machine learning in climate science

Competing Topographic Mechanisms for the Summer Indo-Asian Monsoon

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Journal Club

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The Indo-Asian Monsoon (IAM)

1
- Basic Properties
- Role of topography
- Monsoonal Behavior

Existing Theories & Methods

2
- 3 competitive Theories
- Methods
- Temperature Measure

Results

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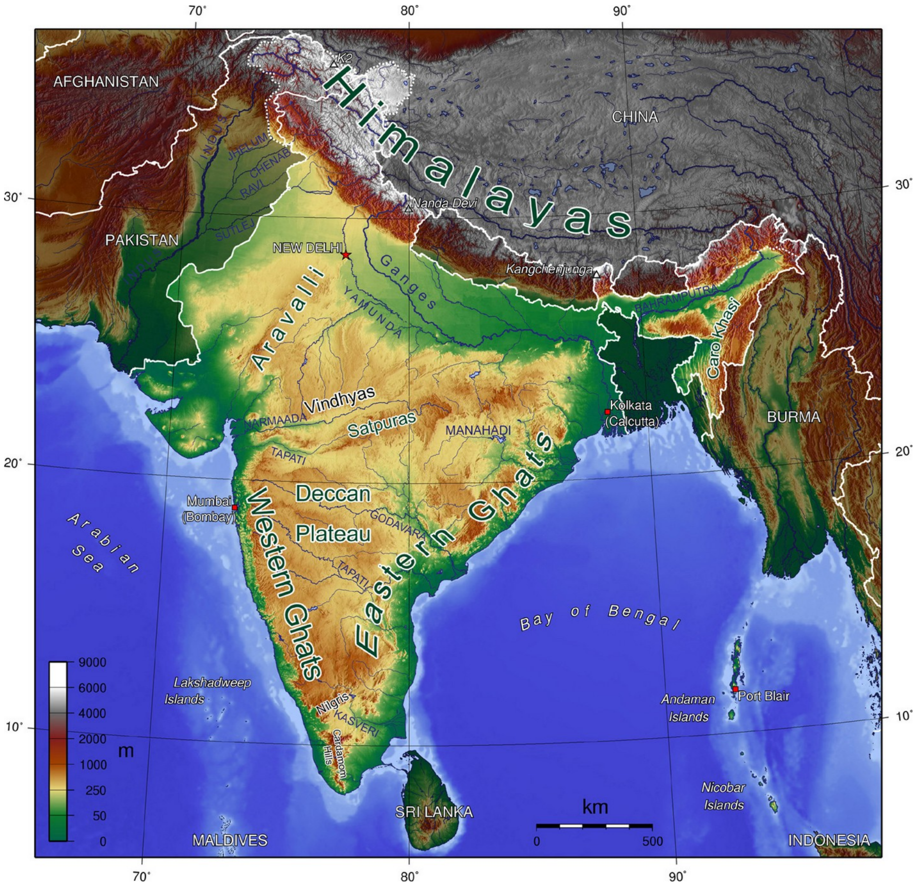
- Remove Topographies
- Compare Different Runs
- Consistency with Theory?

Summary

4
- Global Monsoon
- Regional Differences
- Personal Take-Home Messages

The Indo-Asian Monsoon (IAM)

- Northward Movement of ITCZ leads to strong rainfalls during summer (May-September)
- Monsoon onset over the Bay of Bengal in May, at India in June, progression to the South China Sea
- essential characteristics strong onshore flow and strong precipitation rates
- Difficult to accurately predict the quantity, timing, and geographic distribution of the precipitation

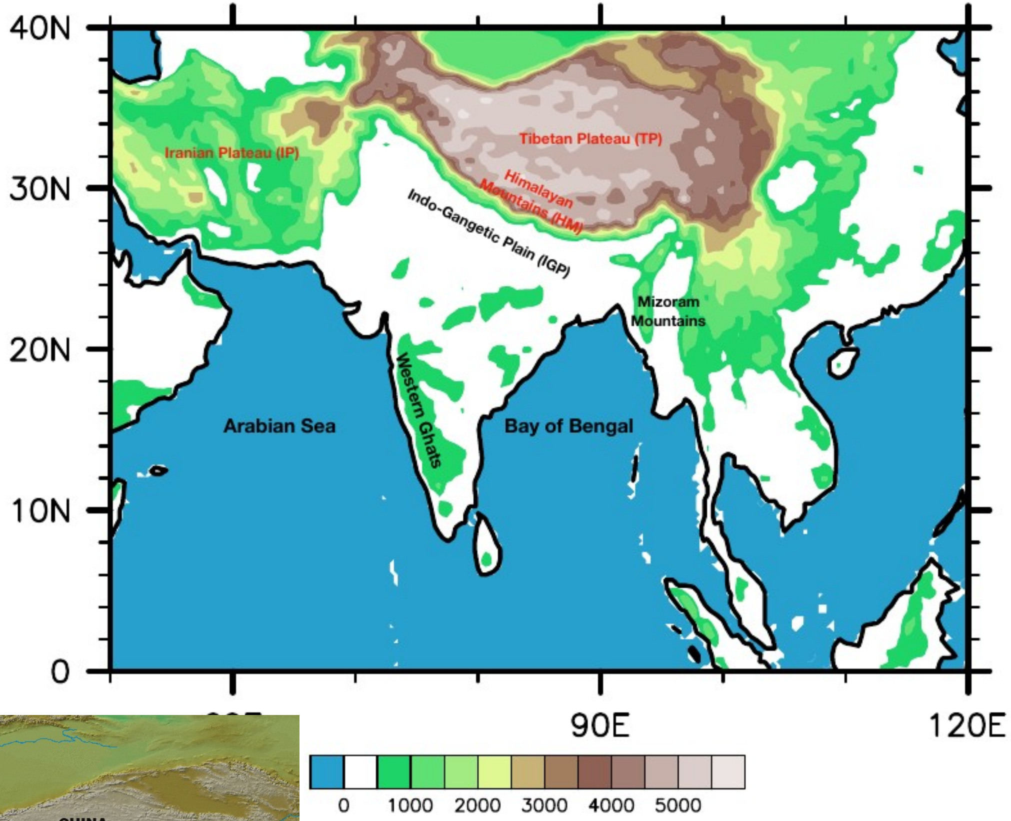


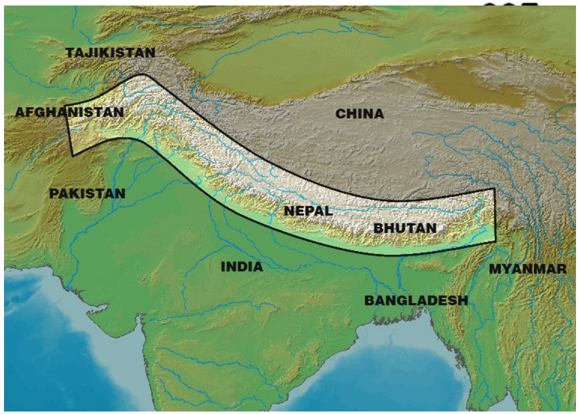
Taken from https://en.wikipedia.org/wiki/Monsoon_of_South_Asia

Topographic Influences

- Himalayan Mountains
- Tibetan Plateau
- Iranian Plateau

Topography influences the monsoon rainfalls, but how concretely?





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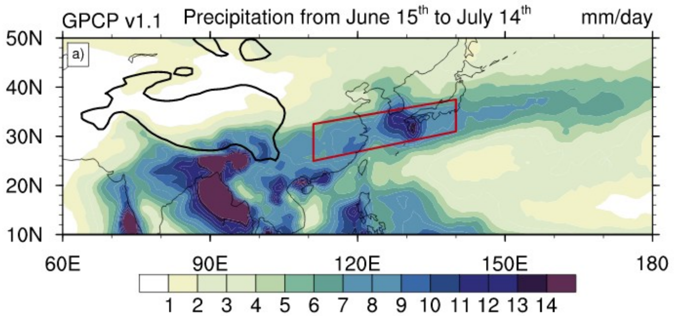
Three competitive theories:

1.) Topographic thermal forcings:

- During summer plateaus increased heat flux reinforces the land–sea thermal contrast

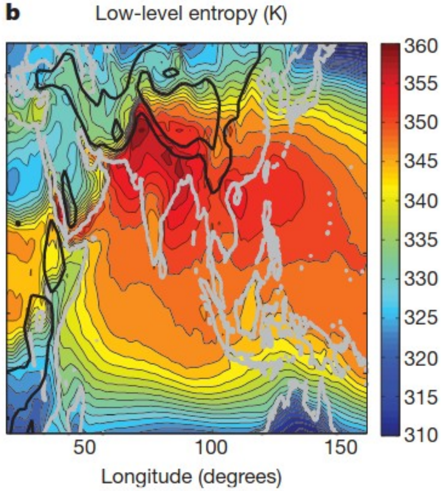


Chen et al. 2014

2.) Insulation mechanism

- Himalaya as insulating barrier for warm, moist air over continental India from the cold and dry extratropics.

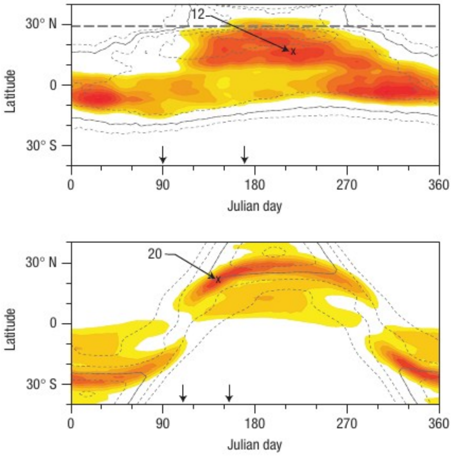
Boos et al. 2010



3.) Eddy-driven mechanism

- Monsoonal behavior due to solar radiation and corresponding mitigation of ITCZ

Schneider et al. 2014; Bordoni et al. 2008



Two possible approaches

Paleo-Climatic Reconstructions:

- Using paleoclimate proxy data to estimate change of ISM
- E.g. strong ISM observed even before uplift Tibetan Plateau
- Problem of complex geological history: spatially heterogeneous, controversial and time uncertainties

Idealized Modelling:

- Topography is carved out from modern
- So far, most of the idealized work has been performed in lower model resolution
- A full demonstration of the impact of the various topographies using a model with a better-resolved topography-atmosphere interactions is timely.

Methods

- Performing multiple high-resolution (0.23° × 0.31° ~ 25 km) runs with Community Climate System Model version 4 (CCSM4), each as a 10-year averaged equilibrium simulations run for 16 years.
- Neglects feedbacks between atmospheric changes and ocean state
- Runs with different topographic configurations (Table 1)

Table 1
List of Simulations and the Applied Topographic Configurations

Case name	Tibetan Plateau	Himalayan Mountains	Iranian Plateau
MODERN	✓	✓	✓
HM	X	✓	X
IP	X	X	✓
TP	✓	X	X
Flat	X	X	X
BK10	X	✓	✓
No HM	✓	X	✓

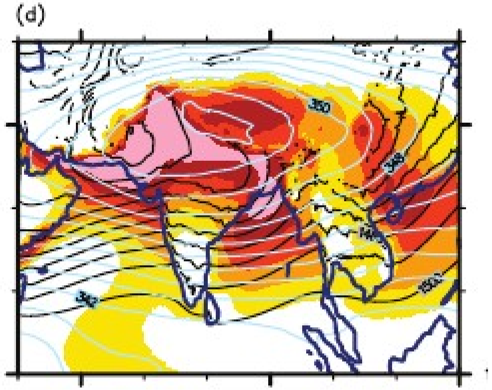
→ Check which of the 3 theories are necessary or sufficient conditions for modern-like IAM.

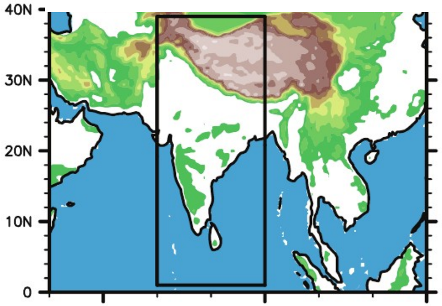
Equivalent Potential Temperature (θ_e)

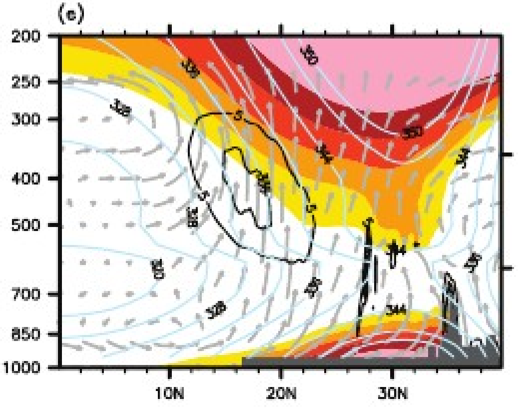
- Wikipedia: “EPT is the quantitity parcel of air would reach if all the water vapor in the parcel were to condense, releasing its latent heat, and the parcel was brought adiabatically to a standard reference pressure, usually 1000 hPa which is roughly equal to atmospheric pressure at sea level.”

- Create vertical equivalent potential profiles, meridional average over 68°E–92°E

- Helps to visualize how topography alters the temperature







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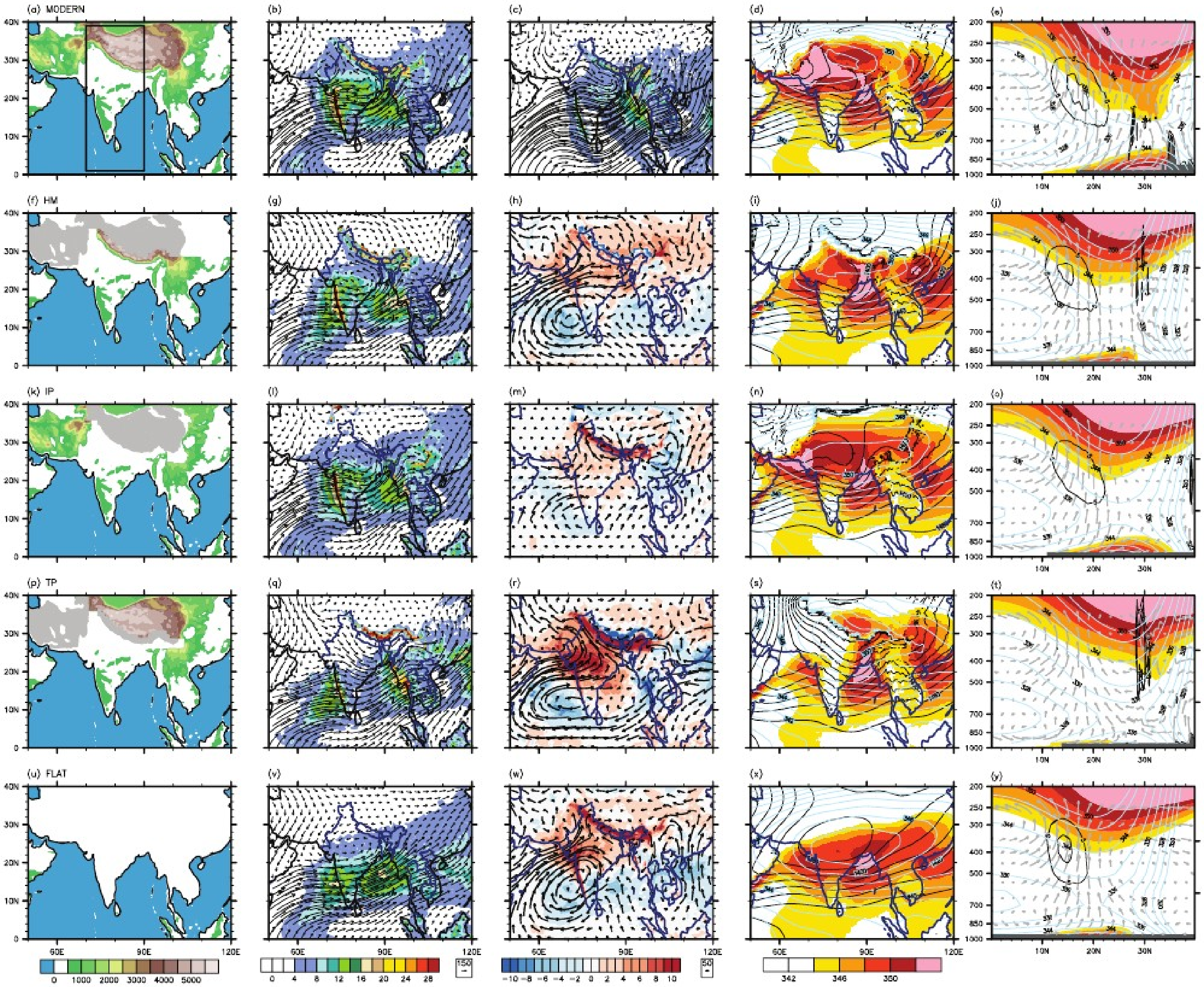
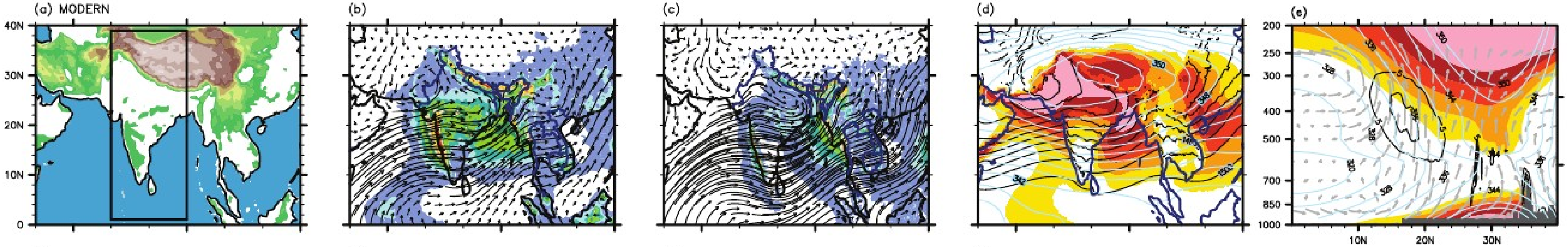
Results:

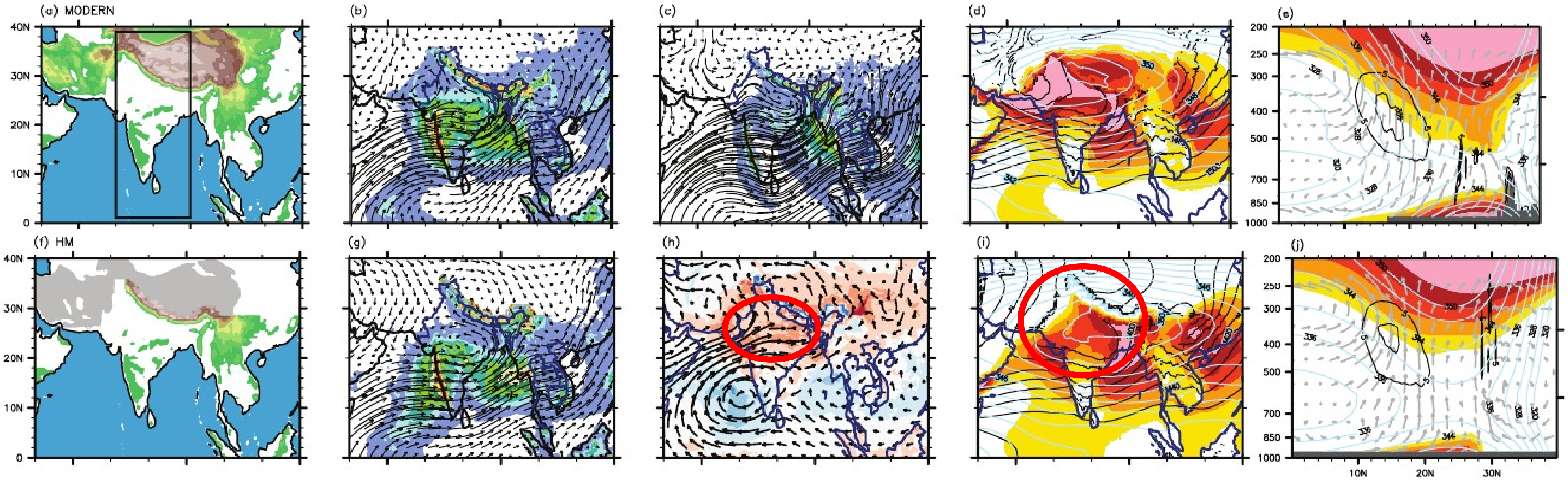

(a) MODERN
(f) HM
(k) IP
(p) TP
(u) FLAT
60E 90E 120E
0 1000 2000 3000 4000 5000
0 4 8 12 16 20 24 28
-10 -8 -6 -4 -2 0 2 4 6 8 10
342 346 350
10N 20N 30N

Results: MODERN-case (TP, HM, IP)



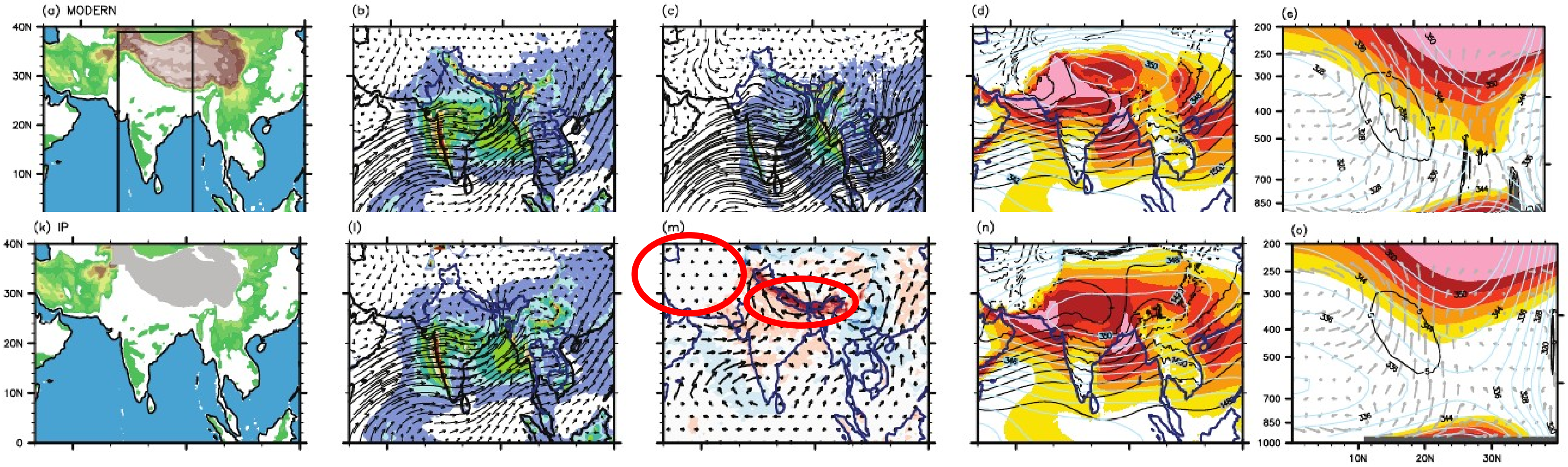
- Both precipitation and moisture flux fields are qualitatively similar to the reanalysis products ERA5
- Enhanced EPT found in Northern India and Western China
- Enhanced vertical velocities found at 20-30°N

Results: HM-case (HM)



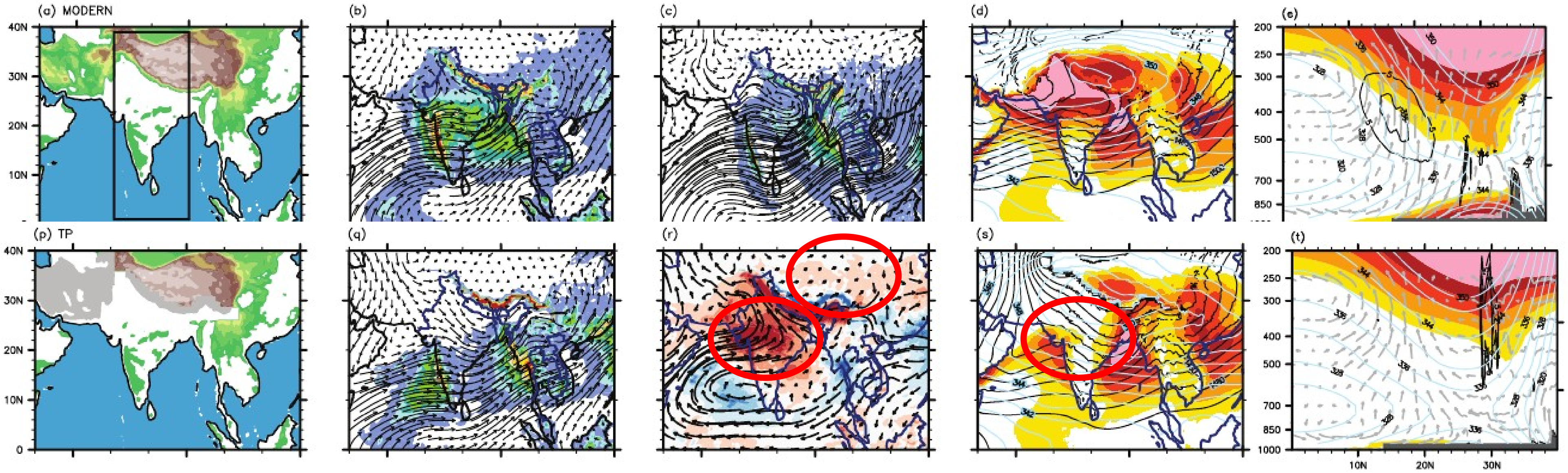
- moisture flux convergence and rainfall rates are weaker in monsoon region, the easterly moisture flux from the Bay of Bengal into the IGP is strengthened
- the HM simulations are sufficient to sustain the IAM
- Much of the high EPT over Northwestern India and Tibetan Plateau not preserved
- Overturning circulation sufficiently preserved

Results: IP-case (IP)



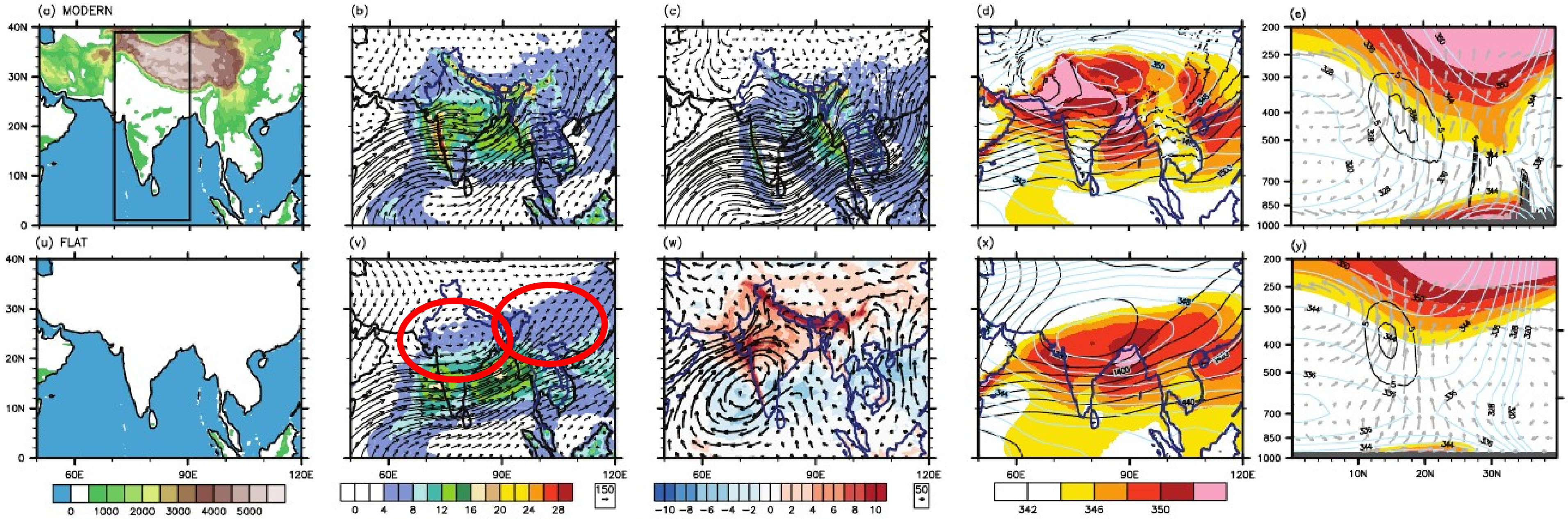
- Rainfall over Himalayan missing; stronger moisture flux from the Arabian Sea into Northwestern India
- The IP prevents the low-enthalpy air from mixing with the monsoon high-enthalpy air → IP as “gatekeper”
- The persistence of onshore monsoon: Thermal forcing over an elevated plateau not a necessary conditions for the IAM!

Results: TP-case (TP, ie. both insulation mechanisms are now removed)



- Weaker precipitation over Northern India, induced by the influx of dry westerly air
- Extensive drying and removal of the EPT maximum
- But: the overturning circulation at 20°N still present, strong influx of moisture from the Bay of Bengal
  → The insulation mechanism is not a necessary condition for the IAM to exists.

Results: FLAT-case (No topography)



- The advection of moist air from Northern Bay of Bengal into Asia persists
- Decreased onshore moisture flux from the Arabian Sea and along the IGP
- But: Most basic aspects of the IAM circulation (occurrence of subtropical precipitation, moisture flux into Indo-Asia), exist without any topographic forcing

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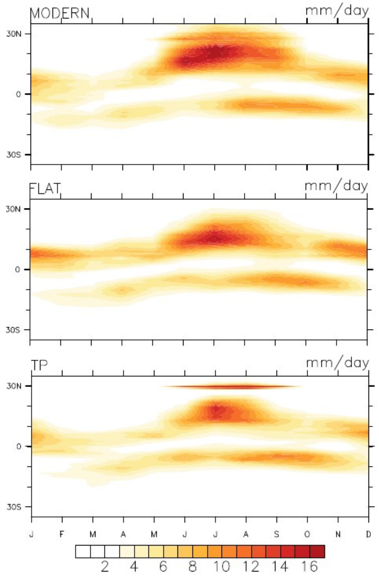
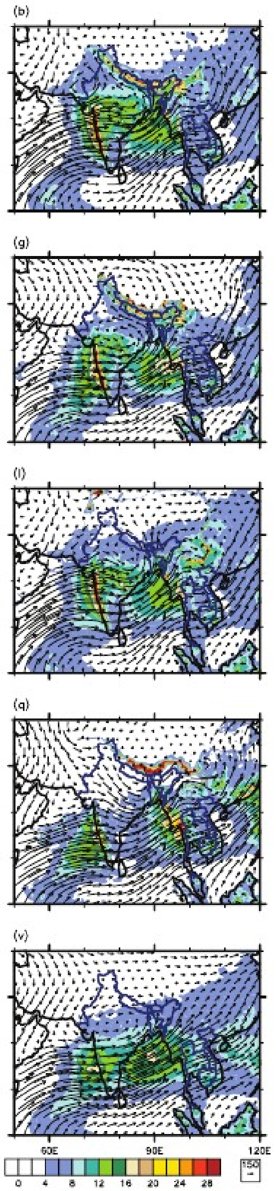
Summary of Findings: Monsoonal Behavior

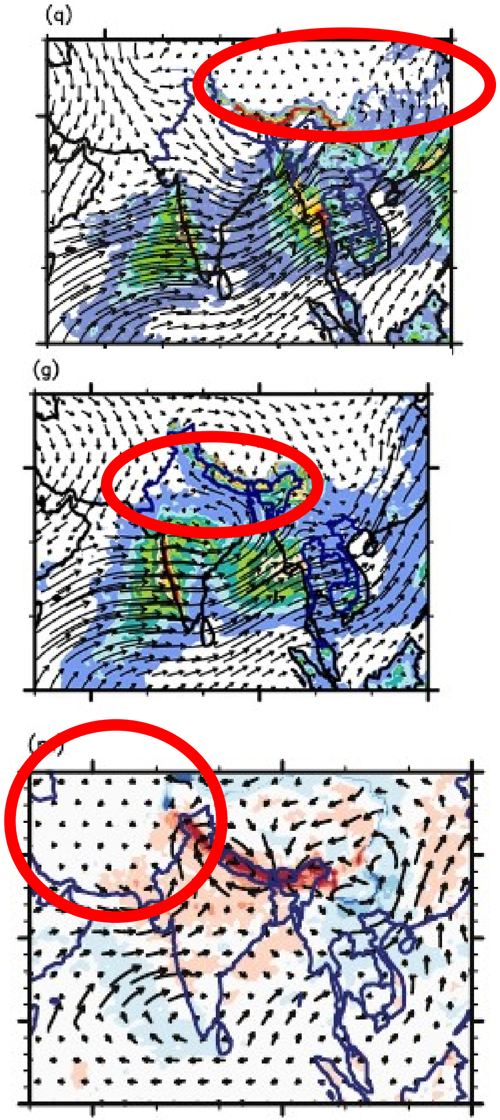
- Basic monsoon circulation as a response to surface temperature gradients, especially variations in SST distribution
- still a monsoonal maximum in precipitation similar to modern observations occurs
- Robust response to changes with various topographic forcings suggests that precipitation over these smaller mountain ranges is strongly tied to the large-scale Hadley cell circulation.





Summary of Findings: Specific Orographic Influences

- Tibetian Plateau: Ventilates the concentrated high-enthalpy air along the IGP through mechanical downwind convergence
- Himalayan: HM mountain range initiates and maintains the Indo-Gangetic LLJ
- Iranian Plateau: Acts (together with HM) as gatekeeper to prevent the flow of cool, dry air in the IGP from westerly advection, the moisture flux from the Arabian Sea into Asia is only enhanced with raised IP



Personal Summary:

- Influence of specific topography plays an important role for *regional* phenomena.

- Overall *global* monsoonal behavior occurs independent of topography.

- Question of what drives the global phenomena not really addressed.

Thank you for your attention!

Questions?