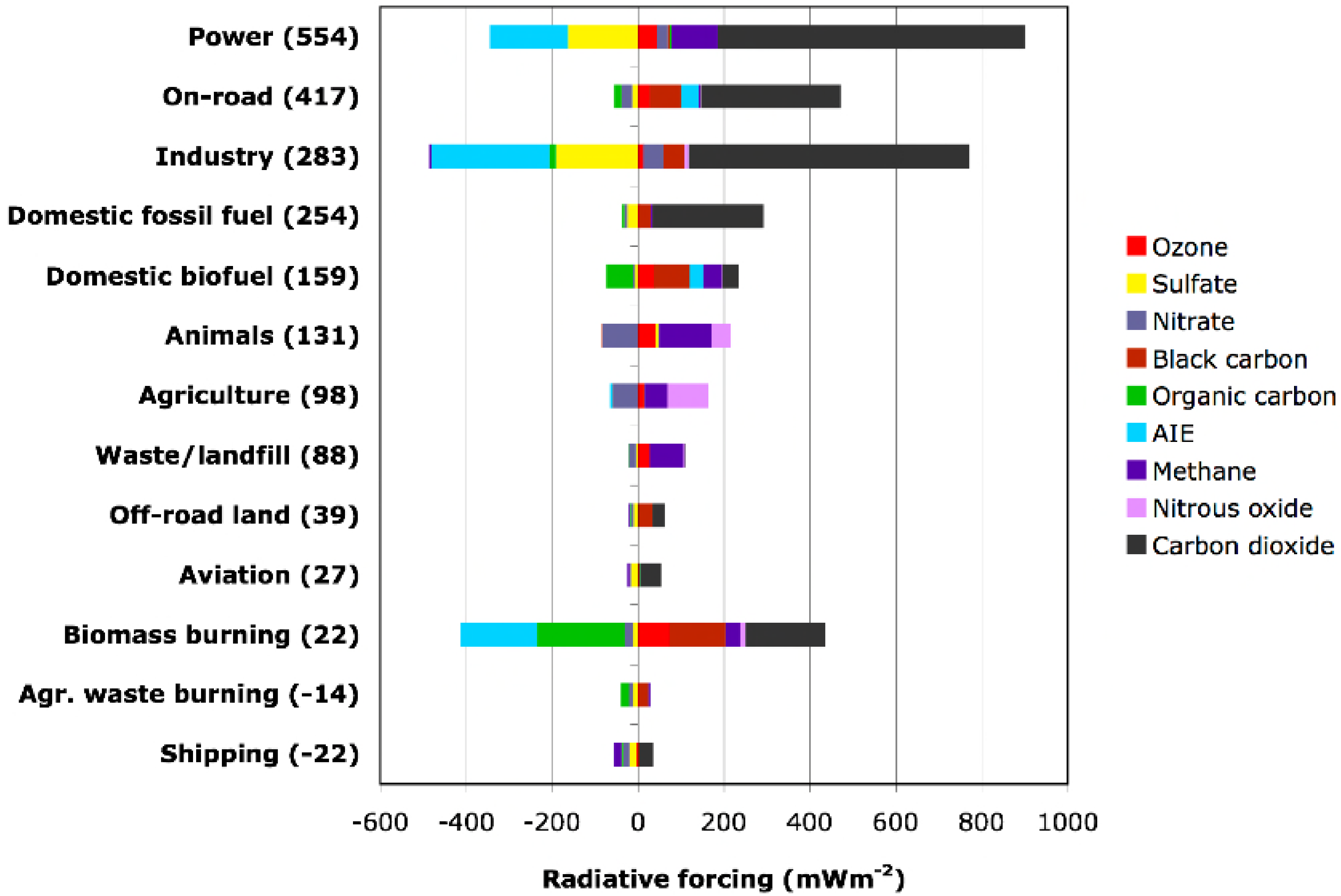
- We can estimate the climate impacts of realistic actions in the fact of uncertainty

Historical Forcing by Emitted Species



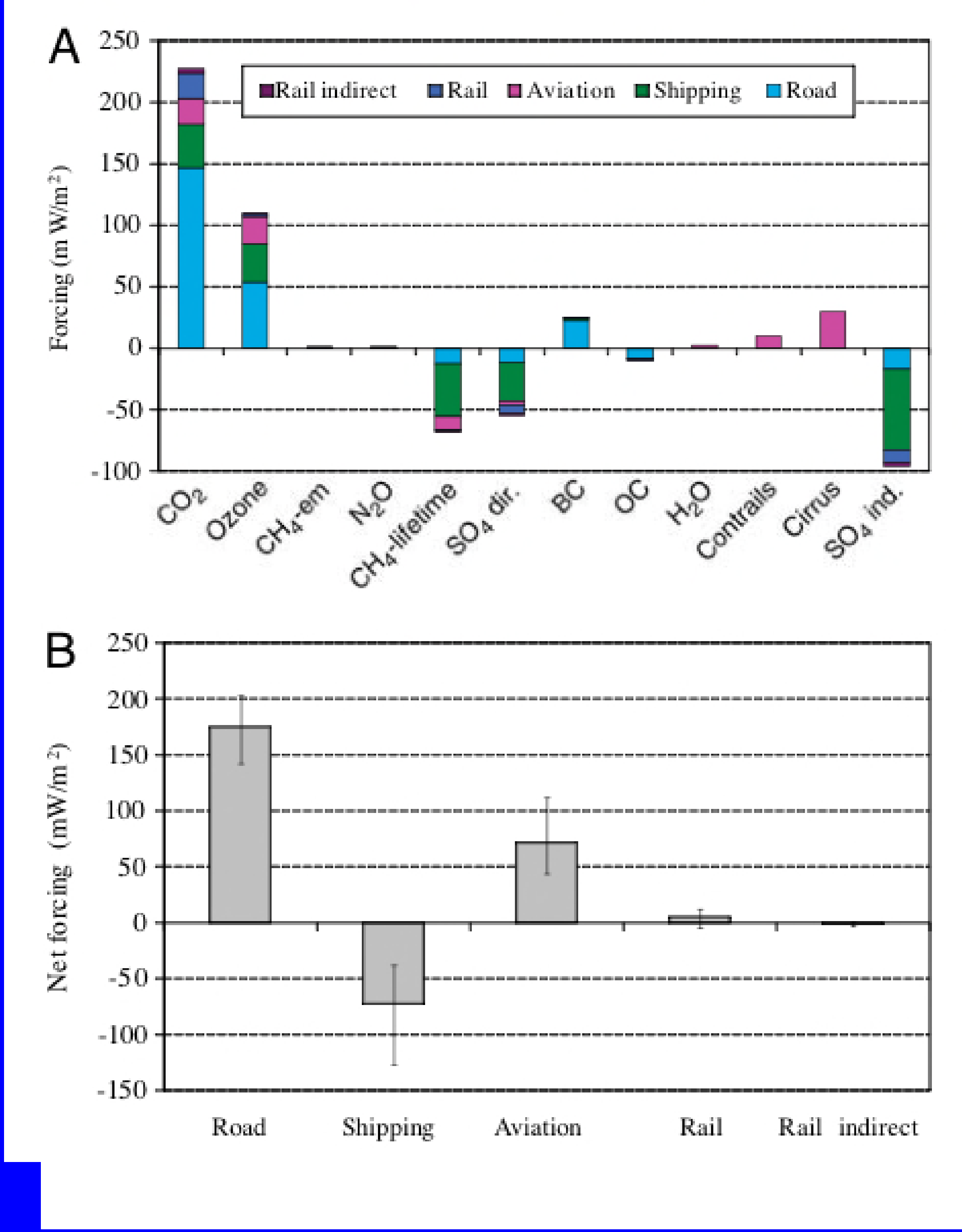
Shindell et al., Science, 2009

Forcing by sector (100-yr)



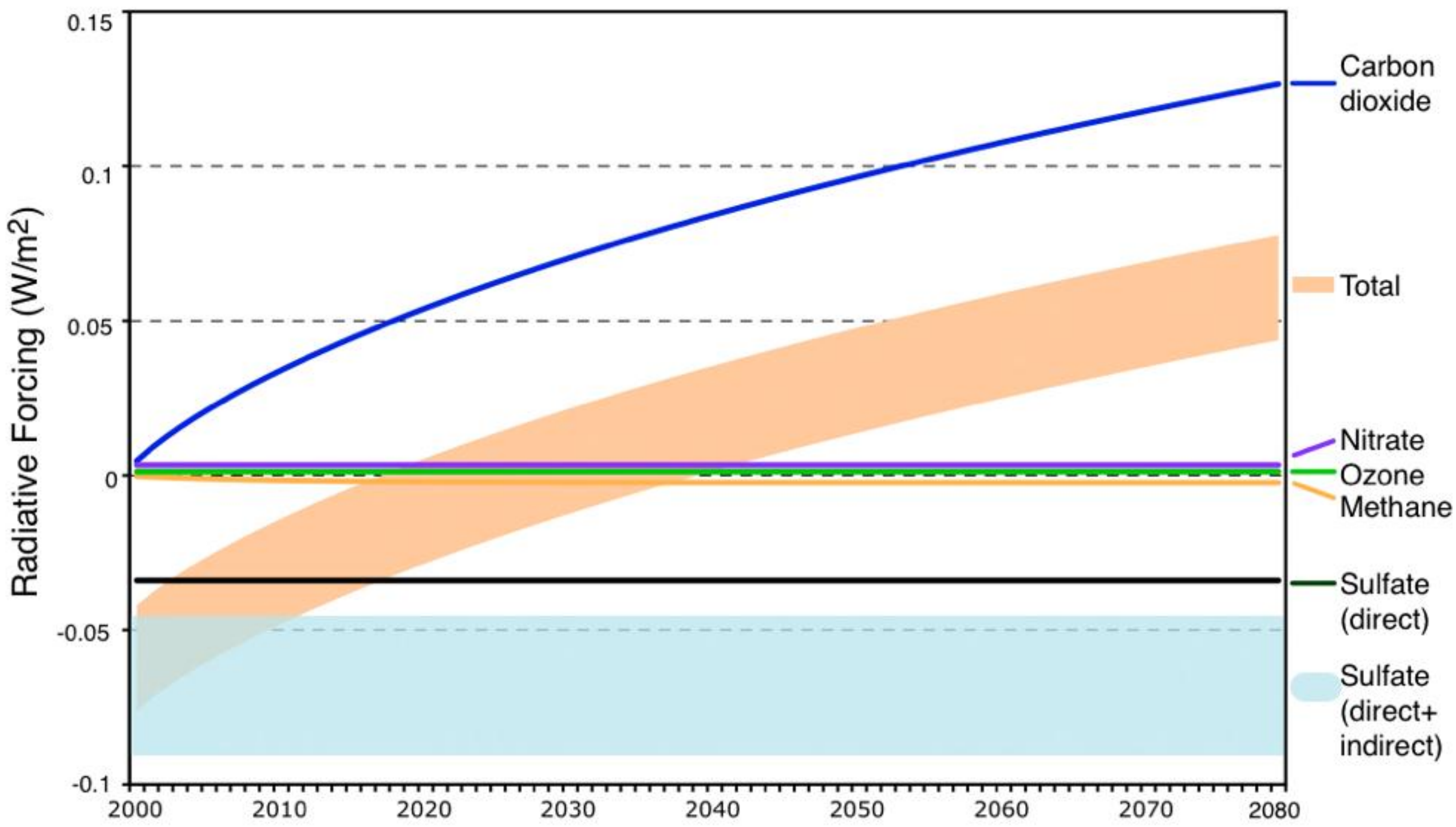
Unger et al., PNAS, 2010

Forcing by sector (100-yr)



Fuglestvedt et al., PNAS, 2008

Net forcing by coal plants



Forcing from current Chinese & Indian coal plants

Shindell & Faluvegi, ACPD, 2009

Net forcing by coal plants

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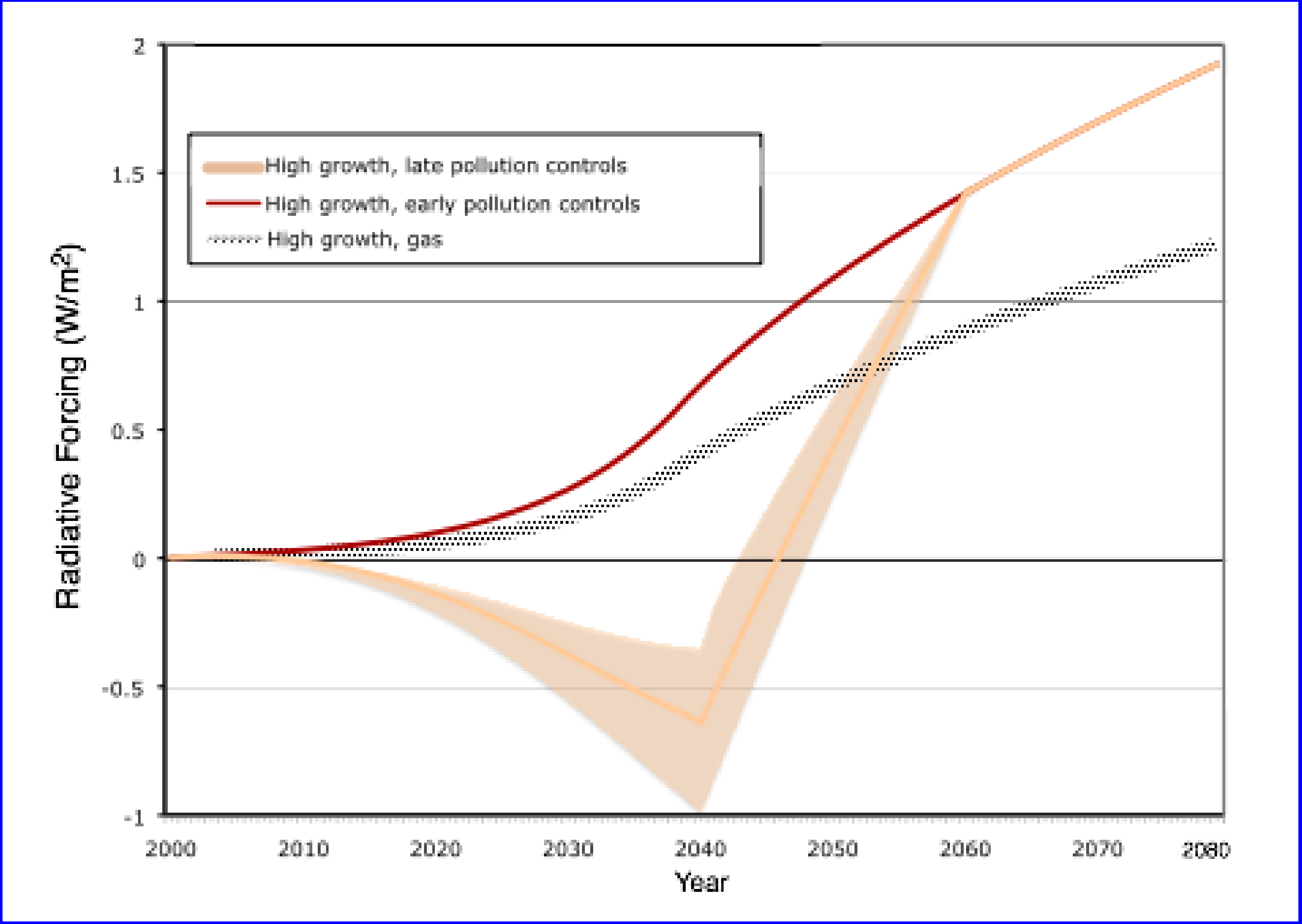

Shindell & Faluvegi, ACPD, 2009

Net forcing by coal plants

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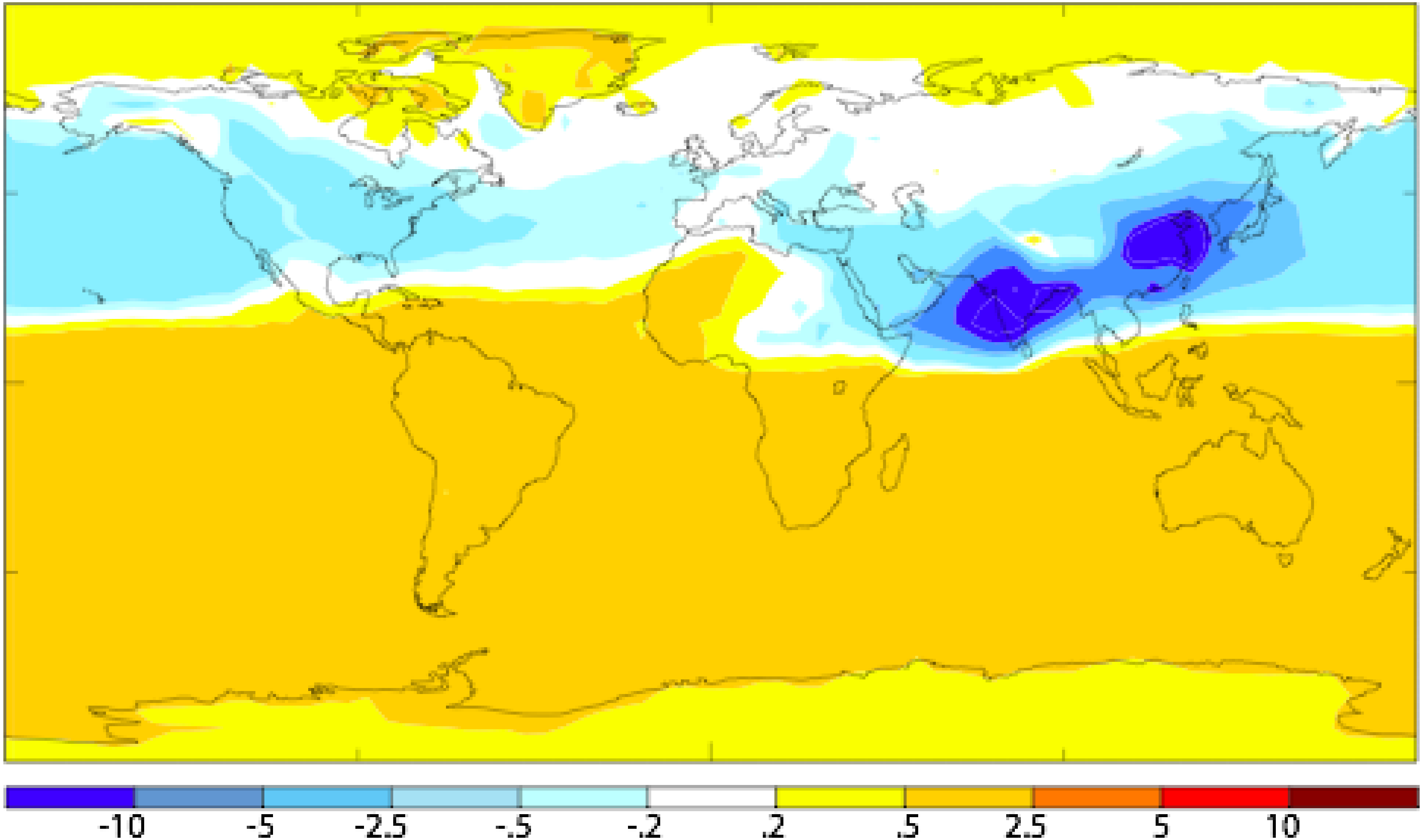

Forcing (W/m²) at 2046 for high growth, late pollution controls

Shindell & Faluvegi, ACPD, 2009

Net forcing by coal plants

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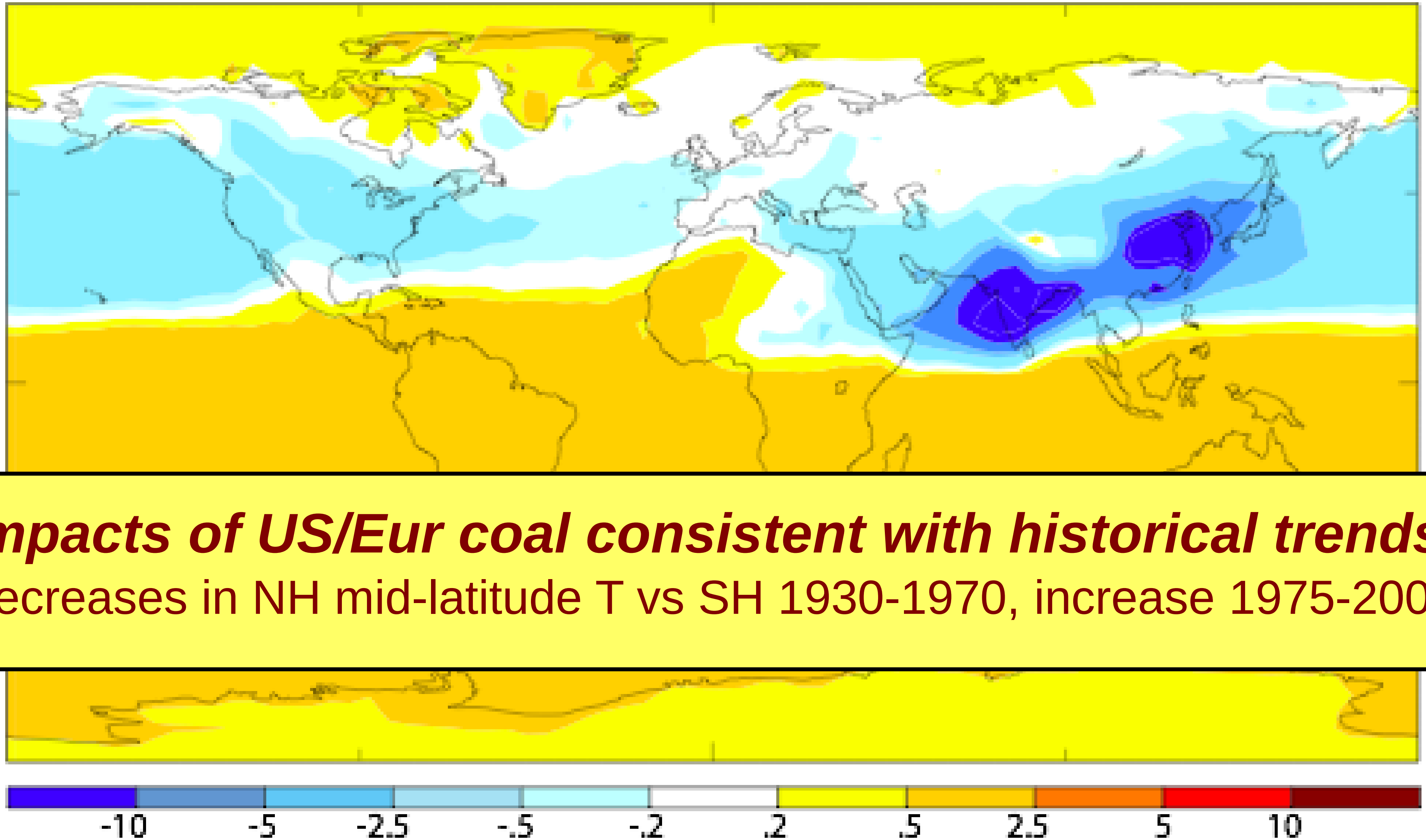
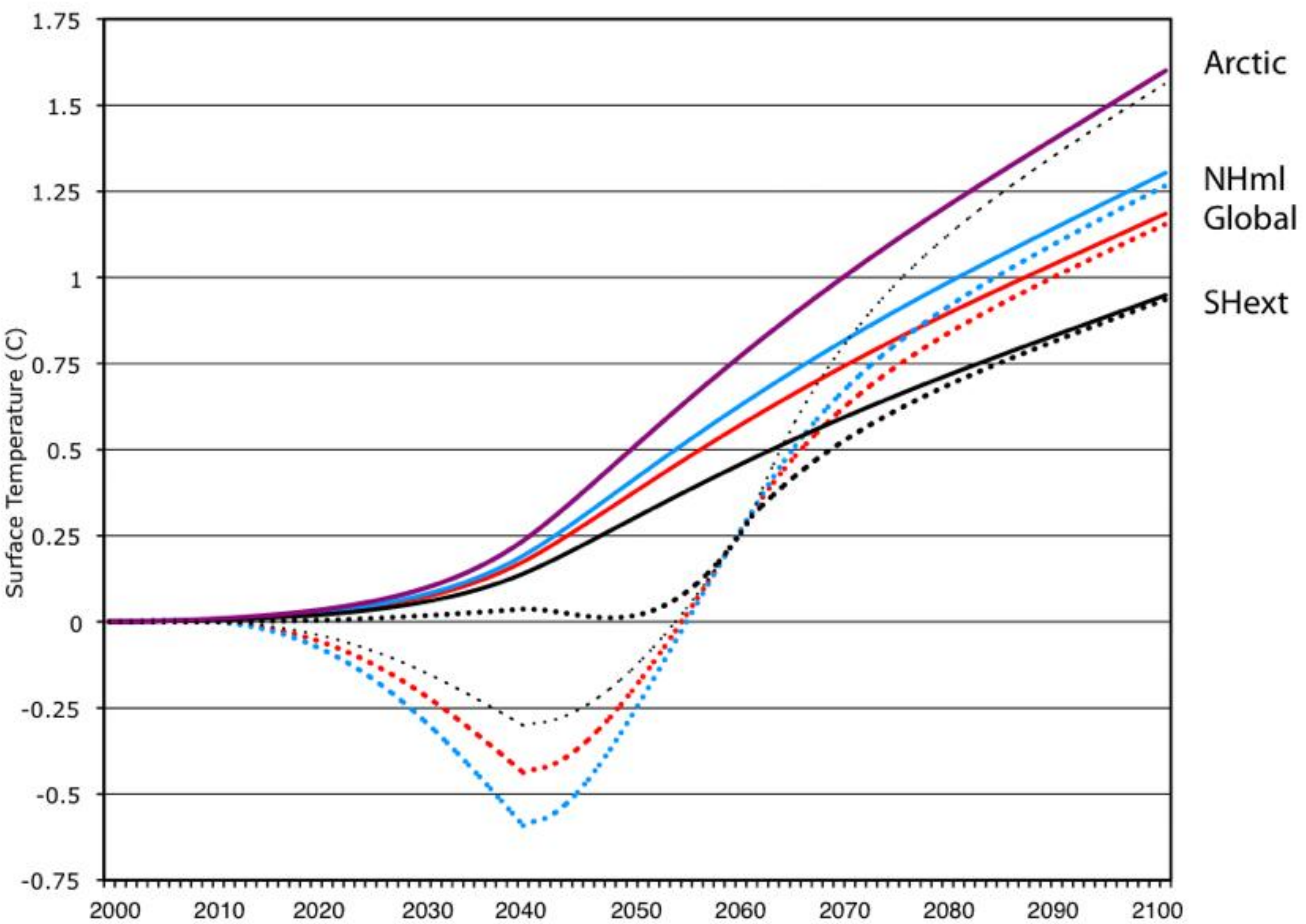


Impacts of US/Eur coal consistent with historical trends:
decreases in NH mid-latitude T vs SH 1930-1970, increase 1975-2005

Forcing (W/m^2) at 2046 for high growth, late pollution controls

Shindell & Faluvegi, ACPD, 2009

Regional response



Regional response

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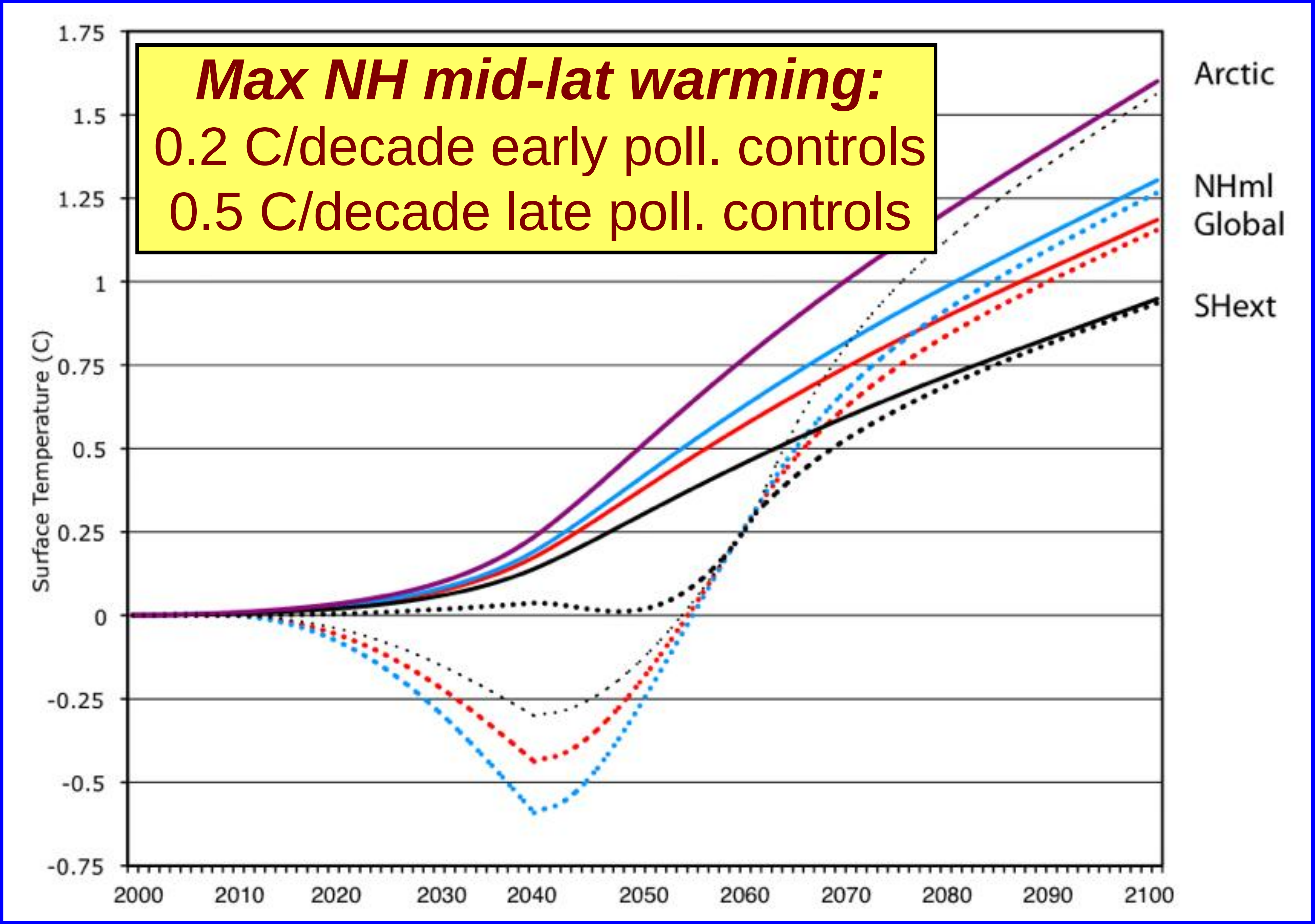


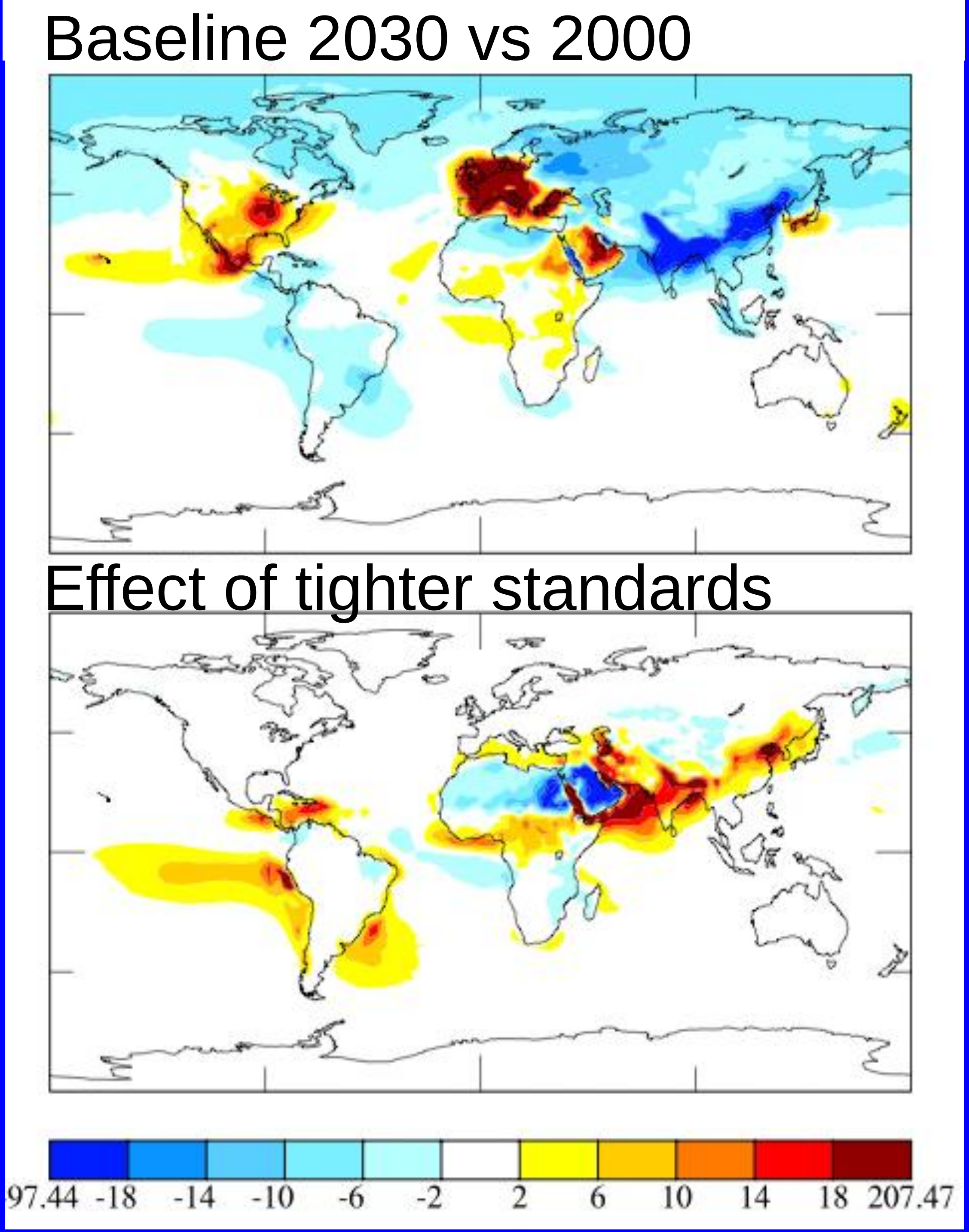
Transport sector

Regional differences

•Due to relatively ‘clean’ emissions, projected changes cause positive forcing in W. Europe (near-neutral in US)

•With ‘dirty’ emissions, changes in China, India, and FSU lead to cooling. Tighter standards have little effect in US/EU, weaken cooling elsewhere except N Africa/ME

Transport sector *Continued*



Sub-sectors

- Diesel has weaker warming mitigation potential in China & India than gas, but greater potential in other regions (BC vs SO_2/O_3-precusors)

Summary

- Incomplete combustion yields short- and long-lived climate forcers - response cannot be characterized solely by a global mean value at a particular time

- *Response to inhomogeneous forcing extends very far zonally, ~30 degrees meridionally*

- Extratropical zones are sensitive to location of forcing, responding 3-10x more strongly to local than remote forcing (global response also enhanced ~40-50%); enhancement for BC near snow/ice

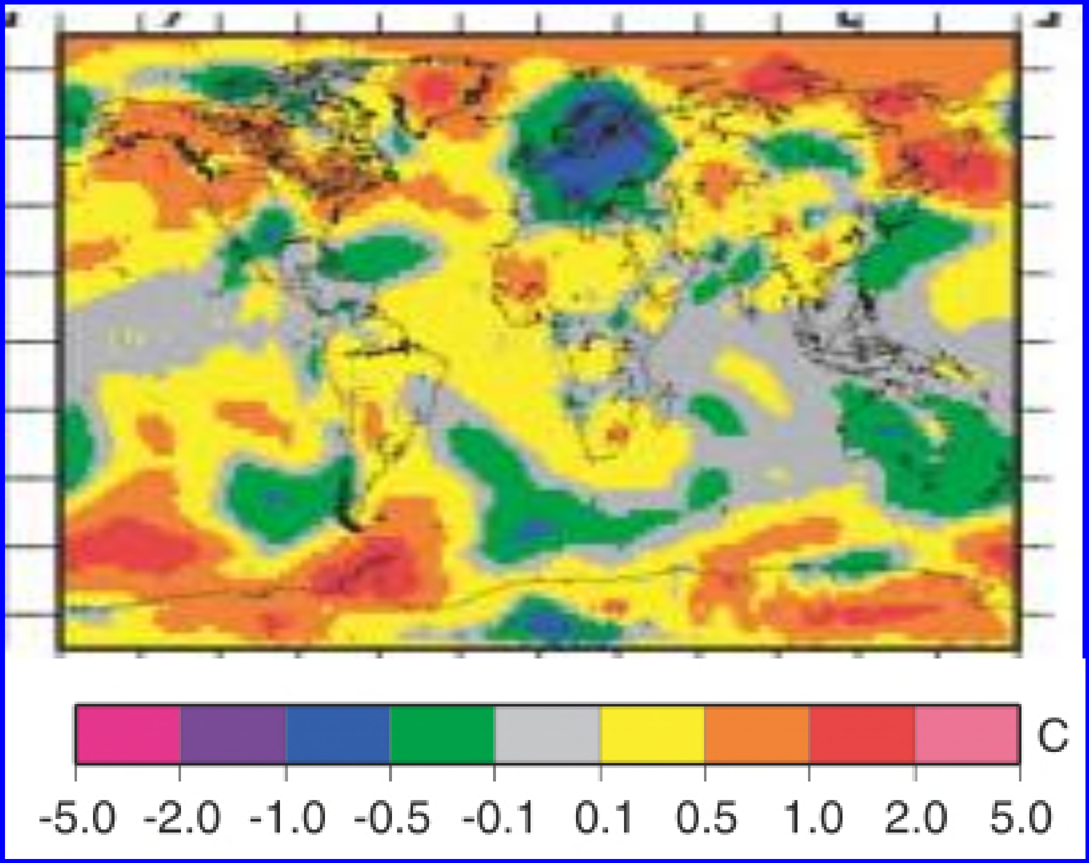
Summary

Continued

- *Knowledge of regional response to inhomogeneous forcing and to homogeneous forcing (e.g. via ENSO, NAM, monsoon, etc) both necessary to improve regional projections and validate regional impacts (precipitation, glaciers, etc.) - detection/attribution not yet successful for regional temperature/precip/glaciers/etc.*

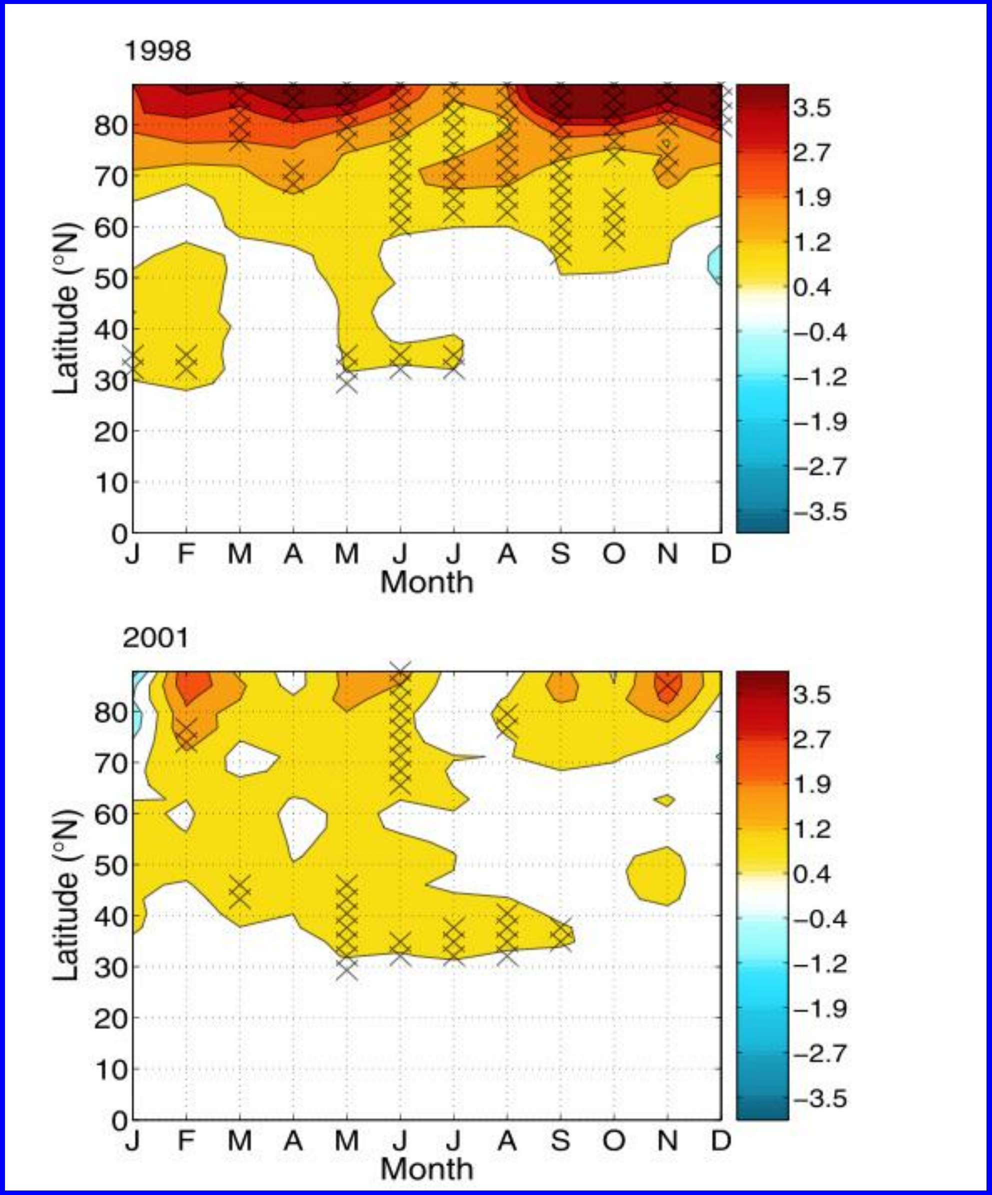
- Knowledge about forcing/response relationships plus regional/sector impacts on regional forcing can hopefully lead to better AQ/climate policies, but need for additional detail is great

Surface temperature: BC on snow



dT=0.2 C

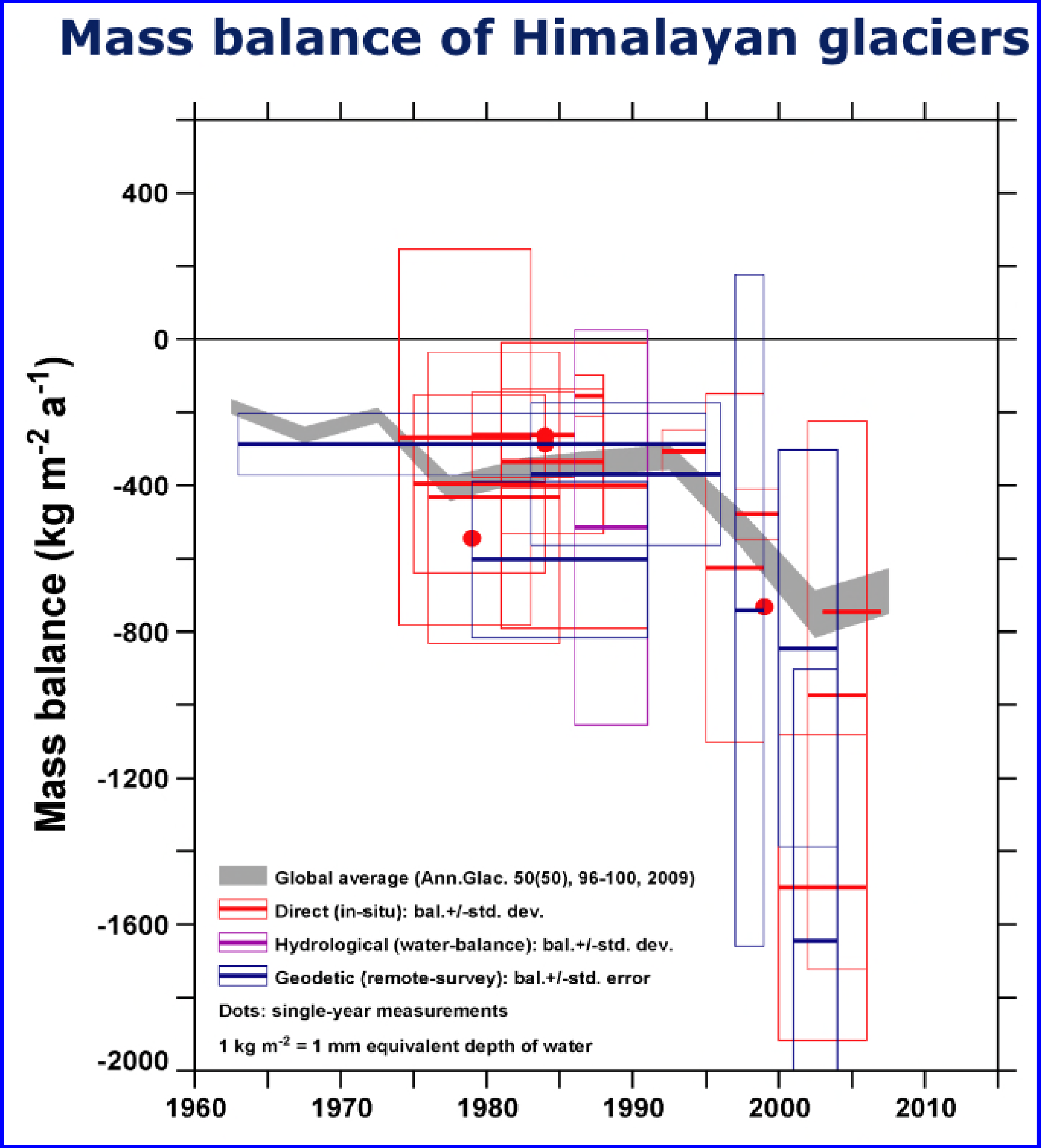
Koch et al, J Clim, 2009



dT=0.15-0.10

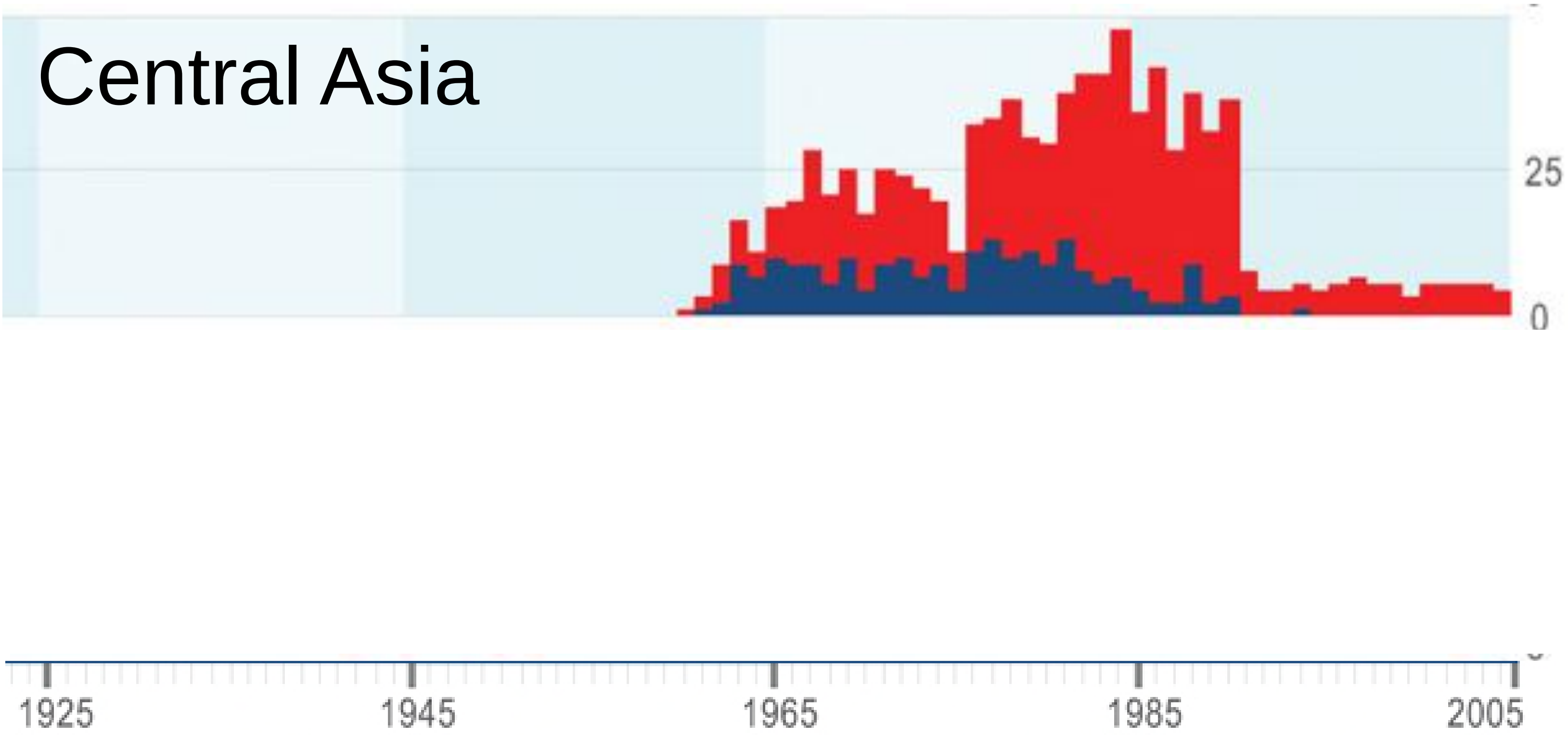
Flanner et al, JGR, 2007

Observed trends in Asian glaciers



G. Cogley, AGU, 2009

Observed trends in Asian glaciers *Cont.*



Retreating vs Advancing glaciers
(UNEP/World Glacier Monitoring Service)

Earlier melt & 33–38% increase in glacier melt runoff past few decades (Singh & Kumar, J. Hydrol, 1997), extremely similar to stream-flow changes in Western US (Barnett et al, Nature, 2005)