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SPCAM5: Multi-scale Modeling of Aerosols, Clouds and Precipitation

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NASA U.S. DEPARTMENT OF ENERGY NSF

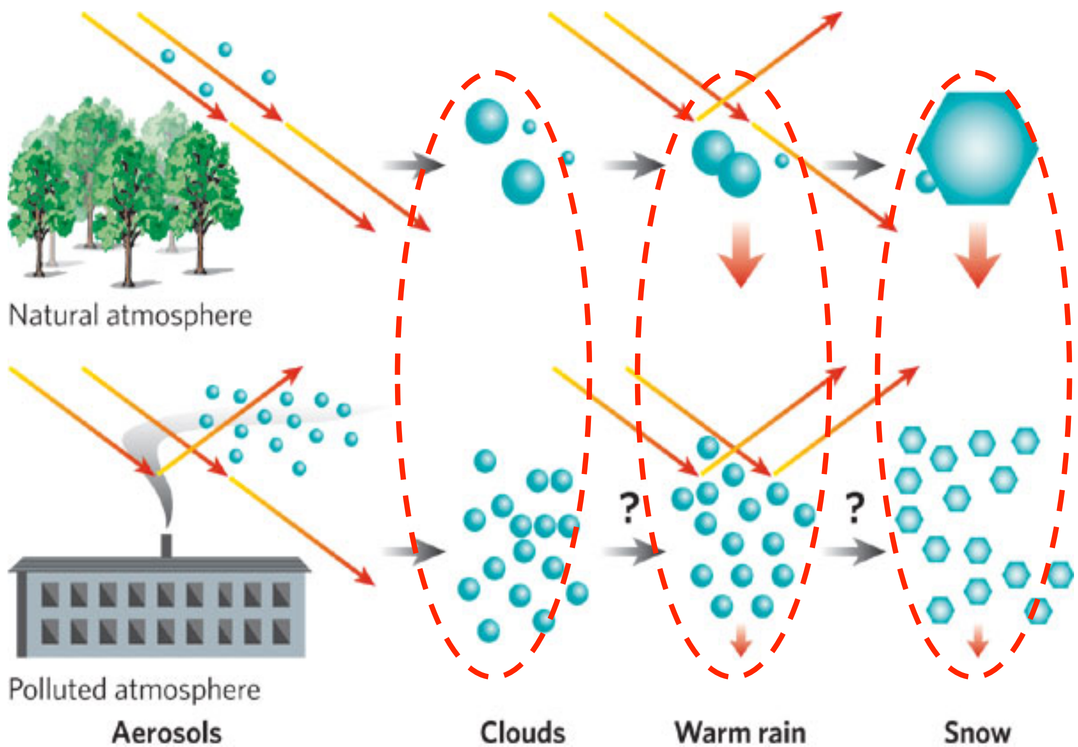
Atmospheric aerosols and their climate effects

Aerosols: Small liquid/solid particles suspended in the atmosphere
range from nm to 100um
Have both anthropogenic and natural sources

Aerosols have important climate effects

- Direct effects: Directly scatter/absorb solar/thermal fluxes
- Effects on snow albedo: Change snow albedo from dark aerosol particles.
- Effects on nutrient deposition
- Indirect effects: indirectly affect climate through modifying cloud properties by acting as cloud condensation nuclei (CCN) or ice nuclei (IN).

Aerosol indirect effects



Source: [Baker and Peter, 2008]

Cloud albedo effect (1st AIE): Increase in droplet number concentration decreases droplet size and increases cloud albedo.

Cloud lifetime effect: Smaller droplet size changes precipitation efficiency, and changes cloud amount

Effects on ice clouds: Changes in ice nuclei and freezing mechanisms change ice crystal number, radius and precipitation efficiency.

Published estimates of aerosol indirect effects

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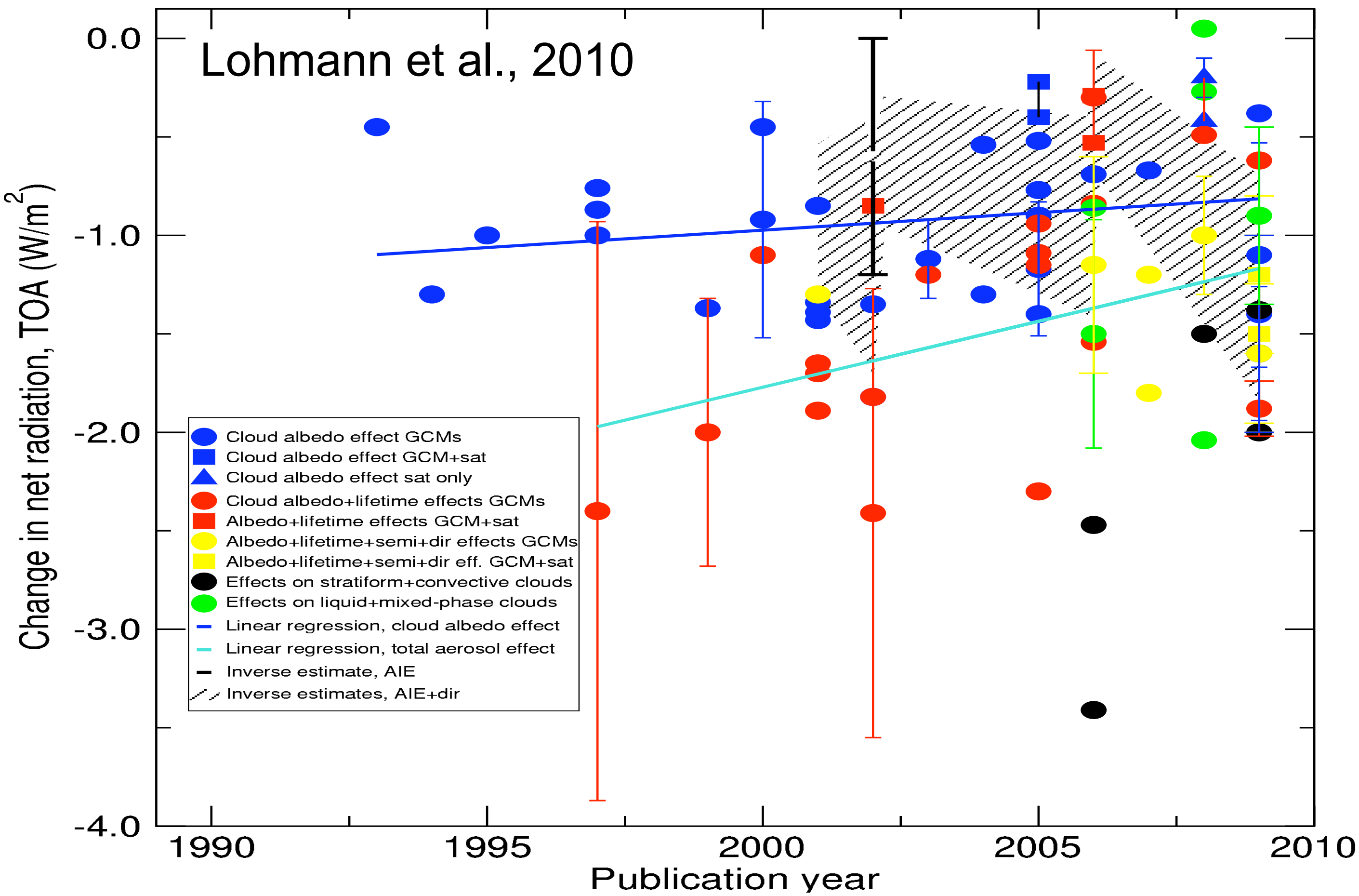
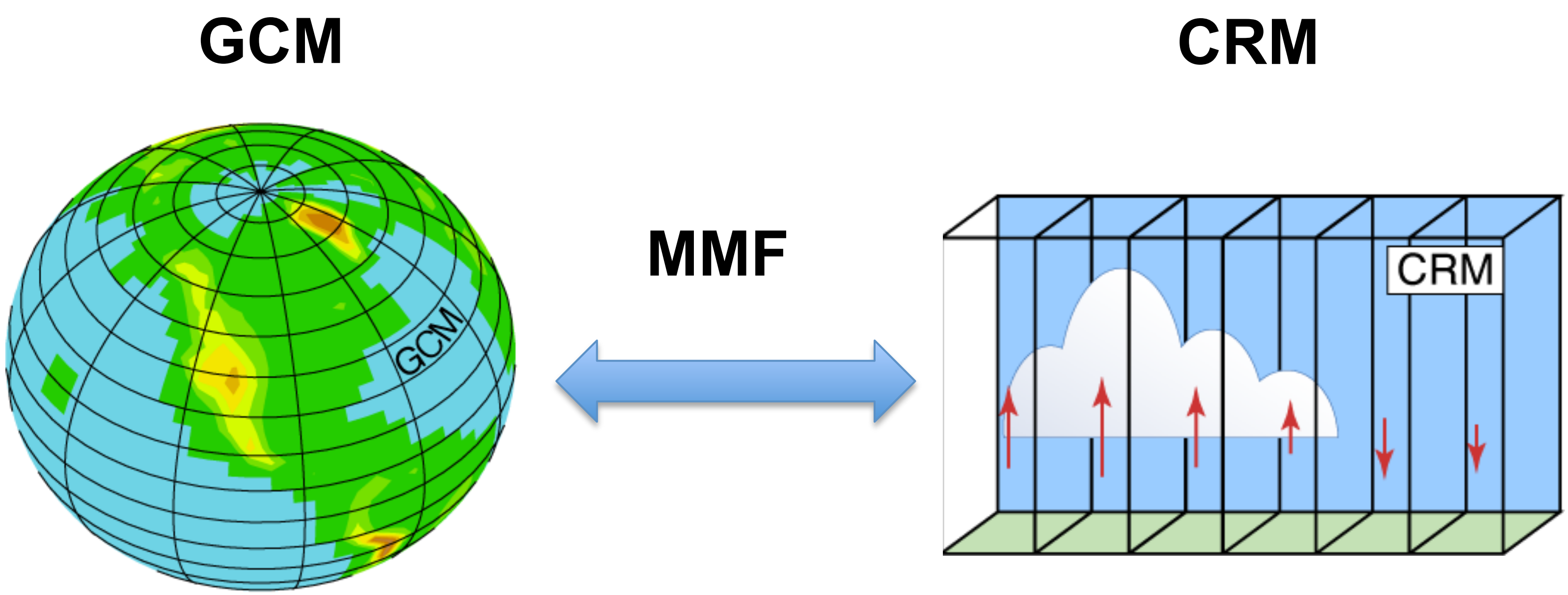


The Challenge: Multi-scale interactions of aerosols, clouds, and precipitation

The Multi-scale Modeling Framework (MMF) approach provides a viable solution



Grabowski, 2001;
Khairoutdinov and Randall, 2001.

Outline

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I. The Multi-scale Aerosol-Climate Model (Aerosol-MMF)

II. Scientific Applications

- Aerosol transport to the polar regions
- Cloud lifetime effects of aerosols
- Aerosol effects on deep clouds

III. SPCAM5: Community MMF

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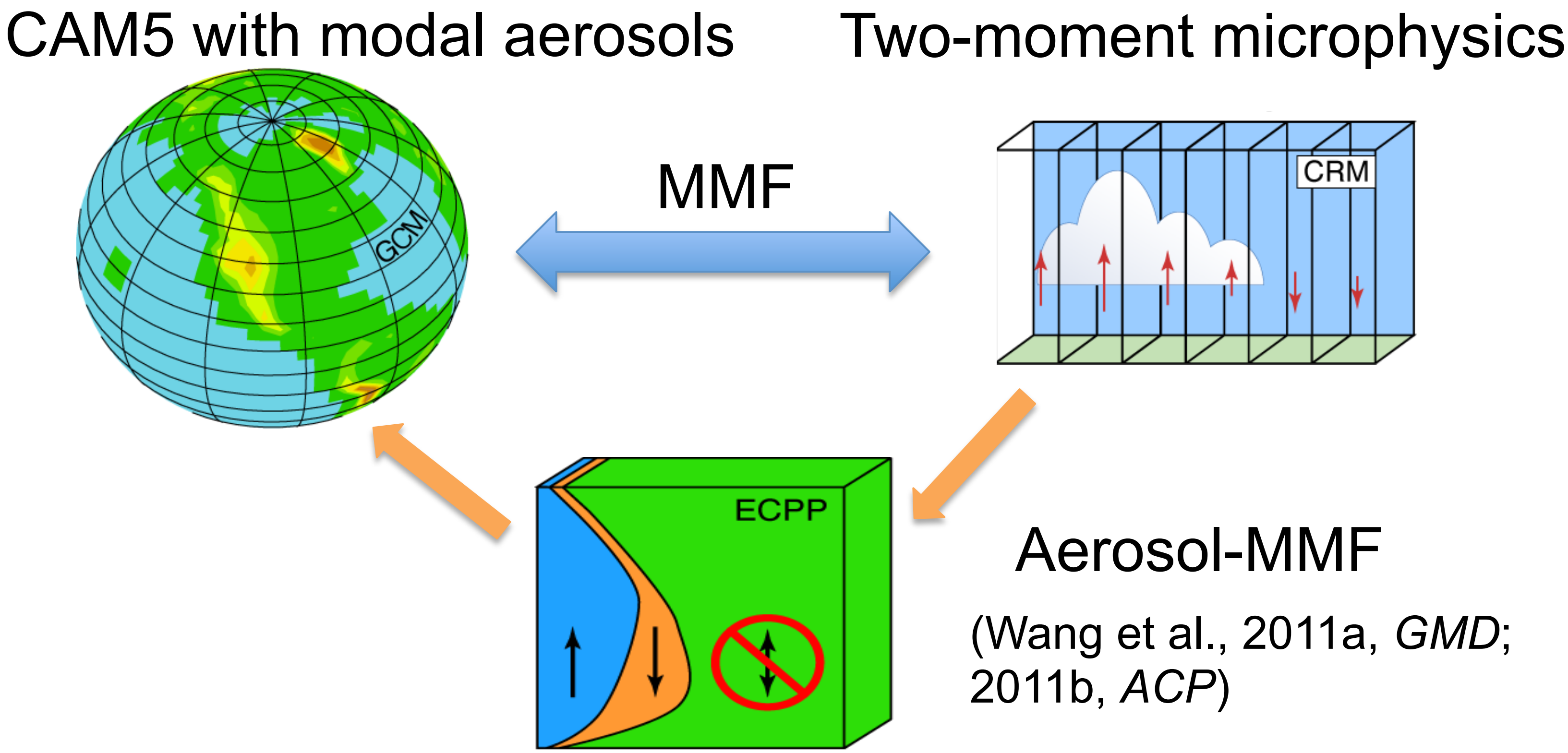
A multi-scale aerosol-climate model



Aerosol-MMF

(Wang et al., 2011a, *GMD*; 2011b, *ACP*)

CRM cloud/precipitation statistics used for cloud processing of aerosols

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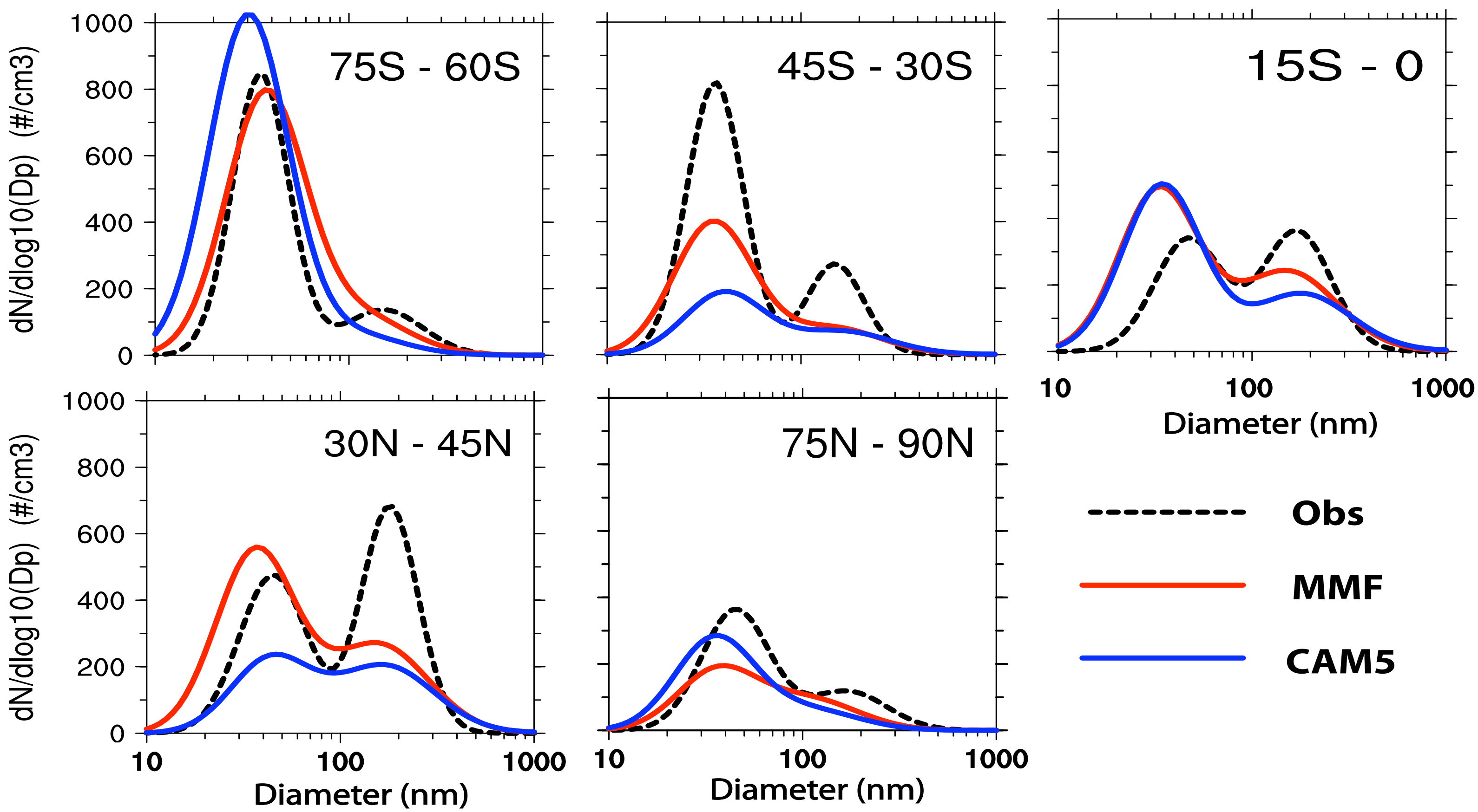
Some unique features of the aerosol-MMF

- Aerosol processing by convective clouds is explicitly treated by using convective cloud fraction, mass flux and vertical velocity in convective updraft from CRM statistics.
- Aerosol water uptake is calculated at each CRM grid point, which accounts for the subgrid variation in relative humidity within each GCM grid cell.
- Droplet activation is calculated at each CRM grid point, using CRM-scale vertical velocity.
- Aerosol effects on both stratiform and convective clouds are explicitly treated.

Aerosol size distributions in the marine boundary layer (Observations: Heintzenberg et al., 2001)



M. Wang et al., 2011, *ACP*

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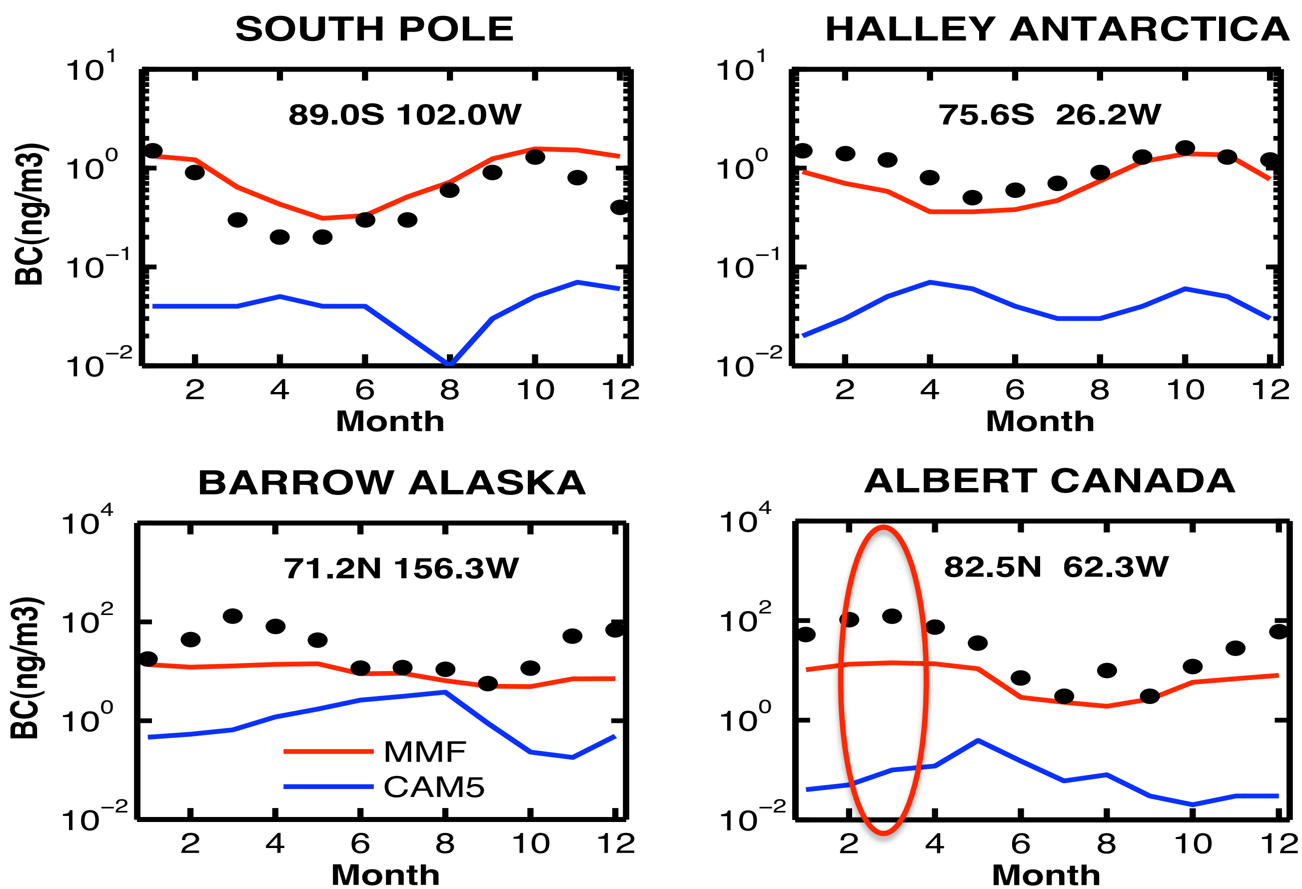
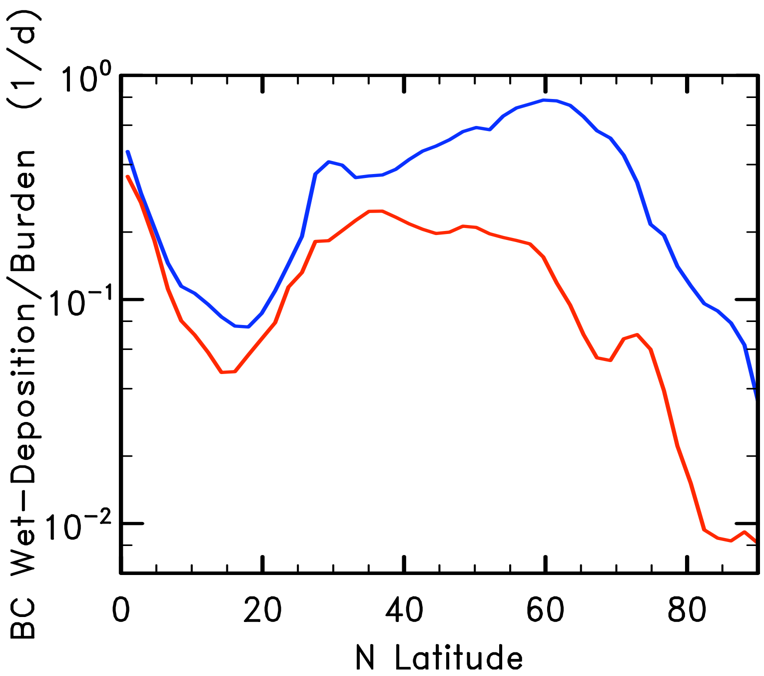
Monthly BC concentrations in the polar regions



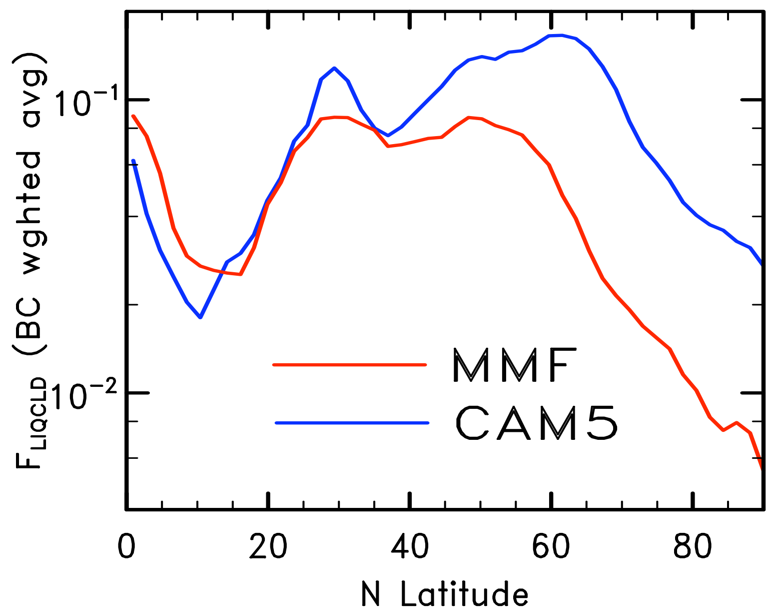
M. Wang et al., 2011, *ACP*

Wet deposition rate of BC and liquid cloud fraction (Jan-Apr)

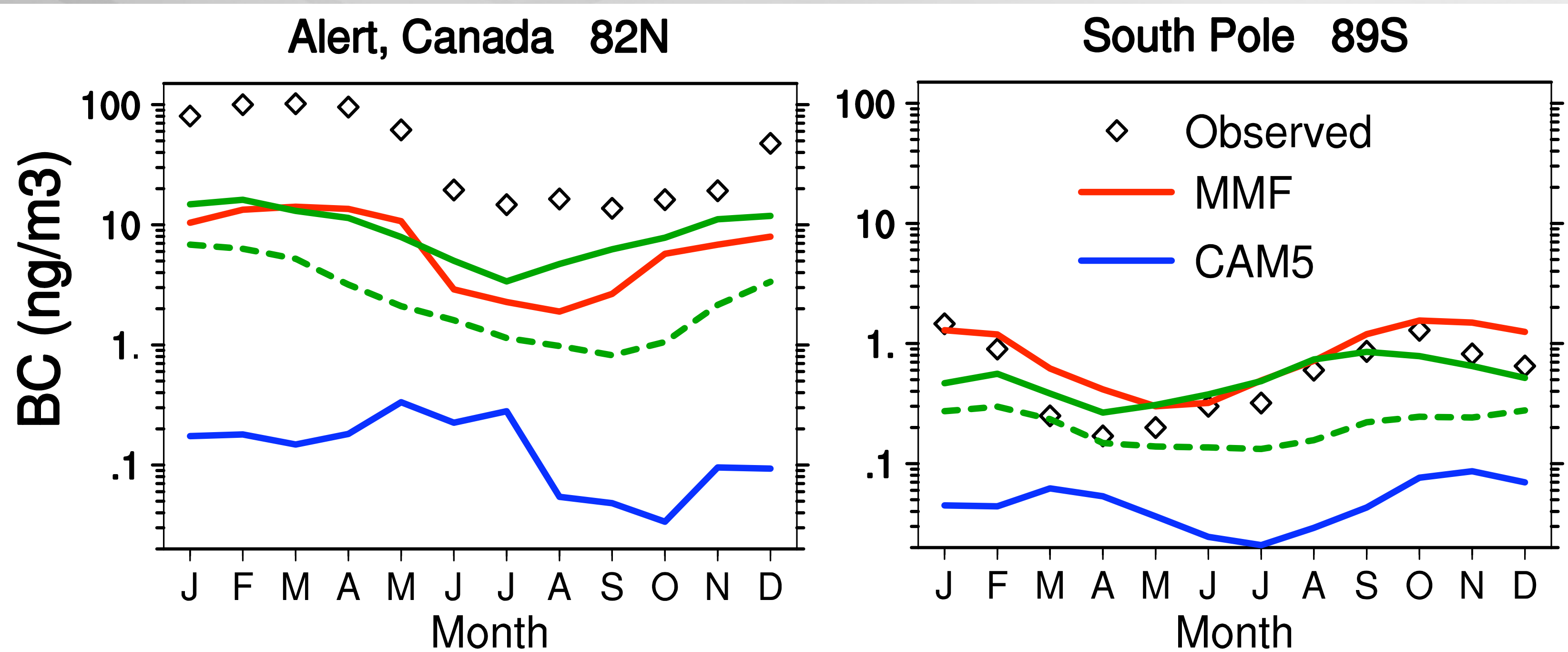
Wet deposition rate (day^{-1})



Liquid cloud fraction



CAM5 sensitivity experiments

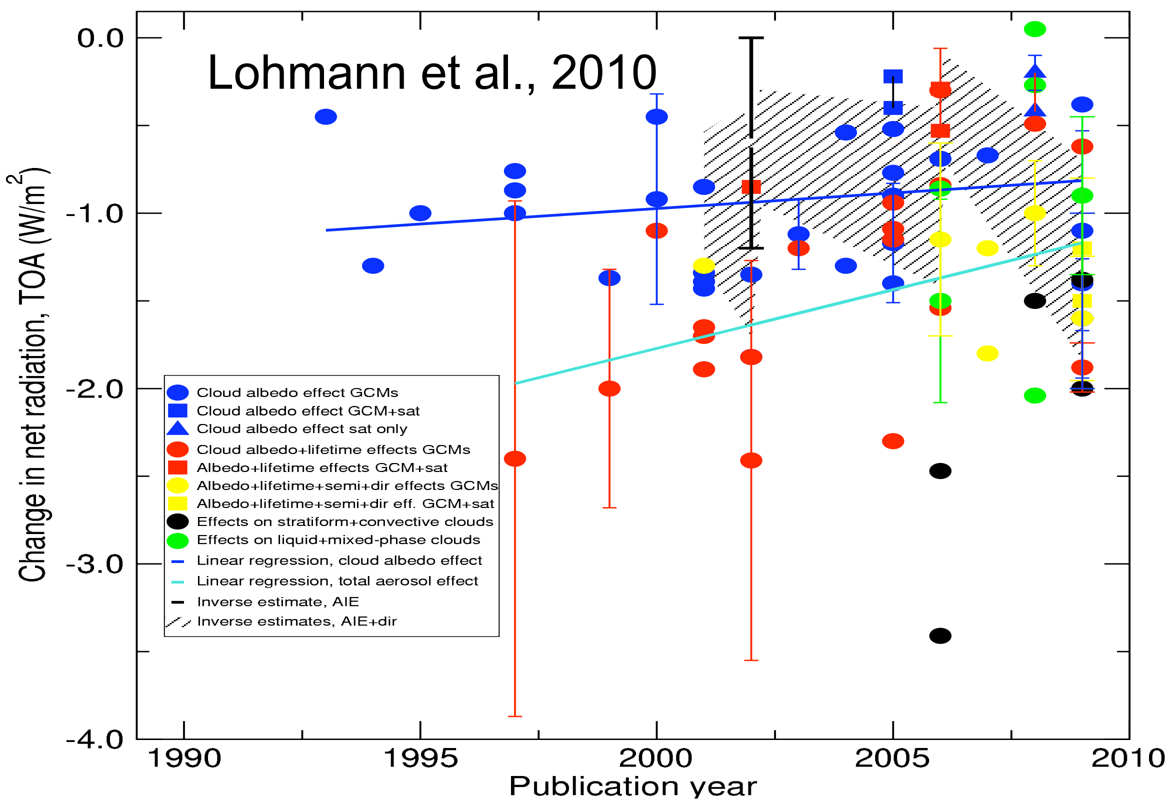


- - - - CAM5 new clouds: Reduced liquid cloud fraction in cold-dry environments; some other changes

—— CAM5 new clouds + slow BC aging

Hailong Wang et al., 2012, submitted, *JGR*

The first estimate of shortwave aerosol indirect forcing from MMF (Wang et al., 2011, *ACP*)



MMF (-0.77 W m^{-2})

CAM5 (-1.79 W m^{-2})

- Increases in liquid water path (LWP): 3.9% (MMF) vs. 15.6% (CAM5)

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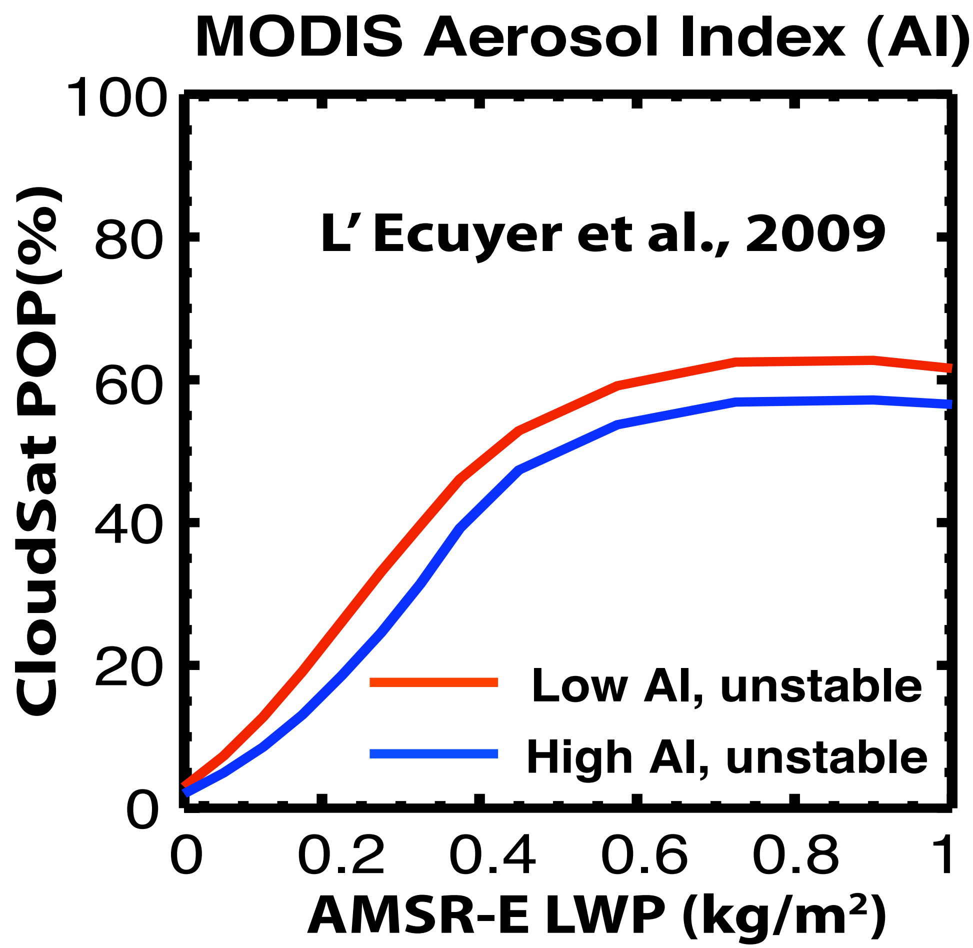
Probability of Precipitation (POP) for warm clouds

At a given LWP:
$POP = N_{rain}/N_c$

N_c: the number of cloud events.
N_{rain}: the number of precipitating events.



- Satellite observations:
  more aerosol → smaller POP

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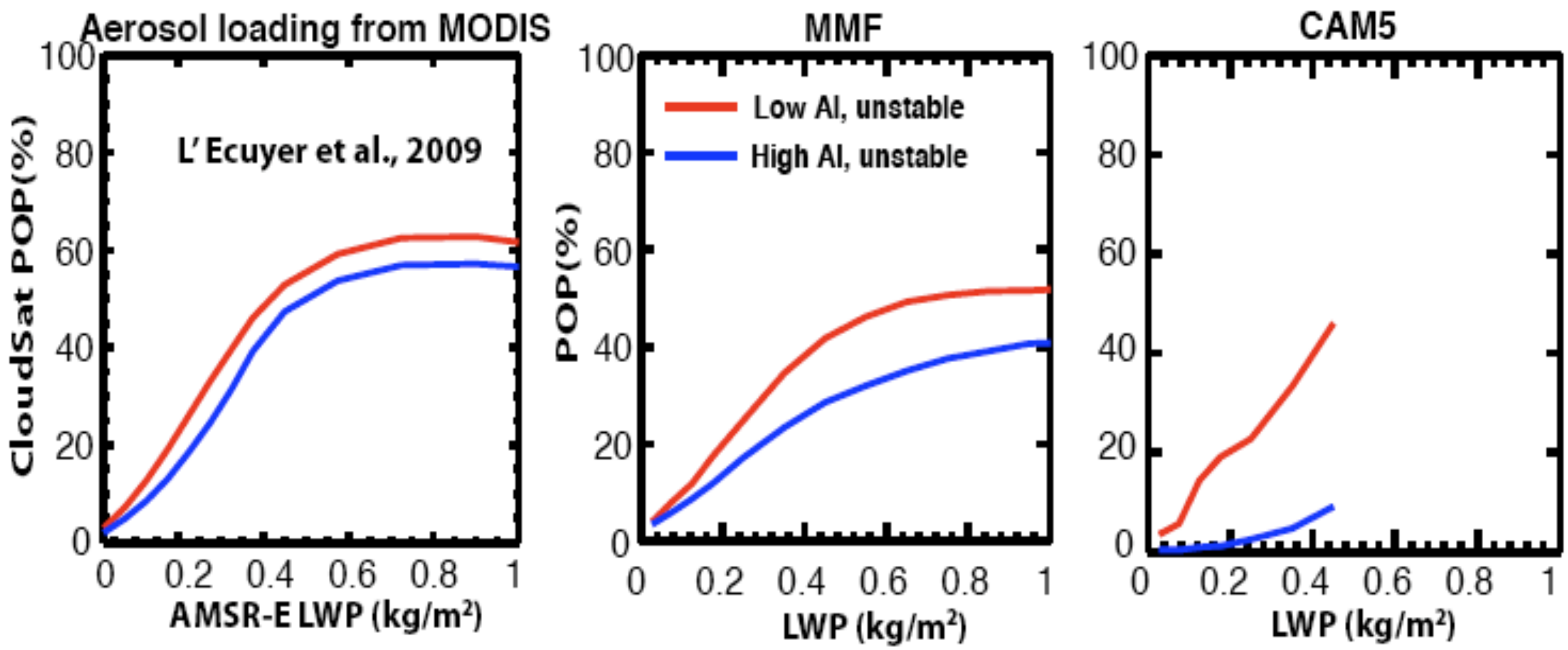
Probability of precipitation (POP) for warm clouds (rain rate > 0.6 mm/day)



► The POP dependence on aerosol loading in MMF is weaker and agrees better with satellite observations

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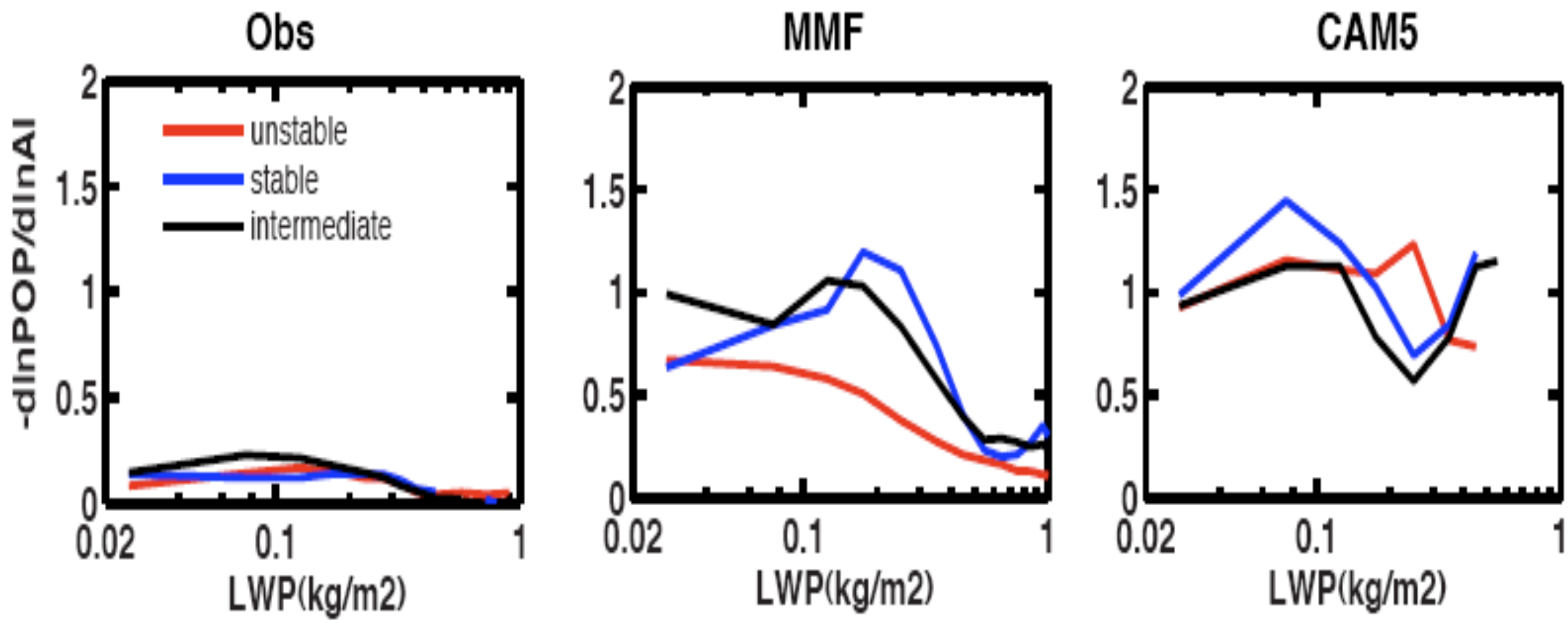
Rain frequency susceptibility: S_{pop}= -dlnPOP/dlnAI, a quantitative measure



- LWP-weighted:

Obs: 0.12; MMF: 0.42; CAM5: 1.06

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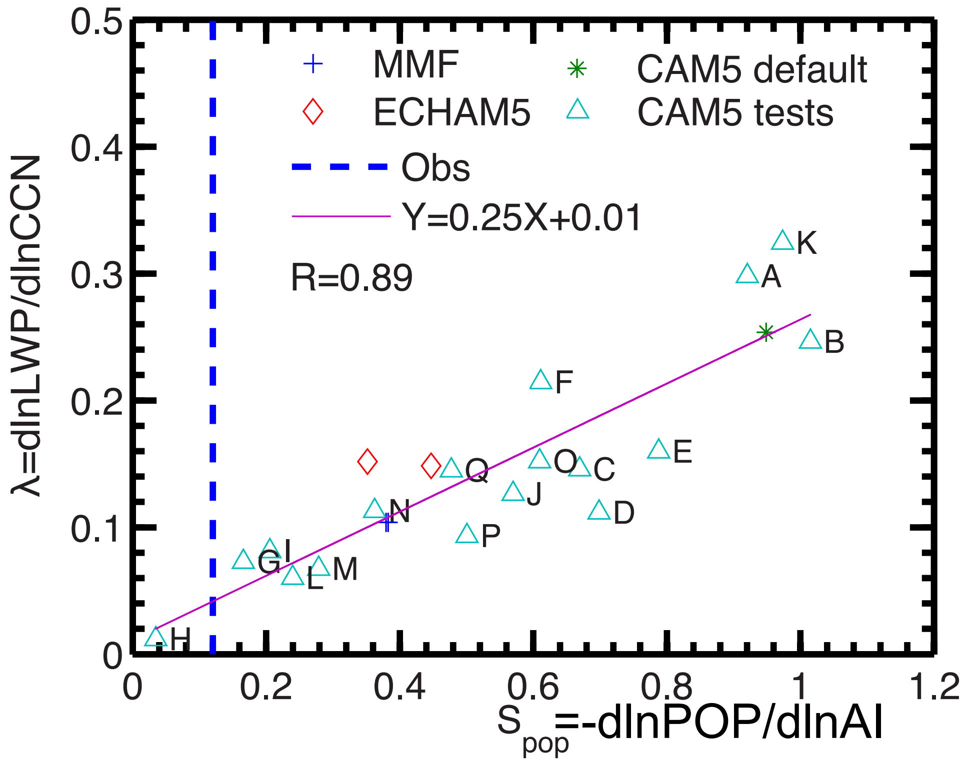
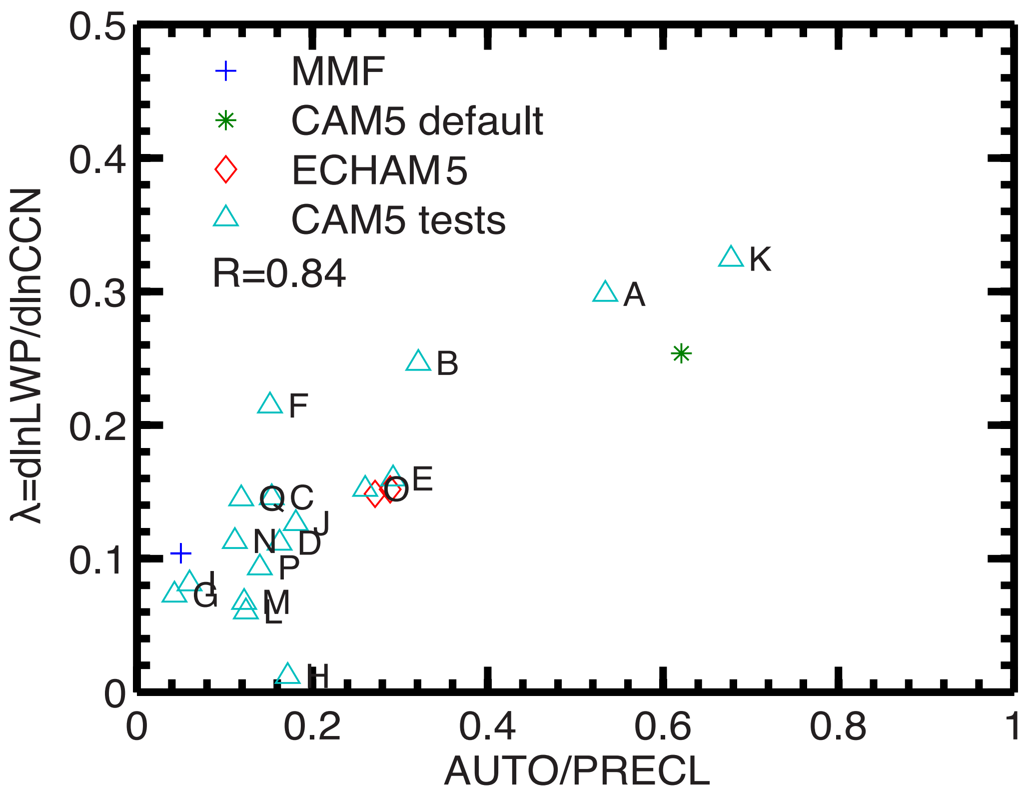
S_{pop} provides a good measure of the LWP response to CCN perturbations.



dlnLWP: (PD-PI)/PI
dlnCCN: (PD-PI)/PI

- Intercept of regression with S_{pop}=0.12 suggests λ=0.04
- Smaller λ implies smaller aerosol indirect effects (one third reduction in NCAR CAM5)

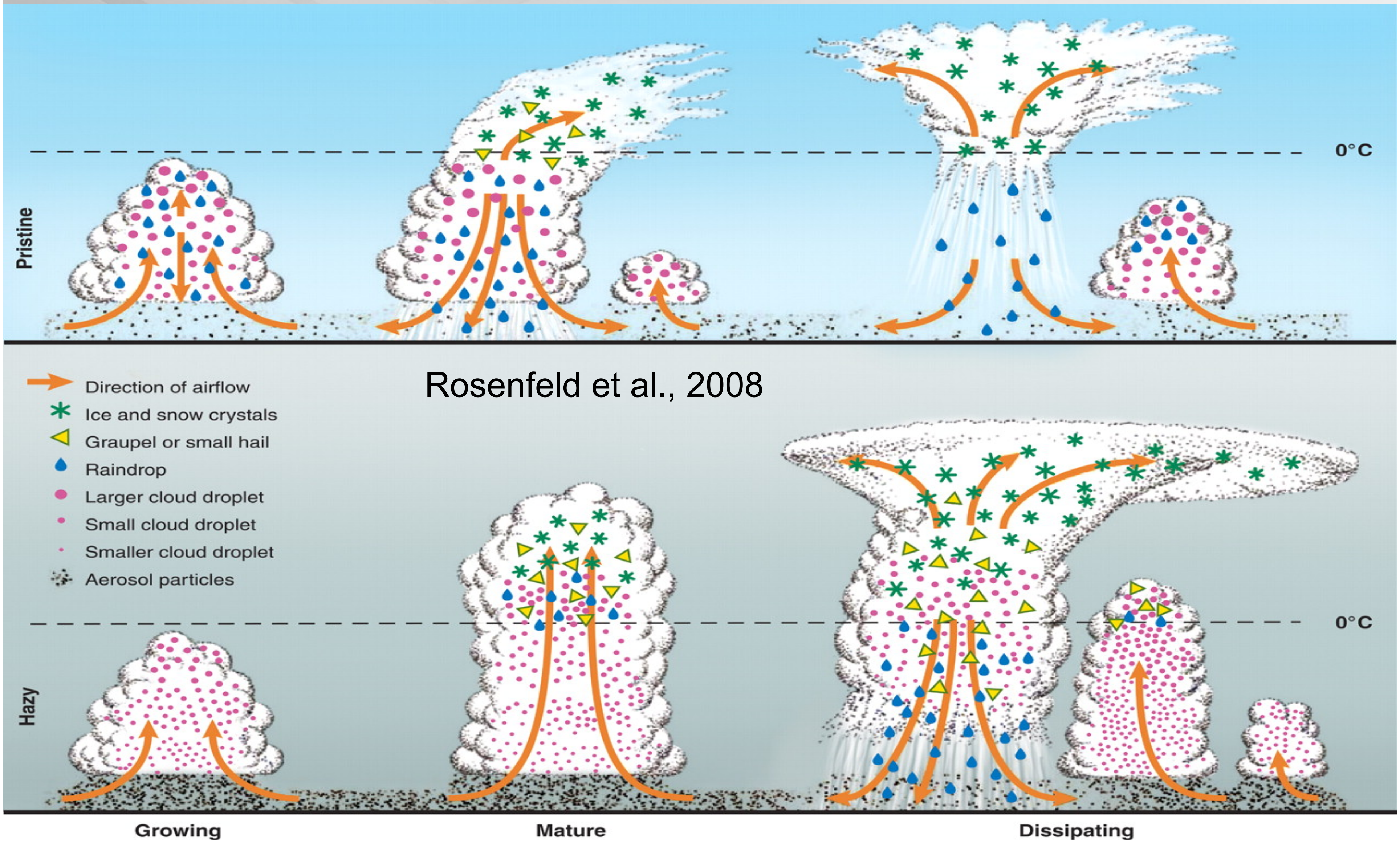
Liquid water response is closely related to role of autoconversion in precipitation



- Small role of autoconversion in MMF might be due to prognostic precipitation

M. Wang et al., 2012, *GRL, in press*

Aerosol effects on deep convection (aerosol invigoration)



Rosenfeld et al., 2008

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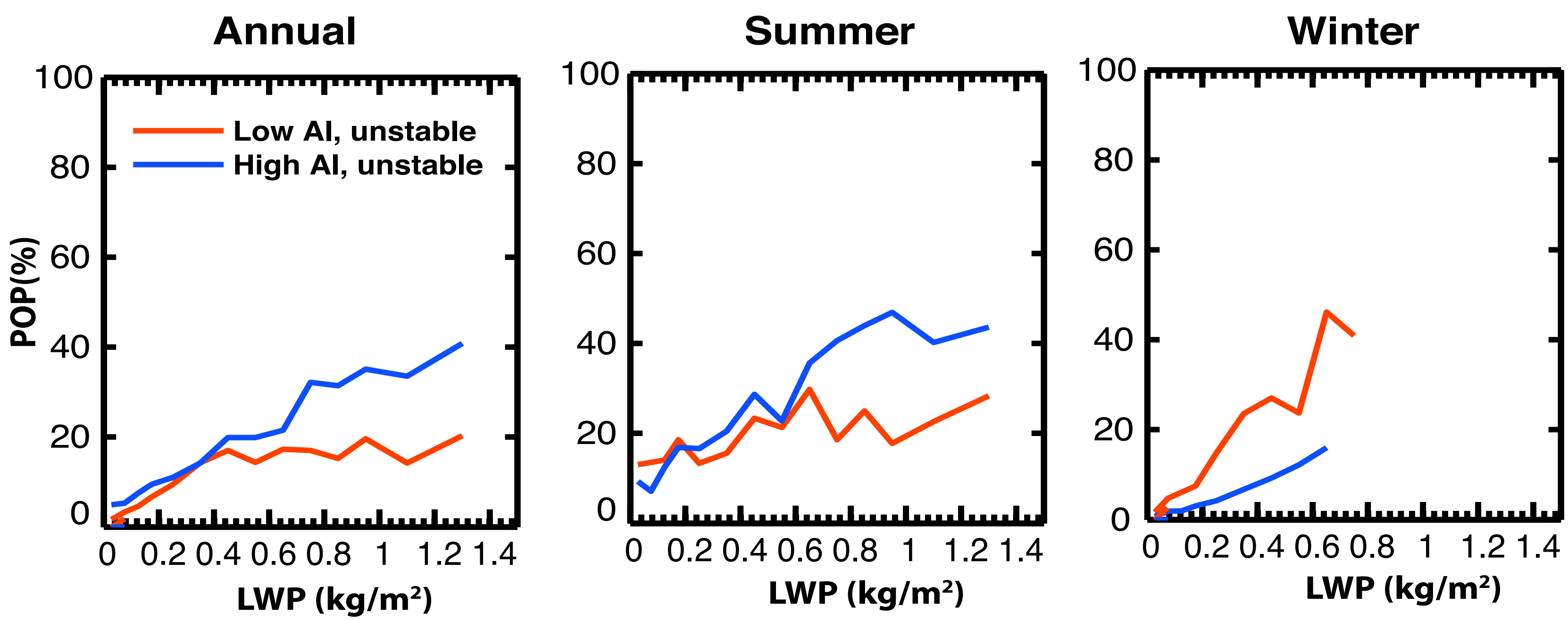
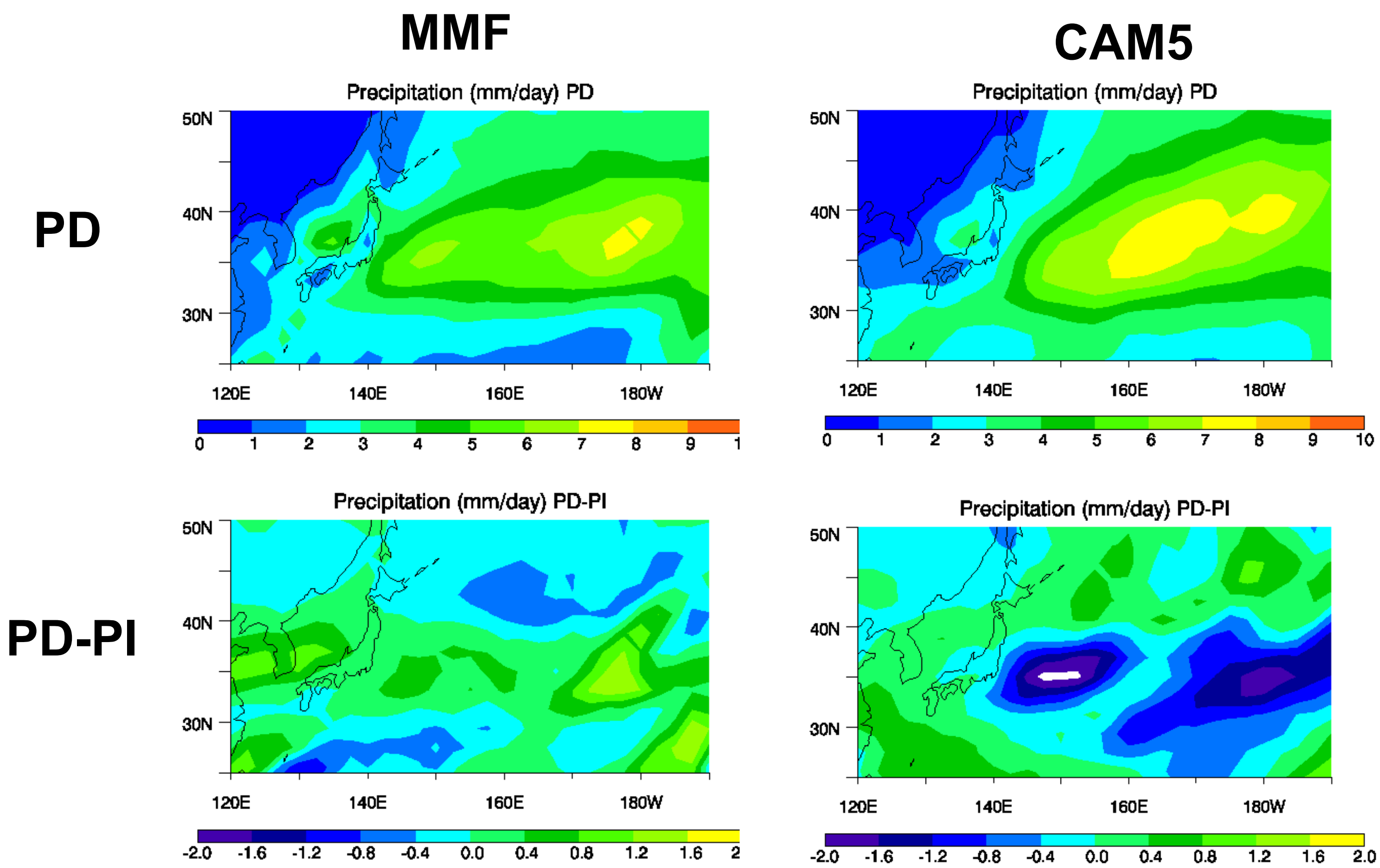
Probability of precipitation in North America (cloud top colder than 263 K, rain rate >10 mm/day)



- Enhanced POP at high aerosols occurs over the summer time, when convection is stronger

Enhanced precipitation in the NH storm track due to anthropogenic aerosols (MMF)



Yuan Wang et al., 2012, in preparation

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Porting the MMF (both aerosol and non-aerosol versions) into CAM5 trunk(SPCAM5)

- Merge the aerosol-MMF (based on the tag cam3_6_26) into a most recent CAM5 tag (cam5_1_31)
- Code changes and restructures:
  - Replace CPP preprocessors with SPCAM logical flags
  - Many many others …
- Remaining tasks:
  - Redesign the SPCAM interface to adhere to CAM interface recommendation
  - Apply new sub-column structure to SPCAM
  - Multi-instance land (new feature)

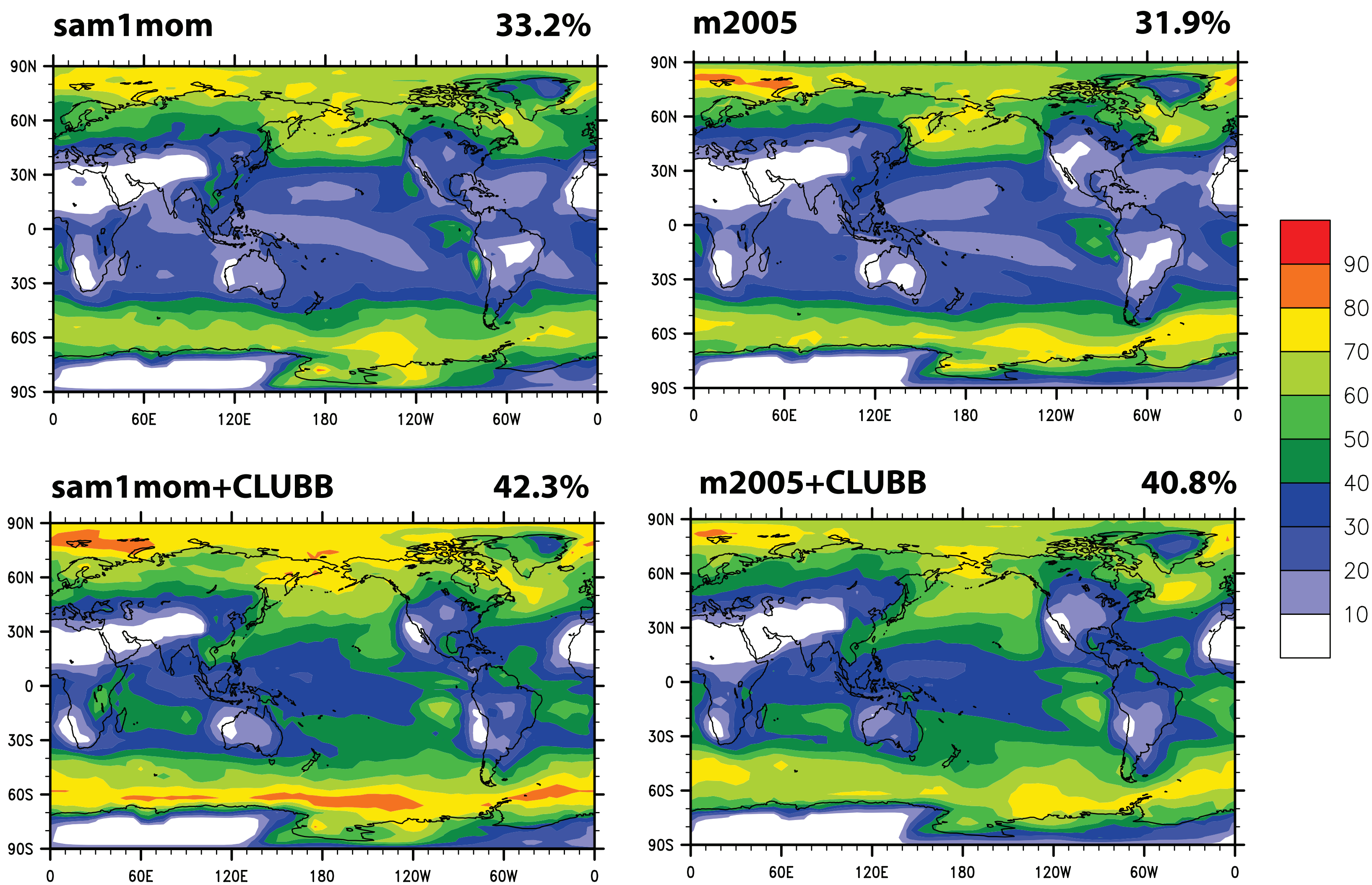
Scientific validation of SPCAM5

- Based on cam5_1_29 + SPCAM with FV dycore
- Run 4 16-month simulations with different configurations at 4x5 horizontal resolution, 32 4-km CRM columns, 20 seconds CRM time step)
  - sam1mom: one-moment cloud microphysics in the CRM (the non-aerosol MMF)
  - m2005: Morrison two-moment microphysics in the CRM (the aerosol-MMF)
  - sam1mom+CLUBB (a high order turbulence scheme)
  - m2005+CLUBB

Single-moment vs. double-moment microphysics

	sam1mom	m2005	CAM5	Obs
LWP (g/m2)	87	54	48	50-87
IWP (g/m2)	47	11	16	10-65
SWCF (W/m2)	-52	-50	-50	-46 to -53
LWCF (W/m2)	28	27	22	27-31
PRECT (mm/day)	2.78	2.76	2.95	2.61
CLDTOT (%)	49.9	51.7	62.7	65-75

Low cloud fraction with and without CLUBB



What the MMF does better than CAM5

- MJO
- Diurnal cycle of deep convection
- Asian summer monsoon
- African Easterly Waves
- Aerosol effects on deep convection
- Aerosol indirect effect
- Cloud effects on the aerosol
- Aerosol transport to the Arctic

Summary

- A multi-scale aerosol-climate model has been built to study aerosols, clouds, and precipitation interactions
- This model has been demonstrated to be a powerful tool to examine aerosols, clouds, and precipitation interactions at the global scale
- The new merged SPCAM code (SPCAM5) works well for both single-moment and double-moment microphysics and is nearly ready for distribution to the climate community
- Further work is needed to improve the SPCAM simulations with CLUBB