Direct and Semi-direct Effects of Aerosols on the Climate System

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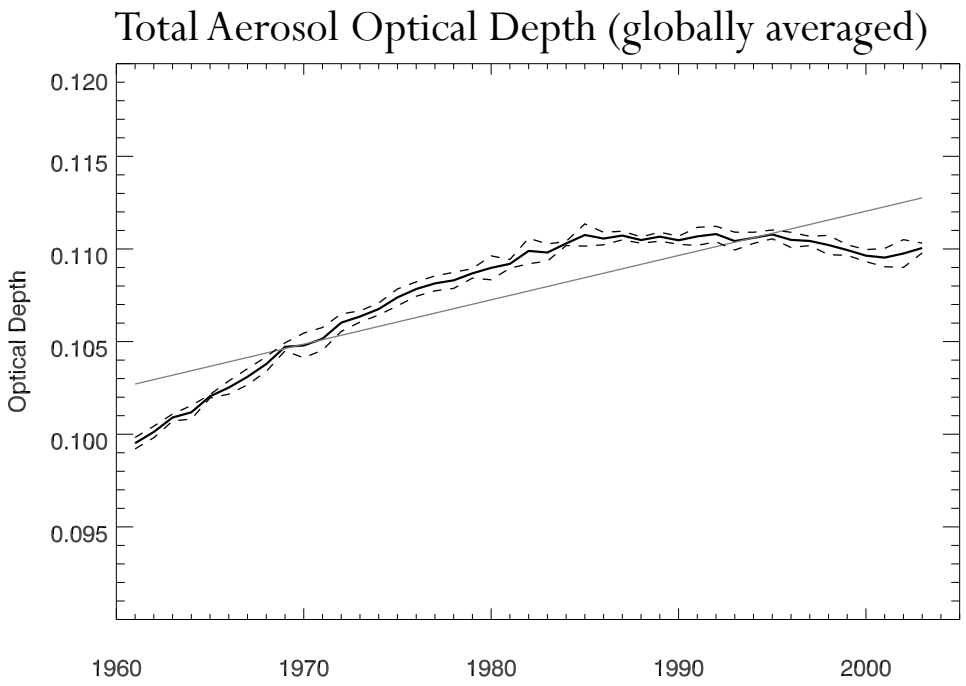
Motivation and Outline

- Studies show aerosol-induced inter-annual variability in regional climate, e.g. Indian Monsoons, West African Monsoons *[e.g. Huang et al. 2009]*

- AR5 Surface Emissions:
  - Decadal temporal resolution
  - No inter-annual variability

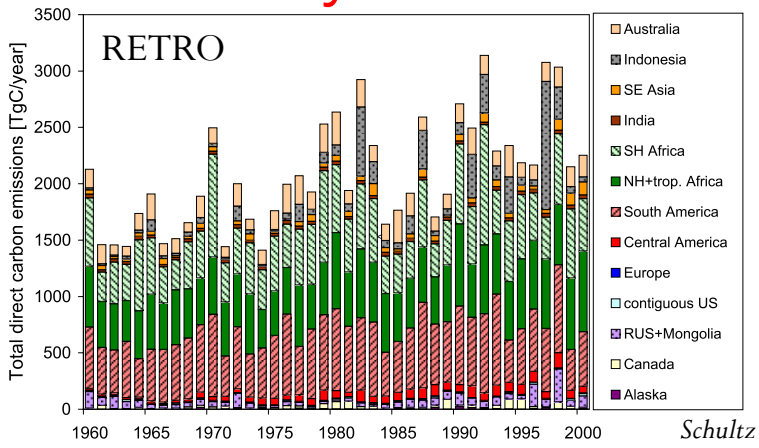
- Outline:
  - Generate a high-resolution aerosol data with monthly temporal resolution
    - Realistic aerosol-induced radiative forcing
  - Study impacts of aerosol-induced variability in experiments using the new dataset
    - Tropical Atlantic
  - Role of thermodynamic feedbacks



Aerosol Optical Depth in experiments performed with aerosol dataset generated from AR5 surface emissions

Generating a High Resolution Tropospheric Aerosols Dataset, with Inter-annual Variability

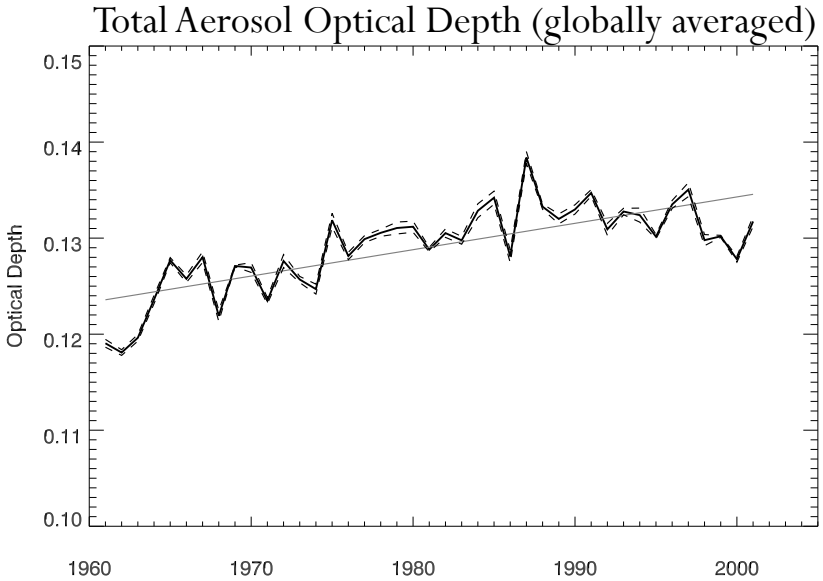
- RETRO Emissions Dataset: (REanalysis of the TROpospheric chemical composition over the past 40 years, *Schultz et al. 2007*)
  - Wildfire emissions
    - Black Carbon, Organic Carbon
    - Sulfate
  - 0.5x0.5 resolution



Schultz et al. 2008

- AR5 + RETRO Wildfire Emissions
  - Monthly surface emissions data from 1960-2000

- Community Atmosphere Model 4 (Finite Volume) + Bulk Aerosol Model (BAM)
  - Sulfur chemistry, wet and dry deposition, etc.
  - Forced with AR5+RETRO emissions
  - Global 3D tropospheric aerosol dataset
    - 0.9x1.25 resolution



Aerosol Optical Depth in experiments performed with aerosol dataset generated from AR5+RETRO surface emissions

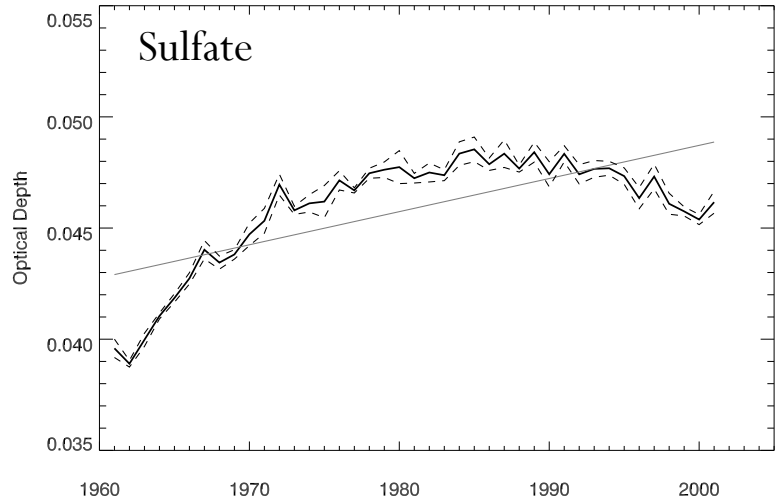
AMIP Simulations: High Resolution Tropospheric Aerosols Dataset

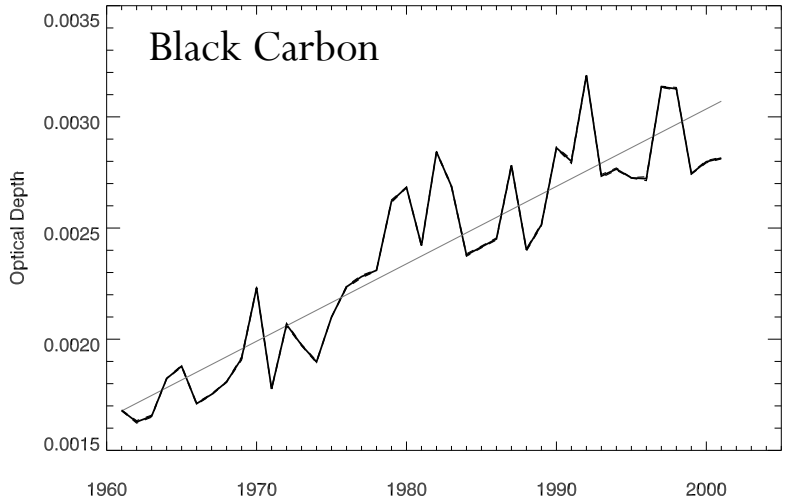
- Community Atmosphere Model (CAM4):
  - Spectral Dynamical Core
    - T85 spatial resolution
  - CAM4 Physics
    - Direct and Semi-direct aerosol effects
    - Sulfates, black carbon, organic carbon, dust and sea-salt
    - Hygroscopic growth
    - No aerosol-cloud micro-physics

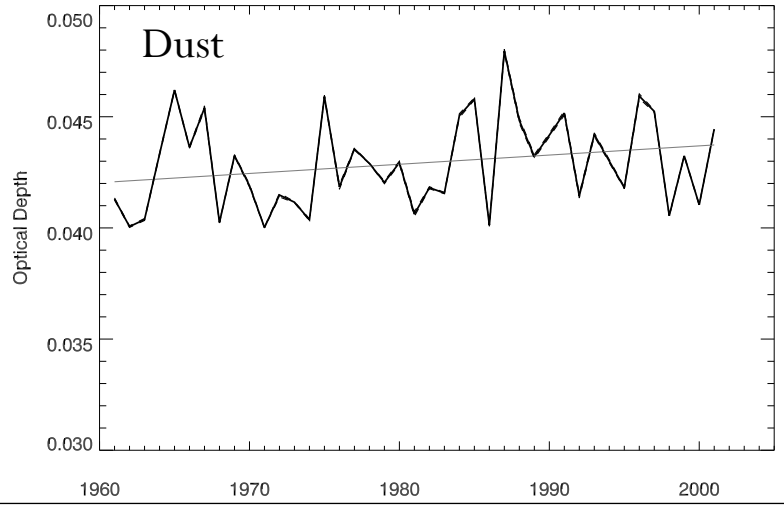
- CAM4 AMIP Experiments:
  - Set 1: CAM4 prescribed with new AR5+RETRO dataset
    - CAM4-AMIP-20AERO (4 runs, 1960-2000)
  - Set 2: CAM4 prescribed with preindustrial estimate of aerosols
    - CAM4-AMIP-1850AERO (4 runs, 1960-2000)

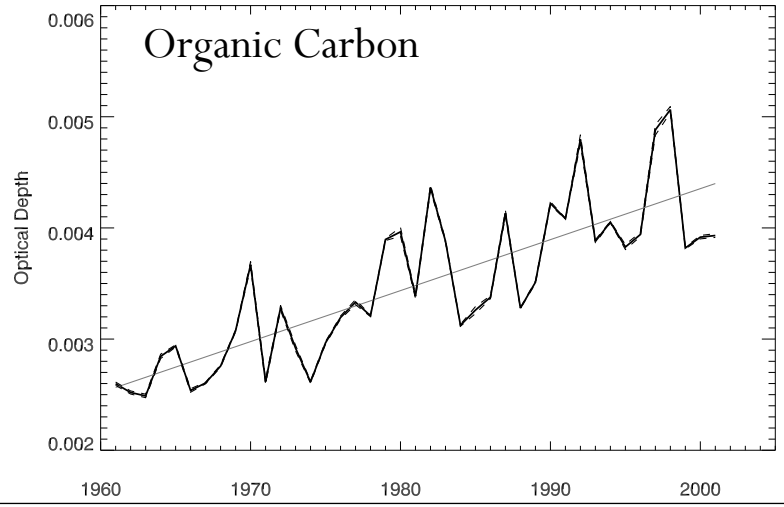
Inter-annual Variability in Tropospheric Aerosols

Optical Depth: Contributions from individual Aerosol species (CAM4-AMIP-2000AERO)





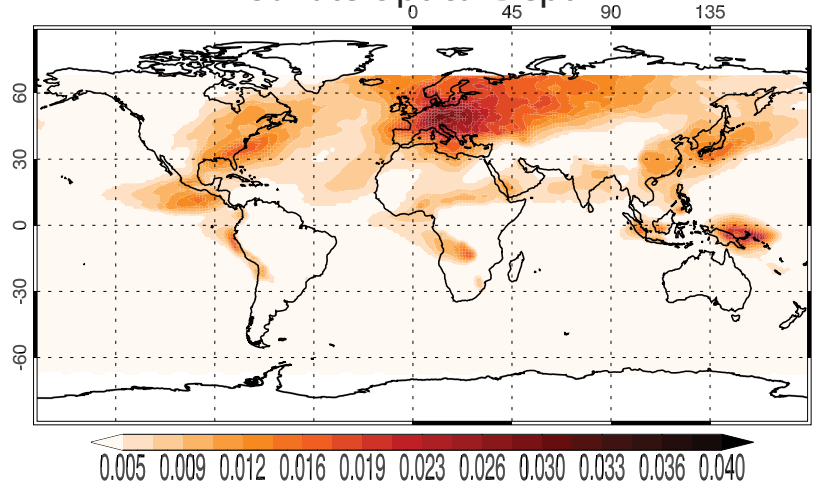




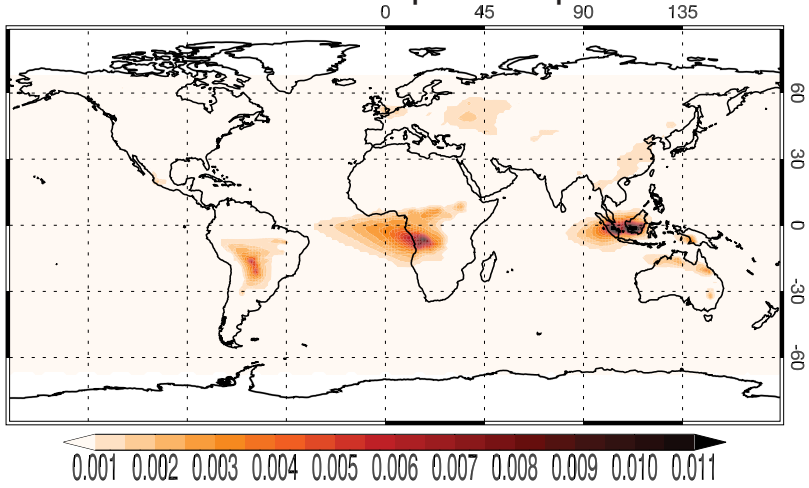
Inter-annual Variability in Tropospheric Aerosols

Standard deviation of linearly de-trended optical depth

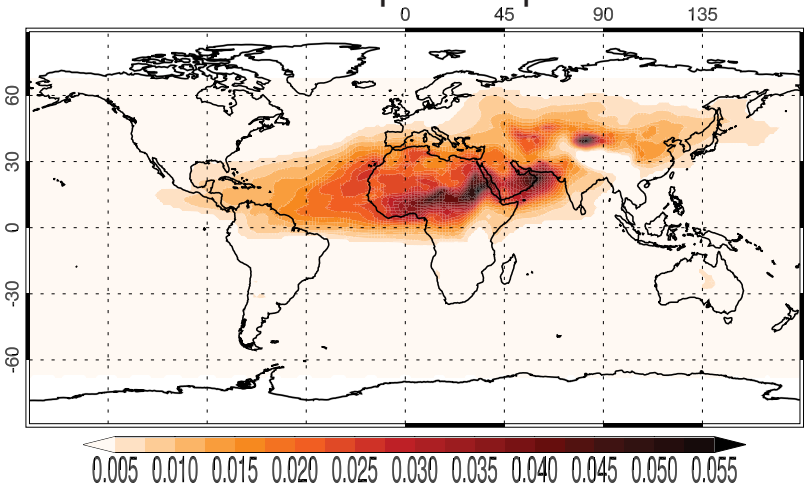
Sulfate Optical Depth



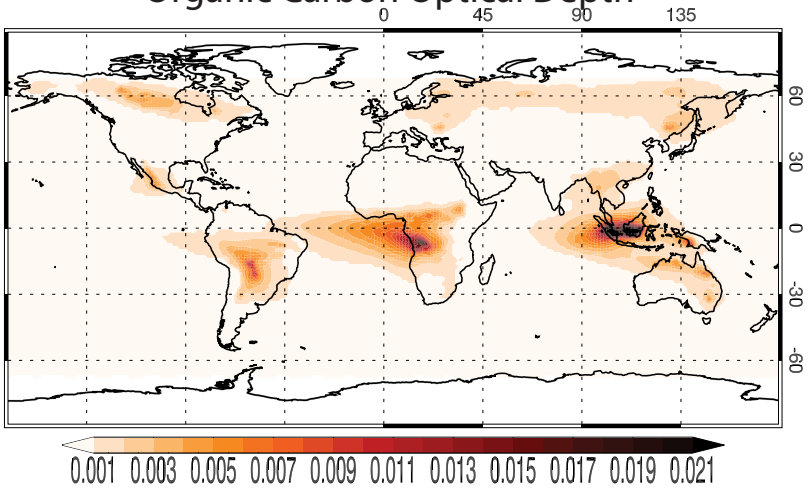
Black Carbon Optical Depth



Dust Optical Depth



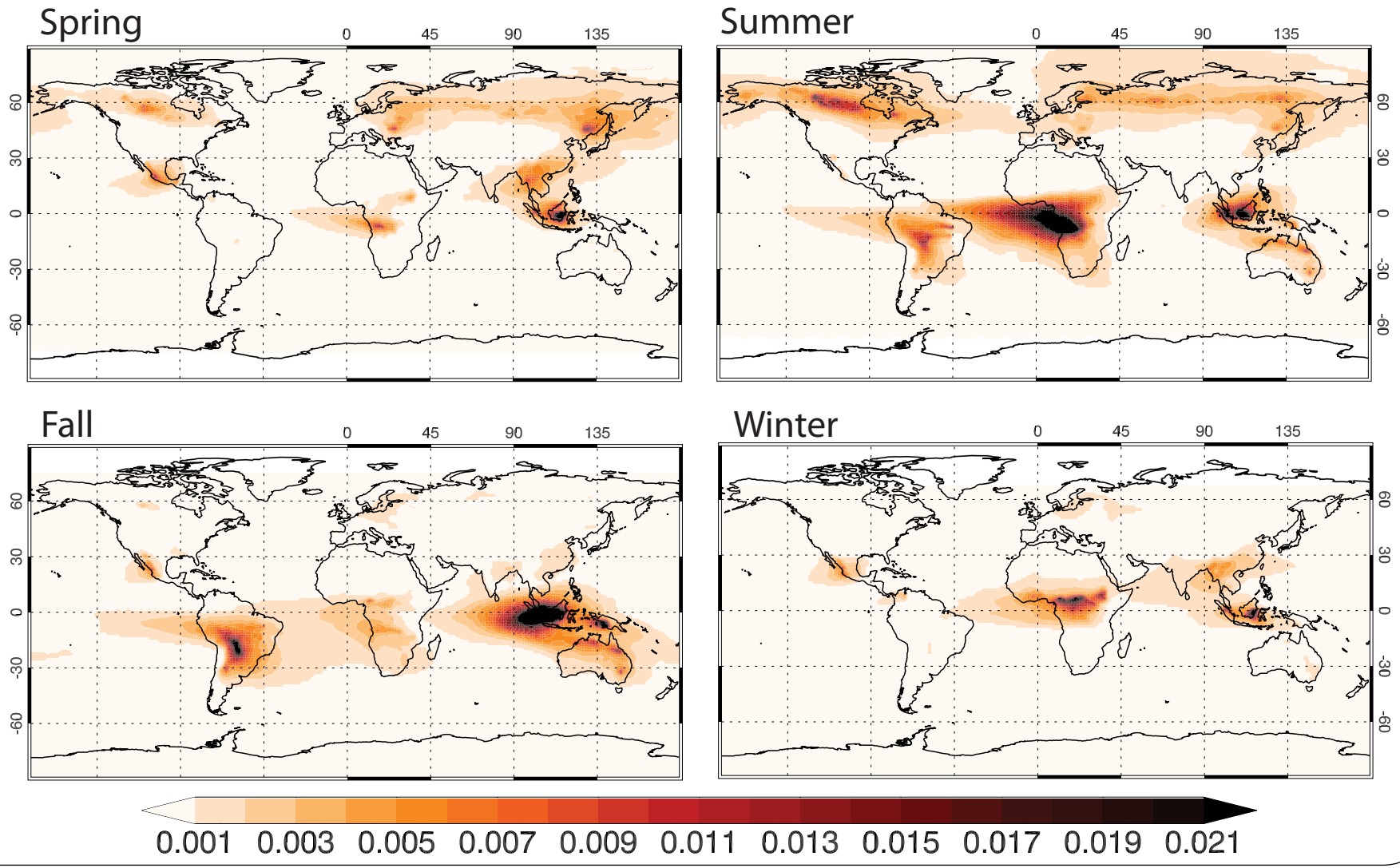
Organic Carbon Optical Depth



Inter-annual Variability in Tropospheric Aerosols

Standard deviation of linearly de-trended

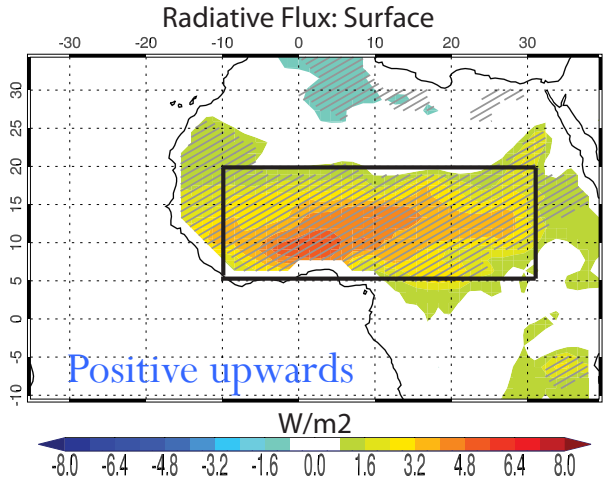
Organic Carbon optical depth for different seasons

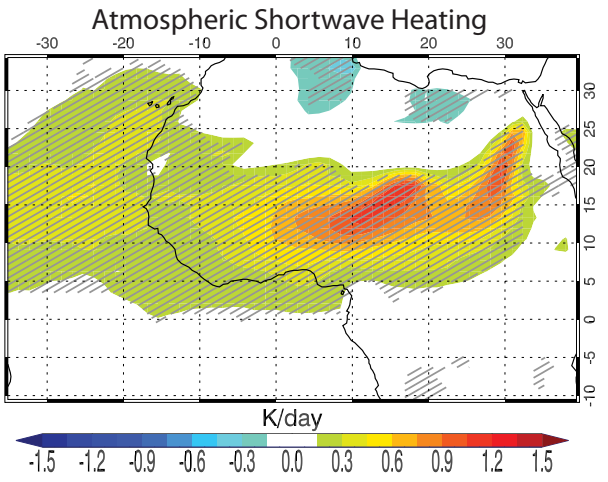


West Africa: Aerosol-induced Variability

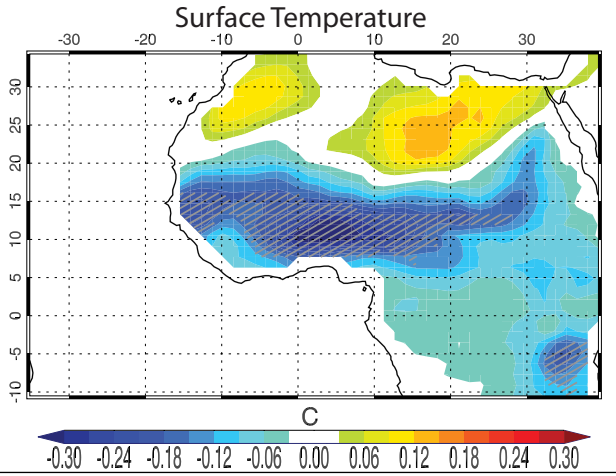
Regression: West African Radiative Forcing and Surface Response on West African Dust Index time-series

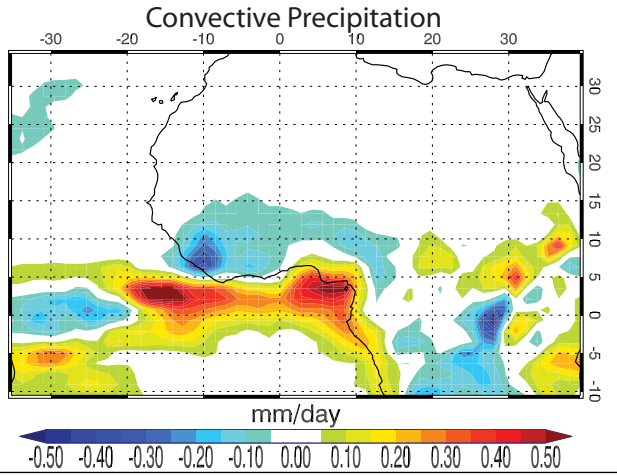
Radiative Forcing:





Surface Response:

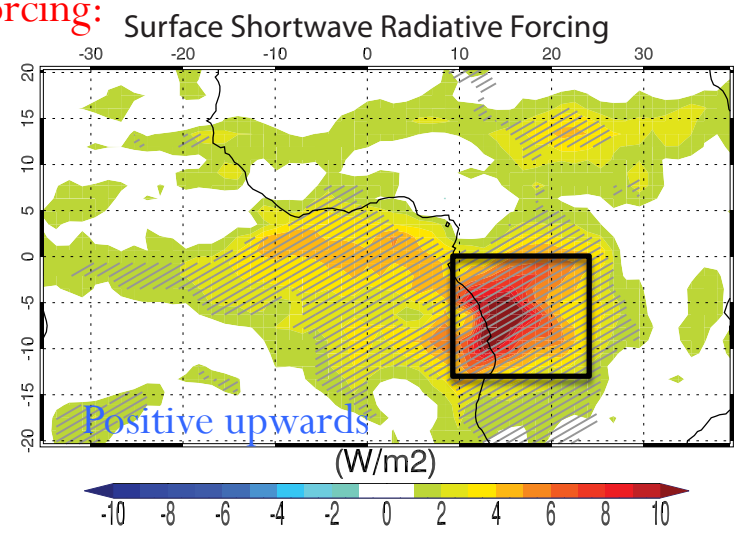


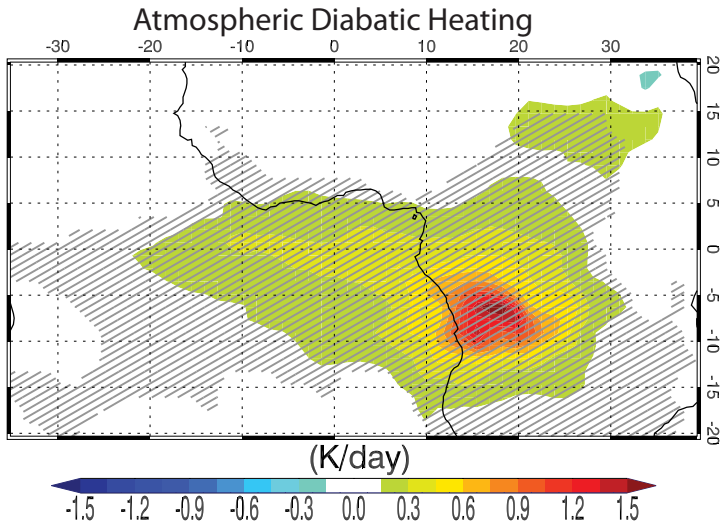


South Tropical Atlantic: Aerosol-induced Variability

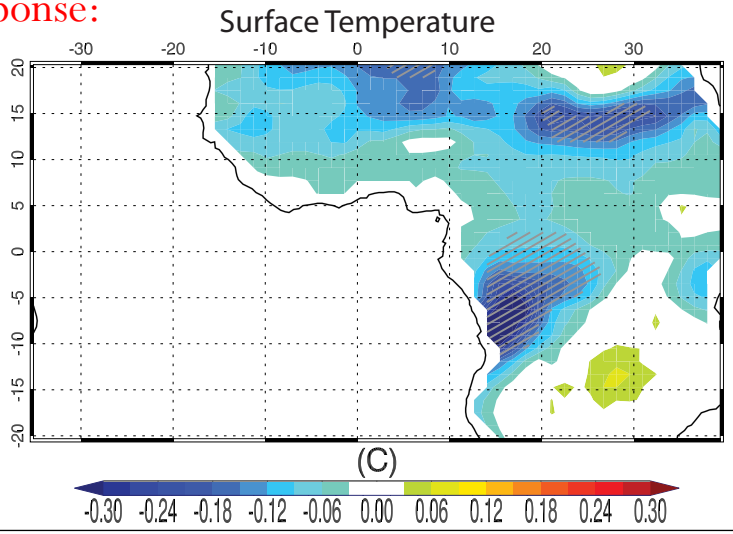
Regression: Tropical Atlantic Radiative Forcing and Surface Response on Black Carbon Index

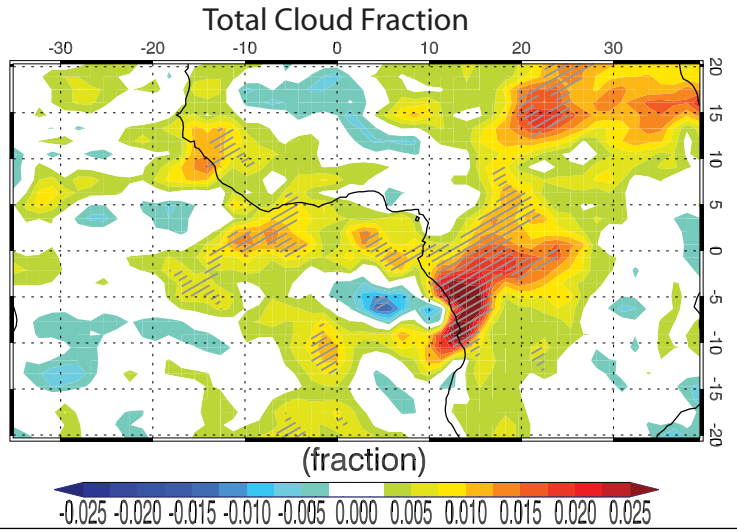
Radiative Forcing:





Surface Response:

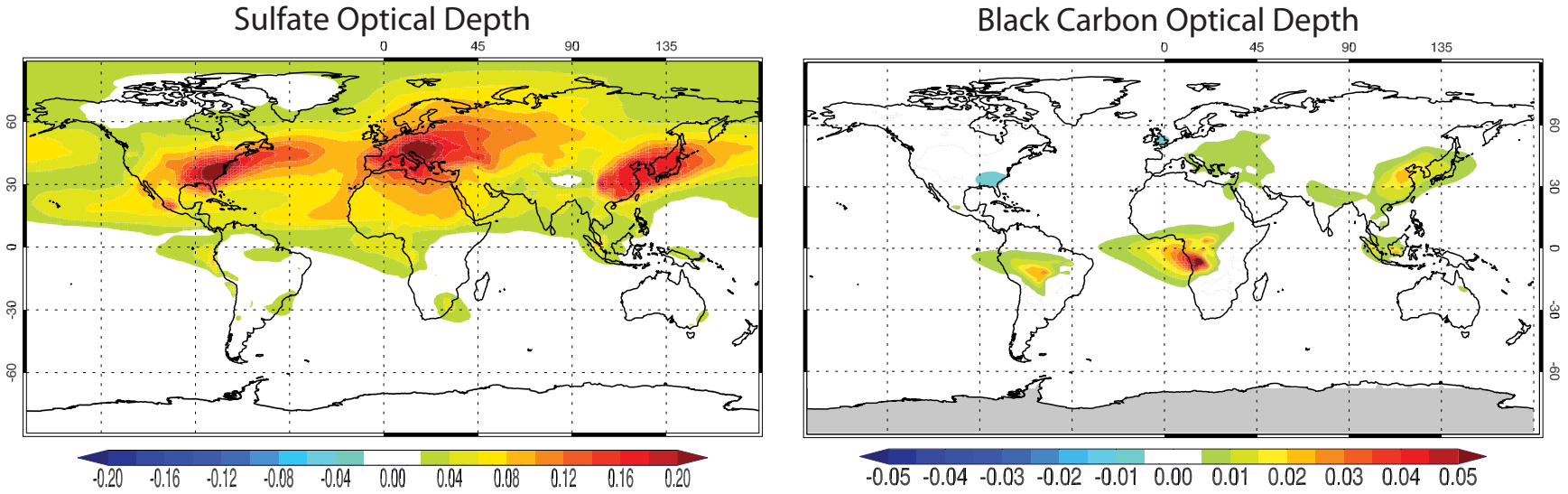




Role of Thermodynamic Feedbacks: Tropical Atlantic

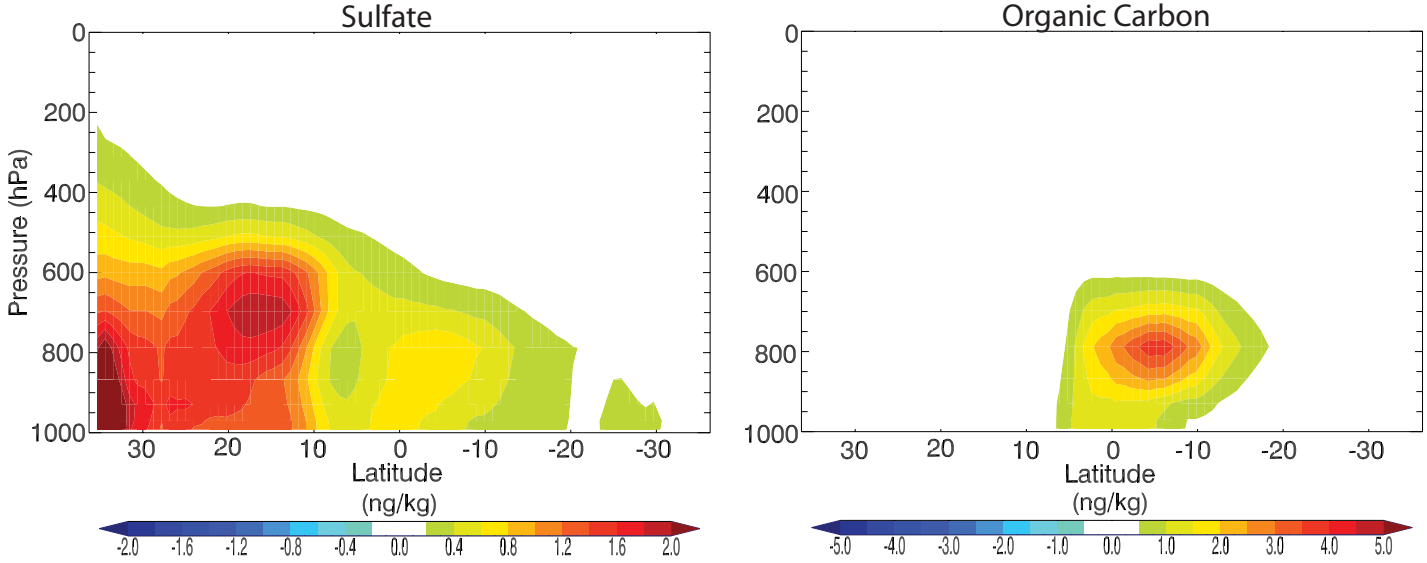
- Experiments with CAM4-SOM (Slab Ocean Model)
  - CAM4-SOM-2000AERO:
    - Prescribed with present day tropospheric aerosol climatology (1981-2001)
  - CAM4-SOM-1850AERO:
    - Prescribed with 1850 aerosol climatology

Difference: Aerosol optical depth (CAM4-SOM-2000AERO - CAM4-SOM-1850AERO)

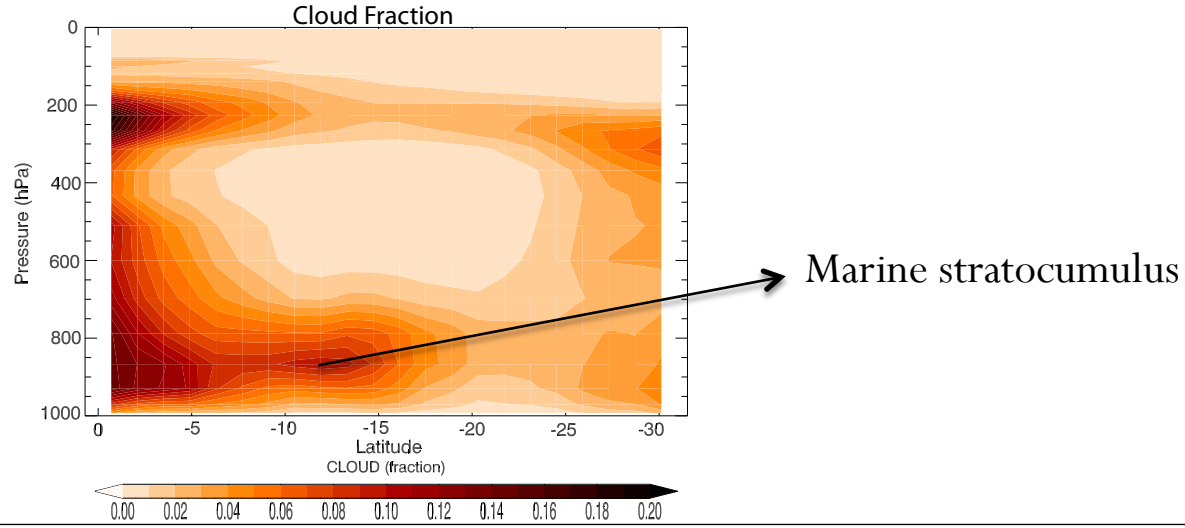


Role of Thermodynamic Feedbacks: Tropical Atlantic

Difference: Aerosol Loadings Vertical Profile (Atlantic, CAM4-SOM-2000AERO - CAM4-SOM-1850AERO)

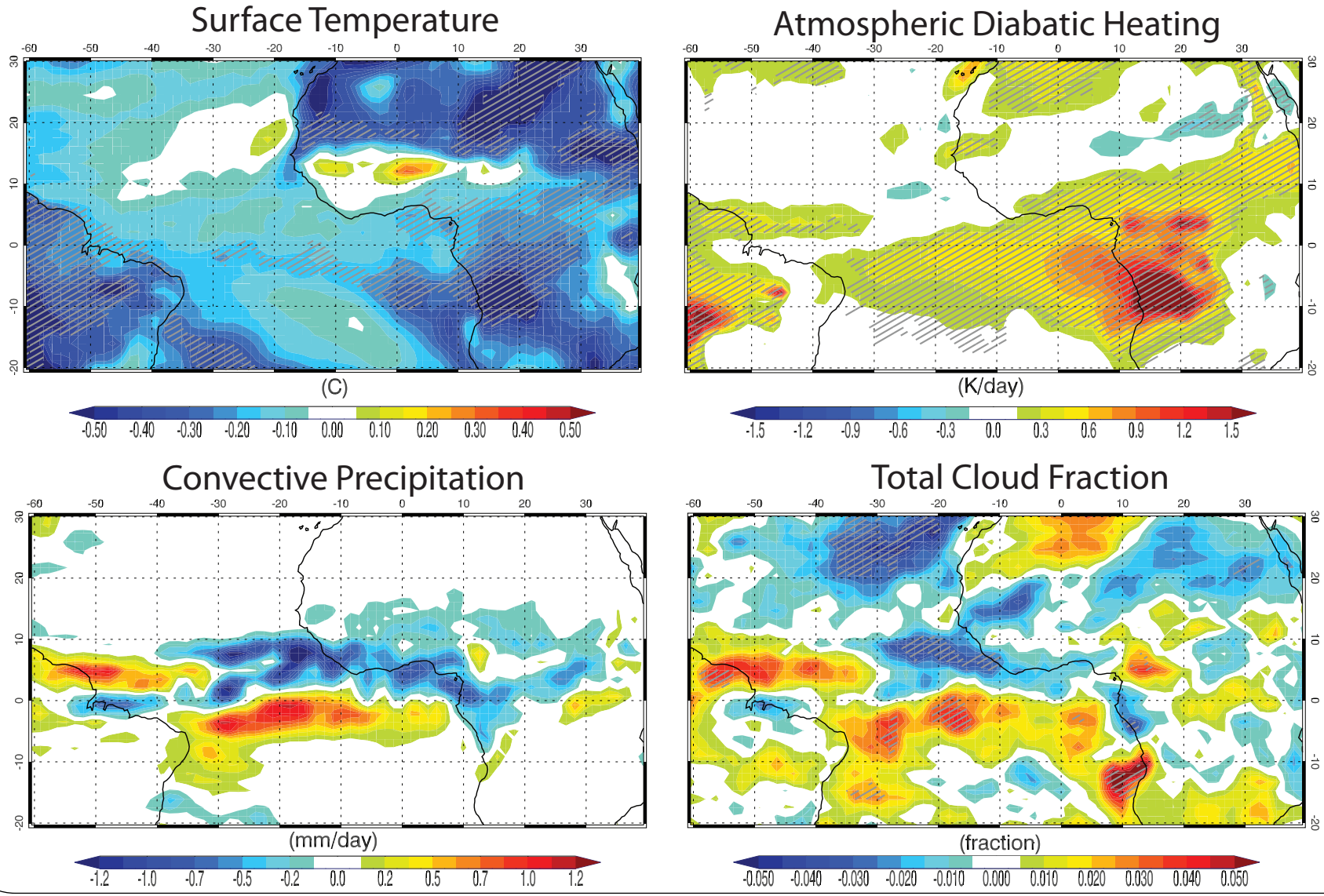


Vertical Profile of Clouds: South Tropical Atlantic



Role of Thermodynamic Feedbacks: Tropical Atlantic

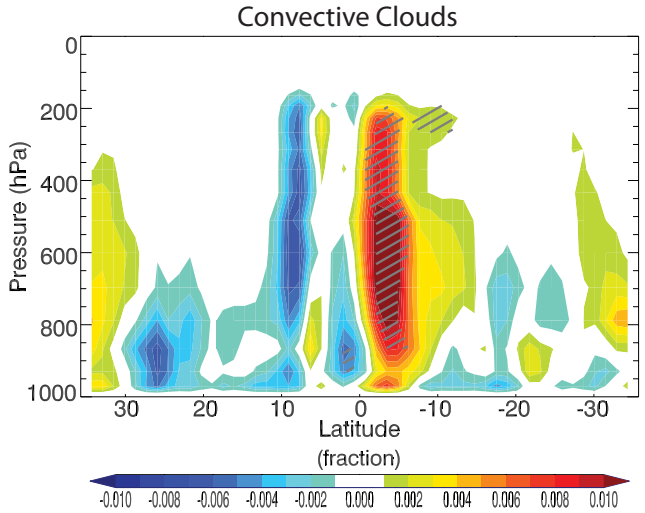
Response of CAM4-SOM to Aerosol Forcing: (CAM4-SOM-2000AERO - CAM4-SOM-1850AERO)

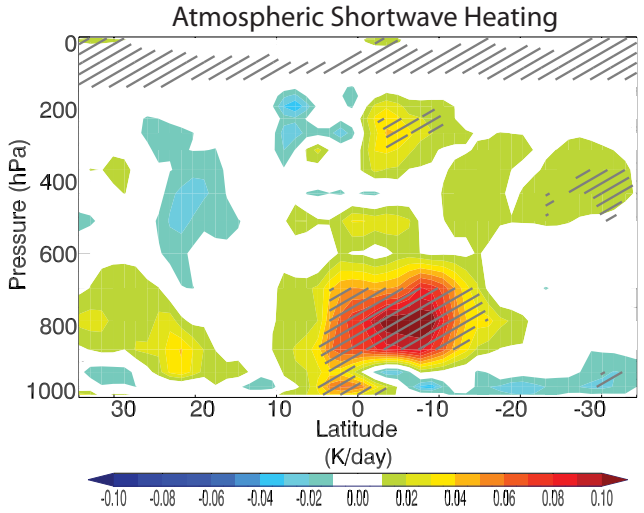


Role of Thermodynamic Feedbacks: Tropical Atlantic

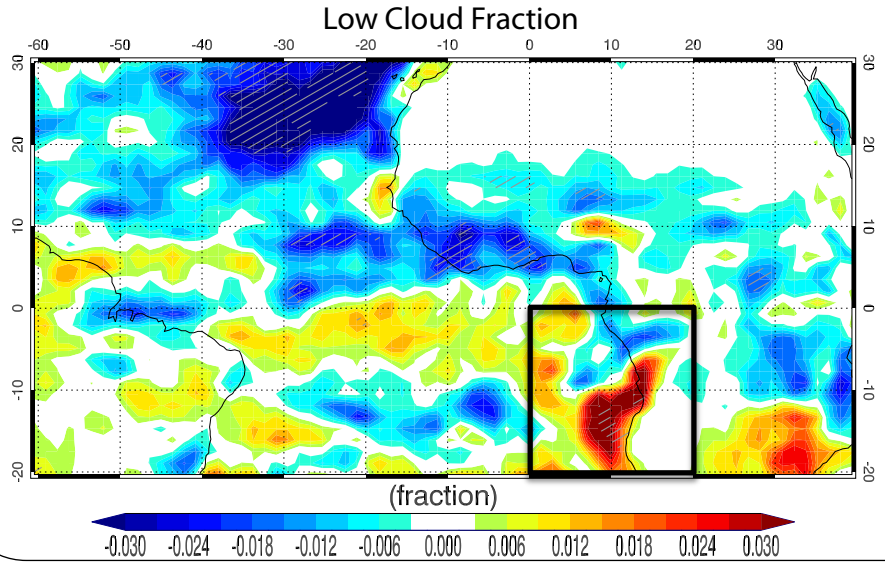
(CAM4-SOM-2000AERO - CAM4-SOM-1850AERO)

Zonally averaged vertical profile over the Tropical Atlantic

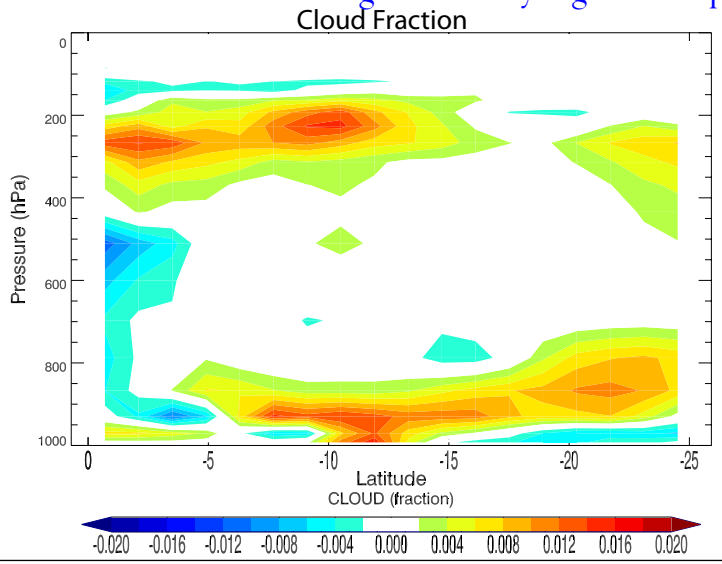




Low Cloud Fraction



Marine Stratocumulus Region: Zonally avg. vertical profile



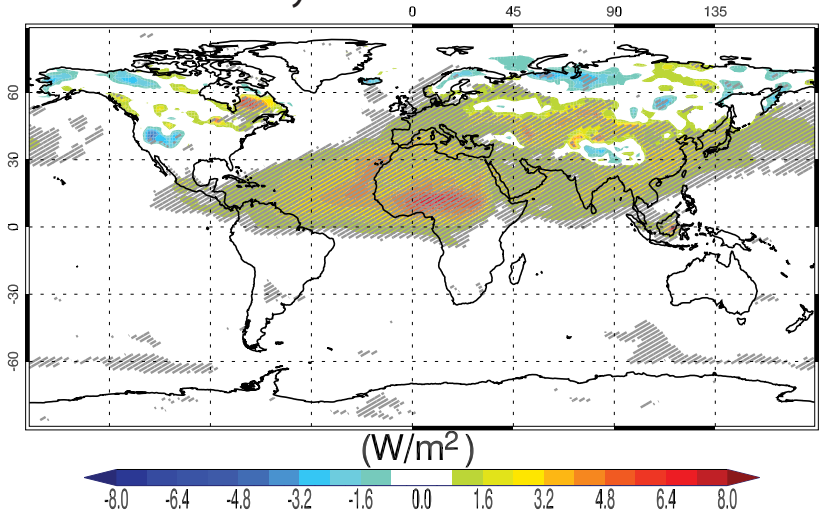
Summary

- Generated a new monthly high resolution tropospheric aerosol dataset, derived from AR5 and RETRO surface emissions
- Inter-annual variability in aerosol distribution induces significant variability in regional climate on inter-annual timescales
- Cooling of the North African landmass associated with an increase in aerosols also related to a southwards shift of the ITCZ there, impacting the West African Monsoon
- Absorbing carbonaceous aerosol over Central Africa are associated with an increase in marine stratocumulus clouds off the west coast of Africa
- Thermodynamics air-sea feedbacks amplify the formation of marine stratocumulus induced by the carbonaceous aerosols and also reduce the SST there.

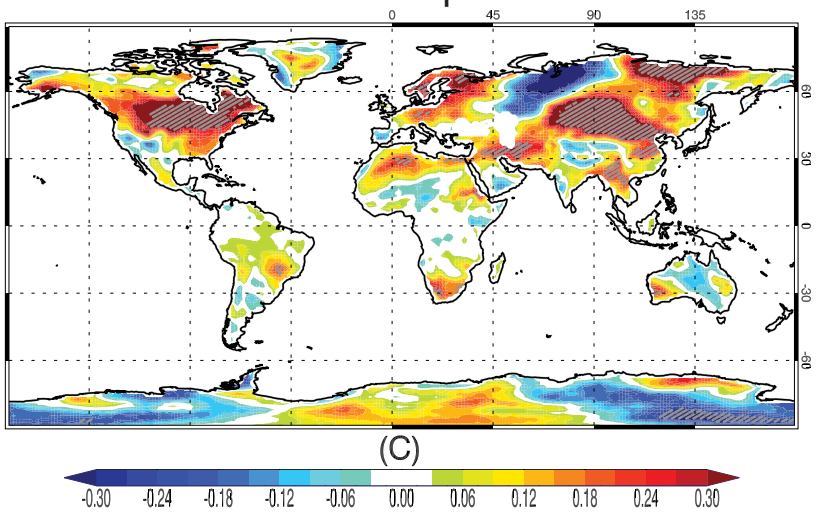
Aerosol-induced Inter-annual Variability

Difference: Standard deviation (CAM4-AMIP-20AEROSOLS) – Standard deviation (CAM4-AMIP-1850AEROSOLS)

Clear-sky Shortwave Radiative Flux



Surface Temperature



Convective Precipitation