Aerosol Effects in China: Observations and Modeling

L. Ruby Leung, Jiwen Fan, Yun Qian
Pacific Northwest National Laboratory

Alexander P. Khain, Barry Lynn
Hebrew University of Jerusalem

Zhanqing Li
University of Maryland

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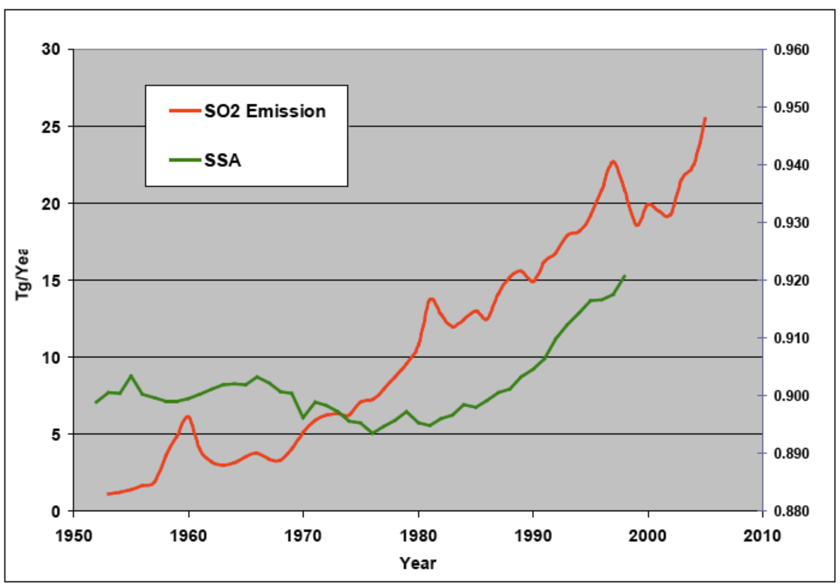
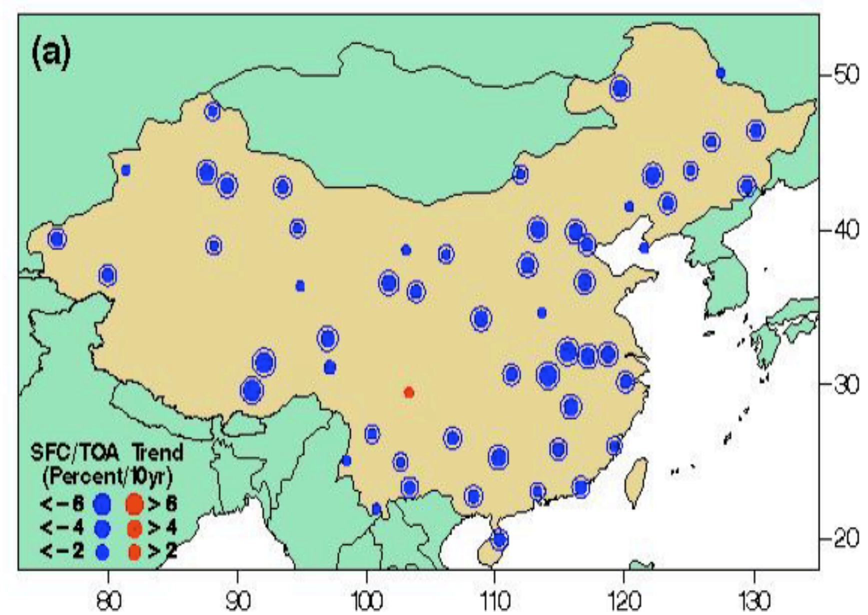
Background

- China has experienced significant changes in air quality – the emissions of fossil fuel sulfur dioxide have increased about nine-fold since 1950
- Aerosols can influence global and regional energy and water cycles through their interactions with radiation and cloud microphysical processes
- Our observational analyses have provided strong evidence of aerosol direct effects in China

Air pollution has been increasing



Global solar radiation under cloud free days has decreased



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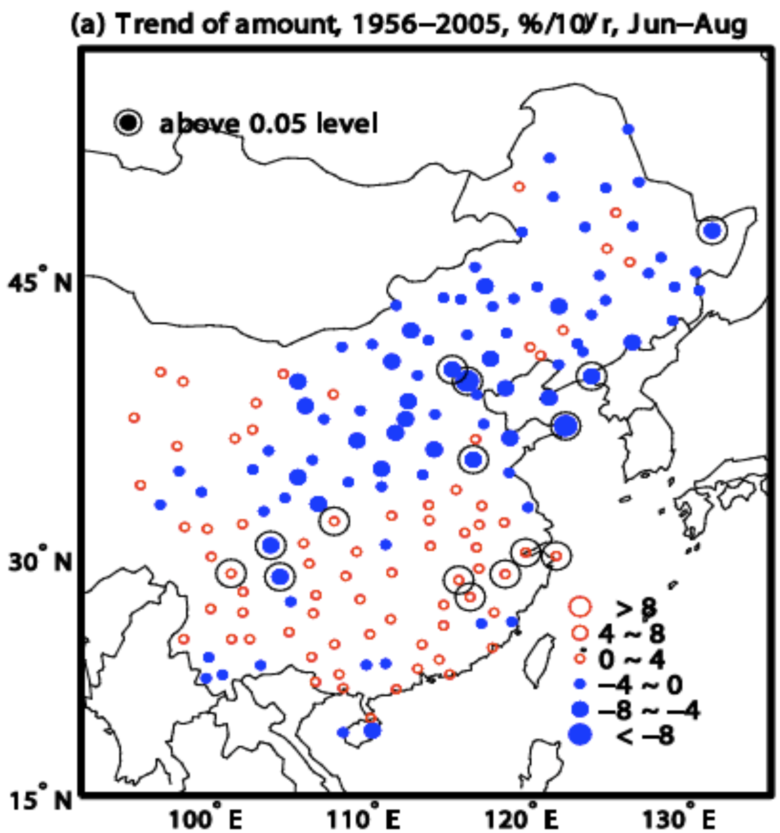
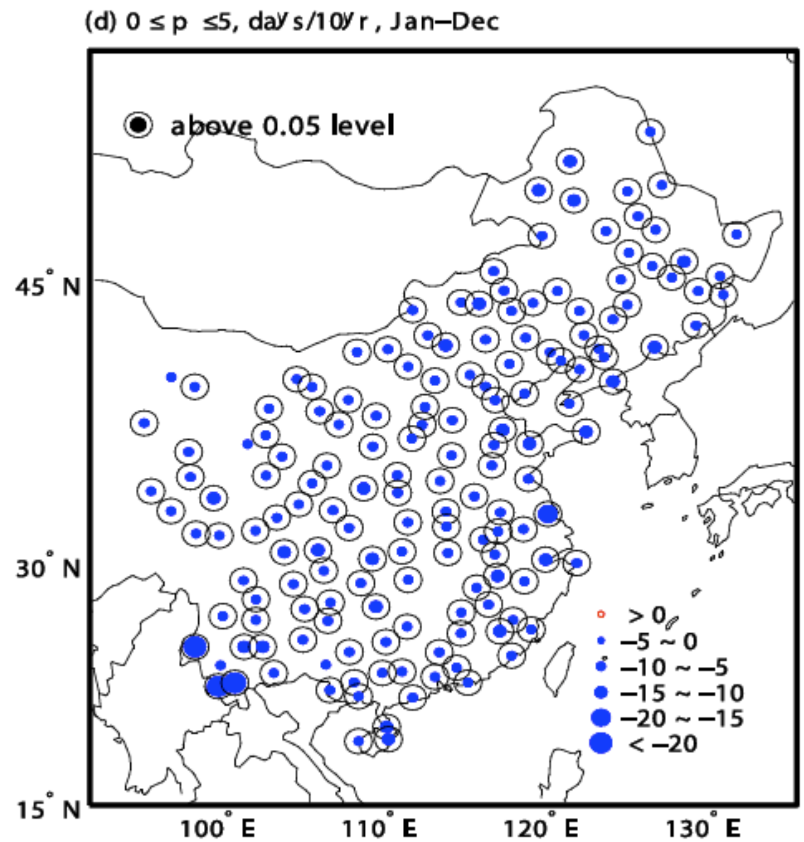
Aerosol effects on precipitation

Total precipitation exhibits the north drought – south flood trend



Light precipitation has, however, decreased uniformly in East China



- How can we more firmly establish the relationships between aerosols and the observed climatic trends in China?
- Do climate models have adequate physics parameterizations to answer the above question, especially aerosol indirect effects?

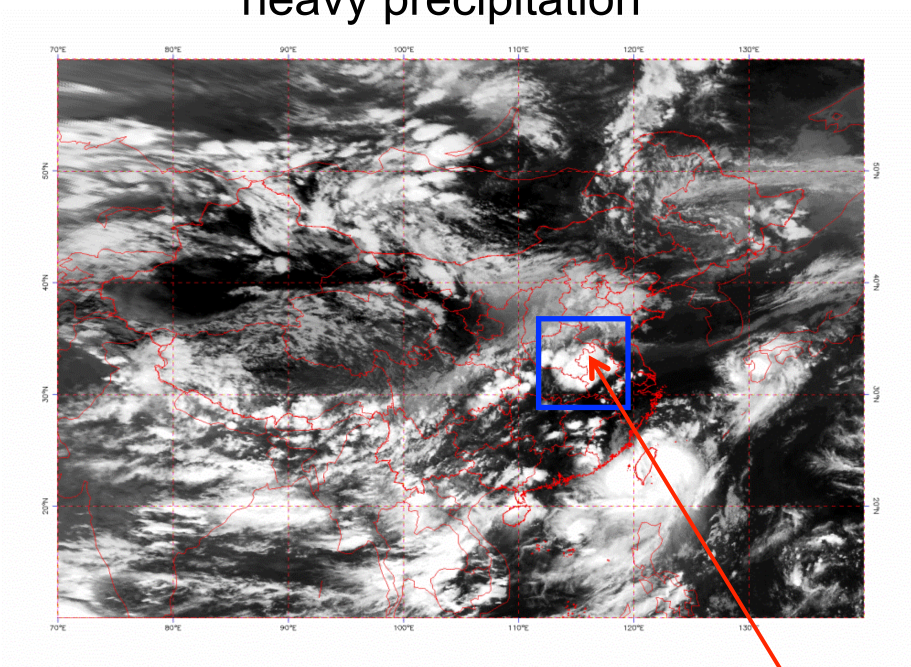
Approach

- Simulations have been performed using the Weather Research and Forecasting (WRF) model
- Measurements (e.g., AMF-China) are used to evaluate the simulations and physics parameterizations
- Two cloud microphysics parameterizations have been compared – the bulk microphysics (BM) typically used in climate models and the highly detailed spectral bin microphysics (SBM)
- Can the BM schemes reproduce the basic cloud microphysical and dynamical features simulated by the SBM scheme?
- Do the BM and SBM schemes produce similar sensitivity of cloud and precipitation to aerosol concentrations?

Case Studies Using Data From AMF-China

- Two different cloud regimes, deep convective and stratiform clouds, have been selected from the AMF-China field Campaign

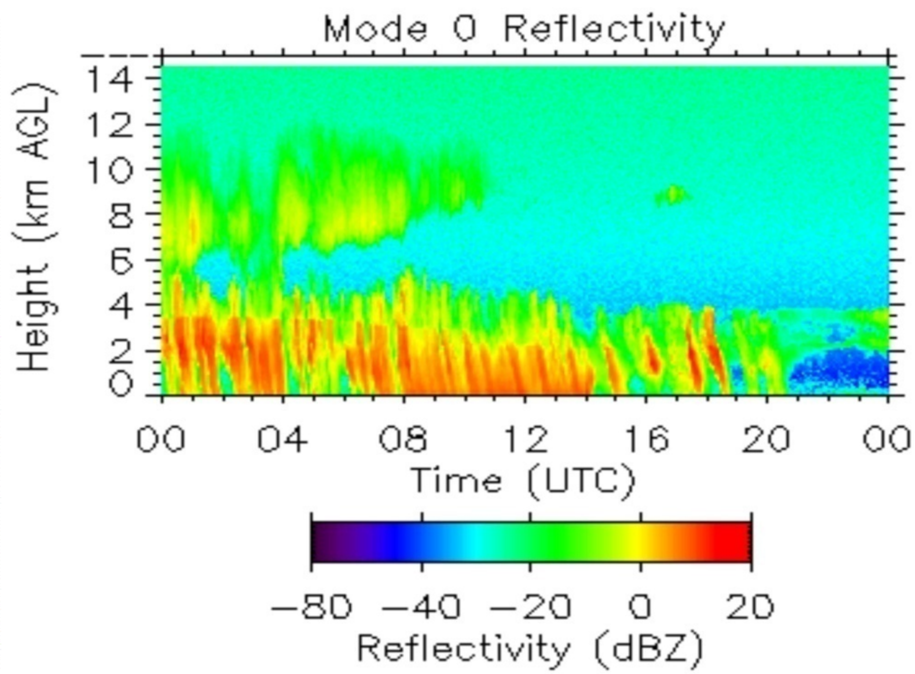
Jul-17: MCS system – deep convective clouds (DCC) with heavy precipitation



MTSAT image

ShouXian

Nov-07: Cold front induced stratiform clouds



WACR Cloud Radar

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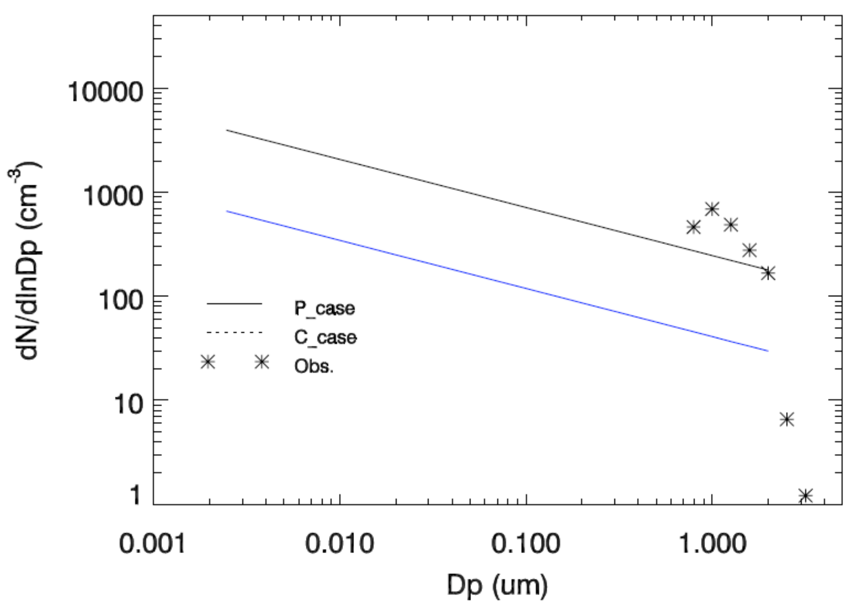
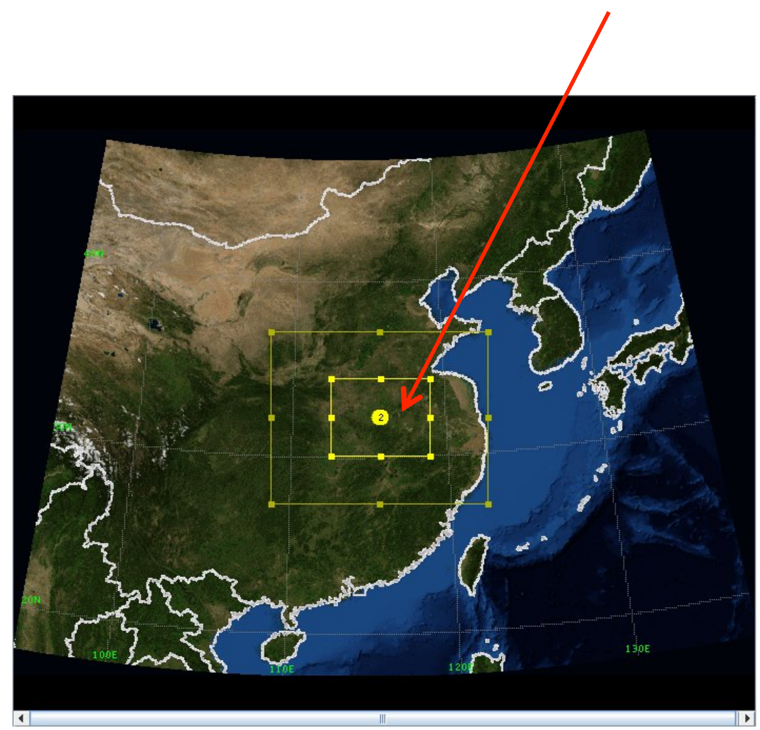
Cloud Resolving Simulations Setup

- WRF coupled with a spectral bin microphysics (SBM) scheme [*Khain and Lynn, 2010*] is employed to simulate clouds under polluted and clean conditions (P_case and C_case)

	Outer domain	**Inner domain**
P-Case	**N_c = 1000 cm^{-3}**	**N_{ccn} = 8600 cm^{-3}**
C-case	**N_c = 300 cm^{-3}**	**N_{ccn} = 1440 cm^{-3}**



ShouXian



Real case driven with NCEP 1°x1° reanalysis data

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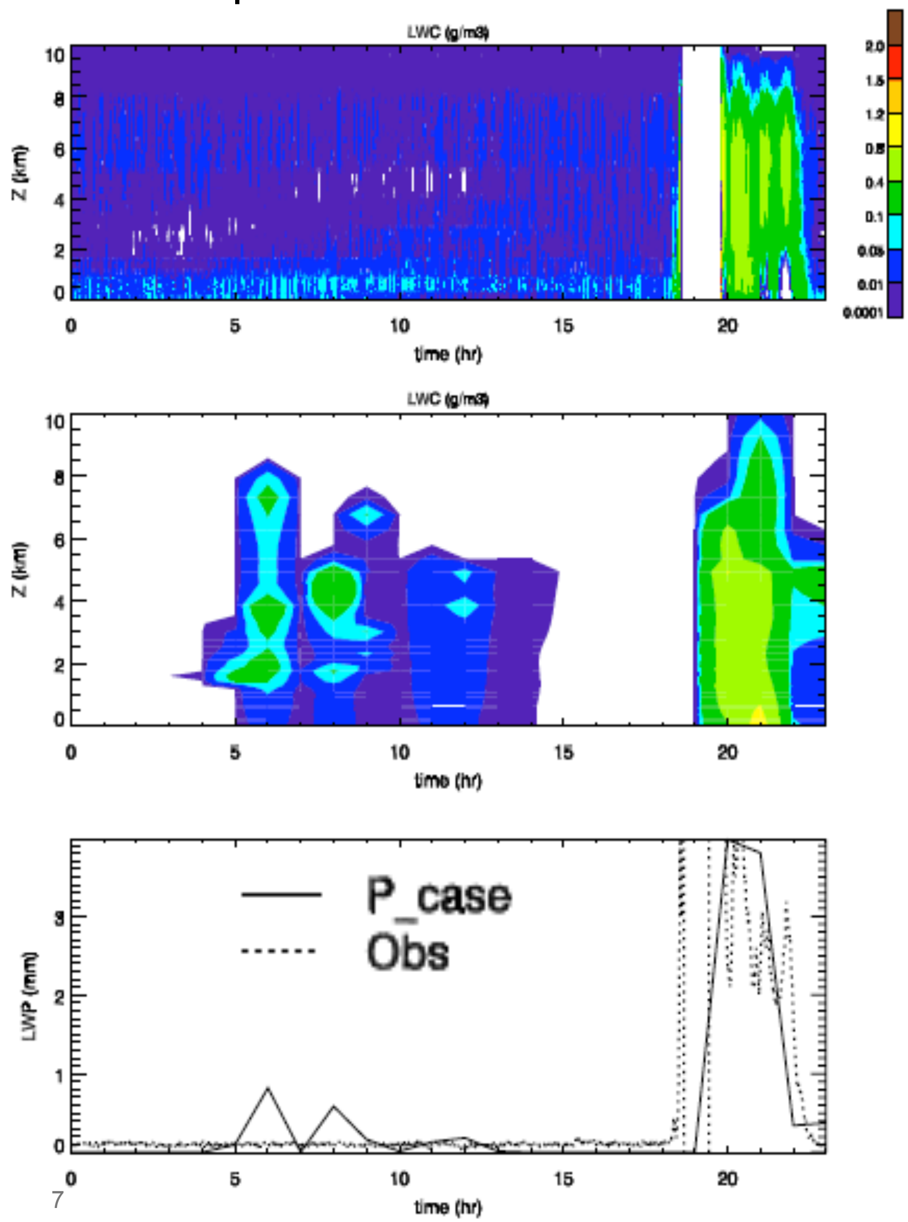
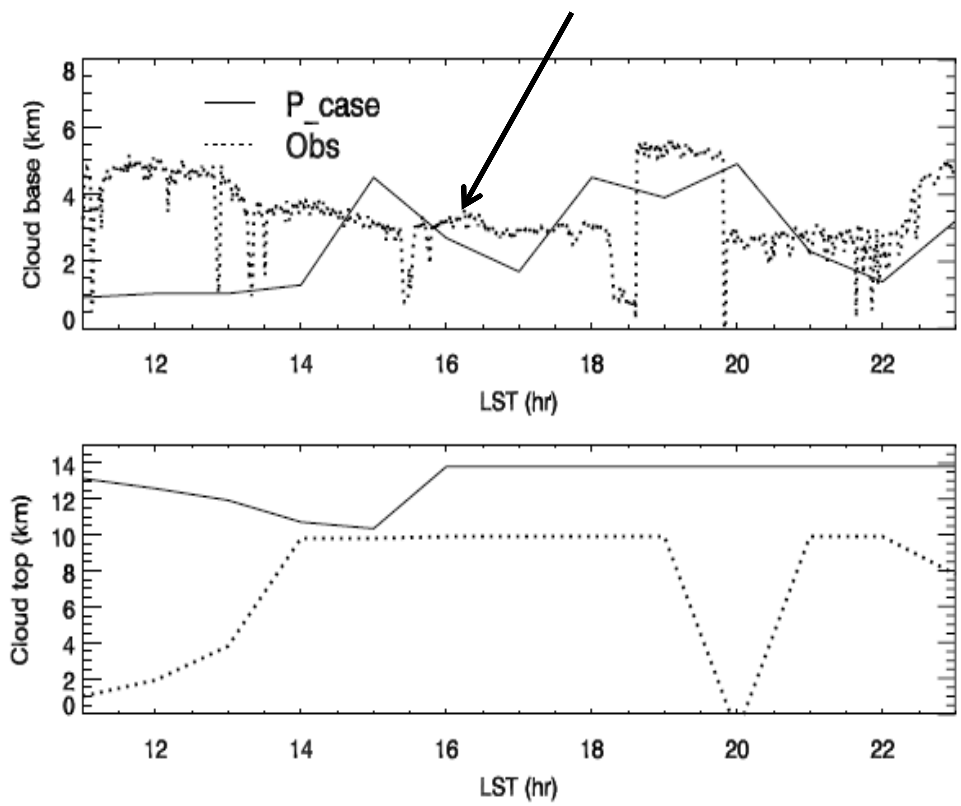
Results: July 17, 2008

Comparison with MWRP data



FY-2 satellite data



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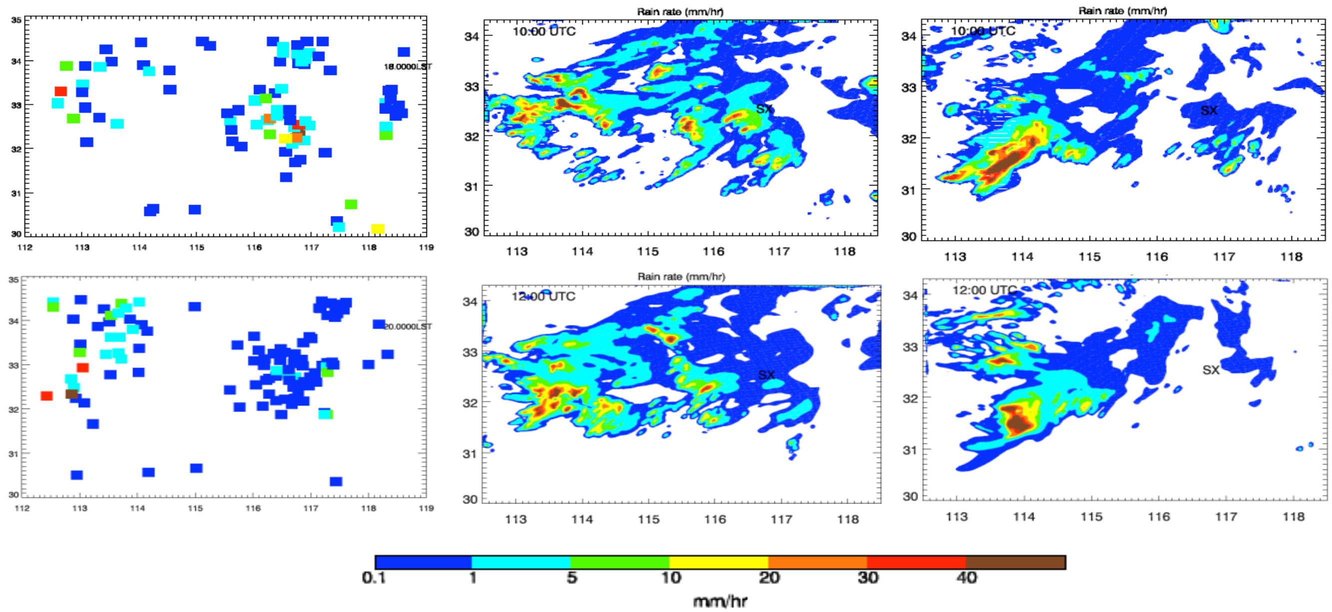
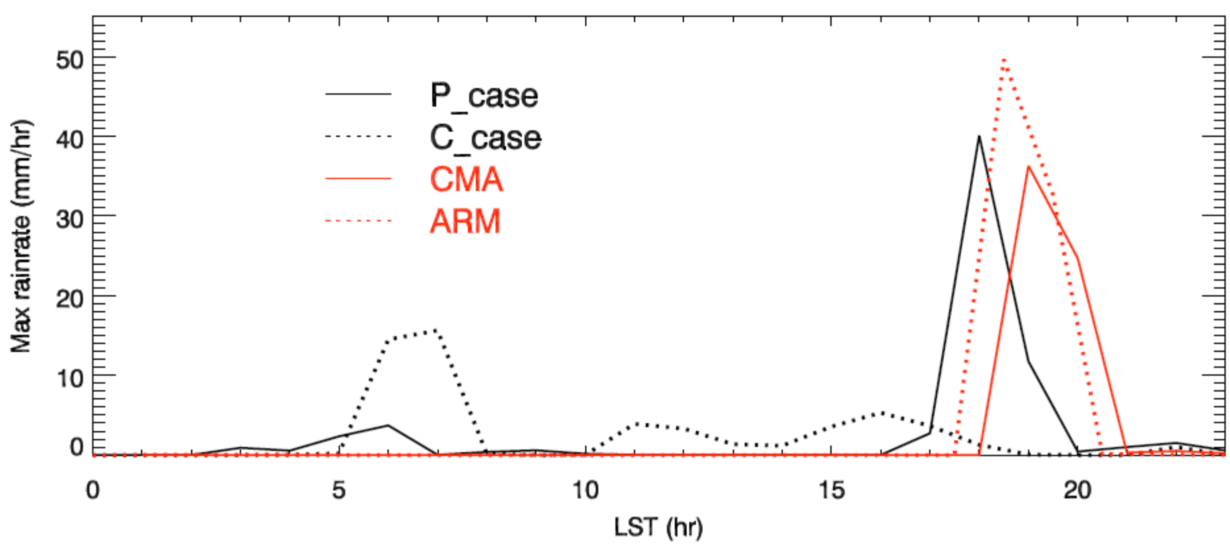
Results: July 17, 2008

Observation **P_case** **C_case**





- Aerosols redistribute clouds spatially; convection is much weaker near Shouxian in the clean atmosphere
- Both spatial and temporal distributions of rain rate in the P_case compare better with observations than the C_case

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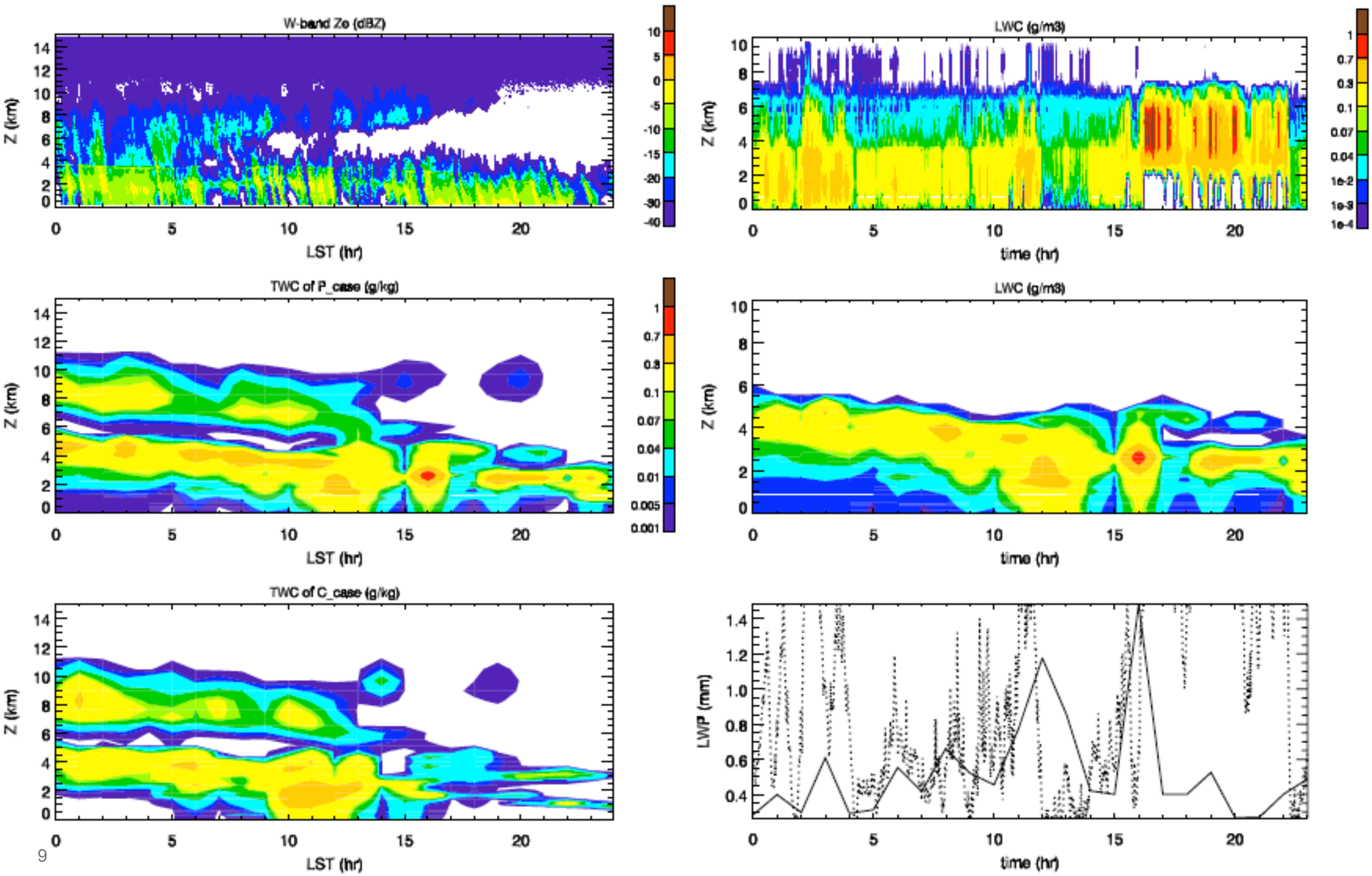
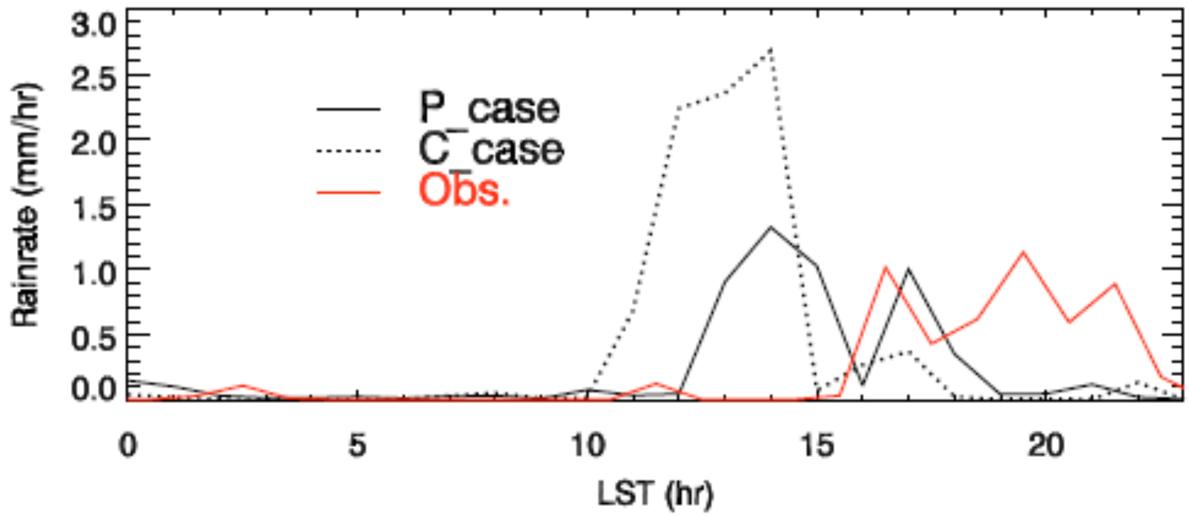
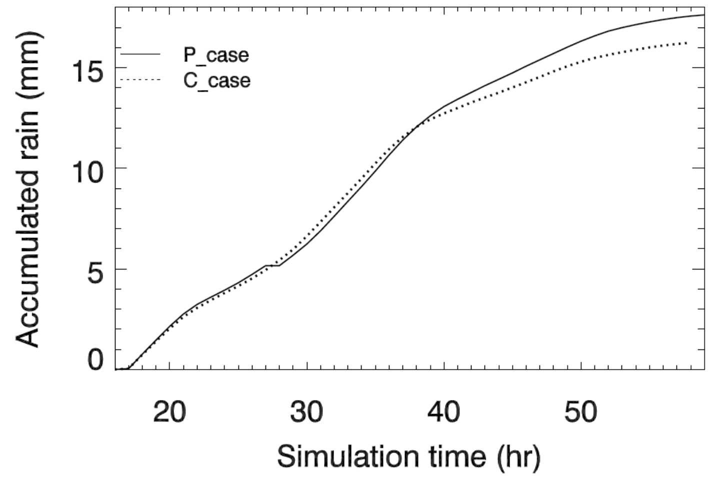
Results: November 7, 2008

Comparison with W-band cloud radar and MWRP data



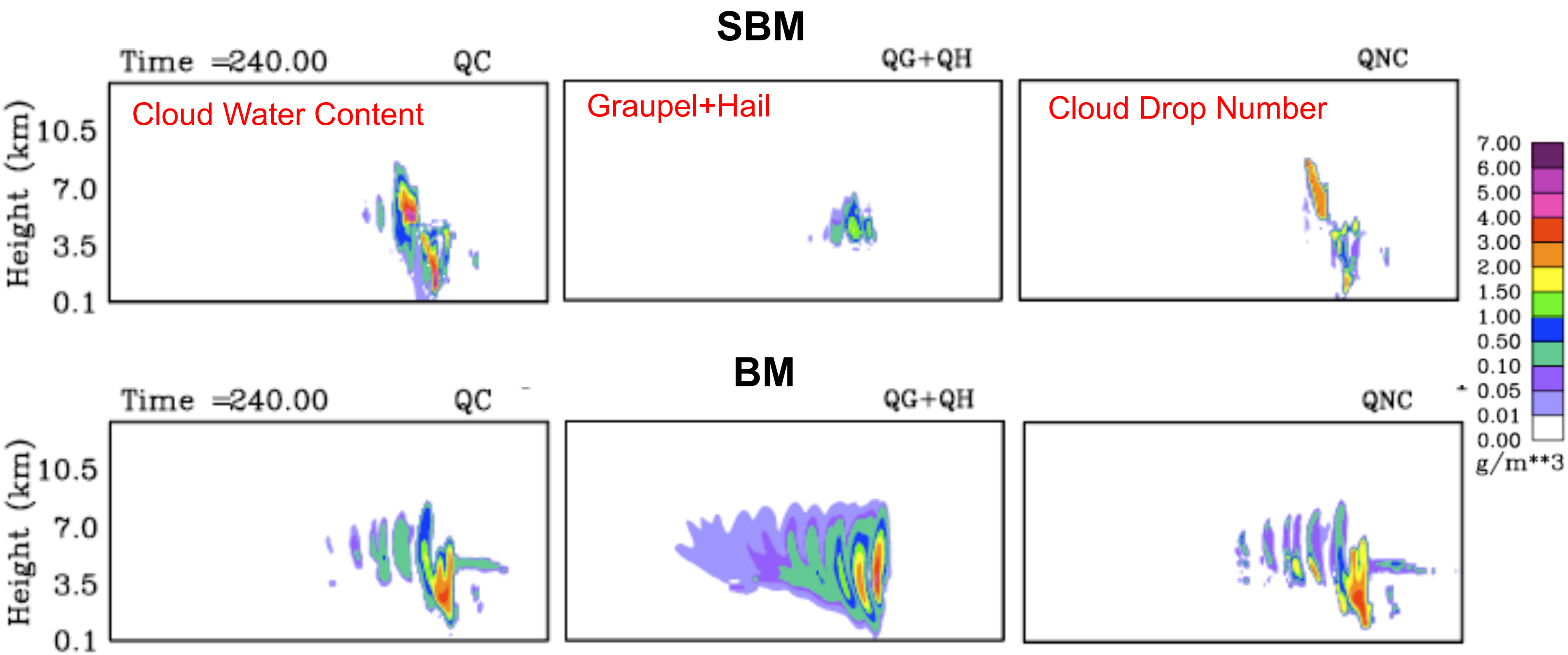
Results: November 7, 2008





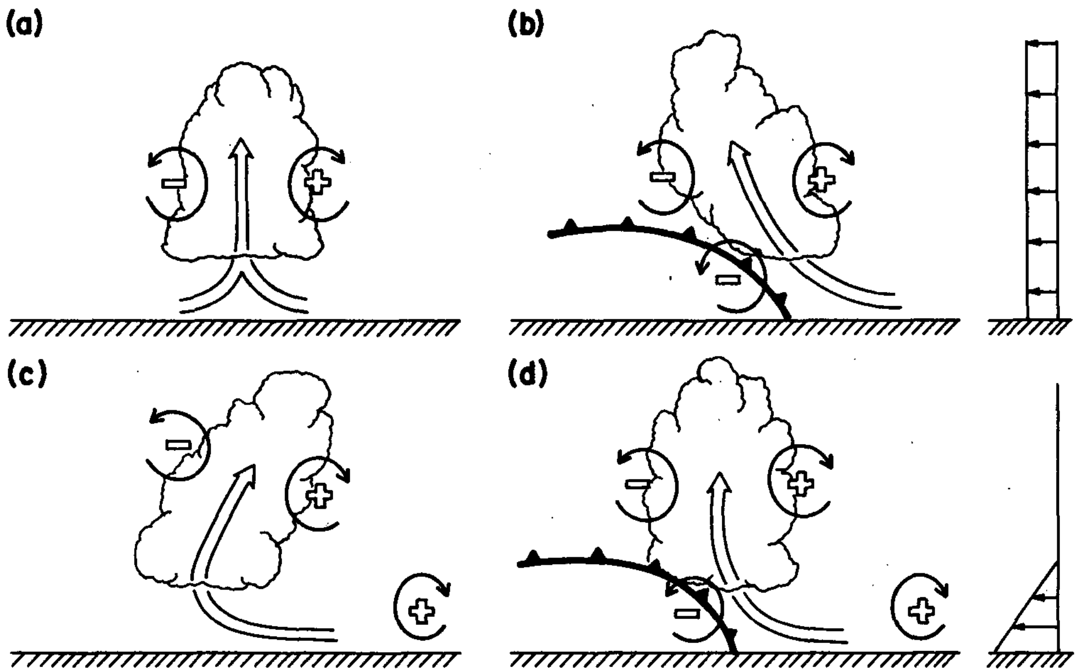
- Rain rates from P_case agree with observations, except starting earlier
- Aerosols prolong cloud lifetime and extend the rainy period
- Aerosols significantly decrease rain rate and delay the onset of precipitation, but they do not redistribute clouds, as seen in the deep convective system of July 17

Idealized simulations of a squall line using the SBM and BM schemes

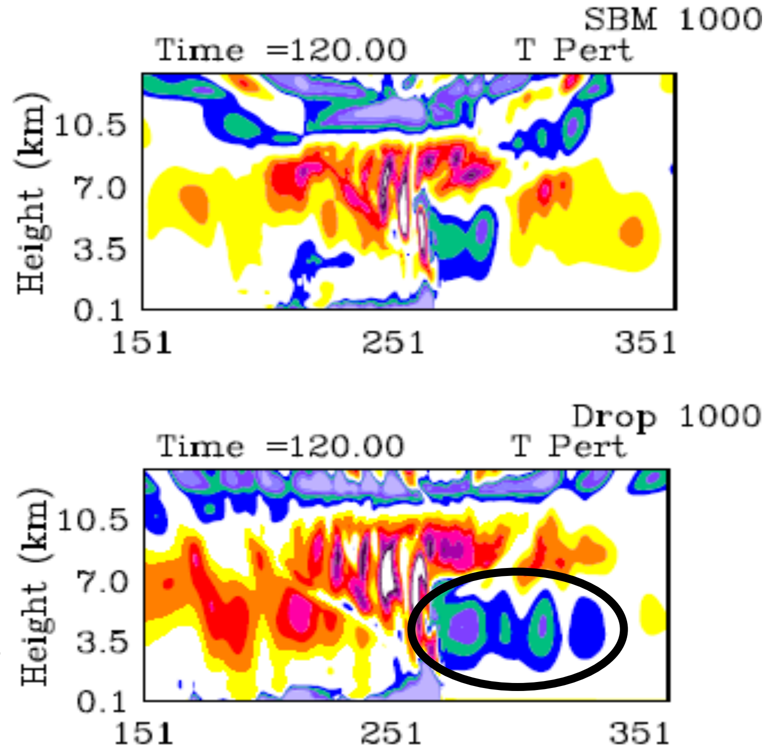


- The BM scheme produces more pronounced multi-cell structure
- The BM scheme also produces significantly more graupel and hail, as well as snow and ice (not shown)

Conceptual Model of a Squall Line



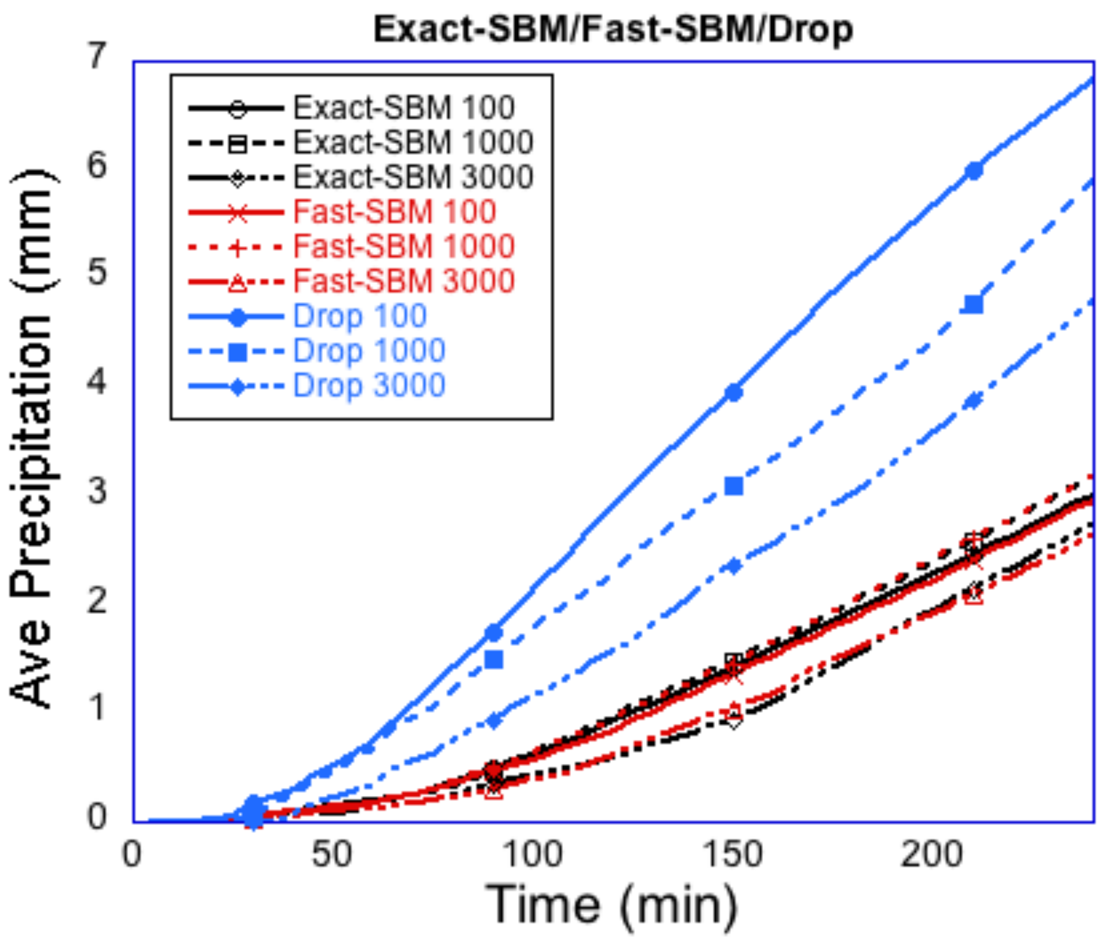
Rotunno et al. (1988)



- Squall line structure depends on the balance between near surface cool pool and vertical wind shear
- Upshear tilt and cell splitting can result when the cool pool overwhelms the wind shear effect
- In bulk schemes, rain drops follow simple distribution functions – mean rain drop size decreases after evaporation, which accelerates evaporation, leading to stronger cool pool and multi-cell structures (Li et al. 2009)

What are the implications?

- The BM scheme produces much higher precipitation amount and large and monotonic reduction of precipitation in response to increasing aerosol concentrations



Summary

- Using an SBM scheme at the cloud resolving scale, the structure of different types of clouds including deep convective, stratiform, and squall line are realistically simulated
- Aerosols significantly redistribute precipitation regionally in the deep convective system, but not in the stratiform cloud regime
- Aerosols delay precipitation and extend cloud life time and precipitation, leading to an overall increase in accumulated rain for all three cloud regimes
- With many simplifying assumptions, the BM schemes can produce rather different microphysical and dynamical structures of clouds compared to the SBM, leading to different sensitivity to aerosol concentrations
- Detailed comparison of the BM vs SBM parameterizations can provide guidance on improvements to the BM schemes for long term simulations of aerosol effects