Precipitating Cloud-System Response to Aerosol Perturbations

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Wet removal of the aerosol from the atmosphere is a dominant loss mechanism.

Studies on aerosol scavenging have been sparse compared to those on the emission and formation of the aerosol.

Previous single-cloud modeling studies [Flossmann, 1991; Respondek et al., 1995] have shown that scavenging efficiency is positively correlated with precipitation efficiency.
Aerosol can change the microphysical and dynamical properties of mesoscale cloud ensembles (MCEs) driven by deep convective clouds [Khain et al., 2005, 2008; Seifert and Beheng, 2006; Tao et al., 2007; Lee et al., 2008a,b; Lee et al. 2009a,b; Lee et al. 2010].

Goals:
(i) Explore aerosol effects on precipitation and scavenging in a MCE driven by deep convective clouds
(ii) Examine connection between precipitation efficiency and scavenging efficiency
Goddard Cumulus Ensemble (GCE) model coupled with Saleeby and Cotton’s [2004] double-moment microphysics is used.
Case

• A mesoscale system of deep convective clouds (reaching the tropopause)

• Based on observations during TWP-ICE (12:00 LST January 23th – 12:00 LST January 25th 2006) Darwin, Australia [Fridlind 2009]
Simulations

2-D domain: 256 x 20 km$^2$
$\Delta x = 500$ m and $\Delta z = 200$ m

PBL aerosol number concentration:
- Control run: $\sim 400$ cm$^{-3}$ (M)
- High-aerosol run: $\sim 4000$ cm$^{-3}$ (10M)
Cumulative Precipitation

Cumulative Precipitation (mm)

Control: 88.6
High-aerosol: 95.7 (9% increase)
Cumulative Precipitation and precipitation efficiency (PE)

Convective cloud

Stratiform cloud

Cumulative Precipitation (mm)

Control: 88.6
High-aerosol: 95.7

PE = (Water mass reaching the surface) / (Water mass condensed)
Scavenging efficiency (SE)

Convective cloud

SE = (aerosol mass reaching the surface) / (aerosol mass activated)

SE and PE track well for both Convective and Stratiform clouds

Stratiform cloud
Aerosol mass vertical distribution

Cloud-top height

Graph showing aerosol mass distribution with height (km) on the y-axis and mass concentration in μg m⁻³ on the x-axis. Three lines are depicted:
- Solid: High-aerosol
- Dotted: Control
- Grey: First time step
- Red: Last time step
Relaxation time back to the control aerosol (M)

The larger the aerosol perturbation, the faster the removal rate!

Relaxation time ~ 10 days!
Discussions and Conclusions

- Microphysical pathways tend to compensate to yield a small overall aerosol effect on total precipitation
  - buffered aerosol-cloud-precipitation system [Stevens and Feingold, 2009]

- Strong correlation between the SE and PE for a cloud ensemble simulated over two days
  - Correlation is unlikely to be dependent on cloud-system life span, organization, and cloud type

- Relaxation back to base aerosol state is ~10 days in spite of decreased PE and SE
  - Stronger aerosol perturbations have faster removal rates
  - ~6 days in BL and ~17 days in upper troposphere
  - Implications for upper tropospheric transport and chemistry