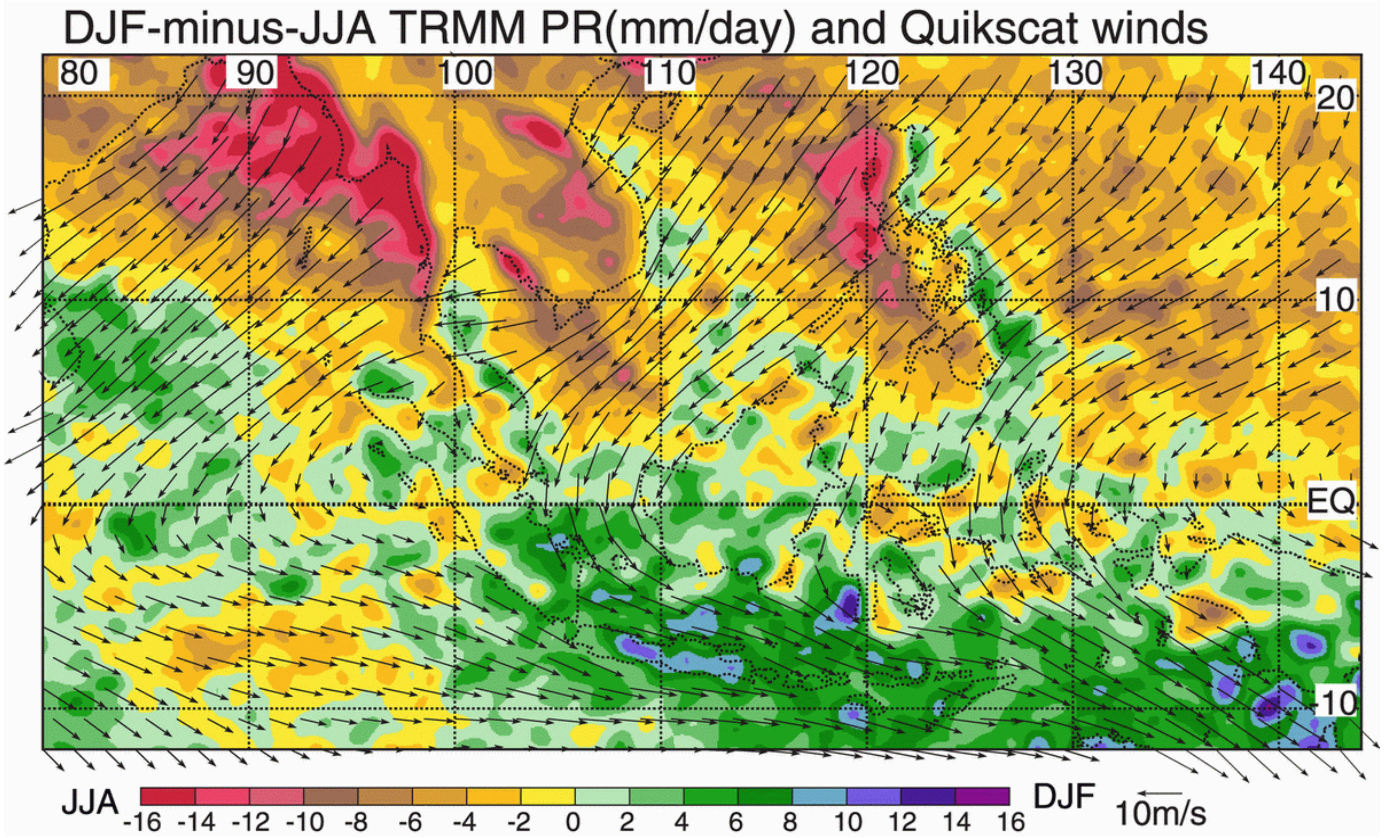
Terrain Effects in Southeast Asian Monsoon Onset

Zhuo Wang and Chih-Pei Chang
Department of Meteorology
Naval Postgraduate School
Monterey, CA 93943

Satellite Observation



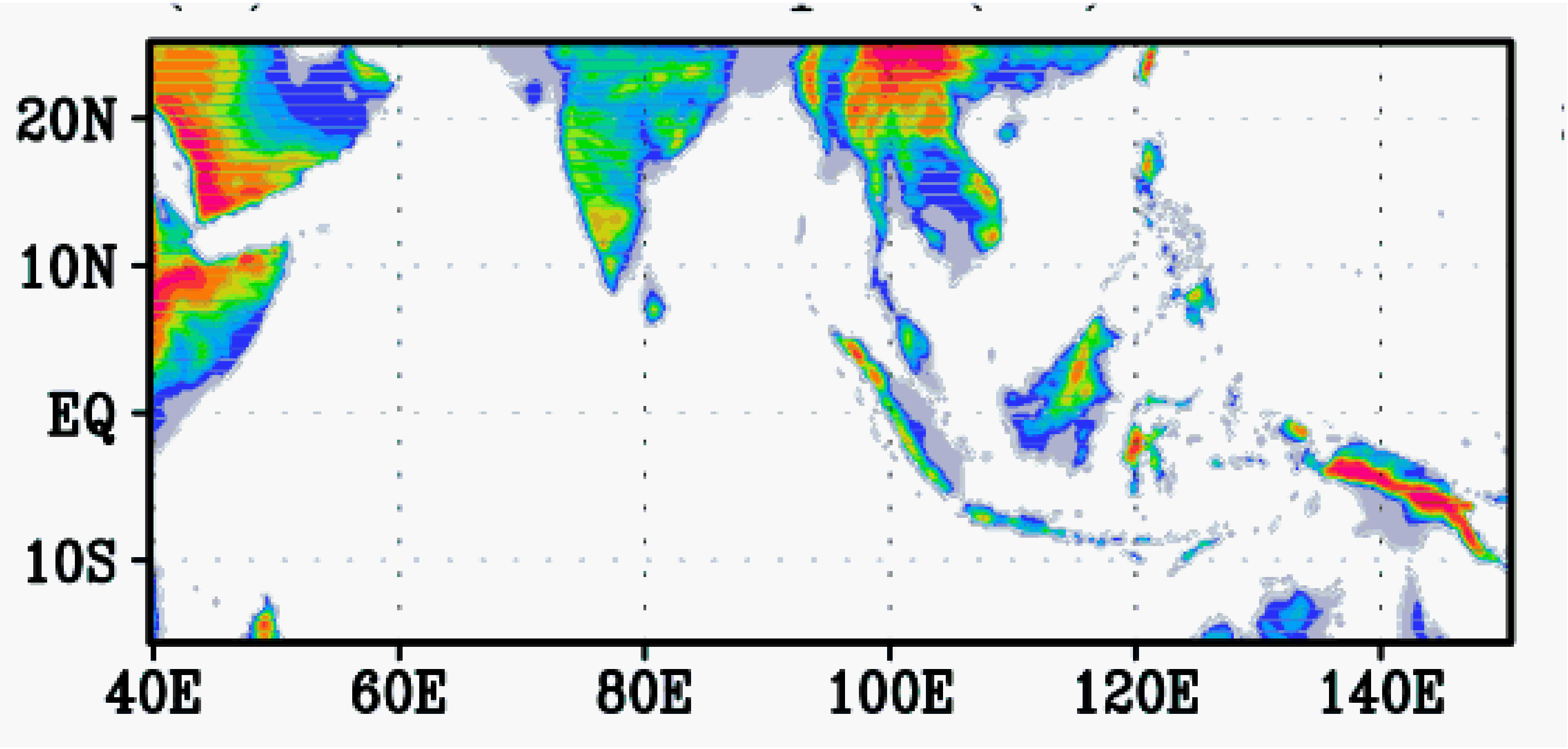
1) Annual cycle of SE Asian monsoon dominated by interaction between the complex terrain and a simple annual reversal of the surface monsoonal winds

2) Heavy precipitation tends to occur on the windward side of high terrains rather than near the center of large-scale monsoon circulations.

RegCM Simulation

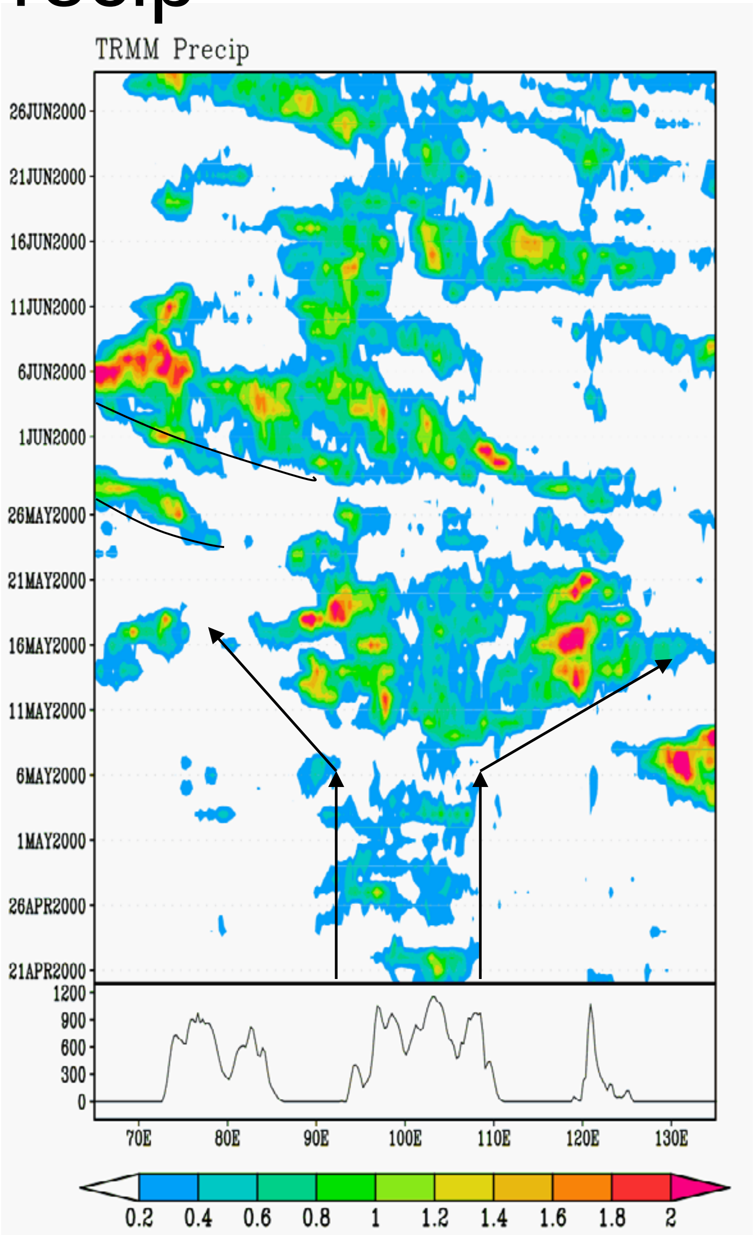
- **Objective: Understand wind-terrain interaction in the Asian monsoon circulation and impacts on its onset.**
- We choose 2000 monsoon onset period, an ENSO neutral year.
- Model
  - RegCM3.0: version 3 of the regional climate model (RCM) developed by NCAR
  - A primitive equation, grid point limited-area model with a terrain-following σ vertical coordinate
  - Weekly mean SST data from NOAA Optimum Interpolation (OI) SST V2; 6 hourly ECMWF reanalysis (ERA-40)
  - **1st April 2000 to 30th June 2000**
  - Horizontal Resolution: 30 km

Model Domain and Topography

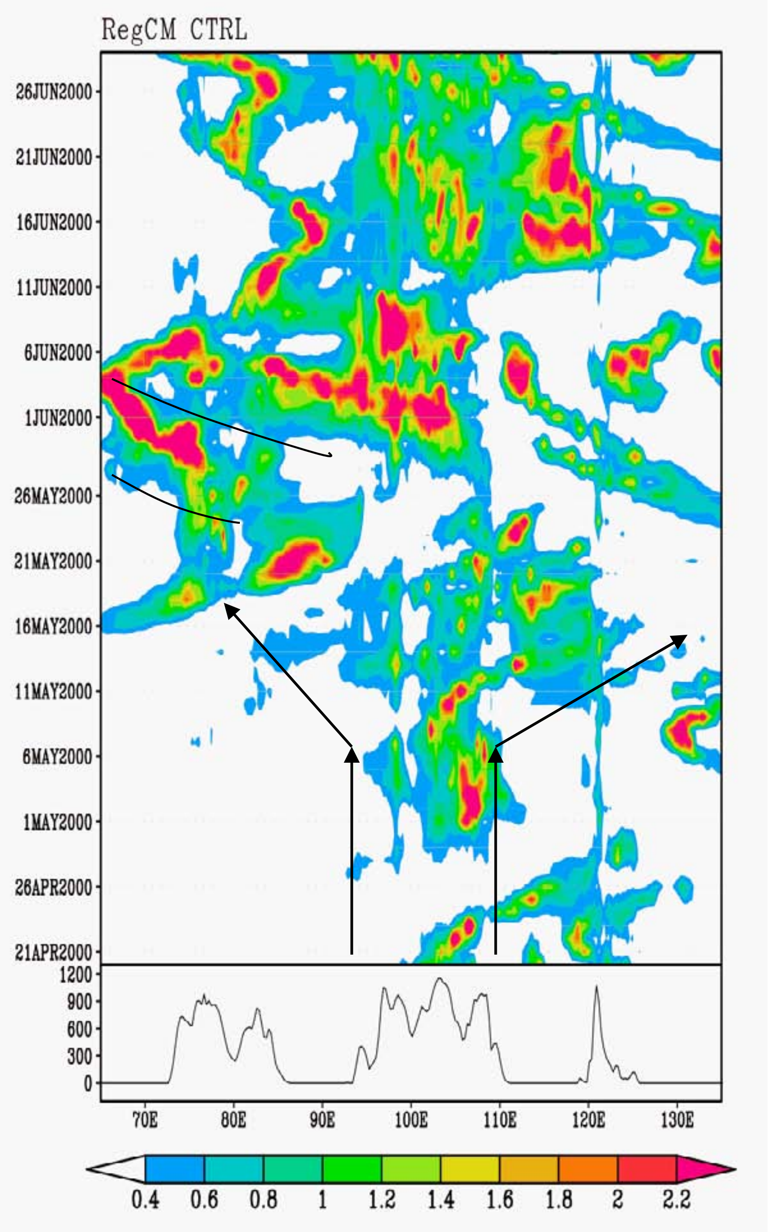


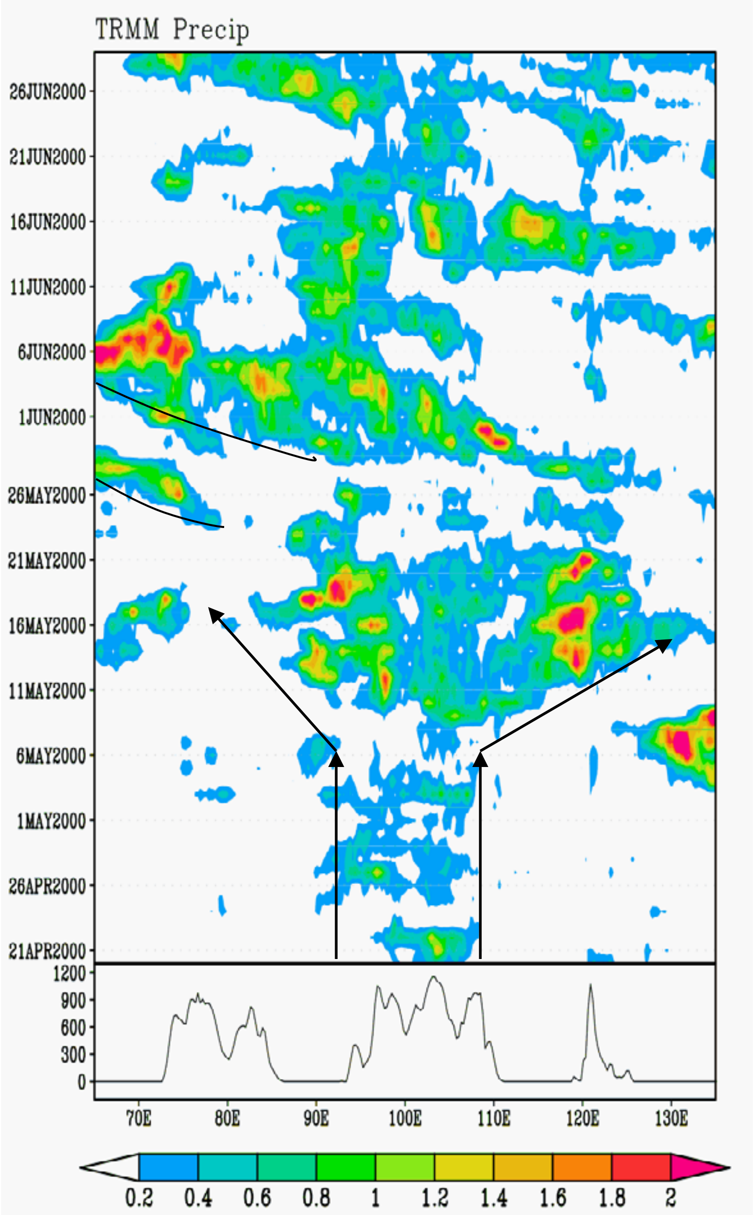
Monsoon Onset and Progression in TRMM Precip

1. The earliest onset occurred in the central Indo-China Peninsula in late April and early May.
2. It then advanced northward and westward up to the Bay of Bengal and extended eastward to the SCS in mid May.
3. Indian monsoon onset occurred in the last pentad of May.



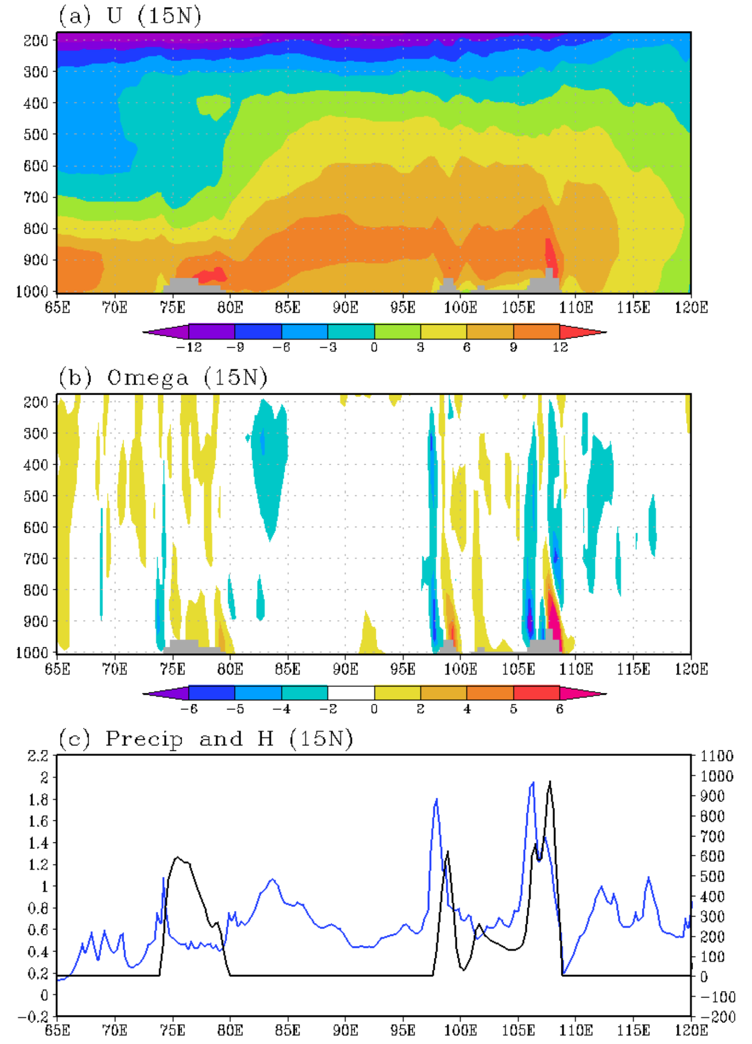
Monsoon Onset and Progression in RegCM CTRL-run





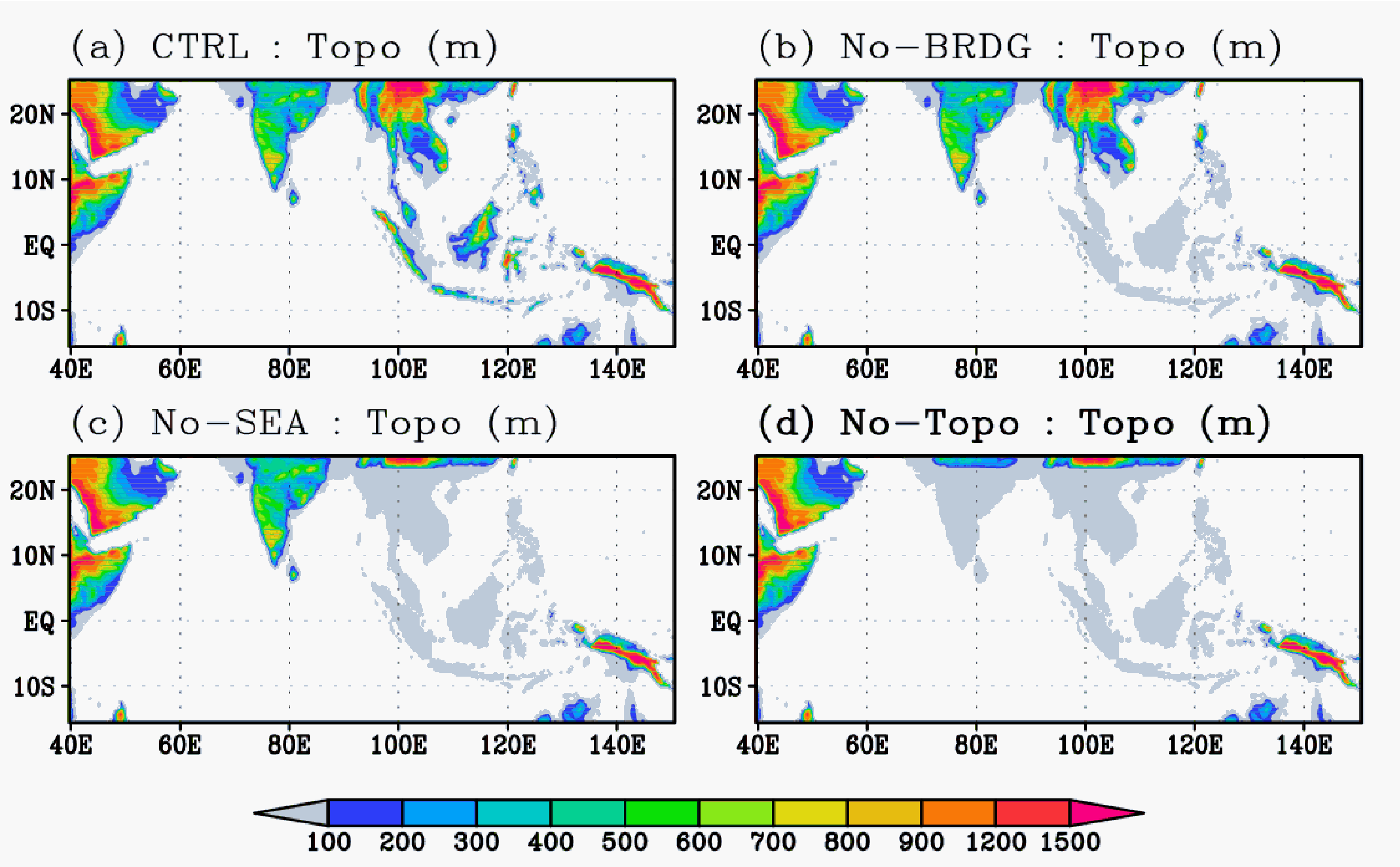
Wind-Terrain Interaction in RecGM Control Run

- Westerlies prevail in the monsoon region from sfc up to 400 hPa with the maximum below 800 hPa.
- Heavy precipitation tends to occur on windward side of high terrain, consistent with observations.



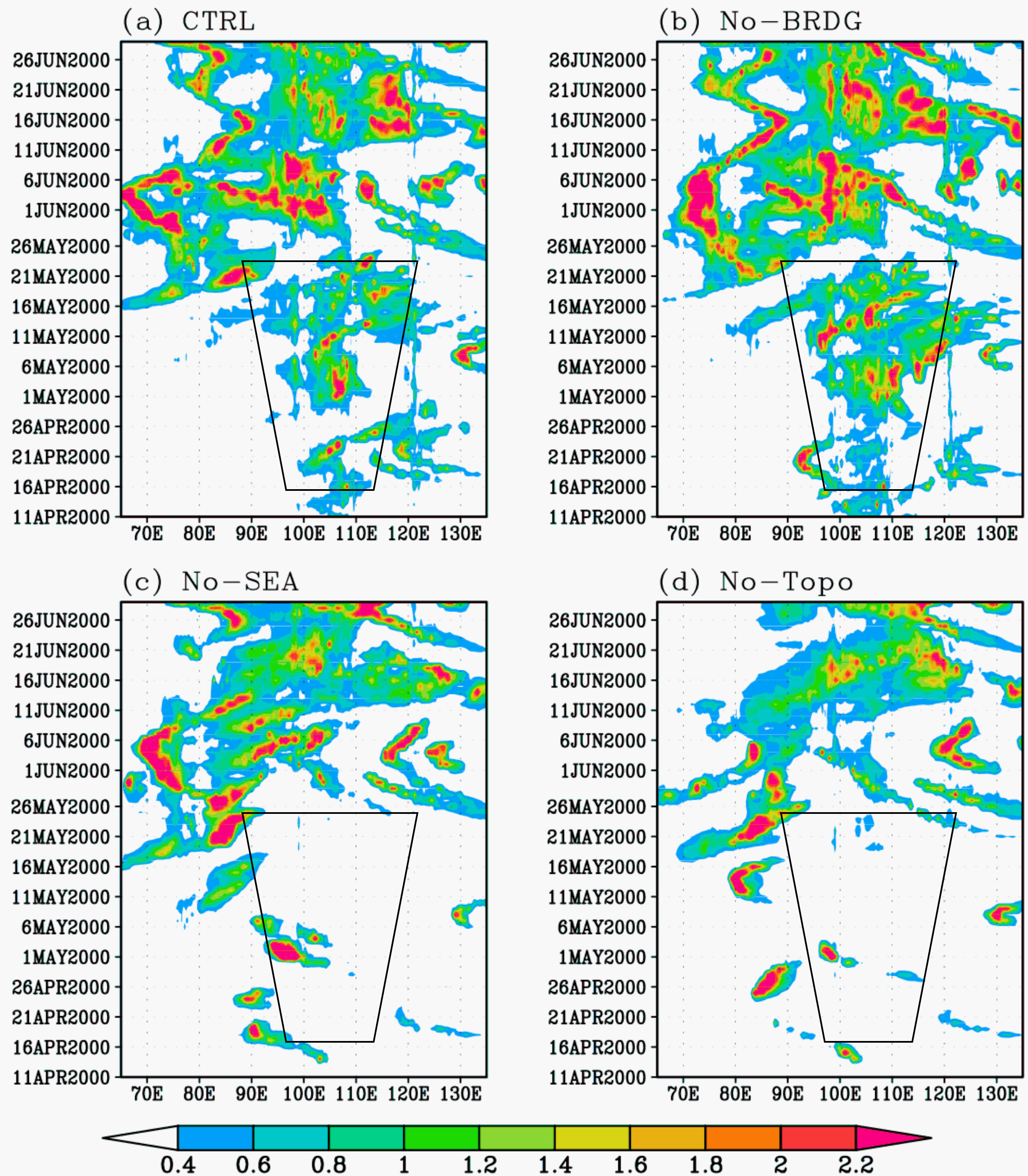
Sensitivity Tests to Topography

- Impacts of terrain in different regions on monsoon onset and precipitation distribution:



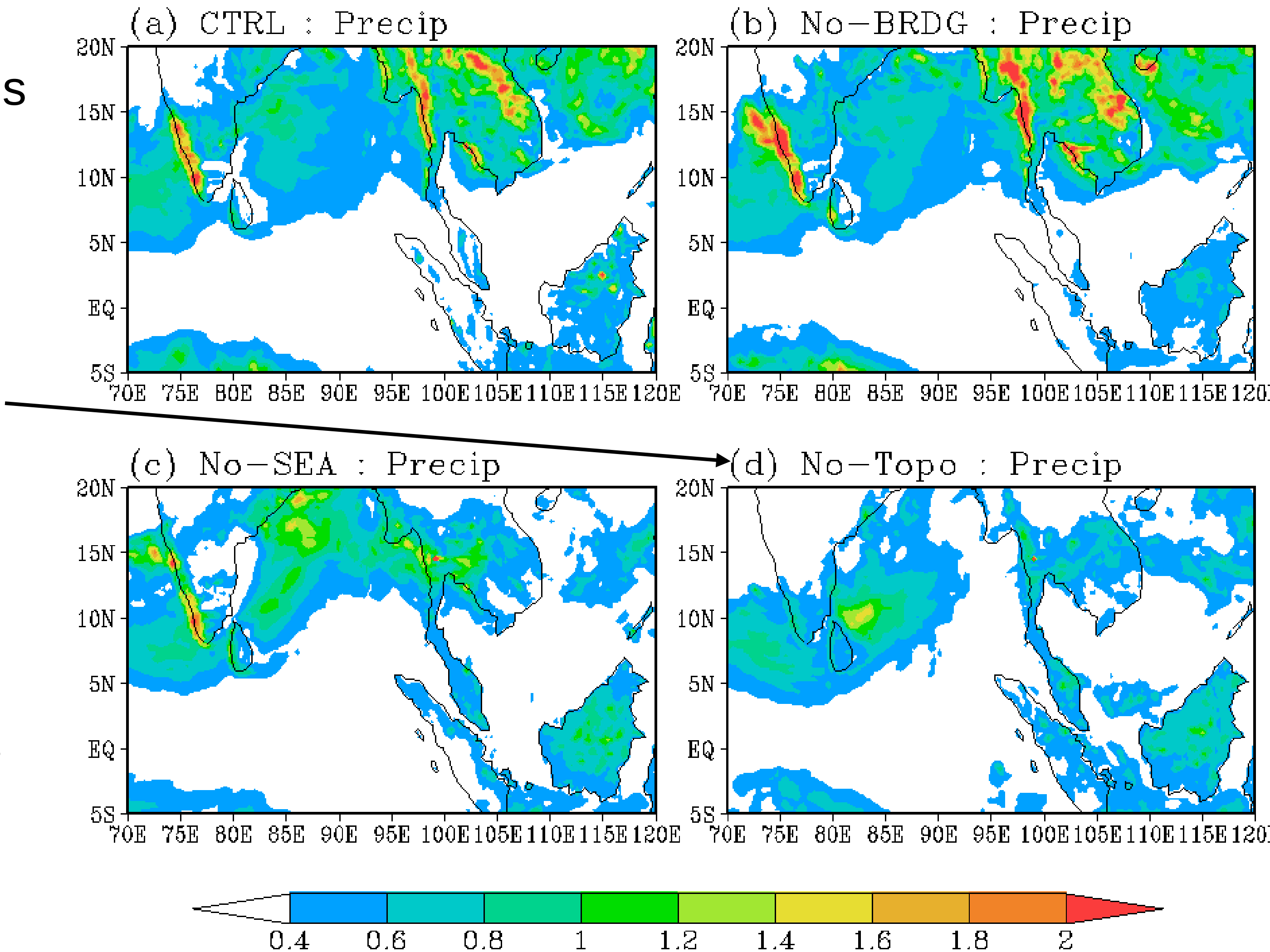
Monsoon Onset in Sensitivity Tests

- When topography over SEA is removed, the onset over the Indo-China Peninsula is significantly delayed while the onset of the Indian monsoon is nearly unchanged.
- ➔ monsoon onset over the Indo-China Peninsula is triggered by the wind-terrain interaction while the Indian monsoon onset is mainly controlled by the land-sea thermal contrast.

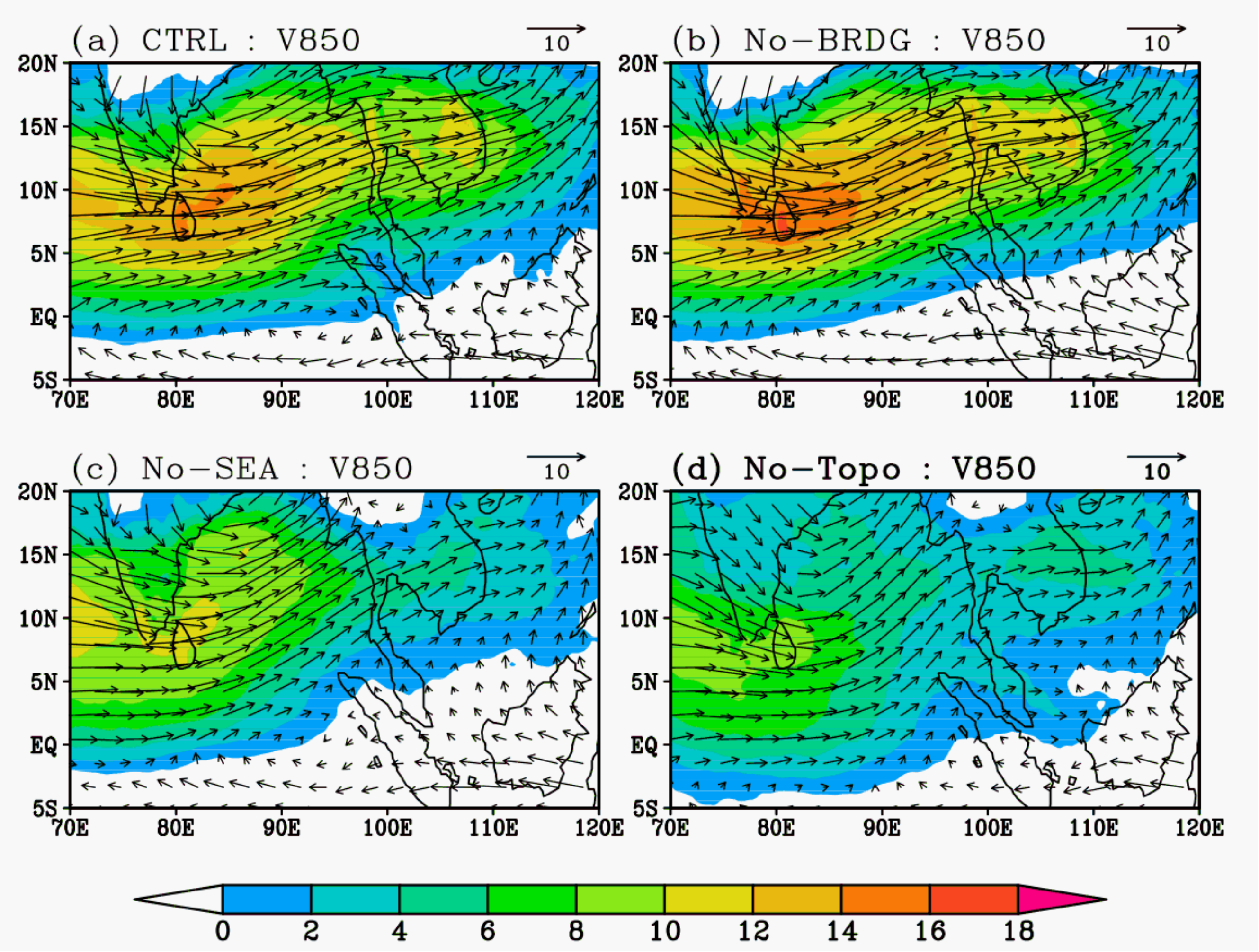


May-June Averaged Precip

- As topography is removed, precipitation is weakened and become more spatially homogeneous.
- When the SE Asia terrain is removed, precipitation along the west coast of India is also reduced.



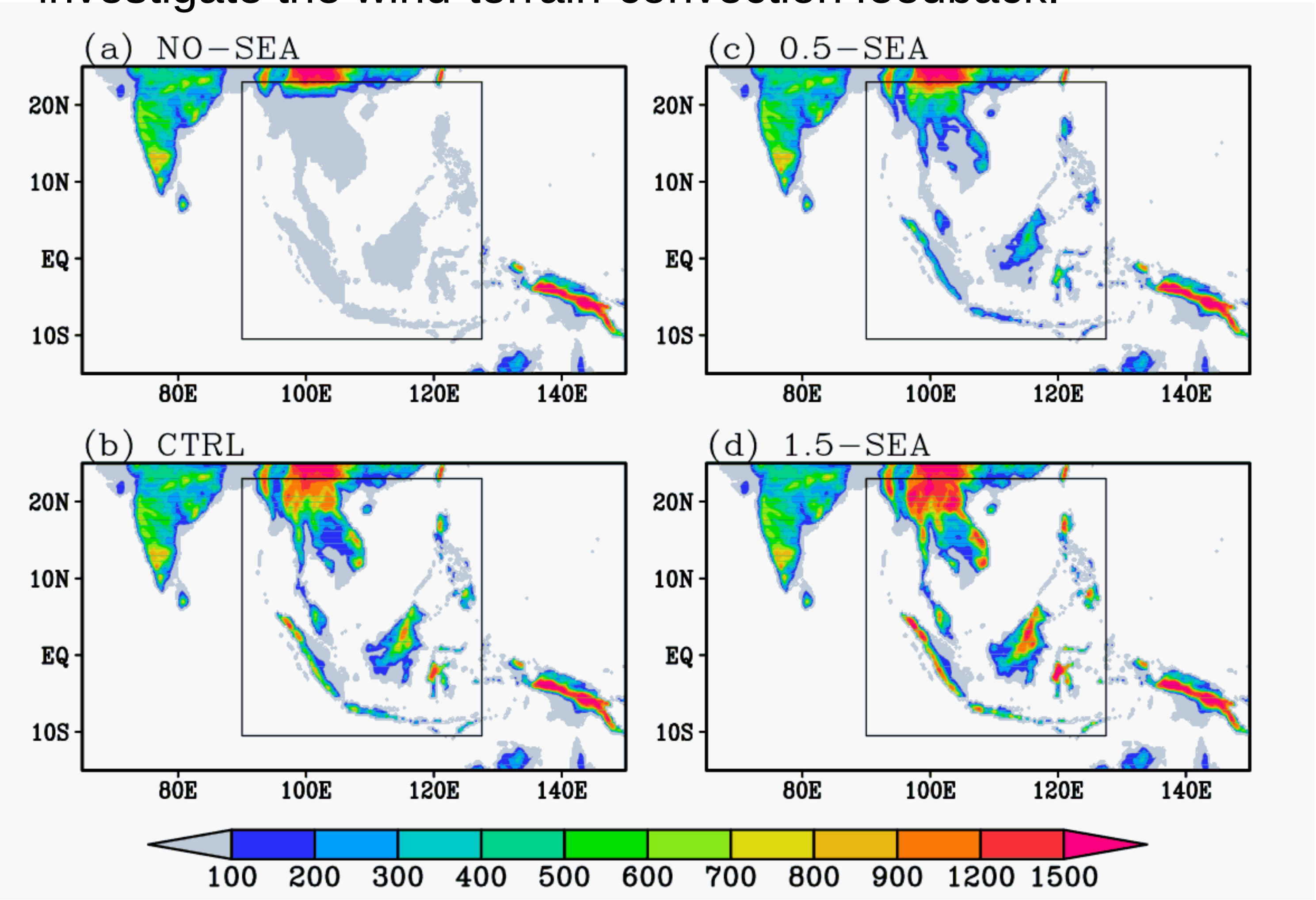
May-June Averaged 850 hPa Wind



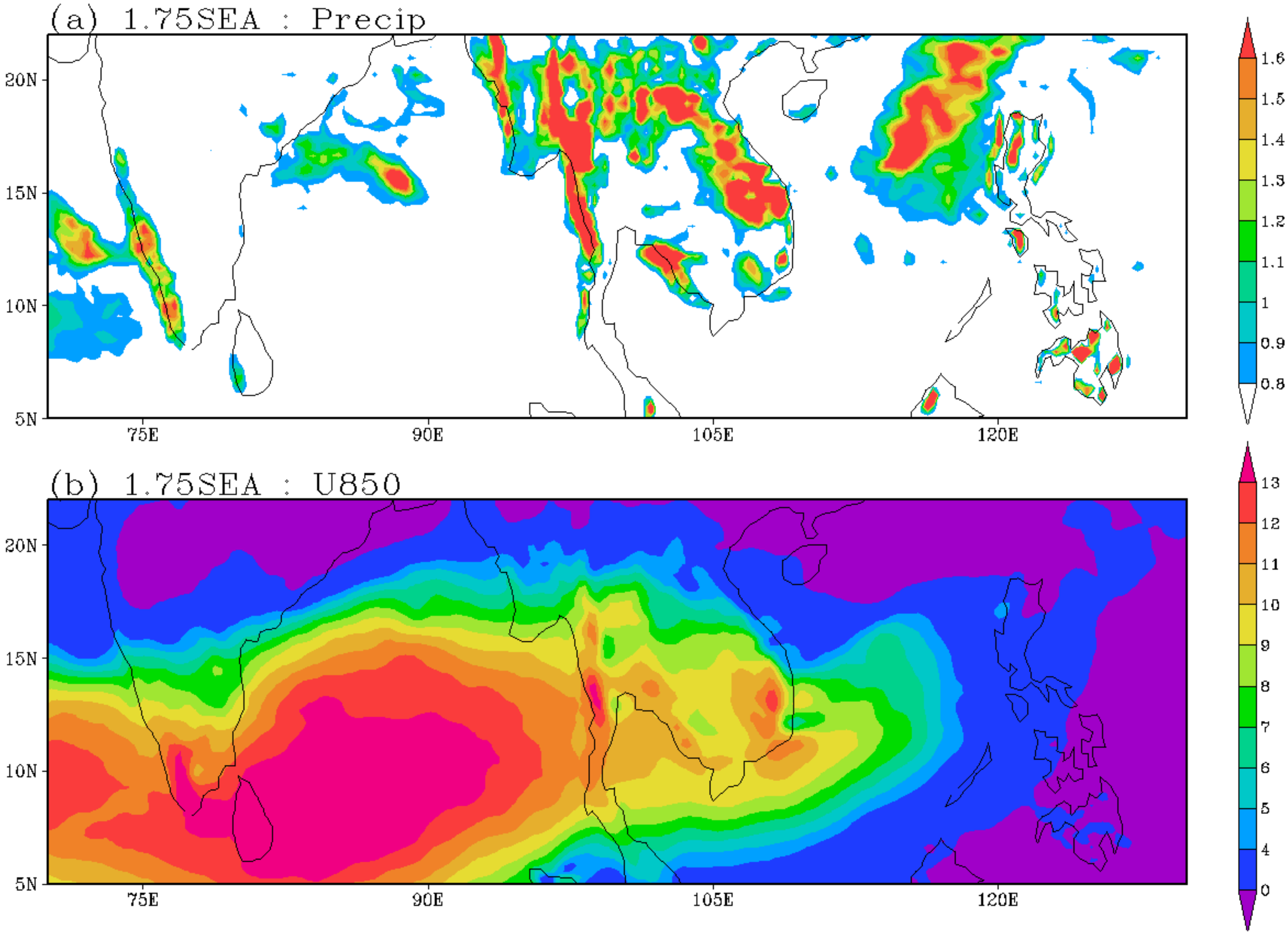
- As precipitation is reduced with the removal of the topography, the upstream westerly flow is also weakened.
- ***Any interaction between wind and convection?***

Sensitivity Tests to SEA Terrain Height

- Terrain height in the SE Asia is changed from 0% to 175% to investigate the wind-terrain-convection feedback.



U850 and Precip



Wind-Terrain-Convection Interaction

As terrain height is increased from 75% to 175%:

1) Precipitation over the windward side is increased
2) Upstream westerlies are strengthened.
3) A stronger westerly in turn leads to stronger convection.

A positive Wind-Terrain-Convection interaction.

Terrain height 25%-100% westerlies are weaker than 0%

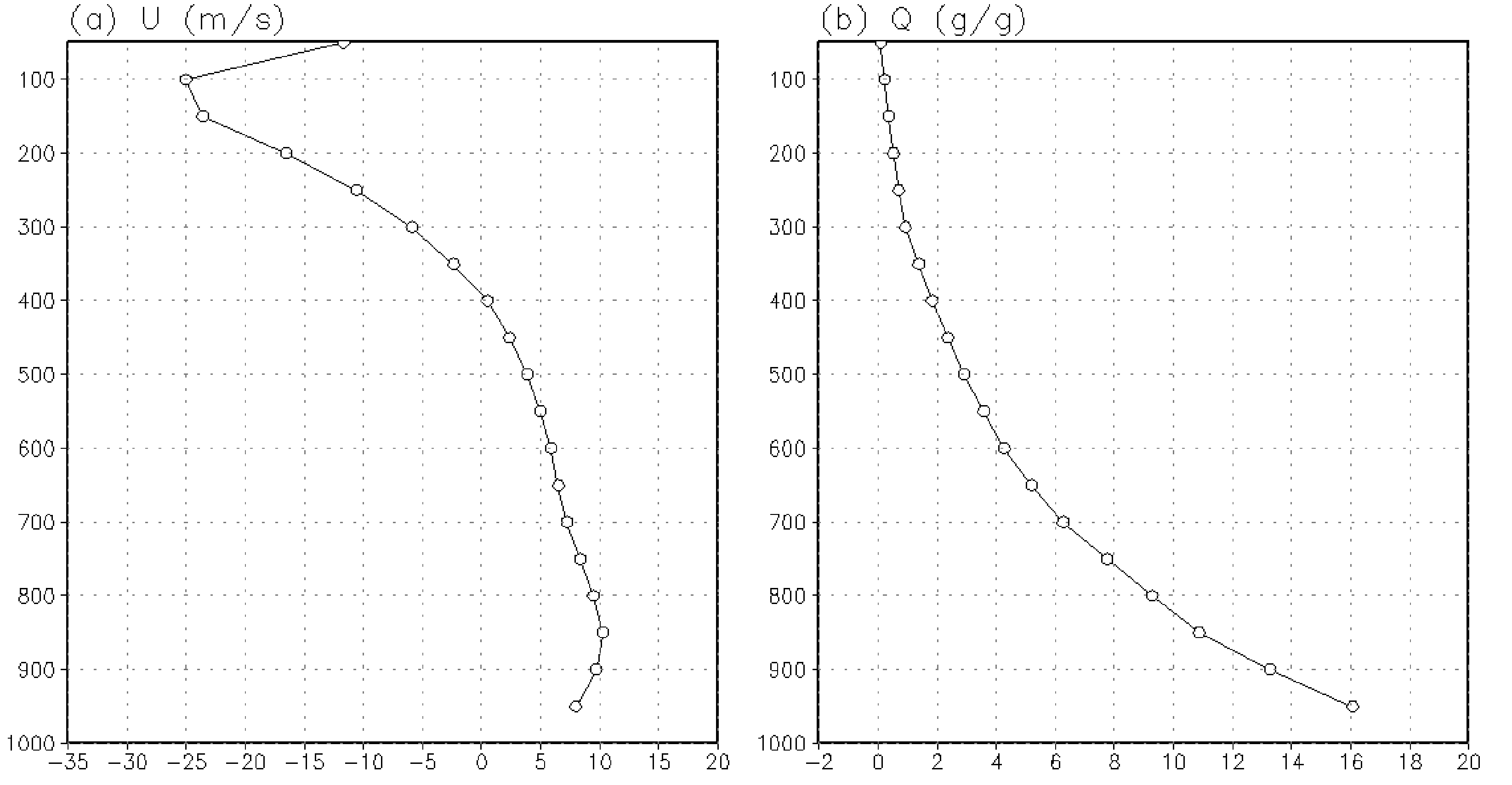
Terrain height 125% westerlies comparable to 0%

Surface friction damping?

Idealized WRF Simulation

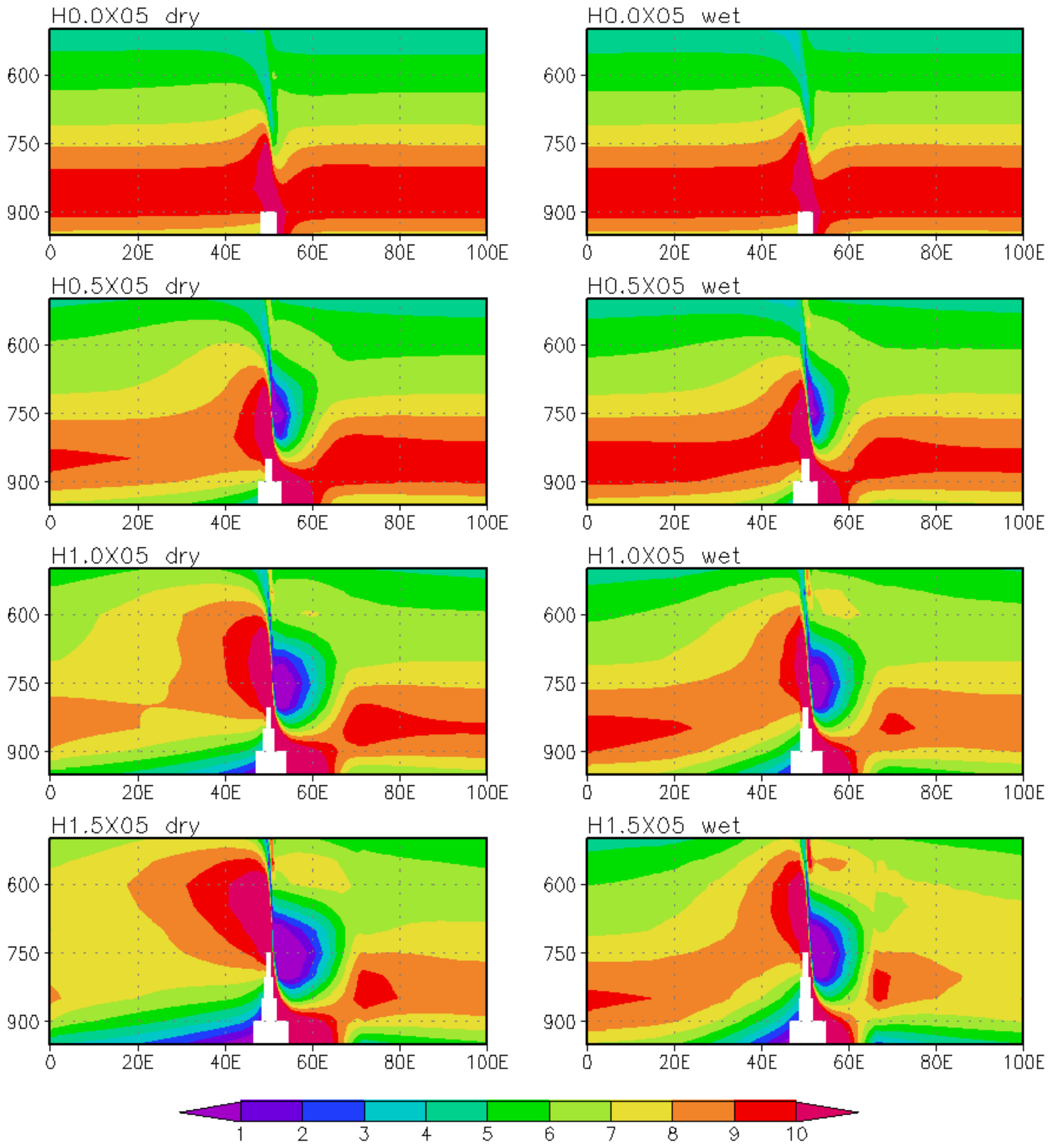
- The idealized version of WRFV3.0 (hill2D)
- The model is 2D on the x-z plane, and initialized with a zonally uniform condition based on the mean sounding derived from NCEP long-term mean data in June over the (85-95E, 8-15N).
- For the “dry” simulations, the moisture field (mixing ratio) is simply set as zero.
- The horizontal resolution is 25 km, and it covers 1000 km in the west-east direction.
- A bell-shaped mountain was placed in the center of the domain, and the model was integrated for ten days with various terrain heights (from 0-2000 meters), with and without moist processes.

Basic State



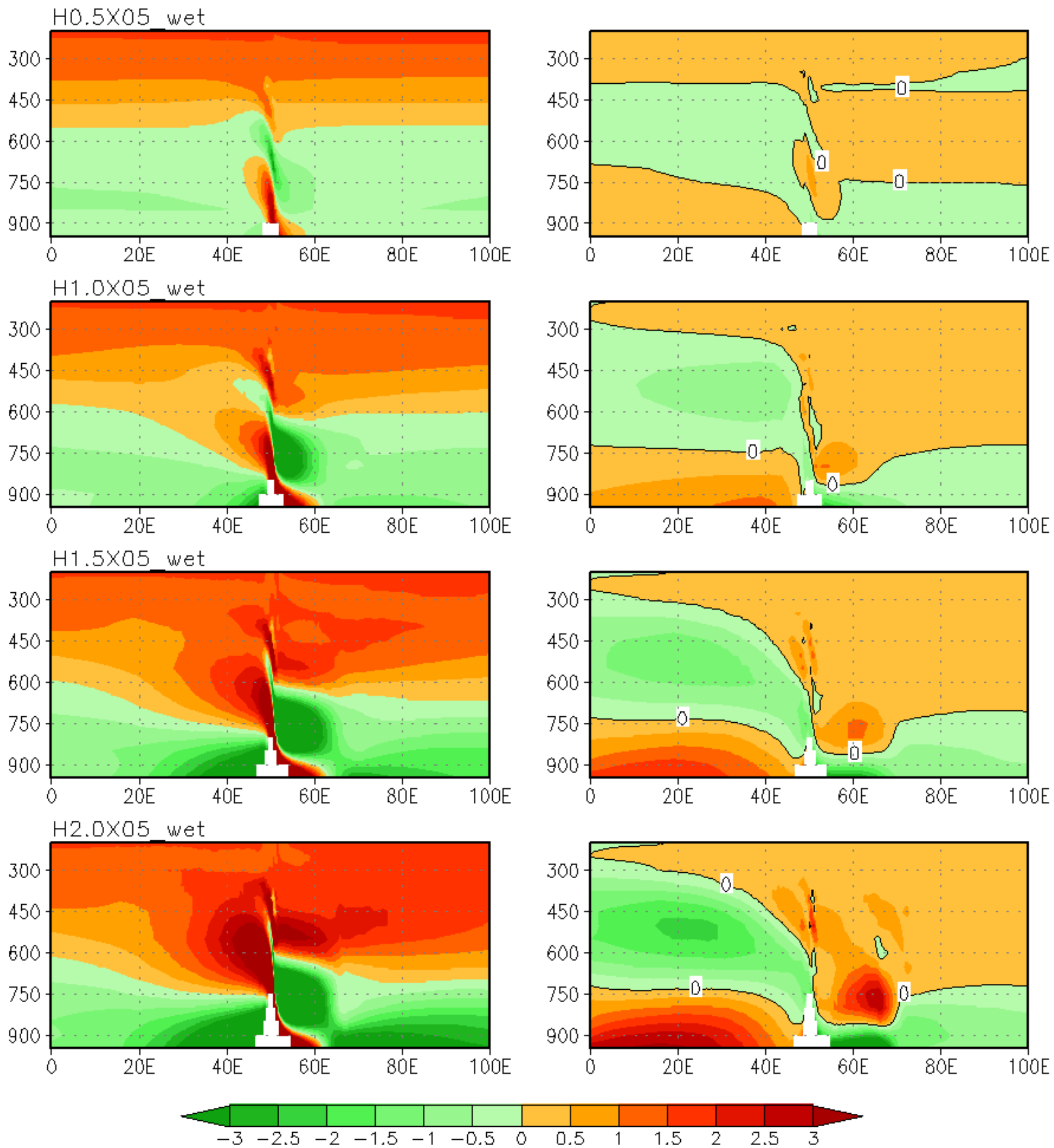
(a) U (m/s)
100
200
300
400
500
600
700
800
900
1000
−35 −30 −25 −20 −15 −10 −5 0 5 10 15 20
(b) Q (g/g)
100
200
300
400
500
600
700
800
900
1000
−2 0 2 4 6 8 10 12 14 16 18 20

Vertical Cross Section of Zonal Wind: Dry vs. Moist



Role of Terrain and Moist Processes

Diff From non-Topo   Wet “minus” Dry



Conclusions

- In the control run, heavy precipitation is anchored on the windward side of the terrain, which is consistent with observations.
- In the sensitivity tests, as topography is removed, the onset over the Indo-China Peninsula is significantly delayed while the onset of the Indian monsoon is nearly unchanged. ➔ monsoon onset over the Indo-China Peninsula is triggered by the wind-terrain interaction while the Indian monsoon onset is mainly controlled by the land-sea thermal contrast.
- As topography is systematically removed, maximum precipitation is reduced and the westerly monsoon flow is weakened. ➔ a positive feedback between the westerly monsoon flow and the convection induced by the wind-terrain interaction.
- A surface friction effect becomes conspicuous at lower terrain heights (0%→125%)
- 2-D idealized simulation confirms the surface damping effect of the terrain and the positive feedback of convection to the upstream low-level westerly flow.

Conclusions

- Indochina Peninsula terrain responsible for the earliest onset of Asian summer monsoon; Maritime Continent land bridge has little effect.
- Onset starts in Indochina Peninsula then develops to both east (South China Sea) and west (Bay of Bengal).
- Terrain effect includes a mechanical weakening effect and a rainfall-circulation feedback effect. The former appears at low terrain but the later dominates when the terrain grows to realistic height.

Vertical Cross Section: Omega and U850