

Climate forcing of air pollutants

(short-lived climate forcers, SLCFs)

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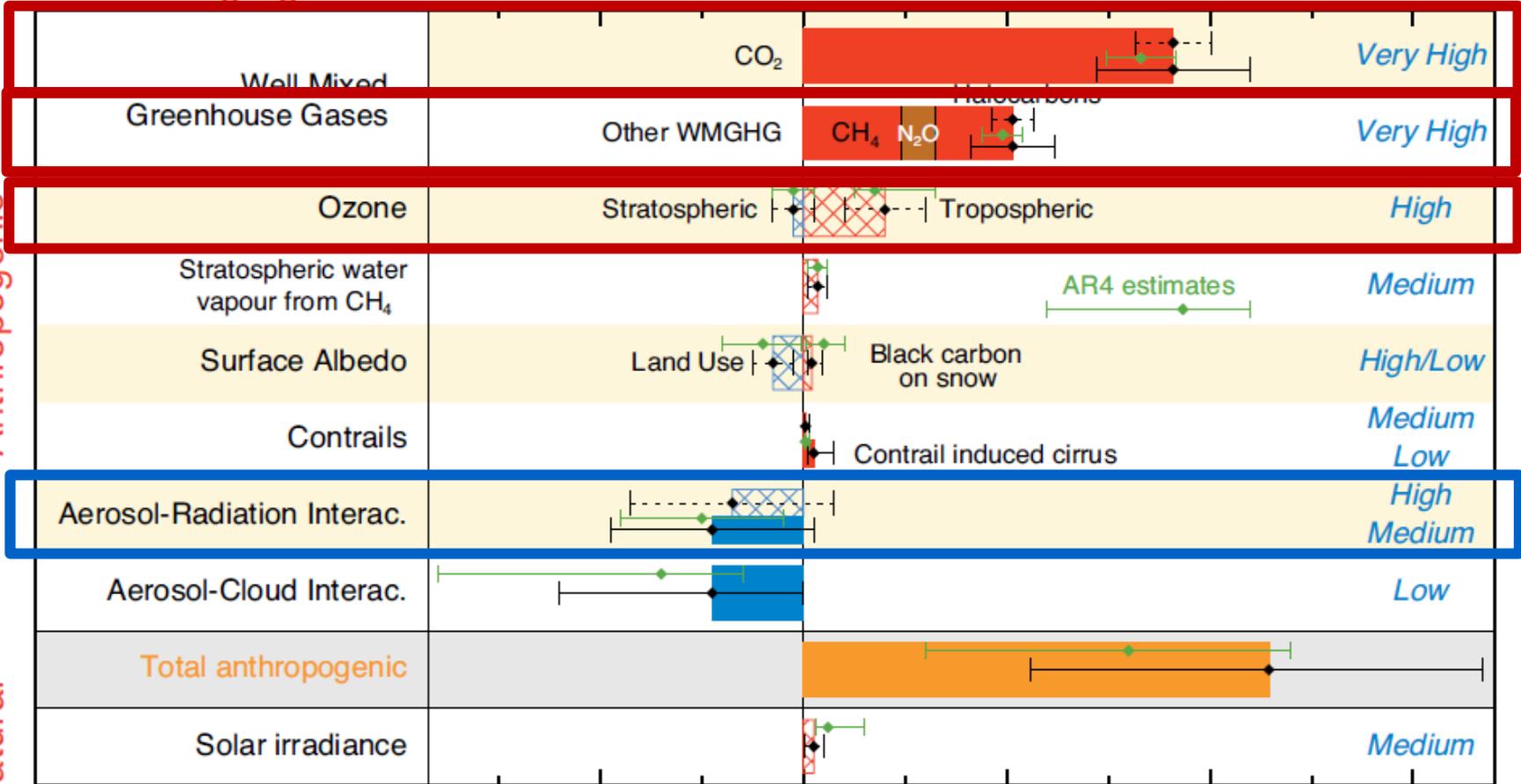


Radiative forcing of climate between 1750 and 2011

Radiative Forcing [Wm⁻²]

Forcing agent

Confidence Level



Anthropogenic

Natural

Radiative Forcing (W m⁻²)

“An aerosol is a suspension of small solid and/or liquid particles in a gas (air)”



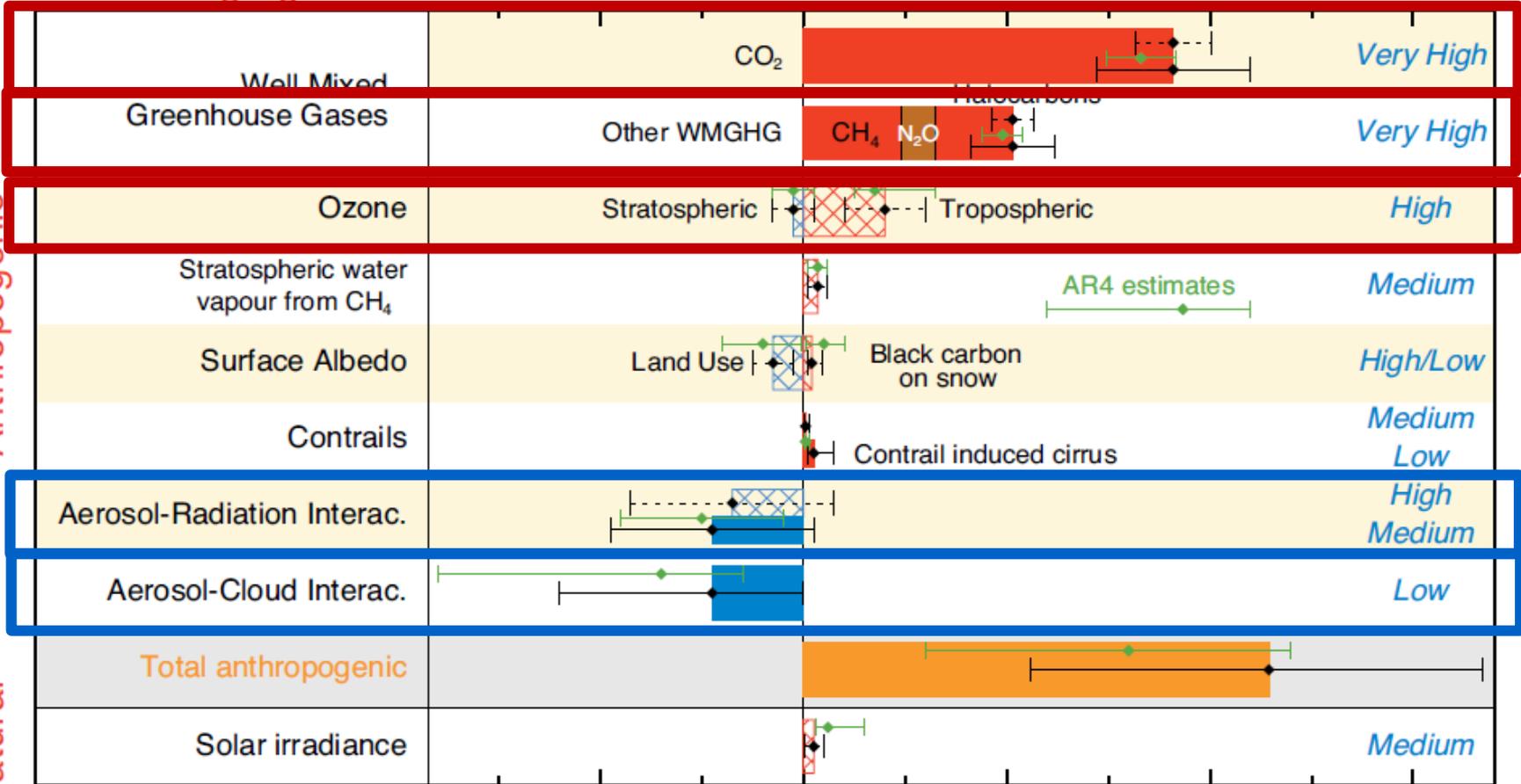


Radiative forcing of climate between 1750 and 2011

Radiative Forcing [Wm⁻²]

Forcing agent

Confidence Level



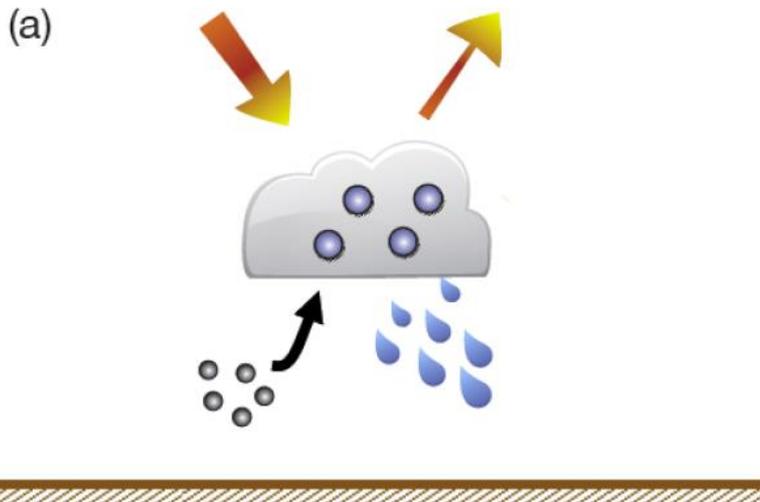
Anthropogenic

Natural

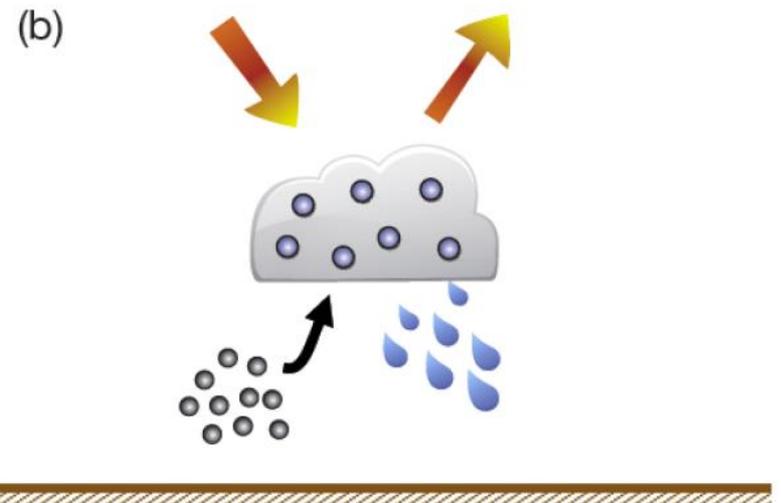
Radiative Forcing (W m⁻²)

Aerosol-cloud-interactions and their climate effects

Few aerosol particles \Rightarrow
Few, large cloud droplets



Many aerosol particles
 \Rightarrow Many small cloud droplets
 \rightarrow **Effects on radiation and precipitation**



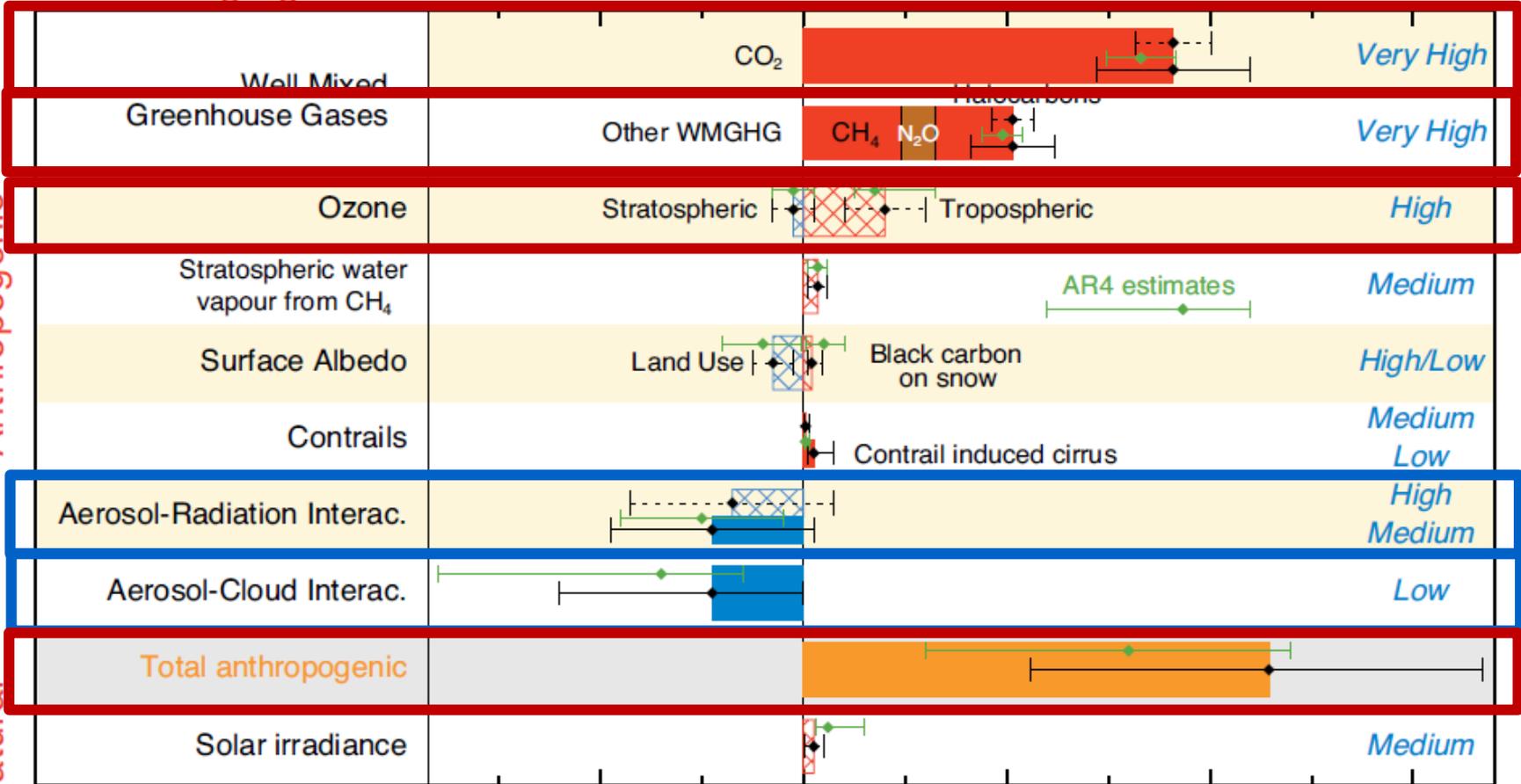


Radiative forcing of climate between 1750 and 2011

Radiative Forcing [Wm⁻²]

Forcing agent

Confidence Level



Anthropogenic

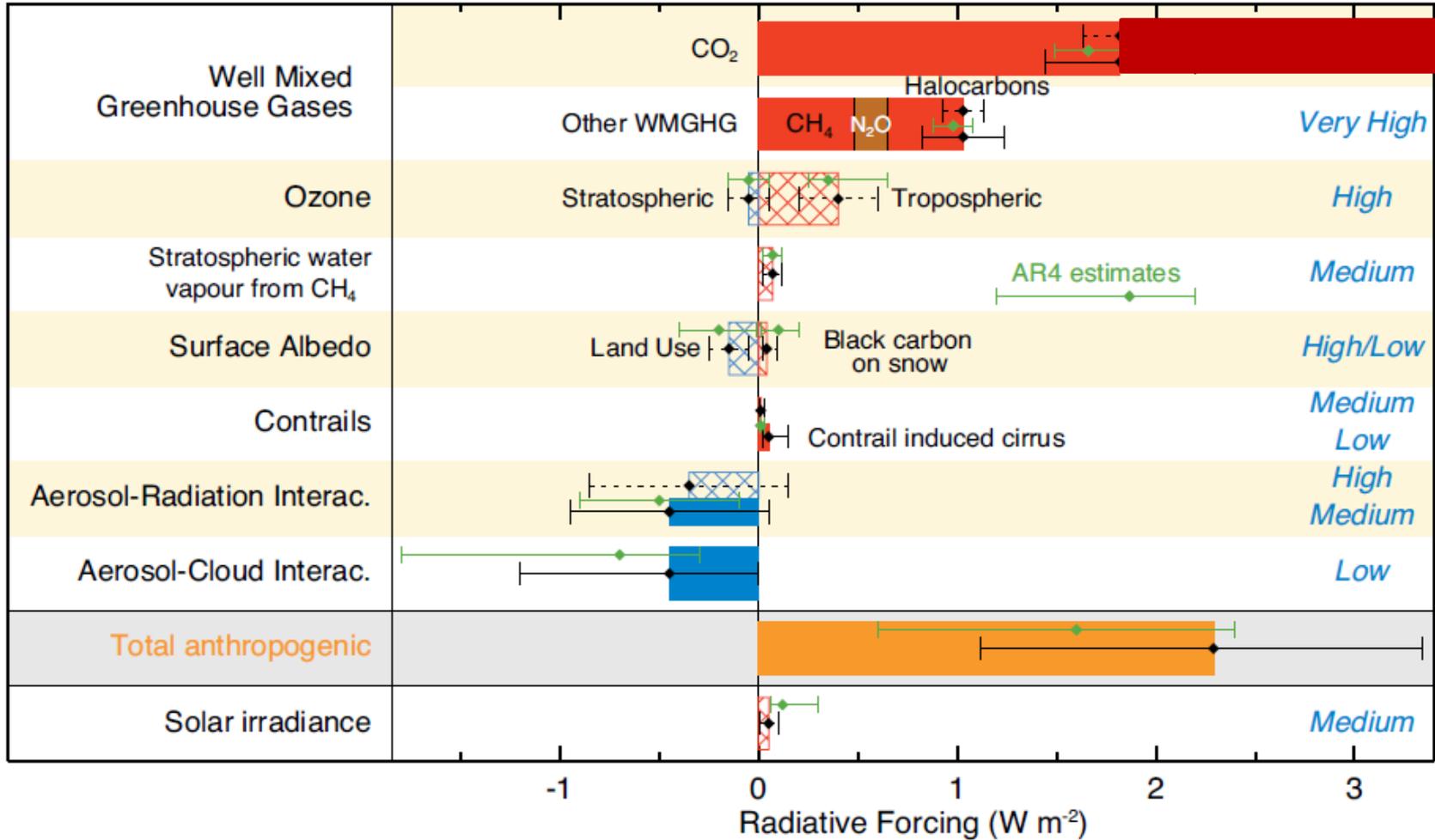
Natural

Radiative Forcing (W m⁻²)

← cooling warming →

RCP4.5 2100

Radiative forcing of climate between 1750 and 2011



Anthropogenic

Natural

Radiative Forcing

~3.5

Confidence Level

cooling warming

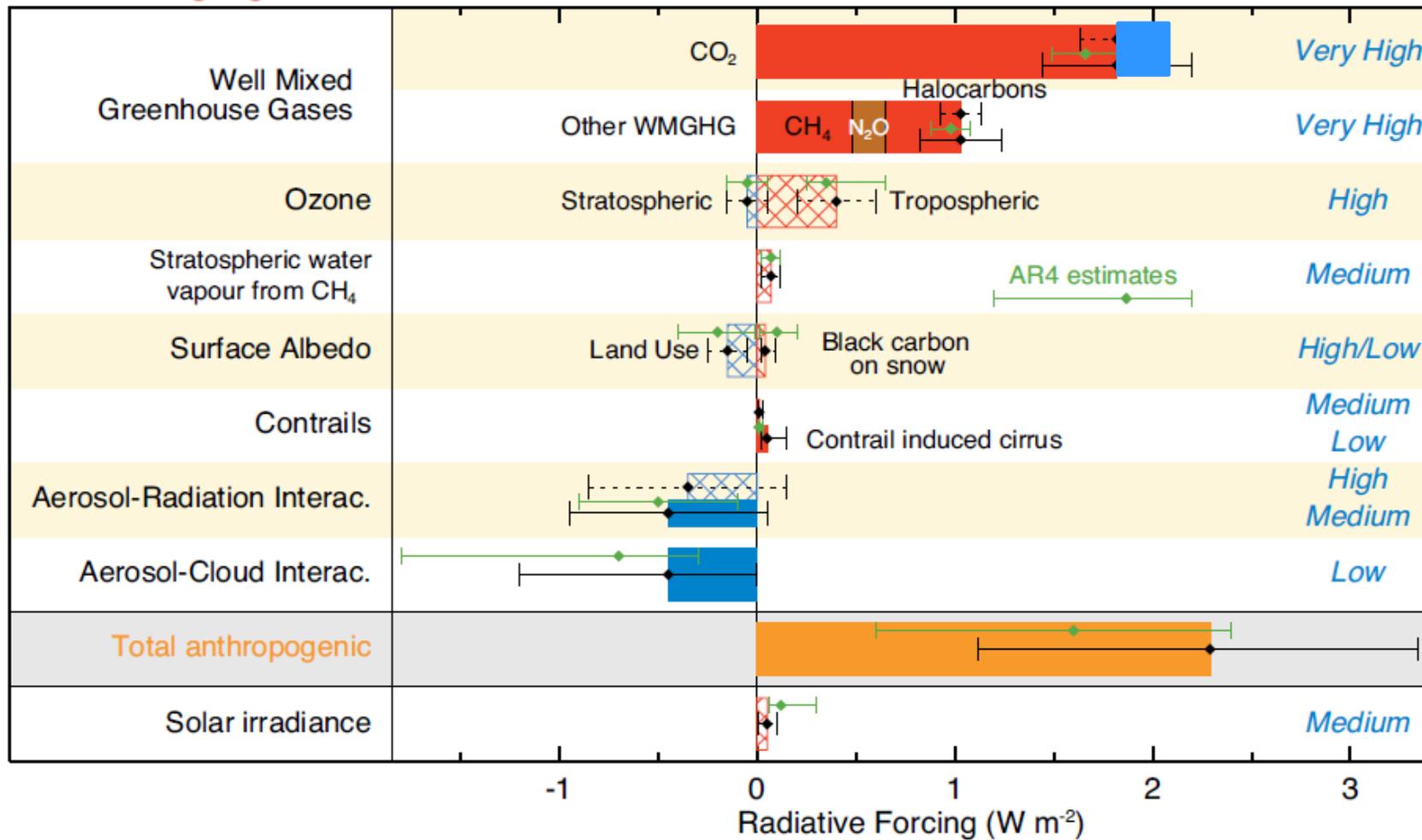
RCP2.6 2100
(2°C target)

Radiative forcing of climate between 1750 and 2011

Confidence Level

Radiative Forcing

Forcing agent



~2.0

Anthropogenic

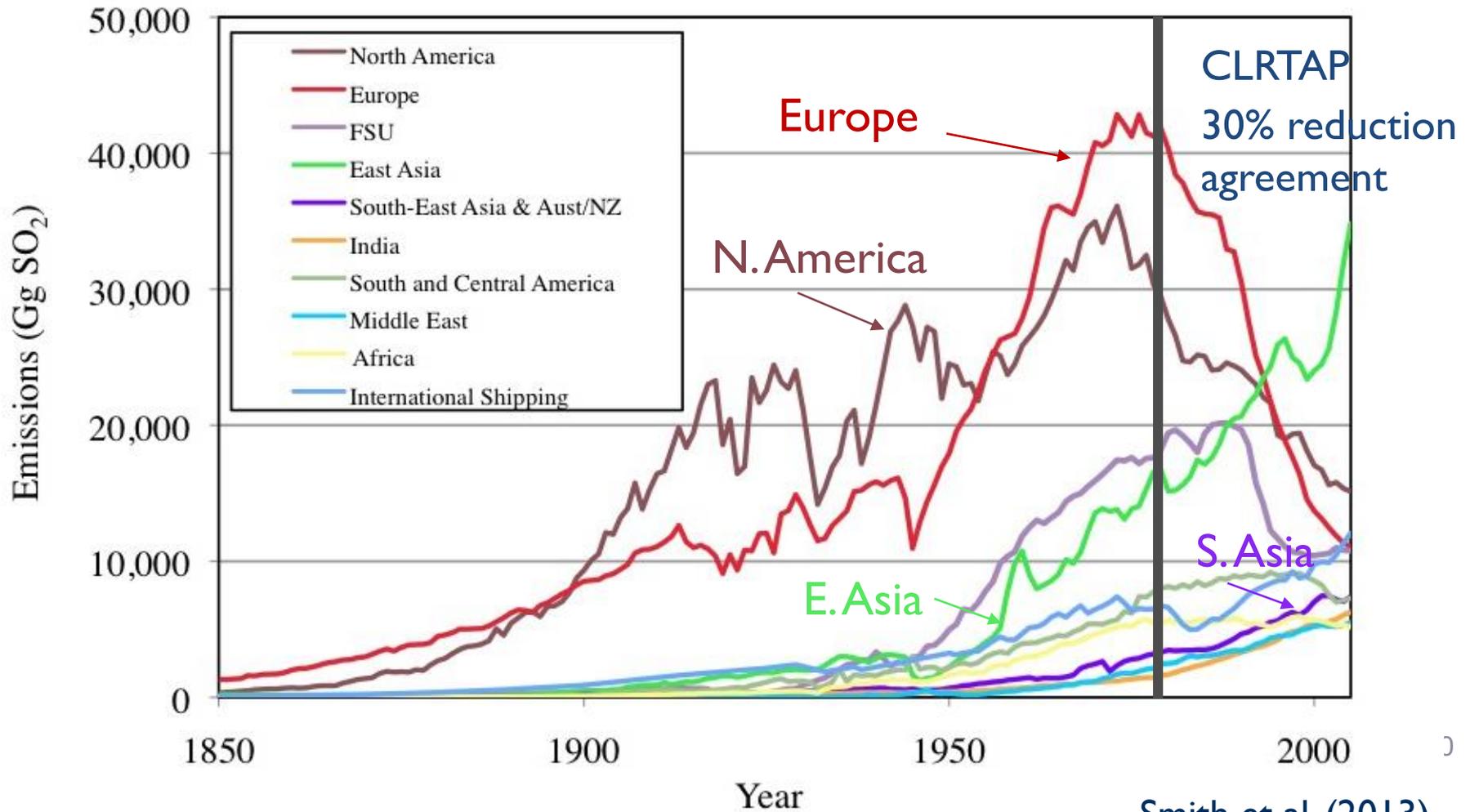
Natural

Conclusion I

- If carbon dioxide emissions are substantially reduced (to reach the 2°C target), SLCFs will become increasingly important.

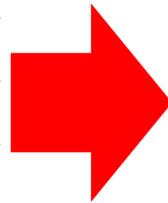
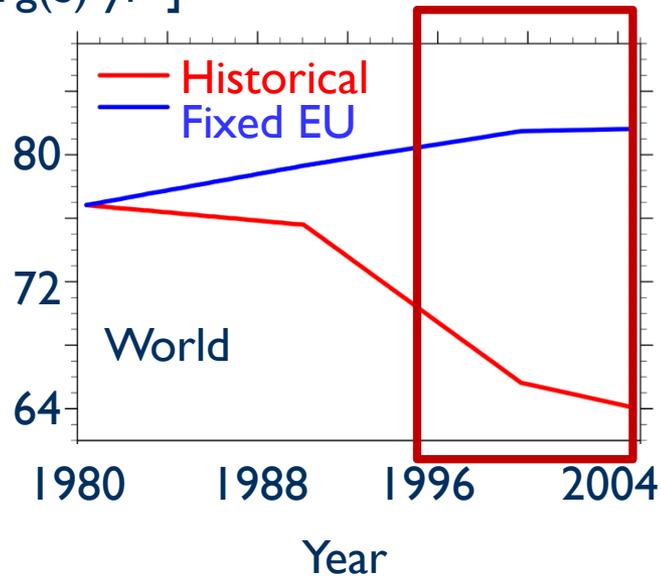
Rapid reduction of SO₂ emissions in North America and Europe since 1980's

Global Anthropogenic SO₂ Emissions

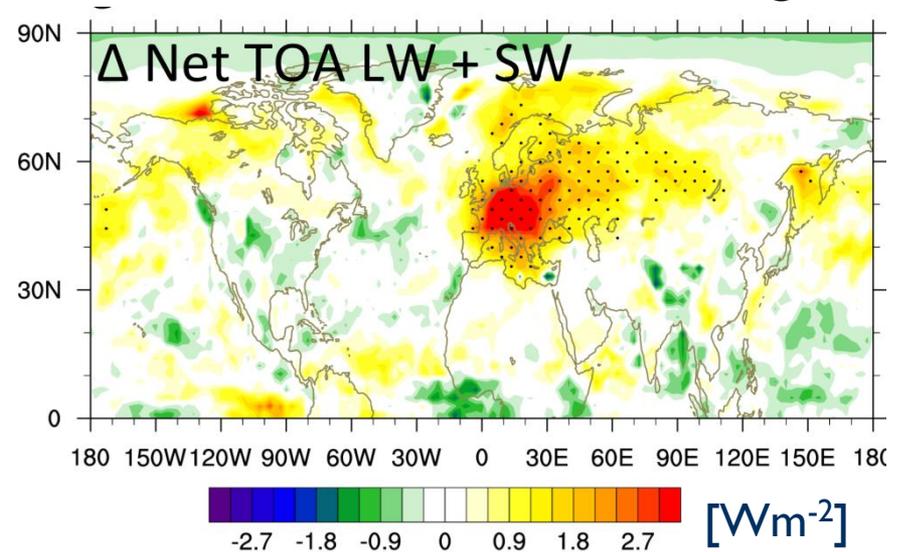


Effect of reduced European SO₂ emissions

SO₂ emissions
[Tg(S) yr⁻¹]



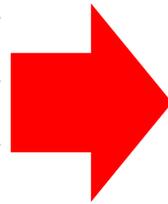
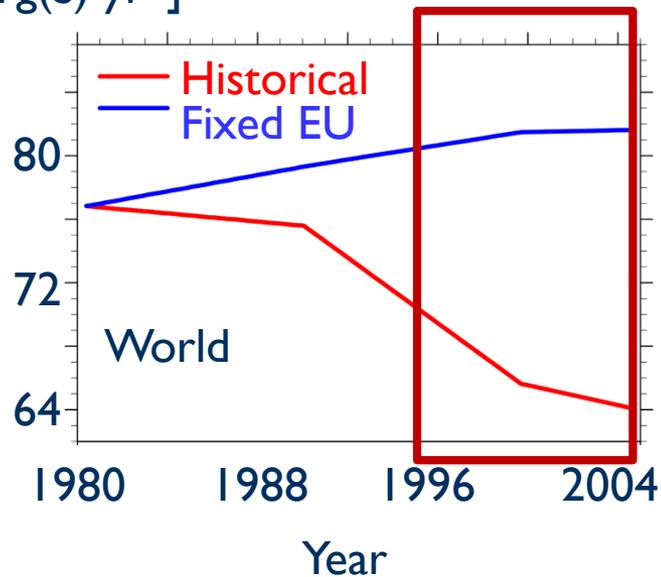
Effective radiative forcing



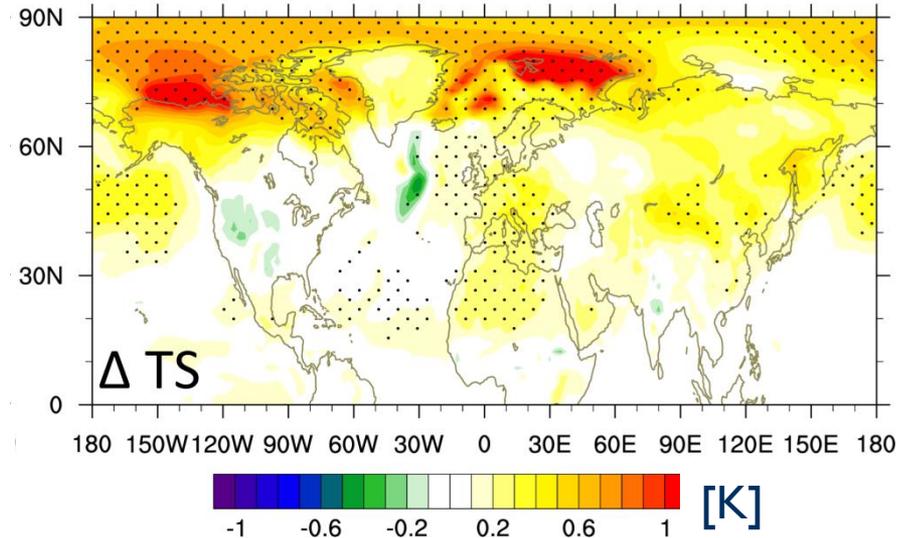
Dotted areas indicate significance at 95% level (student's t-test)

Effect of reduced European SO₂ emissions

SO₂ emissions
[Tg(S) yr⁻¹]



Surface temperature change

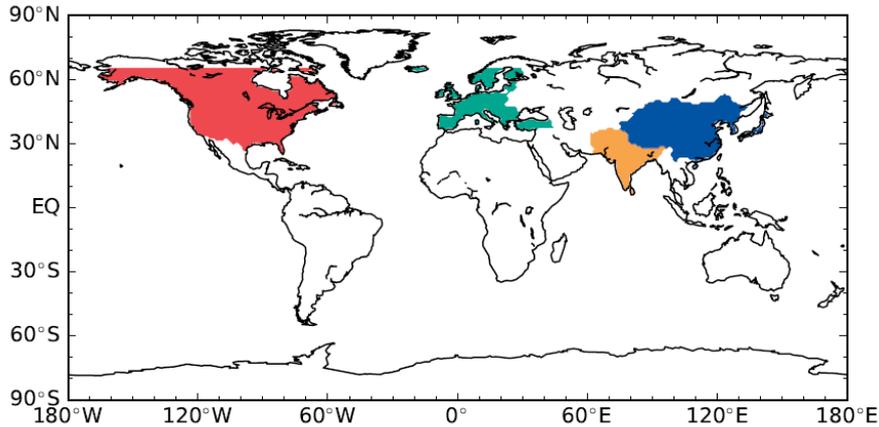


Dotted areas indicate significance at 95% level (student's t-test)

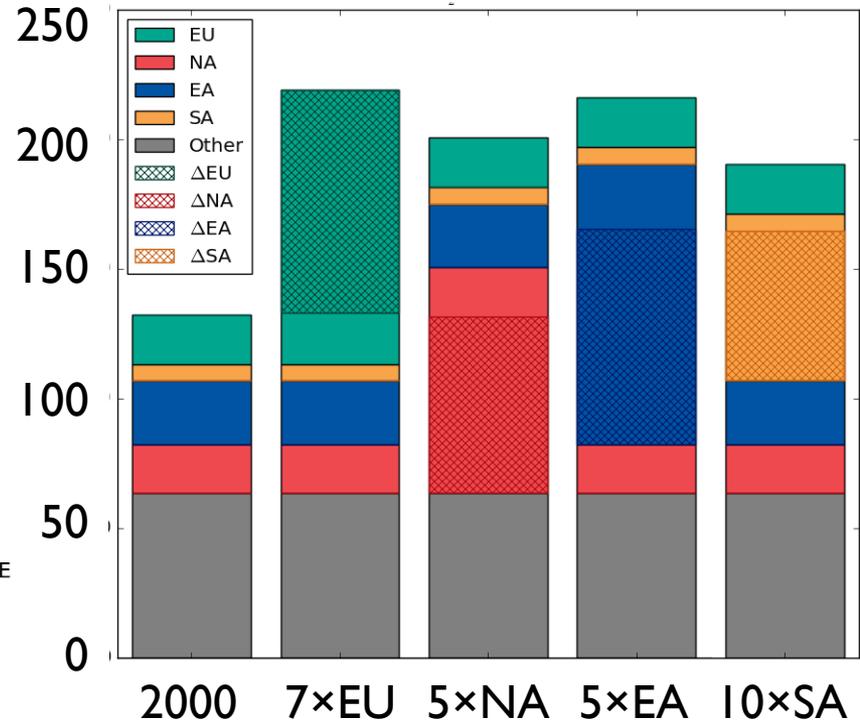
Acosta Navarro et al. (2016). See also Yang et al. (2014); Westervelt et al. (2015); Gagné et al. (2015)

What happens if we put the same forcing in different regions?

Emission regions (HTAP v2)

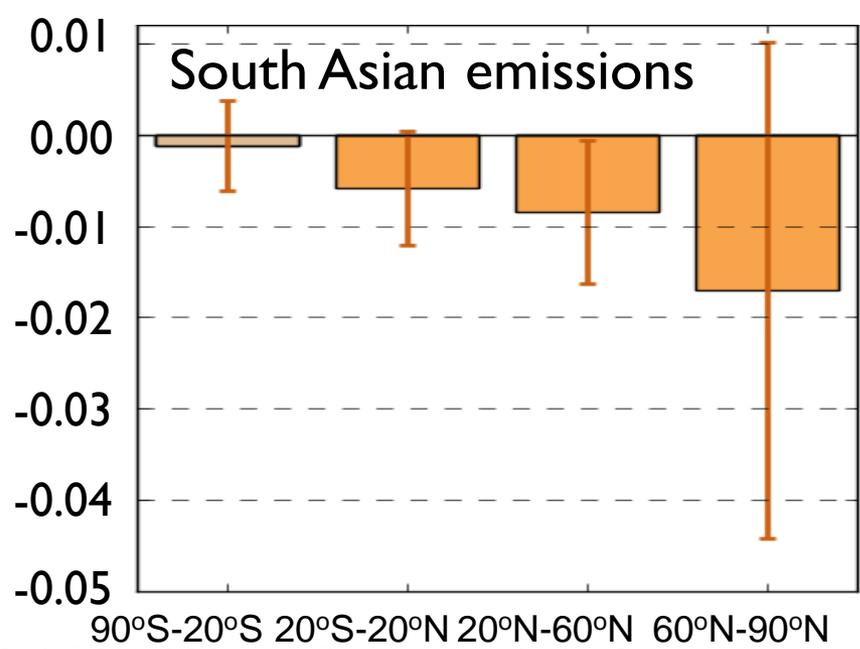
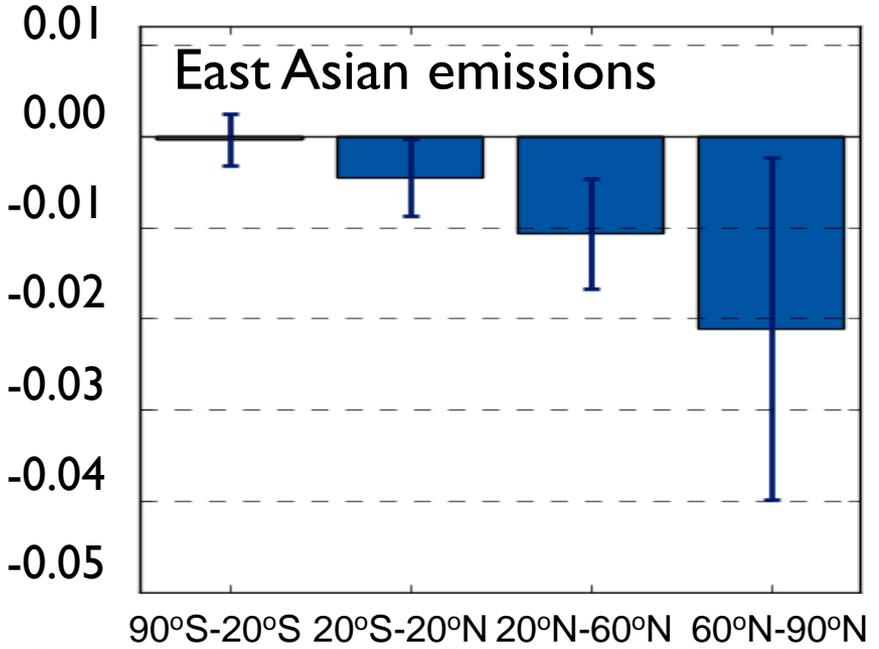
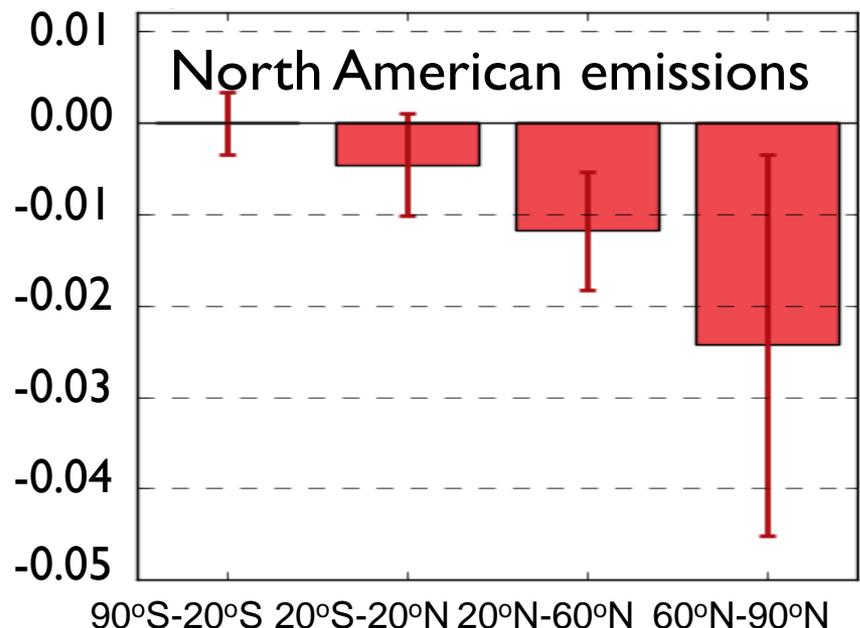
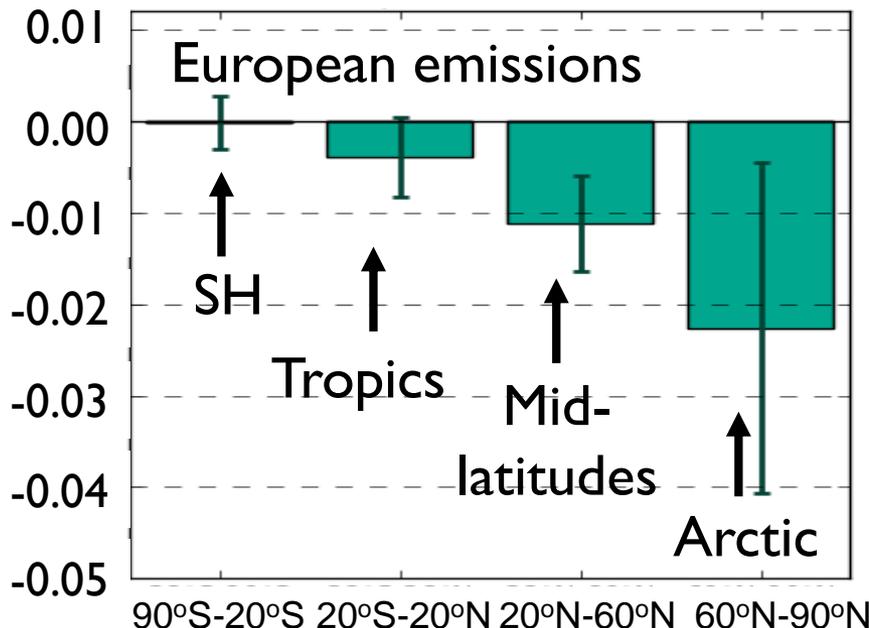


SO₂ emissions [Tg yr⁻¹]



Emission changes normalized to give approximately the same radiative forcing

Temperature change [K] per Tg SO₂ emission per year

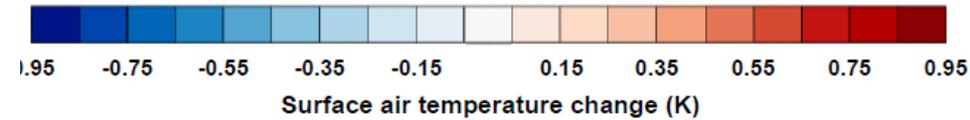
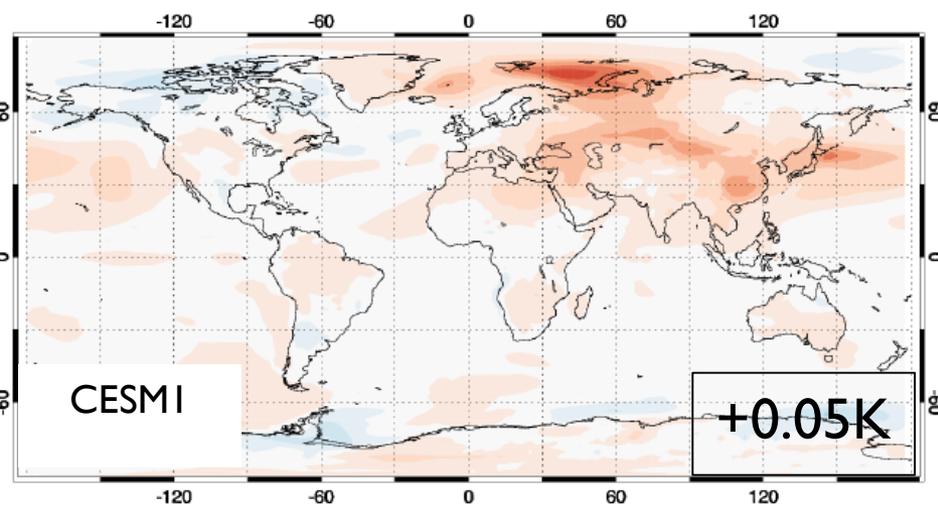
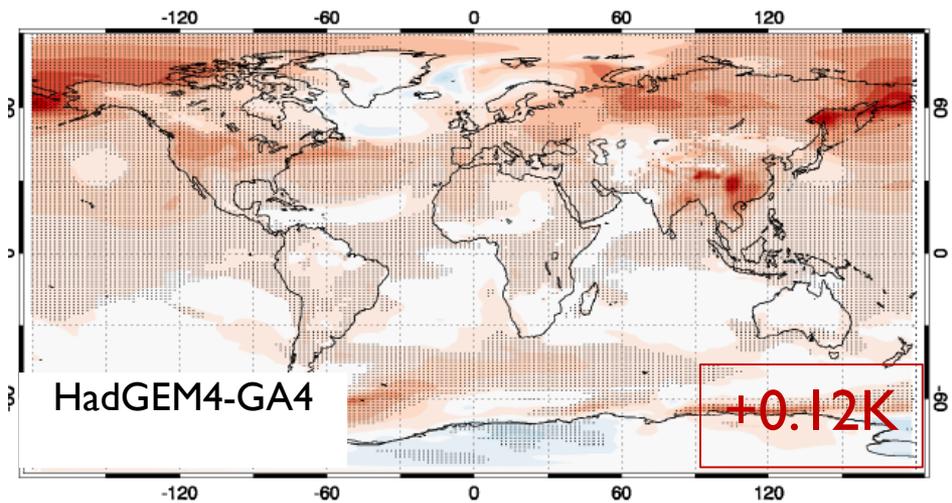
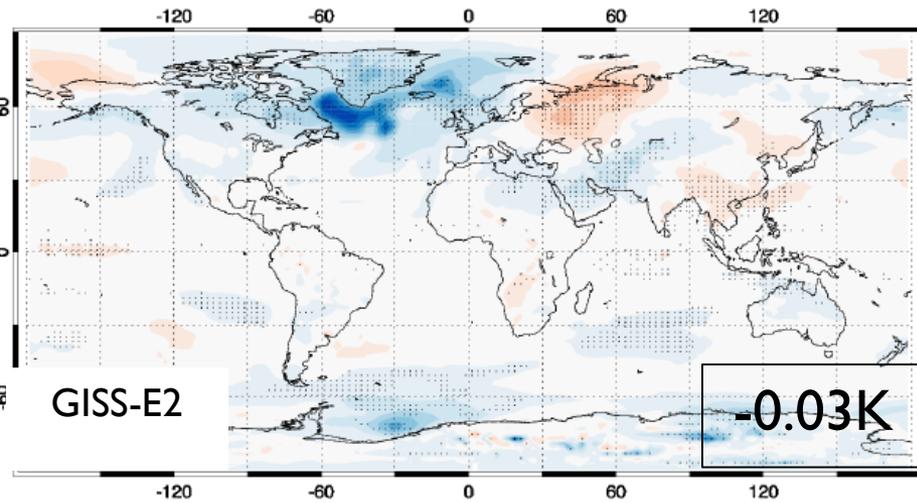


See also e.g. Shindell and Faluvegi (2009); Shindell (2012); Weum-Stjern et al. (2016)

Conclusion II

- If carbon dioxide emissions are substantially reduced (to reach the 2°C target), SLCFs will become increasingly important.
- A regional radiative forcing change (due to a change in SLCFs) will give a large-scale climate response. The largest temperature change will be found in the Arctic.

Diversity in model forcing and response: Complete removal of SO₂ emissions over Asia in three different climate models



removal of SO₂ emissions over China
→ factor of six difference in aerosol
optical depth and short-wave
radiation change (Kasoar et al., 2016)

Conclusion III

- If carbon dioxide emissions are substantially reduced (to reach the 2°C target), SLCFs will become increasingly important.
- A regional radiative forcing change (due to a change in SLCFs) will give a large-scale climate response. The largest temperature change will be found in the Arctic.
- The magnitude of the direct and (in particular) indirect aerosol effect is highly uncertain. The indirect aerosol effect is non-linear and can reach saturation in polluted regions such as Asia. Different models reach saturation at very different aerosol concentration levels.

Questions

- How is the amplified warming in the Arctic from a regional (mid-latitude) forcing by SLCFs triggered?
- How have SLCFs affected other climate variables than temperature, for example precipitation?
- How can we constrain the (indirect) aerosol climate effect and reduce the uncertainty in anthropogenic aerosol forcing?
- What message can we give policy makers...?
 - CH₄ and O₃: positive forcing **certain** – reduce
 - BC: small positive forcing **likely** – no big impact
 - Sulfate, organic carbon, nitrate: negative forcing **certain** – but still reduce?