Convective Microphysics and Interaction of Aerosols, Convection and Large-scale Circulation in the NCAR CAM5

Guang J. Zhang and Xiaoliang Song

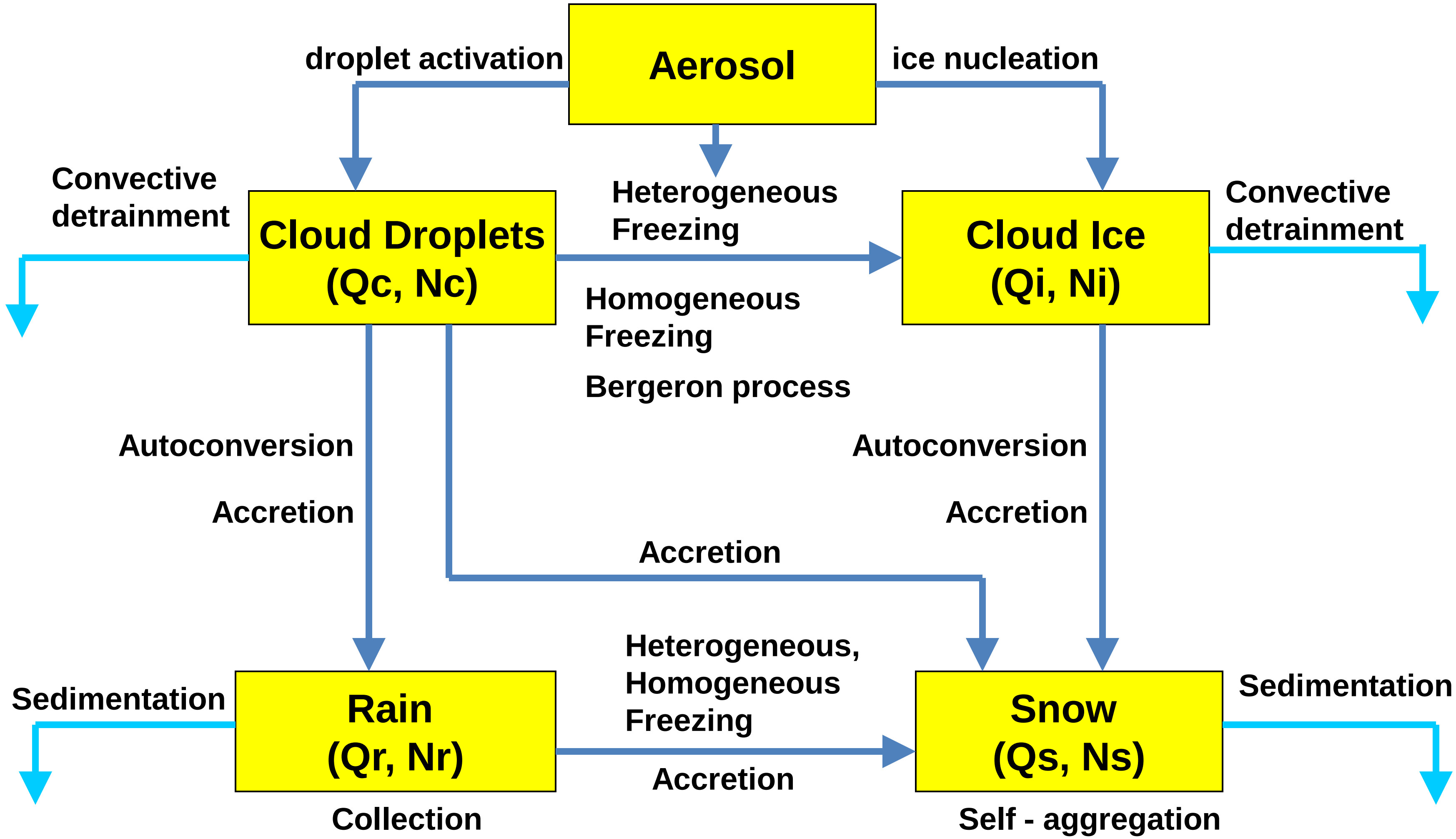
Scripps Institution of Oceanography

La Jolla, CA

Outline

- Convective microphysics
- Aerosol-convection invigoration experiments
- Conclusions

Two-moment microphysics scheme for convective clouds



Song et al., 2012, *J. Climate*

$$\frac{\partial}{\partial z}(M_u q_x) = -D_u q_x + \frac{M_u}{w_u} S_x^q$$

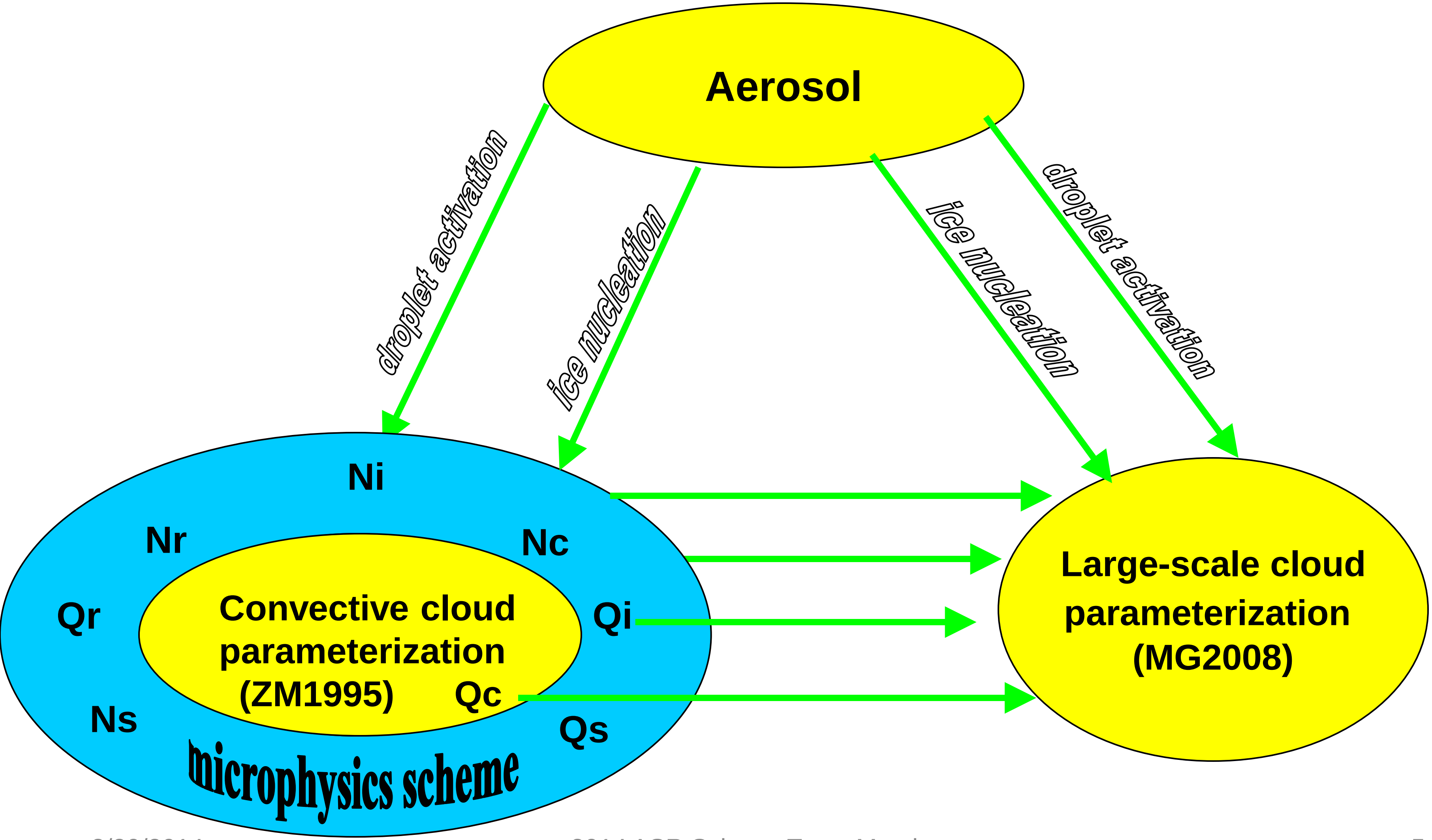
$$\frac{\partial}{\partial z}(M_u N_x) = -D_u N_x + \frac{M_u}{w_u} S_x^N$$

where x refers to c for cloud water, i for cloud ice, s for snow and r for rain. S_x is the source/sink per unit cloud area.

$$\frac{\partial K_u}{\partial z} = -\frac{\nu_u}{M_u}(1+\beta C_d)K_u + \frac{1}{f(1+\gamma)} g \frac{T_{v,u} - T_{v,e}}{T_{v,e}}$$

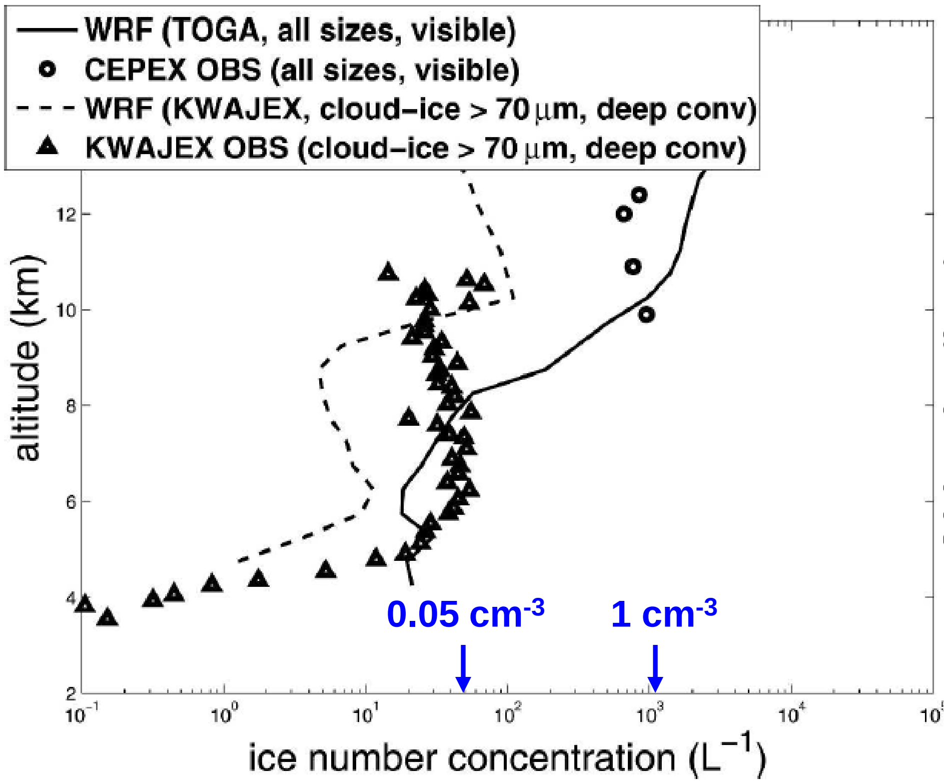
$$K_u = \frac{w_u^2}{2}$$

Implementation of the microphysics scheme in the CAM5

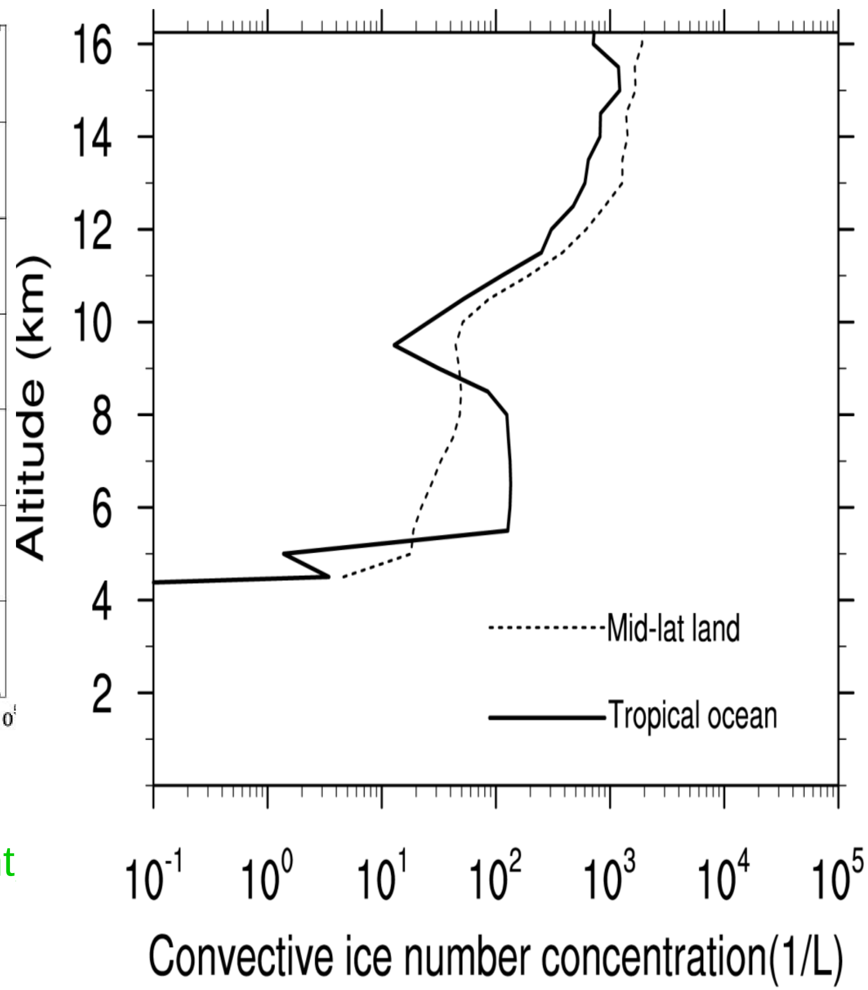


Cloud Ice Crystal Number Concentration

OBS



CAM5



CEPEX OBS: Central Equatorial Pacific Experiment
KWAJEX OBS: Kwajalein Experiment,
WRF: WRF simulations,
(Phillips et al. 2007, *J. Atmos. Sci.*)

Aerosol Effects on Convection

- Conceptual arguments: aerosols invigorate convection through increase of latent heat of fusion (Rosenfeld et al 2008)
- Cloud model simulations: Results vary, depending on many factors (Tao et al. 2007, Khain et al. 2008, Fan et al. 2009, etc.)
- Observations: *in situ* and long term (Andreae et al. 2004, Li et al. 2011)
- GCM simulation (Lohmann 2008)?

CAM5 Experiment Design

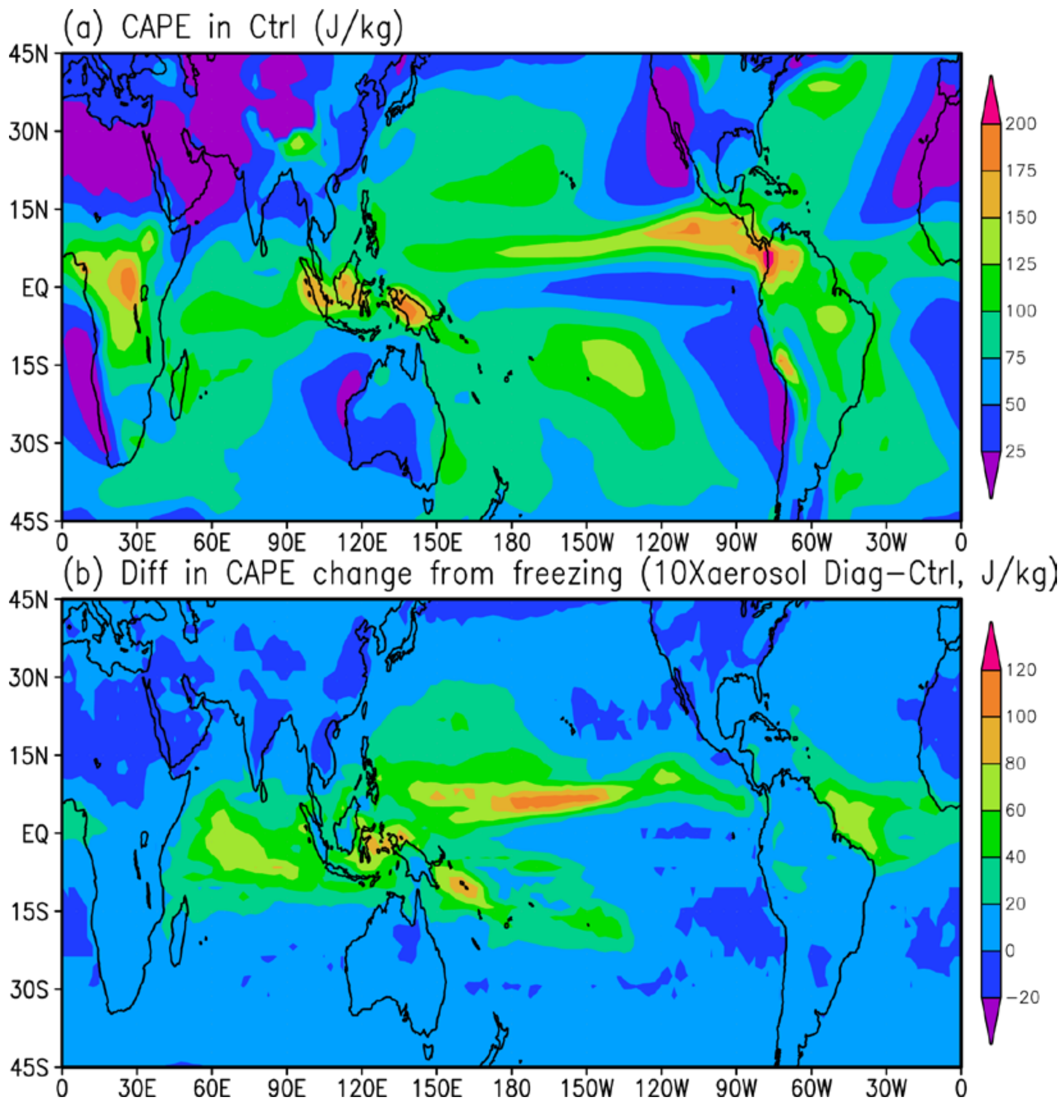
1) 1 x climatological aerosols

    The prescribed aerosol dataset has 12 species including sulfate, sea salt, dust, black carbon, etc.

2) 10 x climatological aerosols to diagnose its one-time-step effect on convection within the 1xaerosol simulation. Thus, it acts like a single column at every GCM grid point where there is convection.

3) 10 x climatological aerosols to predict convection, which feeds back to large-scale fields

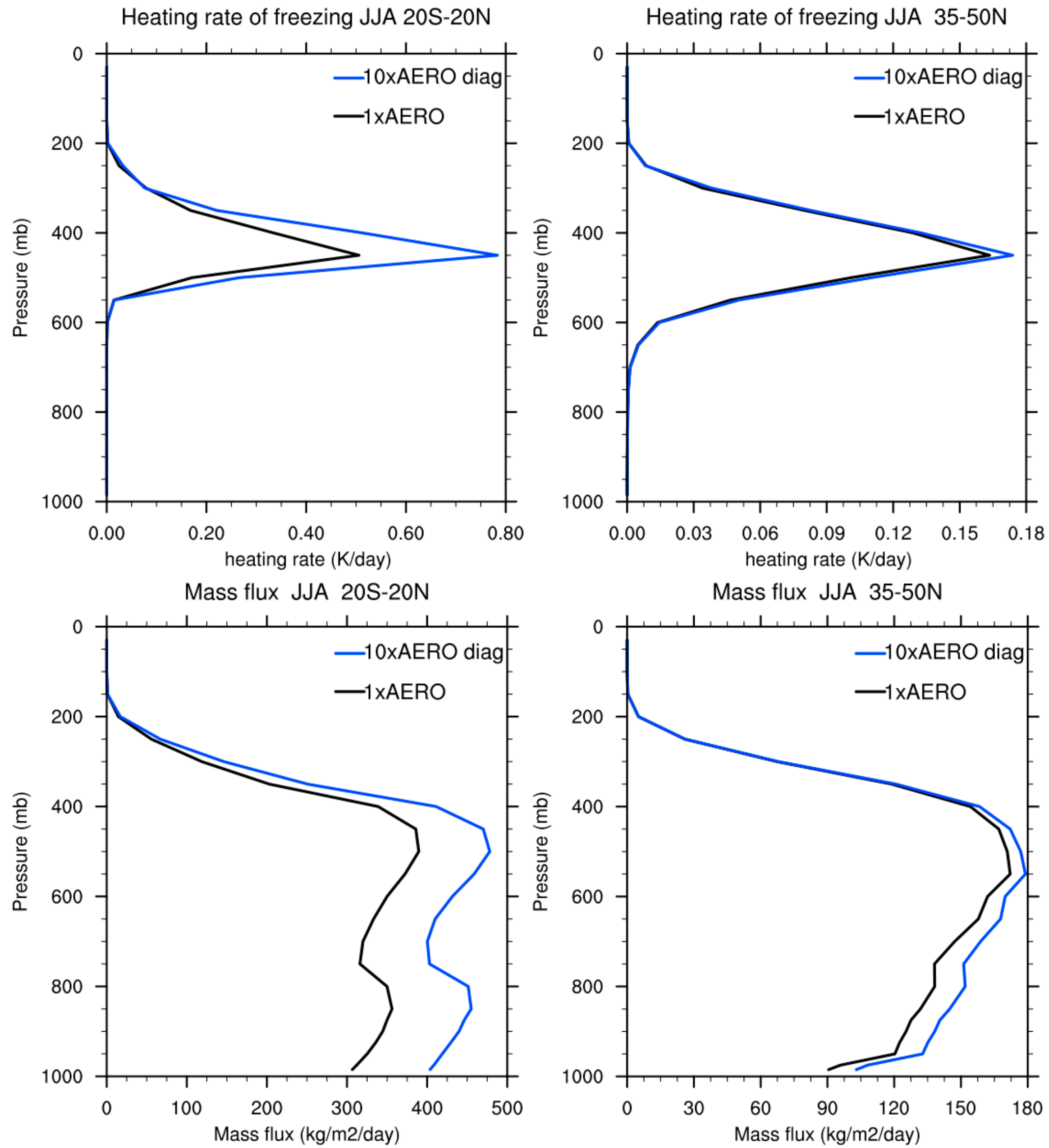
Therefore, (2)-(1) gives the local thermodynamic effect of aerosols on convection under the same large-scale conditions; (3)-(1) gives the total effect including dynamic feedback.



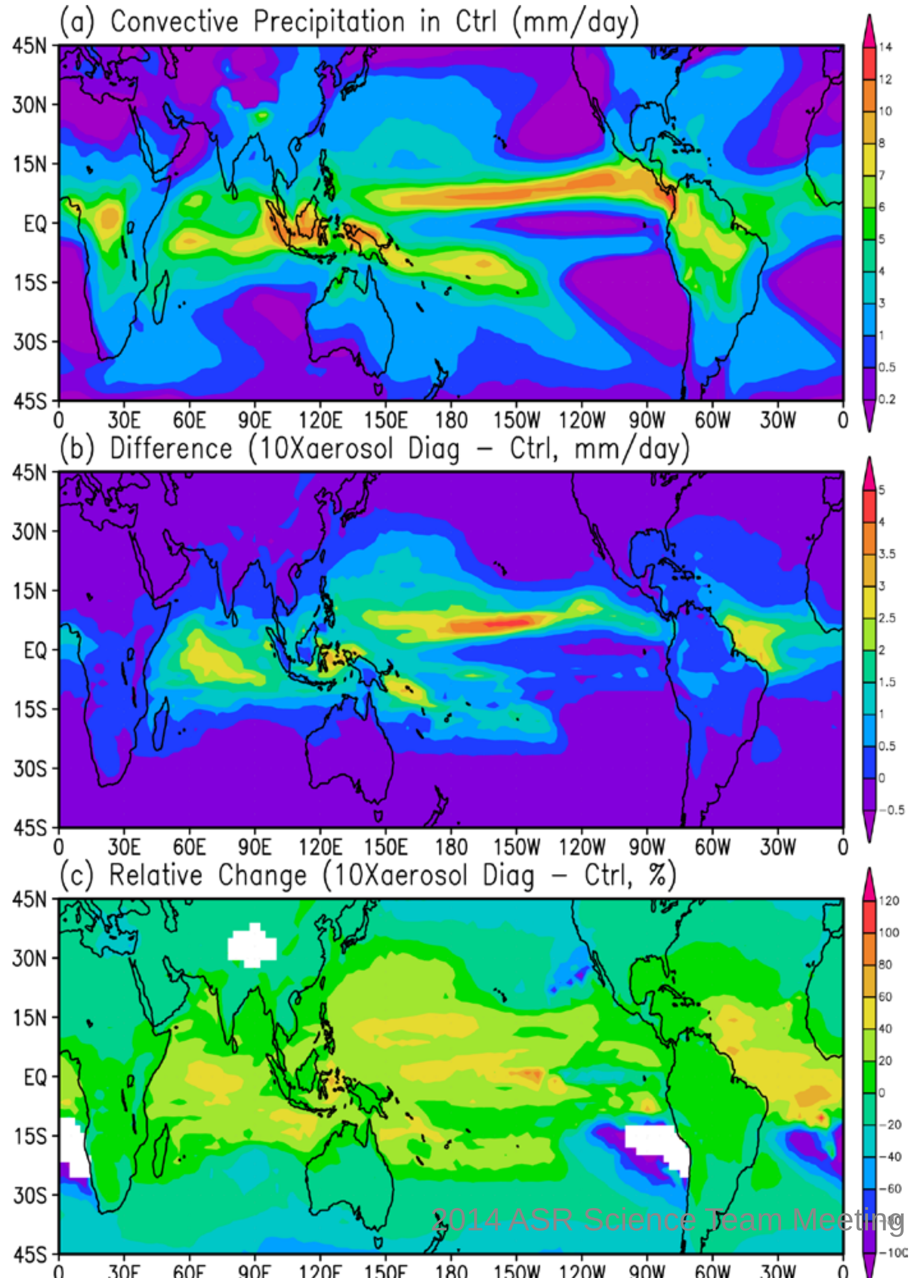
Freezing increases atmospheric CAPE

More aerosols lead to more freezing, thus more CAPE

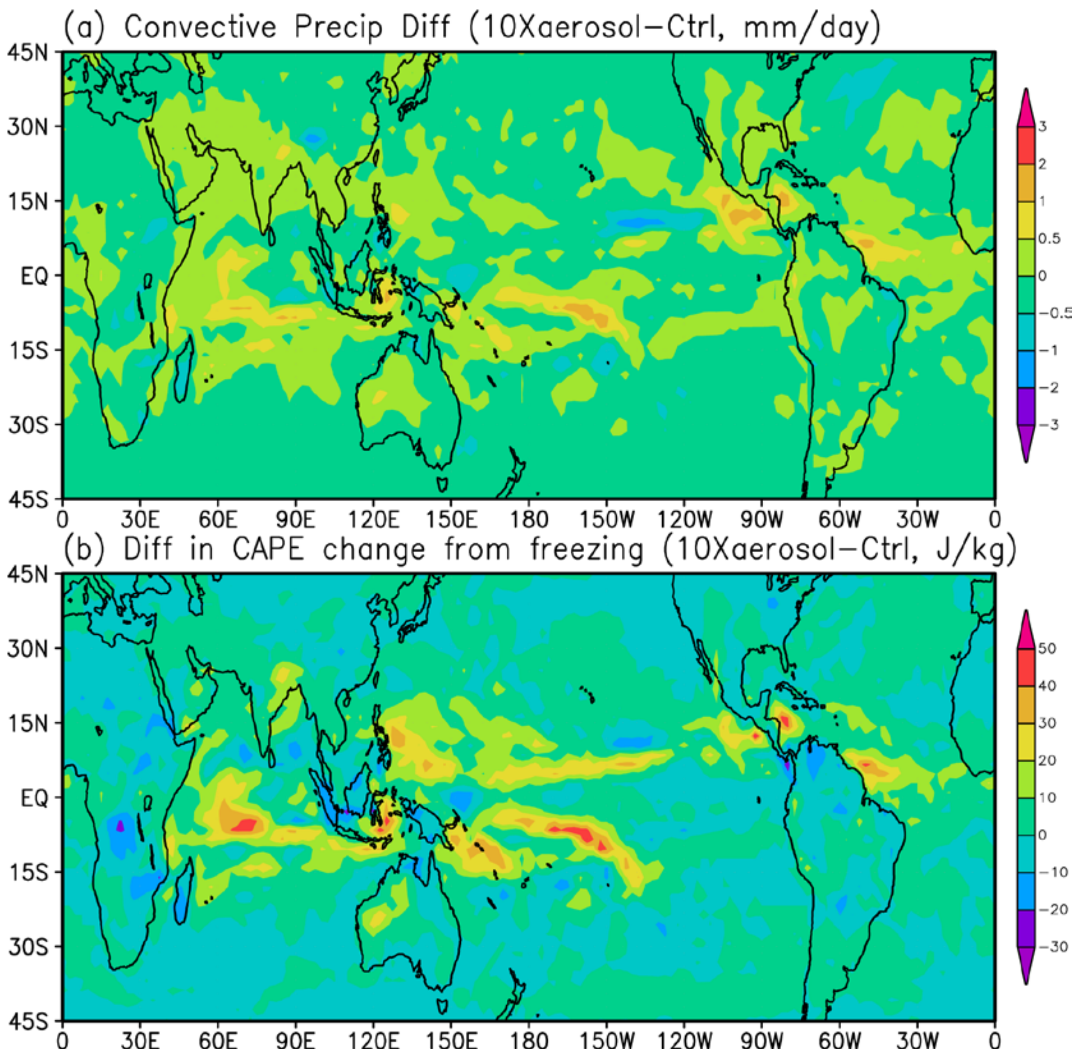
Tropics   Northern Midlatitudes



Impacts on global climate simulation

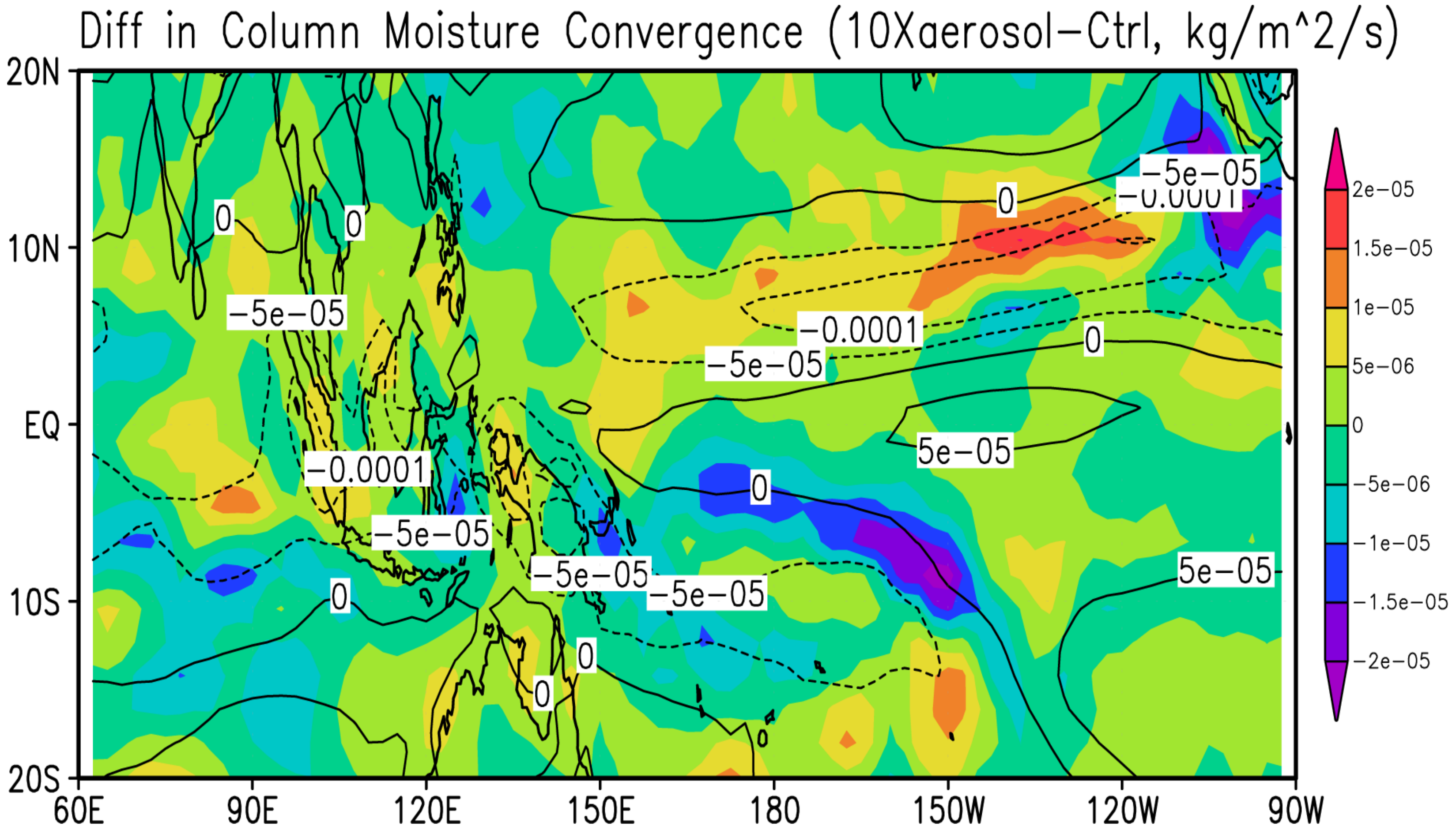


Under the same dynamic and thermodynamic conditions, aerosols invigorate convection.

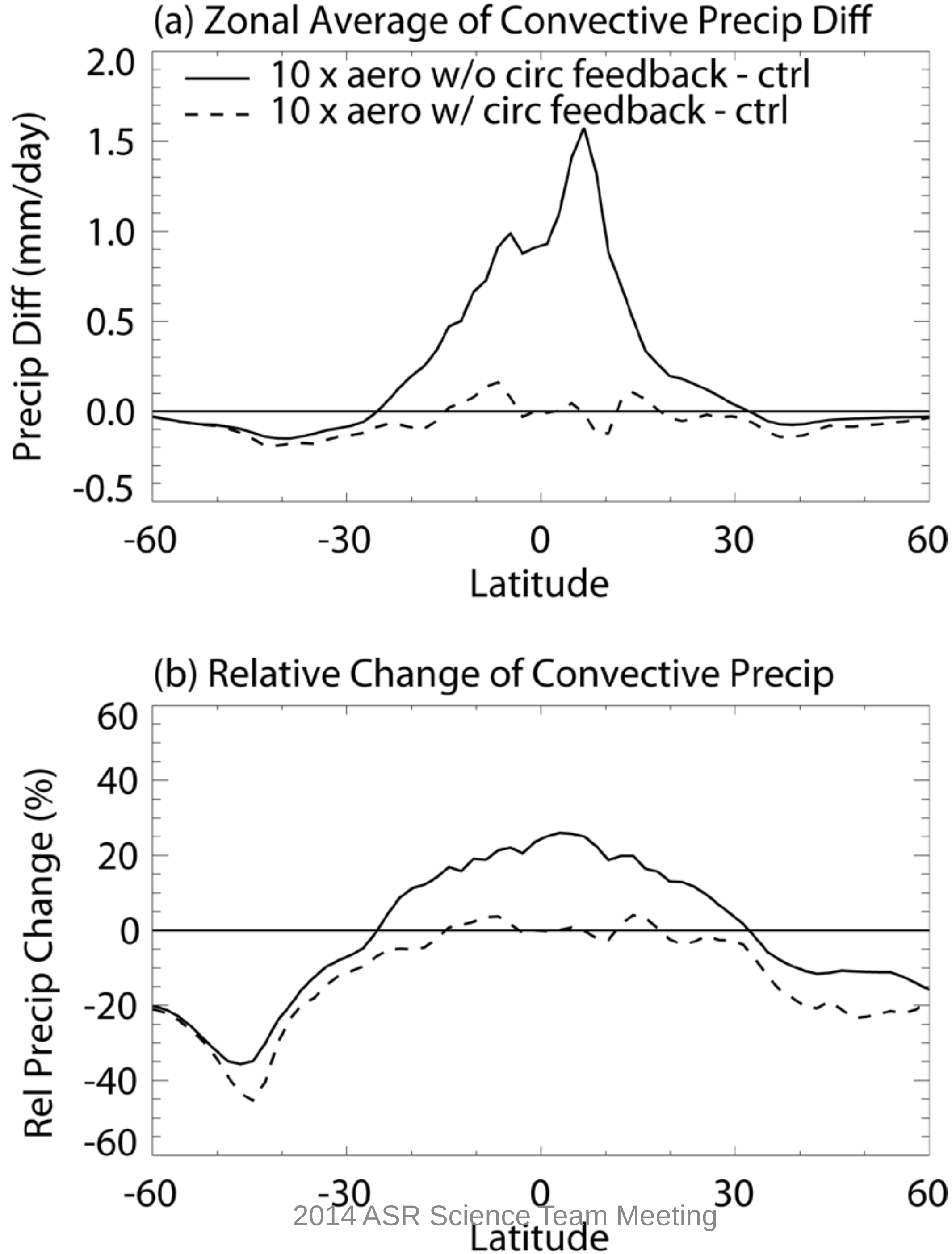


When the invigorated convection is allowed to interact with its environment, the net effect of aerosols is small, and can even change the sign!

Interaction with the environment largely negates the invigoration changes.



Diff in Column Moisture Convergence (10Xaerosol−Ctrl, kg/m^2/s)
20N
10N
EQ
10S
20S
60E
90E
120E
150E
180
150W
120W
90W
0
−5e−05
−0.0001
5e−05
2e−05
1.5e−05
1e−05
5e−06
−5e−06
−1e−05
−1.5e−05
−2e−05


(a) Zonal Average of Convective Precip Diff
10 x aero w/o circ feedback - ctrl
10 x aero w/ circ feedback - ctrl
Precip Diff (mm/day)
2.0
1.5
1.0
0.5
0.0
-0.5
-60
-30
0
30
60
Latitude
(b) Relative Change of Convective Precip
Rel Precip Change (%)
60
40
20
0
-20
-40
-60
-60
-30
0
30
60
Latitude

Conclusions

- The introduction of convective microphysics scheme enables climate models to investigate aerosol-climate interaction.
- For fixed meteorological conditions, the CAM5 model with convective microphysics scheme is able to simulate the aerosol invigoration effect on convection (more CAPE, more convective precipitation).
- However, when the response of large-scale circulation to the invigorated convection is considered, much of the local aerosol invigoration effect is negated by convection response to circulation change, leaving a much smaller net aerosol effect on convection.