Cloud Resolving Simulation of Indian Monsoon Precipitation

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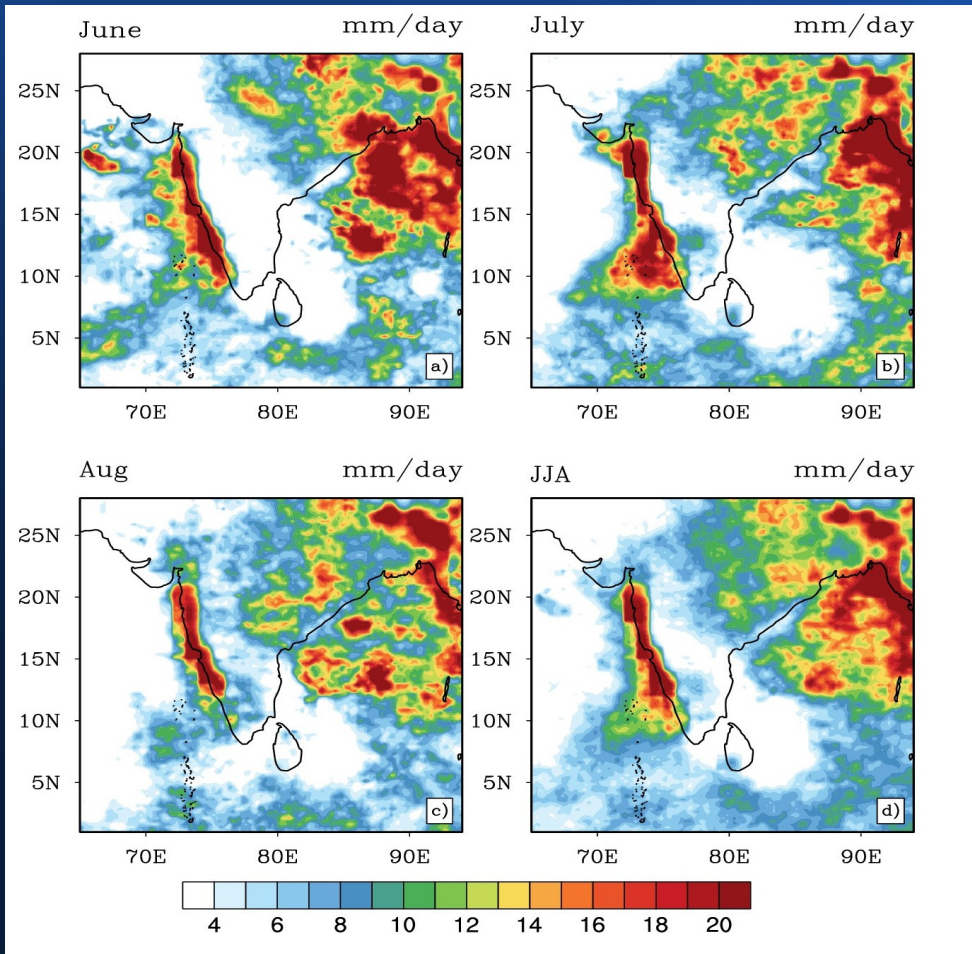
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Outline

- Indian Summer Monsoon characteristics

- GCM simulations of Indian Summer Monsoon Rainfall (ISMR)

- Cloud (system) Resolving model simulations of ISMR

- Meso-scale structures simulated by CRM over Bay of Bengal
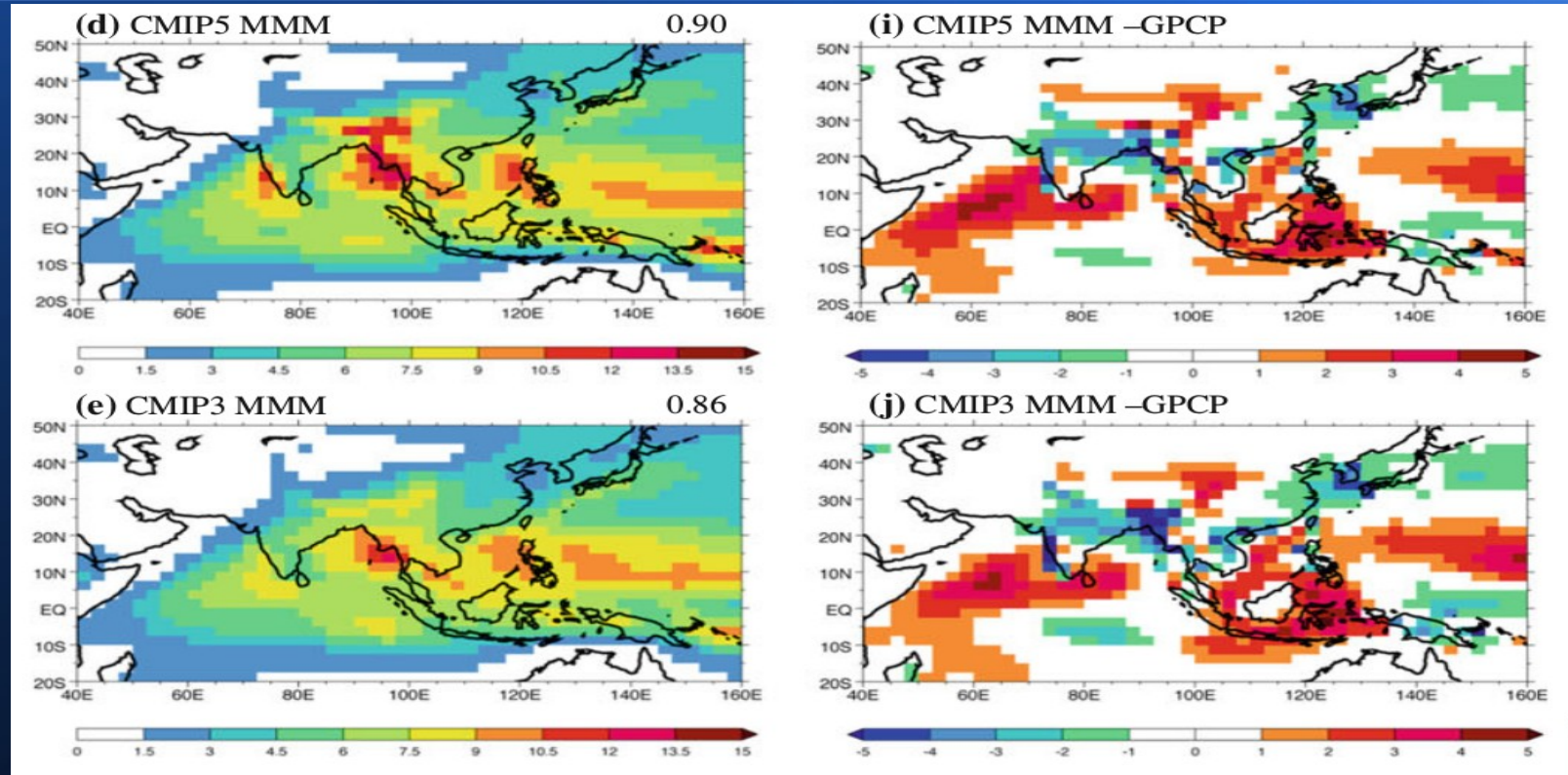
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Indian Summer Monsoon

TRMM

- A very high precipitation region over the Bay of Bengal

- Western Ghats orographic rainfall region is evident

- Peninsular India shows rain shadow region on the lee side of Western Ghats

GCM simulations of ISMR

(Sperber et al. , 2013)
- GCMs overestimate precipitation over Oceans, and underestimate it over Land
- GCMs with explicit cumulus parameterizations perform poorly in simulating ISMR

High resolution simulation using WRF (3km)

- We use Weather Research and Forecasting Model version 3.4.
- The simulation is carried out at cloud system resolving horizontal resolution of 3 km with explicit microphysics (no cumulus parameterization) for the duration of June to August, 2008 over the Indian region.
- The model domain extends 3000x3000 km in the horizontal, the model has 100 levels in the vertical
- The model time step is 5 seconds and model output is saved every 3 hours
- YSU PBL scheme, WSM 3 microphysics scheme,
- The initial and boundary conditions for the model are provided every 6 hours using NCEP FNL reanalysis dataset.

Domain of WRF Simulation
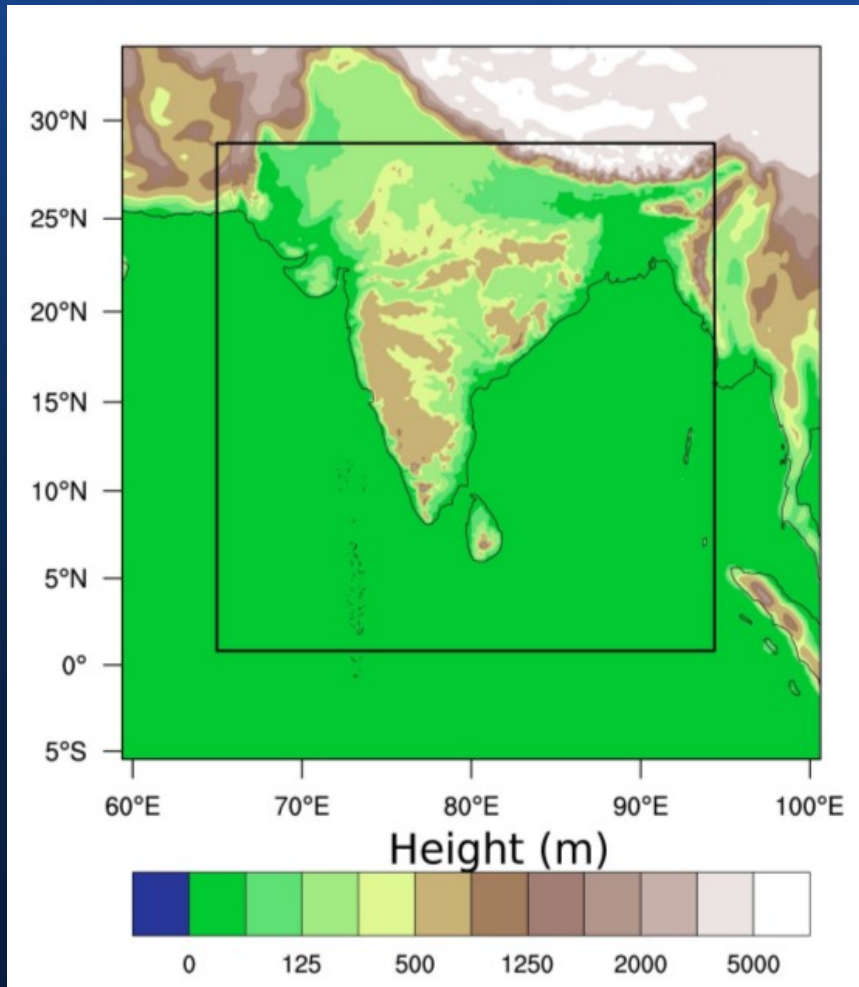
- The choice of the model domain and experimental setup was dictated by the computational expenses involved in simulating, storing, and analyzing the data.
- We chose the domain such that indian Landmass is at the centre
- The wall clock time was 7-8 months for the simulation.
- The total data amounts to 10 terra Byte for one season long simulation
- The domain is the inner black box

TRMM and WRF
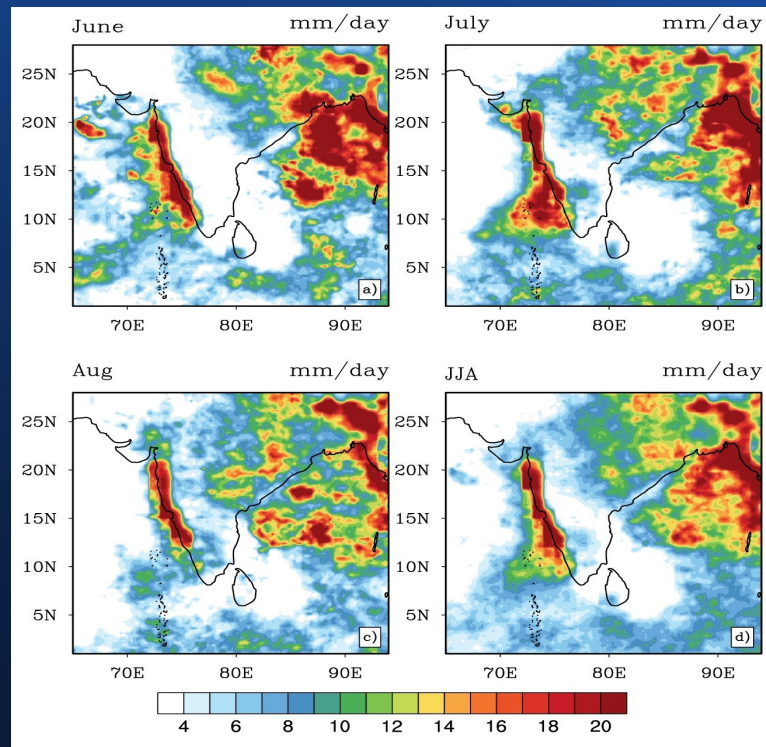
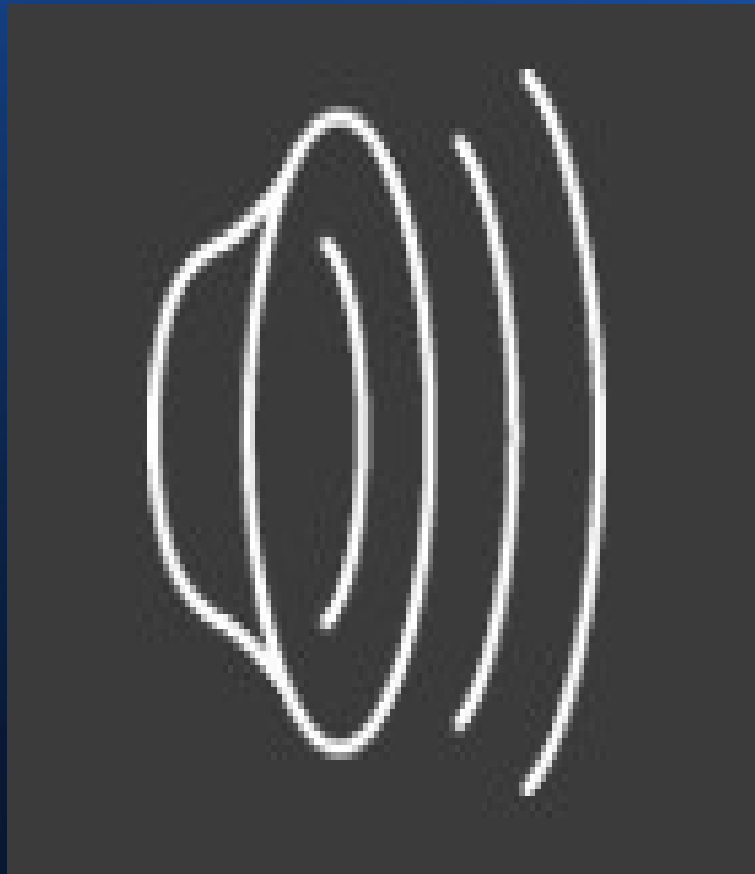TRMM   WRF
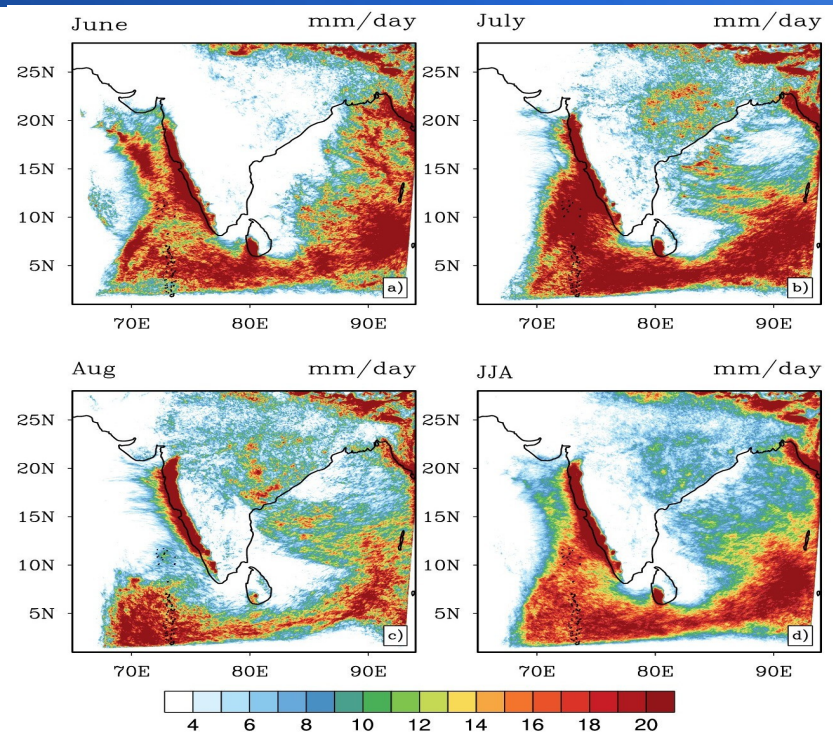
- WRF overestimates precipitation over the Equatorial Indian Ocean.
- It simulates orographic rainfall over Himalayan Foothills reasonably.
- It also simulates precipitation over Indian Landmass reasonably well, though underestimated
- The simulation suggest that a lot of improvements can be made to microphysics schemes

Precipitation

Many mesoscale systems can be seen propagating south over BoB

Western ghats generate gravity waves which result in precipitating systems over Cold pool

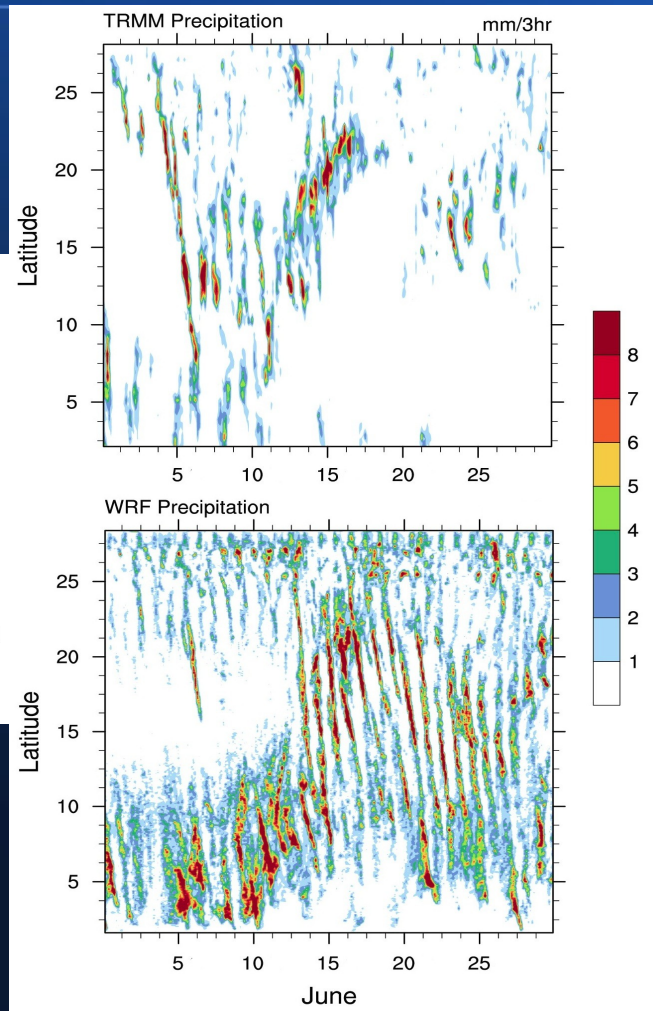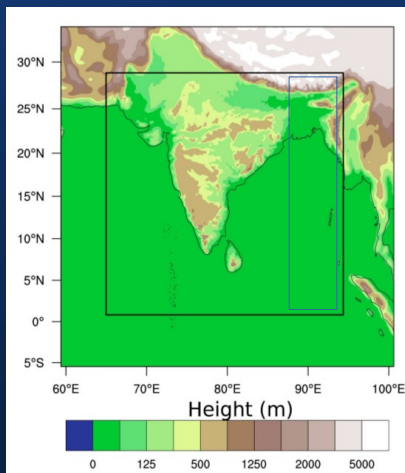Low pressure systems can be seen generating over Head Bay

Propagations in June

The northward propagations over various longitudes show dominant diurnal signal.

As we move towards Bay of Bengal, southwards propagations embedded in slower northward moving envelopes are more prominent
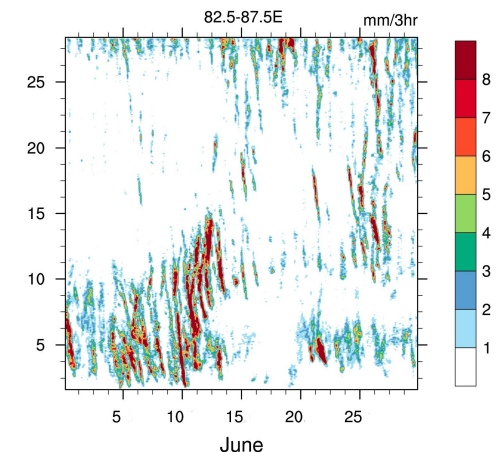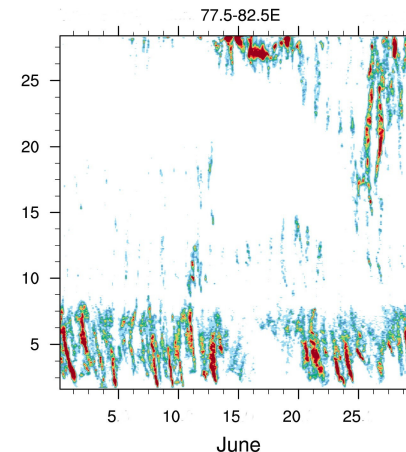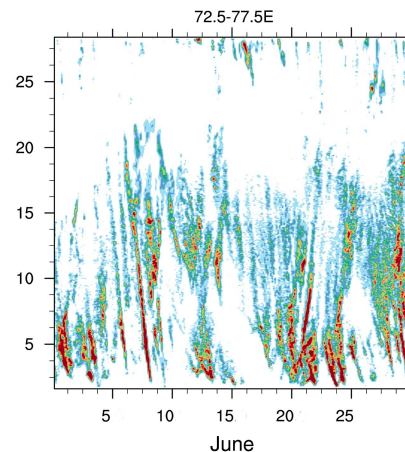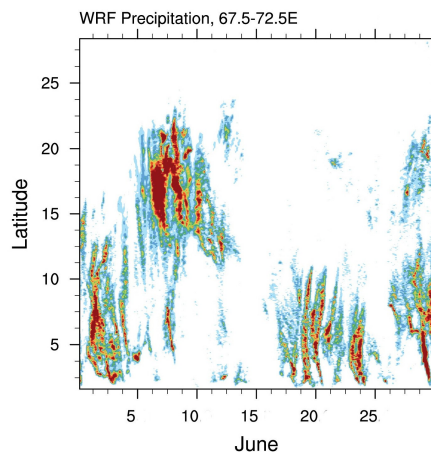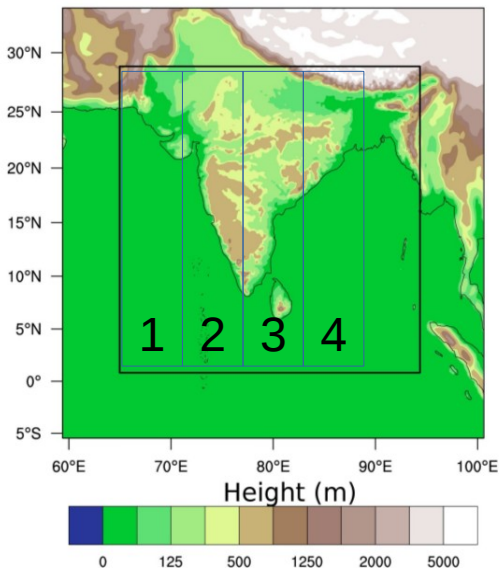
Mesoscale propagations over Bay of Bengal

- One of the mesoscale phenomena simulated well by WRF at high resolution is the equatorward propagating diurnal rainfall signature over the Bay of Bengal.

- This propagation is unseen in most of the coarse resolution model simulations and reanalysis datasets

- While

Houze (2004) has attributed the southward propagating cloud bands over the BoB to the diurnally generated gravity waves,

Miyakawa and Satomura (2006) have found that the surface to 600 hPa wind shear had a southward component and they attribute these winds to be the steering factor

Structure of the Southward propagating system

Max Reflectivity (dBZ)

5 10 15 20 25 30 35 40 45 50 55
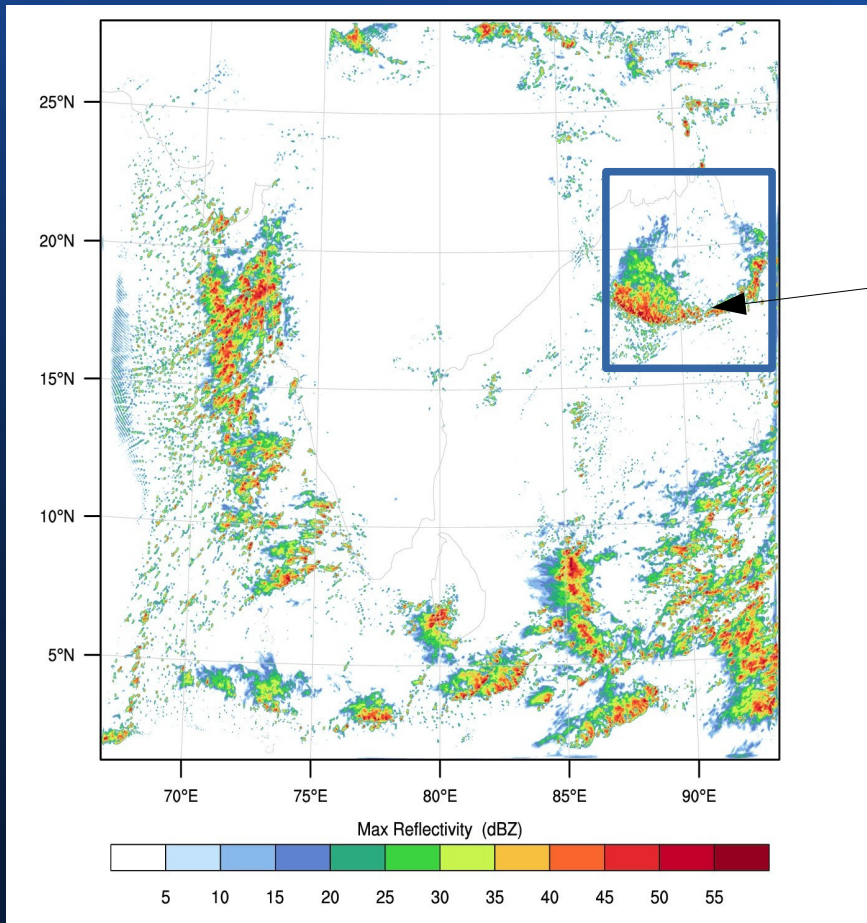
- The structure of the southward propagating meso-scale convective cloud is very similar to the one reported in Houze (2004) using Joint Air-Sea Monsoon Interaction Experiment (JASMINE) Radar reflectivity data.

- The bow shaped structure originates over land, and

- Moves at a speed of 12-15 m/s in the model simulation, which is very similar to the ones observed in JASMINE Radar data as well as in TRMM data.
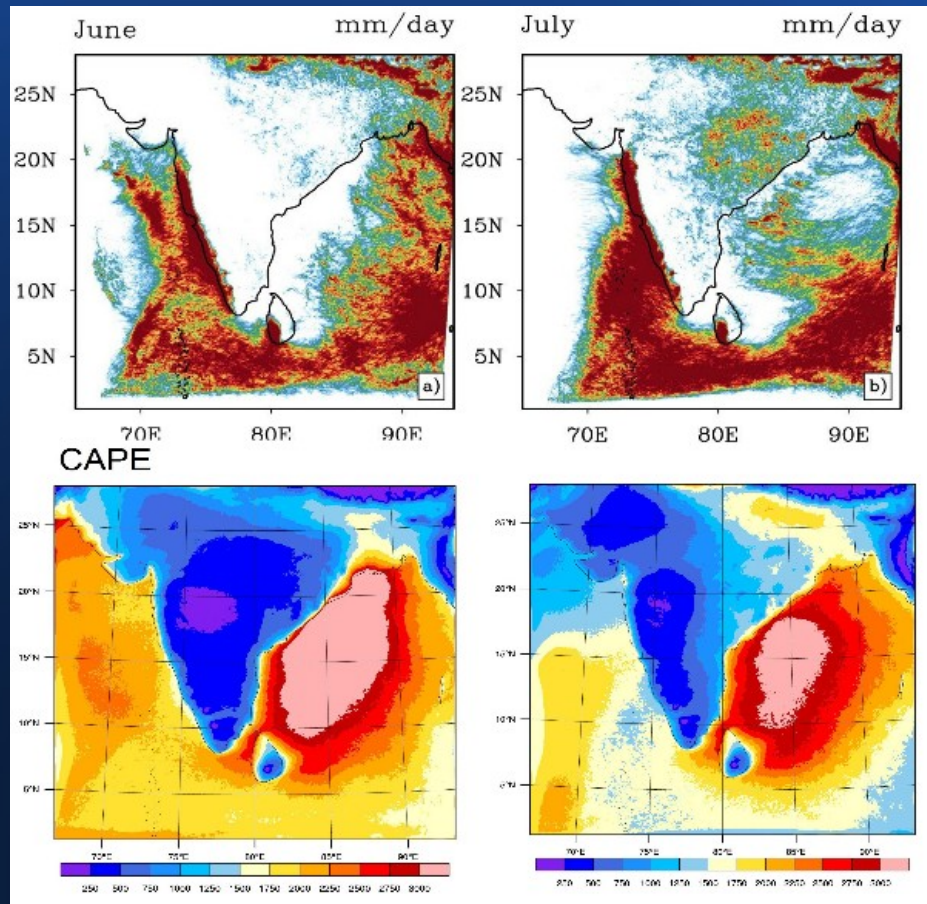
The Steering Wind

Wind (m s-1) at 600 hPa

Monthly mean (June) model simulated horizontal winds at 600hpa
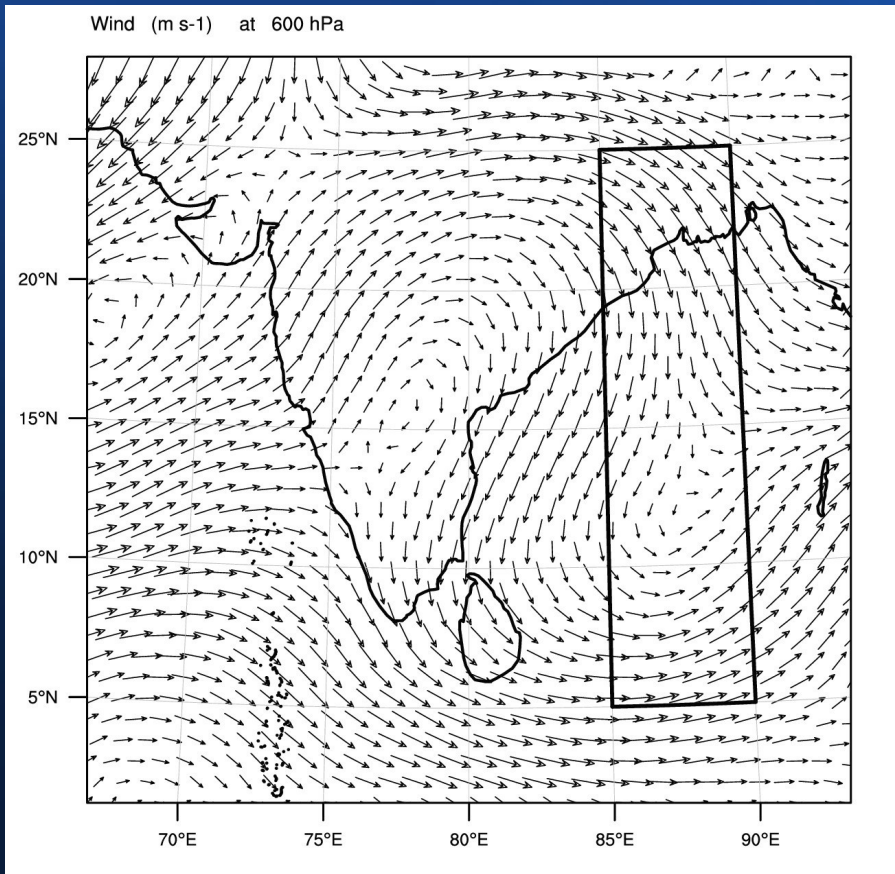
- WRF simulates the 600hpa northerlies
- These winds are believed to be steering the convection south (Miyakawa and Satomura (2006))

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Precipitation-CAPE relationship

One of the most striking feature is the lowest rainfall over the maximum CAPE region.

Whereas, the maximum precipitation regions are also the regions with least CAPE

Precipitation-CAPE

- The simulation shows that the consumption of CAPE is the result of a deep convective system propagating over the Bay of Bengal

- Also, the CAPE values are significantly lower over land, where the observations show deeper convective clouds

Precipitation-CAPE Correlation
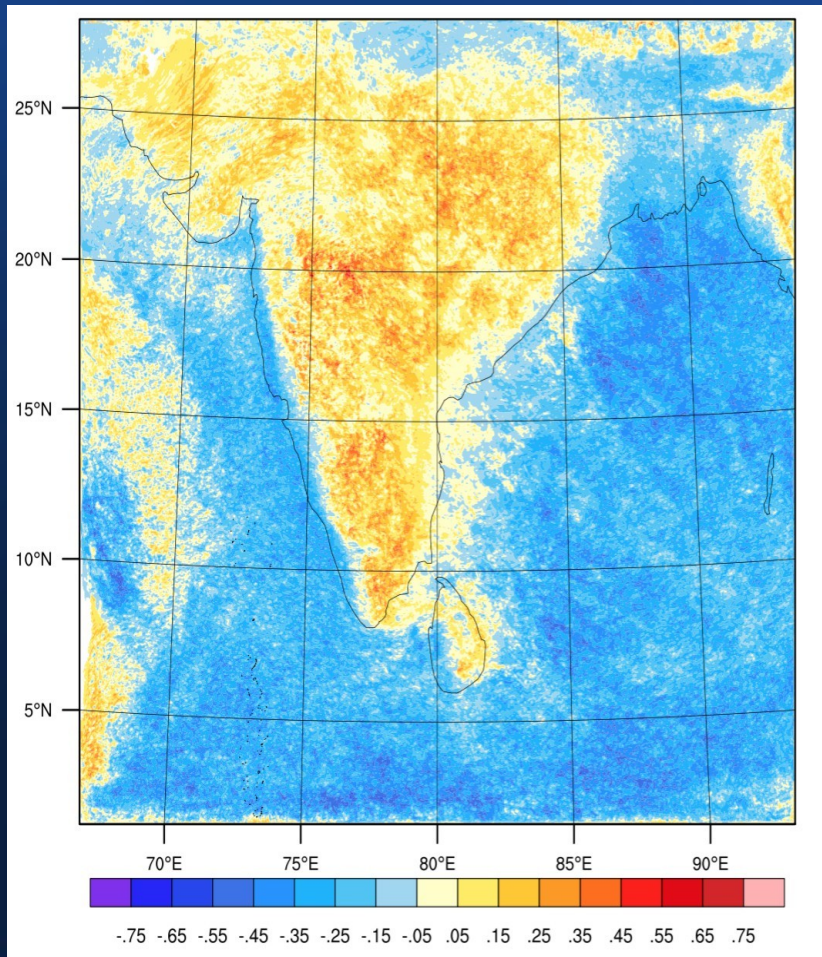
Correlation between CAPE and precipitation is negative over most of the oceanic region,

While it is positive over most of the land region, indicating that Cumulus parameterizations need to take this into account

Could it related to the fact that SSTs are above the convection threshold? --- Needs to studied further

Relationship Between Precipitation & CINE

- Unlike CAPE, which does not show such a strong diurnal cycle, CINE shows a very strong diurnal cycle. Most of the meridionally propagating systems in our simulation are diurnal in nature

- Southward Propagations appear to initiate over regions with low CINE and relatively high CAPE i.e land-ocean boundary

Diurnal Cycle of SST-Land Surface temperature
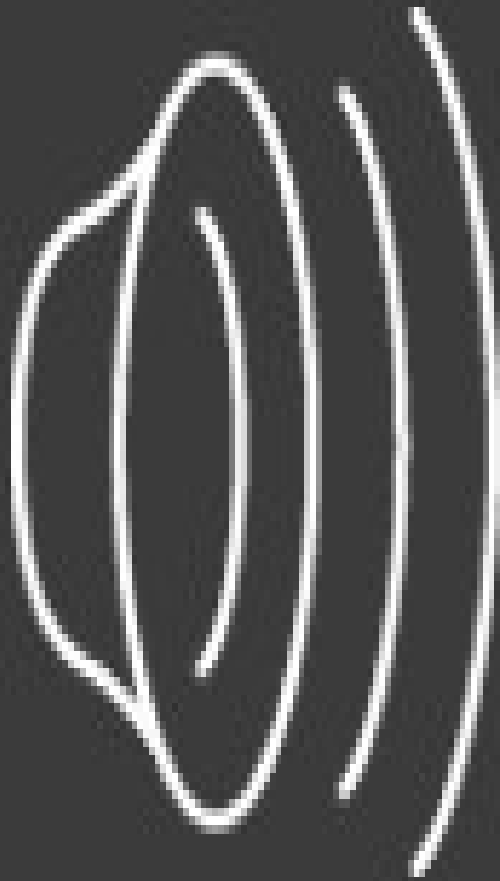
Sea Surface temperature is updated ones a day at 00z. While land surface temperature shows a strong diurnal cycle which can be associated with deep convection initiation near coastal boundaries.

# Convergence associated with a propagating system
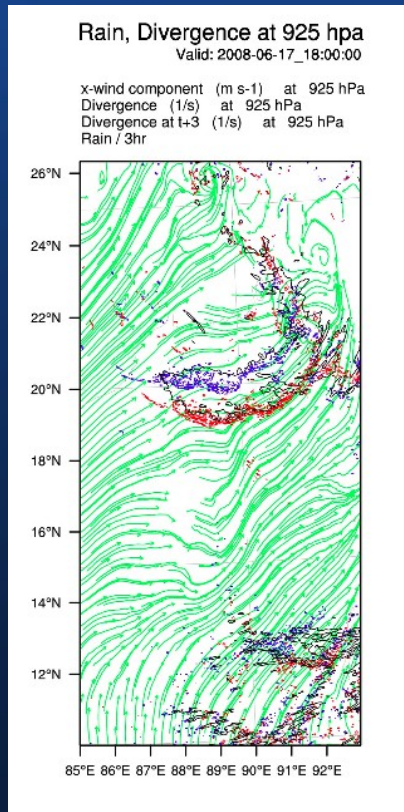
The figure shows cloud water mixing ratio and convergence for one of the southward propagating Mesoscale system.

The red contours show convergence region at the present time, while the blue region shows convergence region at previous time stamp (3 hours earlier). We can see that convergence zone precedes the system.

Where do Southward Propagations Terminate?

We find that southward propagations occur over regions of high Precipitable water and terminate when they encounter lower precip water
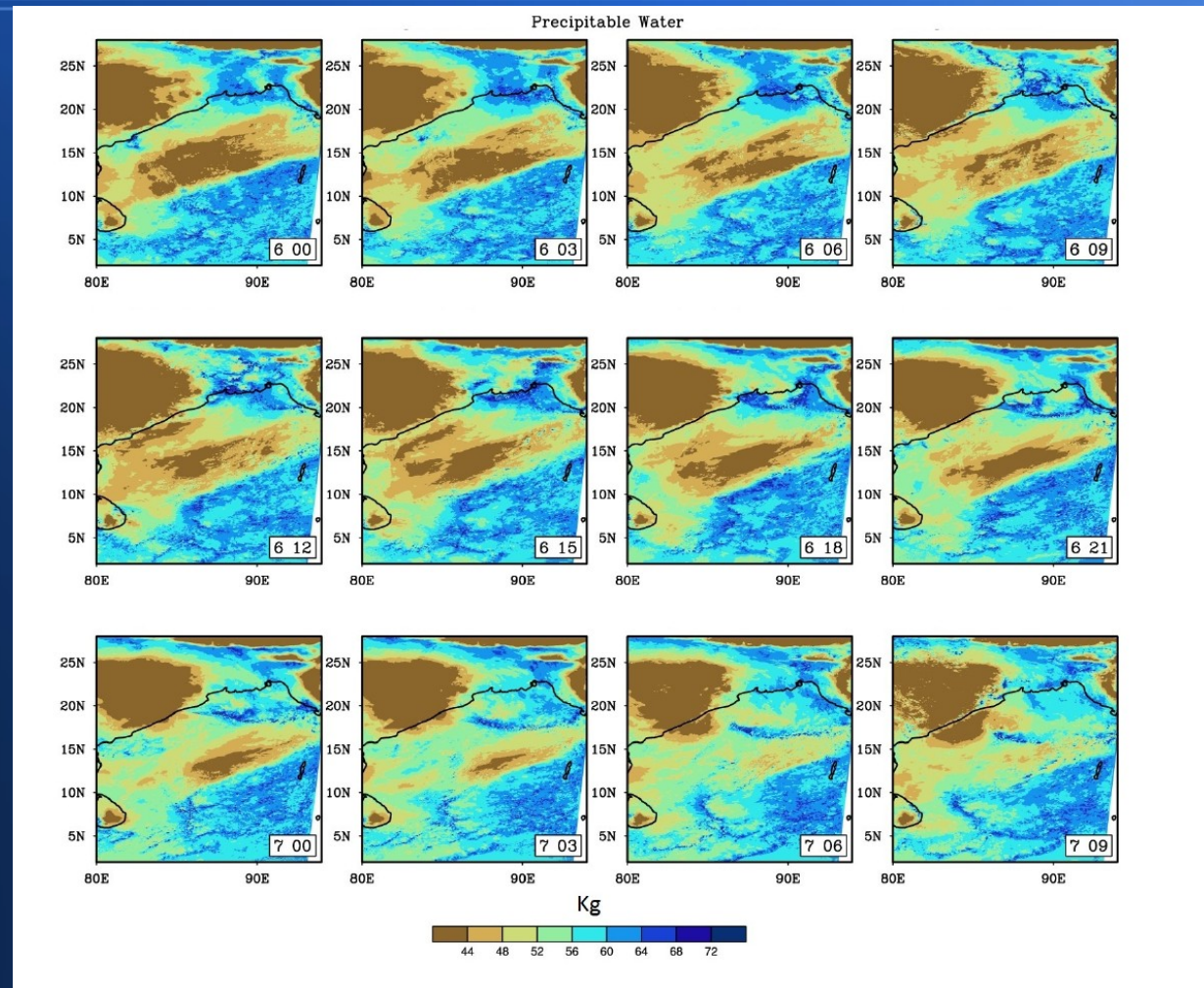
Simulations with Cumulus Parameterization
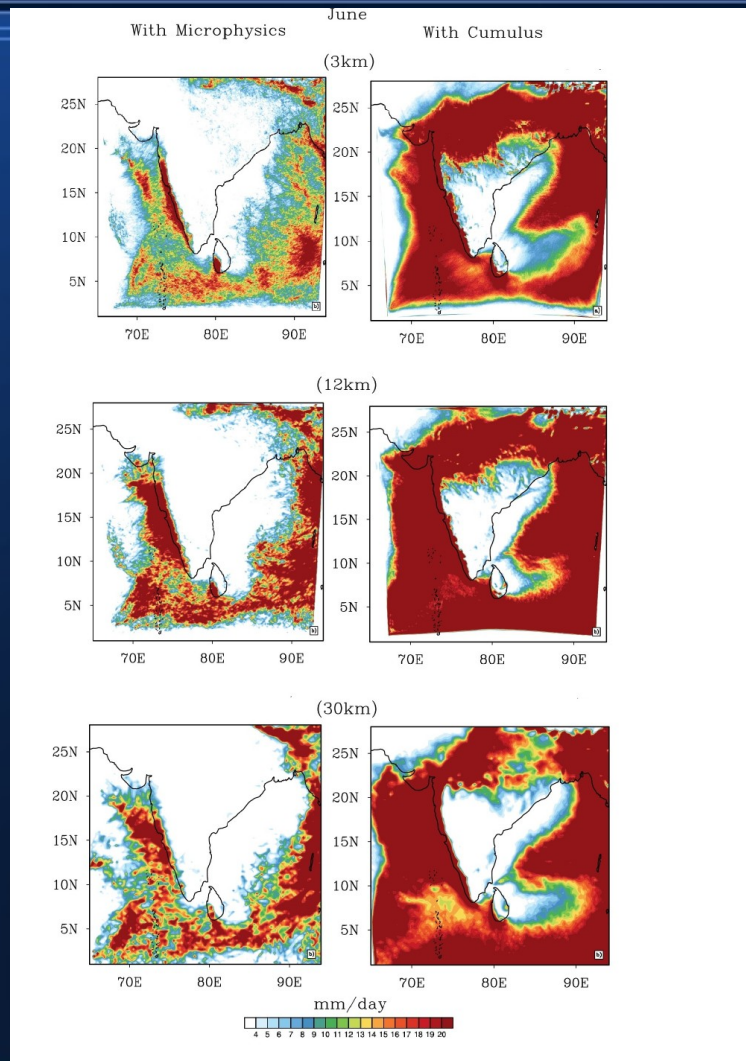
- Simulations with Cumulus Parameterization (Kain-Fritsch) do not show the detailed structure of rain systems revealed by Microphysics

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- No noticeable southward moving structures seen in cumulus simulations

Summary

- A high resolution simulation, capable of resolving mesoscale cloud systems and corresponding dynamics, is performed for the duration of Indian Summer Monsoon (ISM) season using the Weather Research and Forecast model.

- The model is able to simulate observed southward propagating mesoscale convective system absent in coarser resolution GCM simulations as well as reanalysis datasets

- The simulated MCS has a bow structure also seen in Radar observations

- The model is also able to simulate the 600hpa southward winds believed to be the steering level for the propagations

- There is a different relationship between CAPE and rainfall over land and ocean

- The propagating systems show strong diurnal signal, which can be associated with strong diurnal surface temperature contrast between land and ocean

- CINE also shows strong diunal cycle

- Exact nature of mechanism still being studied

- The rich structure of convection is not simulated when cumulus parameterization is switched on

Acknowledgements
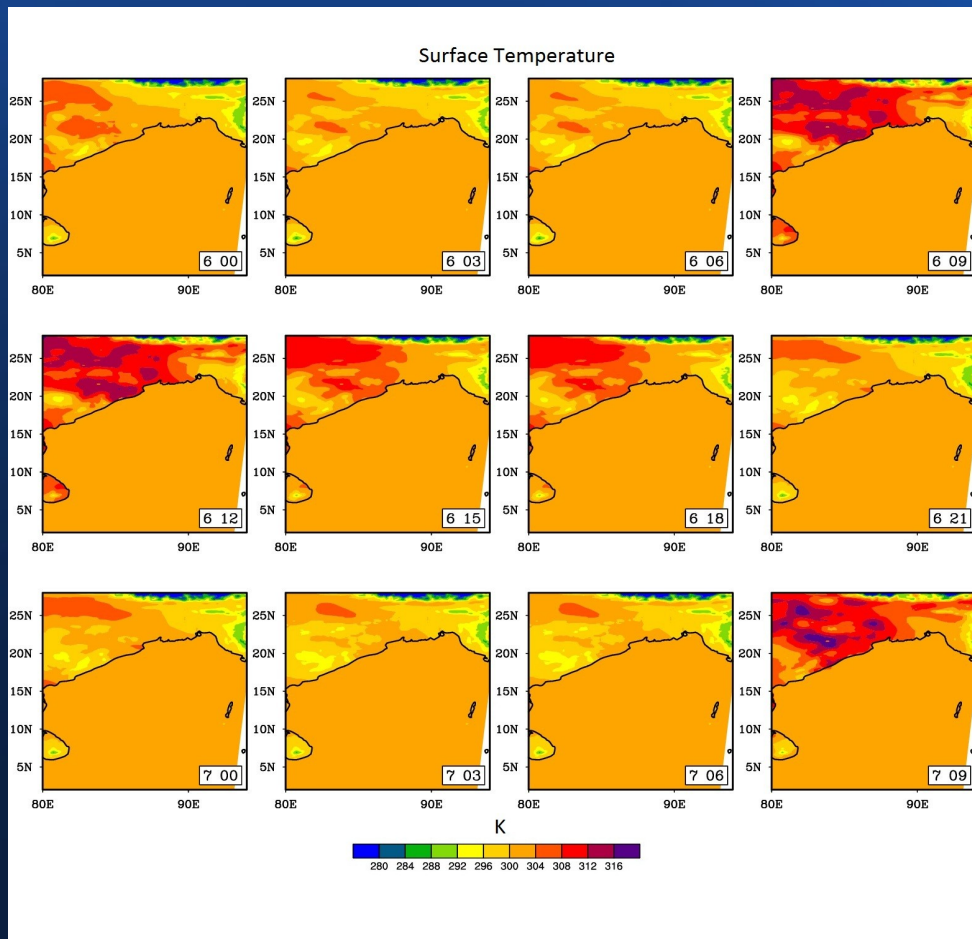
Supplementary slides

Rainfall
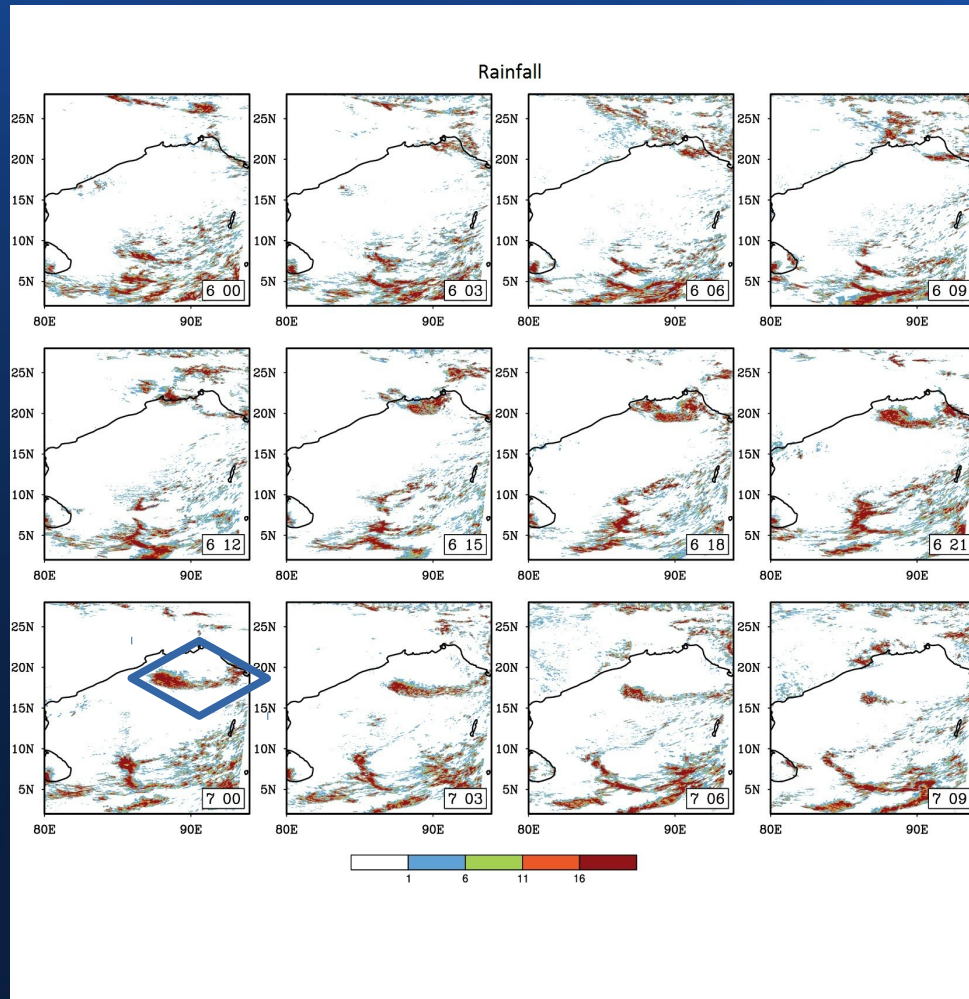
WRF simulated 3 hourly snapshots of precipitation for the southward propagating system
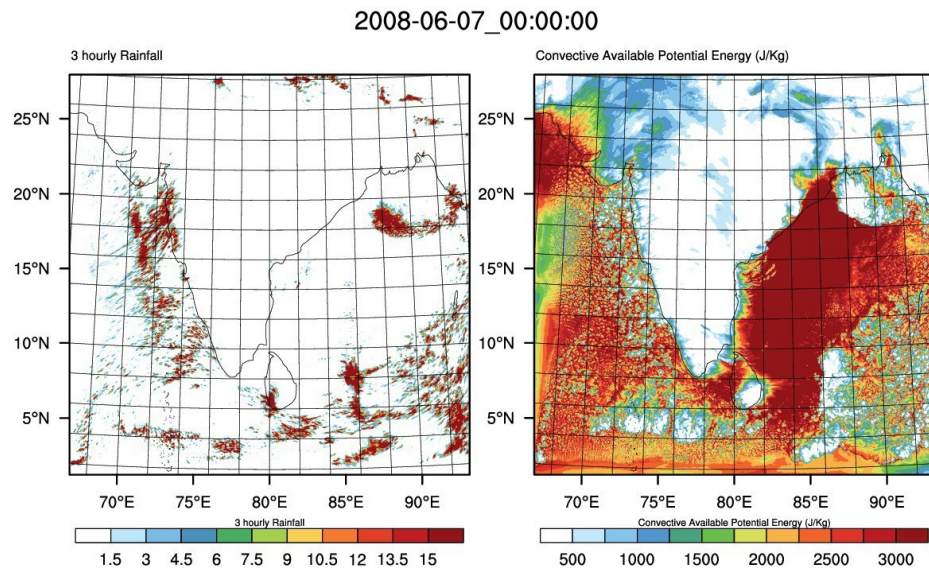
• The system originates over land and propagates over BoB

Supplementary slides

Surface Temperature

- The triggering of convection over land is associated with diurnal cycle of land surface temperature.

- The simulated land surface temperature shows a maxima just before the convection initiation of the southward propagating MCS
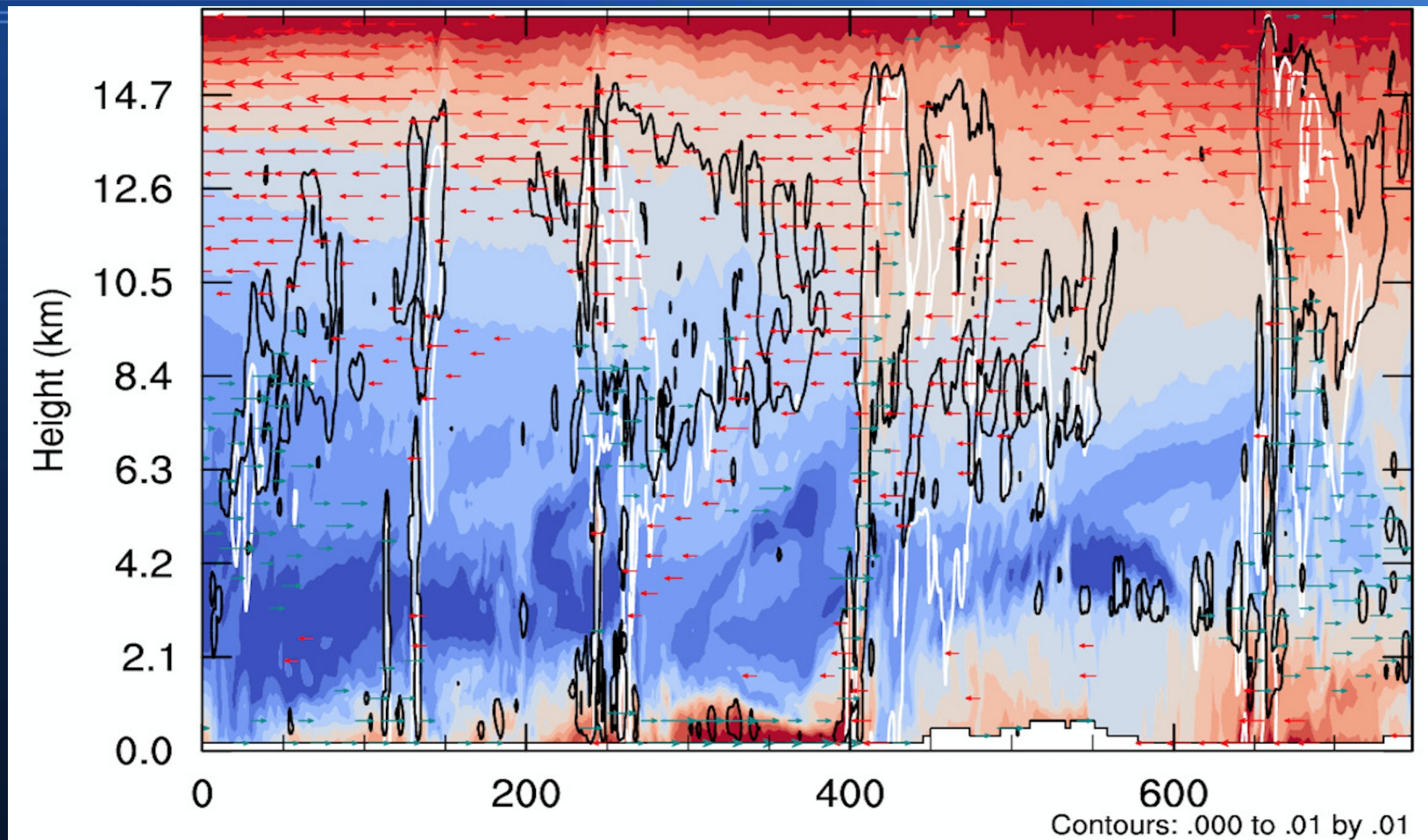
Supplementary slides

- The CAPE values are higher over BoB.

- The CAPE is consumed as the system propagates south.

- In most of the GCMs, CAPE consumption is used to decide if convection will happen or not

- CAPE consumption is the result of system propagating over a particular region and not the reson for convection

Convective Triggering over the Bay revealed by CRM

Contours for cloud water mixing ratio, shading for equivalent potential temperature

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