Aerosol Effects on Convection in the NCAR CAM5

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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)?
Outline

• Introduction
• Convective microphysics
• GCM simulation
• Aerosol-convection invigoration experiments
• Conclusions
Aerosols and Convective Microphysics

D Rosenfeld et al. Science 2008;321:1309-1313
Two-moment microphysics scheme for convective clouds

Cloud Droplets (Qc, Nc)

- Convective detrainment
- Autoconversion
- Accretion
- Sedimentation

Aerosol

- Ice nucleation
- Heterogeneous freezing

Cloud Ice (Qi, Ni)

- Convective detrainment
- Autoconversion
- Accretion

Rain (Qr, Nr)

- Collection

Snow (Qs, Ns)

- Self-aggregation

Heterogeneous, Homogeneous freezing

Song et al., 2012, J. Climate
Implementation of the microphysics scheme in the CAM5

Aerosol

Ni - Nc - Qi - Qr - Qs

Convective cloud parameterization (ZM1995)

Large-scale cloud parameterization (MG2008)

microphysics scheme

droplet activation

ice nucleation
Two 6-yr NCAR Community Atmosphere Model v5 (CAM5) simulations are conducted:

**CTL**: standard CAM5

**MPHY**: with convective microphysics scheme

*For aerosol-convection expt*: 1xaerosol and 10xaerosol runs

- Resolution: $1.9^\circ \times 2.5^\circ$, 30 levels
- Forcing: climatological aerosol and SST data.
  The prescribed aerosol dataset has 12 species including sulfate, sea salt, dust, black carbon, etc.
- Results from the last 5-year simulations are presented here
Evaluation of the microphysics scheme with observations

Ice Water Content (IWC)

Jan

July

CloudSat

CTL

MPHY
Cloud Droplet Number Concentration

**OBS**

- **Maritime cumuli:** 20~60 per cm³ (Wood et al., 2011)

**Continental cumuli:**

- 50~300 per cm³ or even higher

**CAM5**

- Squires, 1958, *Tellus*

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[Graph showing distribution of droplet concentration per cm³ for different conditions]
Cloud Ice Crystal Number Concentration

OBS

- WRF (TOGA, all sizes, visible)
- CEPEX OBS (all sizes, visible)
- WRF (KWAJEX, cloud–ice > 70 μm, deep conv)
- KWAJEX OBS (cloud–ice > 70 μm, deep conv)

CAM5

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

1) $1 \times$ climatological aerosols

2) $10 \times$ climatological aerosols to diagnose its one-time-step effect on convection within the $1\times$ aerosol simulation. Thus, it acts like a single column at every GCM grid point.

3) $10 \times$ 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.
SCM simulation without latent heating effect

Convective precipitation vs. Aerosol

Song and Zhang (2011, JGR)
Global Aerosol Distribution

- **DUST**: mg/m²
- **SEA SALT**: mg/m²
- **Organic Carbon**: mg/m²
- **Black Carbon**: mg/m²
- **Sulfate**: mg/m²
- **Total Aerosol**: mg/m²
Impacts on global climate simulation

Under the same dynamic and thermodynamic conditions, aerosols invigorate convection.
More aerosols lead to more freezing, thus more CAPE.

Freezing increases atmospheric CAPE.
Aerosols make convective cloud top higher
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.
Conclusions

• The introduction of convective microphysics scheme enables climate models to investigate aerosol-climate interaction.

• Convective cloud microphysical properties simulated by the new scheme are in good agreement with available observations.

• For a given environmental condition, aerosols invigorate convection (more CAPE, deeper convection and more convective precipitation)

• However, if the convective environment is allowed to respond to the invigoration of convection, aerosol effect is much reduced and can even change sign.