Thunderstorm and stratocumulus: How does their contrasting morphology affect their interactions with aerosols?

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Motivation

- Aerosol enhances precipitation in convective clouds, contrary to the well-known precipitation supprression in warm stratiform clouds

- Delayed autoconversion increases latent-heat release from freezing,leaing to the invigoration of convection and precipitation enhancement (Rosenfeld et al., 2008)

- However, the precipitation enhancement can be simulated in the absence of freezing through the intensification of gustiness (Lee et al., (2008a,b))

- These studies indicate a possible interplay between aerosol effects on ice physics and aerosol effects on gustiness

- Lee et al. (2008) showed aerosol effects on gustiness were stronger in deeper clouds

- The interplay may depend on cloud type

Goal

- The study aims to gain an understanding of the dependence of the interplay between aerosol effects on gust front and those on ice physics for precipitation enhancement on the types of convective clouds

- This study also examines mechanisms which differentiate the precipitation response to aerosols in convective clouds from that in warm stratiform clouds

Model Description

- Goddard Cumulus Ensemble (GCE) model coupled with Saleeby and Cotton's [2004] double-moment microphysics is used

- Full stochastic collection solutions with realistic collection kernels are employed

- Sedimentation of hydrometeors is simulated by emulating a full-bin model with 36 bins

Cases

DEEP

\# A case of deep convective clouds

Observed during the ARM sub-case A
(13:30 UTC June 29th – 13:30 UTC June 30th 1997)
campaign at (36.61N, 97.49W)

MID

\# A case of shallow convective clouds

Identical to DEEP but with lower surface humidity,
leading to lower CAPE and thus cloud-top height

STRATIFORM

A case of stratocumulus clouds

Identical to DEEP but with strong temperature forcing around 1 km, generating an inversion layer and thus leading to the formation of stratocumulus clouds

Average aerosol number at the surface (cm^{-3})

- ◦High-aerosol run : ~ 4000
- ◦Low-aerosol run: ~ 400

Model Setup

DEEP and MID

- 3D framework (168 km x 168 km x 20 km) is used
- Δx and Δy = 200 m and Δz = 100 m

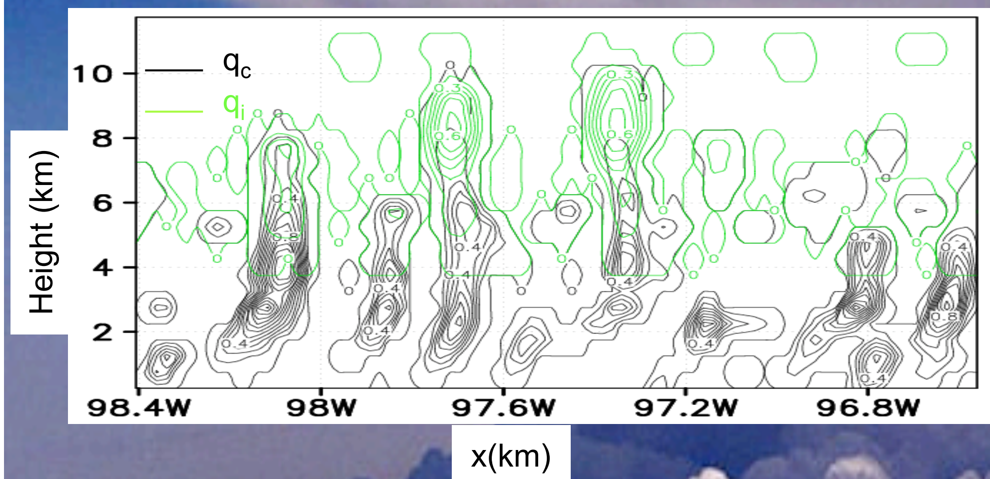
STRATIFORM

- 3D framework (12 km x 12 km x 20 km) is used
- Δx and Δy = 50 m and Δz = 40 m

Mixing ratio of cloud particles (g kg^{-1})

Cumulative precipitation (mm)

DEEP



With ice

#High-Aerosol: 34.2

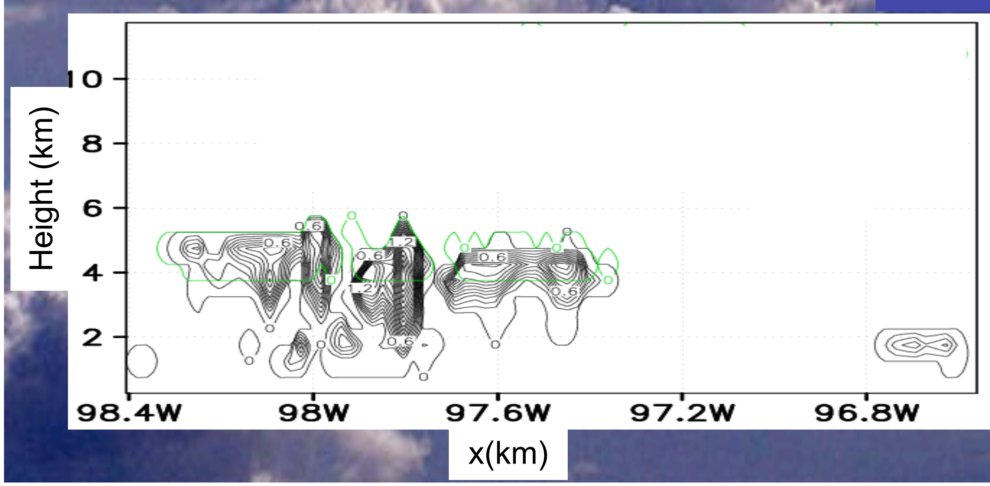
#Low-Aerosol: 29.9

With no ice

#High-Aerosol: 31.5

#Low-Aerosol: 28.1

MID



With ice

#High-Aerosol: 6.5

#Low-Aerosol: 5.3

With no ice

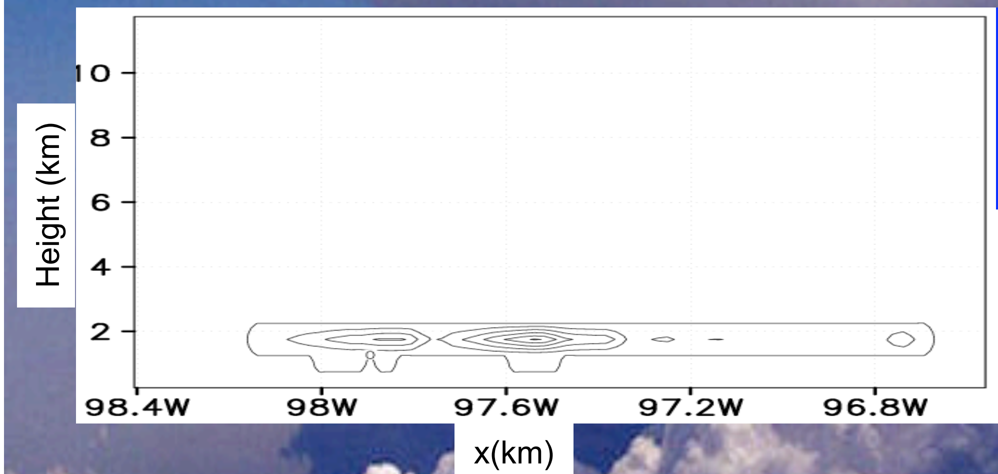
#High-Aerosol: 4.2

#Low-Aerosol: 5.0

Mixing ratio of cloud particles (g kg^{-1})

Cumulative precipitation (mm)

STRATIFORM

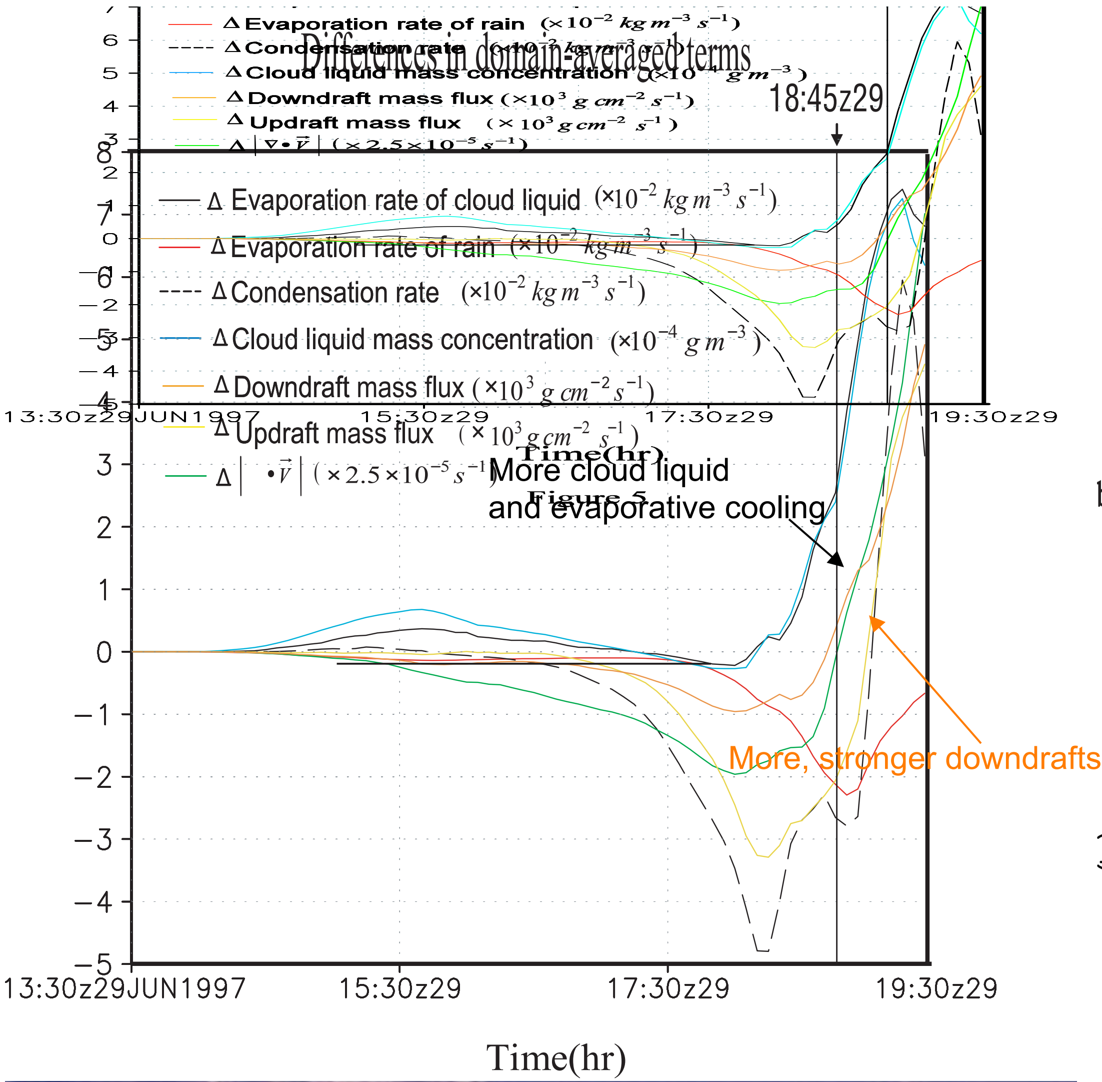


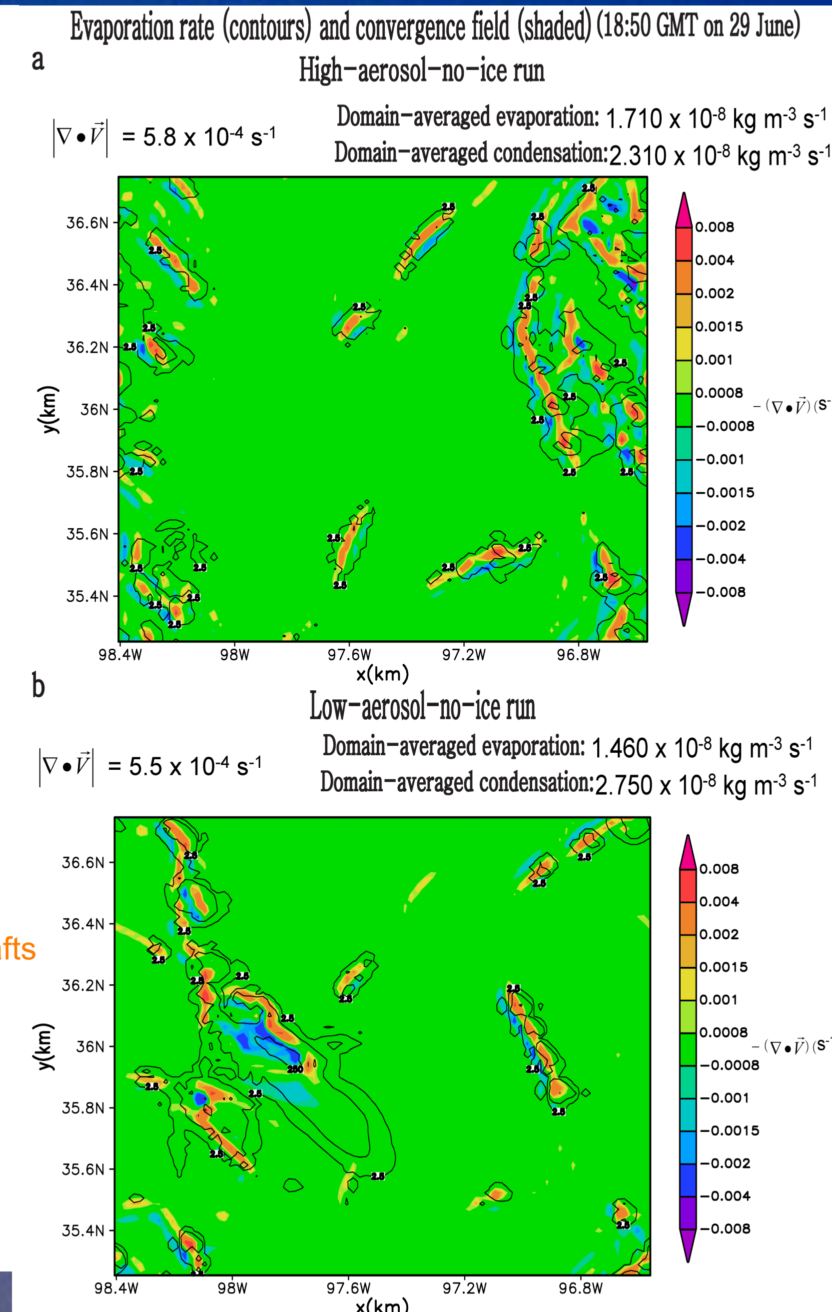
Ice (NOT formed)

#High-Aerosol: 0.08

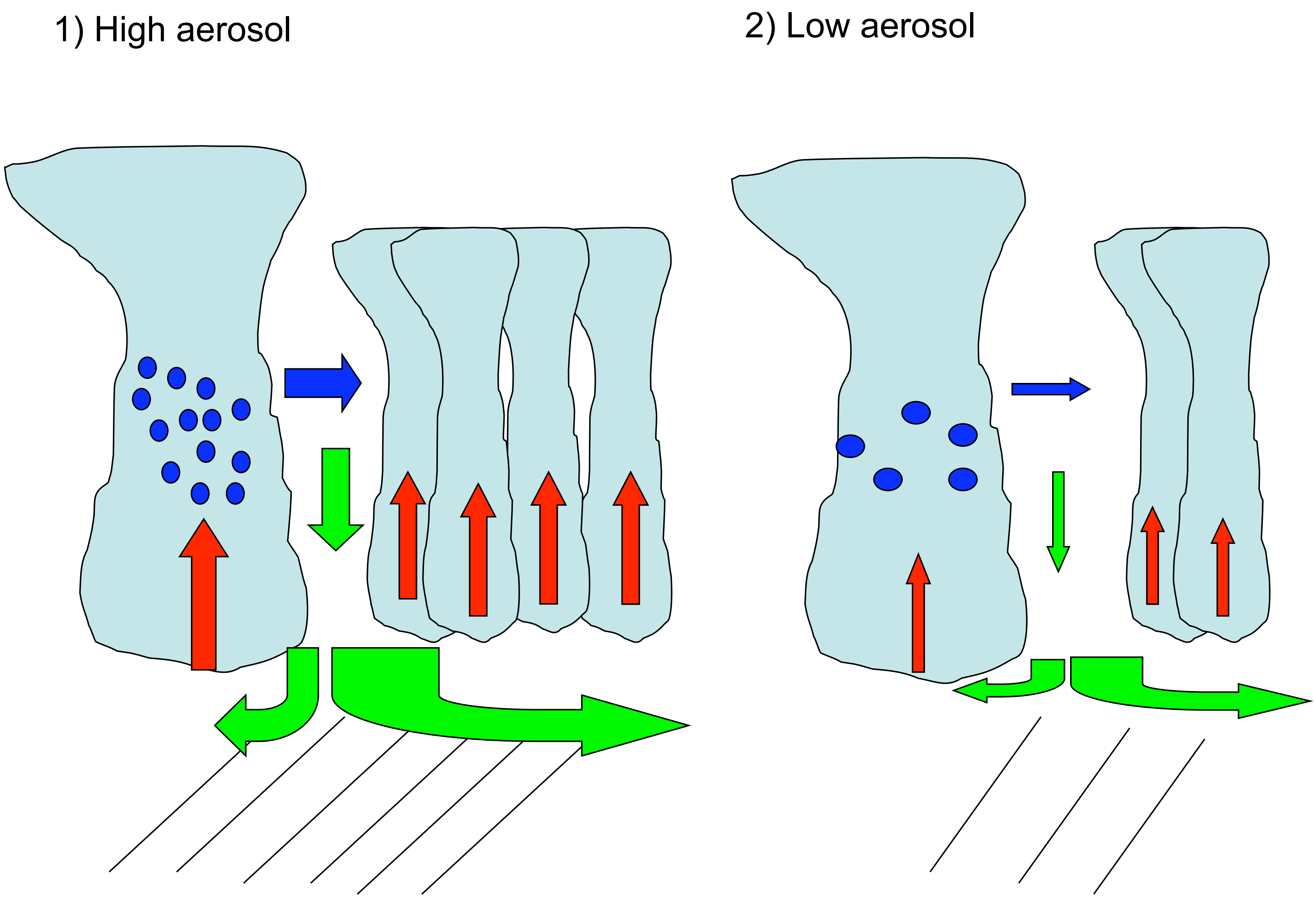
#Low-Aerosol: 0.5

Differences (High - Low) in domain averaged terms associated with low-level convergence



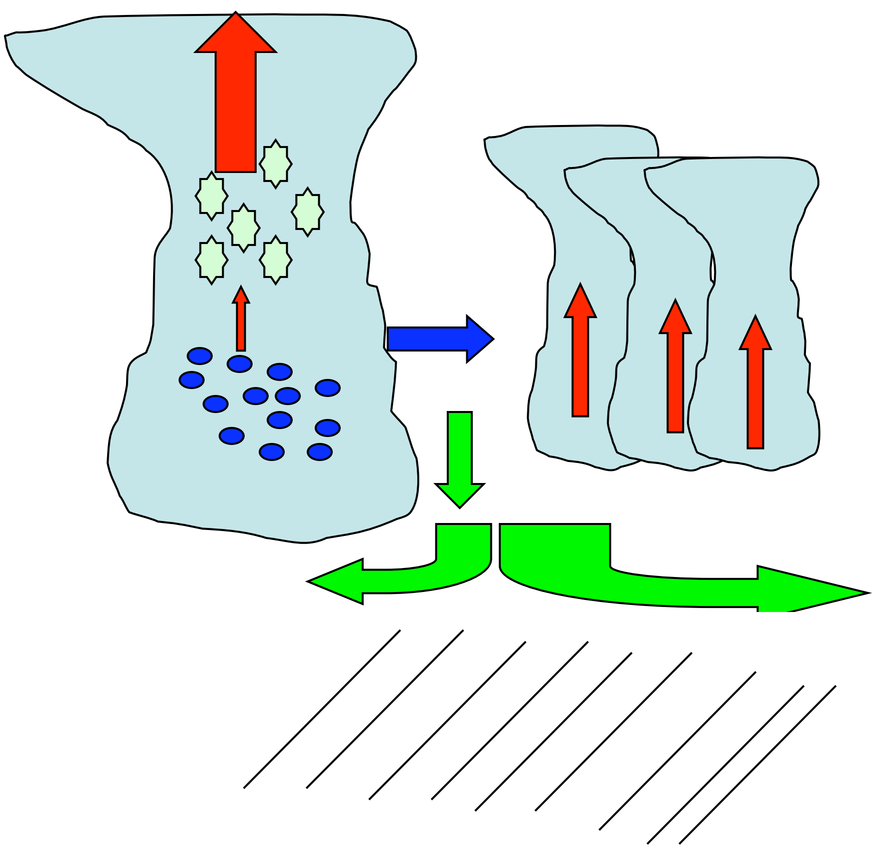


DEEP

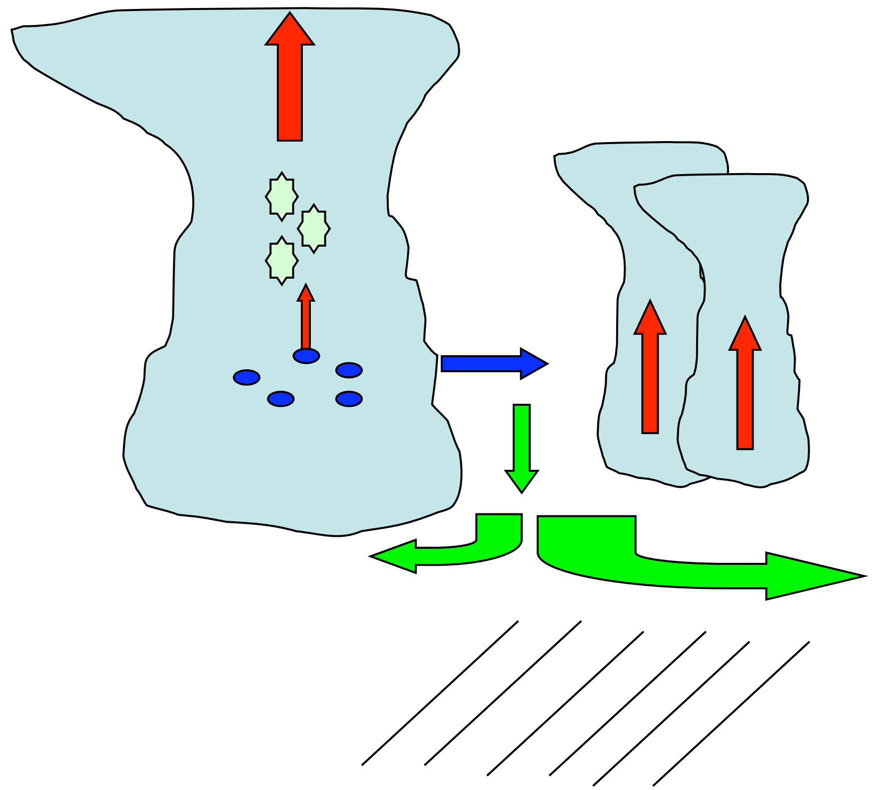


MID

1) High aerosol



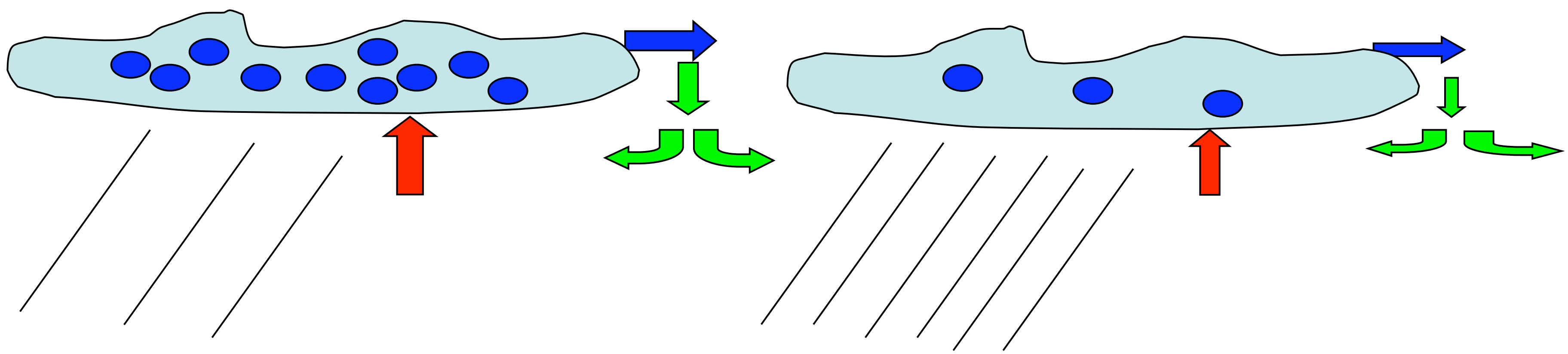
2) Low aerosol



SHALLOW

1) High aerosol

2) Low aerosol



Summary and Conclusion

- In deep convective clouds with tops reaching above the level of homogeneous freezing, the effect of aerosols on gust front alone can increase precipitation.
- In shallow convective clouds with tops below the level of homogeneous freezing, the effect of aerosols on ice physics is necessary for the precipitation enhancement at high aerosol.
- In warm stratiform clouds with no freezing and no well-developed gust front, precipitation is supresssed at high aerosol.
- Possible increases in CAPE with the increasing greenhouse gases act in favor of the role of the aerosol effects on gustiness.

- Aerosol induced changes in cloud-scale interactions between microphysics and dynamics were effective in deep convective clouds

- These changes involves those in the cloud-system instability; an associated change in Thermodynamic Forcing (TF) is 125 W m^{-2}.

- Although these changes do not affect the net energy budget in the Earth, they can modify the vertical temperature gradient

- Systems like the Indian and Asian Monsoon, storm tracks, and ITCZ, playing important roles in global circulations, are driven by deep convective clouds.

- **Lee et al. (2009) and Lee and Penner (2009) showed that cumulus parameterization (CP) was not able to simulate changes in the instability induced by cloud-scale motions; generally, CP only considers these changes induced by large-scale forcings**

Thanks !!

- Possible increases in CAPE with the increasing greenhouse gases act in favor of the role of the aerosol effects on gustiness.

- Cloud-scale interactions between microphysics and dynamics modified environmental instability effectively in deep convective clouds

- Aerosol-induced changes in the instability is associated with a substantial change in latent-heat distribution; an associated change in Thermodynamic Forcing (TF) is 125 W m^{-2}.

- Although these changes do not affect the net energy budget in the Earth, they can modify global water and dynamic circulations significantly

- Systems like the Indian and Asian Monsoon, storm tracks, and ITCZ, playing important roles in global circulations, are driven by deep convective clouds.


Thanks !!