Continual Development and Application of Modal Aerosol Module in the Community Earth System Model: Aerosol Radiative Forcing and Climate Impacts

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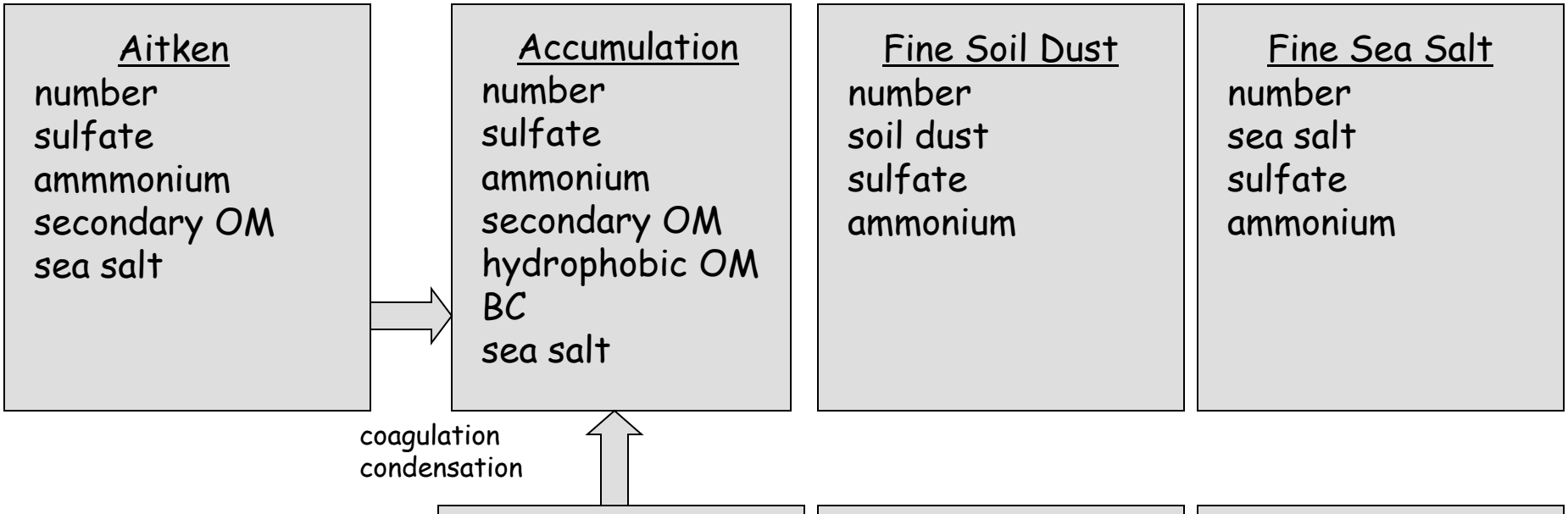
Outlines

- Modal Aerosol Module (MAM) in CESM1
- Evaluation and improvement of aerosol simulations from MAM (e.g., black carbon)
- New capabilities for MAM
  - Prescribed aerosol
  - Decomposition of aerosol radiative forcing
- Aerosol impact on climate

Benchmark 7-Mode Modal Aerosol Model (MAM)



All modes log-normal with prescribed width.

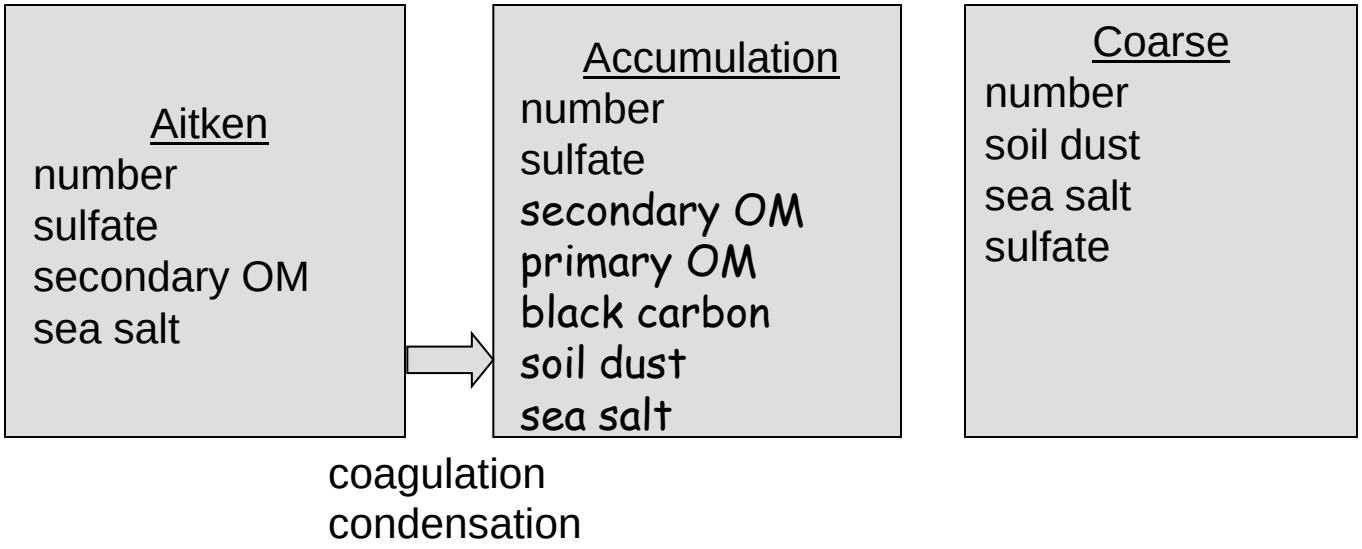
Total transported aerosol tracers: 31

Cloud-borne aerosol and aerosol water predicted but not transported.

Computer time is ~100% higher than BAM

Simplified 3-mode version of MAM

Assume primary carbon is internally mixed with secondary aerosol.
Sources of dust and seasalt are geographically separate
Assume ammonium neutralizes sulfate.

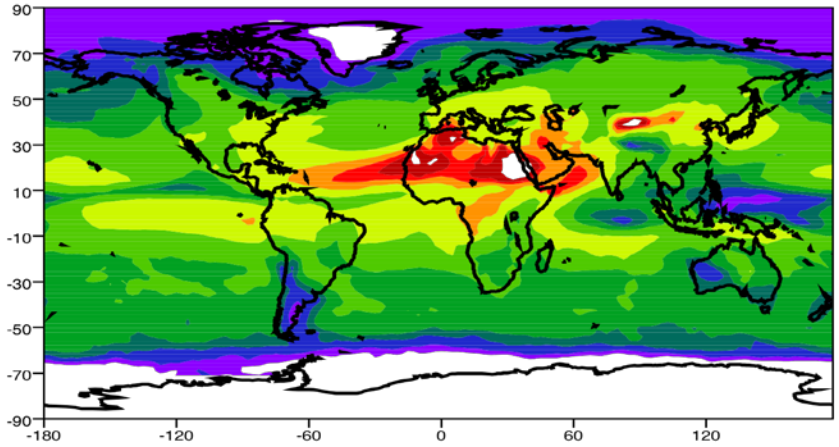


Total transported aerosol tracers: 15

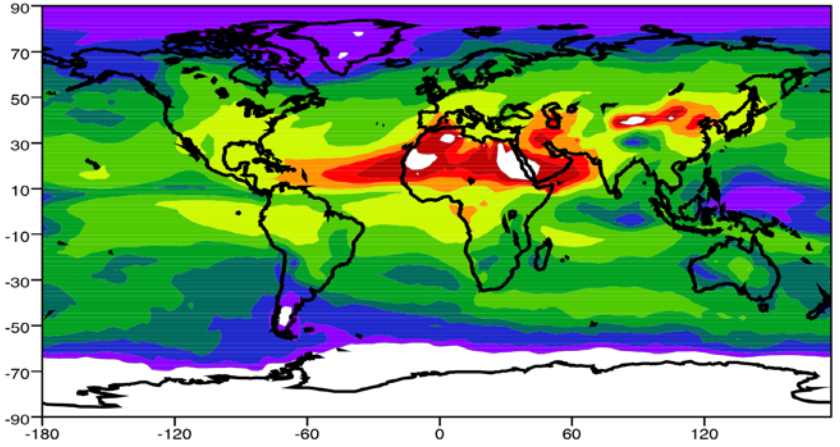
Computer time is 30% higher than BAM

Aerosol Optical Depth - July

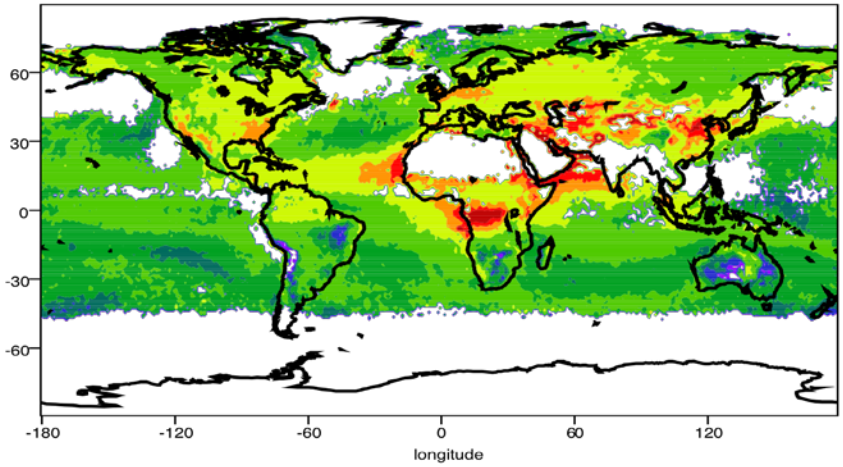
MAM3 AOD=0.16



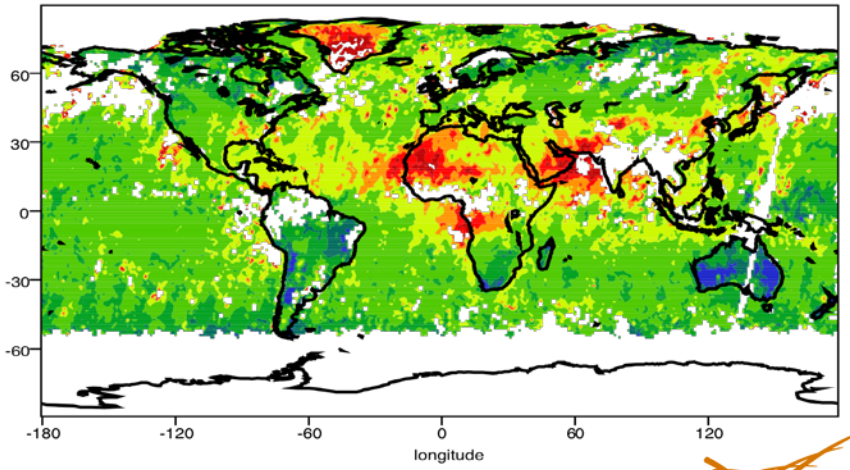
MAM7 AOD=0.16

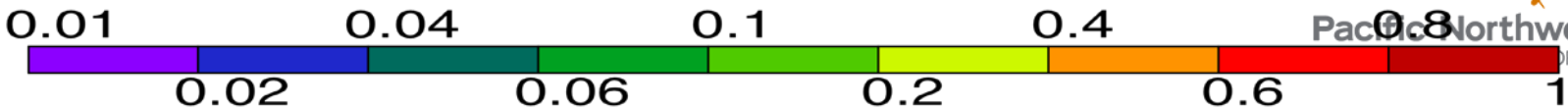


MODIS



MISR





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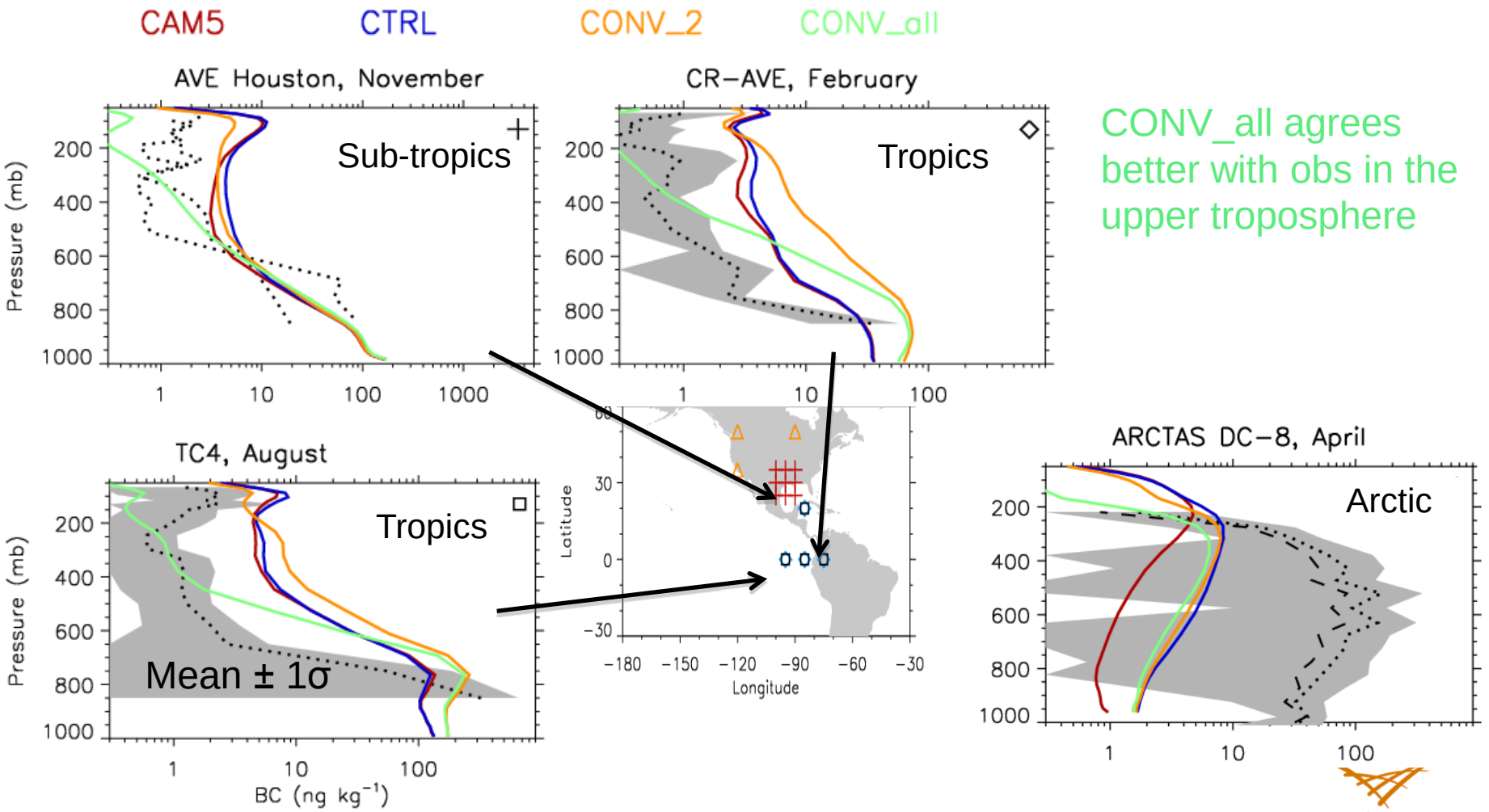
A new unified treatment of aerosol vertical transport and removal in convective clouds

BC vertical profiles (compared to observations, Koch et al. 2009)



CONV_all agrees better with obs in the upper troposphere

H. Wang et al. poster

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Prescribed Aerosol

- Model Tag: pmam03_cam5_0_54
- Two experiments
  - Control: Predicted Aerosol are archived (aerosol number and mass)
  - Prescribed run: Read-in archived aerosols, use in radiative transfer calculation and cloud microphysics
  - Goal is to produce similar climates.

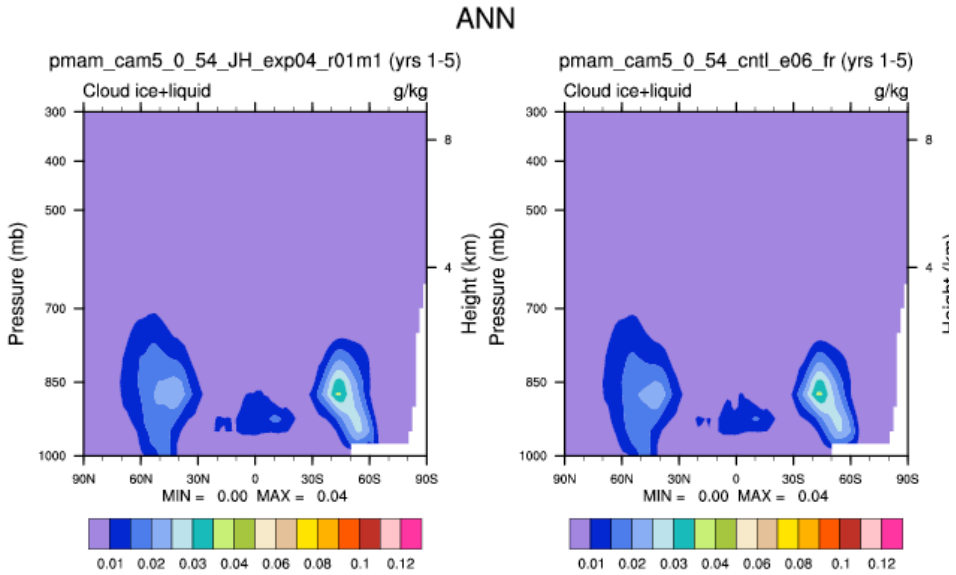
- A linear combination of "conditionally sampled aerosols when there are clouds" and "aerosols in all conditions".
  $X_{prescribed} = X_{cloudy} * F_{liq} + X_{ALL} * (1 - F_{liq})$

  X = aerosol mix rat or num
  F_{liq} = liquid cloud fraction

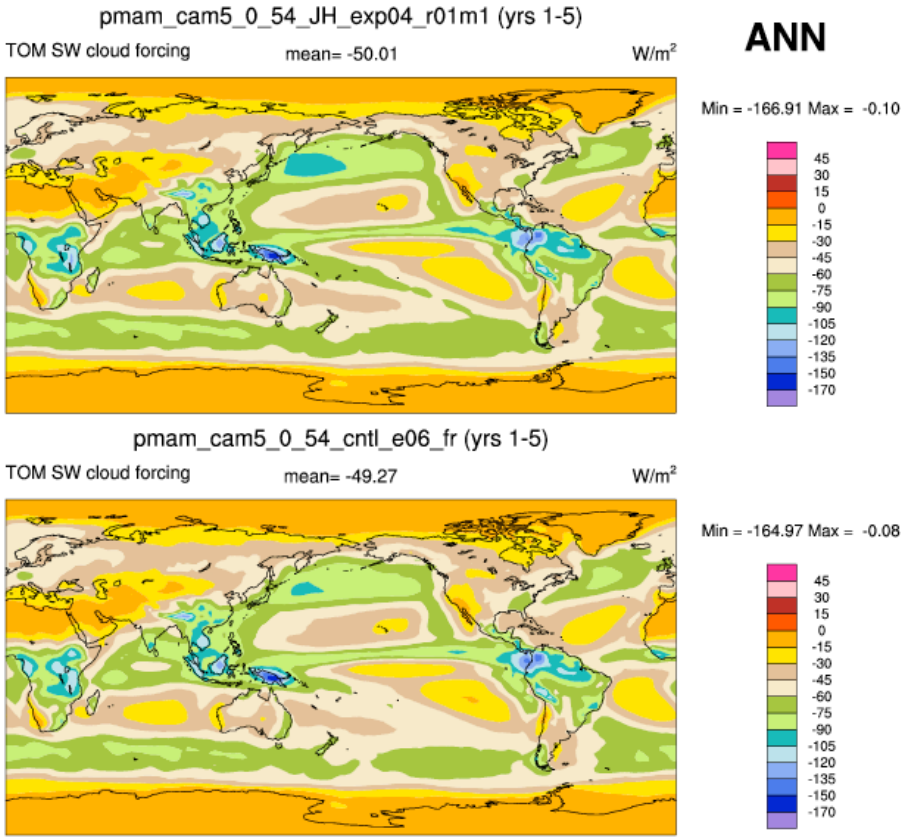
- We sample and use aerosol number and mass time averages in liquid clouds ("conditional" sampling).
  - Droplet differences are ~ less than 3%
  - Global averages of surface fluxes differ by < 1 W/m2
  - Almost within "natural variability"

J.H. Yoon et al.

Prescribed Aerosol



- Cloud water content
- Remaining tasks:
  - Remaining differences are found in Arctic region
  - Aerosol deposition fluxes to surface need to be prescribed, too.



- Short-wave cloud forcing

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Decomposition of Forcing by Anthro Aerosol

Let S = net solar flux at TOA L = net longwave flux at TOA
Δ = PD - PI

- Solar direct forcing = $\Delta(S\text{-}S_{noaerrad})$
- Snow albedo forcing = $\Delta S_{clear,noaerrad}$
- Solar indirect forcing = $\Delta S_{noaerrad}$
- Solar semi-direct = ΔS –Direct–SW Indirect–Snow

previously not distinguished

- Longwave indirect forcing = $\Delta L_{noaerrad}$
- Longwave semi-direct = $\Delta(L\text{-}L_{clear})$ - LW indirect

previously not distinguished

- 6-year simulations at 1.9°x2.5° resolution with year 2000 ocean surface conditions
  - PD & PI: Present day & pre-ind. emissions from IPCC AR5

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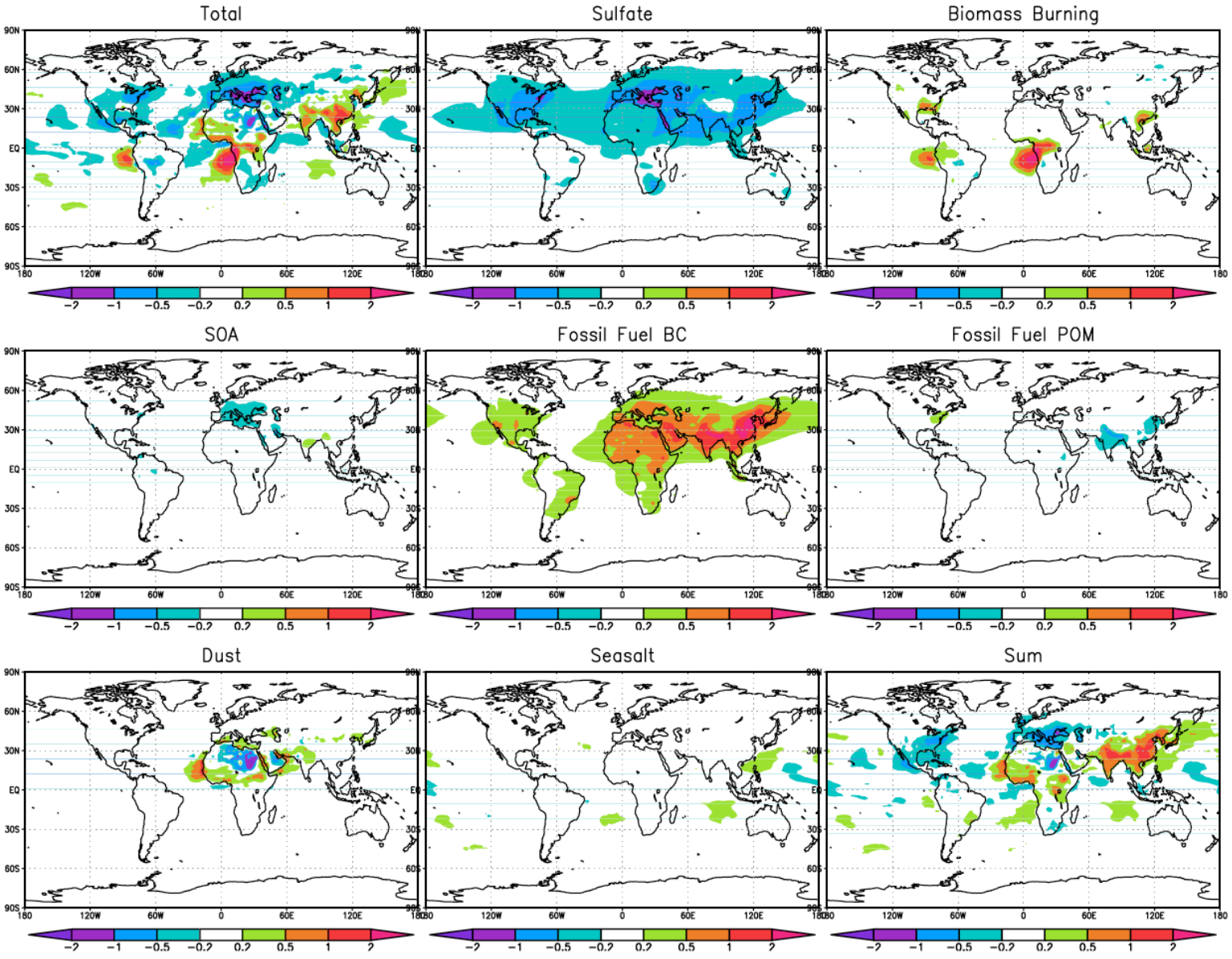
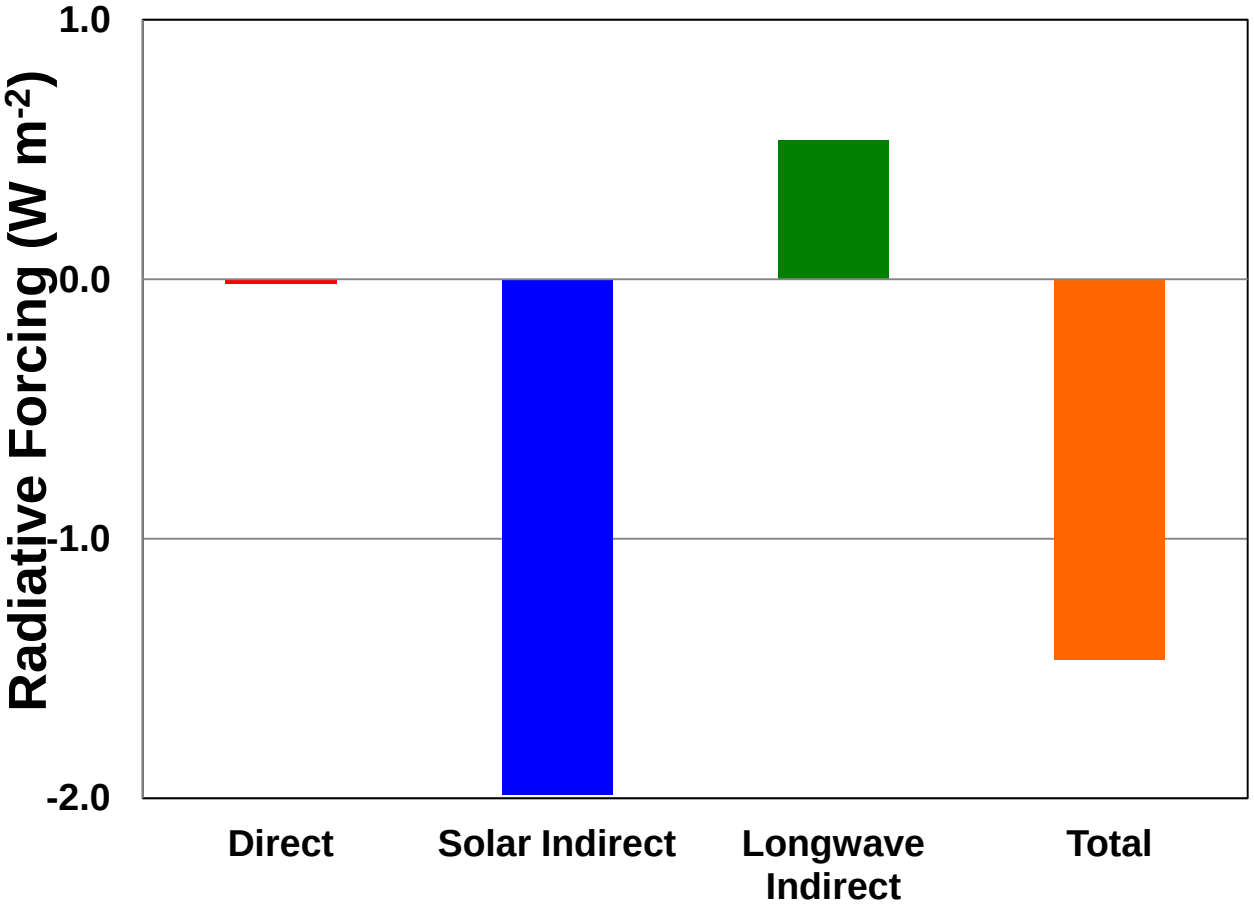
Sign of direct forcing depends on aerosol component and albedo below the aerosol



Global Mean Forcing by Other Mechanisms



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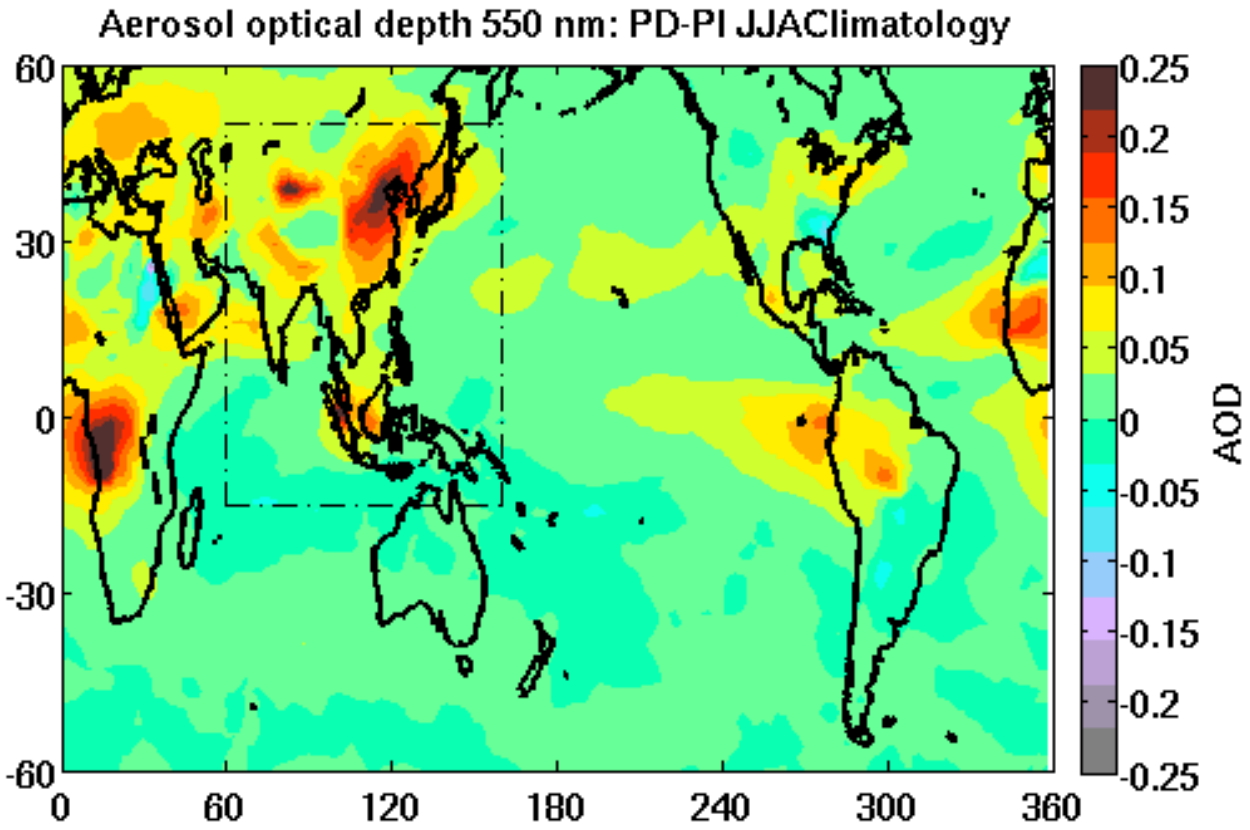
Impact of Anthropogenic Aerosol on Climate



- The South-East Asia shows substantial increase (more than double) of aerosol pollution from pre-industrial to present-day conditions.

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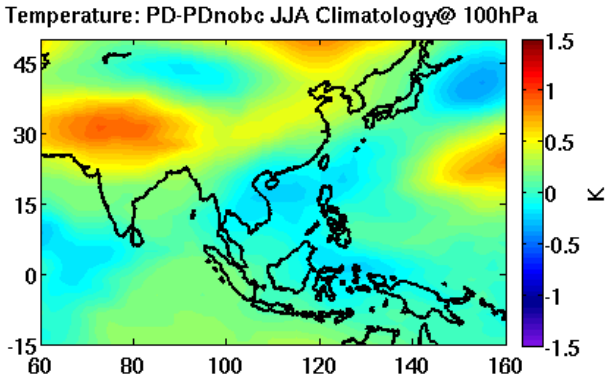
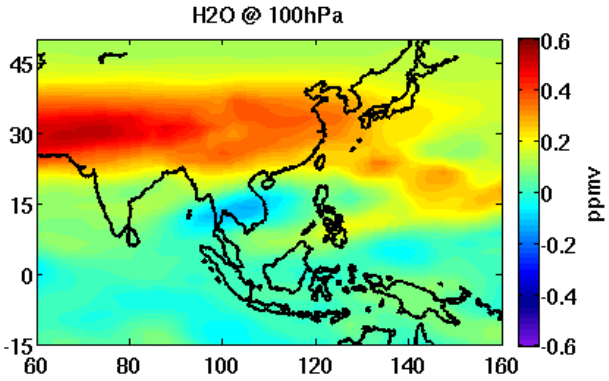
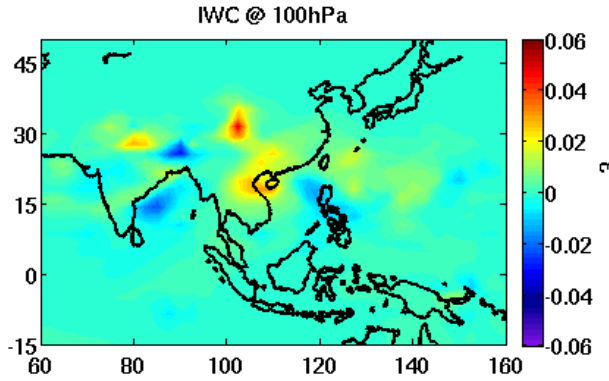
Radiative Heating of BC (PD – PDnobc)

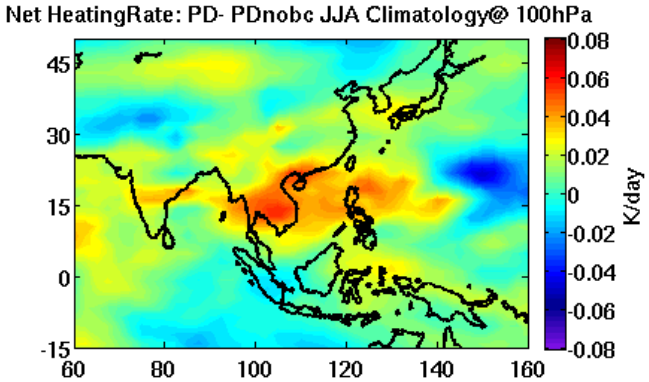


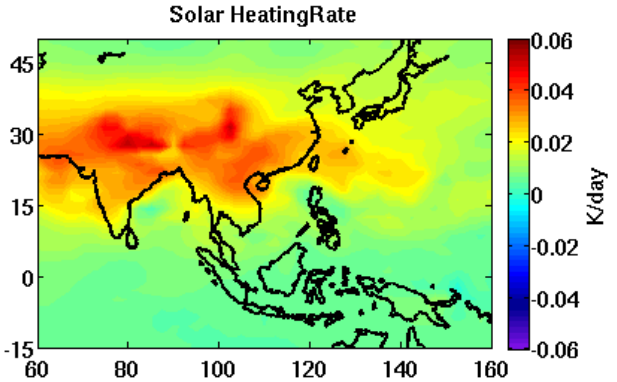
T = 0.292 K

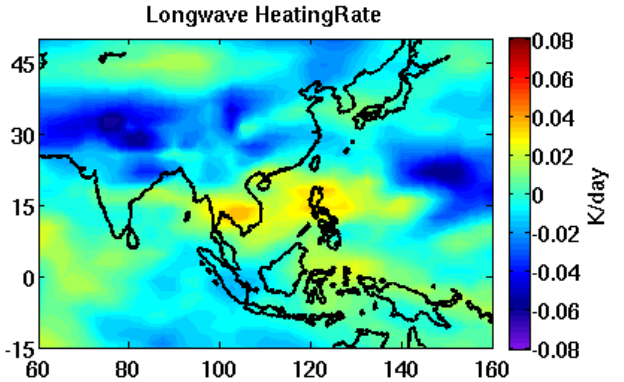


T = 0.285 ppmv









- Radiative effect of black carbon increase radiative heating, and the increase of temperature and water vapor in the tropical tropopause Layer (TTL) (100 hPa). Consistent with Su et al. (2010) observational analysis

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Summary

- Continue evaluation and development of MAM:
  - Unified convective transport and wet removal to improve vertical and polar transport of BC
  - Prescribed aerosol for long-term climate simulations
  - Decomposition of aerosol forcing by aerosol species and by forcing agents
- Investigate aerosol effects on cloud, precipitation and climate:
  - Increase temperature and water vapor in the TTL in the South-East Asia, related to the increasing radiative heating due to the absorbing BC

Backup slides

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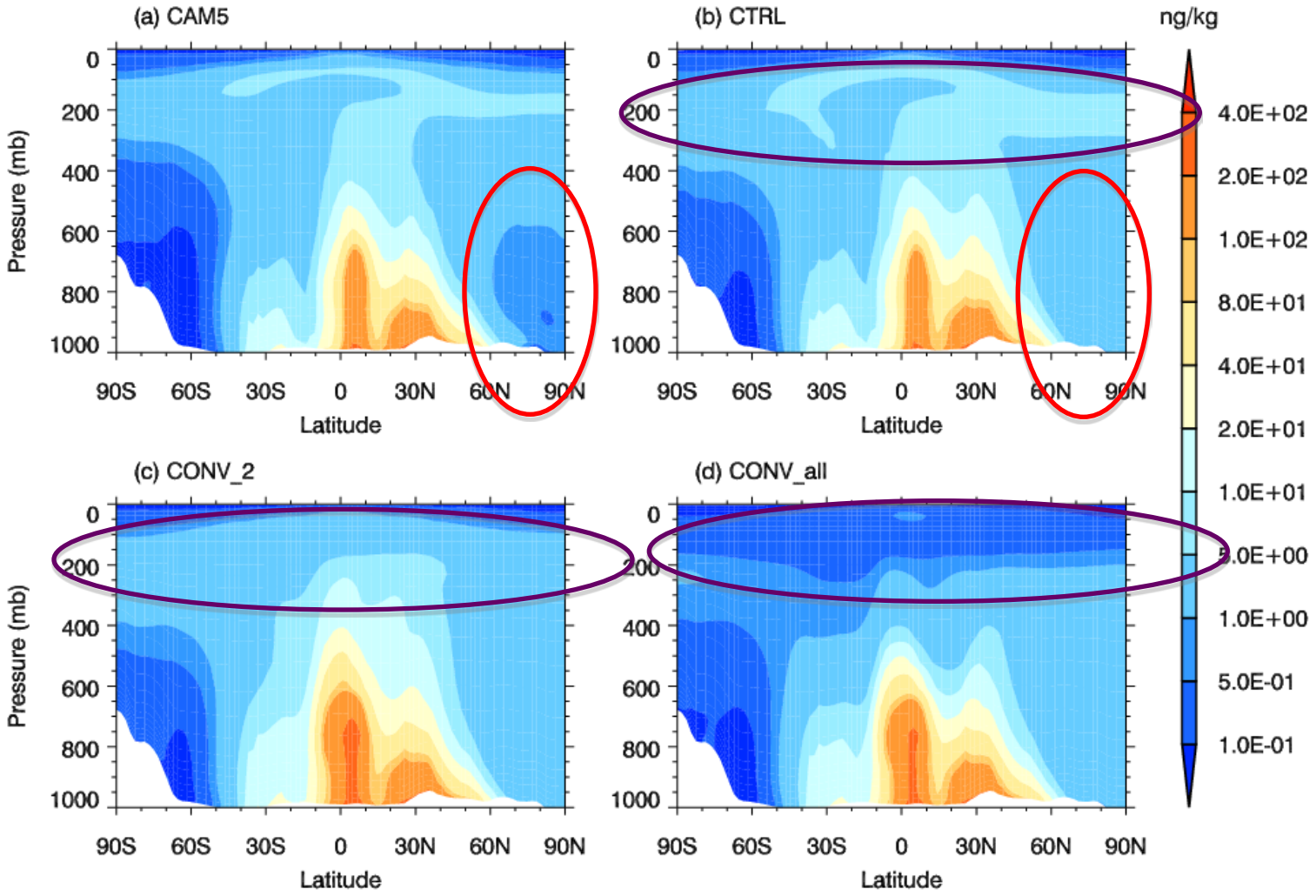
A new unified treatment of aerosol vertical transport and removal in convective clouds

Zonal-mean BC concentrations (DJF, 10-year simulation)



Wang et al., 2011 (to be submitted; poster)

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Prescribed Aerosol

- We preprocess archived aerosol data using the "time-diddling" scheme by K. Taylor (just like SST).
  - Thus, the monthly mean values of aerosol mass and number are consistent even after time-interpolation with monthly mean values.
- Now, we'll move on to constrain aerosol fluxes at surface which might explain remaining difference in Arctic region.
- More details:
  - We are really using a linear combination of "conditionally sampled aerosols when there are clouds" and "aerosols in all conditions".

    $X_{prescribed} = X_{cloudy} * F_{liq} + X_{ALL} * (1 - F_{liq})$

    X = aerosol mix rat or num
    F_{liq} = liquid cloud fraction
- For Radiation: we use X_{ALL}

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