Improving Aerosol Wet Removal during the Transport to High-latitudes in CAM5

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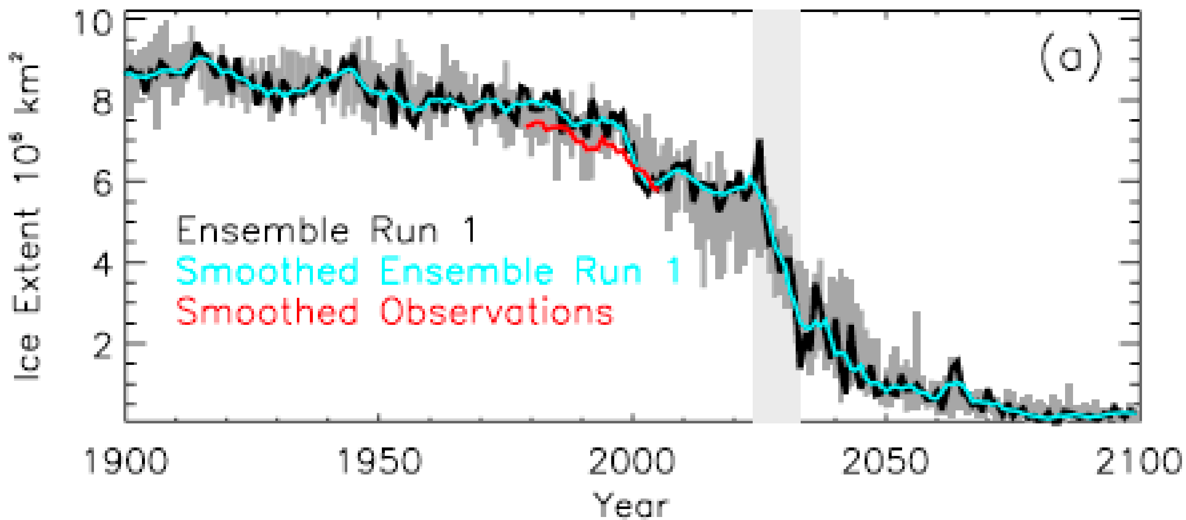
Outline/Summary slide

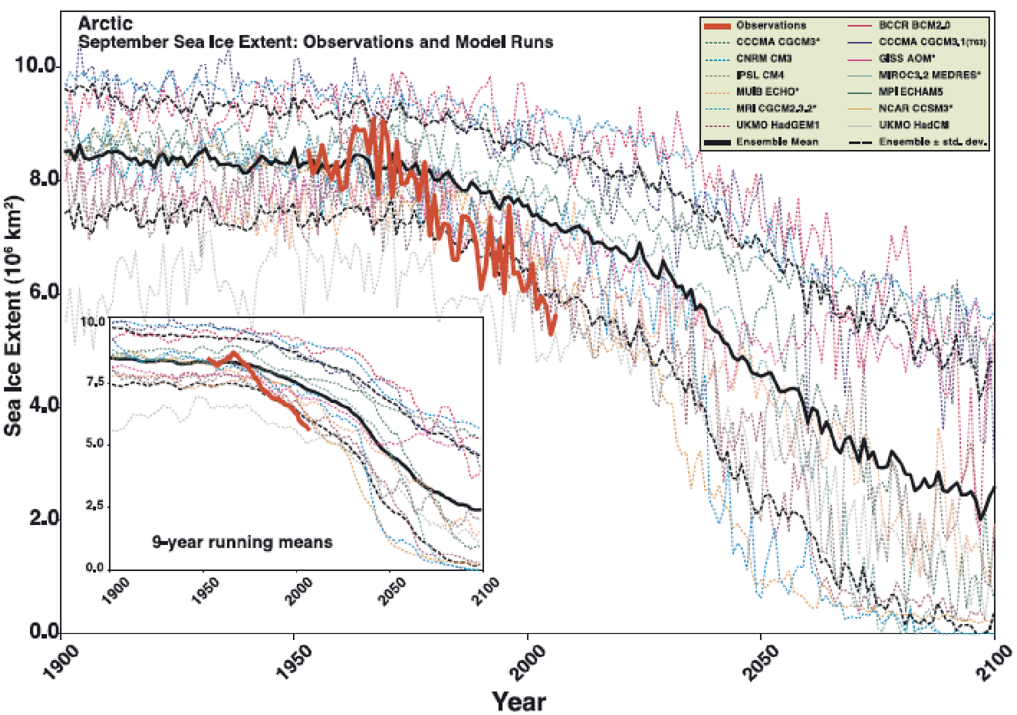
- An intro to CESM/CAM5. Some signatures of high latitude climate are quite reasonable (probably many other climate models).
- The standard model is not correctly characterizing arctic forcing from BC. (again, signatures are quite similar to other models)
- Systematic Biases that exist in BC:
  - Concentrations higher than obs at high altitudes
  - Concentrations lower than obs near surface
  - Poor seasonal cycle
- Contributing factors in our model, and improvement from:
  - Emissions
  - Scavenging (particularly by liquid clouds < 0C)
  - Eddy transports/circulation
  - Resolution

Older versions of CCSM do “OK”

- Holland et al, 2006
- CCSM3 (CAM3 or 3.5)
- An example of one out of a dozen or so ensemble members



STROEVE ET AL.: ARCTIC ICE LOSS—FASTER THAN FORECAST



High Latitude Climate Change is a tough problem.

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CAM - the Atmospheric Component of CCSM & CESM

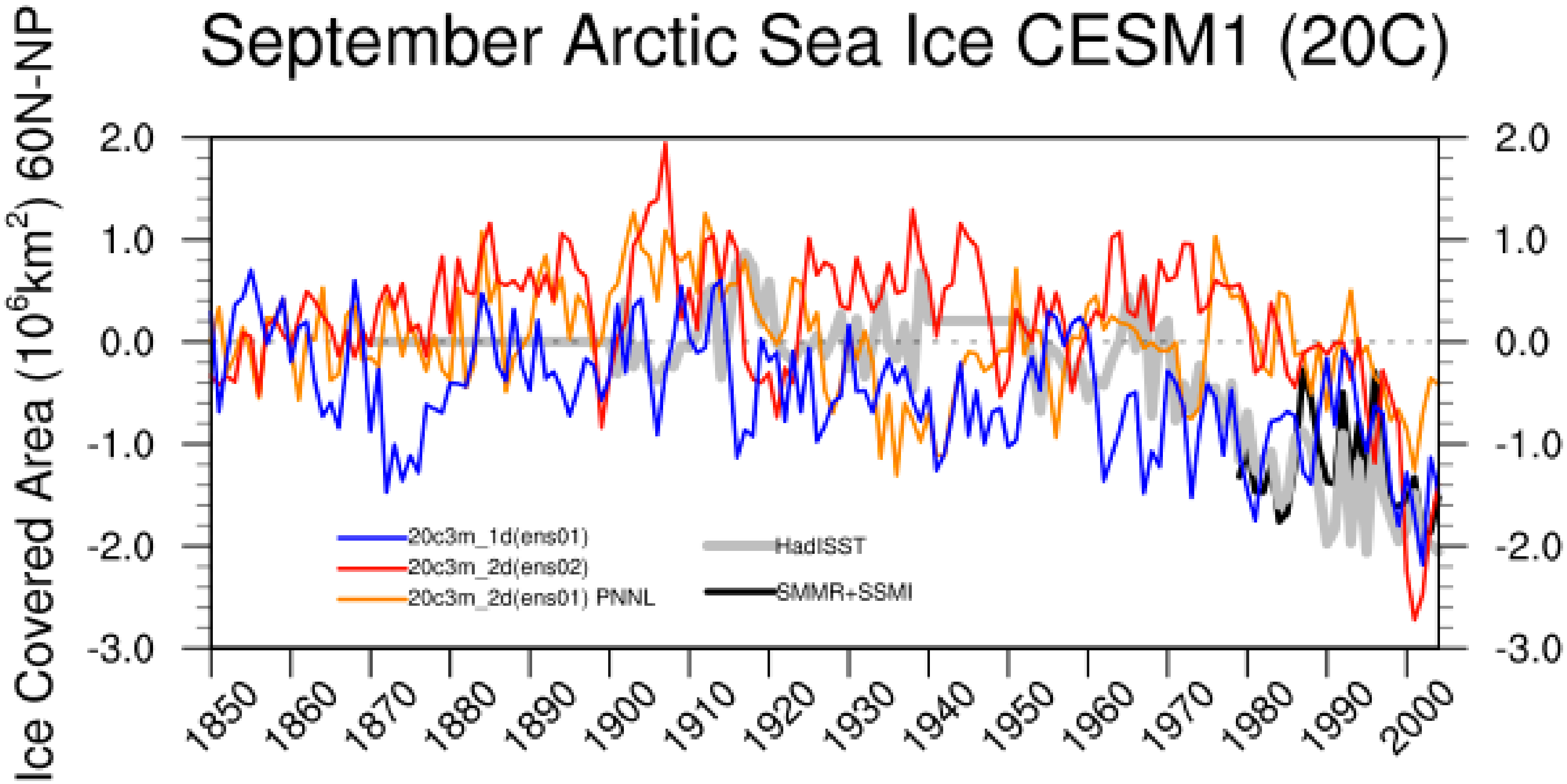
Virtually every atmospheric process has been revised/replaced with a goal of improving the physical representation.

Particular focus on aerosols, and aerosol/cloud interactions
•3 mode 2-moment internally mixed aerosol (standard)
•7 mode internal/external mixtures "benchmark" (optional)

(Liu et al, 2011, GMD)

Mod			M4 2010)	CESM1 (Jun 2010)
Atmosp			4 (L26)	CAM5 (L30)
Boundary Turbule			g-Boville	Bretherton-Park (09) Moist Turbulence
Shall Convec			ack	Park-Bretherton (09) Shallow Convection
Deep Con			lcFarlane et al.(08) asch (08)	Zhang-McFarlane Neale et al.(08) Richter-Rasch (08)
Clou Macroph			g et al. avrus' mods.	Park-Bretherton-Rasch (10) Cloud Macrophysics
Stratif Microph			RK *Moment*	Morrison and Gettelman (08) *Double Moment*
Radiation /			MRT	RRTMG Iacono et al.(08) / Mitchell (08)
Aeros			AM	Modal Aerosol Model (MAM) Liu & Ghan (2009)
Dynam			Volume	Finite Volume
Oce			2 - *BGC*	POP2.2
Lan			4 - *CN*	CLM4
Sea Ice	CSIM4	CSIM4	CICE	CICE

September Arctic Sea Ice

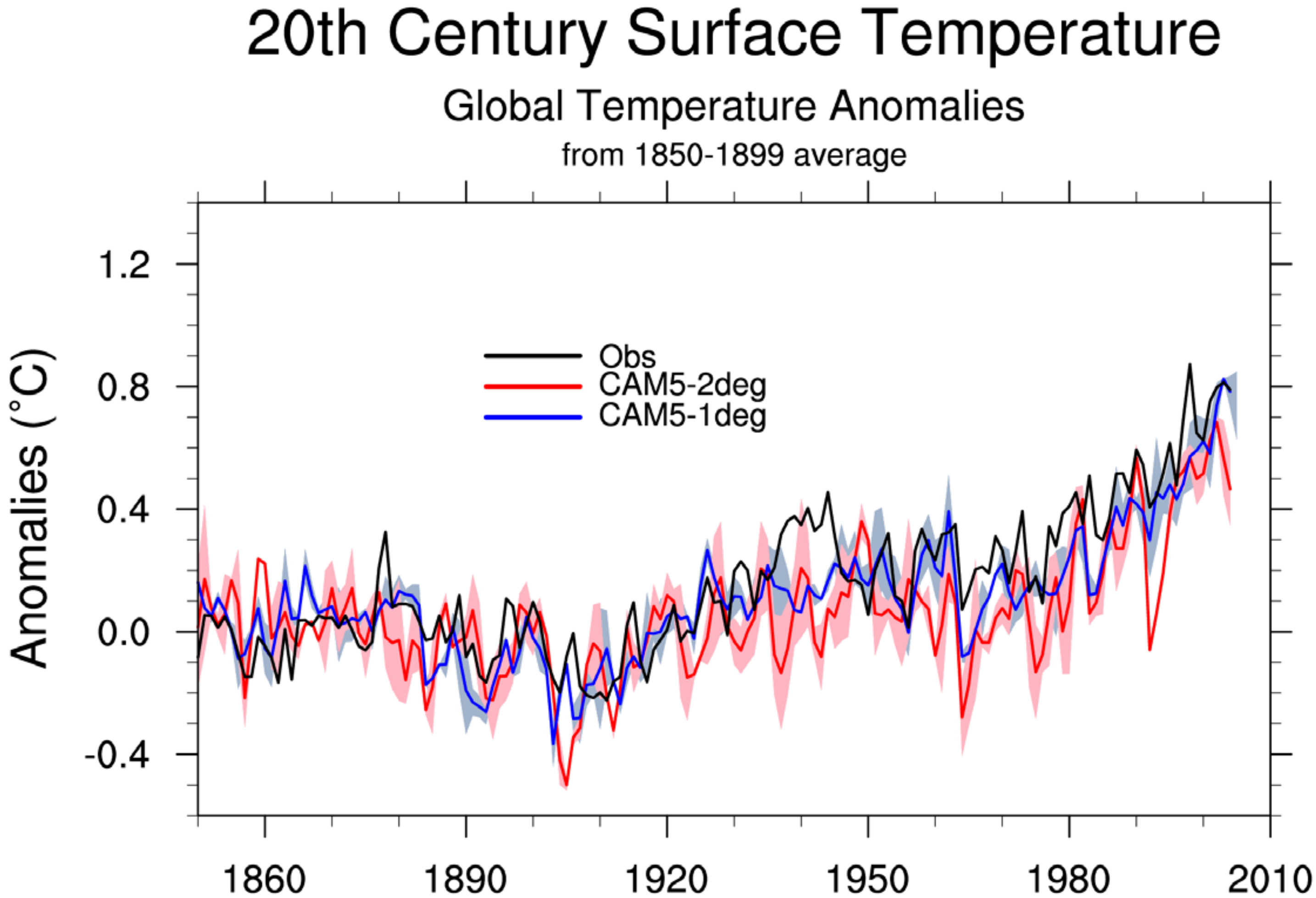


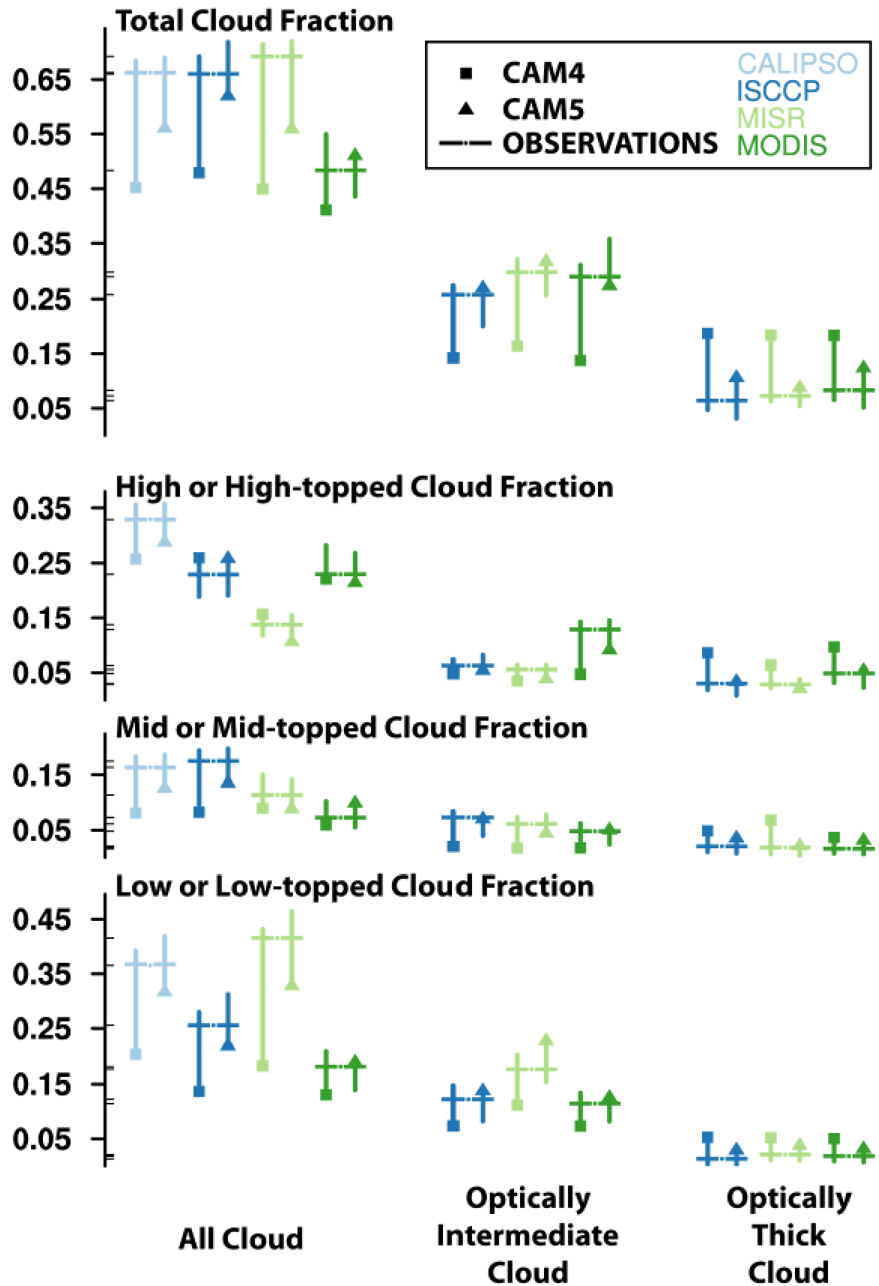
Simulated reduction of Arctic Ice similar to observations.
Observation: Hadley Center (grey); NSIDC (SMMR+SSMI, black).

CESM1/CAM5 and the climate record

Climate Sensitivity: 4.5K to $2xCO_2$

Aerosol Indirect effect: -2W/m2 in Shortwave, +0.7 W/m2 in Longwave (Ghan et al, 2012)





CAM5 is quite accurate in monthly mean cloud amount compared to recent measurements when viewed as satellites do.

Kay et al, 2011,

High latitude summer clouds optically too thin

Winter clouds too extensive

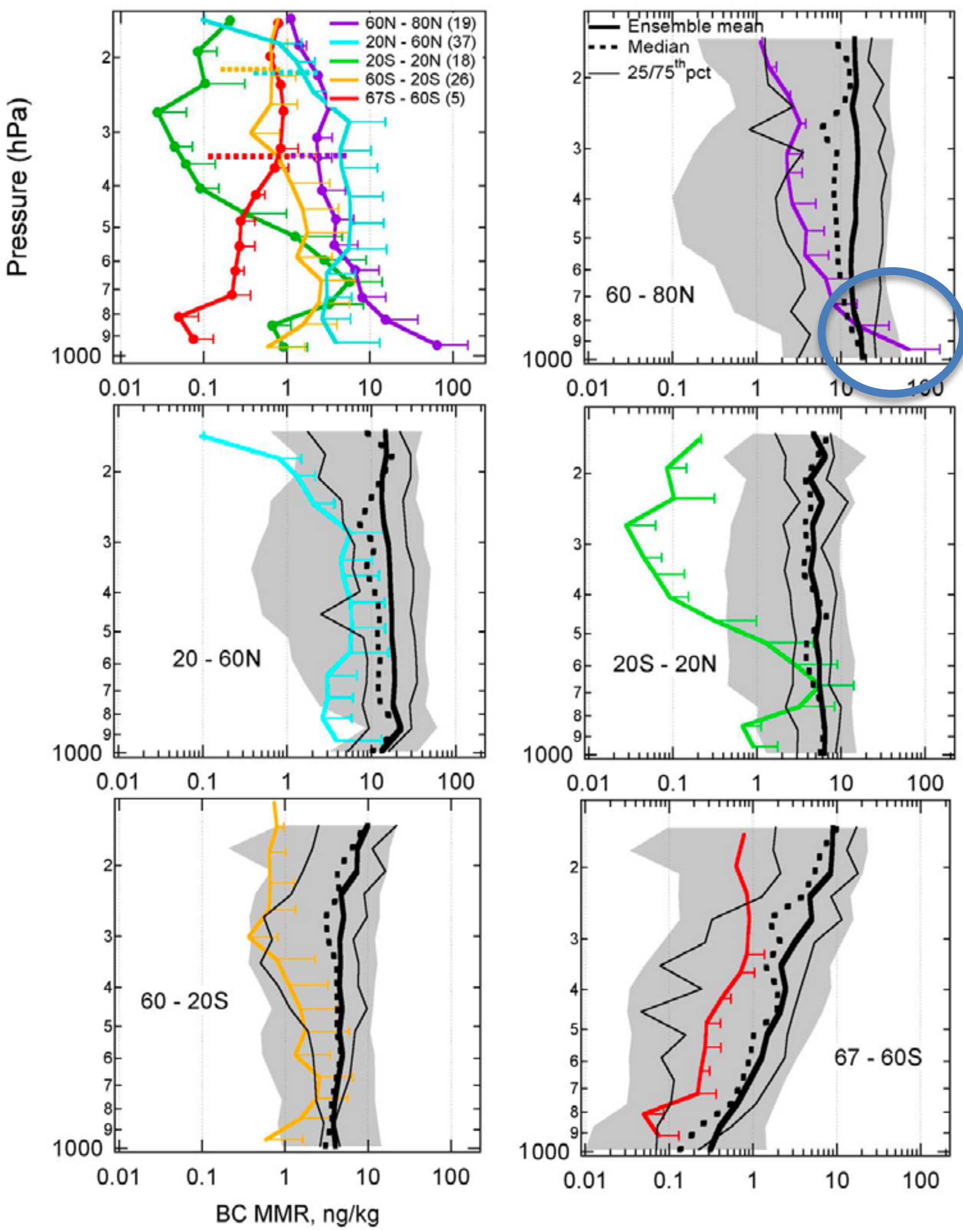
Figure 4. Observed and COSP-simulated global (60 S to 60 N) annual mean cloud fractions.

BC Aerosols and their forcing:

The HIPPO measurements of BC vs AEROCOM
Schwarz et al, 2010

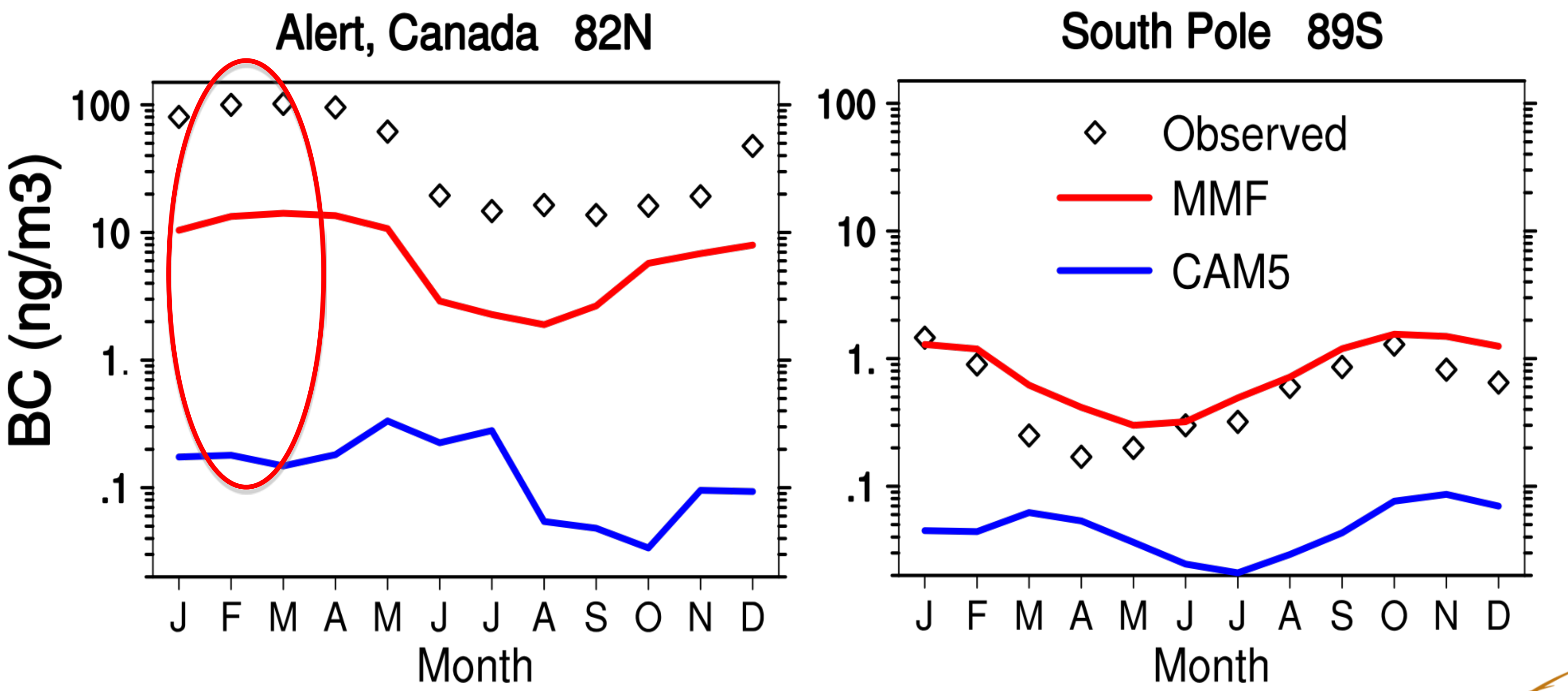
Colors are Obs
Black is AEROCOM model mean
Grey is model range

Other comparisons (Koch et al) are consistent with these results



Aerosol transport to polar regions

Monthly mean BC surface concentrations
(Wang et al. 2011, ACP)



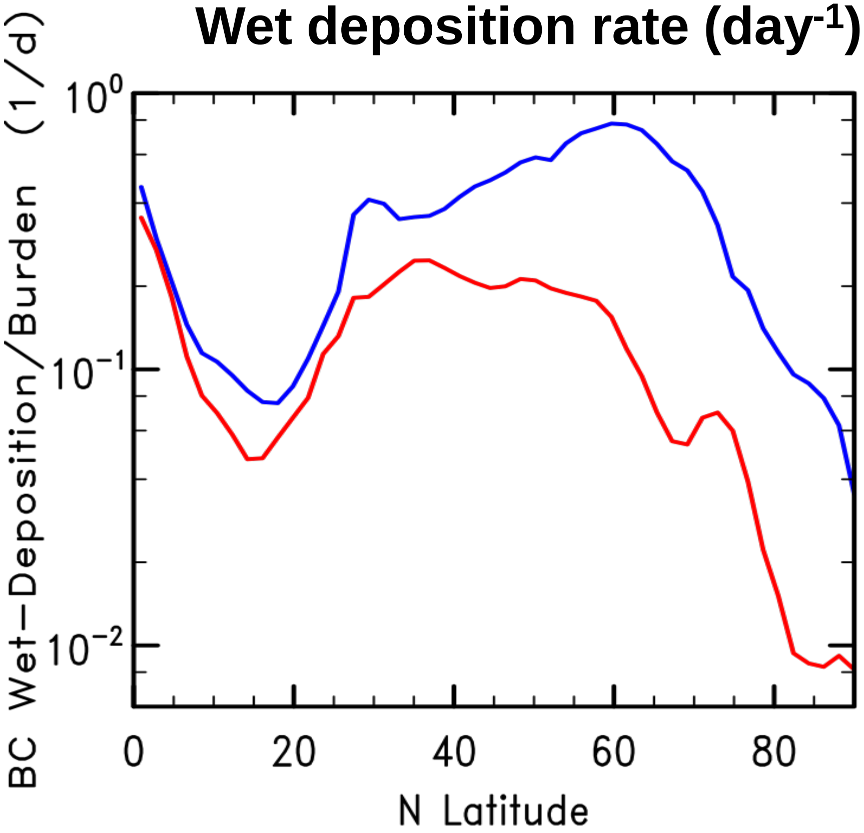
Model (CAM5) and Experimental setup

- 10-year run (1.9° x2.5°) with AR5 emissions
  - with 3-mode modal aerosols (MAM-3)
    - Improved liquid clouds in drop activation
    - Unified convective transport & wet removal of aerosols
    - Some other mods to reduce DJF high-latitude liquid clouds and wet removal efficiency
  - with a more complete 7-mode aerosols (MAM-7)
    - Slower BC aging
    - Year 2000 emissions vs. 1980 emissions

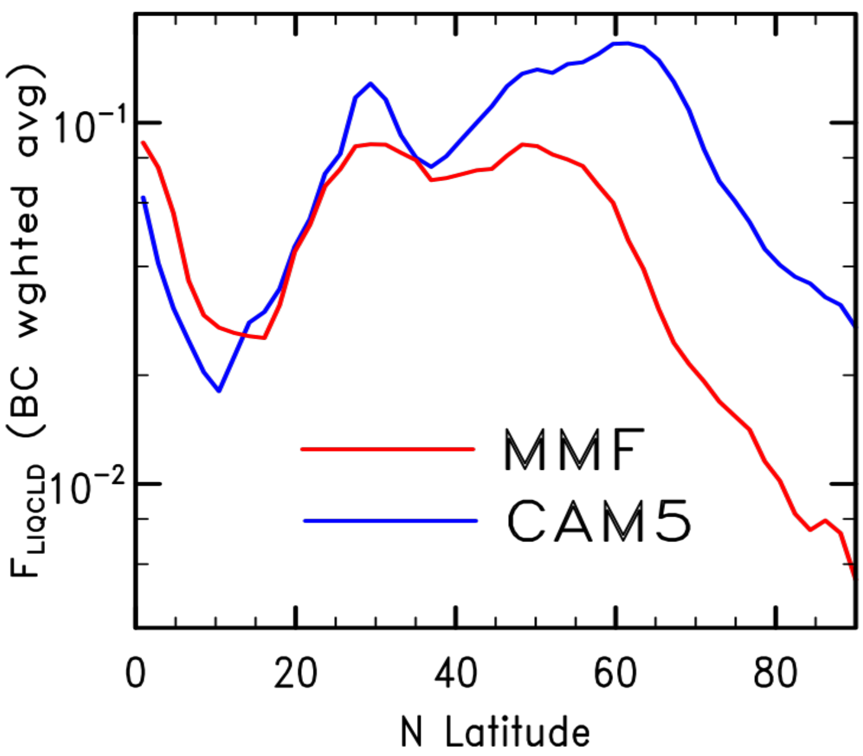
- PNNL-MMF (an aerosol multiscale modeling framework, with a 2-D cloud-resolving model embedded in CAM5 grids) 3-year run with the same year 2000 emissions

Liquid clouds and BC wet removal rate (Jan-Apr)

Wet deposition rate (day^{-1})



Liquid cloud fraction



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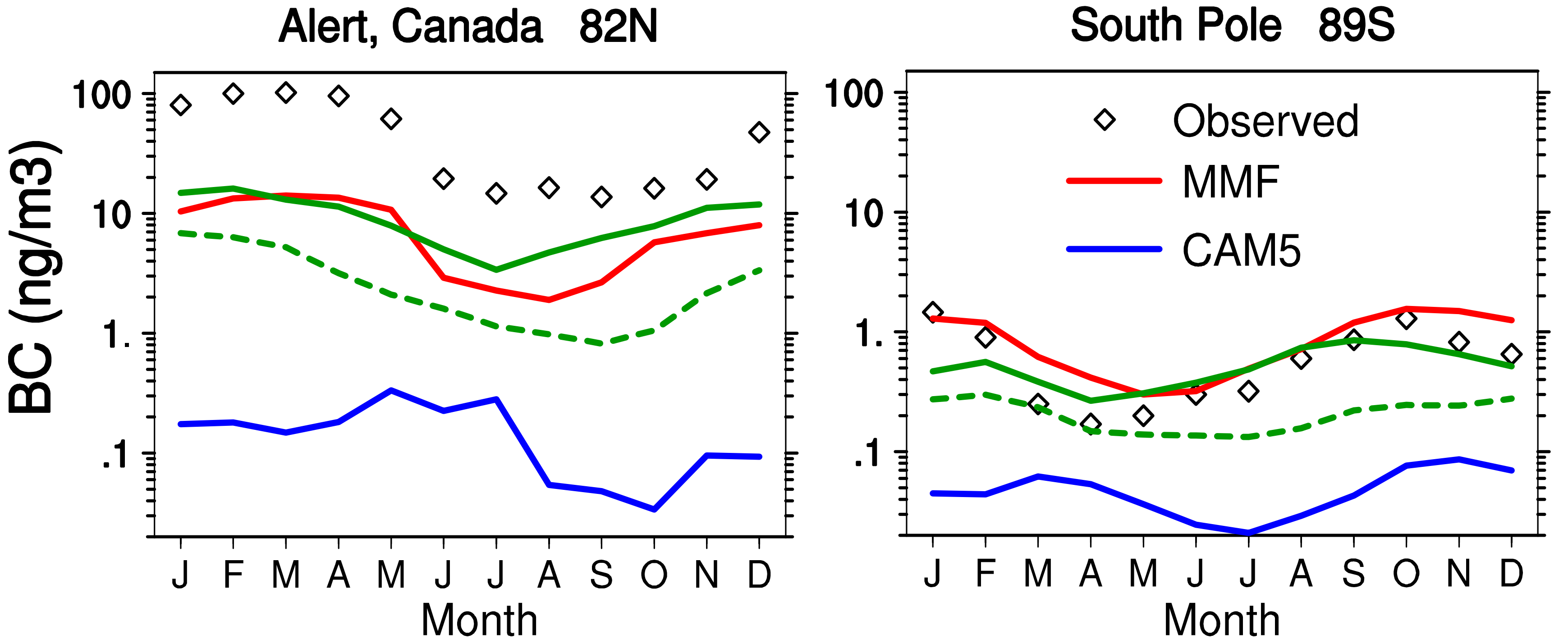
Seasonal cycle of BC at polar sites



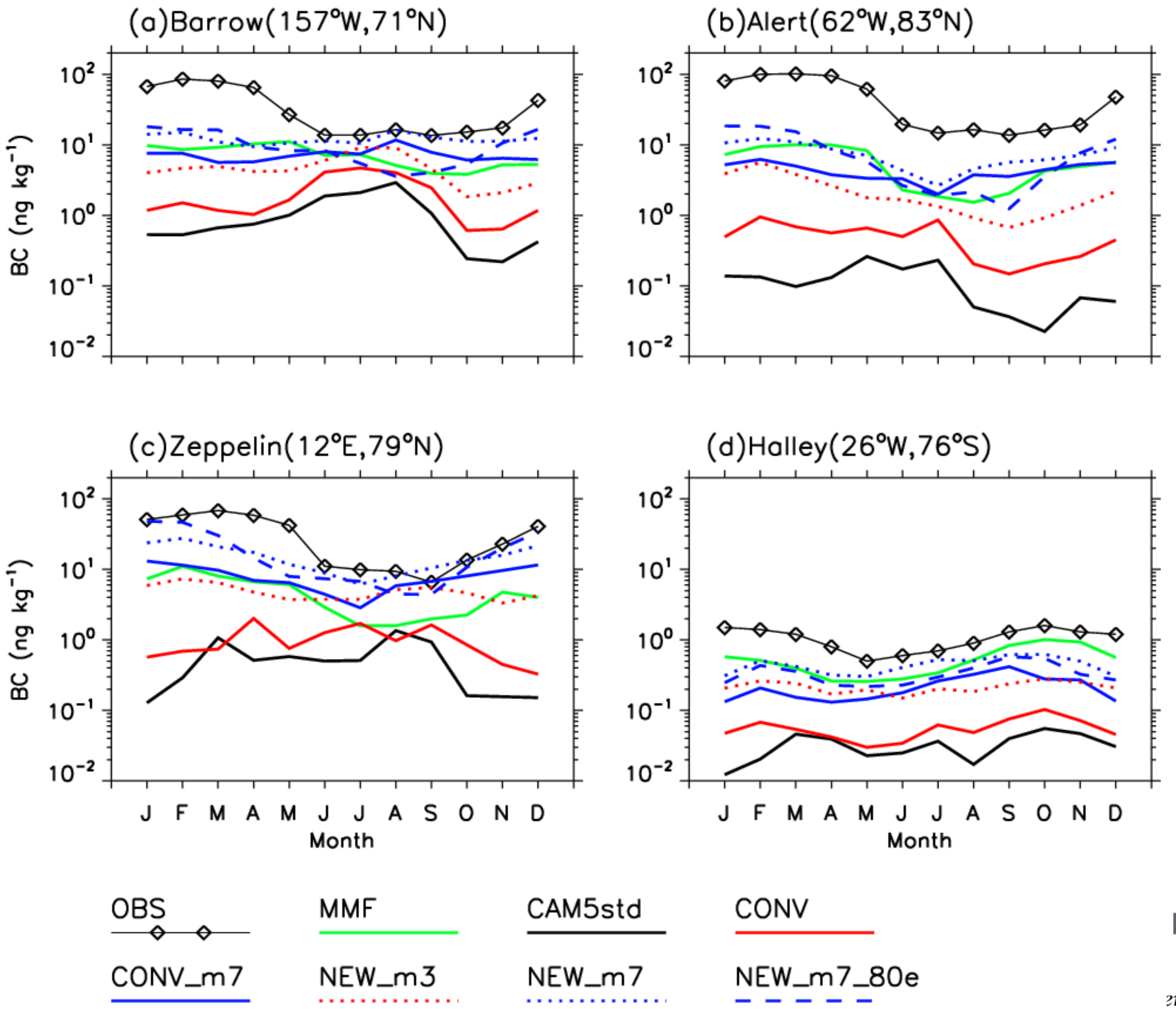
Obs updated from Bodhaine (1995).

- - - - CAM5 new clouds: changed drop activation; changes to liquid cloud extent*; unified convective aerosol transport and wet removal

—— CAM5 new clouds + slow BC aging

*See particularly, Garrett et al, 2011, ACP

Monthly mean BC surface concentrations



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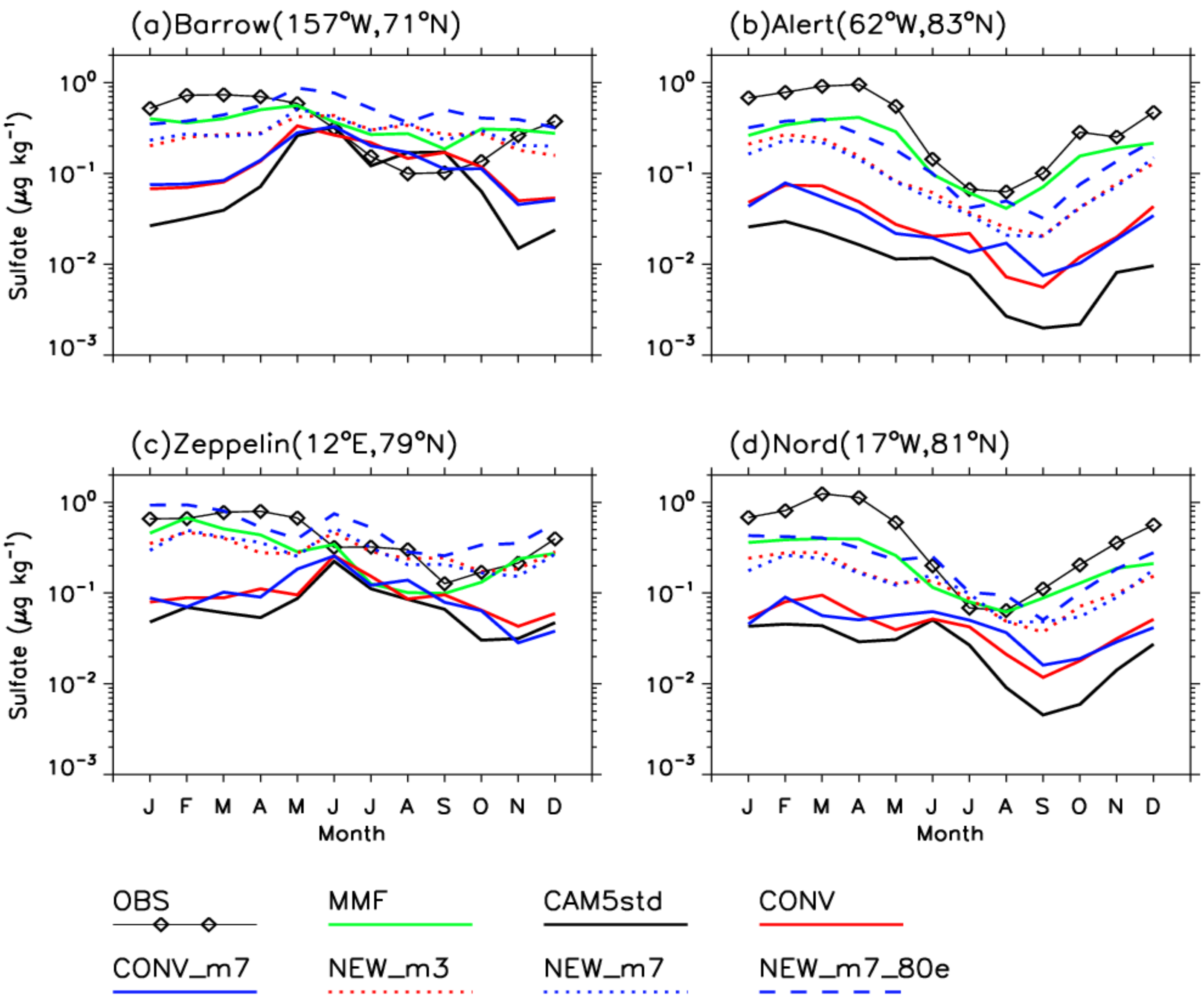
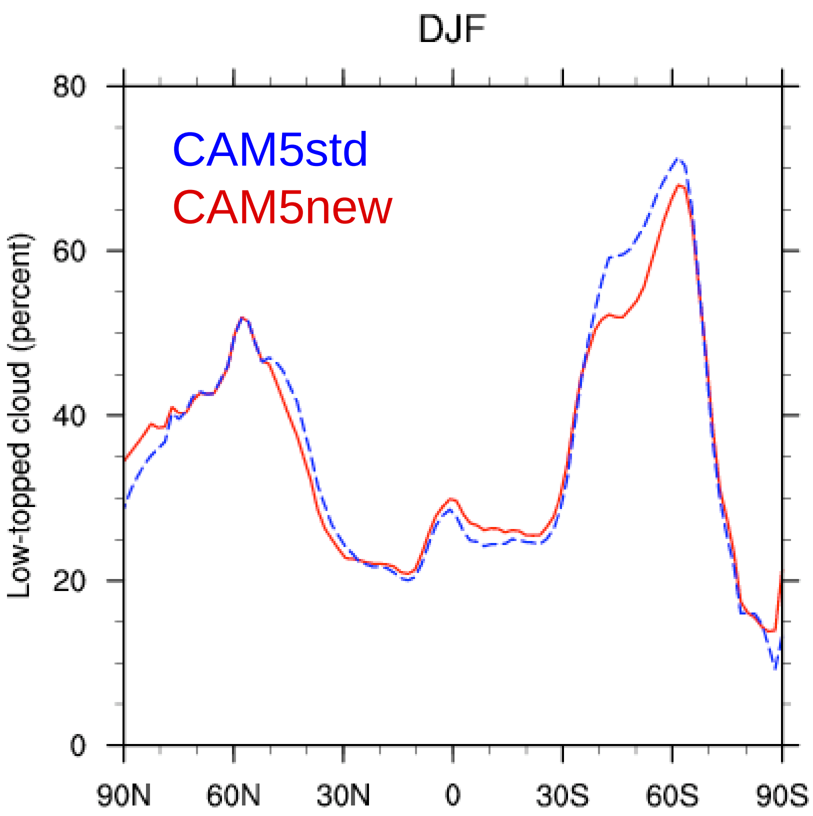
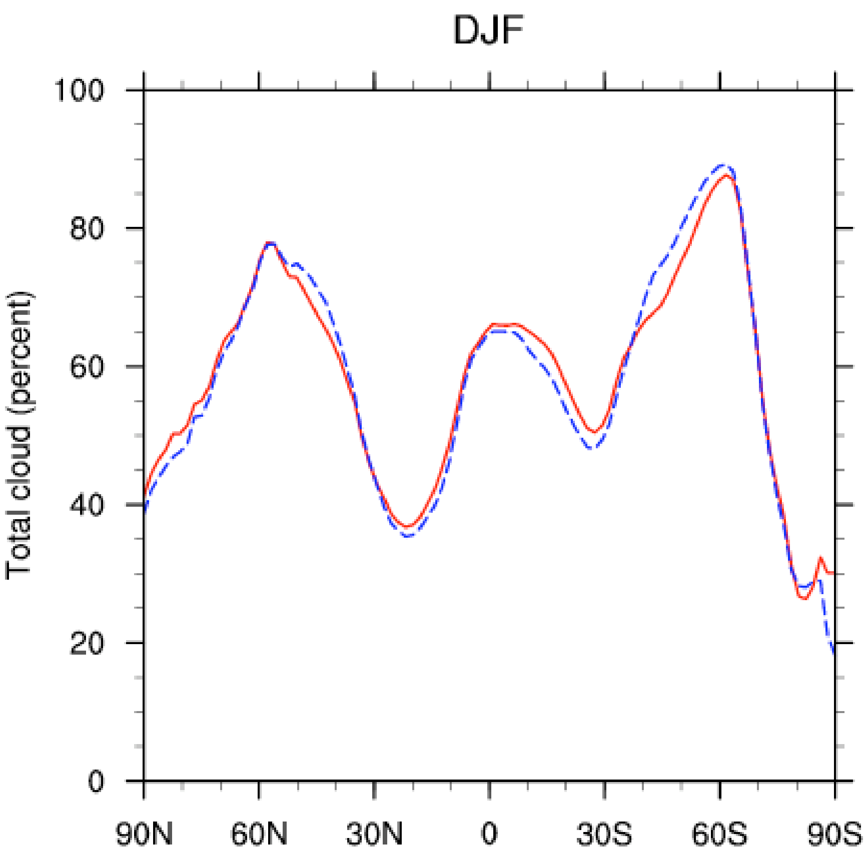
Monthly mean sulfate surface concentrations



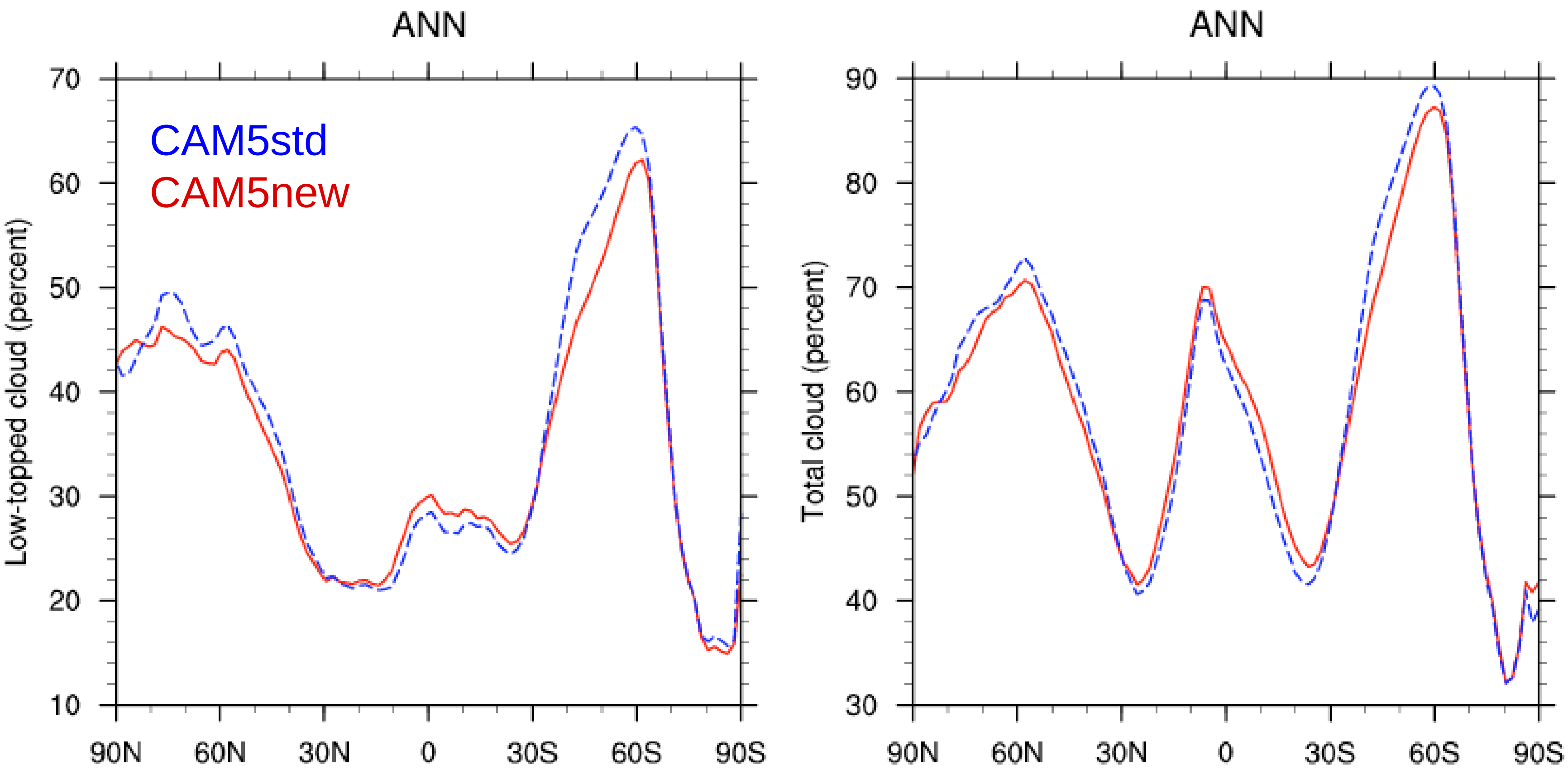
DJF low and total cloud fraction (COSP): CAM5std vs. CAM5new





Reducing liquid cloud fraction has little impact on total cloud fraction.

ANN low and total cloud fraction (COSP): CAM5std vs. CAM5new



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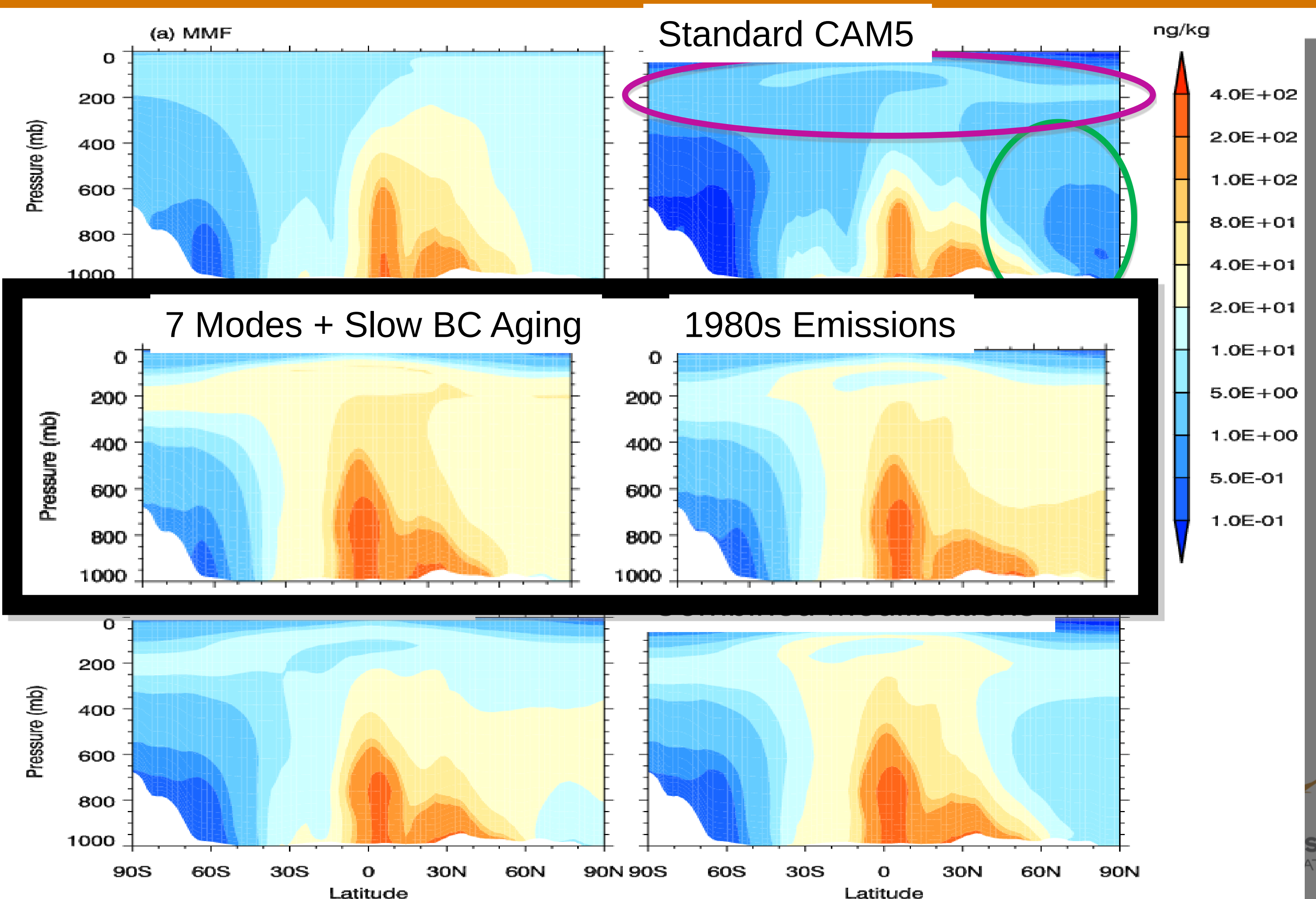
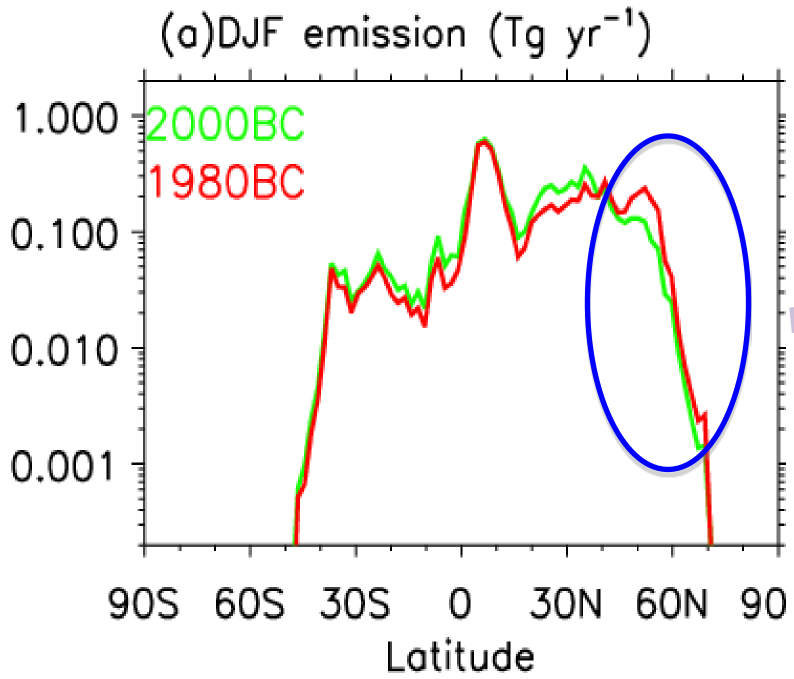
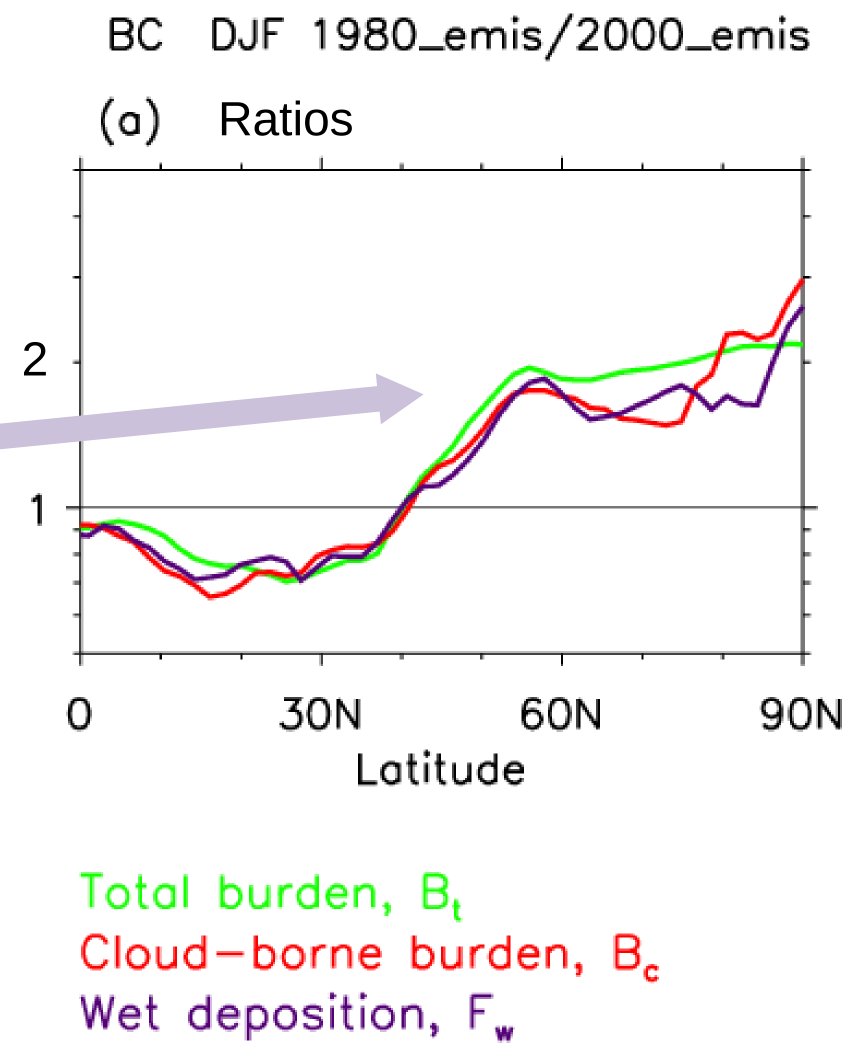
DJF zonal mean BC concent

1980 Emissions Double the Arctic BC burden



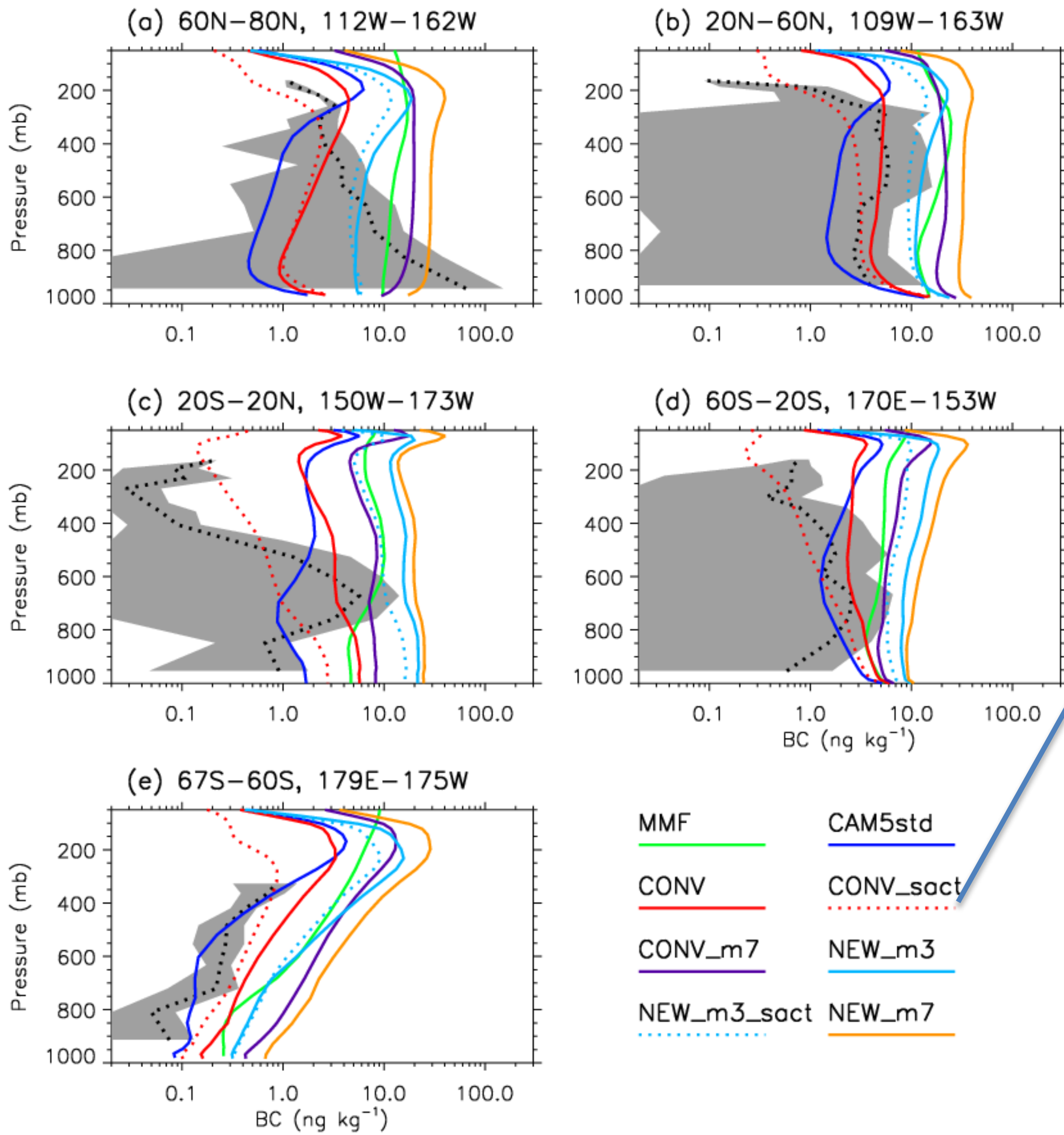
Sensitivity tests with AR5 year 2000 vs. 1980 emissions





Increase of mid-/high-latitude BC emission double the arctic BC burden

Vertical profiles of BC: CAM5 vs. HIPPO1

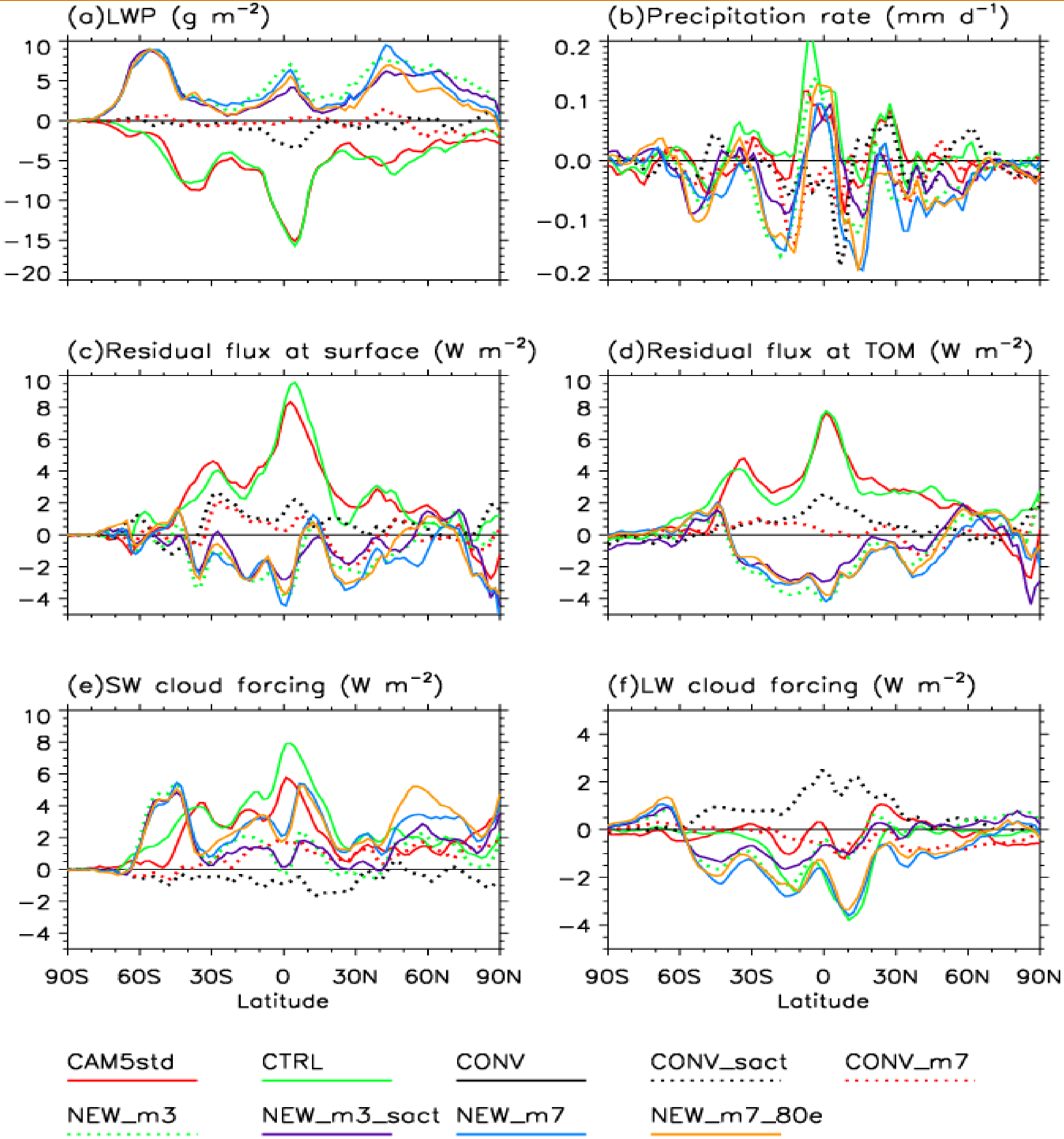


Secondary activation in the new treatment of convective transport strongly reduces mid- to upper-tropospheric BC.

Summary:

- Many processes must be treated carefully to produce a reasonable representation of Arctic aerosols in CAM5
  - Emissions
  - Vertical transport at mid and low latitudes
  - Scavenging (wet removal), particularly at mid-latitudes, by liquid-phase processes
  - Aerosol aging and mixing (hygroscopicity)
  - Atmospheric dynamics and model resolution
- All these things must be “OK” before aerosol (BC in particular) climate impacts may be explored.

Impact of mods on LWP, precipitation, energy fluxes, and cloud forcing



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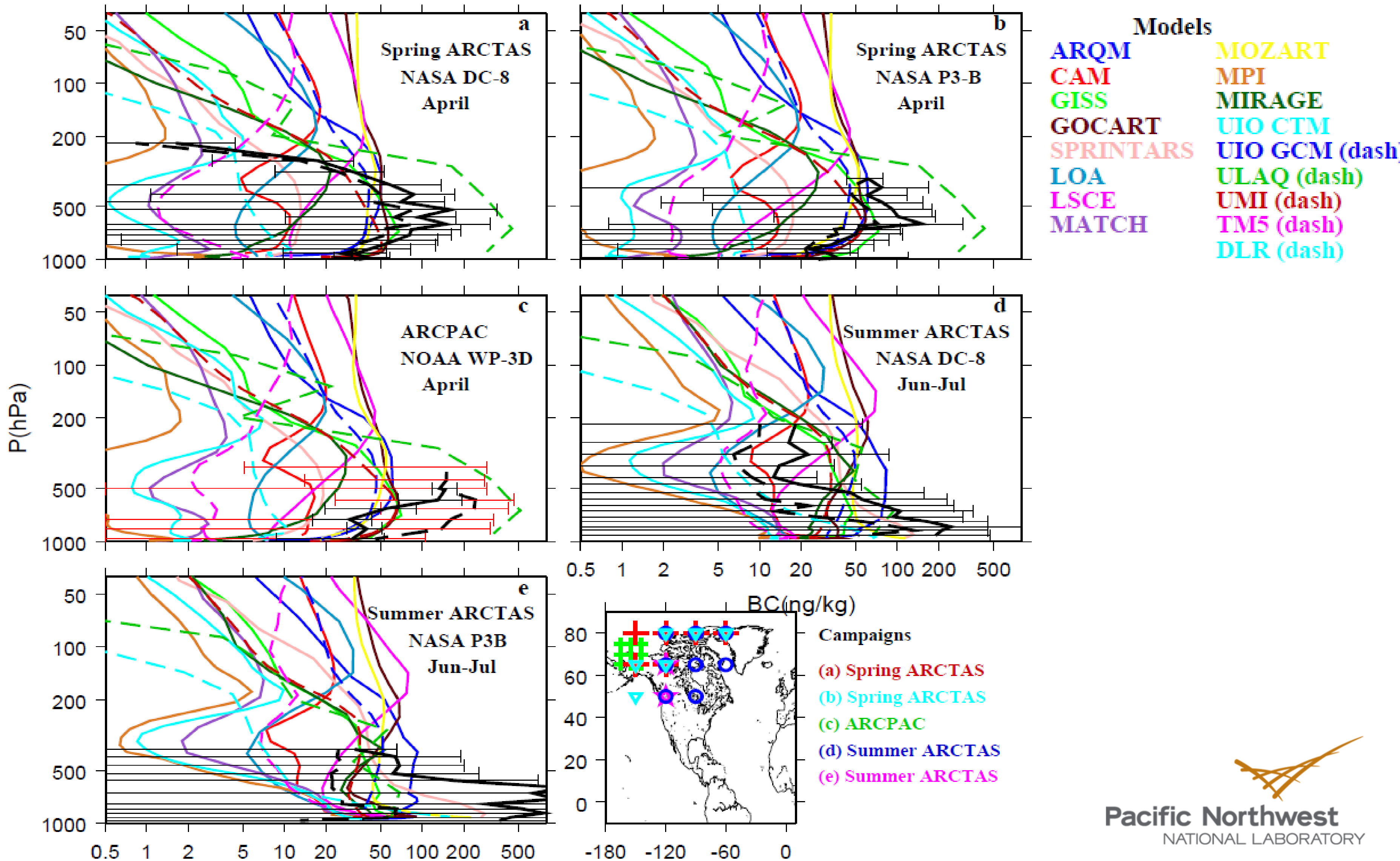
Vertical profiles of BC: from other models
(AeroCom intercomparison by Koch et al., 2009)



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First-order BC wet removal

$$R_w = F_w / B_t = \overset{\text{I}}{\frac{F_w}{B_c}} \cdot \overset{\text{II}}{\frac{B_c}{f \cdot B_t}} \cdot \overset{\text{III}}{\frac{f \cdot B_t}{B_t}}$$

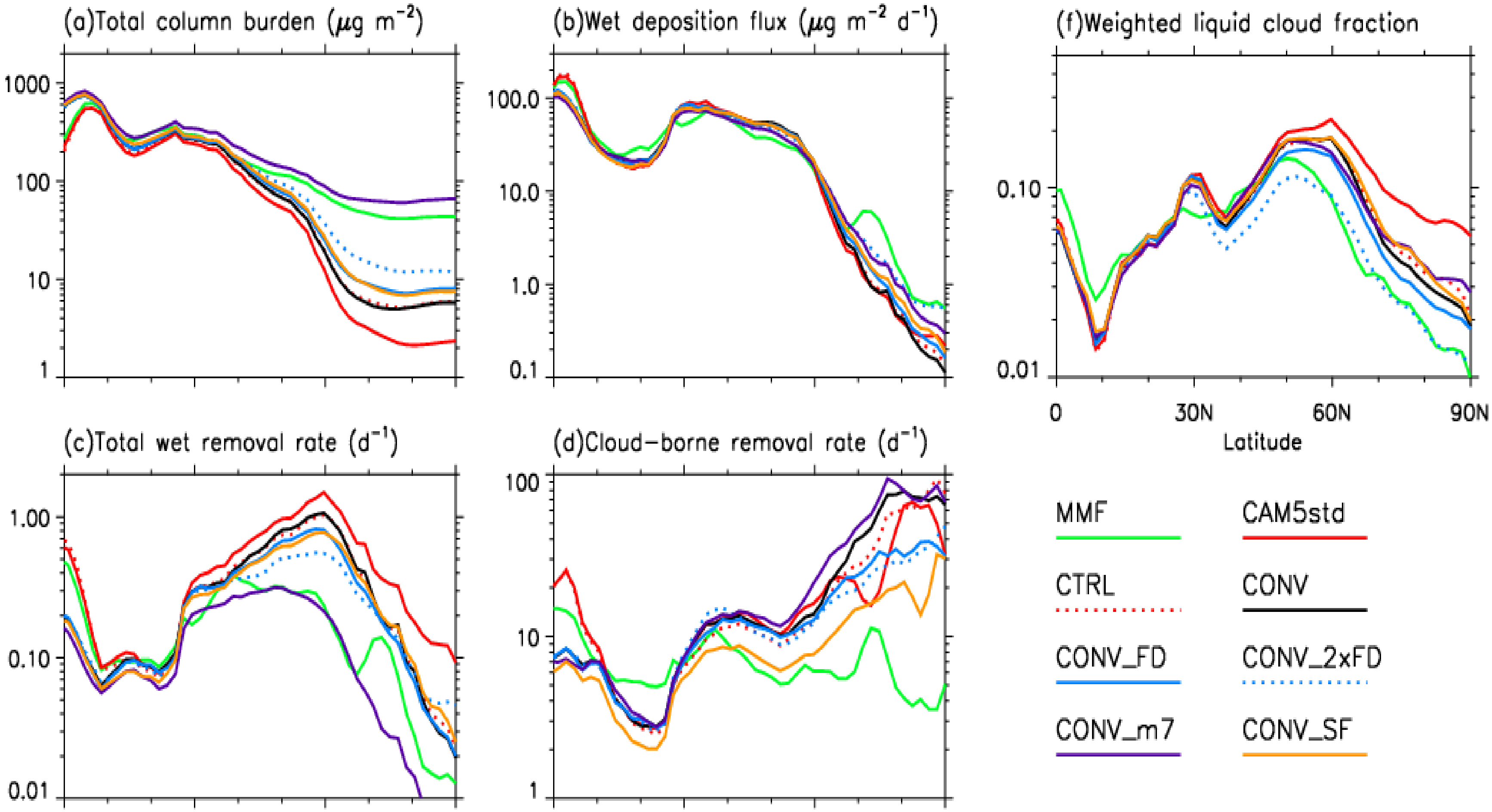
F_w : surface wet deposition flux ($\mu g\ m^{-2}\ d^{-1}$)
B_t : column burden of total (interstitial + cloud-borne) aerosol
B_c : column burden of cloud-borne aerosol
f : sub-grid liquid cloud fraction

R_w: total wet removal rate
I: cloud-borne removal
II: activation fraction
III: BC burden weighted liquid cloud fraction

Summary of sensitivity experiments and changes made to the standard CAM5

Experiment	modification/improvement
CTRL	An inconsistency involving the stratiform liquid cloud fractions used in the aerosol activation and in the cloud microphysics and macrophysics modules is removed
CONV	In additions to those in the CTRL, a unified treatment of aerosol vertical transport, activation, and removal in convective clouds is implemented.
CONV_sact	Same as CONV, but secondary aerosol activation is applied in the unified convective treatment in addition to the primary activation at cloud base.
CONV_FD	A freeze-dry scheme in cloud macrophysics is switched on to reduce liquid cloud fraction: $f=f_0$ x $\max[0.15,\min(1, q_v/q_{v0})]$, where f ($f_0$) is liquid cloud fraction and the threshold water vapor mixing ration q_{v0}=0.003 kg kg^{-1}.
CONV_2xFD	Same as CONV_FD, but with q_{v0}=0.006 kg kg^{-1} to further reduce liquid cloud fraction in a broader area.
CONV_SF	Same as CONV, but with the wet removal adjustment factors reduced.
CONV_m7	Same as CONV, but using a more complete 7-mode aerosol module instead of the standard 3-mode; moreover, a slow BC aging can be applied.
NEW_m3	Combined changes in CONV_FDnew and CONV_SFs; in addition, solubility factor for in-cloud wet removal by convective clouds is reduced from 1.0 to 0.5.
NEW_m3_sact	Same as NEW_m3, but secondary aerosol activation is applied.
NEW_m7	Same as NEW_m3, but using the 7-mode aerosol module and slow BC aging.
NEW_m7_80e	Same as NEW_m7, but using the AR5 1980 emission inventory

Zonal-mean BC burden, removal rate, …



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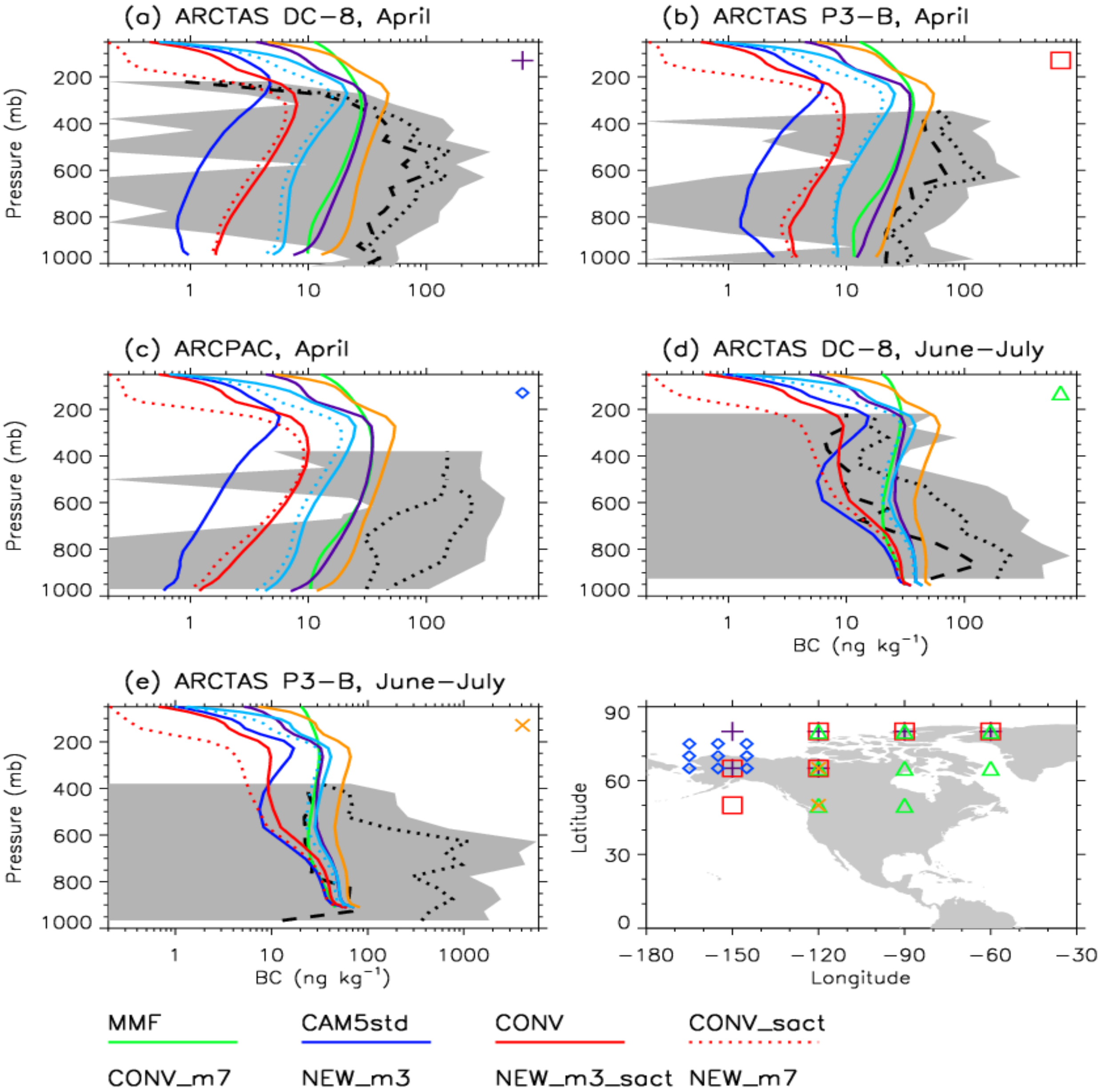
Vertical profiles of BC: CAM5 vs. observations
(obs are from Koch et al., 2009)



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