Aerosol effects on deep convection over the Indian region during ARM GVAX Campaign

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Brief Introduction

Deep Convective Clouds: DCCs

- DCCs play significant role in the hydrological and radiative balance of the atmosphere. Tropical DCCs constitute the upward branch of the Hadley cell and provide a conduit for transport of energy, momentum, moisture, aerosols and chemical species from the BL to the UT&LS.

- Aerosols alter thermodynamics the lower atmosphere through direct effects (Ramanathan et al. 2005). They even affect the tropical monsoon by inducing meridional ΔT (Lau et al. 2006)

- In DCC, warm rain suppression by aerosols in the lower part of the cloud allows greater amount of LWC to be lifted to above the freezing level by updrafts which releases additional latent heat to invigorate clouds (Andreae et al. 2004; Koren et al. 2005; Rosenfeld et al. 2008).

- Using 10 years' of ARM data, Li et al. (2011) showed CTH & thickness are proportional to aerosol loading for mixed-phase DCC with low bases, but very weak dependence for high cirrus and low water clouds, & clouds with high bases. Precipitation is suppressed for low clouds with small LWP, but enhanced for DCC. Similar relationships also found using global A-Train data (Niu and Li 2012).

- Fan et al. (2013) has proposed that pollution particles always enlarge CF and increase CTH & thickness; however, the increased CF, CTH & thickness occur primarily in the stratiform/anvil regimes rather than the convective cores of DCCs.

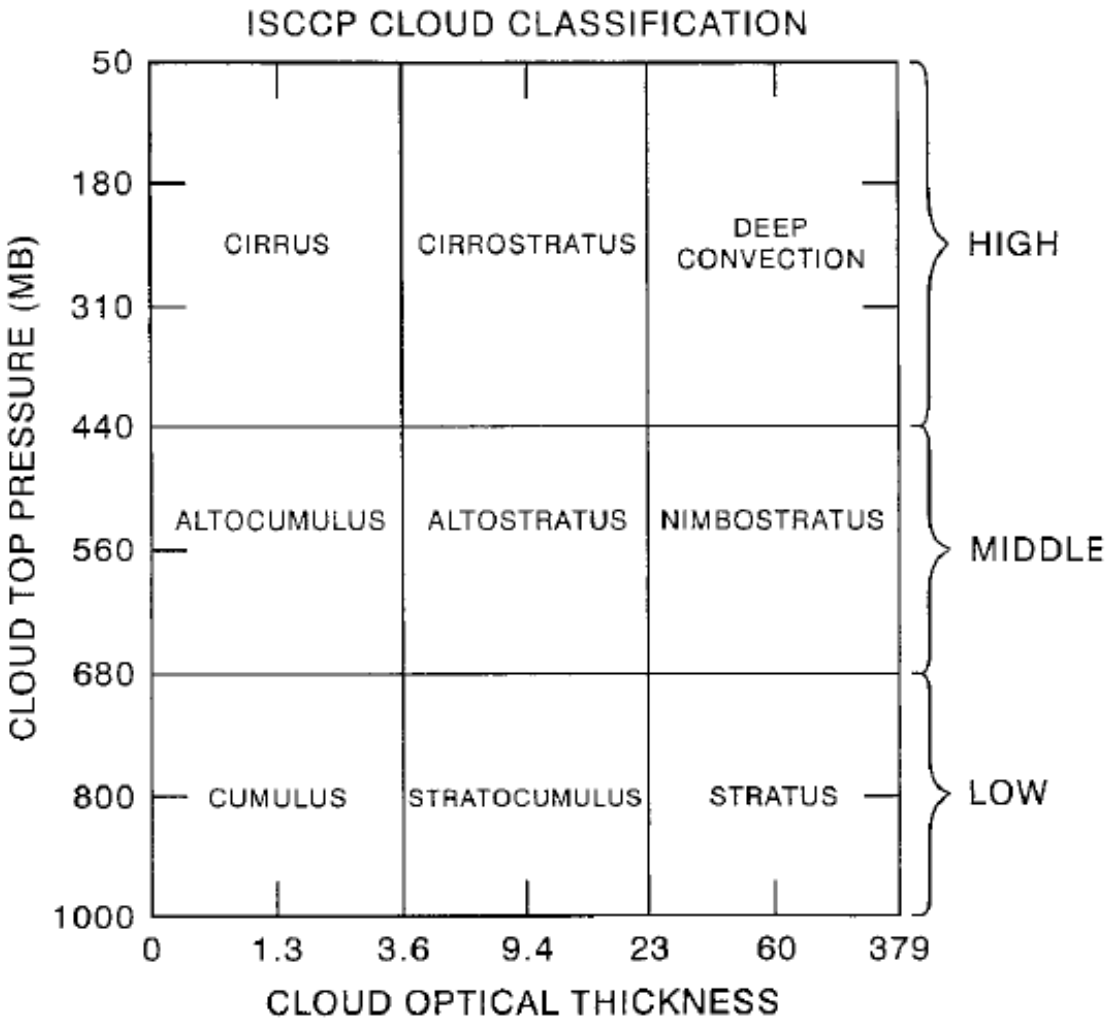
Research Question

How is the deep convection favored in a heavily polluted atmosphere through competing aerosol effects?

- ✓ **How is the PBL stabilization overcome through direct and feedback mechanisms?**
- ✓ **How does microphysical invigoration work under a greatly polluted atmosphere?**

Identification of DCCs: ISCCP Criteria

Identification of deep convective clouds by COD and CTP



Rossow and Schiffer (BAMS, 1999)

Identified DCC Cases

- Gathered the GVAX, Re-analysis and complimentary satellite data over IGP related to aerosol, cloud and the atmospheric state variables when DCCs formed.

- The DCCs formed during the JJAS period are analyzed:

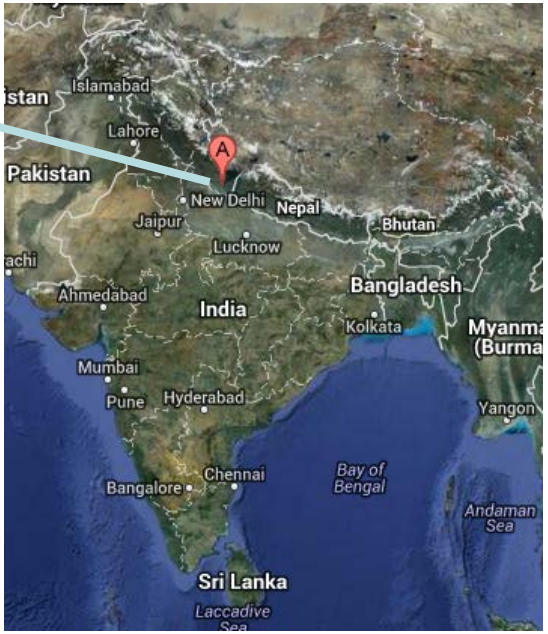
DCCs	02, 07, 08, 12, 17, 24 Jun 15 Jul, 27 Aug, 16 Sep
No-DCCs	01, 04 Jun, 09,13,21, 31 Aug 04,18,25 Sep

Data Sets.

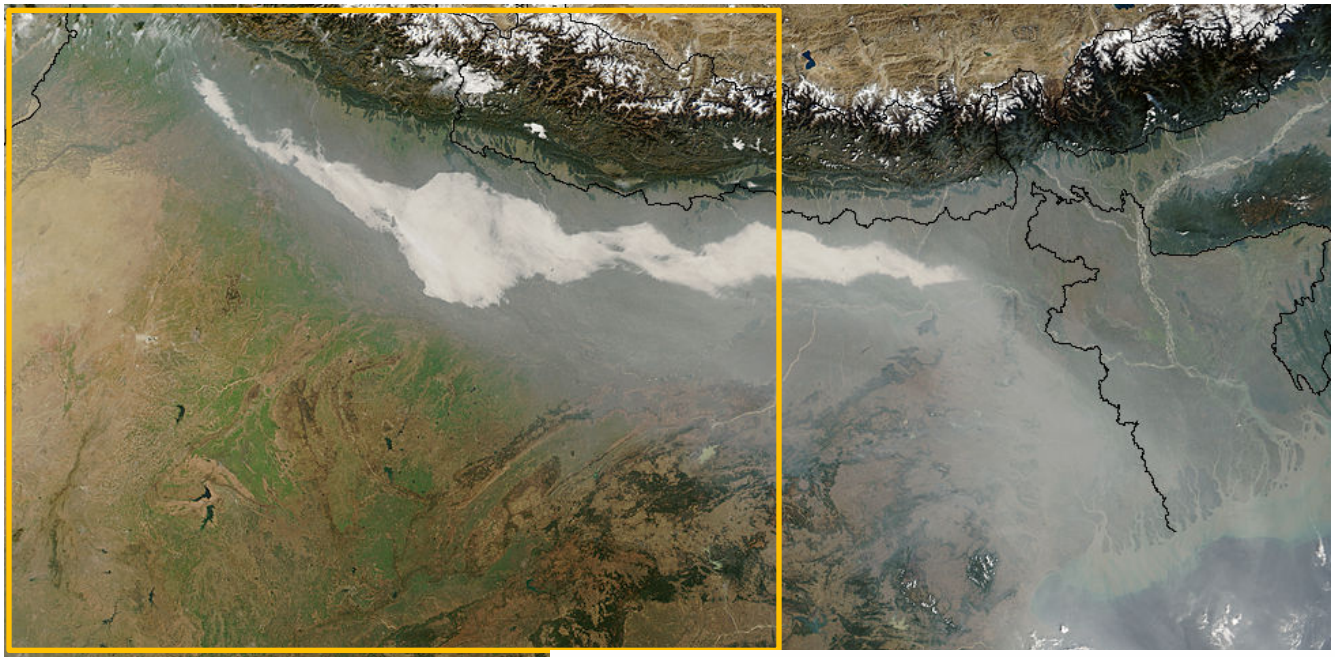
The following parameters are key to the present study period (JJAS-2011).

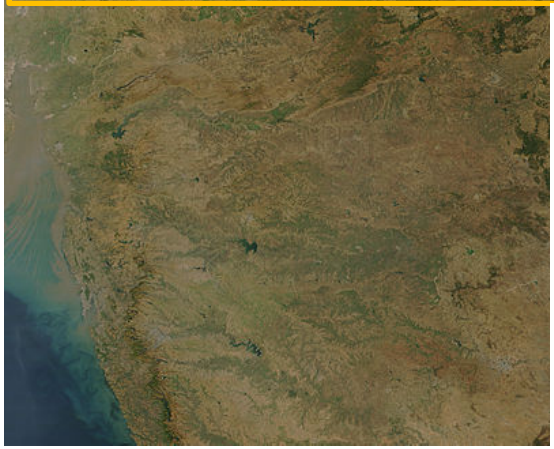
Aerosol Extinction Coefficient	CALIPSO-L2
CCN Concentration	CCN Counter
TCO, AI	OMI
Profiles of P, T, RH; and BLH	Radiosonde
AOD, COD, CLWP, CIP, CF, CER, CODice, CTP, CERice, PWC	MODIS-L3
Convective & Stratiform Fractions	TRMM-L2-2A25
Meteorological variables, Evaporation, BLH, SCIC,TIWC, CAPE etc.	ERA Interim (1.5°×1°)

GVAX Site: Nainital (79° 27', 29° 21' N)

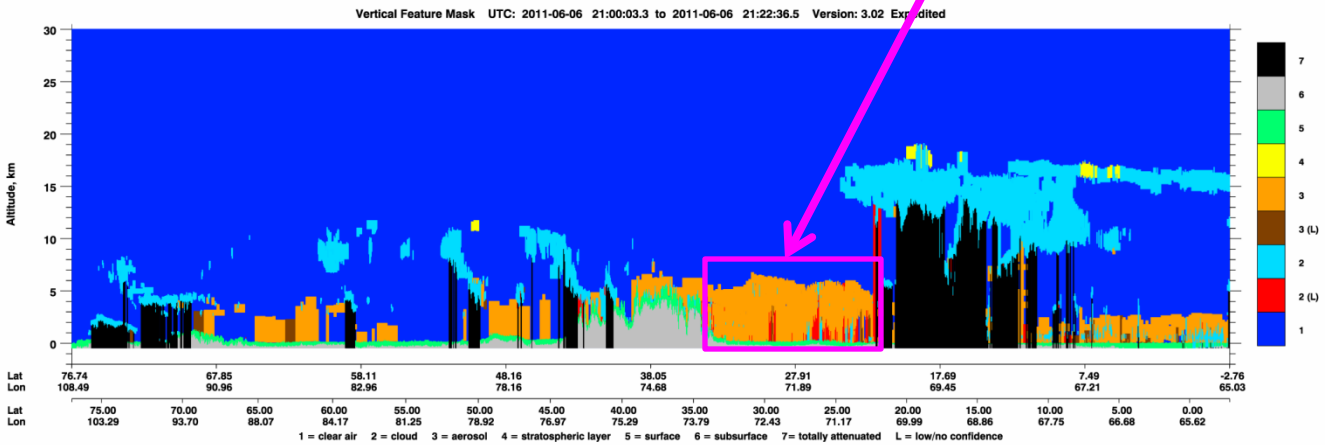


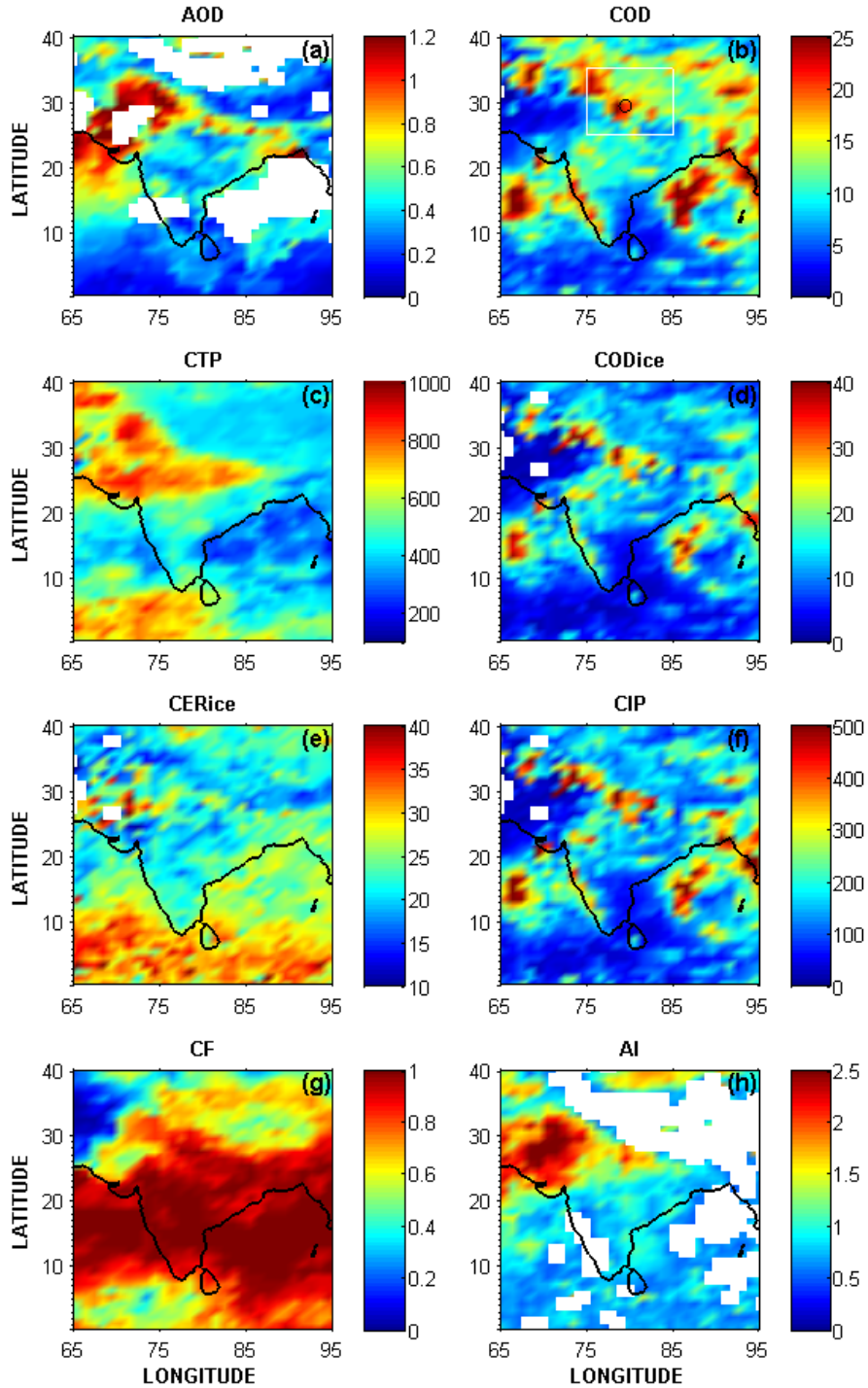
Present Study:
North Central India
(75-85E, 25-35N)
10° X 10° Box





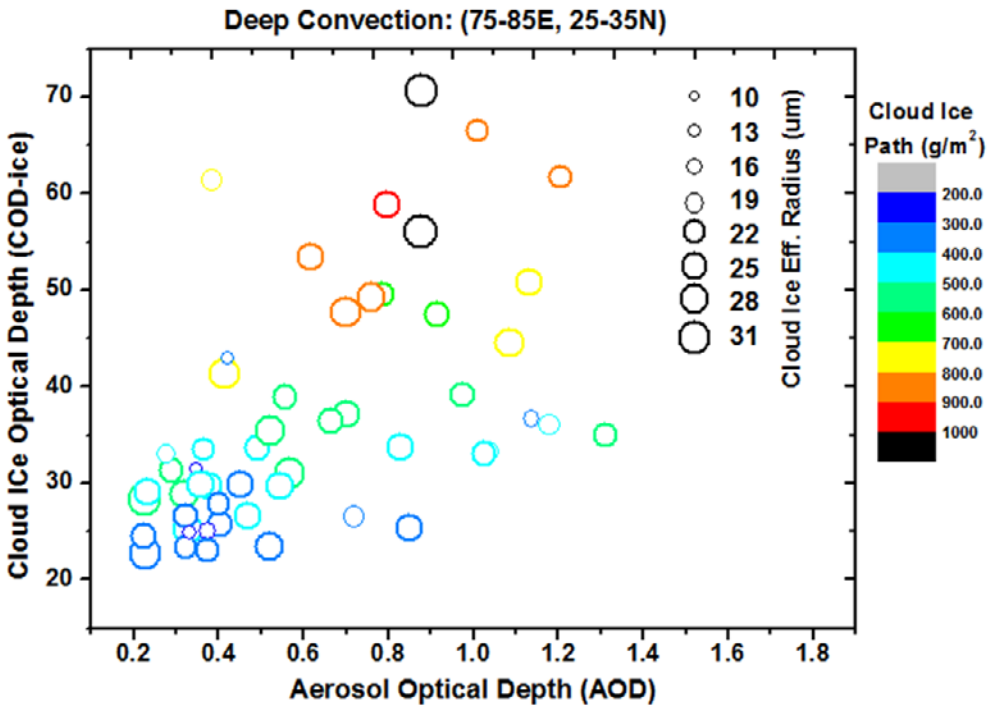
CALIPSO Profile:
Aerosol layers up to 6 km





Spatial Distribution of Aerosol/Cloud Parameters: DCC Composites

Radiative and Microphysical effects

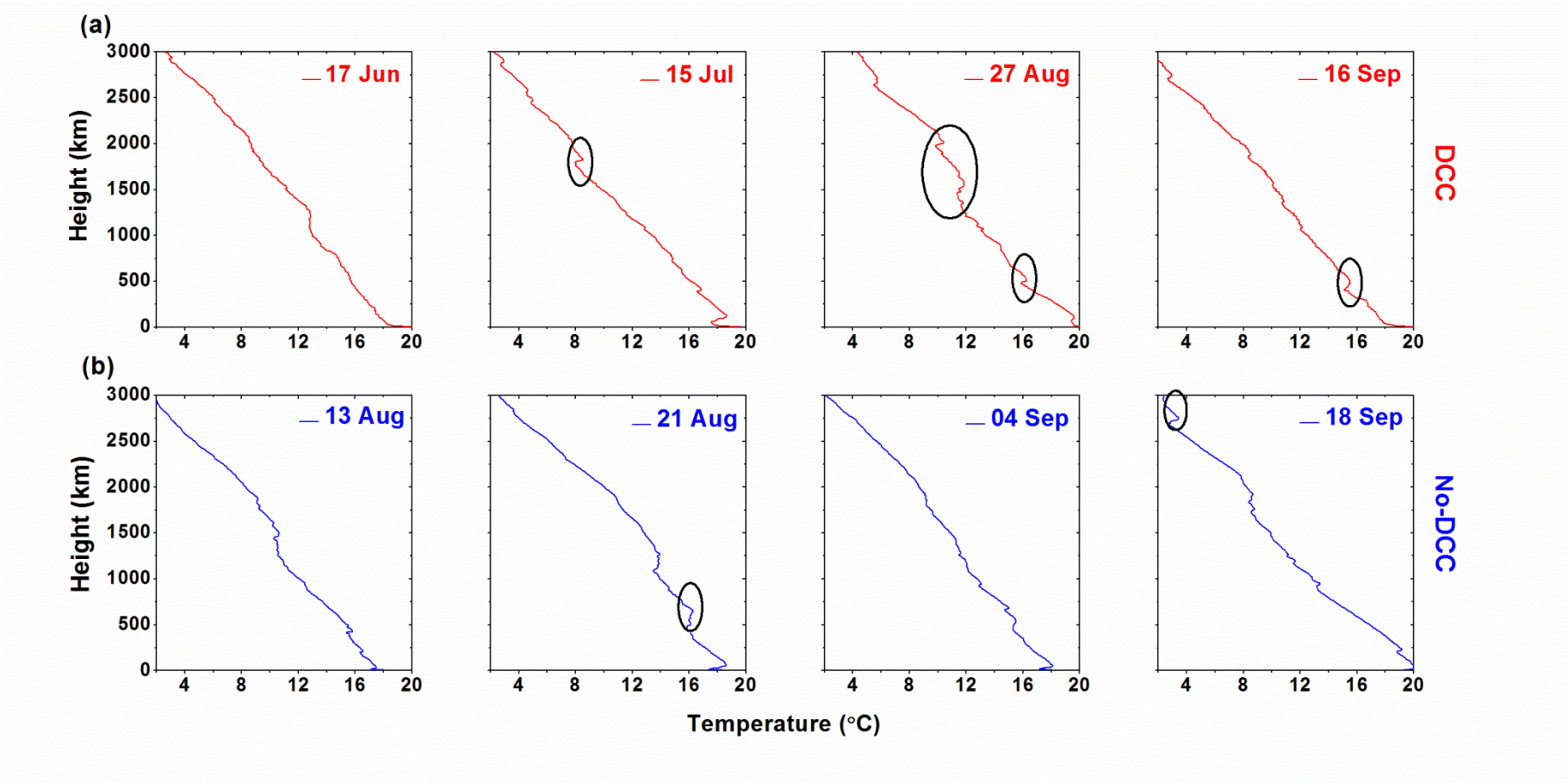


AOD x CODice: r=0.58
AOD x CIP: r=0.43

Increase in Ice Clouds with Aerosols

PBL Temperature

Radiative Effect



More inversion events during DCCs compared to No-DCC events.
The diurnal variation could be even very different during the two cases!

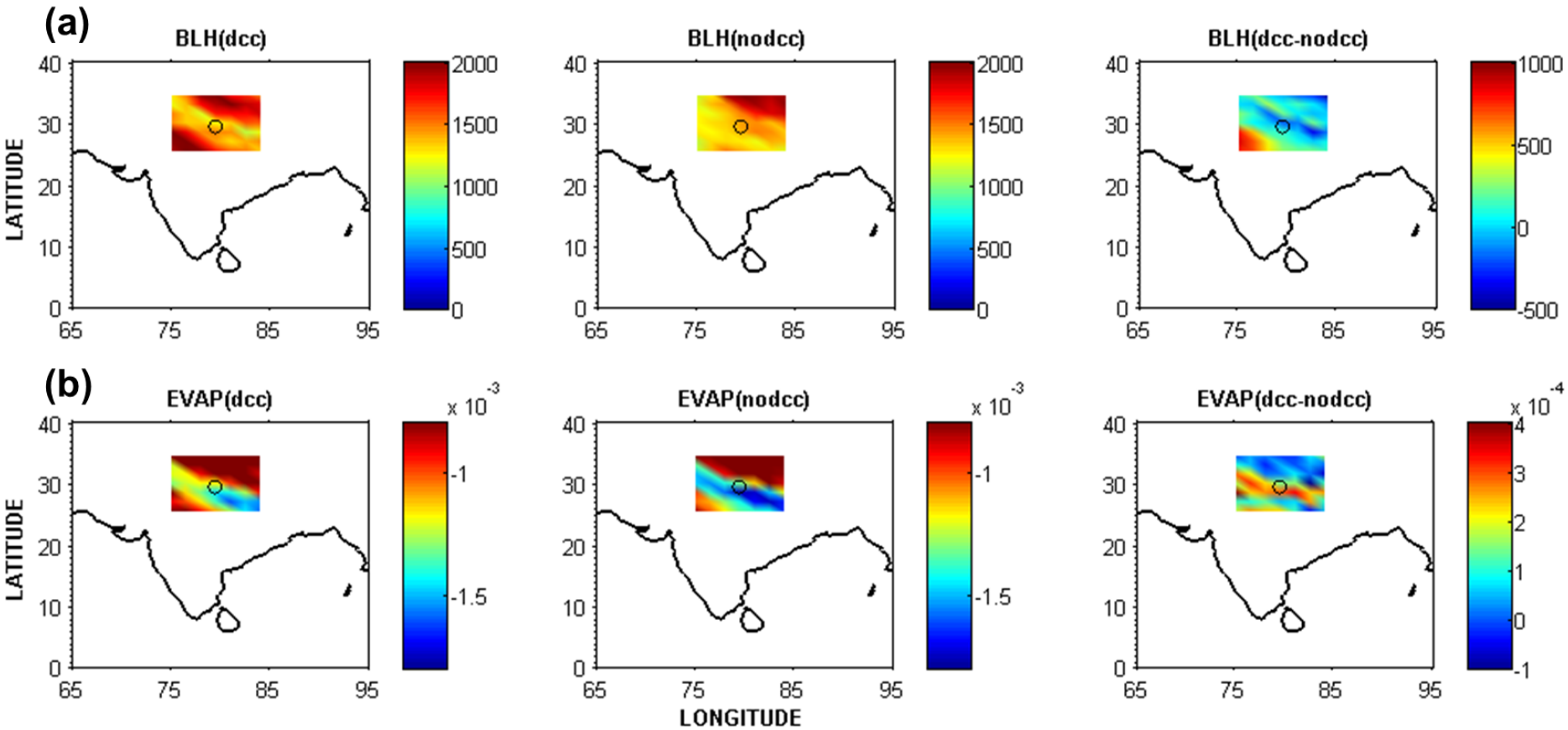
However profiles 1-2 hours prior to convection for DCCs.

Aerosols modulate the BL stability

PBL height and Evaporation

Radiative Effect

Increase in PBL height during DCC formation
Evaporation is reduced, but marginally

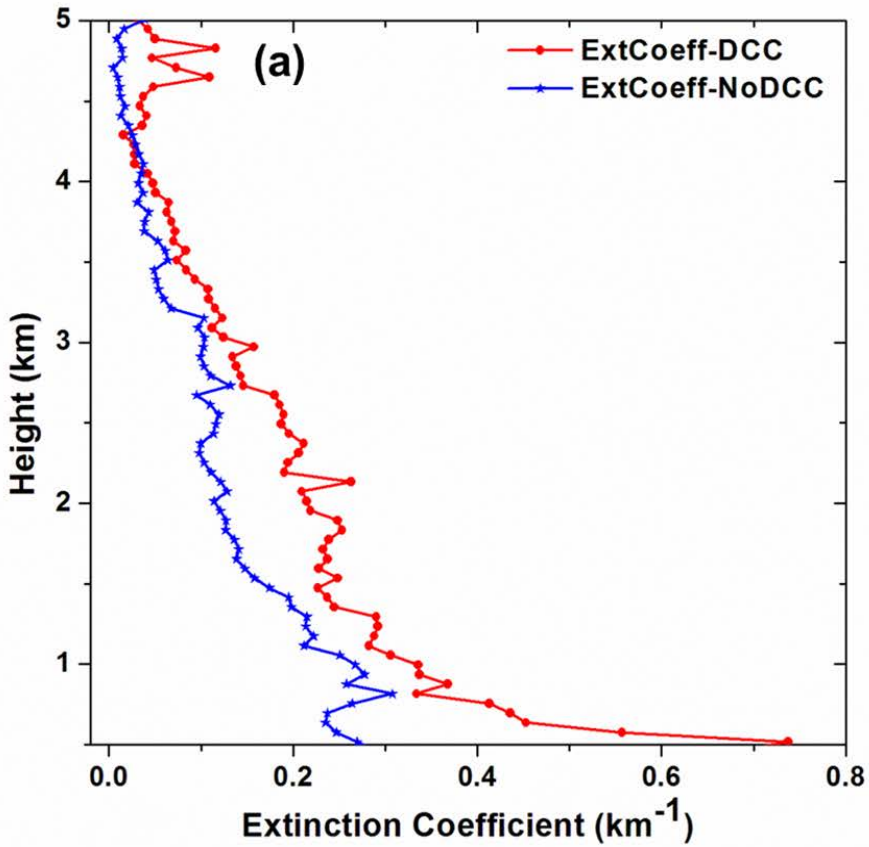


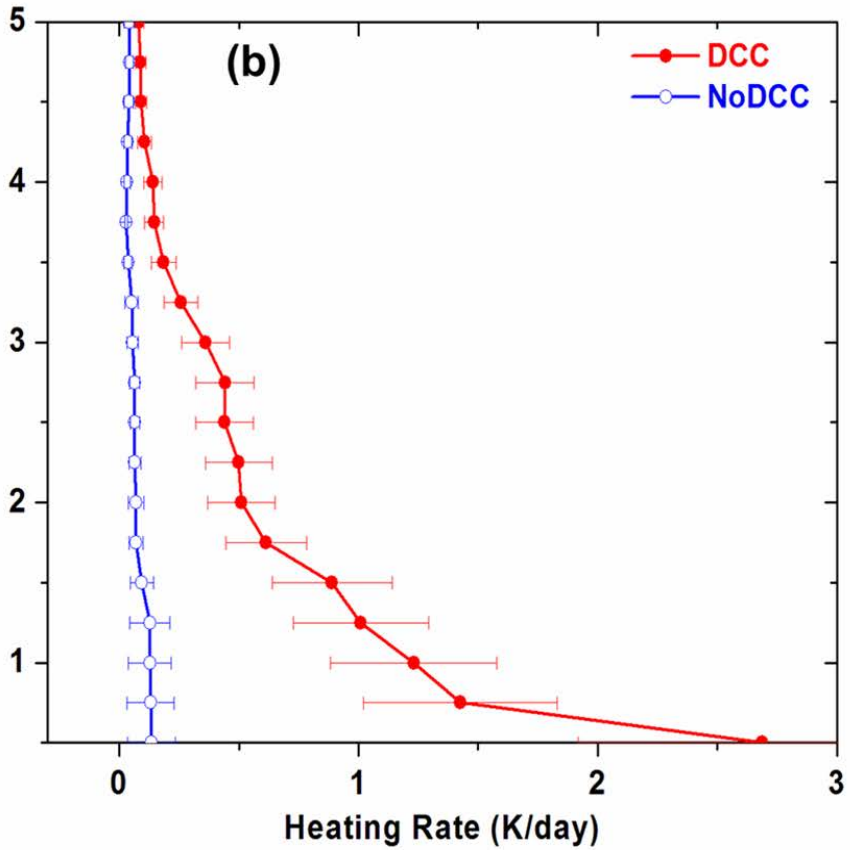
Convection, sometimes, not exactly centered at Nainital

Aerosols modulate the BLH & Evaporation

Radiative Effect

PBL HR





More aerosols in the PBL during DCCs (CALIPSO)

Considerable increase in PBL HR during DCCs

Aerosols heat the lower atmosphere

The Moist Static Energy:

A variable representing a parcel's thermodynamics state

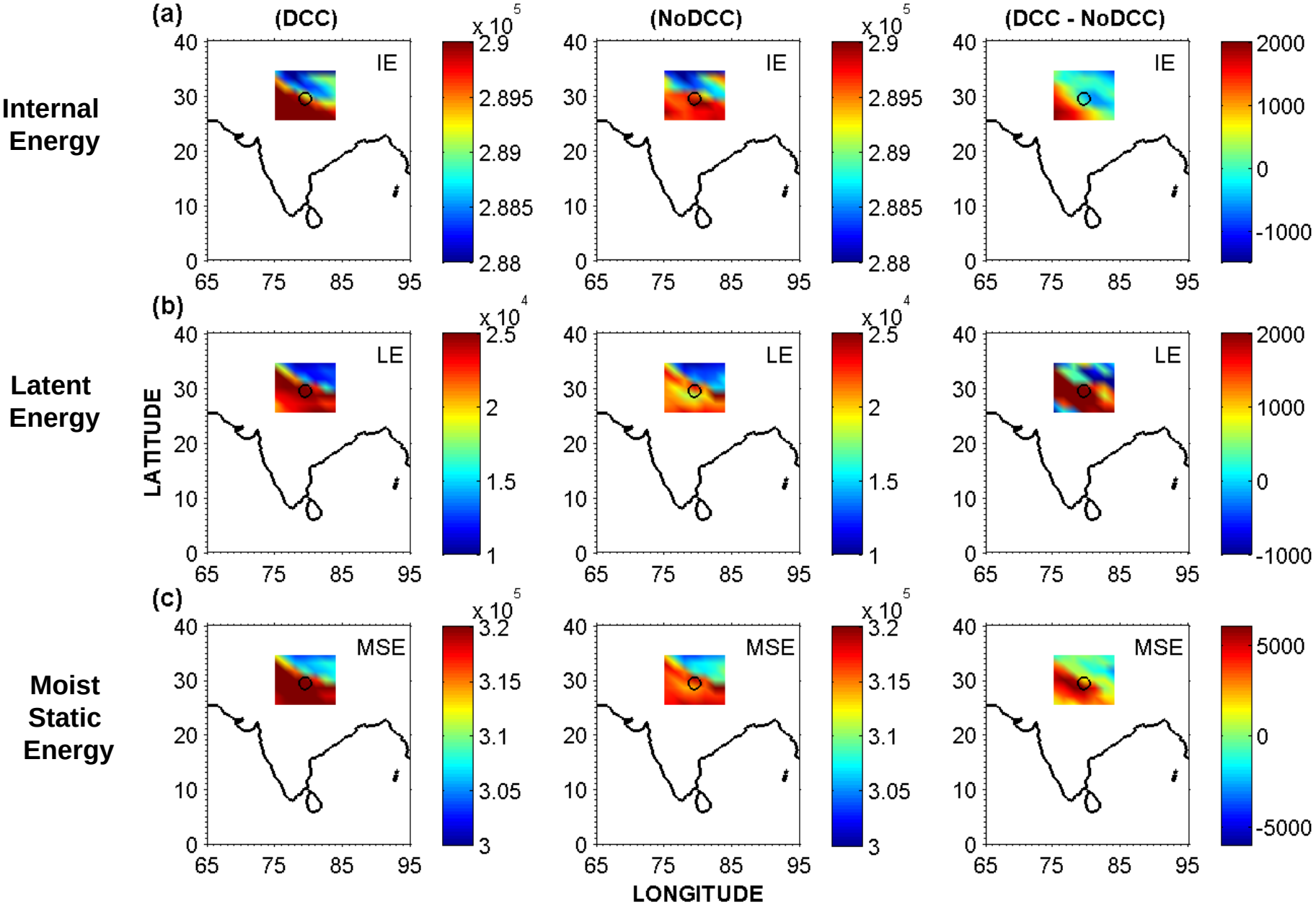
$$MSE = C_p \times T + g \times z + L \times q$$

(IE) (PE) (LE)

***C_p*-Specific heat of moist air**
***T*- Dry bulb temperature**
***L*- Latent heat of vaporization**
***q*- Specific humidity**
***g*- Gravity**
***z*- Height**

Aerosols change the temperature and hence the MSE through direct effect, and lead to modification of thermal structure and stability.

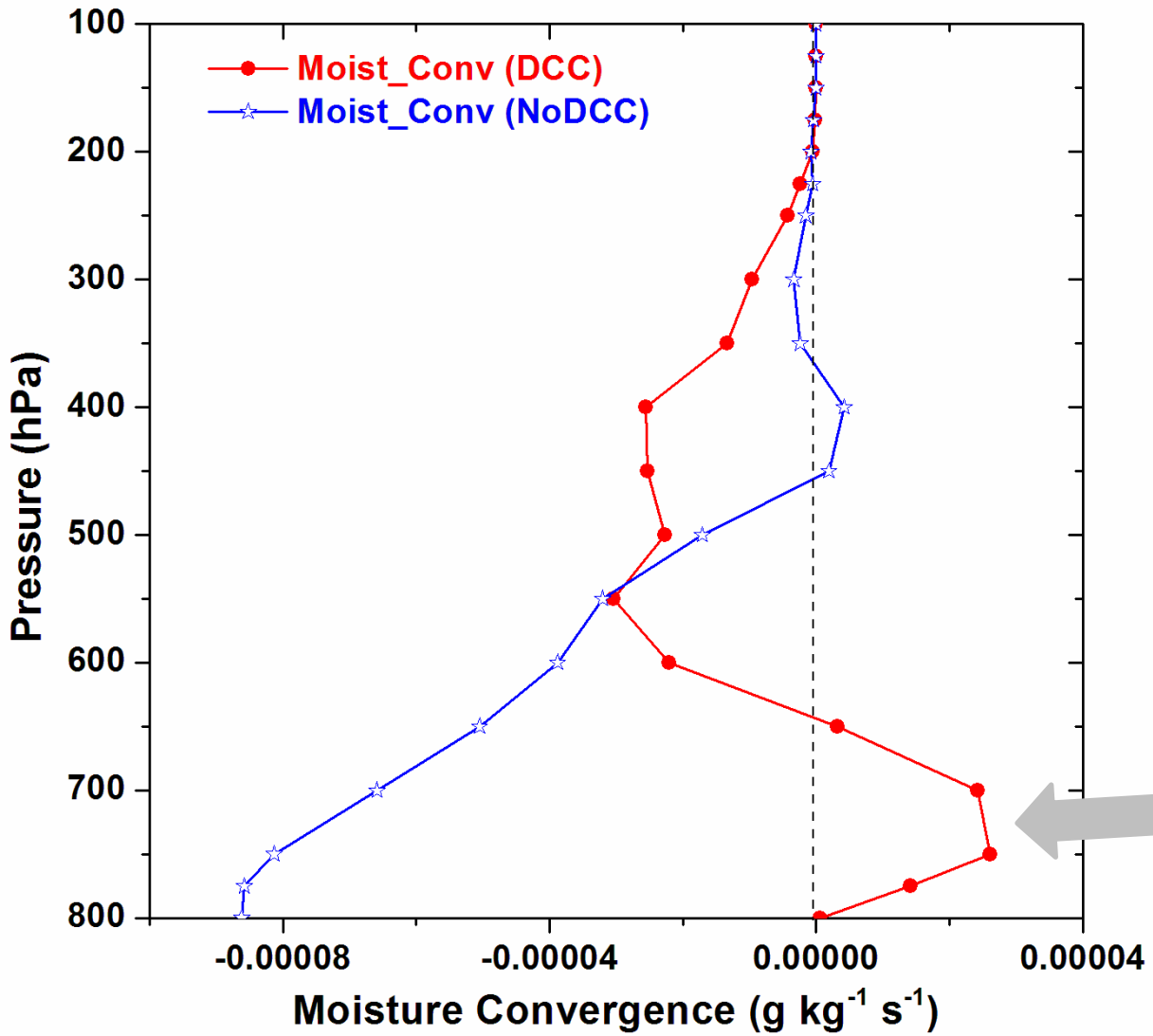
Radiative Effect



Aerosols increase the MSE through direct effect

Dynamical feedback

Radiative Effect: Feedback



ERA Interim Data

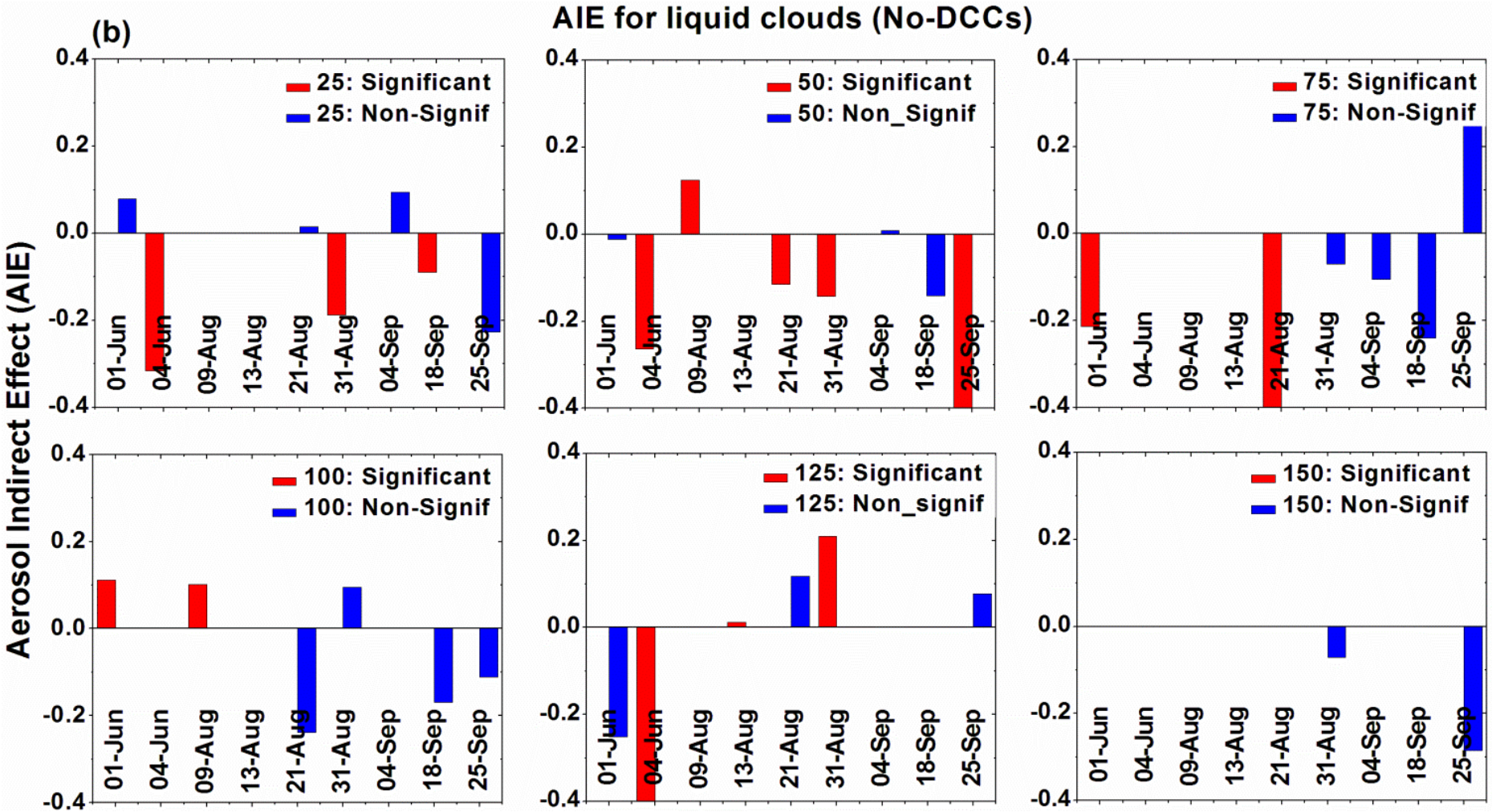
$$MC = \frac{\partial(uq)}{\partial x} + \frac{\partial(vq)}{\partial y}$$

Enhanced moisture convergence; less dense air below

Aerosols lead to dynamical feedbacks which helps to overcome stabilization

Indirect effect and possible invigoration

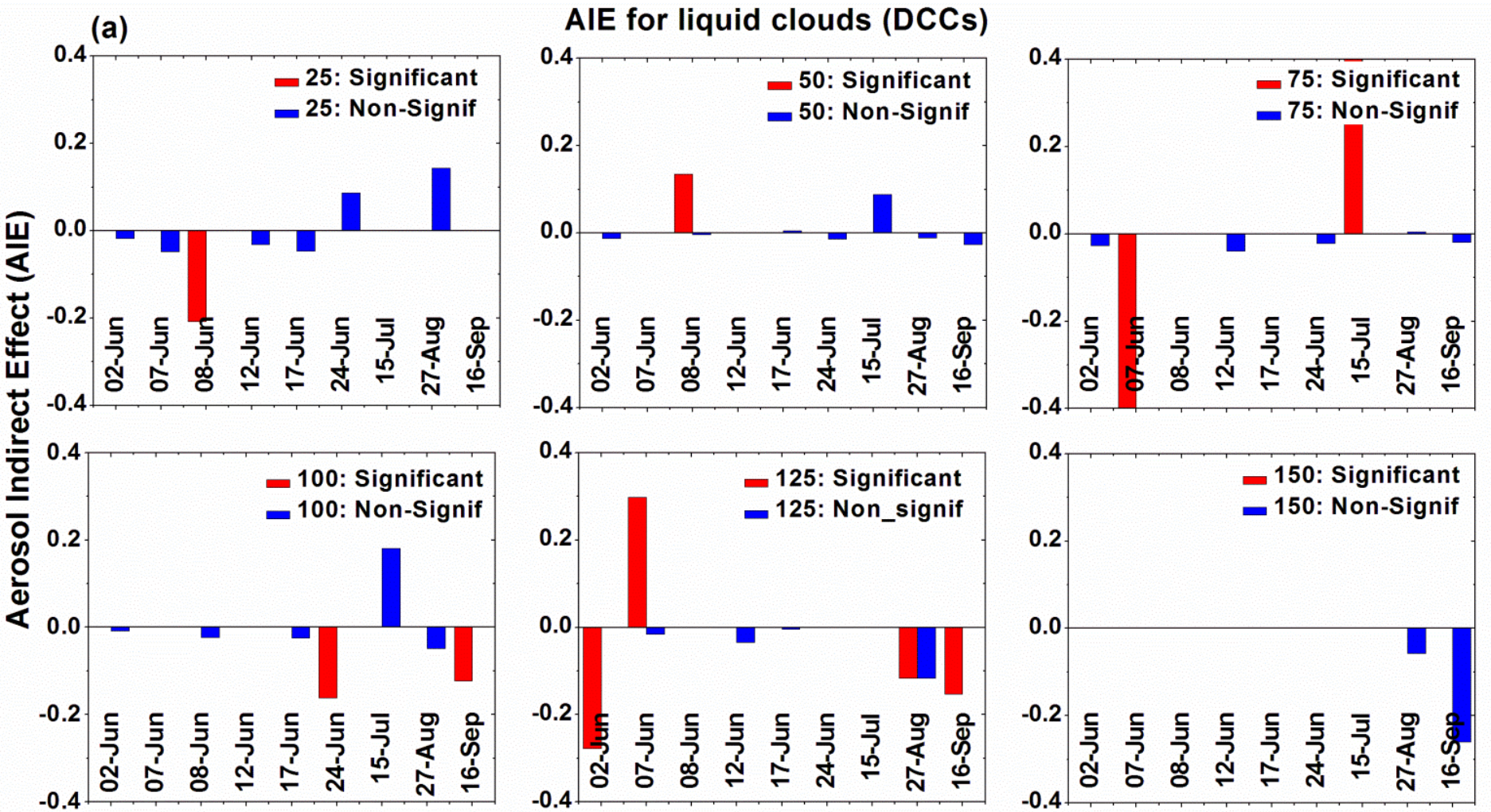
Microphysical Effect



Anti-Twomey effect high for No-DCCs.
Opposite observed for DCCs.

No warm rain suppression in No-DCCs

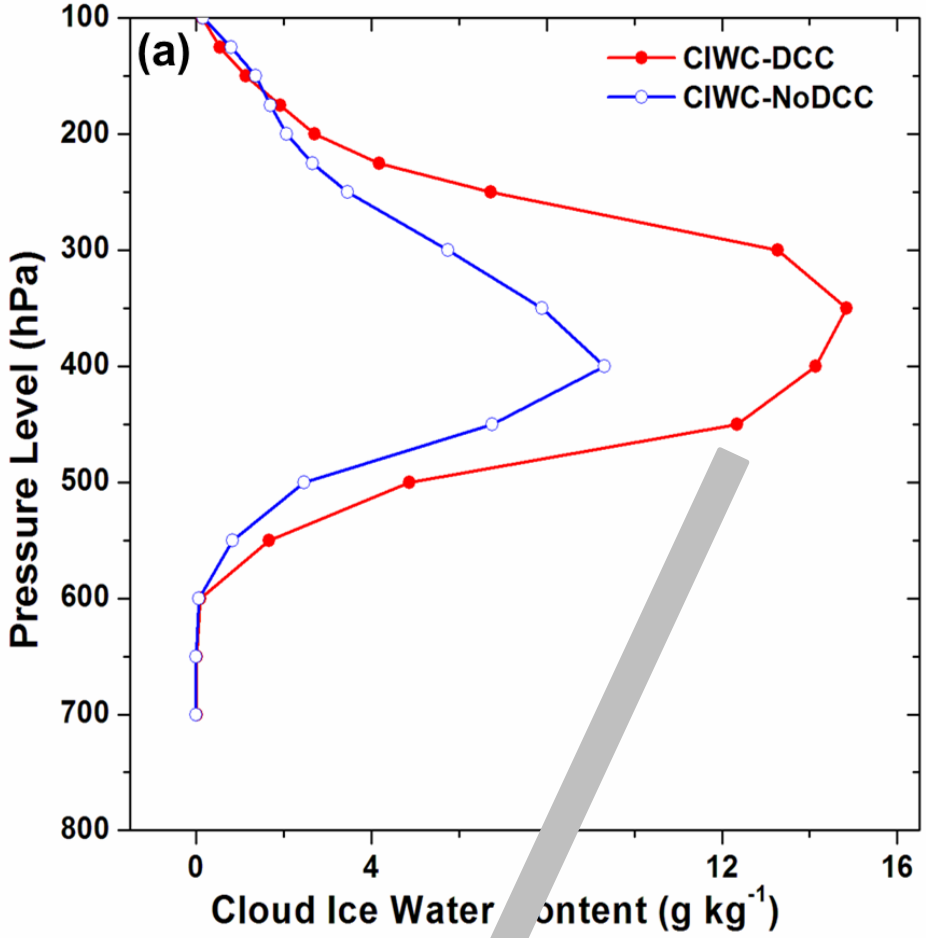
Indirect effect and possible invigoration: (Continued…)

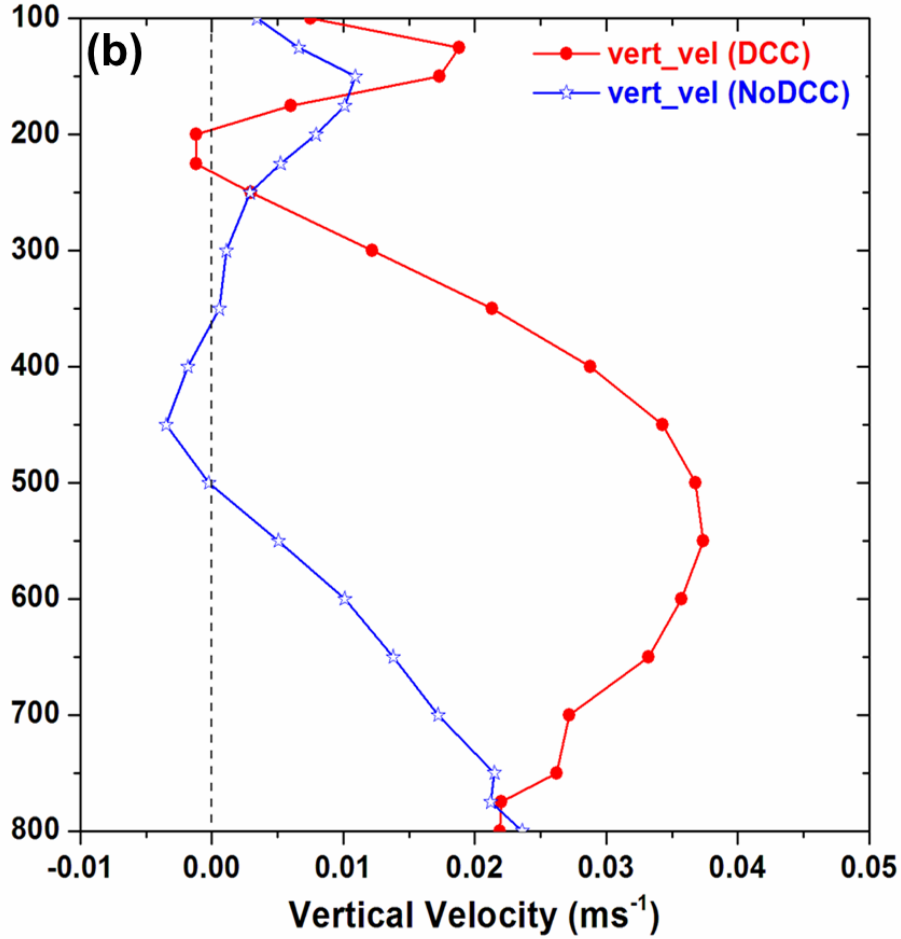


Weak tendency towards Twomey effect high for DCCs.

Weak warm rain suppression for DCCs

Microphysical Effect





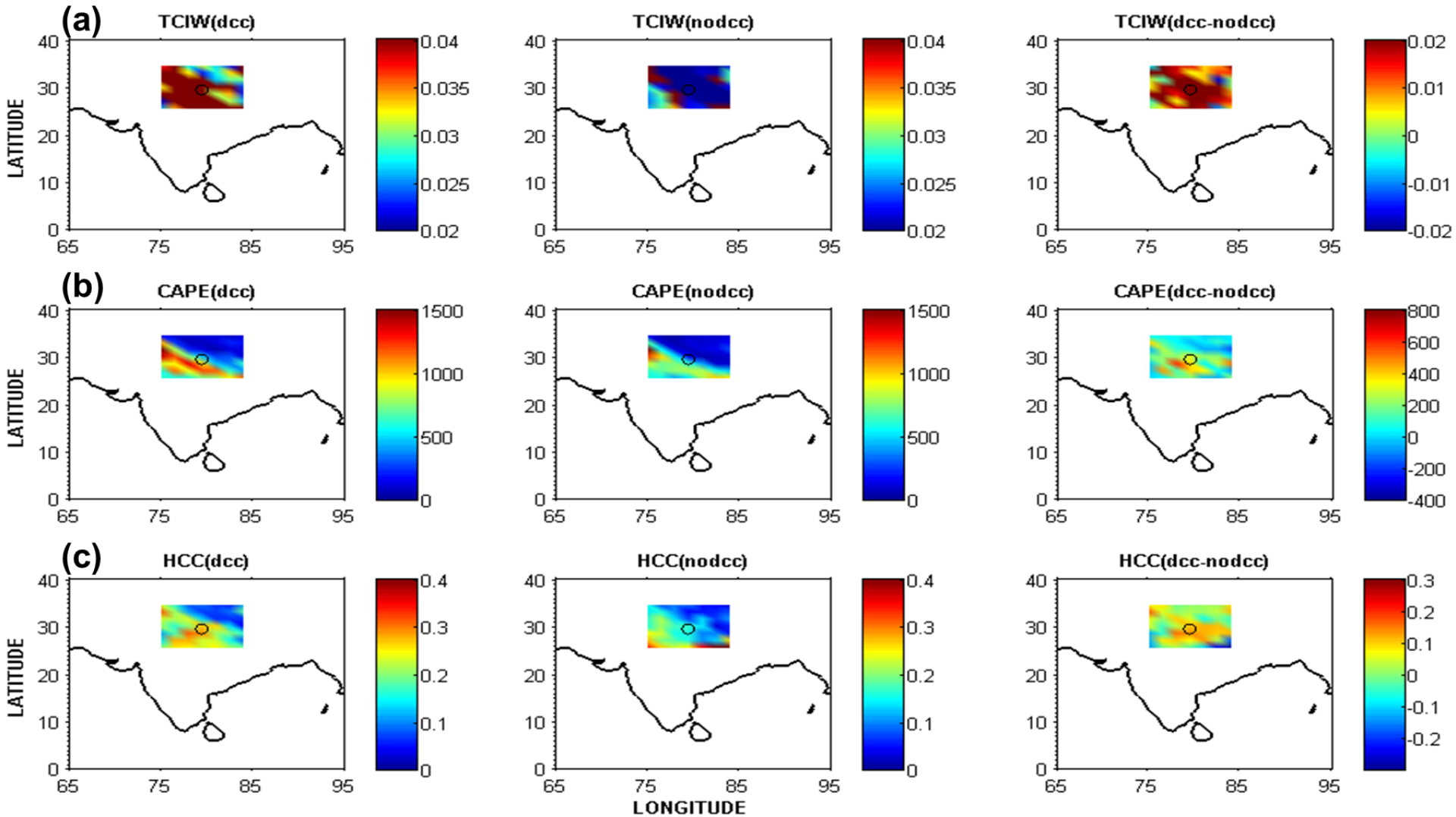
Enhanced CIWC for DCCs

Enhanced vertical velocity during DCCs (ERA Interim)

Indication of microphysical invigoration in DCCs

Composites of spatial pattern of TCIW, CAPE & HCC

Microphysical Effect

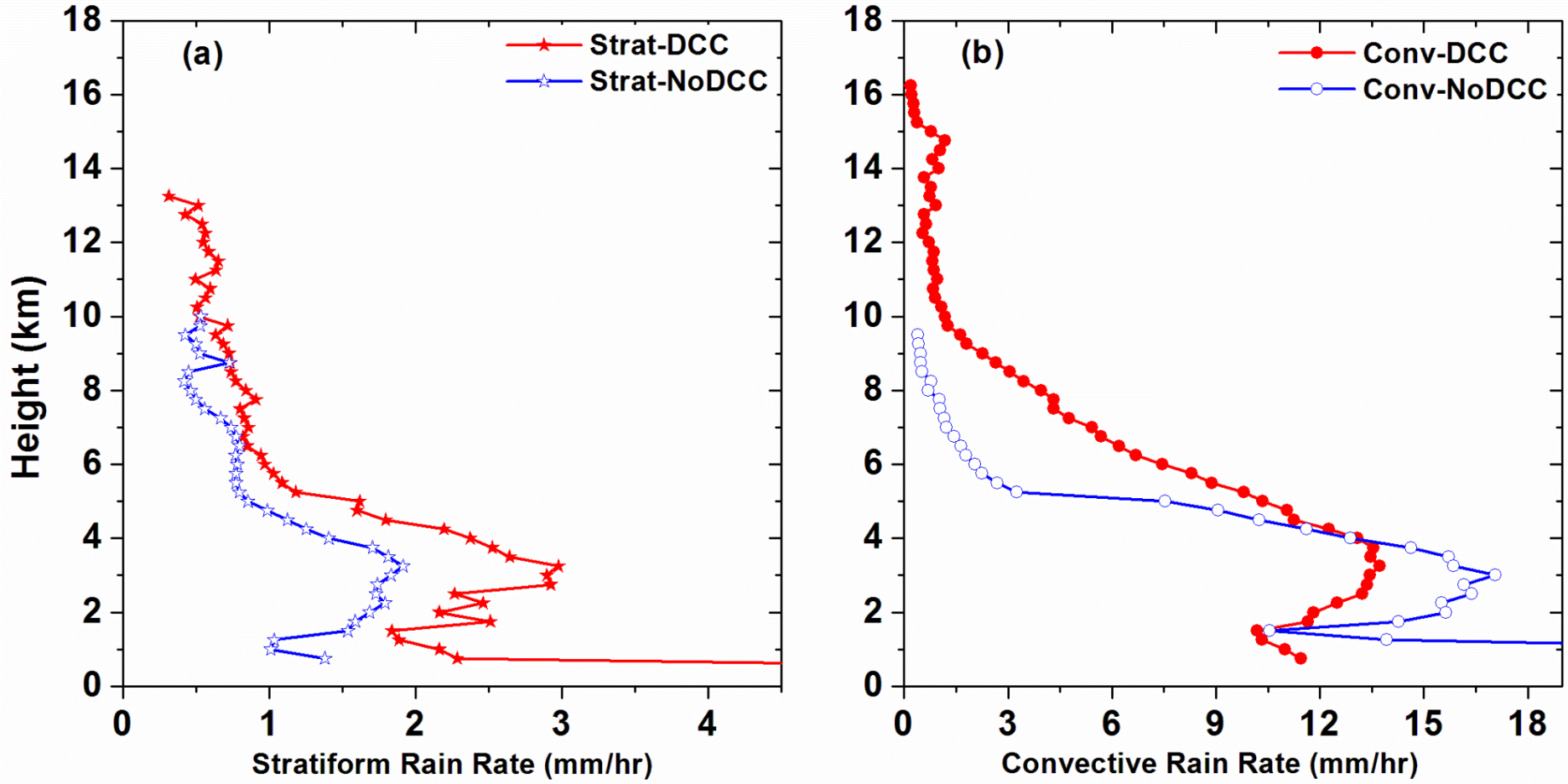


TCIW, CAPE and HCC more for DCCs → Strengthened convection

Indication of microphysical invigoration in DCCs

Convective and Stratiform fraction

Microphysical Effect



Stratiform rain fraction is not affected by aerosols for No-DCCs.

Convective warm rain fraction is more for DCCs.

Indication of convective warm rain suppression and microphysical invigoration in DCCs

Conclusion

The study proposes the following results during DCCs:

1. **A seminal role of aerosols in increasing the MSE through enhancement of both IE & LE of the lower atmosphere is identified as a primary feature that supersedes the stabilization effect.**

2. **Dynamical feedback in the form of enhanced MC to increased aerosol heating, thereby overcoming the stabilization effect.**

3. **The increase in vertical velocity at the middle levels could be partly attributed to the invigoration effect due to weakened anti-Twomey effect.**

4. **The significant correlation between aerosol and high clouds suggests that the aerosol direct effect in stabilizing the PBL is overcome by the combined effect of increased MSE and MC; and to a lesser extent by aerosol microphysical effect.**

5. **A comprehensive study by incorporating observations and model sensitivity tests are necessary to understand the intricate feedbacks arising from radiative and microphysical processes under different environmental conditions.**

Thank You!