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Improving Convective Transport, Wet Removal and Vertical Distribution of Aerosols in CAM5

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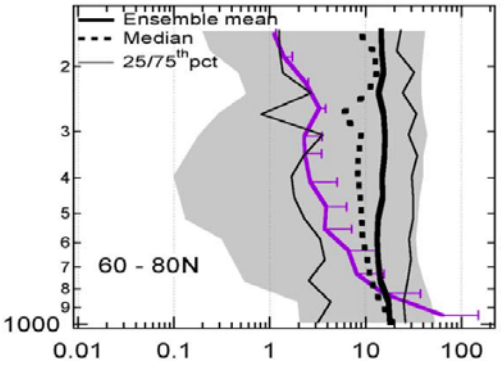
Background/Motivation

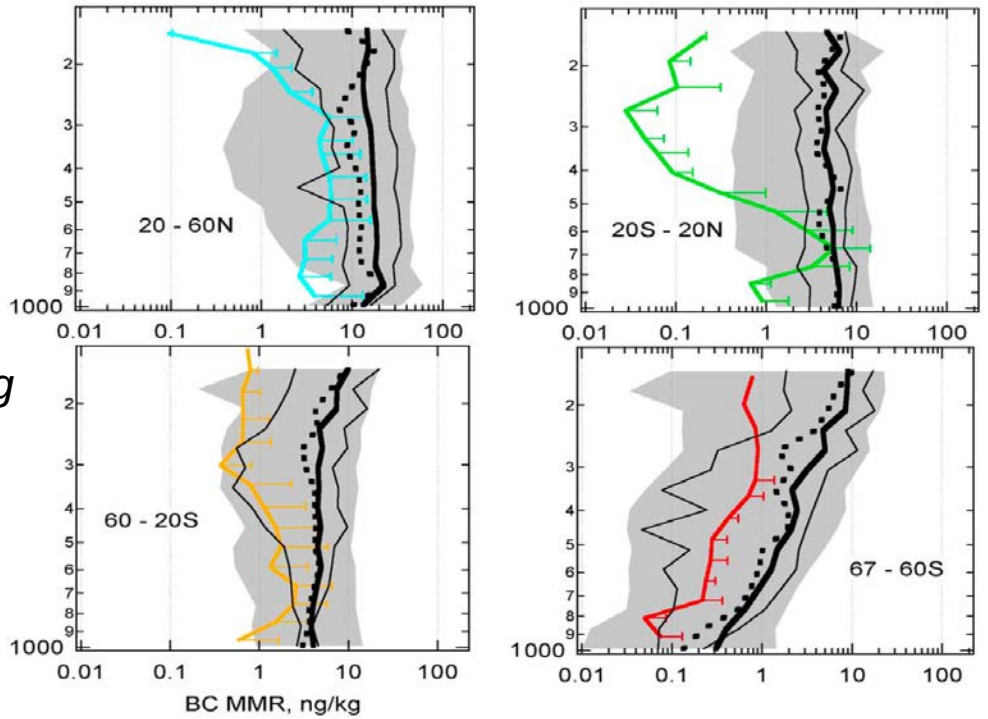
- Climate models have systematic biases (*Koch et al. 2009; Schwarz et al. 2010*) in predicting remote aerosols:
  - Over-prediction at high altitudes
  - Under-prediction and poor seasonal cycle near surface at high latitudes



HIPPO1 vs. AeroCom models

(*Schwarz et al., 2010*)

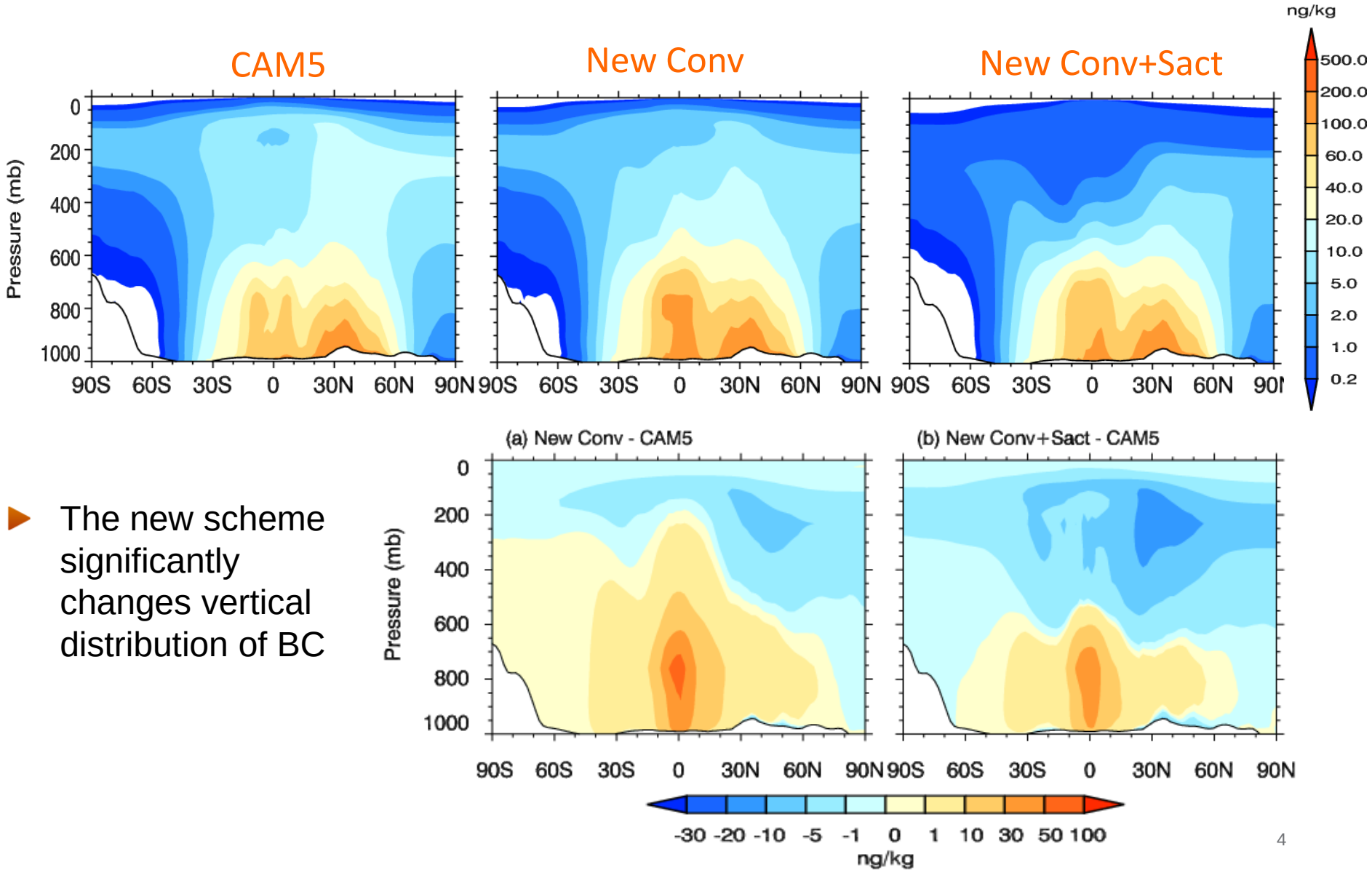
- Possible contributing factors:
  - Aerosol aging (*Liu et al. 2012*)
  - Meteorology/circulation (*Ma et al. submitted*)
  - Model resolution (*Ma et al., in preparation*)
  - Emissions (*Ma et al., submitted; Wang et al., in preparation*)
  - Cloud parameterizations (*Liu et al.; Caldwell et al., in preparation*)
  - Convective transport and wet removal (*Wang et al. 2013, GMDD*)



Convective transport and wet removal of aerosols in CAM5

- The vertical distribution of aerosols depends strongly on convective transport and wet removal.
- Treatment in the Community Atmosphere Model (CAM5)
  - The existing scheme treats in-cloud wet removal (by a prescribed fraction) and convective transport sequentially
  - A new scheme has been developed (*Wang et al. 2013, GMDD*)
    - Aerosol activation is treated explicitly in updrafts; cloud-borne aerosols are subject to wet removal by convective rain
    - w/ an option of explicit secondary aerosol activation above cloud base, in addition to the primary activation at cloud base
- Model simulations
  - Control (CAM5), with the new scheme (New Conv) and plus the secondary activation (New Conv+Sact)
  - CAM5.1 (2 deg), 3-mode aerosol, prescribed emissions and SST

Impact on aerosol vertical distribution



- The new scheme significantly changes vertical distribution of BC

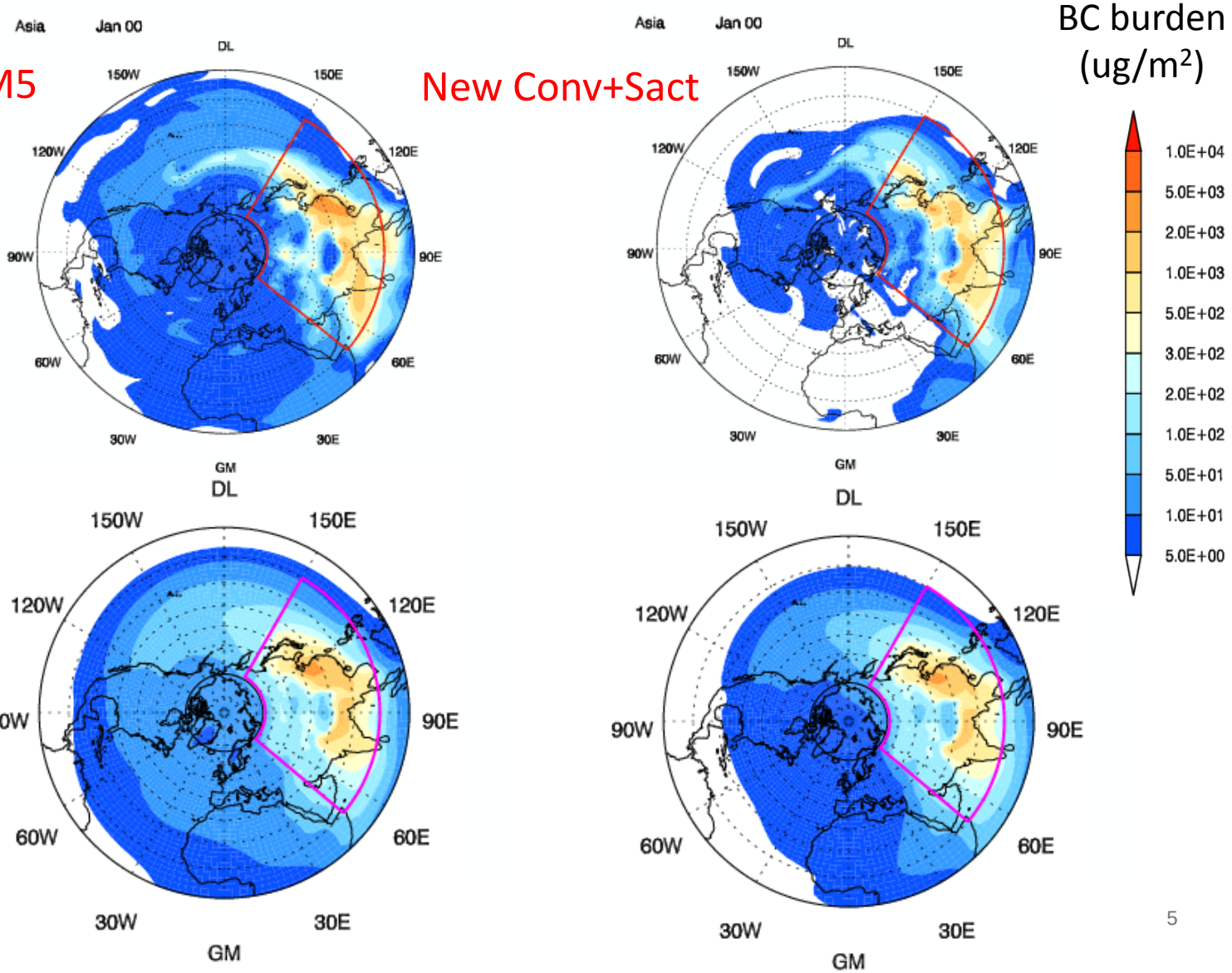
Impact on horizontal long-range transport

Regional emission tagging (BC from Asia)

CAM5

New Conv+Sact

BC burden (ug/m²)

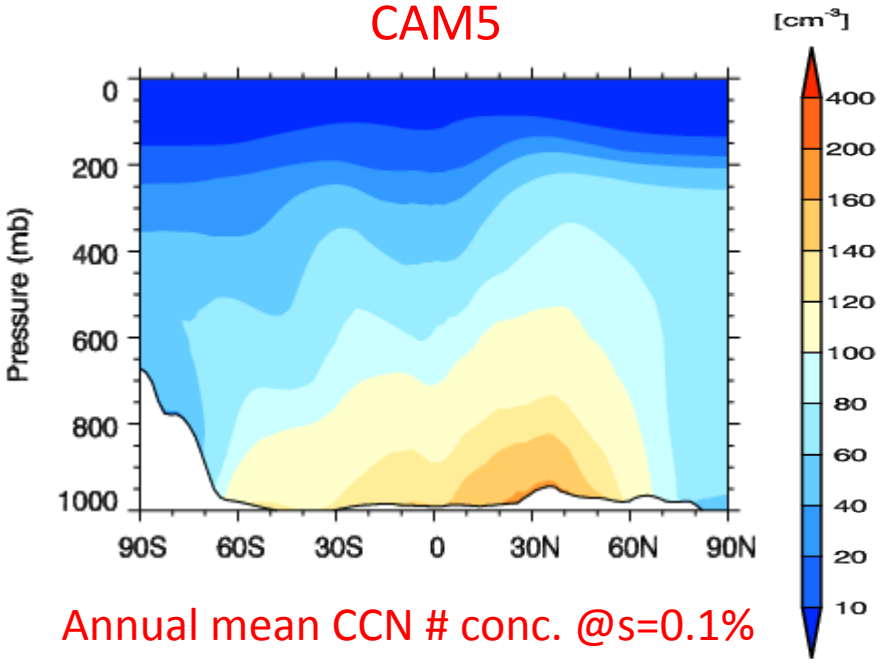


Daily mean for a month

10-year annual mean

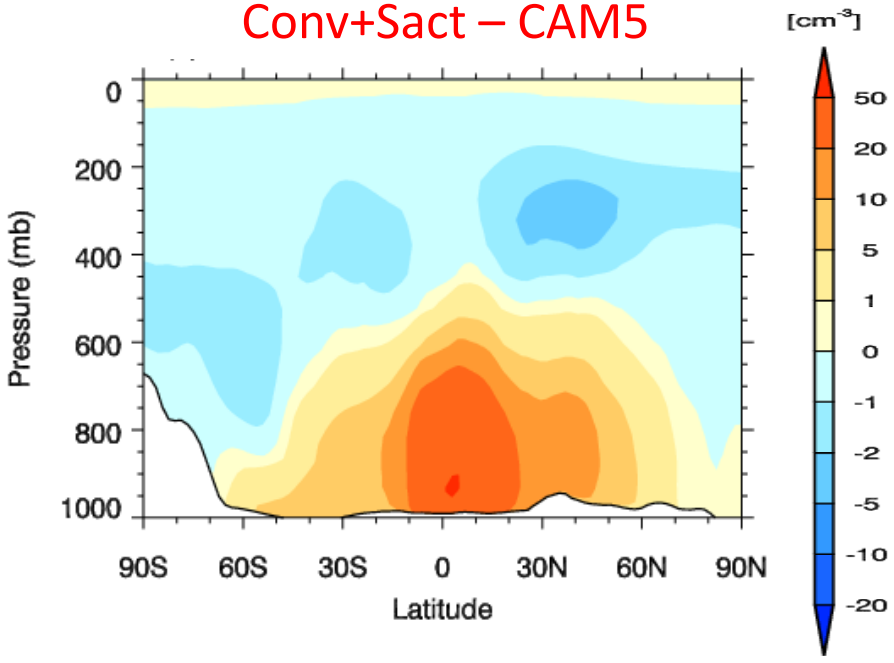
Changes in aerosols affect CCN and clouds

CAM5



Annual mean CCN # conc. @s=0.1%

Conv+Sact – CAM5



- Changes in aerosols affect CCN, cloud drop number concentrations and, potentially, ice nucleation
- Also lead to improvements in global LWP (low bias in the default model)

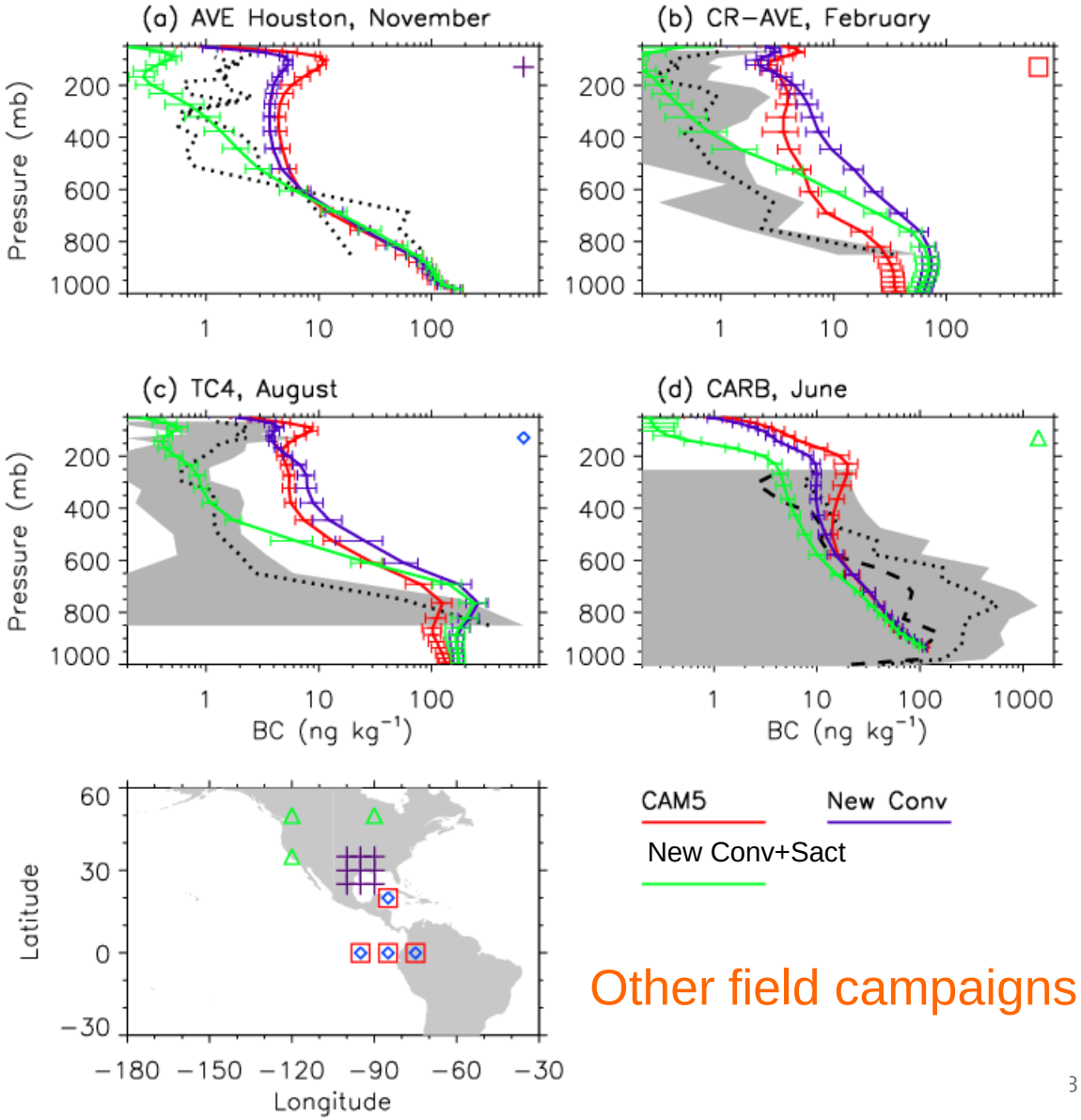
Changes in aerosols affect anthropogenic aerosol indirect effects

- Impact on cloud forcing and anthropogenic aerosol indirect effects (PD-PI): New Conv+Sact vs. CAM5
  - ΔAOD increased by 23%
  - ΔLWP slightly increased
  - ΔSWCF reduced by 0.15 Wm^{-2}
  - ΔLWCF reduced by 0.03 Wm^{-2}

PD-PI	ΔAOD	ΔLWP (g m^{-2})	ΔSWCF (W m^{-2})	ΔLWCF(W m^{-2})
CAM5	0.013	3.4	-1.91	0.67
New Conv+Sact	0.016	3.5	-1.76	0.64

The new scheme improves aerosol vertical distribution

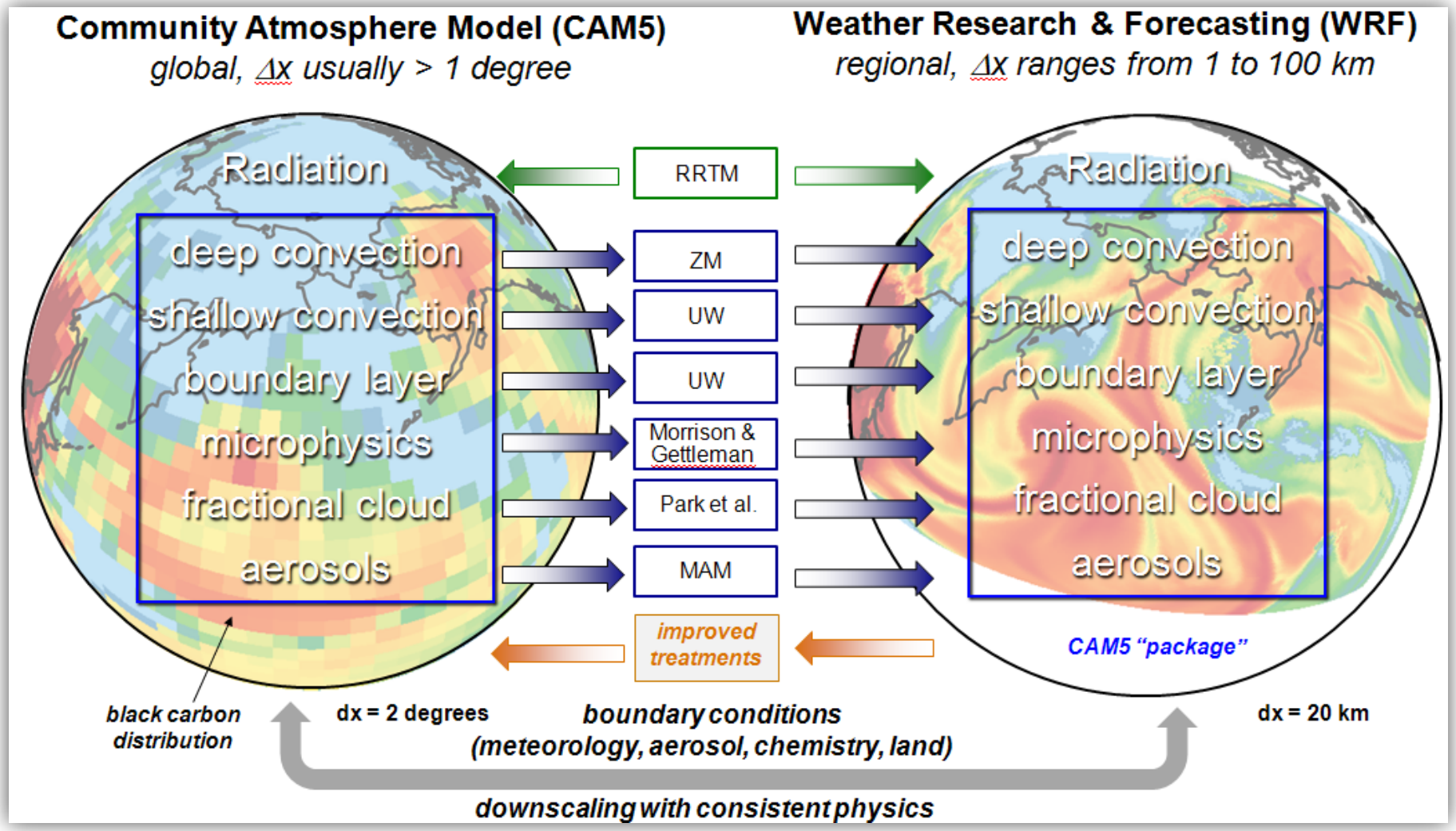
- Effectively reduces the excessive BC aloft
- Better simulates the observed decreasing trend from mid- to upper troposphere
- Tends to overestimate lower tropospheric BC
  - Improving the treatment of aerosol below-cloud scavenging and re-suspension might help (*Ganguly et al., in preparation*)



Other field campaigns

(Wang et al. 2013, GMDD)

The Measurements-WRF-CAM5 approach



Ma et al.; Fast et al., in preparation

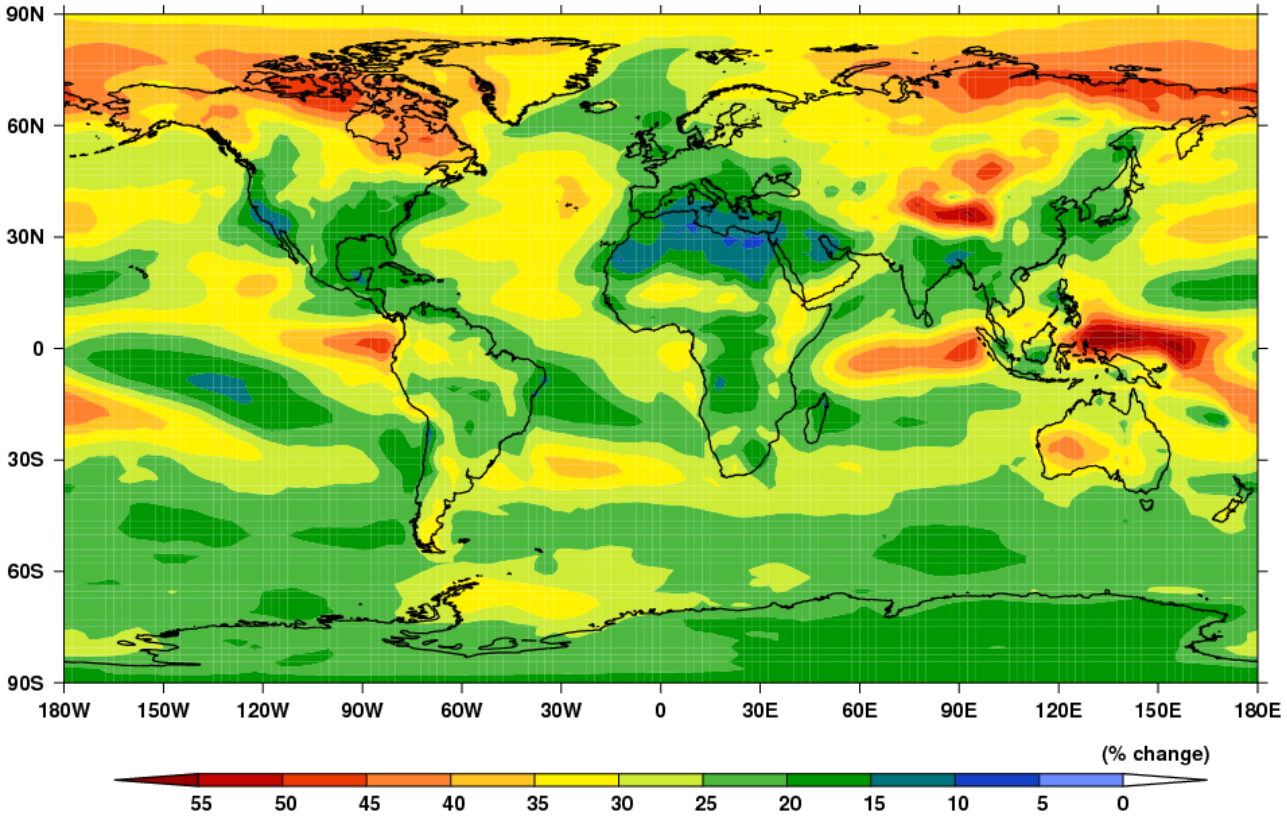
Summary and ongoing work

- The new scheme for convective transport and wet removal of aerosols, with aerosol activation above cloud base, reduces the excessive aerosol aloft and better simulates observed vertical distribution in CAM5
- The improved aerosol distributions have many other impacts, e.g., on the global mean AOD, LWP, cloud forcing, and aerosol indirect effects
- The new scheme along with other changes are being merged to CESM to assess the impact on aerosol/cloud forcing, Arctic snow/sea-ice change, and the coupled climate system
- We currently use a regional (WRF) modeling framework with CAM5 physics to study transport and scavenging of aerosols by deep convective clouds, with cloud-resolving simulations and coarser resolution simulations employing convective cloud parameterizations
- Measurements from recent field campaigns will be utilized for process-level evaluation of model simulations to improve the parameterizations

Sensitivity of lower tropospheric aerosols to re-suspension assumptions

Default:
Aerosol particles are released back to original modes at the bulk rain evaporation rate

New:
To release one larger aerosol particle upon complete evaporation of a raindrop (Gong et al. 2006; Mitra et al. 1992)



(*Ganguly et al., in preparation*)

Relative contribution of lower tropospheric CCN (at s=0.1%) # conc. by aerosol re-suspension in CAM5

Changes in Aerosols Impact Clouds and Climate

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	AOD	LWP (g m^{-2})	SWCF (W m^{-2})	LWCF(W m^{-2})
CAM5	0.101 (0.122*)	41.2	-49.12	23.67
New Conv	0.130 (0.153*)	47.0	-51.42	23.78
New Conv+Sact	0.116 (0.136*)	46.2	-52.06	24.74
Observed	- (0.213*)	(50,87)	(-46,-53)	(27,31)

*Mean value of measured AOD at 75 AERONET sites

Case	E. Asia (11)	S. Asia (5)	Europe (14)	N. Africa (6)	S. Africa (3)	N. Ameri. (23)	S. Ameri. (4)	Global (75)
CAM5	0.158 (0.020)	0.093 (0.010)	0.093 (0.010)	0.287 (0.032)	0.078 (0.010)	0.074 (0.007)	0.103 (0.008)	0.122 (0.013)
CONV	0.180 (0.020)	0.157 (0.012)	0.112 (0.010)	0.410 (0.041)	0.092 (0.011)	0.095 (0.008)	0.155 (0.011)	0.153 (0.014)
Conv+Sact	0.165 (0.019)	0.131 (0.011)	0.100 (0.010)	0.360 (0.036)	0.081 (0.010)	0.086 (0.007)	0.126 (0.009)	0.136 (0.013)
Observed	0.339 (0.027)	0.391 (0.041)	0.183 (0.015)	0.515 (0.046)	0.183 (0.021)	0.133 (0.007)	0.208 (0.024)	0.213 (0.017)