Cloud-Aerosol Interactions in a Multiscale Aerosol Climate Model

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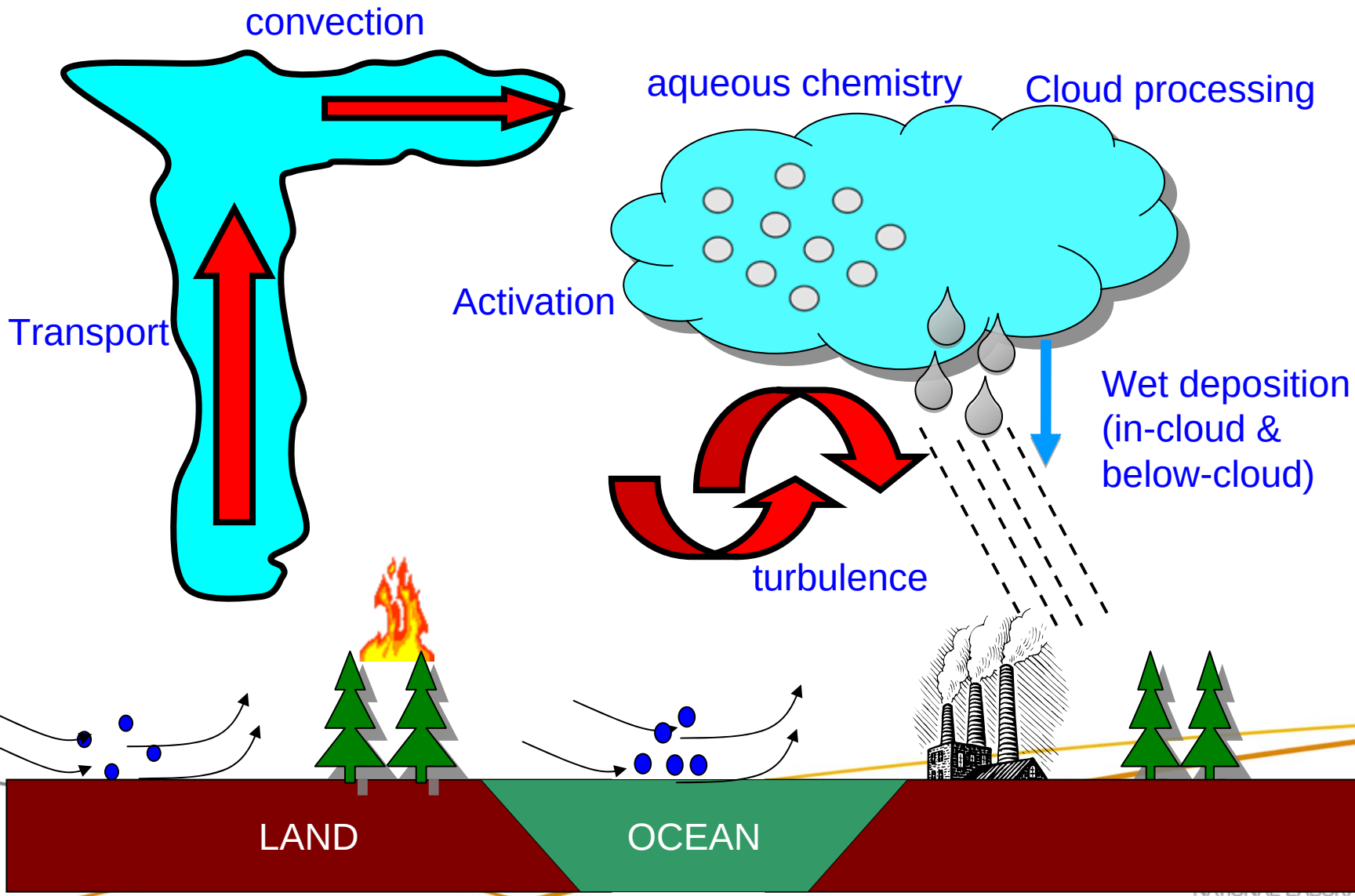
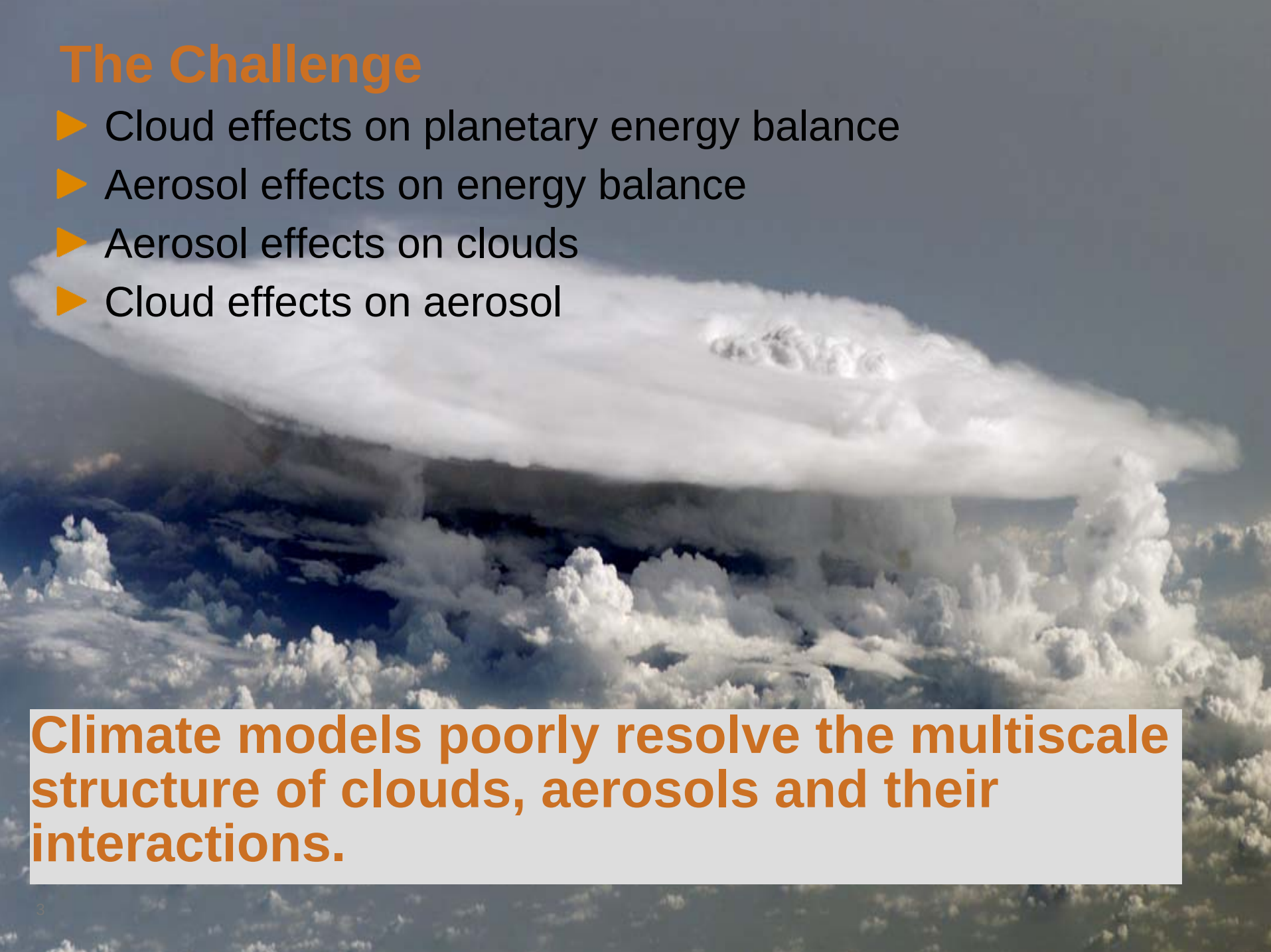
Aerosols and clouds interact with each other across multi-scales



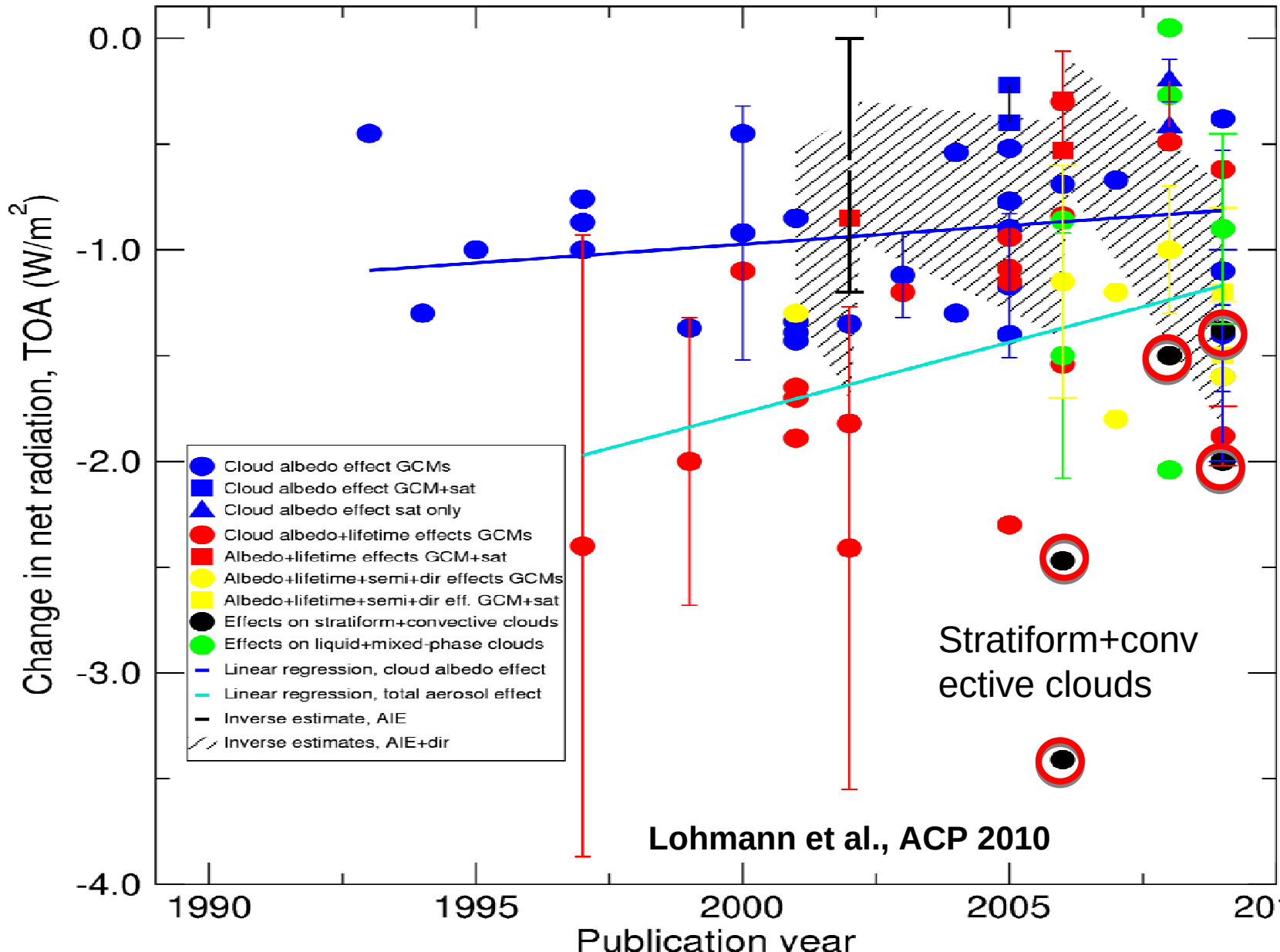
The Challenge

- Cloud effects on planetary energy balance
- Aerosol effects on energy balance
- Aerosol effects on clouds
- Cloud effects on aerosol



Climate models poorly resolve the multiscale structure of clouds, aerosols and their interactions.

Estimates of Aerosol Indirect Effect



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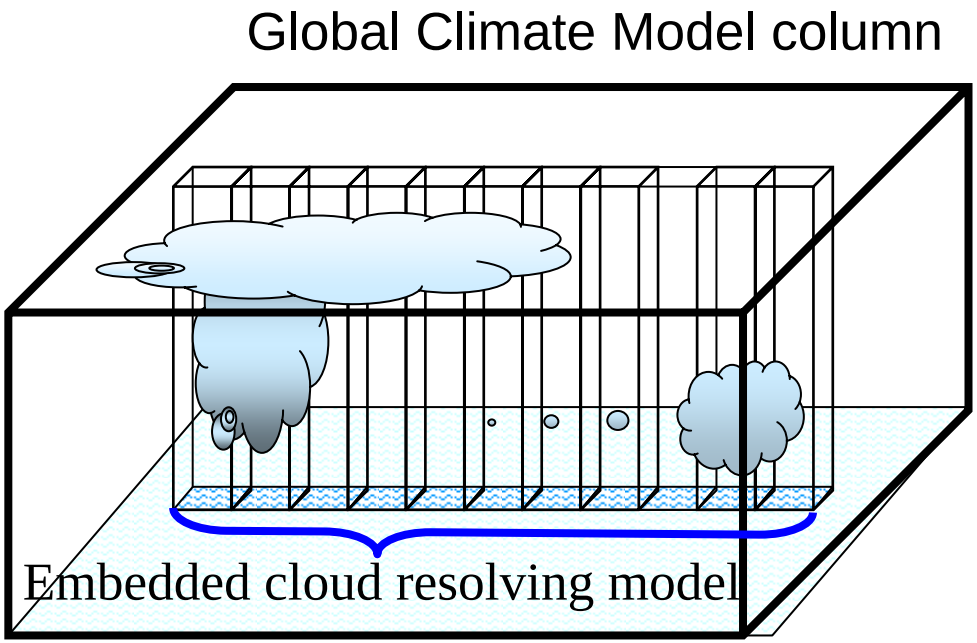
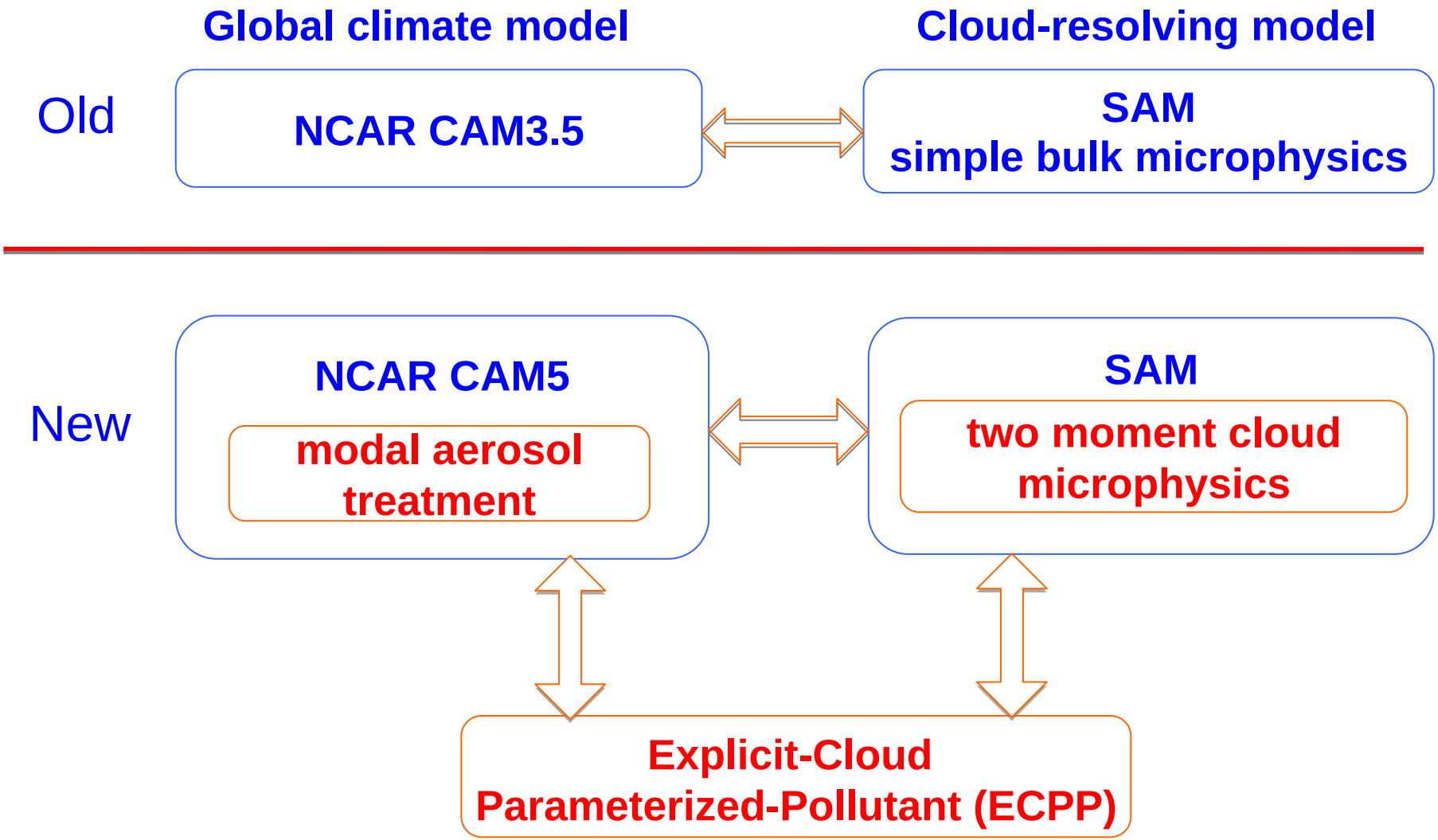
A Multiscale Modeling Framework (MMF) is a physically-based solution …



- Embed a cloud-resolving model (CRM) within each grid cell of a global model.
- Embed the aerosol transport, transformation, and removal within the CRM.
- Predict droplet number within the CRM using aerosol from the CRM.

that would be a computational monster.

We have extended the original MMF to treat aerosol-cloud interactions ...



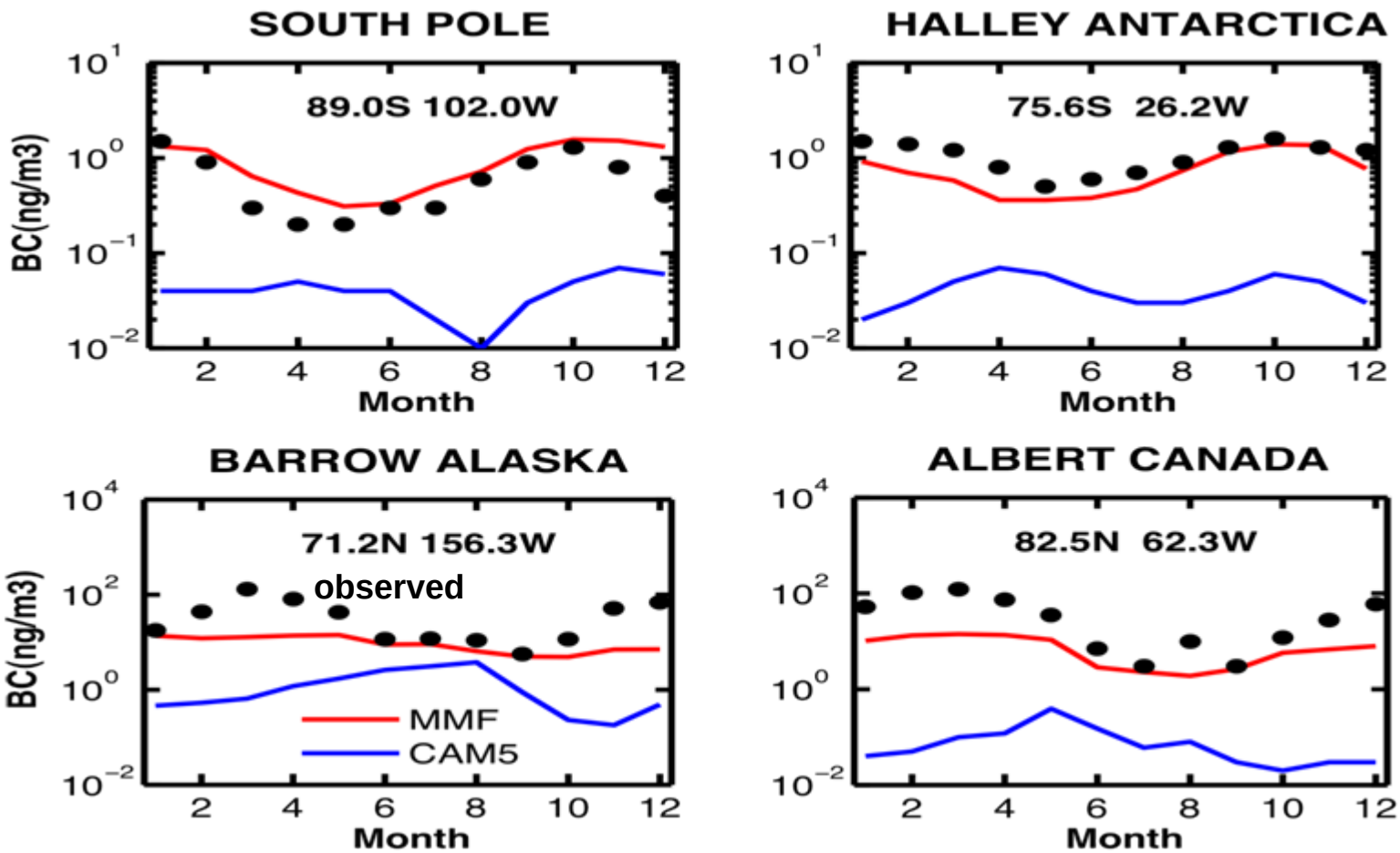
without the computational cost of embedding aerosols in the CRM.

Some unique features of PNNL MMF

- Aerosol effects on both stratiform and convective clouds are explicitly treated.
- Droplet activation is calculated at each CRM grid point, using CRM-scale vertical velocity.
- Aerosol processing by convective clouds is explicitly treated by using cloud fraction, vertical mass flux, cloud water and precipitation 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.

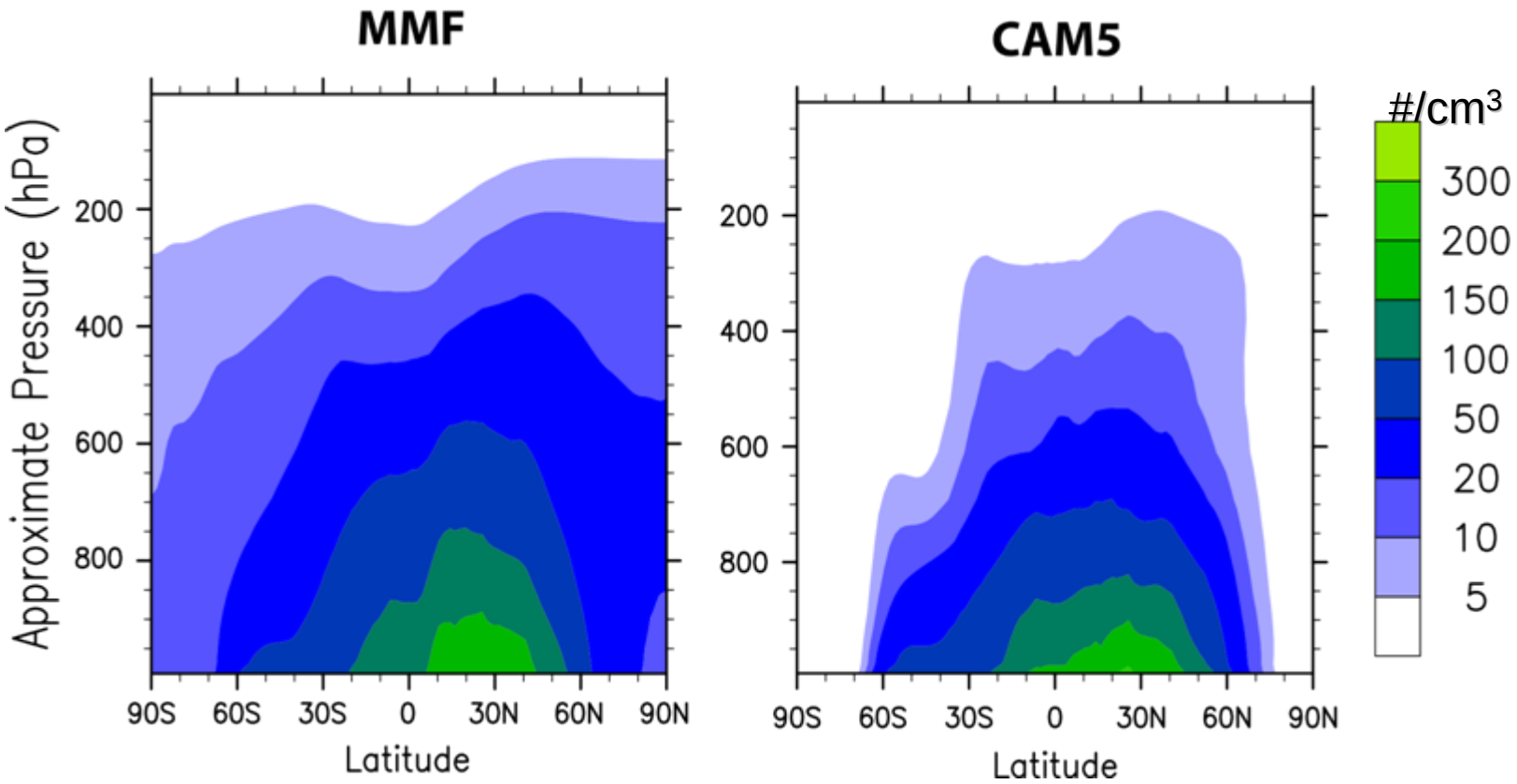
(See Wang et al., 2010, *Geosci. Model Dev. Discuss*. for details)

Monthly BC concentrations in polar regions



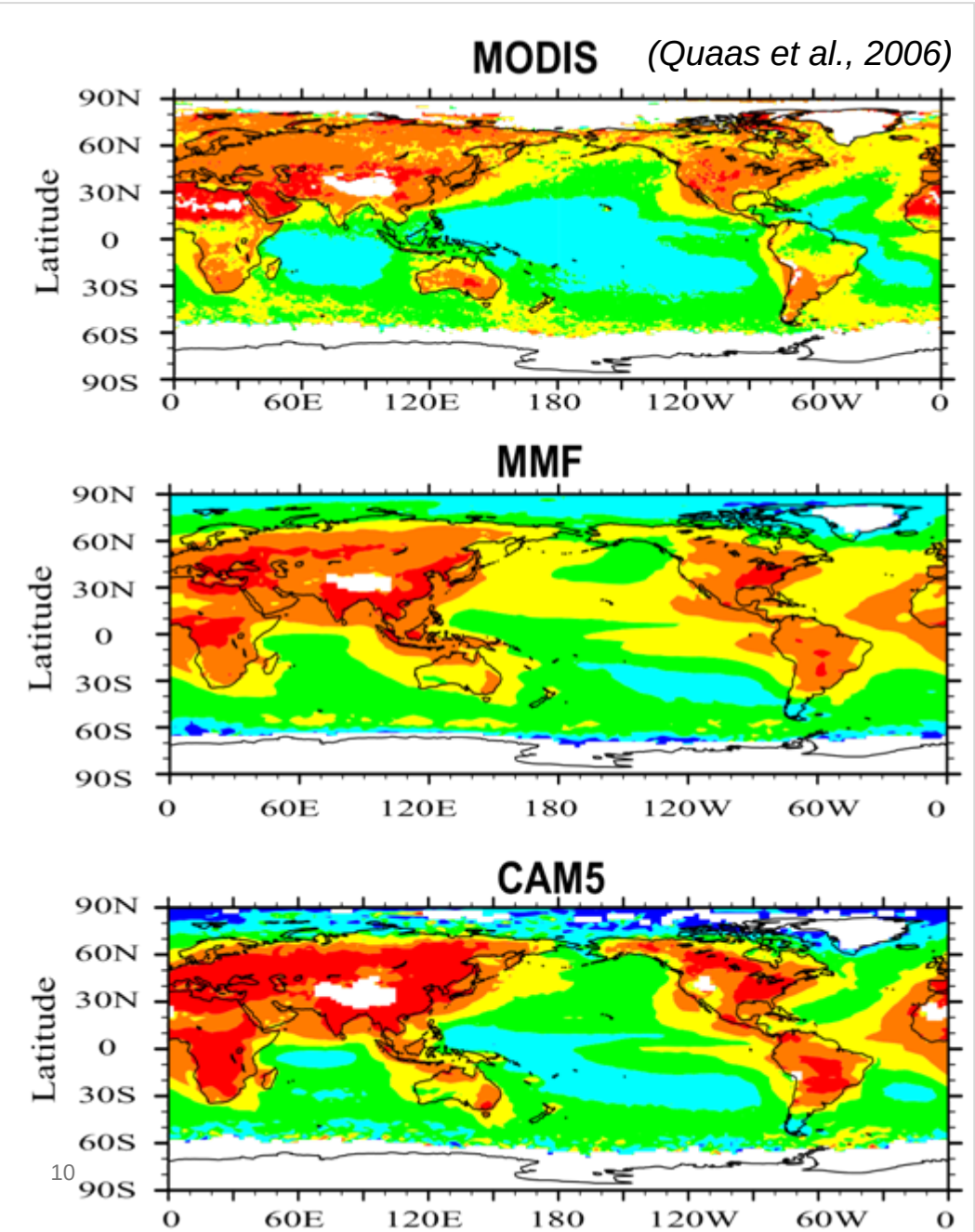
- BC concentrations in MMF agree better with observations.
- MMF simulates a better seasonal cycle.

CCN concentration at 0.1% Supersaturation



MMF predicts more CCN in the upper troposphere and at polar latitudes.

Cloud top droplet number concentration



- MODIS retrieval is unrealistic over deserts.
- MMF produces too many droplets across tropical oceans.
- CAM5 produces excessive continental droplets.

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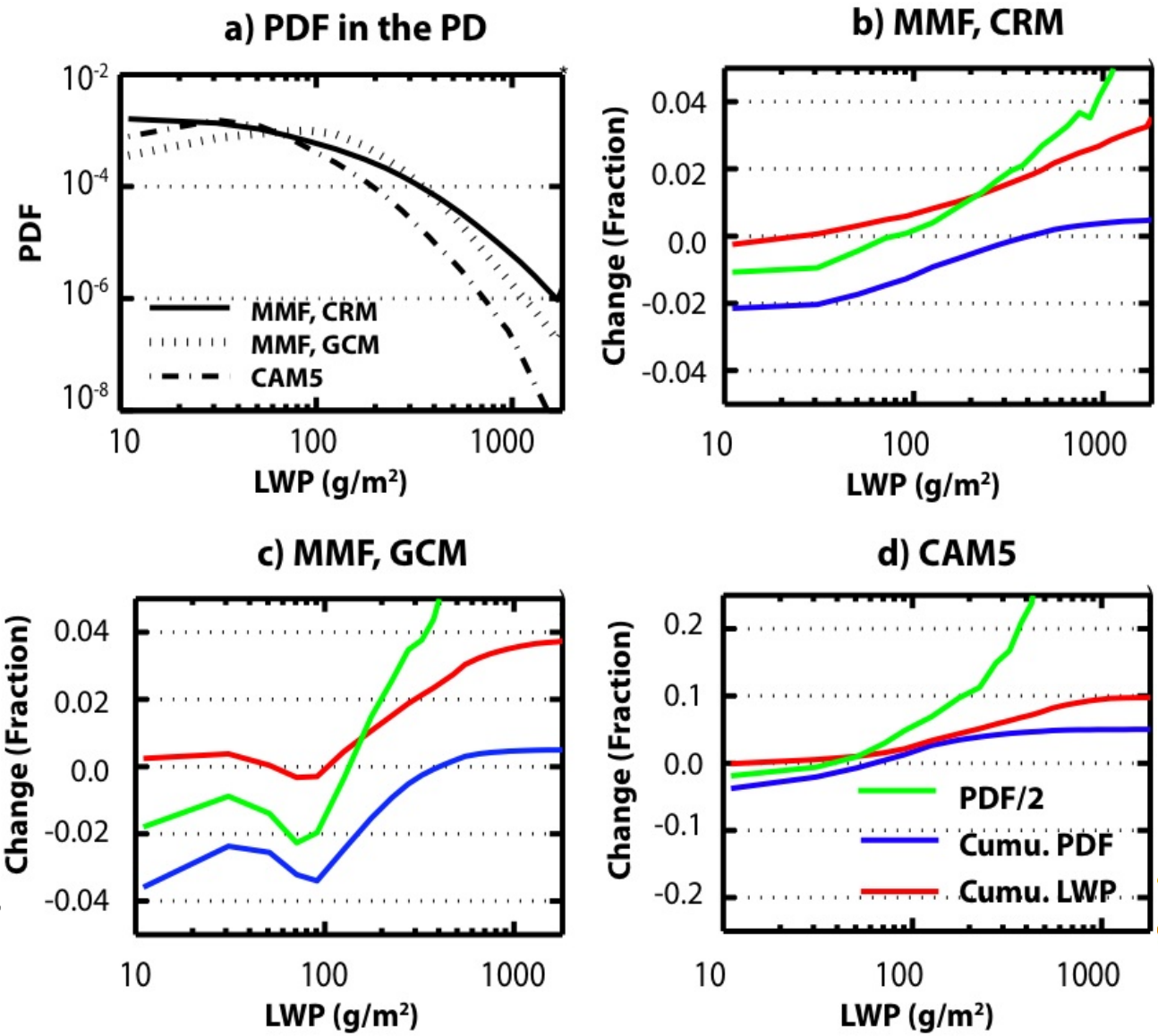
Anthropogenic Aerosol Radiative Forcing

	MMF	CAM5
ΔERB (W m^{-2})	-1.05	-1.66
ΔSWCF (W m^{-2})	-0.77	-1.79
ΔLWP (g m^{-2})	2.1	3.9

ERB: top of atmosphere radiation balance
SWCF: shortwave cloud radiative forcing
LWP: cloud liquid water path

Relative changes in the probability distribution of liquid water path: (PD – PI)/PI



MMF produces a weaker change in liquid water path.

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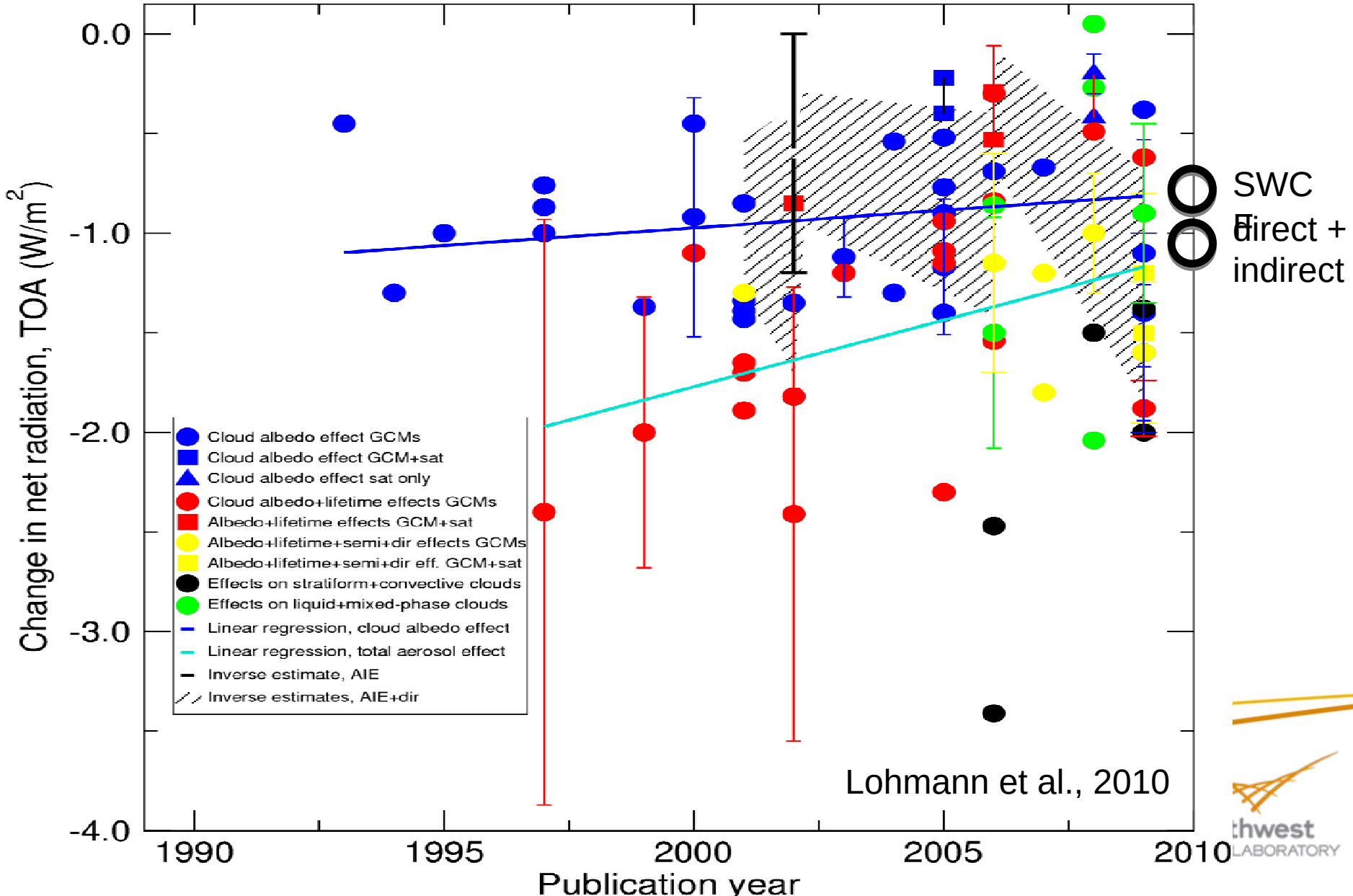
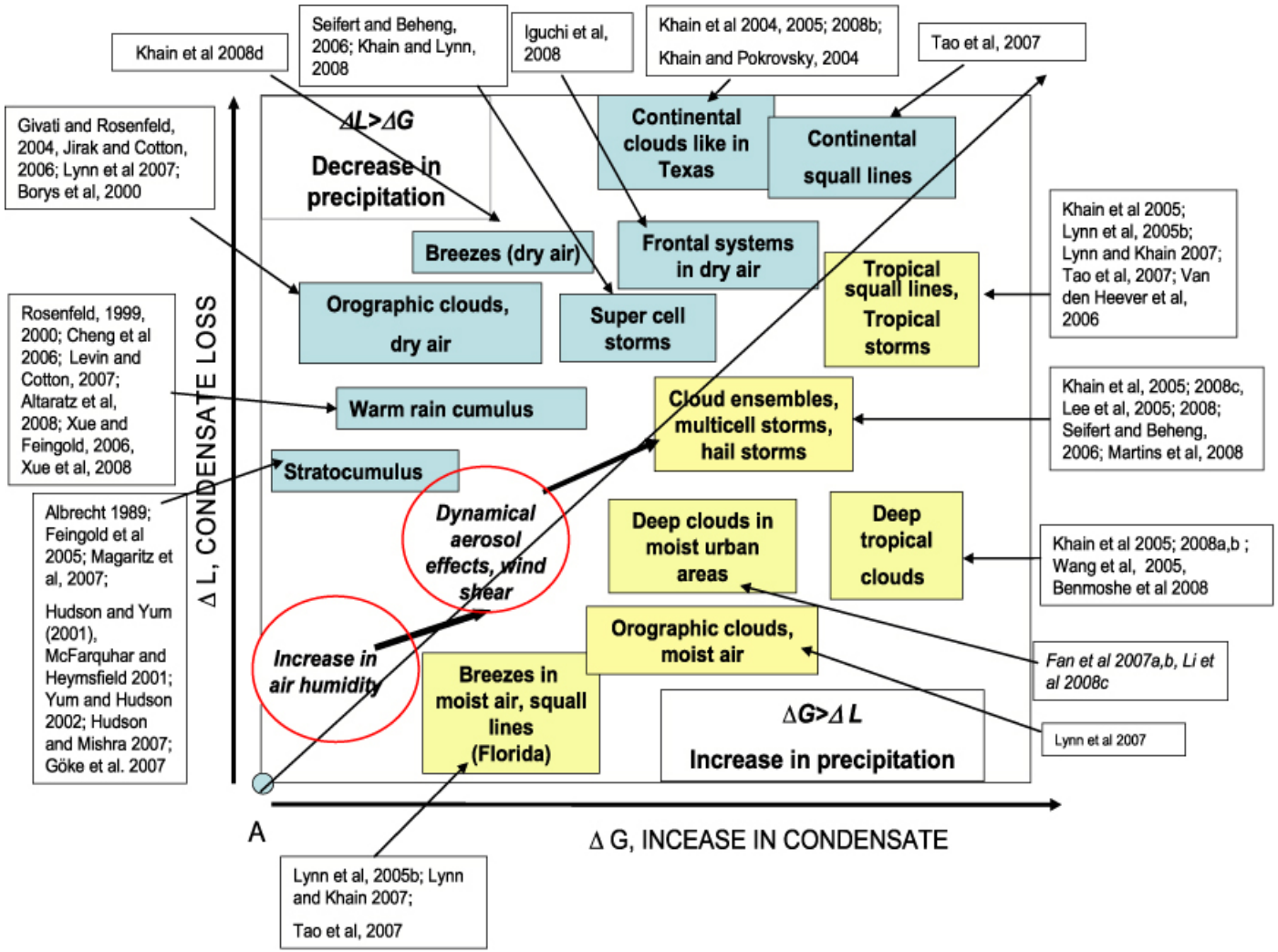
An estimate with a stronger physical basis



Complex cloud-aerosol interactions in convection



Khain (2009), Environ. Res. Lett. 4, 015004

Future work

- Compare MMF and CAM5 to understand the difference in simulated aerosols in the polar regions.
- Run the MMF and CAM5 in the nudging mode to further evaluate simulated aerosols and clouds.
- Compare MMF and CAM5+ to examine aerosol effects on convective clouds.

Questions?