Aerosol – monsoon interactions in the Nepal Himalayas

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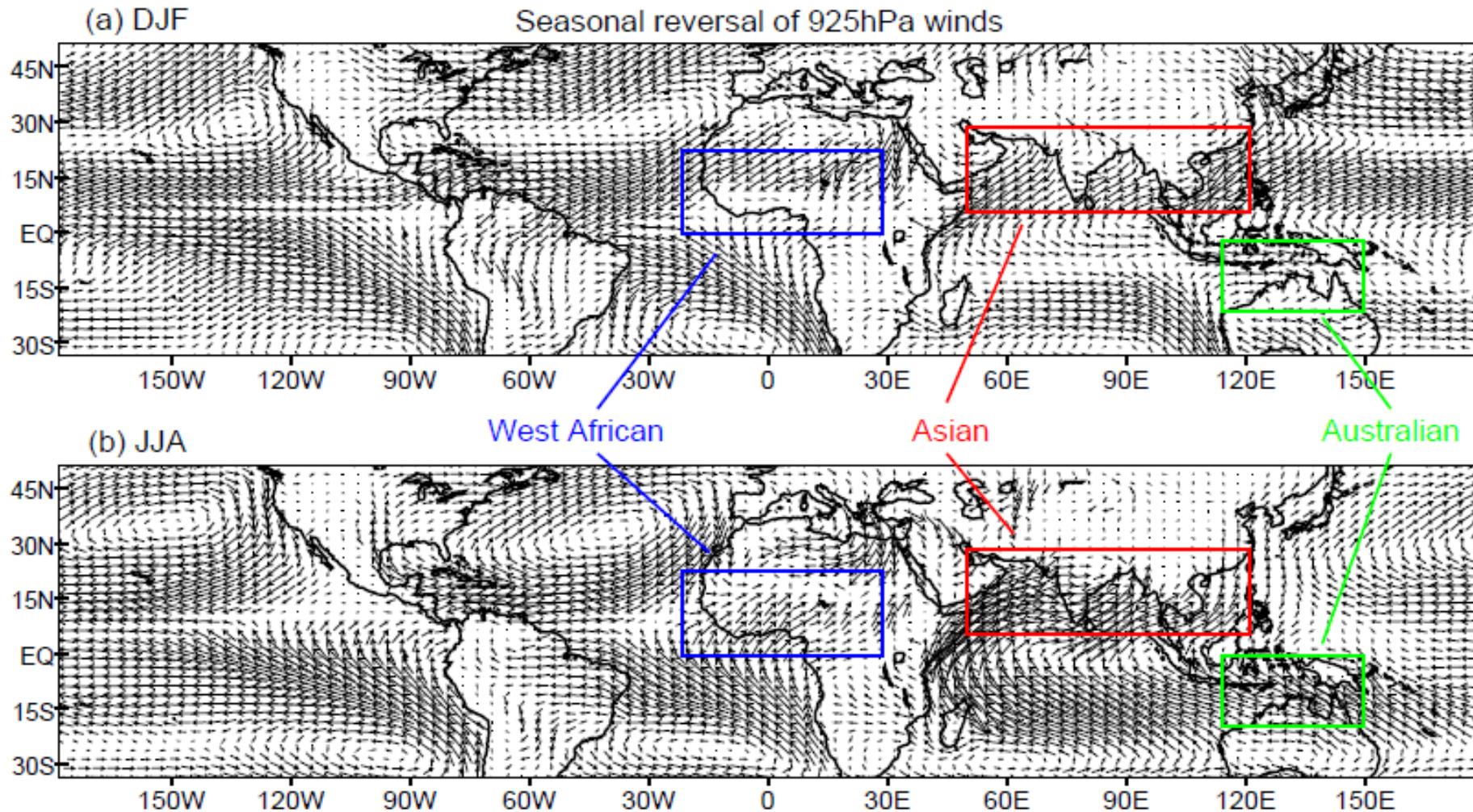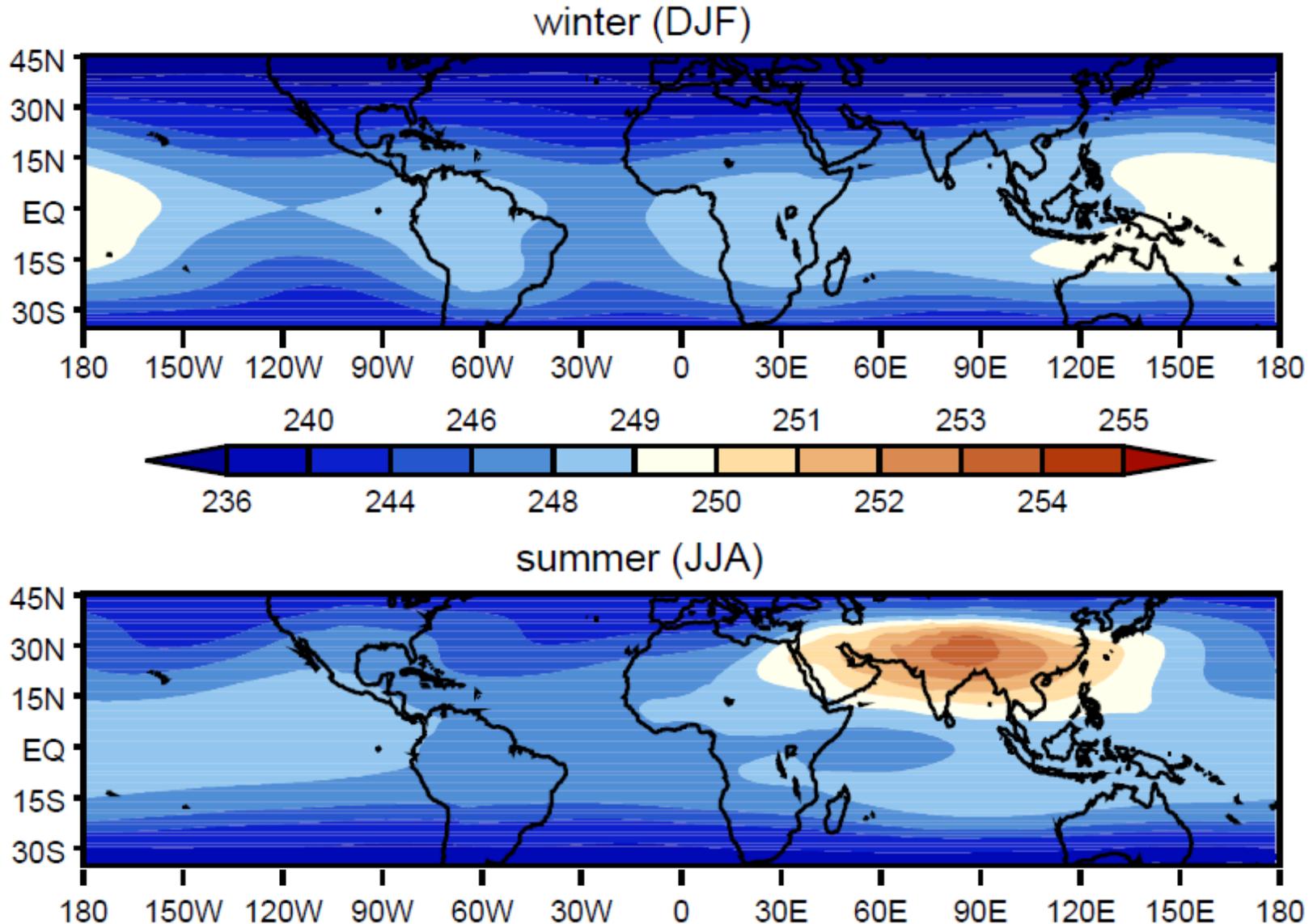**[2] Center for Atmospheric Science, University of Manchester, Manchester, UK**

Overview

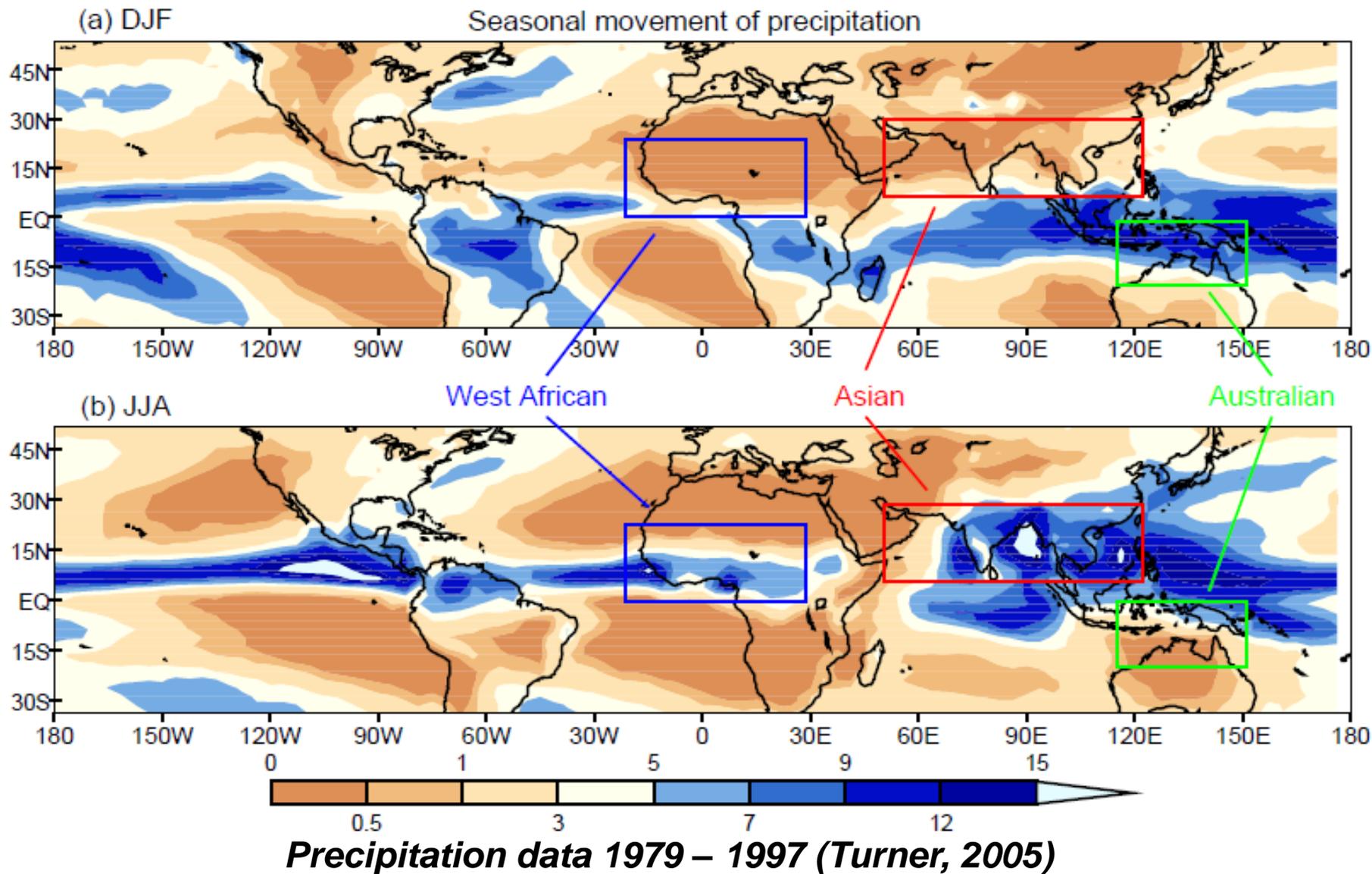- ❑ Monsoon mechanisms
- ❑ Motivation
- ❑ WRF model simulations
- ❑ Summary

Monsoon mechanism

(a) DJF — Seasonal reversal of 925hPa winds

West African   Asian   Australian

(b) JJA

10

ERA-40 Analysis 1958 – 1997 (Turner, 2005)

winter (DJF)

summer (JJA)

ERA-40 Analysis (200-500hpa) temp. (Turner, 2005)

Precipitation data 1979 – 1997 (Turner, 2005)
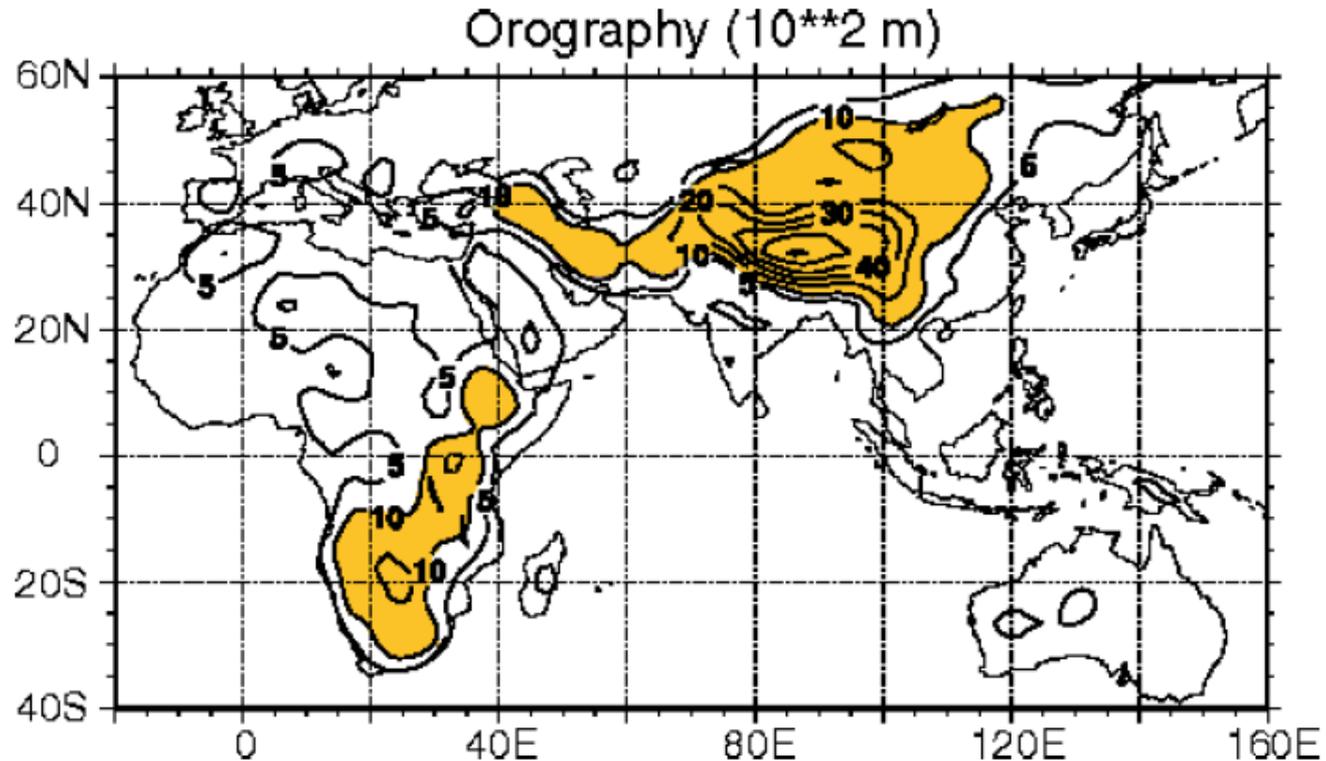
Topography

Figure 11a.(a) Orography and the south Asian summer monsoon. Orographic structure of the eastern hemisphere (units are 102 m). The Indian Ocean is surrounded by the East African Highlands to the west and the Himalayan Mountains to the north. Australia, on the other hand, is devoid of major orography. Orography with elevations >1 km are shaded. .
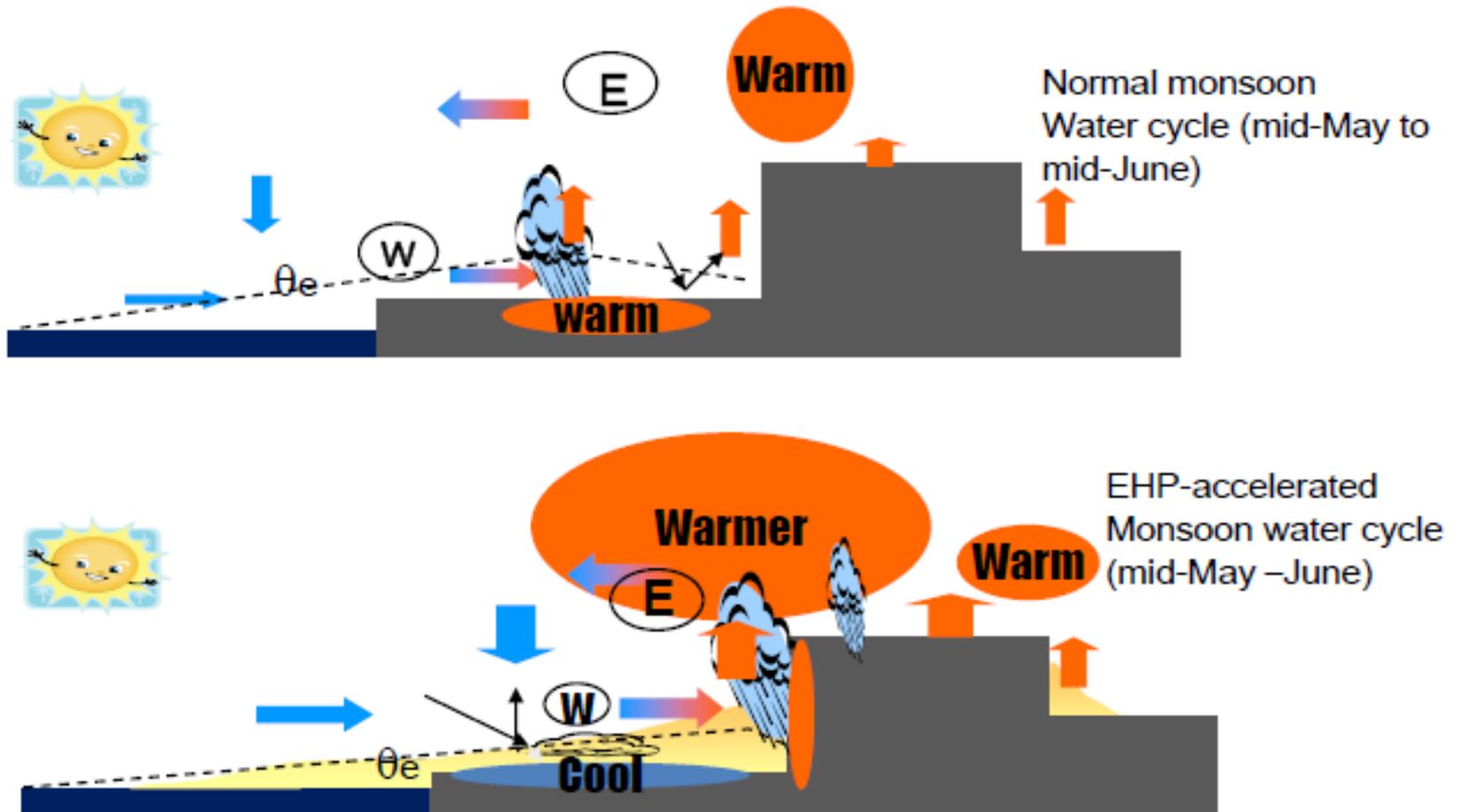
(Webster et. al. 1988)

Aerosol

Delayed warm rain, and prolonged cloud life time by aerosols in a monsoon (moisture-rich) environment may invigorate deep convection
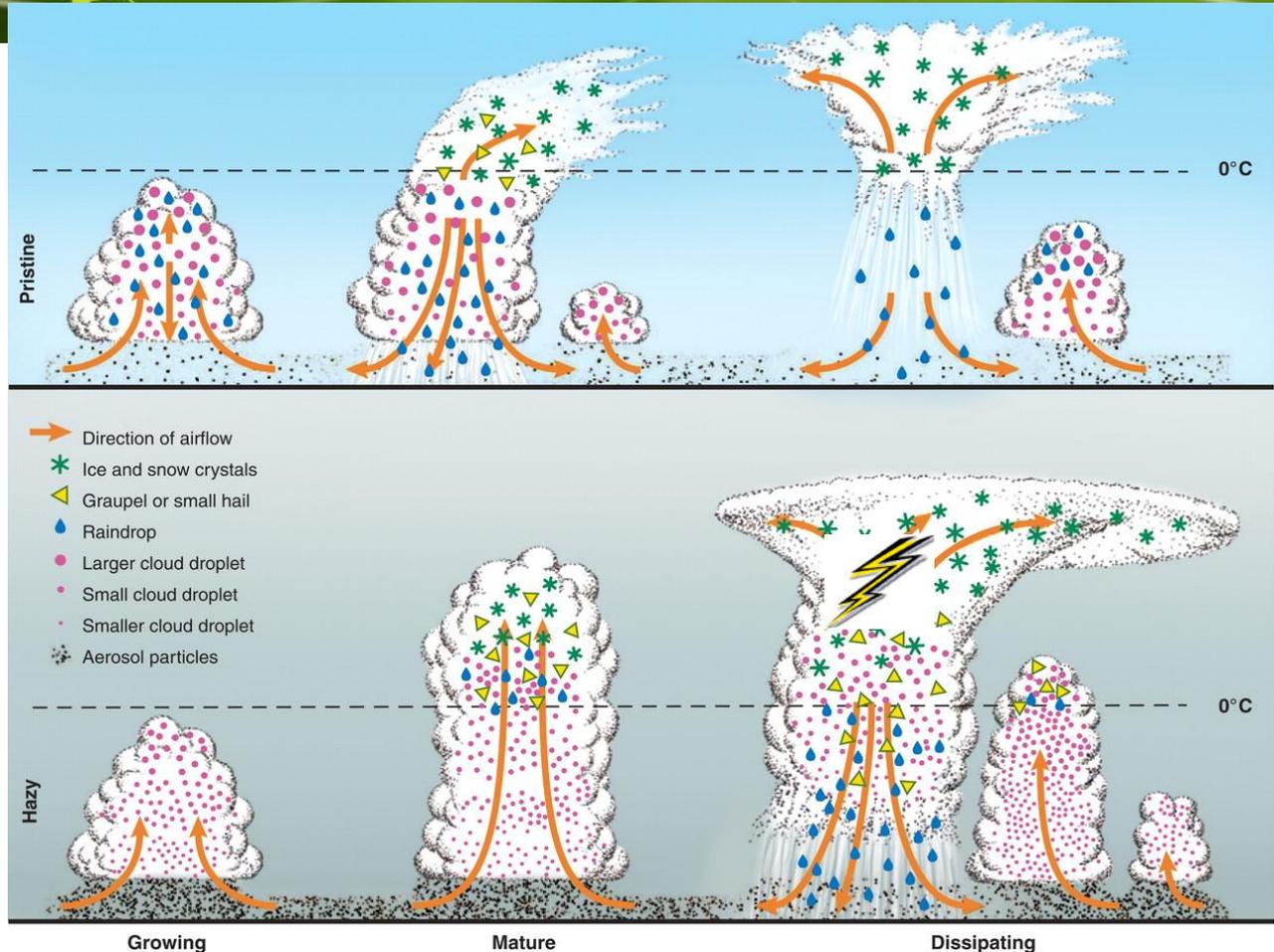
(Rosenfeld et al., 2008)

Elevated Heat Pump (EHP) Hypothesis

*(Lau et al., 2006)*

Other factors such as ENSO, MJO etc…

Motivation: Understanding of the Indian monsoon

❏ The Himalaya region is also known as 'third pole' or 'water tower of Asia' due to its huge reserves of ice.

❏ Over 1.3 billion people in the region are dependent on monsoon precipitation for agriculture and hydro-electricity.

❏ Advected aerosols from the Indo-Gangetic plains are thought to play a significant role in modulating orographic precipitation in the foothills of the Himalayas.
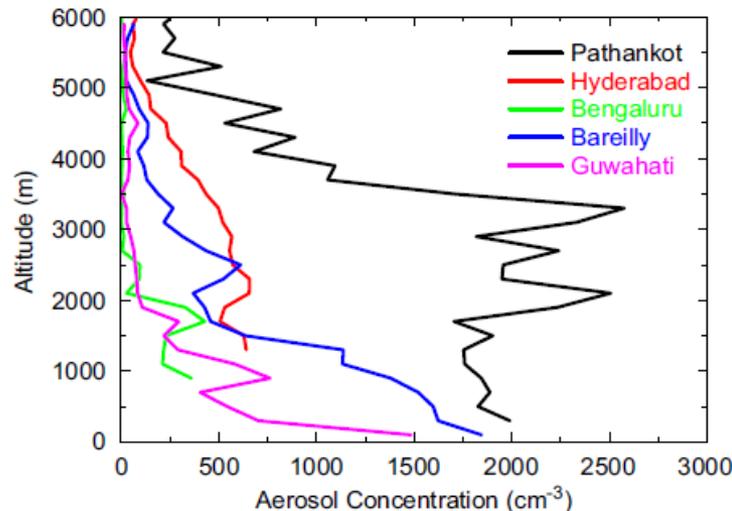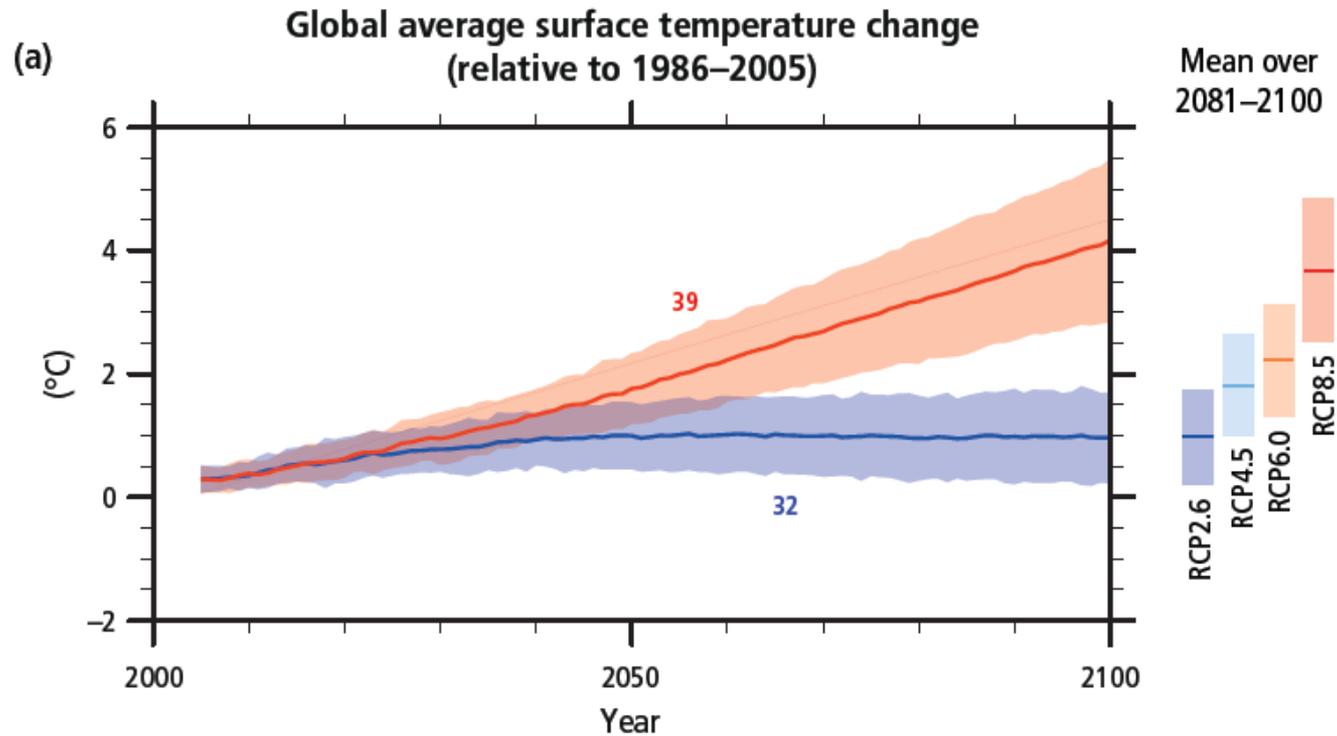

(Morwal et al, 2012)
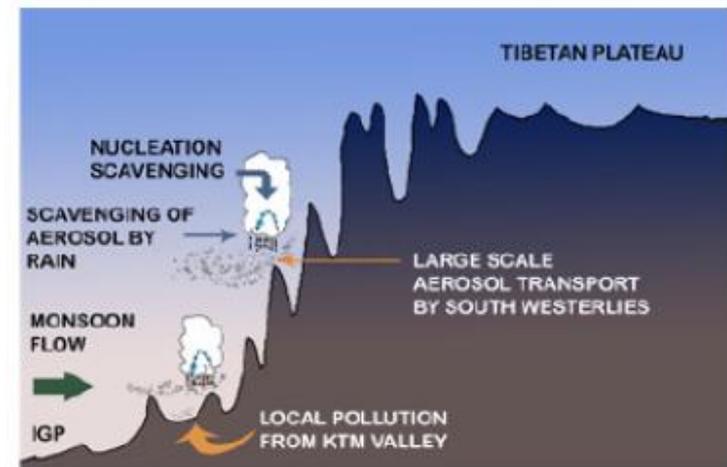
(Shrestha and Barros, 2010)
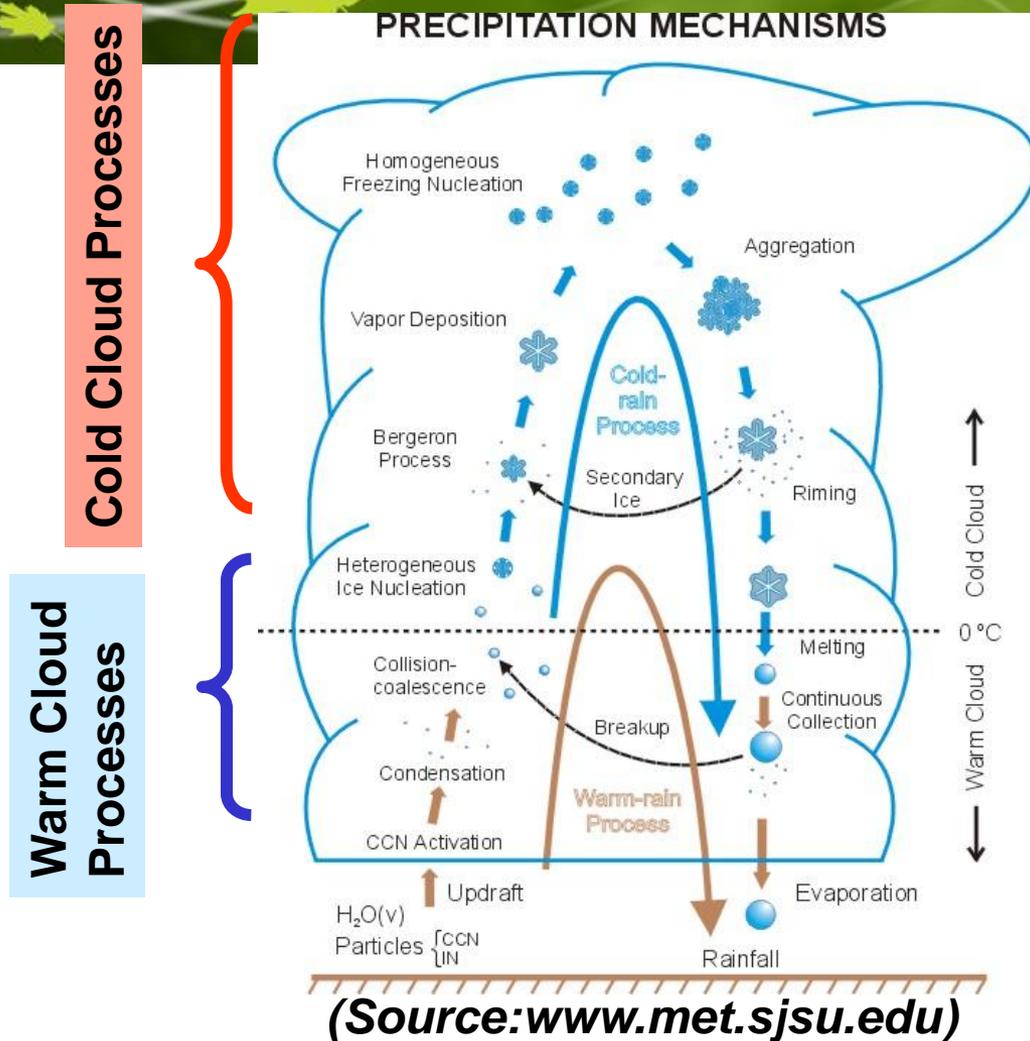
Motivation: Understanding the Indian Monsoon

(IPCC, 2014)

Future rises in the global temperature increase the moisture holding capacity of air, the '**Clausius-Clapeyron effect**'.

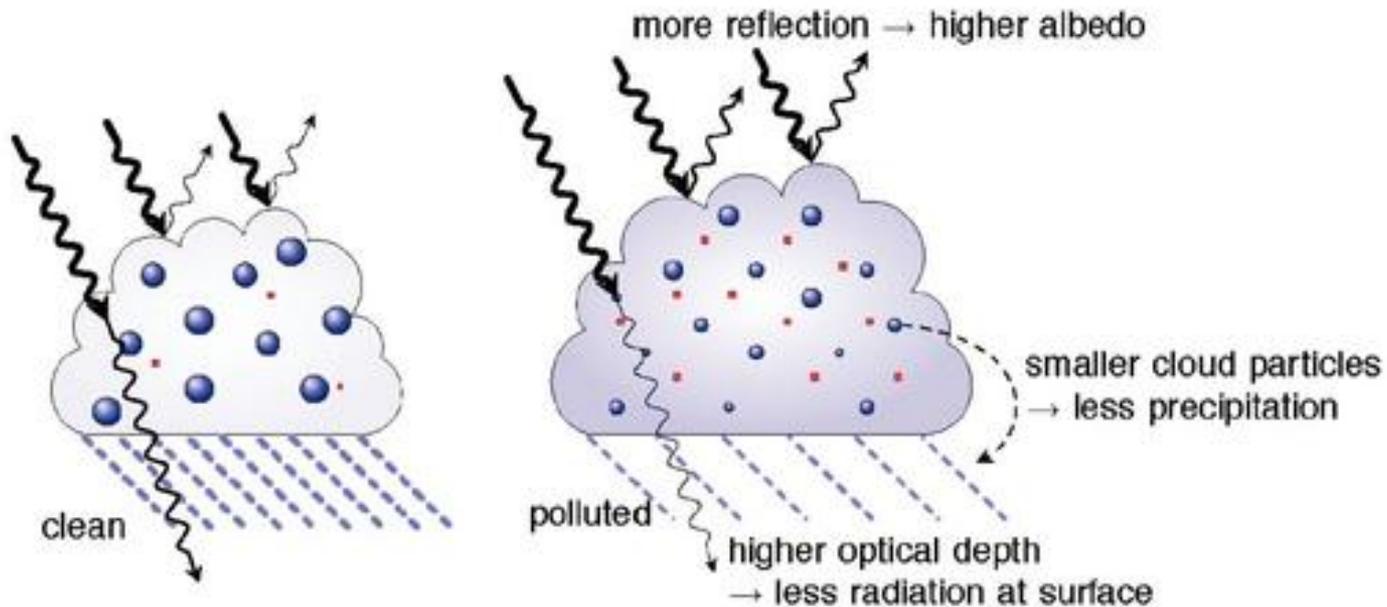# Model Simulations: microphysical processes

PRECIPITATION MECHANISMS

Cold Cloud Processes

Warm Cloud Processes

Homogeneous Freezing Nucleation

Aggregation

Vapor Deposition

Cold-rain Process

Bergeron Process

Secondary Ice

Riming

Heterogeneous Ice Nucleation

0 °C

Melting

Collision-coalescence

Continuous Collection

Breakup

Condensation

Warm-rain Process

CCN Activation

Cold Cloud

Warm Cloud

H₂O(v) Particles {CCN, IN}

Updraft

Evaporation

Rainfall

(Source:www.met.sjsu.edu)

Aerosol indirect effects

Increased CCN concentration increases cloud albedo (Twomey or 1st indirect effect) which in turn reduces precipitation efficiency (Albrecht or 2nd indirect effect)

Cloud albedo and lifetime effect (negative radiative effect for warm clouds at TOA; less precipitation and less solar radiation at the surface)

more reflection → higher albedo

smaller cloud particles → less precipitation

clean

polluted

higher optical depth → less radiation at surface

Warm cloud direct and indirect effects

(IPCC, 2007)

The Clausius–Clapeyron relationship

❑ Relationship between temperature and moisture holding capacity of atmosphere.

❑ At constant relative humidity, specific humidity is increased by 7% K^{-1}

❑ In a warming climate this increases the potential for heavy precipitation in storms.

❑ This is because there is enhancement by additional latent heat release which invigorates the storm.
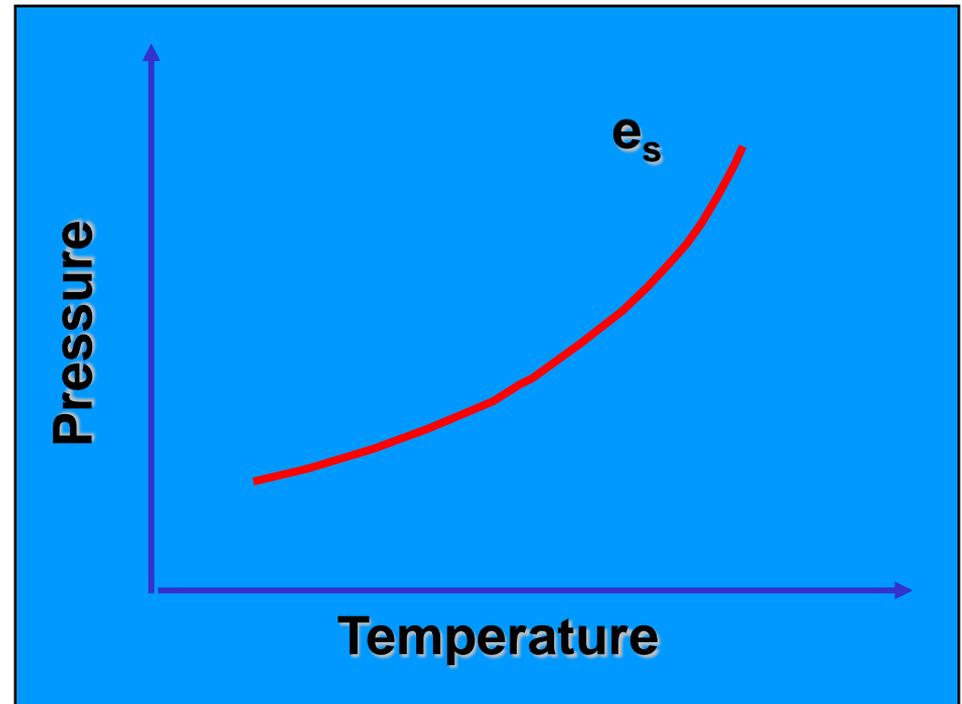
Key questions

❑ How will the monsoon precipitation be affected by pollution and global warming?

❑ How sensitive is the monsoon to perturbations in aerosol and temperature?

❑ How is the spatial distribution of the monsoon affected by aerosol perturbations?

Experimental Design

- ❑ WRF V3.1 model, 3 nested domains: 27, 9, & 3km horizontal resolution, with 40 vertical layer, centred on central Nepal.

- ❑ The model is coupled with a bulk microphysics scheme, set up to resolve convective motions explicitly.

- ❑ Initial and boundary conditions from NCEP/DOE reanalysis II (2.5 x 2.5 deg.x 17; 1.875 x 1.875 deg.)

- ❑ Morrison Double Moment microphysics scheme
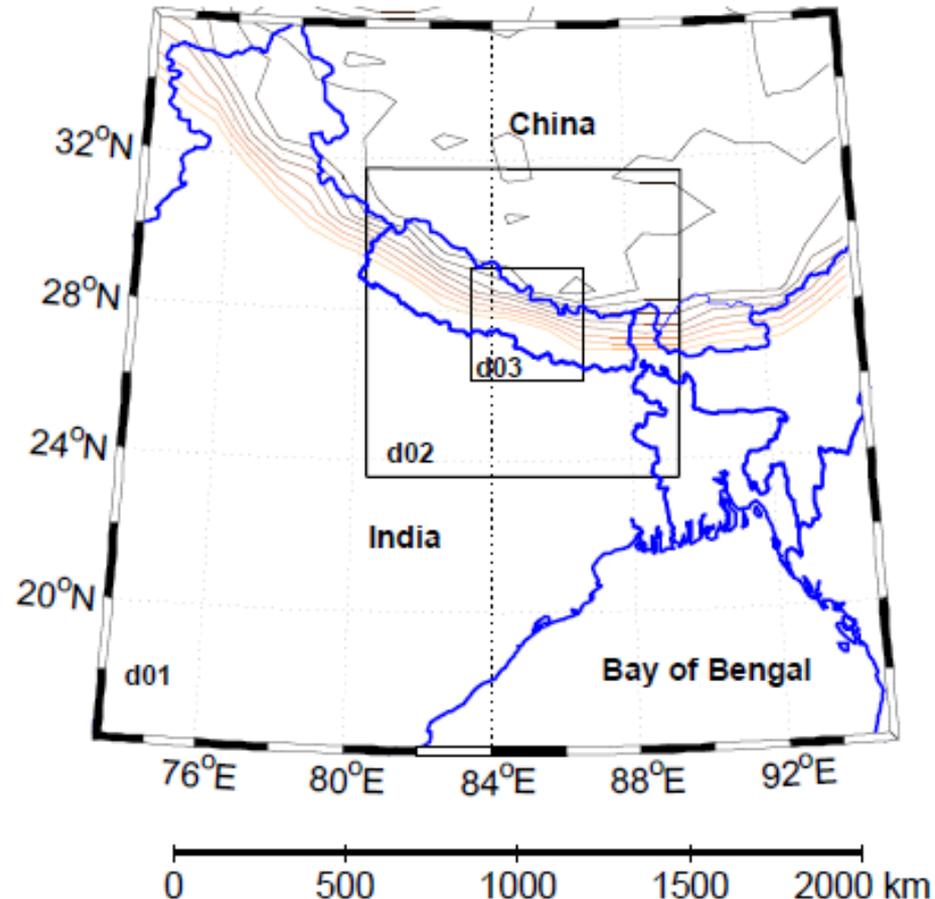
Experimental Design contd…

❑ Atmospheric moisture is altered by perturbing the temperature **i) uniformly and ii) randomly** across the atmosphere by modifying the code and holding the relative humidity constant. Uniform is perhaps more realistic though

❑ The aerosol is introduced in the model in three different scenarios: 'Low' – (500/cm^3), 'Medium' – (1500/cm^3) and 'High' – (3500/cm^3) concentrations.

❑ We modified the code to predict CCN as a function of time and height in the 'prognostic CCN' scenario. This is more realistic.

❑ The sensitivity of rainfall to changes in background aerosol and temperature was analyzed for three real-world case studies covering different seasons of the year with varying rainfall intensity.

❑ A total of 45 WRF simulations were produced and analysed.

Precipitation Sensitivity: Uniform Temp. perturbation
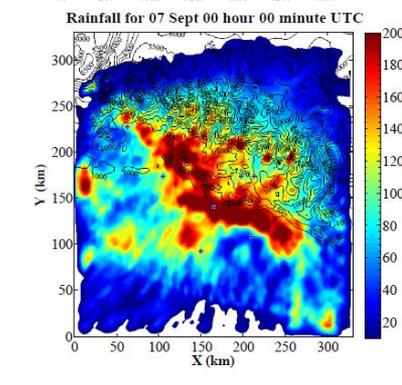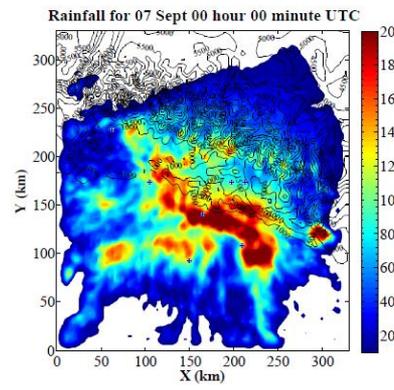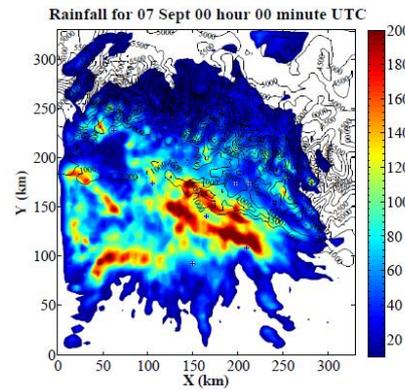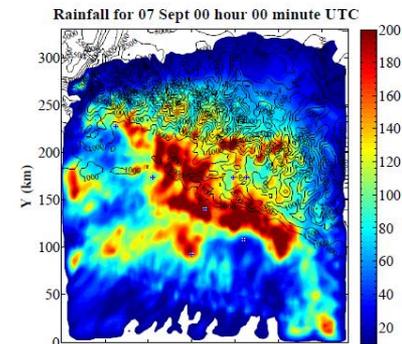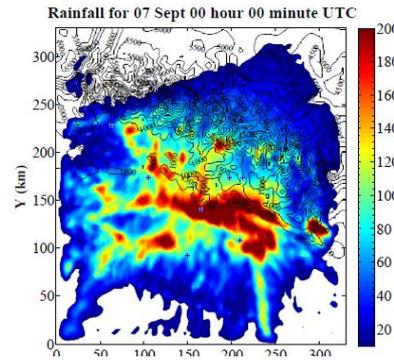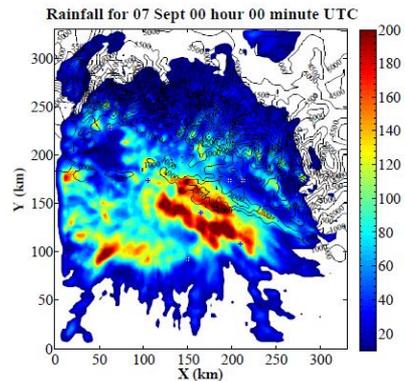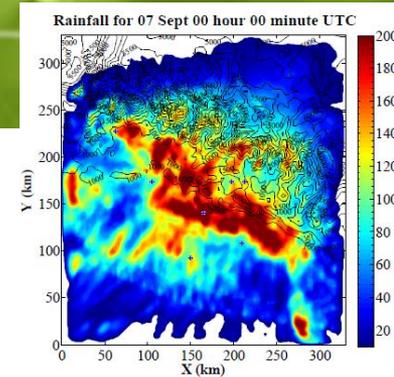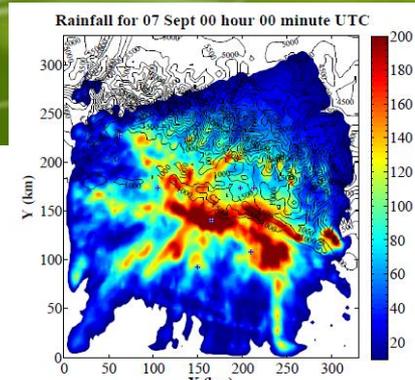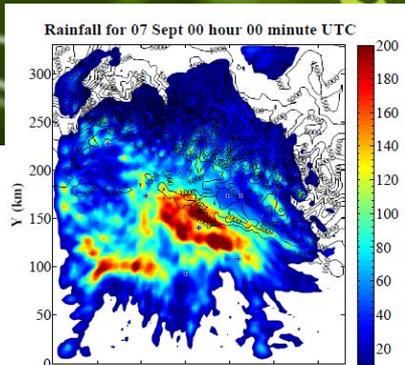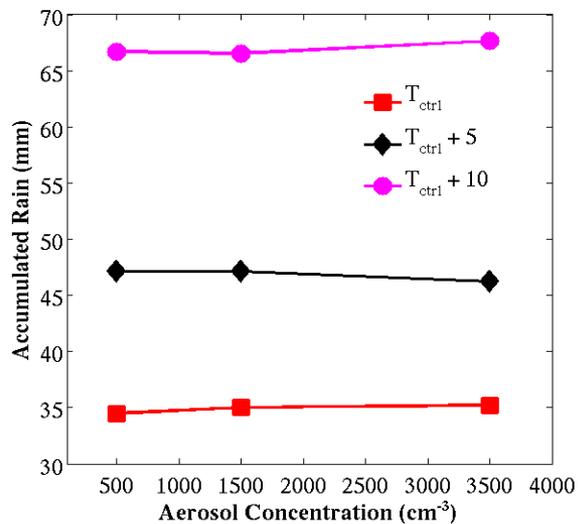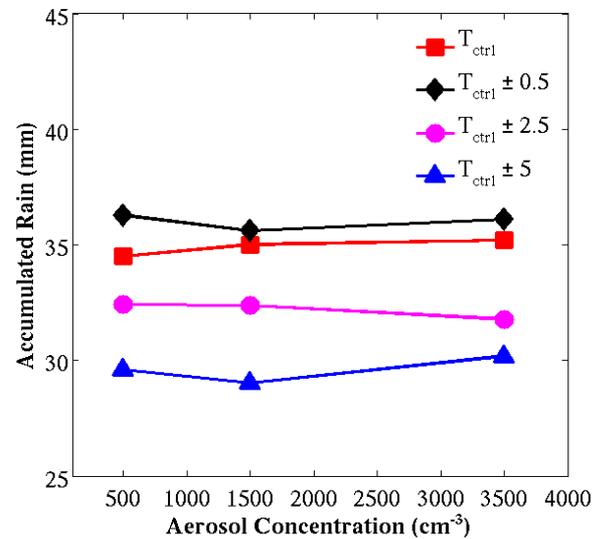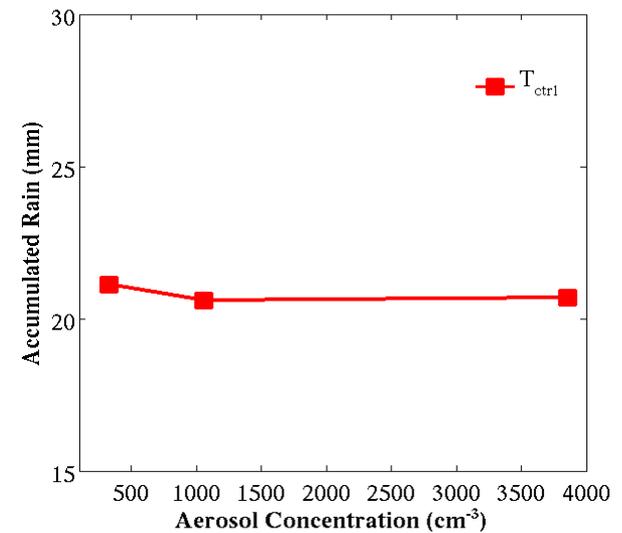
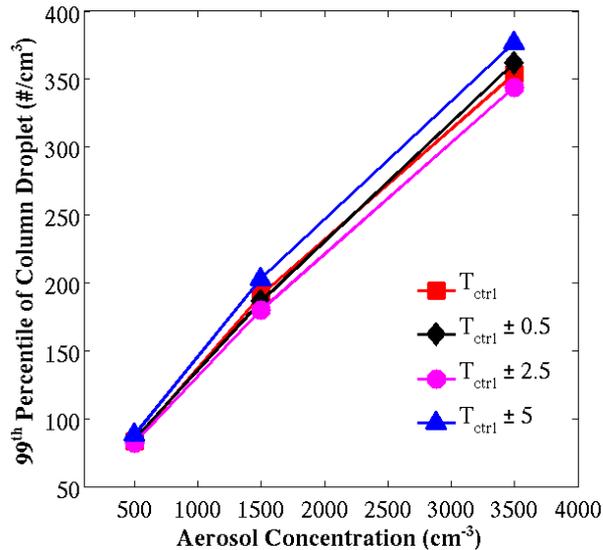# Domain and Time averaged Rainfall

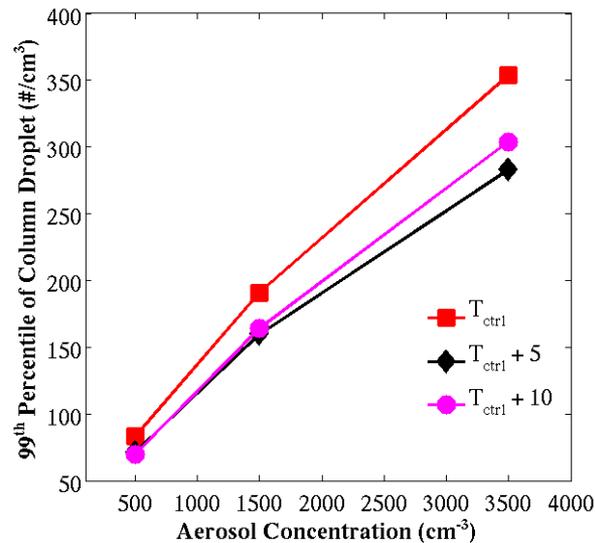

Uniform Temp. Pert.

Random Temp. Pert.
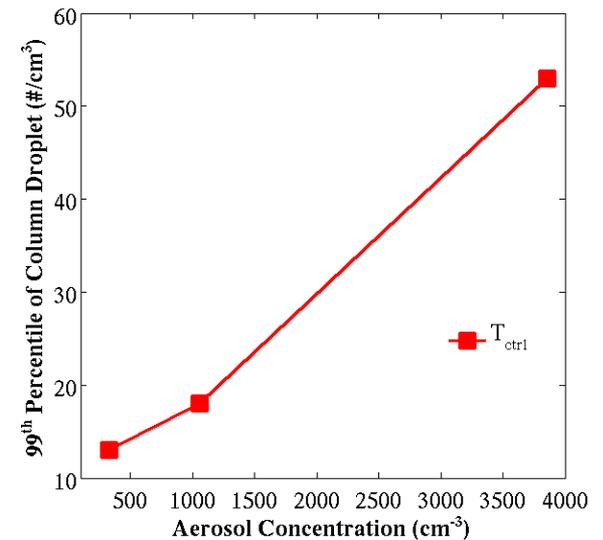
Prognostic CCN

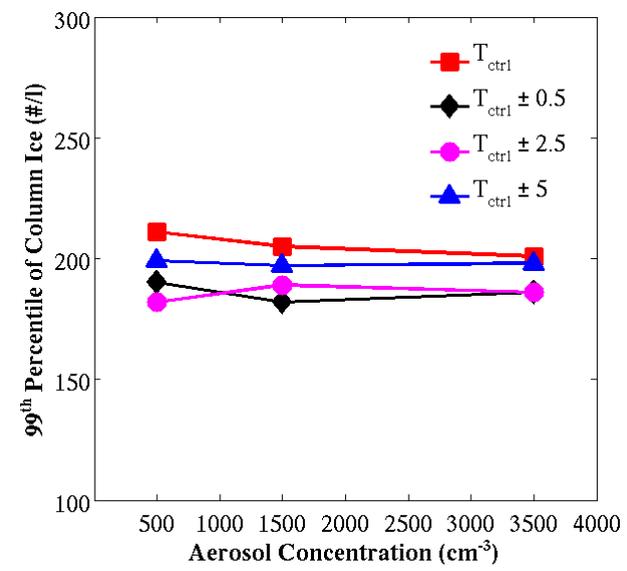# Effect on Droplet Concentration

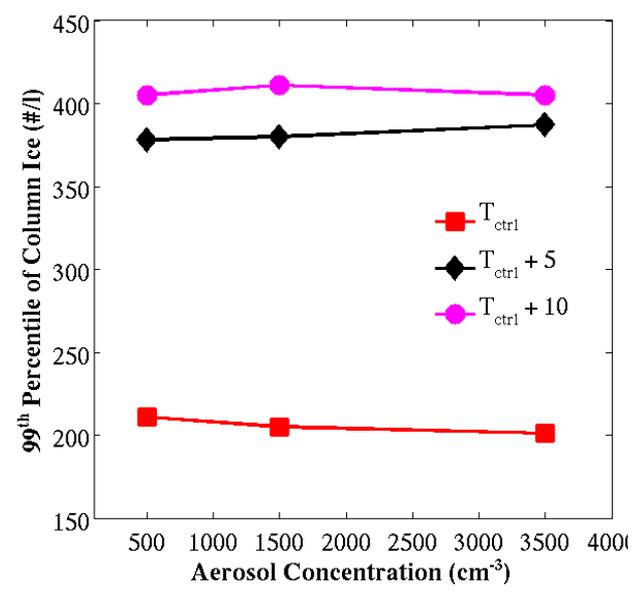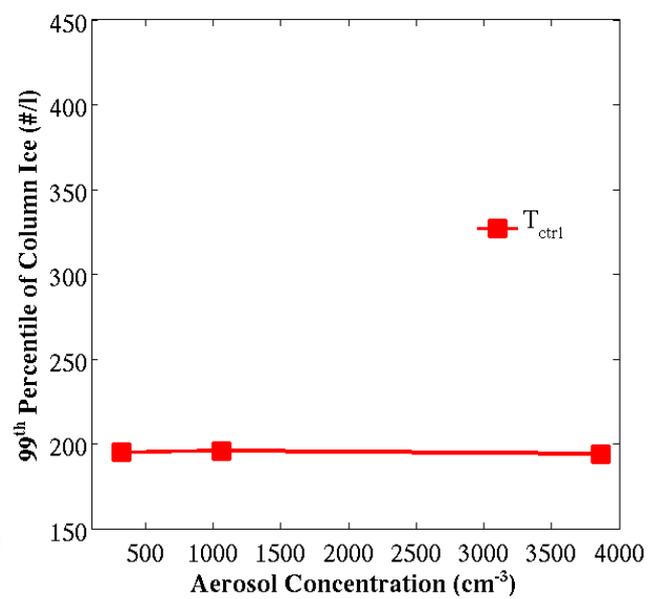**Random Temp. pert.**   **Uniform Temp. pert.**   **Prognostic CCN**

Effect on Ice Concentration

Random Temp. pert.   **Uniform Temp. pert.**   **Prognostic CCN**

Cloud Structure

T$_{ctrl}$ Cases
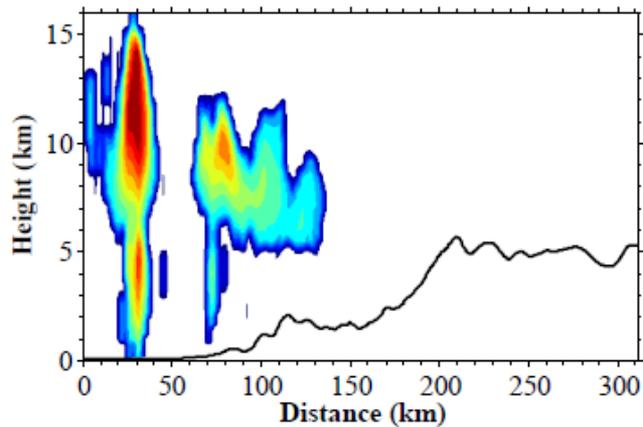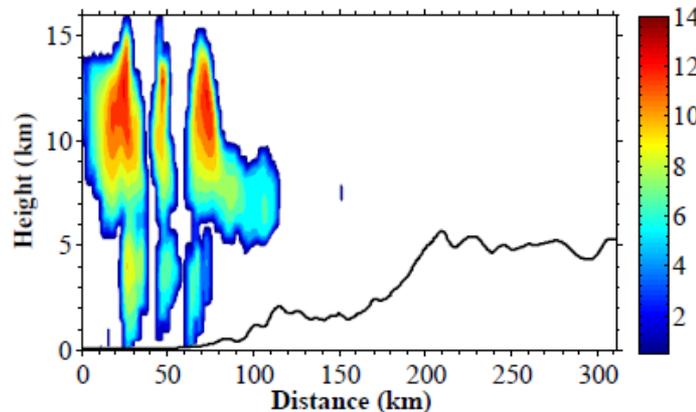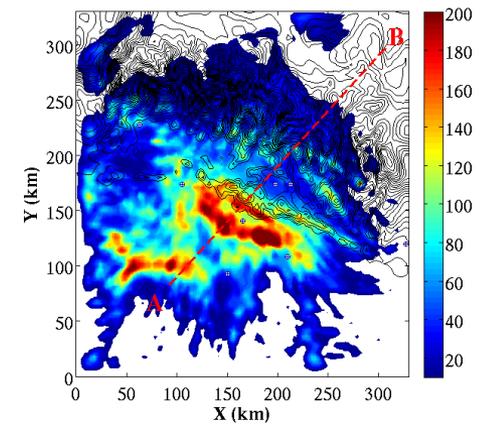

Low
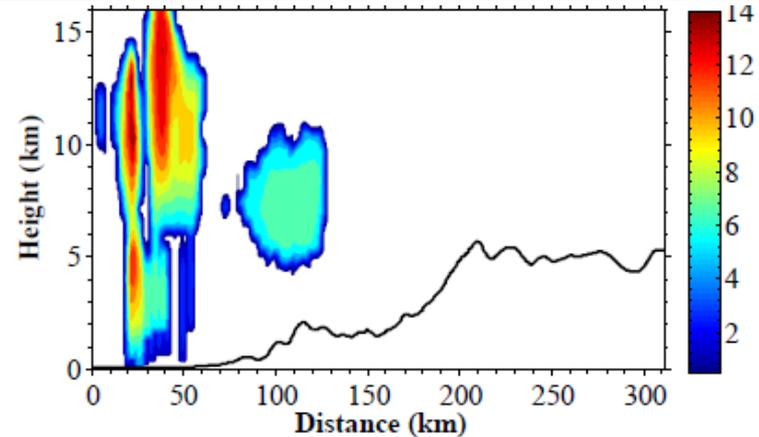
Medium

Water condensate c3500 case I T$_{ctrl}$
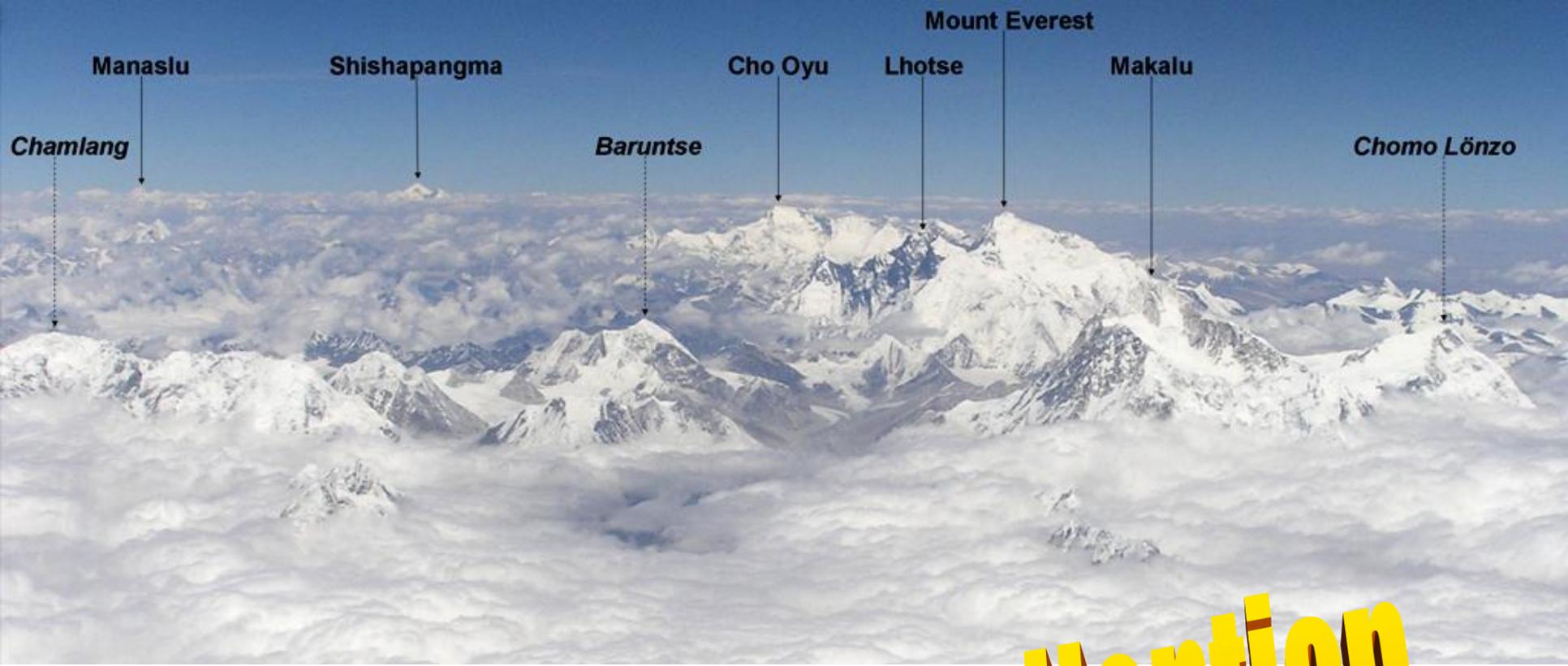

High

Units: g/kg

Summary

❑ The model showed a good representation of aerosol 1st indirect (Twomey) effect, however rainfall is not sensitive to the aerosol perturbations used (-2% to +4%).

❑ Ice phase processes played a crucial role to buffering the sensitivity but current understanding of the impact of aerosol on ice phase processes is poorly documented.

Summary

- ❑ The effect of temperature is more than the aerosol effect, ranging from -17% to +93%.

- ❑ Aerosol perturbations can modify shape, size and spatial distribution of individual cloud regions and their precipitation.

- ❑ Improved parameterizations of aerosol effects on ice phase processes is necessary in order to accurately simulate the precipitation particularly where the ice phase is a dominant process such as in the Himalayas.

Chamlang

Manaslu

Shishapangma

Baruntse

Cho Oyu

Lhotse

Mount Everest

Makalu

Chomo Lönzo

Thank you for your attention