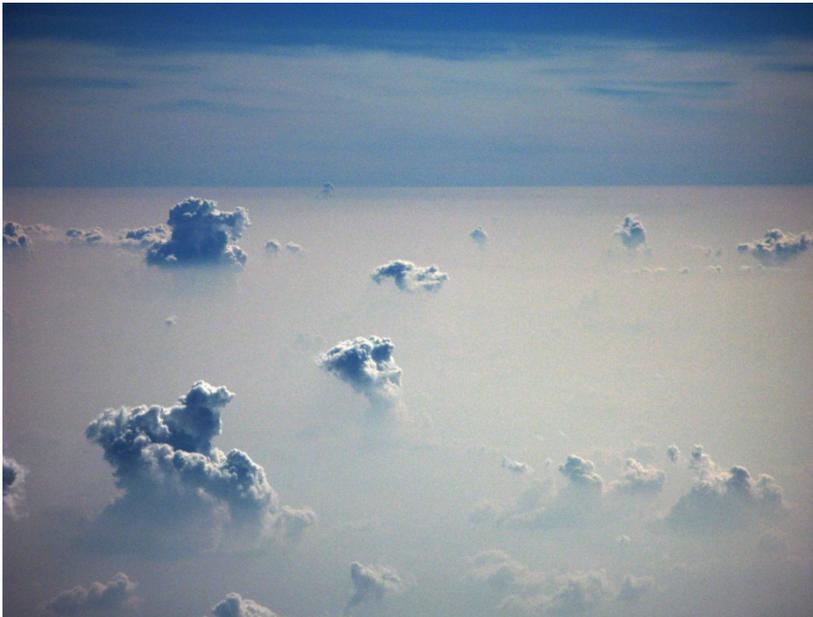


Aerosol particles and their seasonal variability

Are aerosol particles important for seasonal prediction?



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Acknowledgments: Anna Lewinschal, Hamish Struthers

Outline



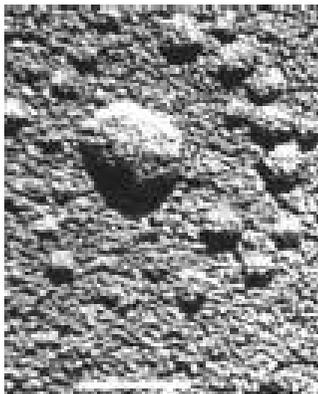
- Aerosol particles in the atmosphere.
- Aerosol direct and indirect effects.
- Aerosol particles, circulation and precipitation:
 - the weakening of the South Asian summer monsoon.
 - changes in extra-tropical stationary wave patterns.
- Aerosol particles and the large-scale surface temperature distribution.
- Conclusions, questions, discussion...

What is an aerosol?

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

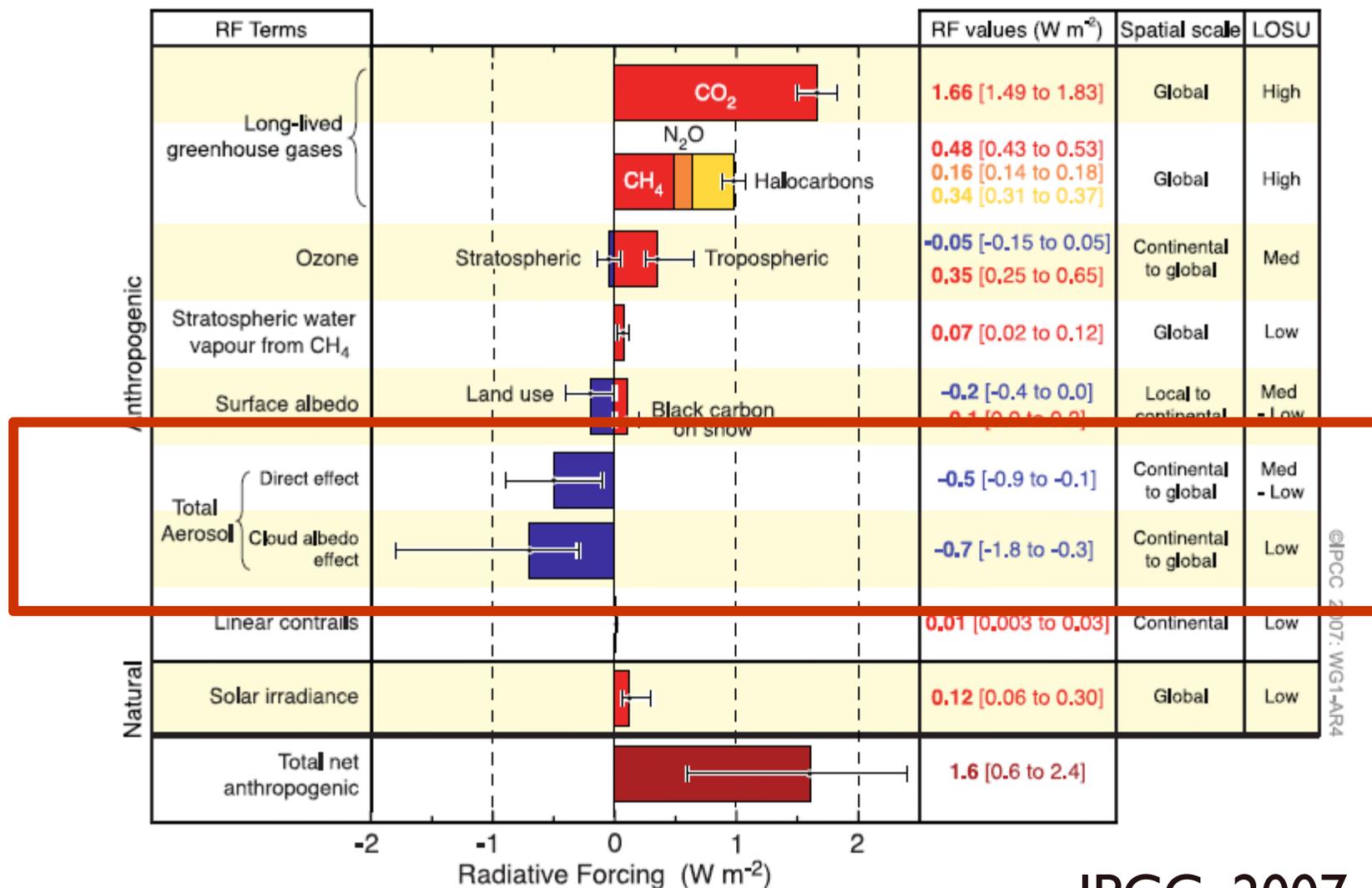


Typical atmospheric aerosol components

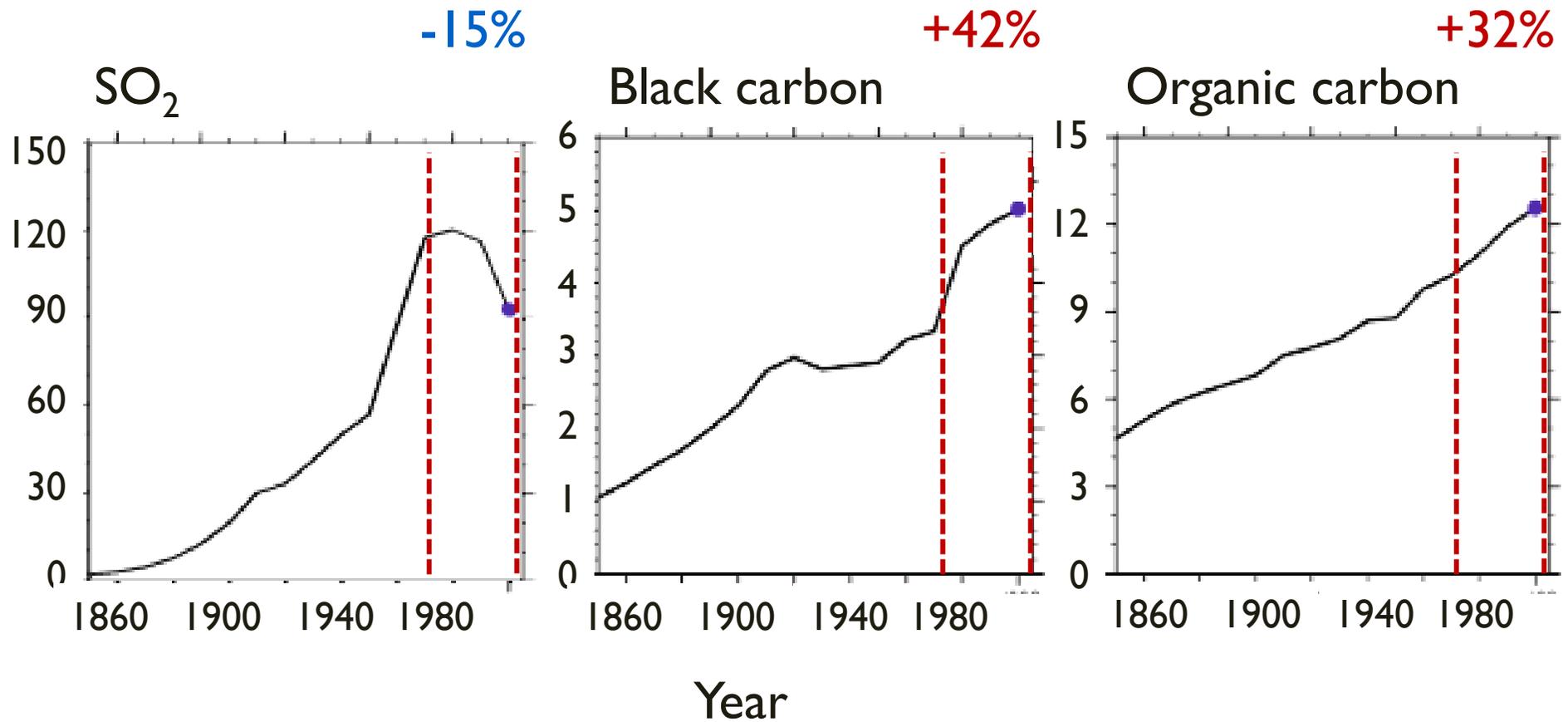


- Sea salt
- Dust
- Sulfate
- Ammonia
- Nitrate
- Organic carbon
- Soot (or BC)
- Water
- ...

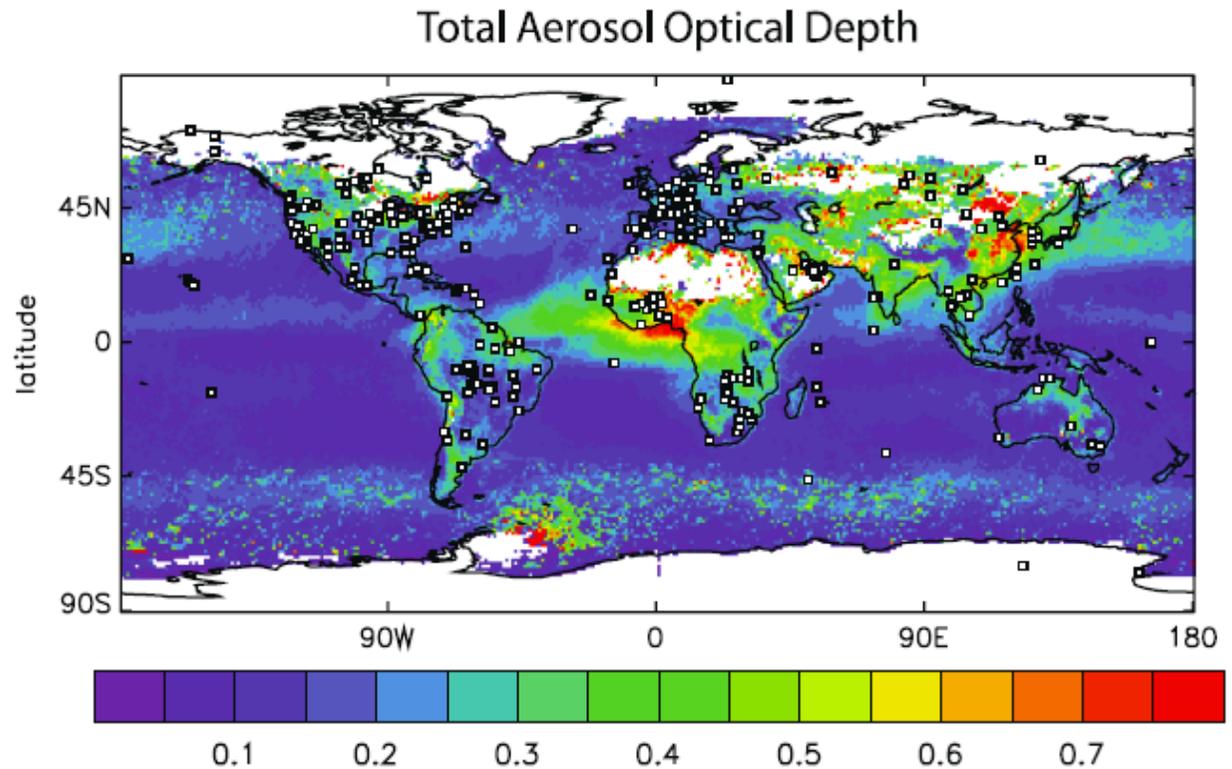
TOA radiative forcing year 2000 vs. 1750



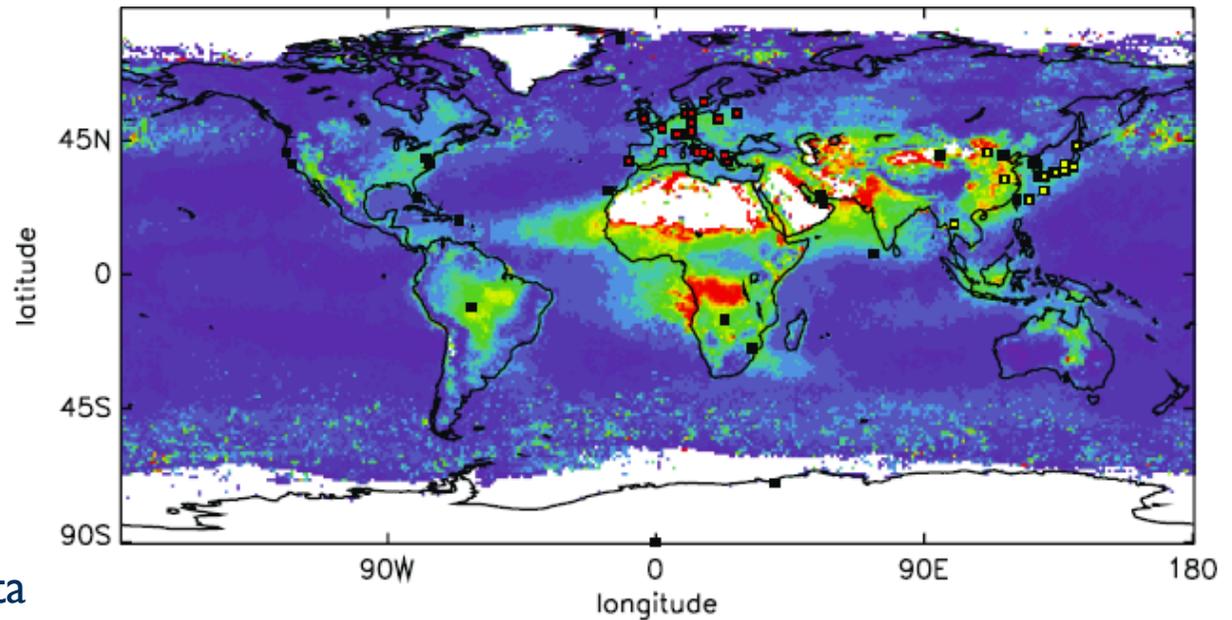
Trends in anthropogenic aerosol particle and precursor emissions [Tg yr⁻¹]



January-March, 2001

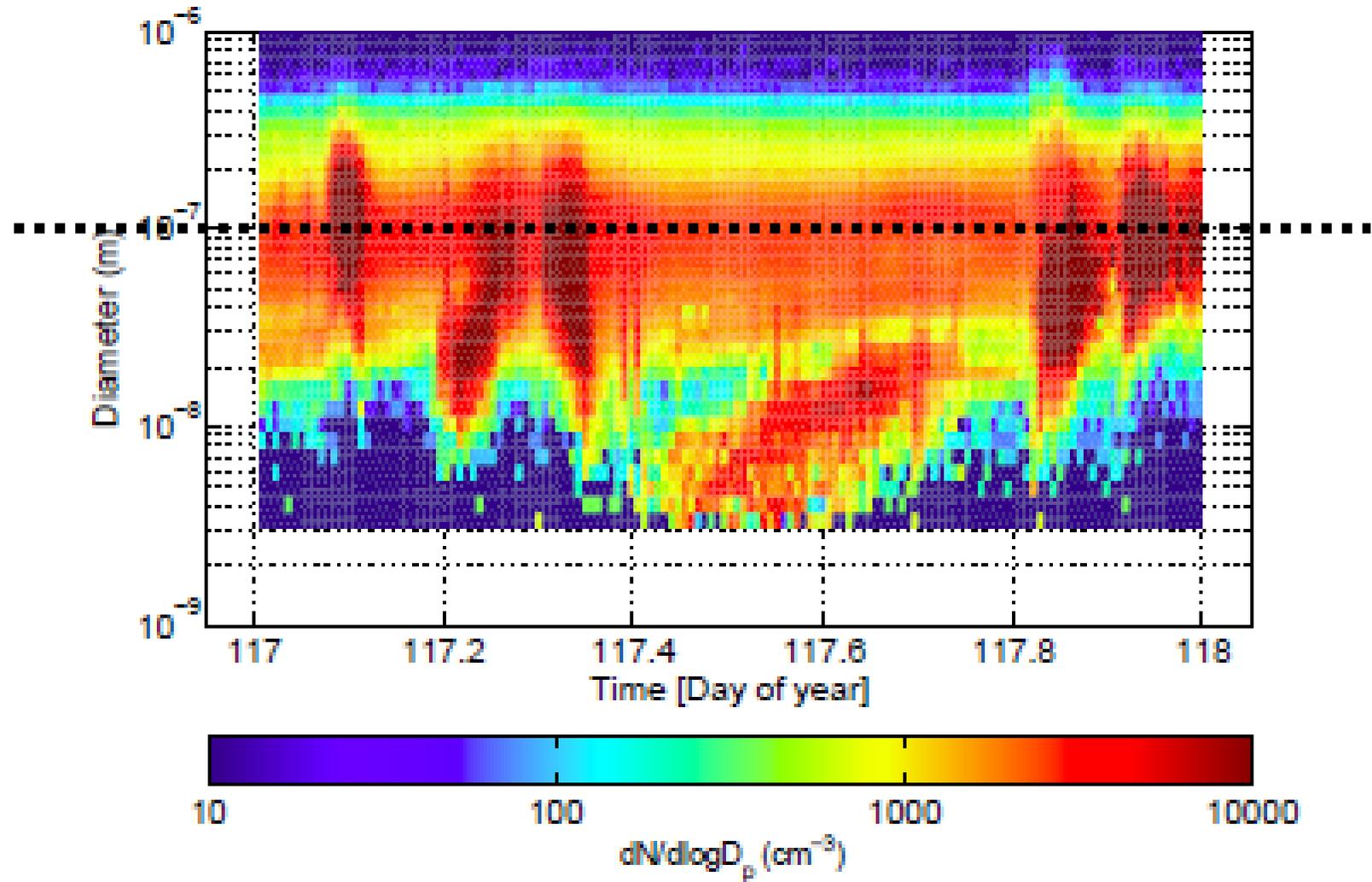


August-October, 2001

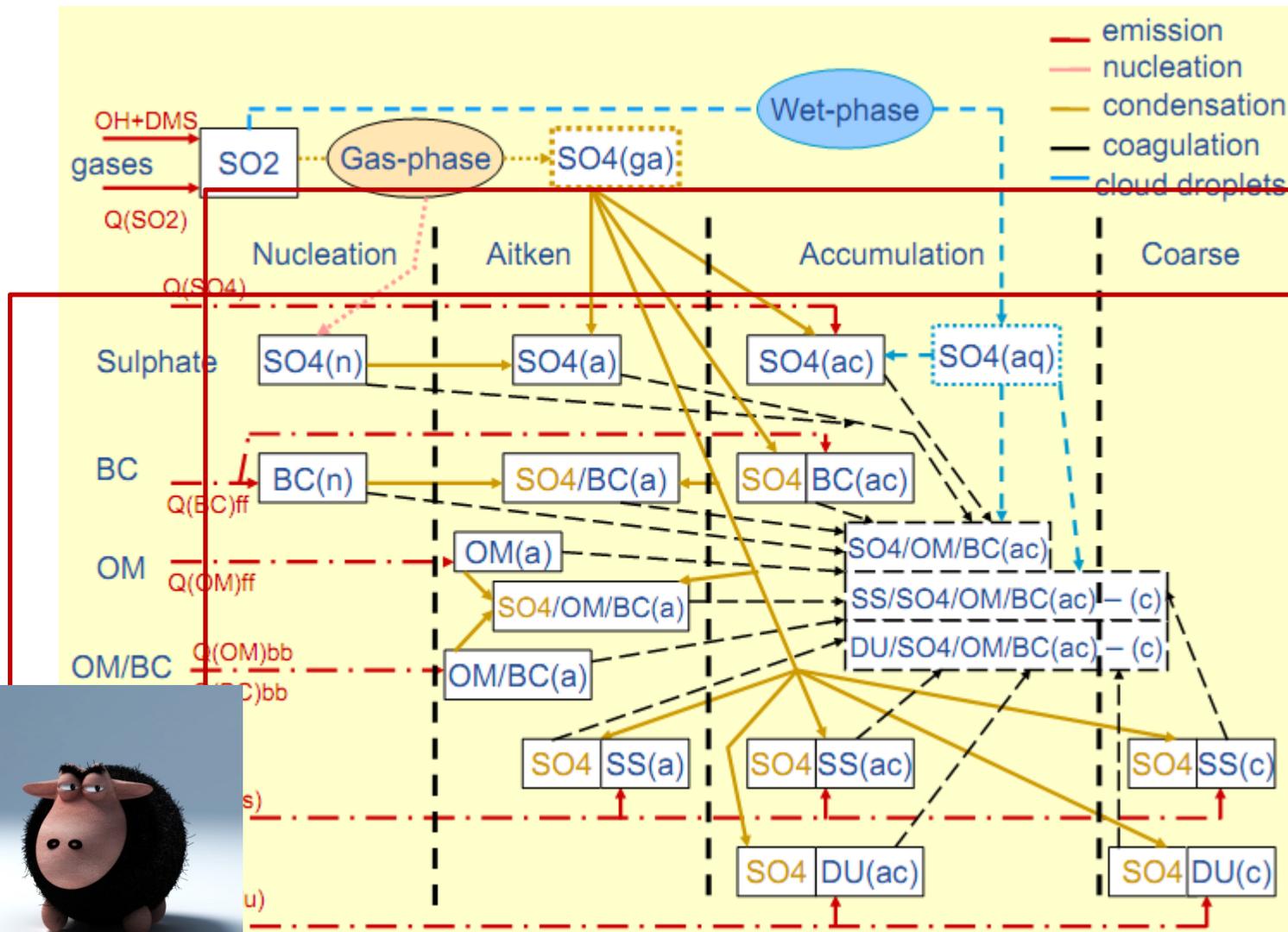


IPCC, 2007, based on MODIS data

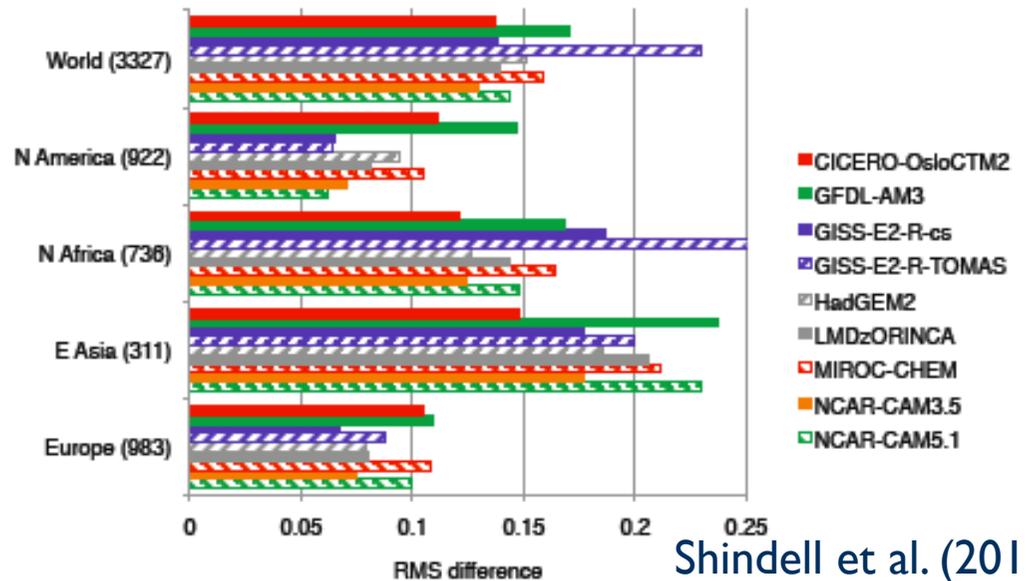
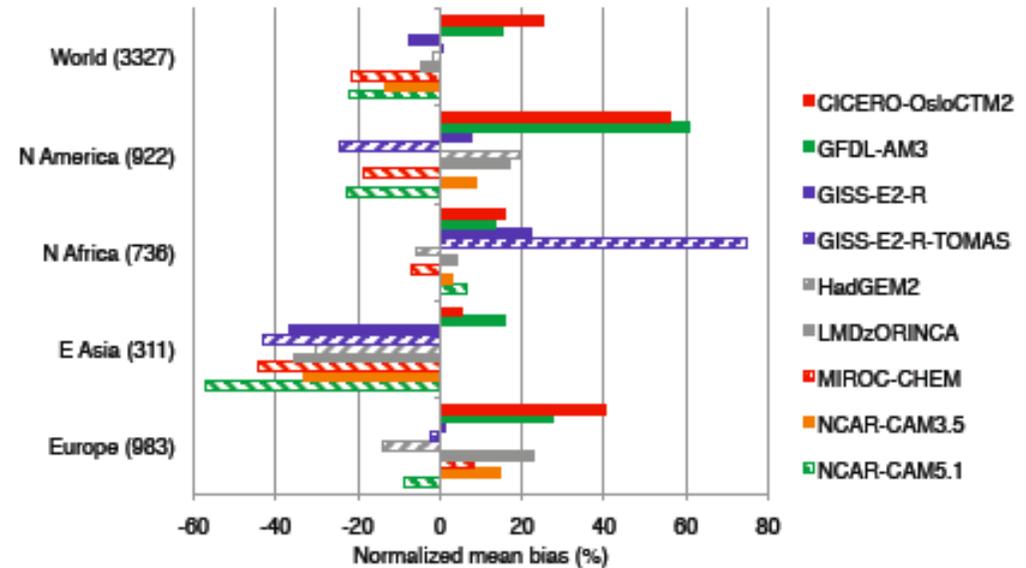
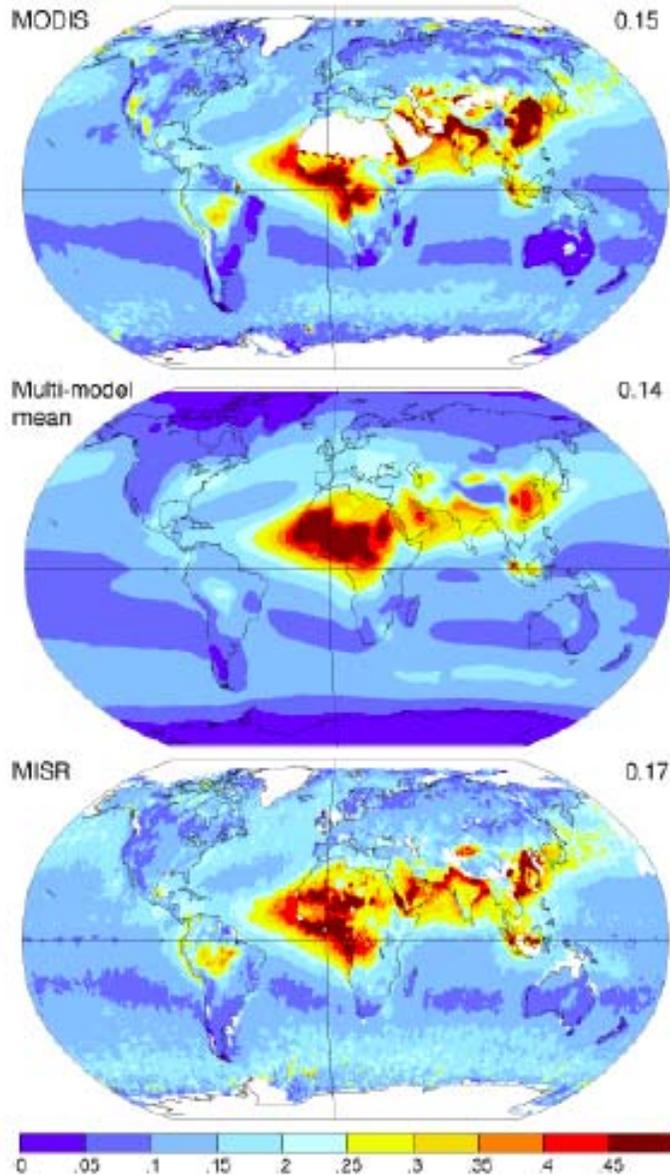
Measured aerosol particle size and number concentration



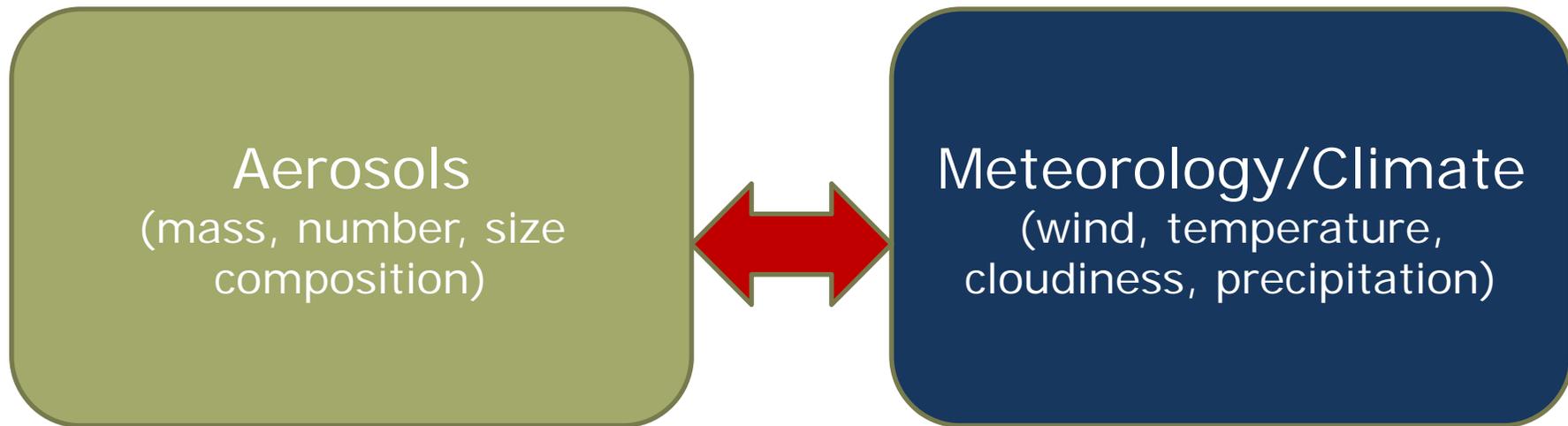
Example of state-of-the-art aerosol module in an ESM



How good are state-of-the-art aerosol modules in global models?



What is the cause of uncertainty?

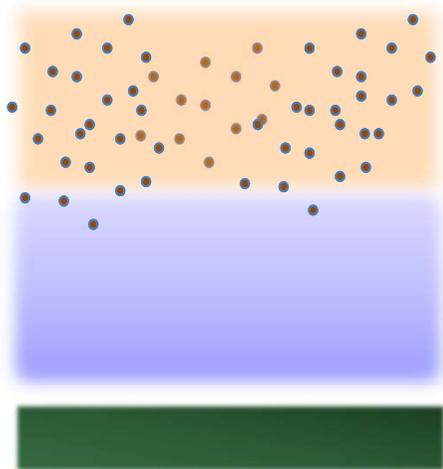


- Wet deposition
- Transport
- Secondary aerosol formation
- Natural aerosol emissions
- ...

- Number of CCN/IN
- Aerosol composition and mixing state

Aerosol direct and indirect effects

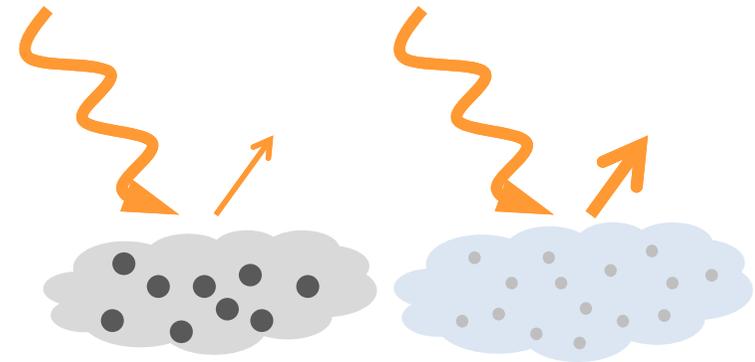
Aerosol direct effect



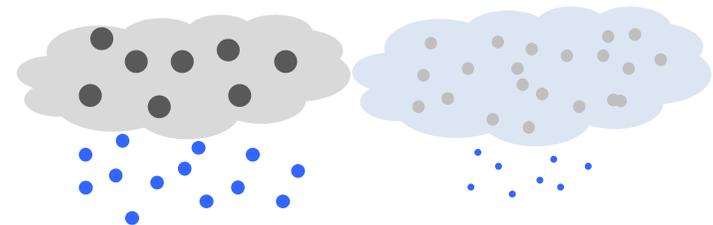
Aerosol indirect effects
=
aerosols as cloud
condensation nuclei
(CCN) or ice
nuclei (IN)



Aerosol 1st indirect effect



Aerosol 2nd indirect effect

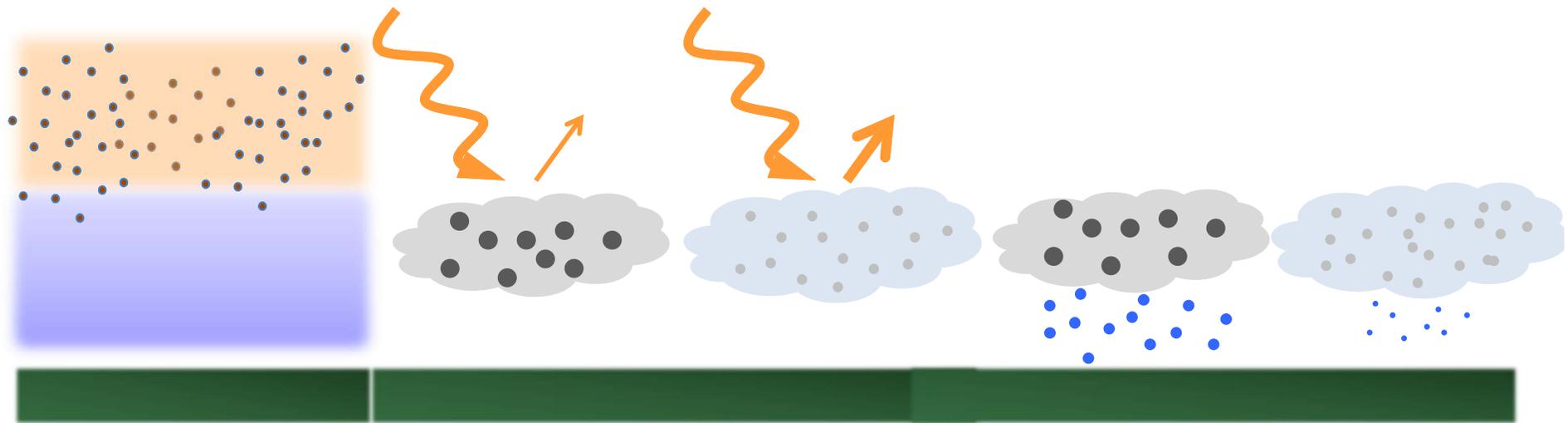


Aerosol direct and indirect effects

Aerosol direct effect

Aerosol 1st indirect effect

Aerosol 2nd indirect effect



Changes in the radiative balance

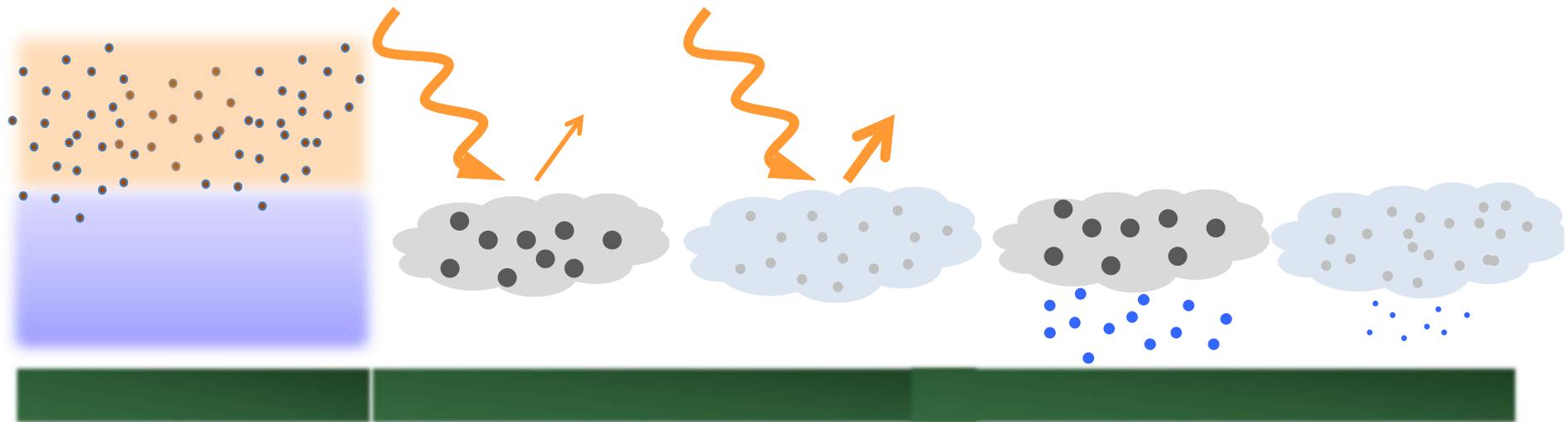
How big impact?

Aerosol direct and indirect effects

Aerosol direct effect

Aerosol 1st indirect effect

Aerosol 2nd indirect effect



Changes in the radiative balance

Changes in large-scale circulation

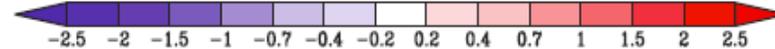
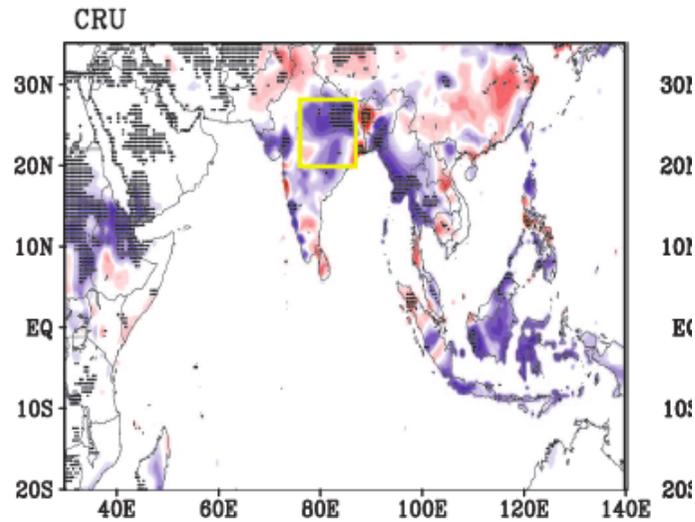
Aerosol effects on atm. circulation and precipitation



- Anthropogenic aerosols may have **weakened the South Asian summer monsoon**.
(e.g. Ramanathan et al., 2005; Chung and Ramanathan, 2006; Wang et al., 2009; Bollasina et al., 2011; Ganguly et al., 2012).
- Anthropogenic aerosols may affect the **Walker circulation** and associated precipitation patterns.
(Bollasina et al., 2011; Rotstayn et al., 2012; Lewinschal et al., in prep.)
- Anthropogenic aerosols affect tropical precipitation (directly and indirectly) which induces **changes in extra-tropical wave patterns**.
(Rodwell and Jung, 2008; Ming et al., 2011; Lewinschal et al., 2012).
- Anthropogenic aerosols (especially BC?) may cause a **widening of the NH tropical belt** (Allen et al., 2012).

Precipitation trends over the South Asian monsoon region (Jun-Sep, 1950-1999)

Obs

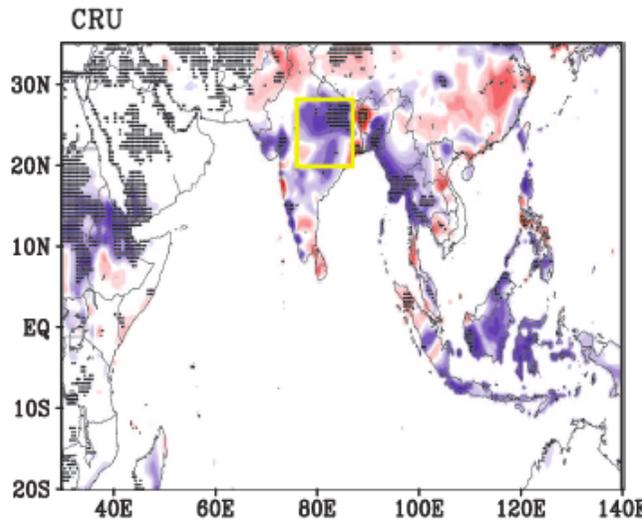


[mm day⁻¹ (50 years)⁻¹]

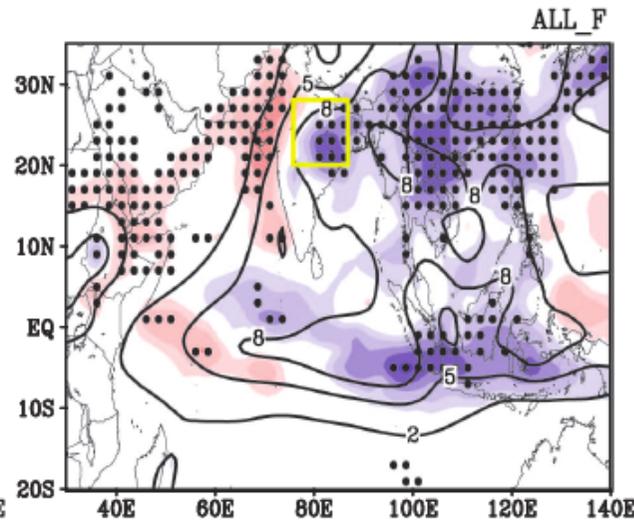
Bollasina et al. (2011)

Precipitation trends over the South Asian monsoon region (Jun-Sep, 1950-1999)

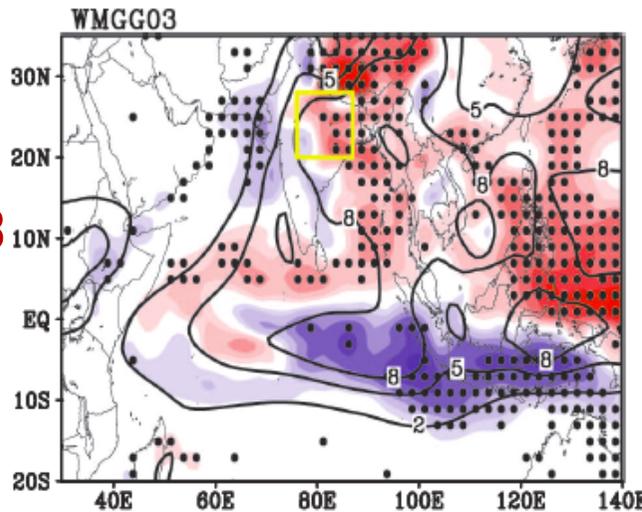
Obs



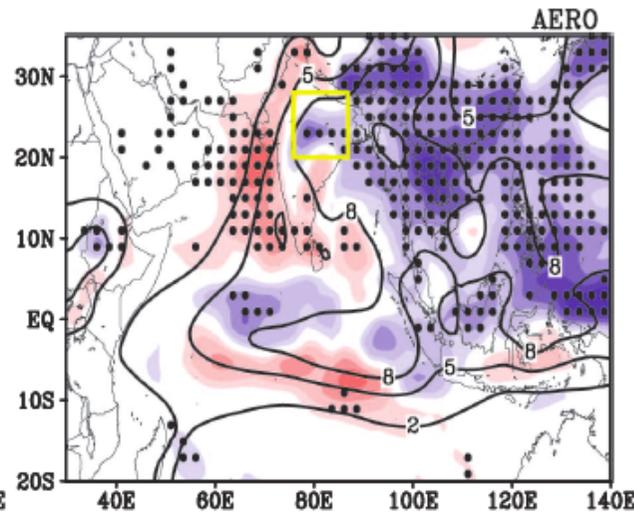
GFDL-CM3
AERO+GHG



GFDL-CM3
GHG



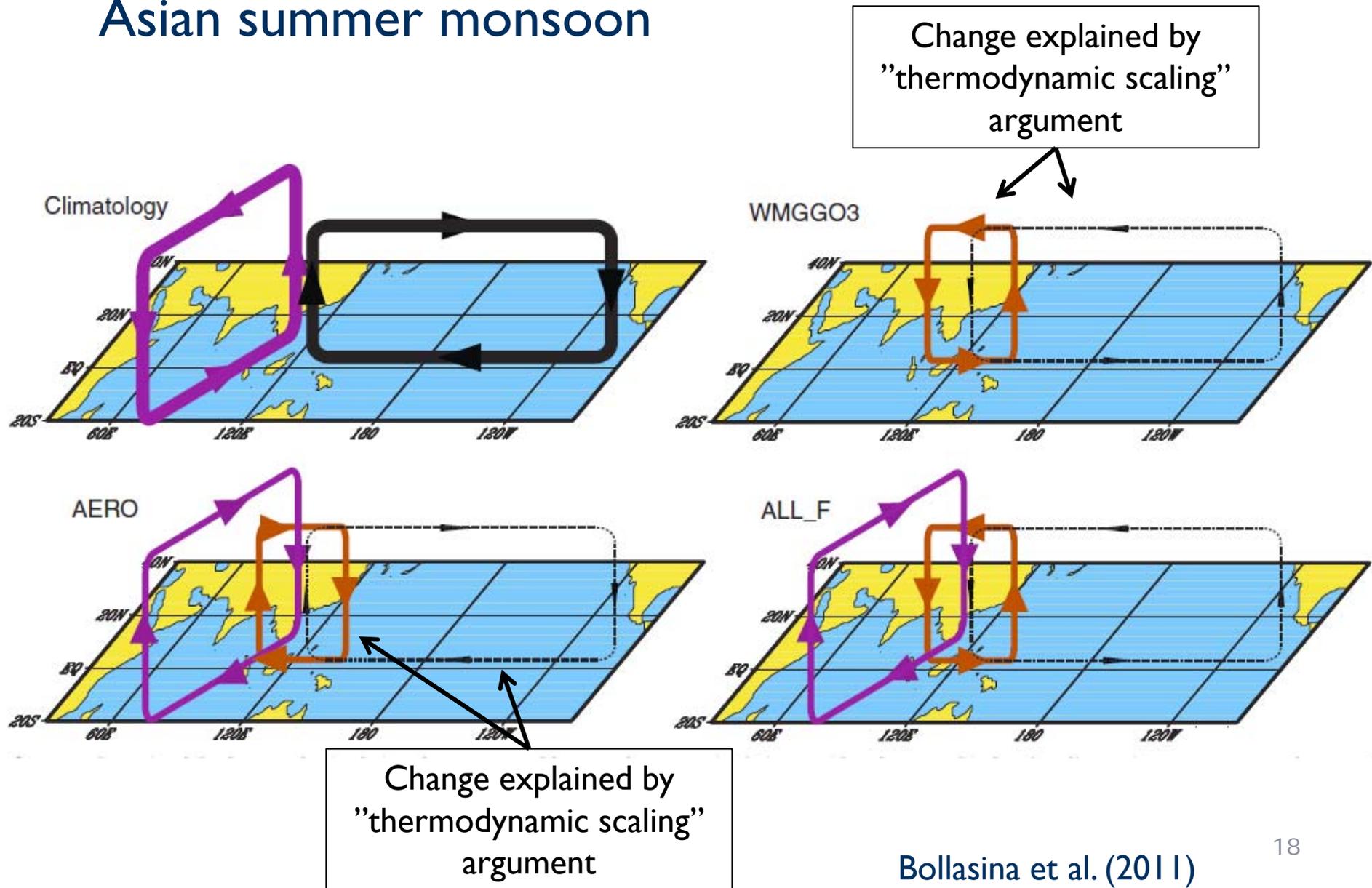
GFDL-CM3
AERO



[mm day⁻¹ (50 years)⁻¹]

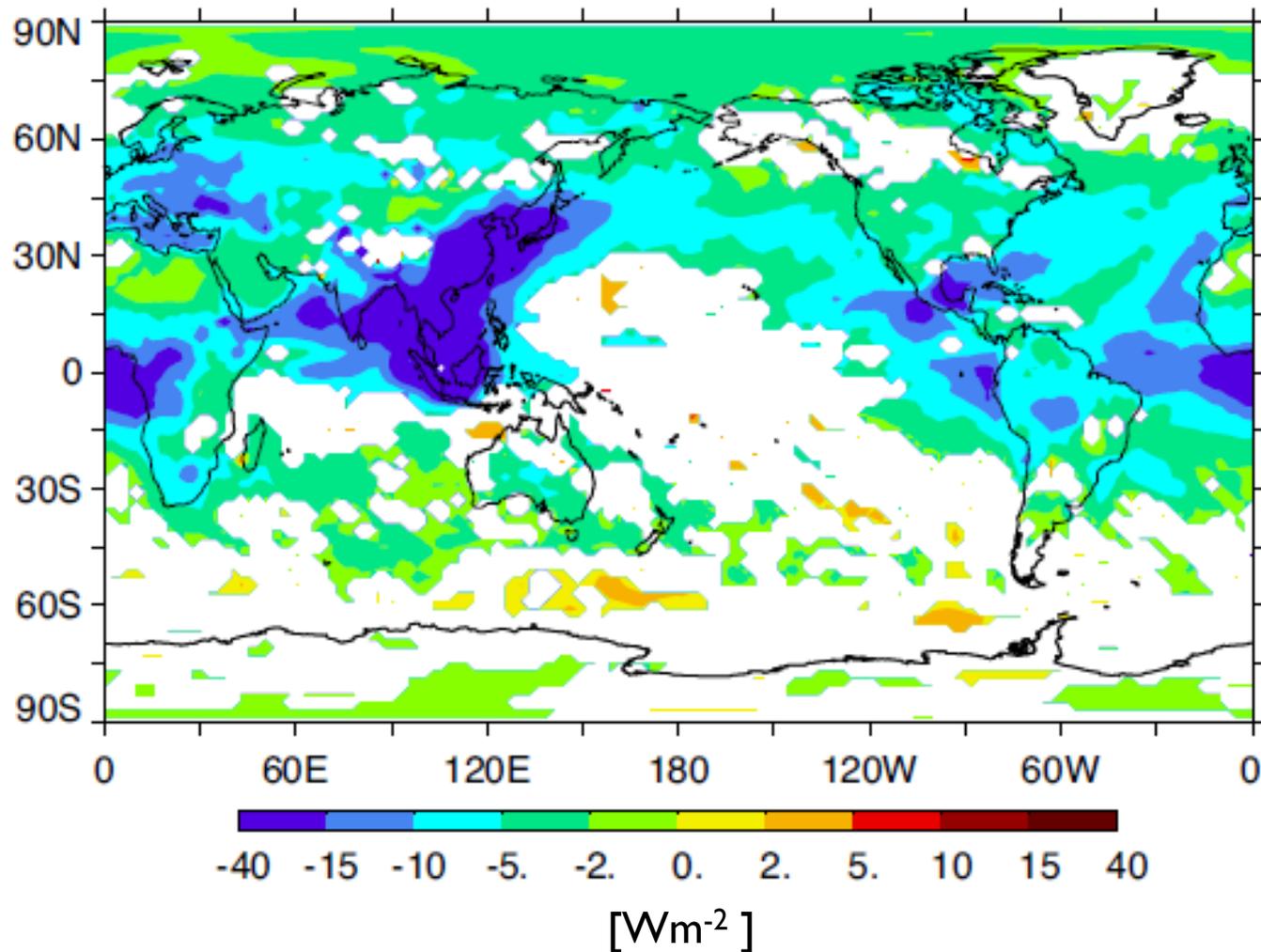
Bollasina et al. (2011)

Aerosols and the weakening of the South Asian summer monsoon

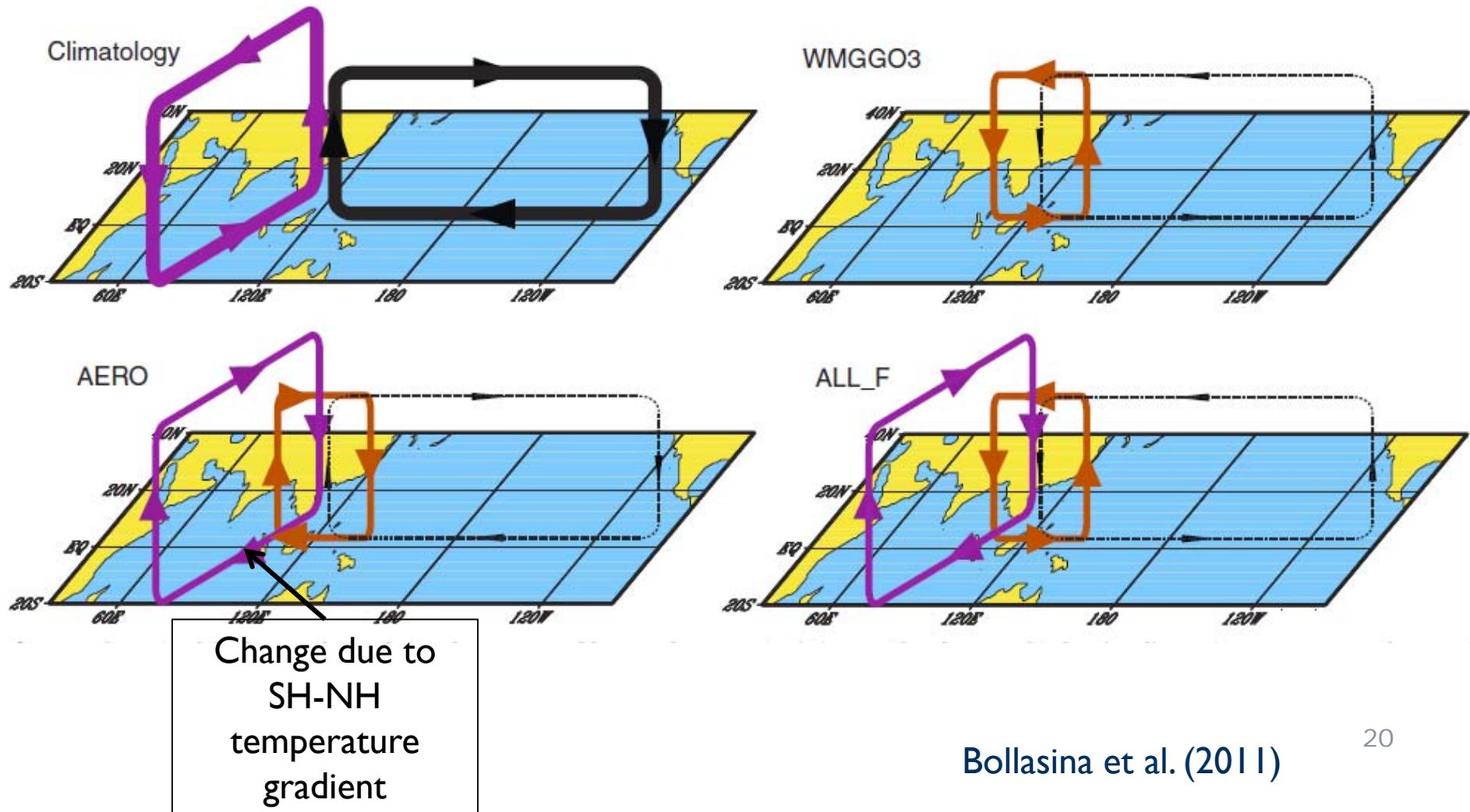


Aerosols and the weakening of the South Asian summer monsoon

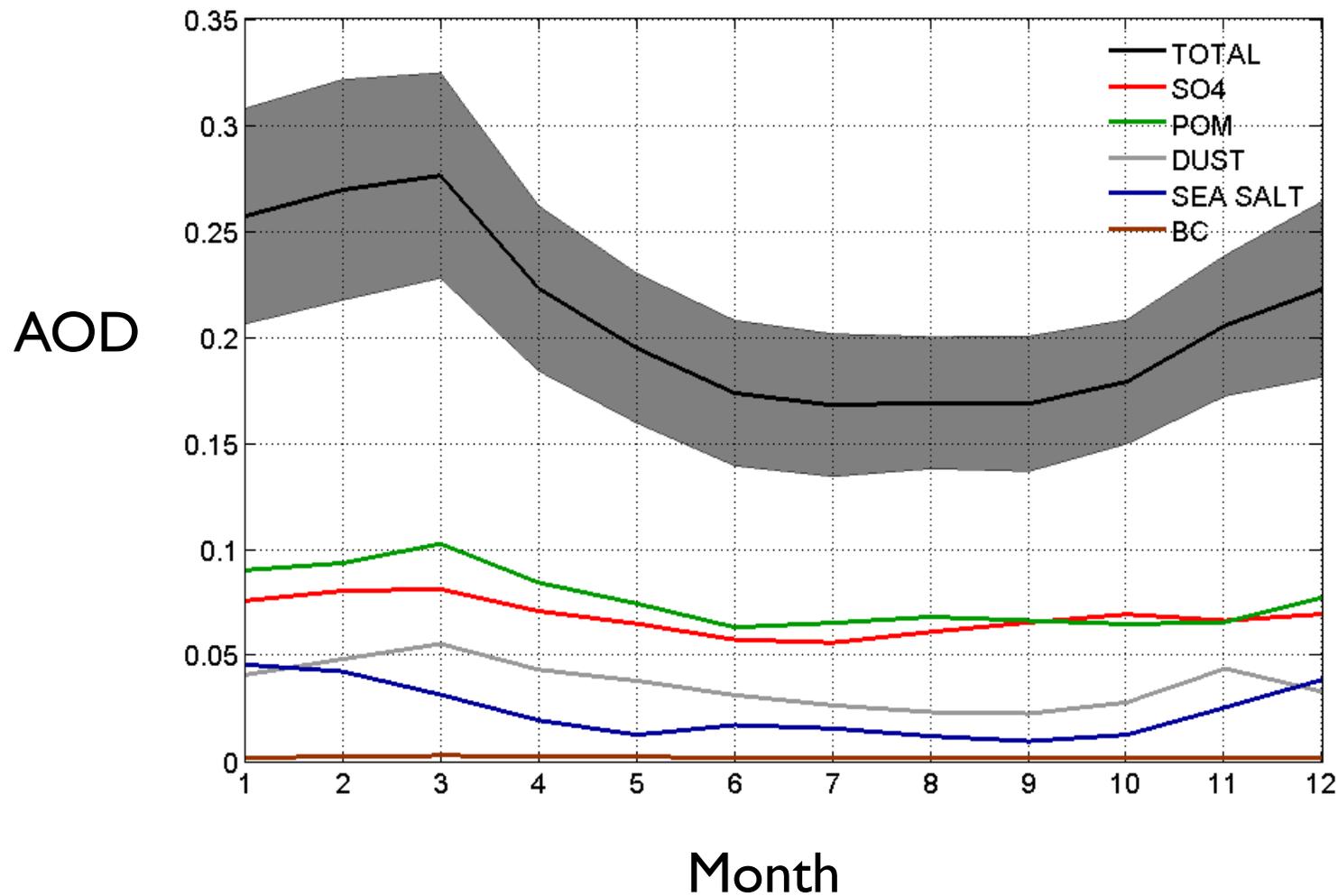
Surface Radiative Flux Perturbation (Jun-Sep)



Aerosols and the weakening of the South Asian summer monsoon



Simulated (CAM-Oslo) monthly AOD variability over Asia (40-year simulation)



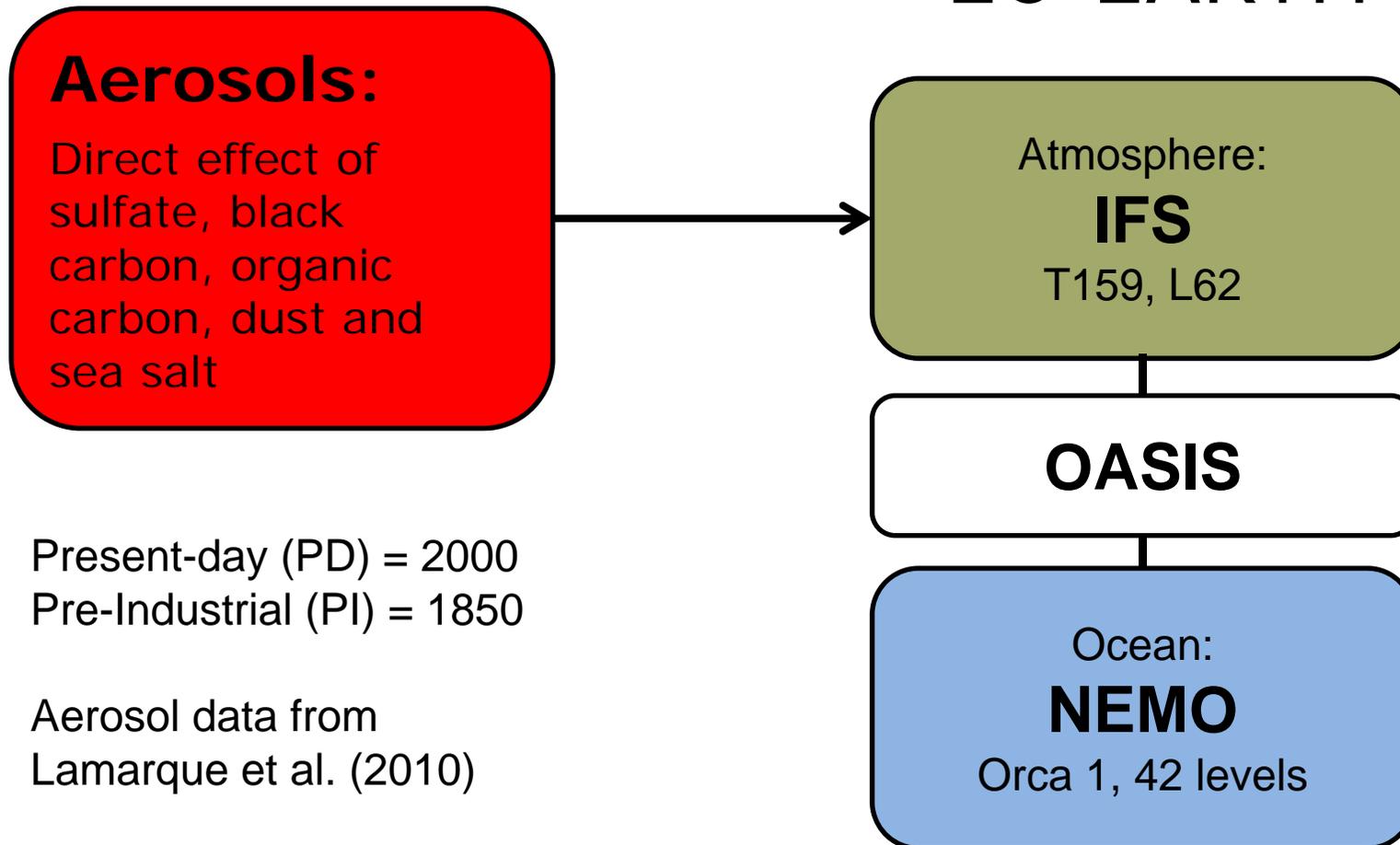
Aerosols and changes in extra-tropical stationary wave patterns.



- Aerosol particles, through their direct and indirect effects, have a potential of altering the location and strength of tropical precipitation (Chen and Ramaswamy, 1996; Ramaswamy and Chen, 1997; Chung et al., 2002; Rotstayn and Lohmann, 2002; Wang, 2004; Allen et al., 2012).
- Latent heat release in tropical deep convection is a major diabatic heat source in the atmosphere.
- Tropical heating is well known to excite waves propagating into the extra-tropics (Hoskins and Karoly, 1981; Simmons, 1982; Jin and Hoskins, 1995; Ting, 1996; Held et al., 2002).

Aerosols and changes in extra-tropical stationary wave patterns.

EC-EARTH



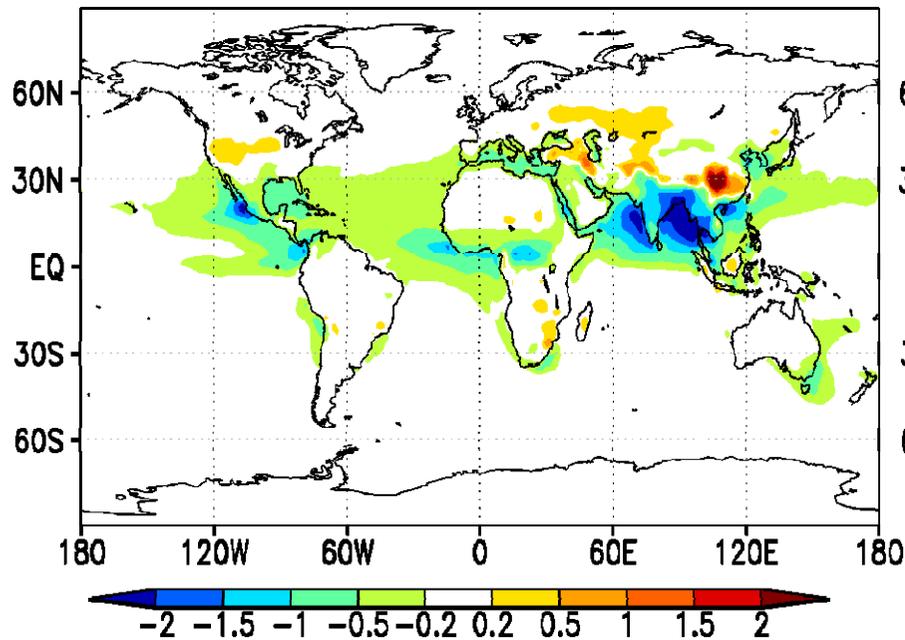
Present-day (PD) = 2000
Pre-Industrial (PI) = 1850

Aerosol data from
Lamarque et al. (2010)

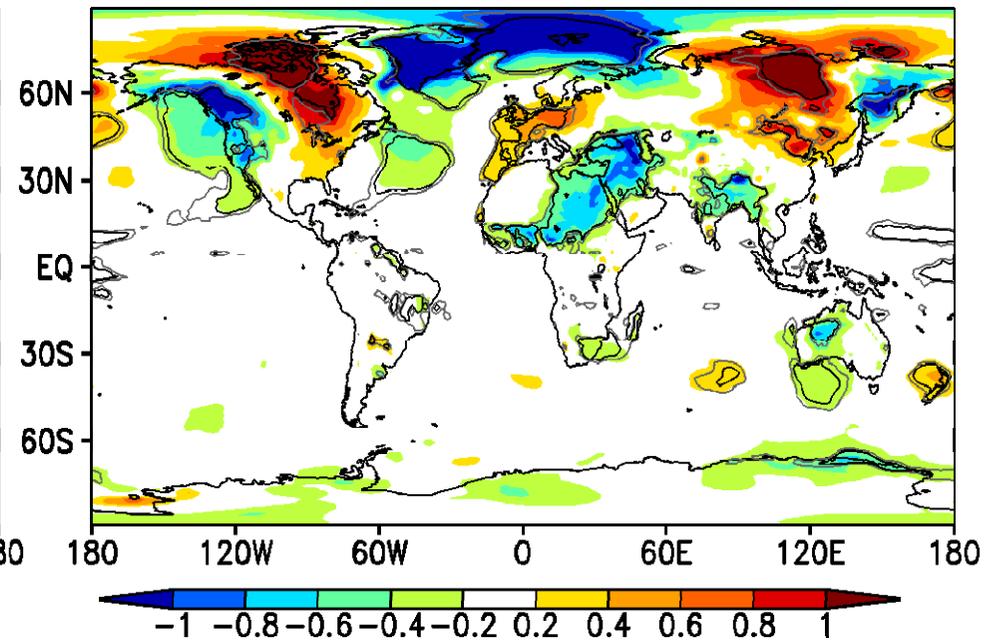
Lewinschal et al. (2012)

Radiative forcing and temperature response: PD-PI, DJF

TOA Radiative forcing [Wm^{-2}]

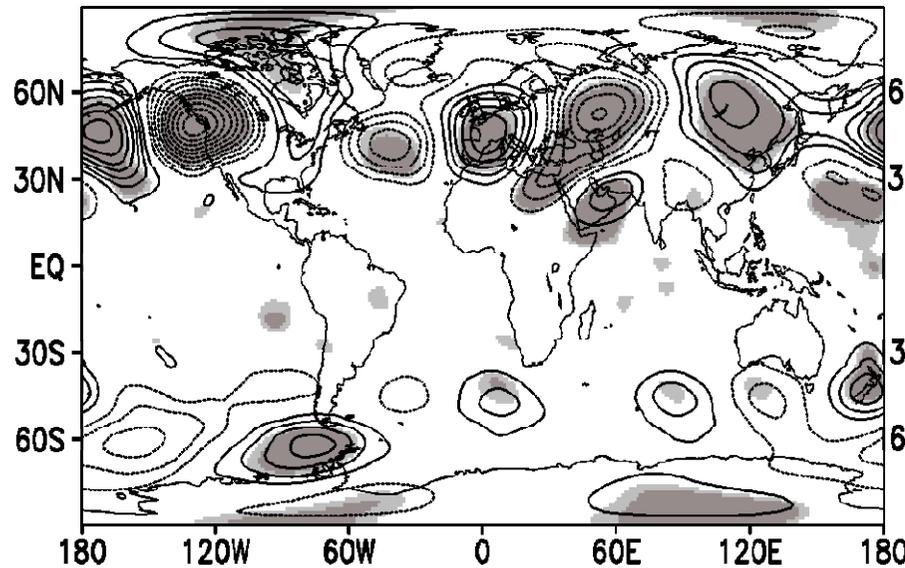


2m temperature response [K]



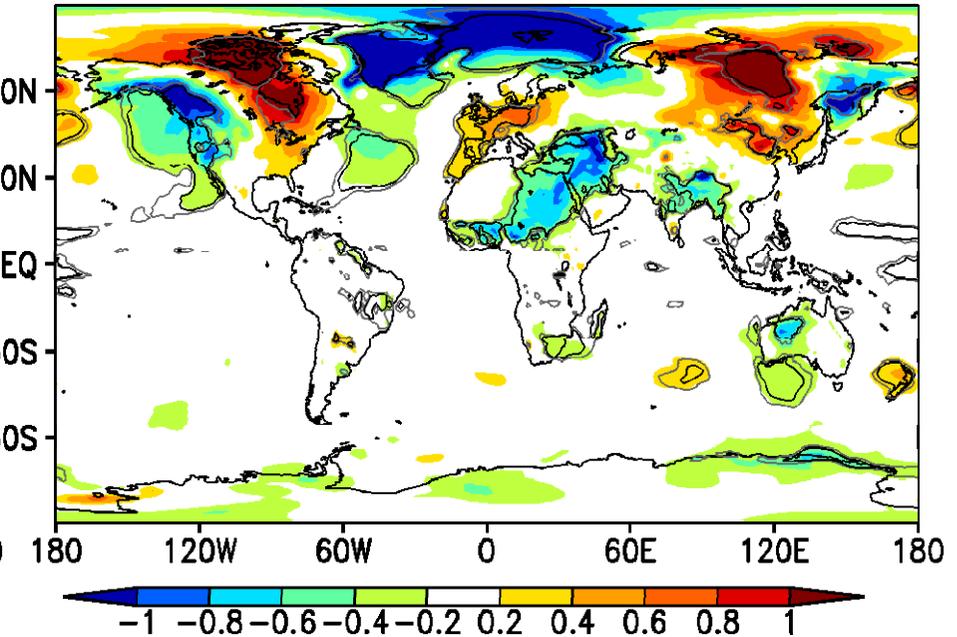
Radiative forcing and temperature response: PD-PI, DJF

Δ geopotential height @ 300 hPa [m]



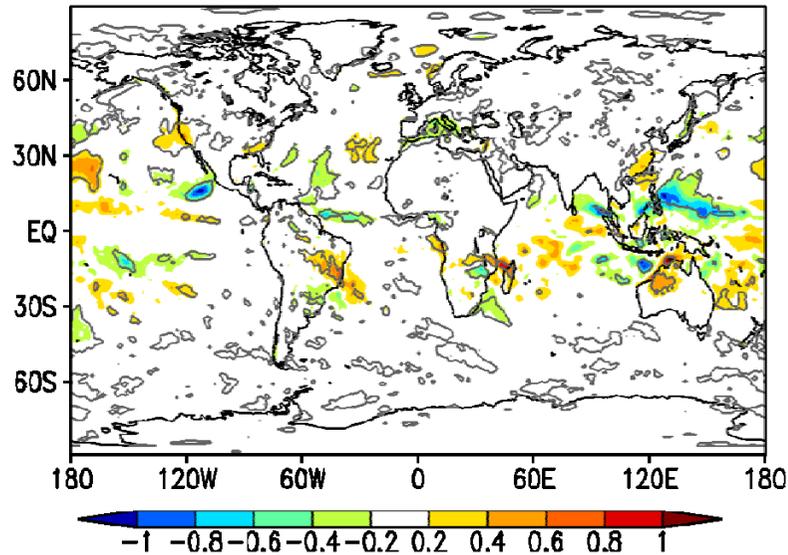
Contour interval = 5m

2m temperature response [K]



Analysis using linear baroclinic model LUMA

Δ Convective precipitation [mm day⁻¹]



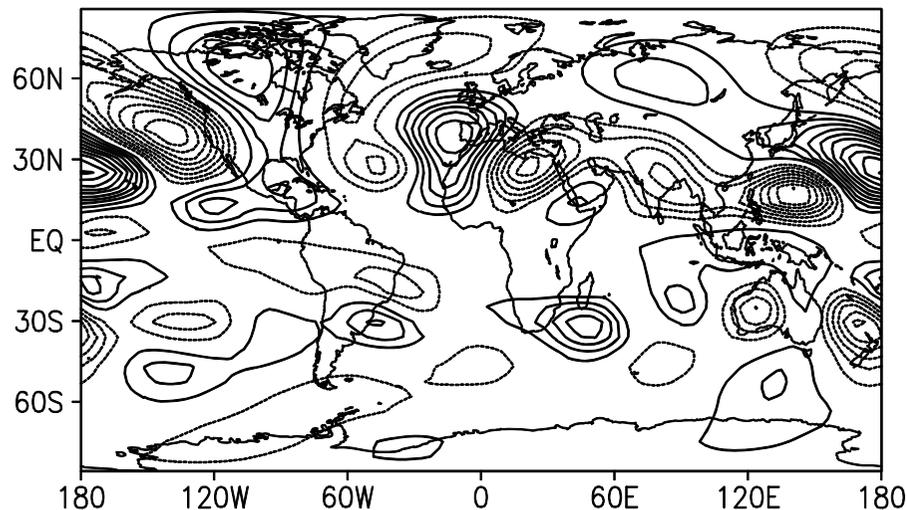
LUMA

Precip change =>
Latent heat source =>
Forcing (F)

$$Y^* = -L^{-1}F$$

Y^* = perturbed state
 L = linear operator
 F = Forcing

Δ Linear stream function @ 0.35 [m²s⁻¹]

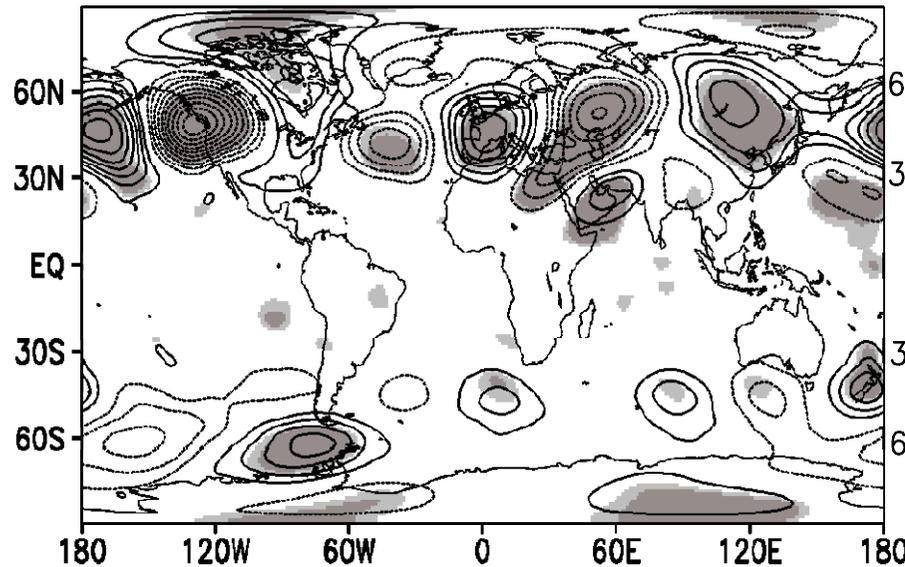


Contour interval = 10⁴ m²s⁻¹

Change in geopotential height (EC-EARTH) vs. Change in linear stream function (LUMA)

EC-Earth

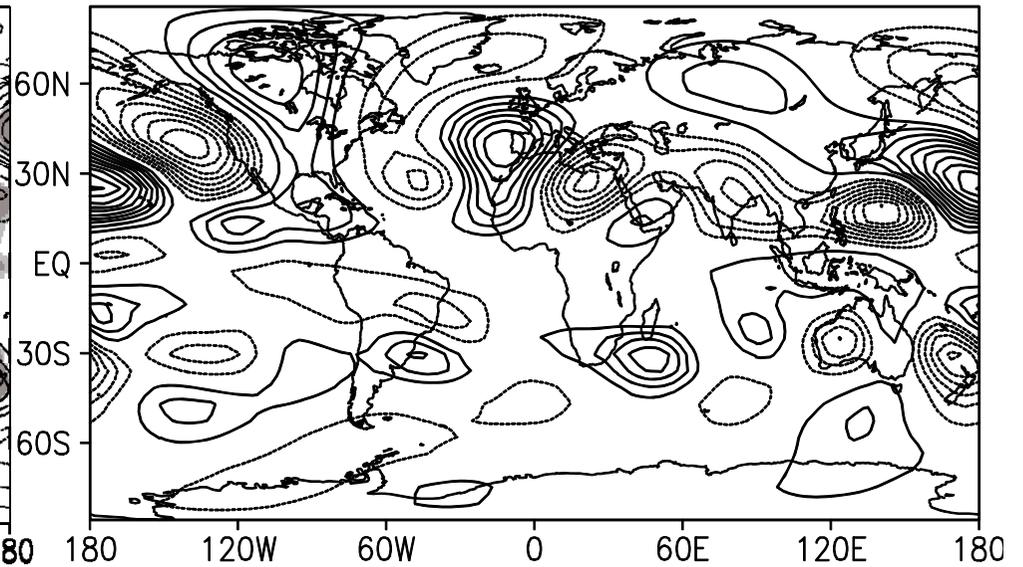
Δ geopotential height @ 300 hPa [m]



Contour interval = 5m

LUMA

Δ Linear stream function @ 0.35 [m^2s^{-1}]



Contour interval = $10^4 \text{ m}^2\text{s}^{-1}$

Aerosols and changes in extra-tropical stationary wave patterns.



- Aerosol forcing → tropical precipitation anomalies → Rossby waves → extra-tropical surface temperature change.

(Rodwell and Jung, 2008):

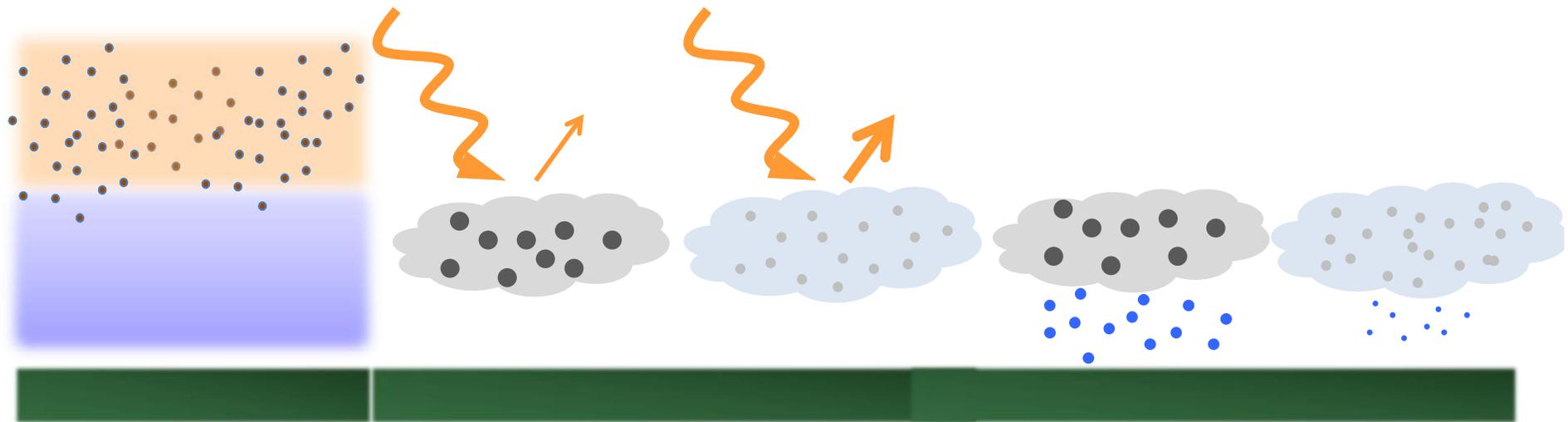
- A more realistic aerosol climatology introduced in IFS led to improved local medium-range forecast skill and reductions in seasonal-mean errors (wind, temperature) throughout the globe .

Aerosol effects on weather and climate

Aerosol direct effect

Aerosol 1st indirect effect

Aerosol 2nd indirect effect



Changes in the radiative balance

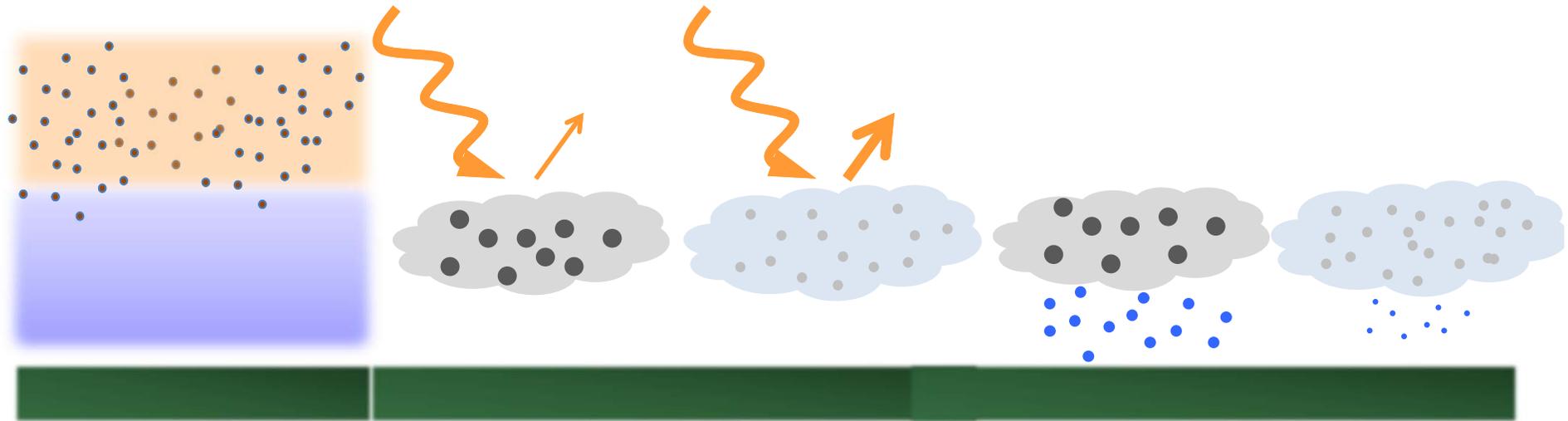
Changes in large-scale circulation

Aerosol effects on weather and climate

Aerosol direct effect

Aerosol 1st indirect effect

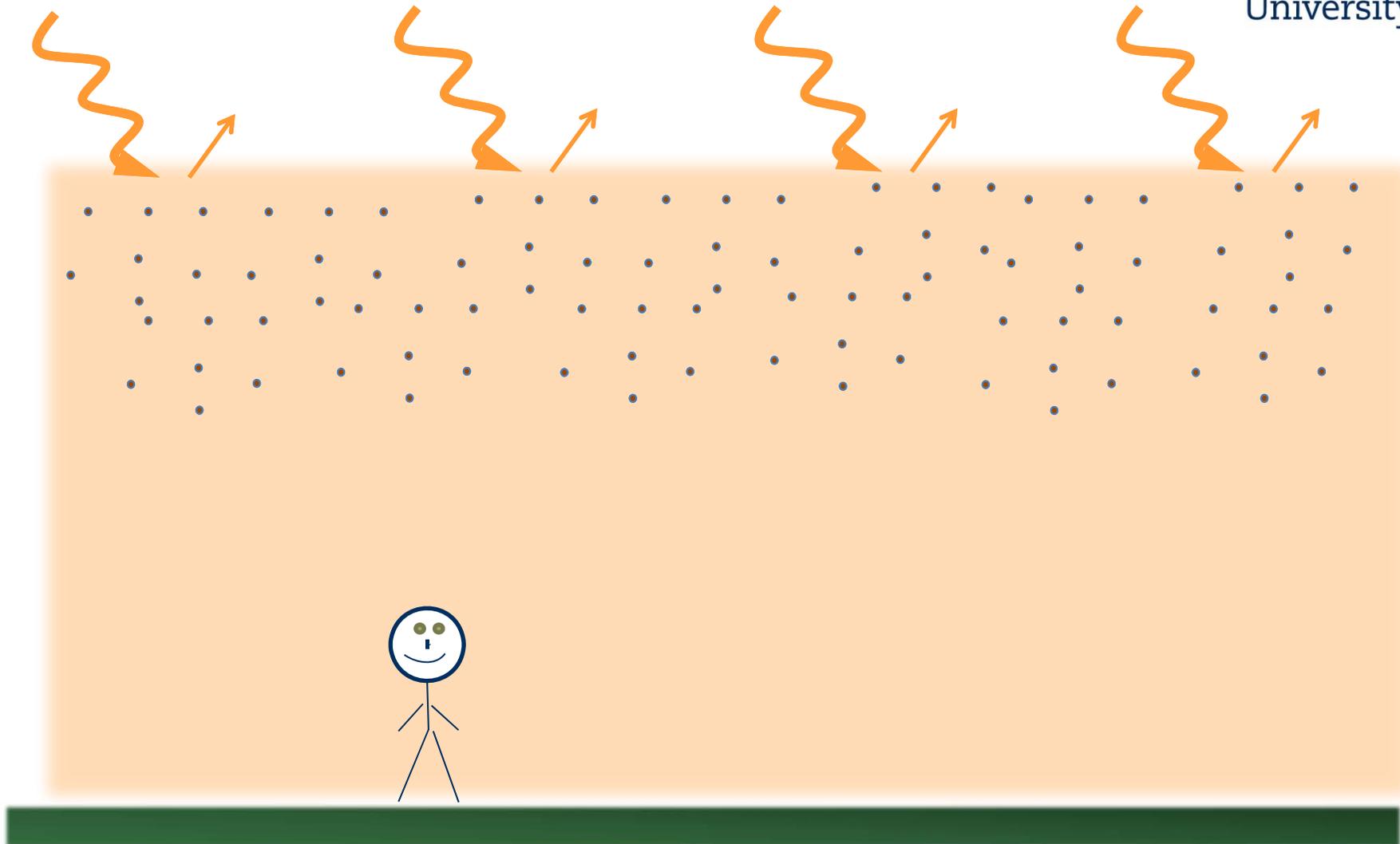
Aerosol 2nd indirect effect



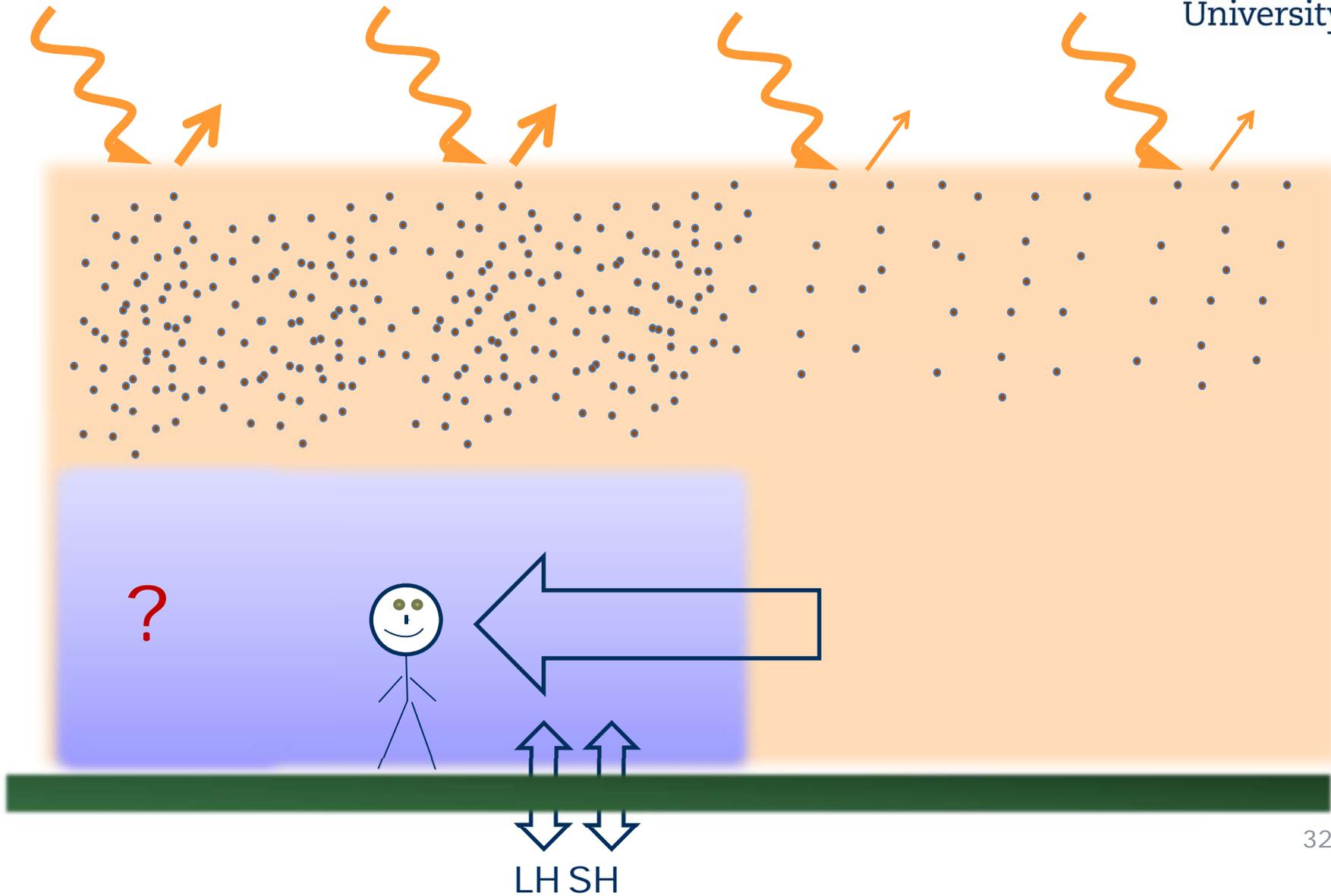
Changes in the radiative balance

What is the local impact on T_{sfc} ?

The aerosol direct effect

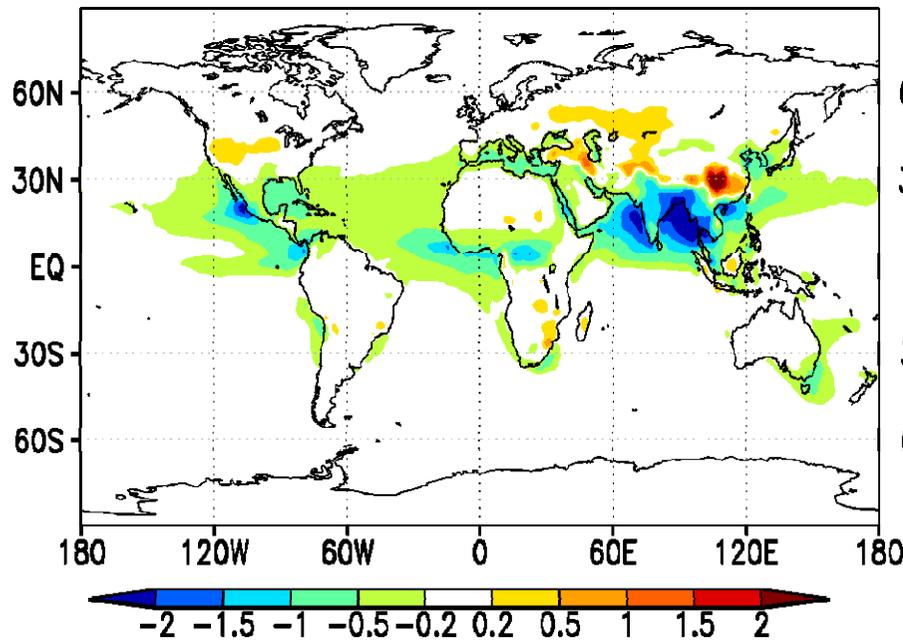


The aerosol direct effect

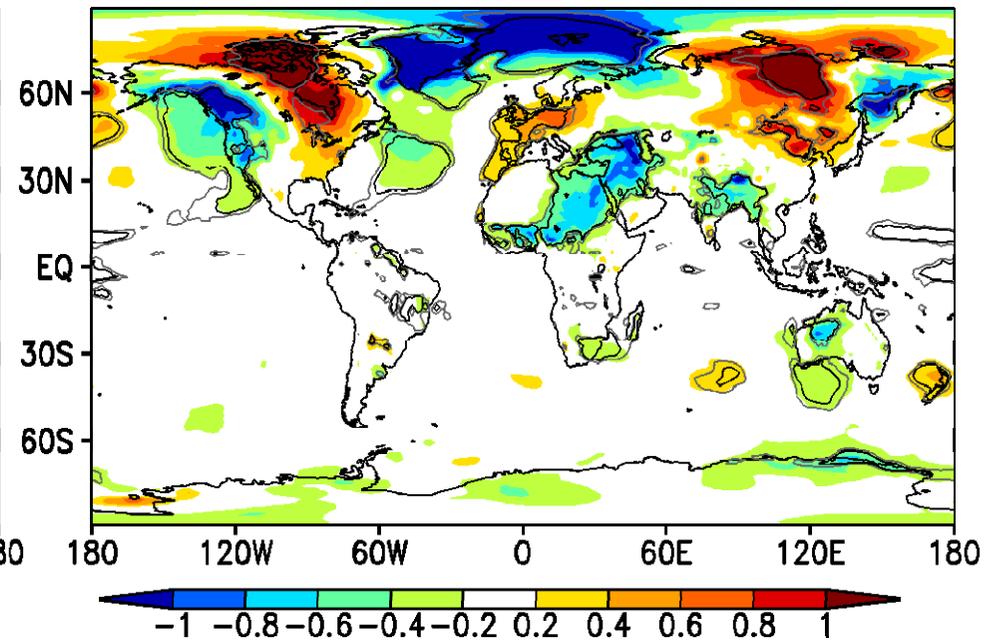


Radiative forcing and temperature response: PD-PI, DJF

TOA Radiative forcing [Wm^{-2}]



2m temperature response [K]



Due to the model and/or that only direct aerosol effects are simulated?

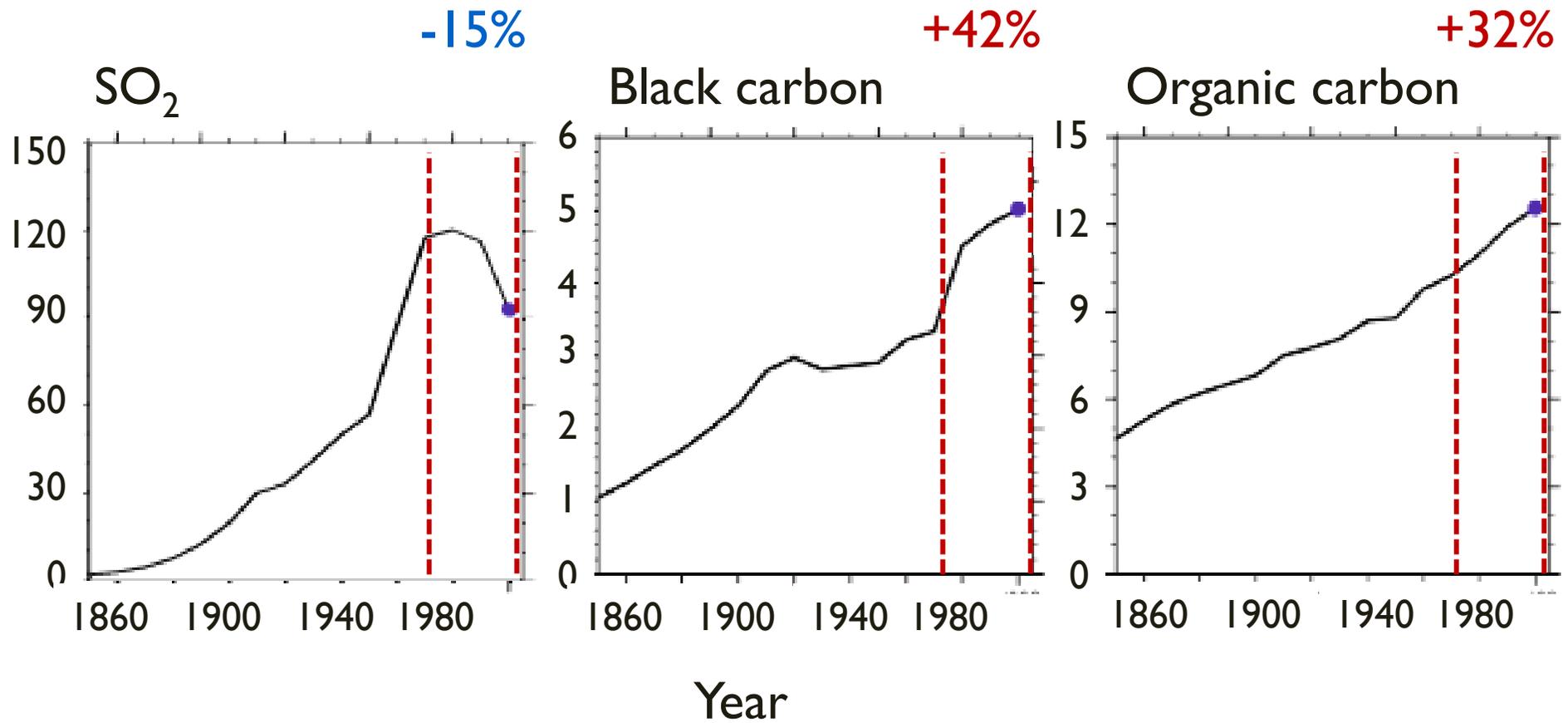
Interactive Aerosol - Global Climate

Model: CAM-Oslo



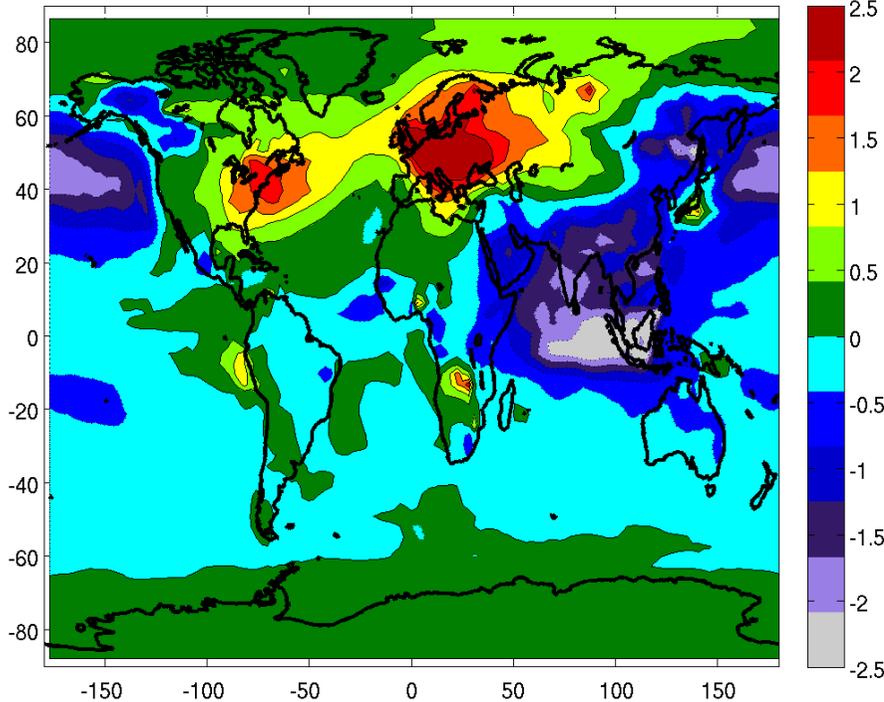
- CAM-Oslo is based on the NCAR-CAM3 general circulation model (Collins et al., 2006).
- In the current set-up, CAM-Oslo is coupled to a mixed-layer ocean.
- Five prognostic aerosol compounds are considered: Sulfate (SO_4), organic matter (POM), black carbon (BC), sea salt (SS) and mineral dust (DU), cf. Seland et al. (2008).
- Two gaseous aerosol precursors are also considered dimethylsulfide (DMS), and sulfur dioxide (SO_2).
- 70 years of equilibrium climate simulations are conducted for the years 2000 and 1970. Last 40 years used for the analysis.
- Both aerosol direct and indirect (albedo and precipitation) effects are considered.

Trends in anthropogenic aerosol particle and precursor emissions [Tg yr⁻¹]

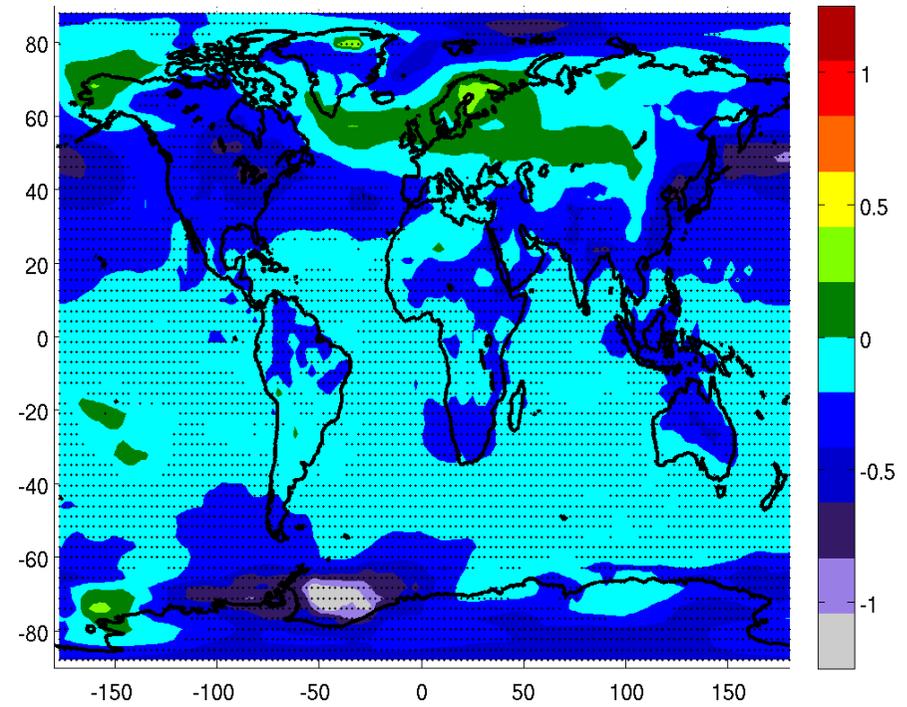


Change in TOA SW RF and T_{surface} 2000-1970_Aero

Total Radiative Forcing
Global average: -0.18 Wm^{-2}
[Wm^{-2}]



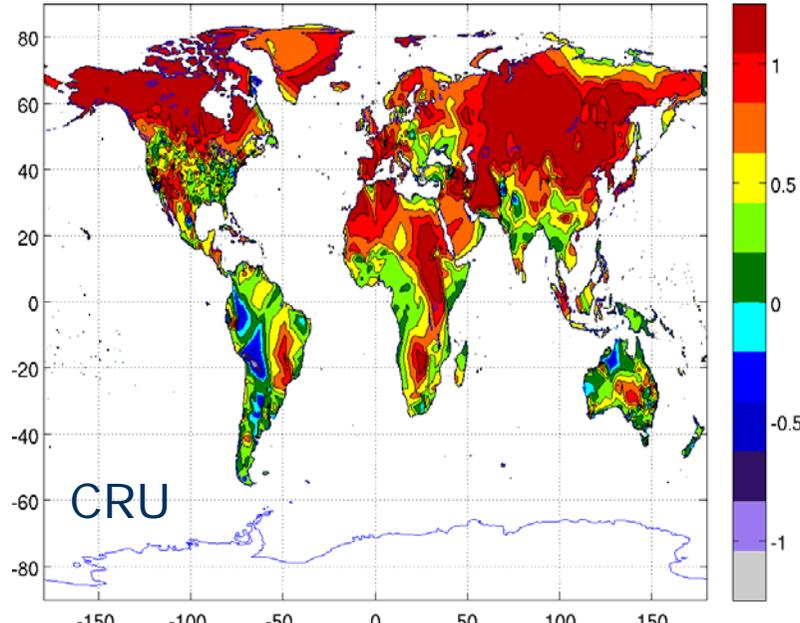
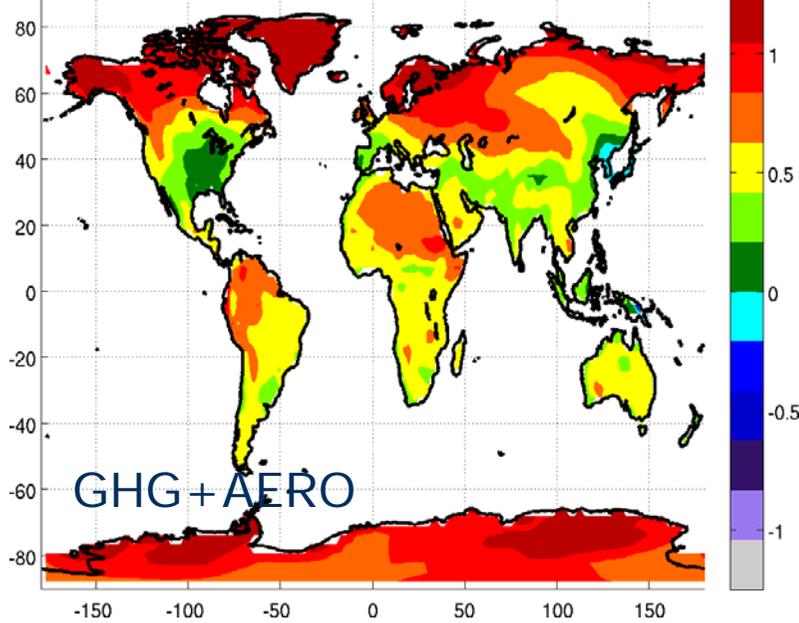
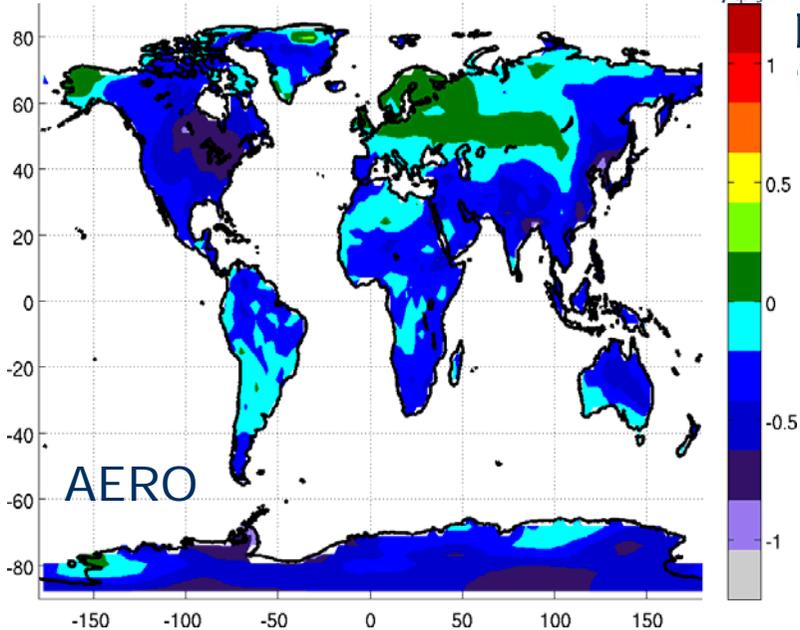
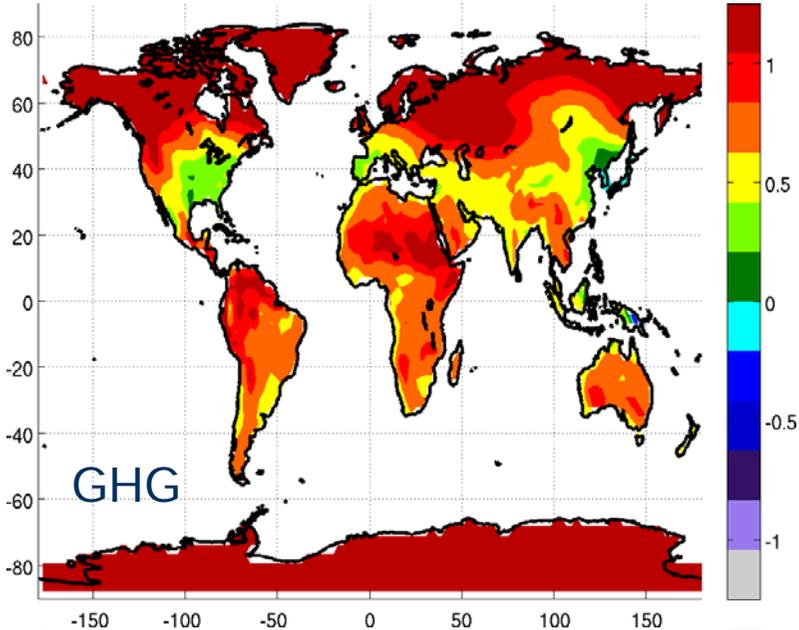
T_{surface} change
Global average: -0.24 K
[$^{\circ}\text{C}$]



Change in T_{sfc} 2000-1970 (CAM-Oslo)



holm
rsity



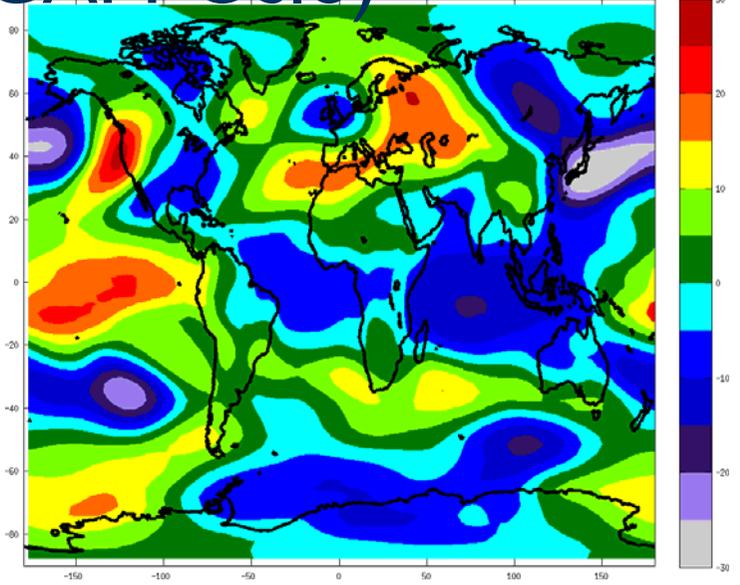
Change in 300 hPa geopotential 2000-1970

(CAM-Oslo)

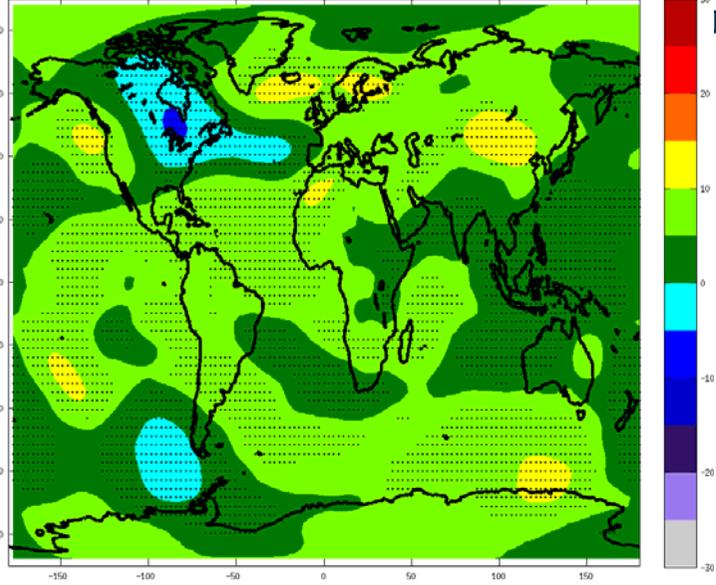


Stockholm University

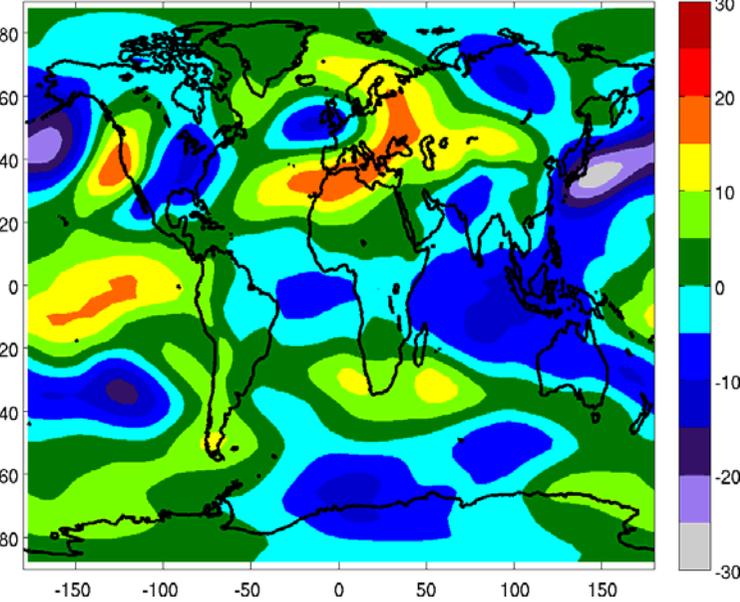
GHG



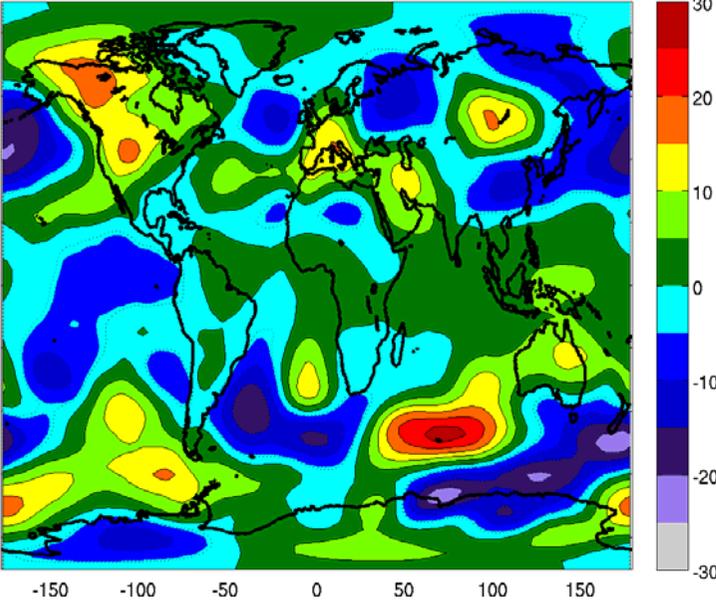
AERO



GHG + AERO



NCEP



Conclusions

- Aerosol particles display a high temporal and spatial variability, i.e. there is a possibility for fast, relatively localized, forcing and response.
- The amount (and type) of aerosol particles over Asia can affect the Indian monsoon, the Hadley circulation and the Walker circulation.
- Aerosol particles affect (directly and indirectly) tropical precipitation (location and intensity) and thereby also extra-tropical stationary waves and surface temperatures.
- In the extra-tropics, the direct relation between the change in SW radiative fluxes and the pattern of surface temperature change is small.
- Other links between aerosols and seasonal prediction: volcanoes, dust storm outbreaks....