

The Changing Monsoon Extremes and Dynamics: Example in Pakistan

S.-Y. Simon Wang¹, R. Davies¹, W.-R. Huang², and R. Gillies¹

1. Utah Climate Center/Dept. Plants, Soils, and Climate
Utah State University
2. City University of Hong Kong

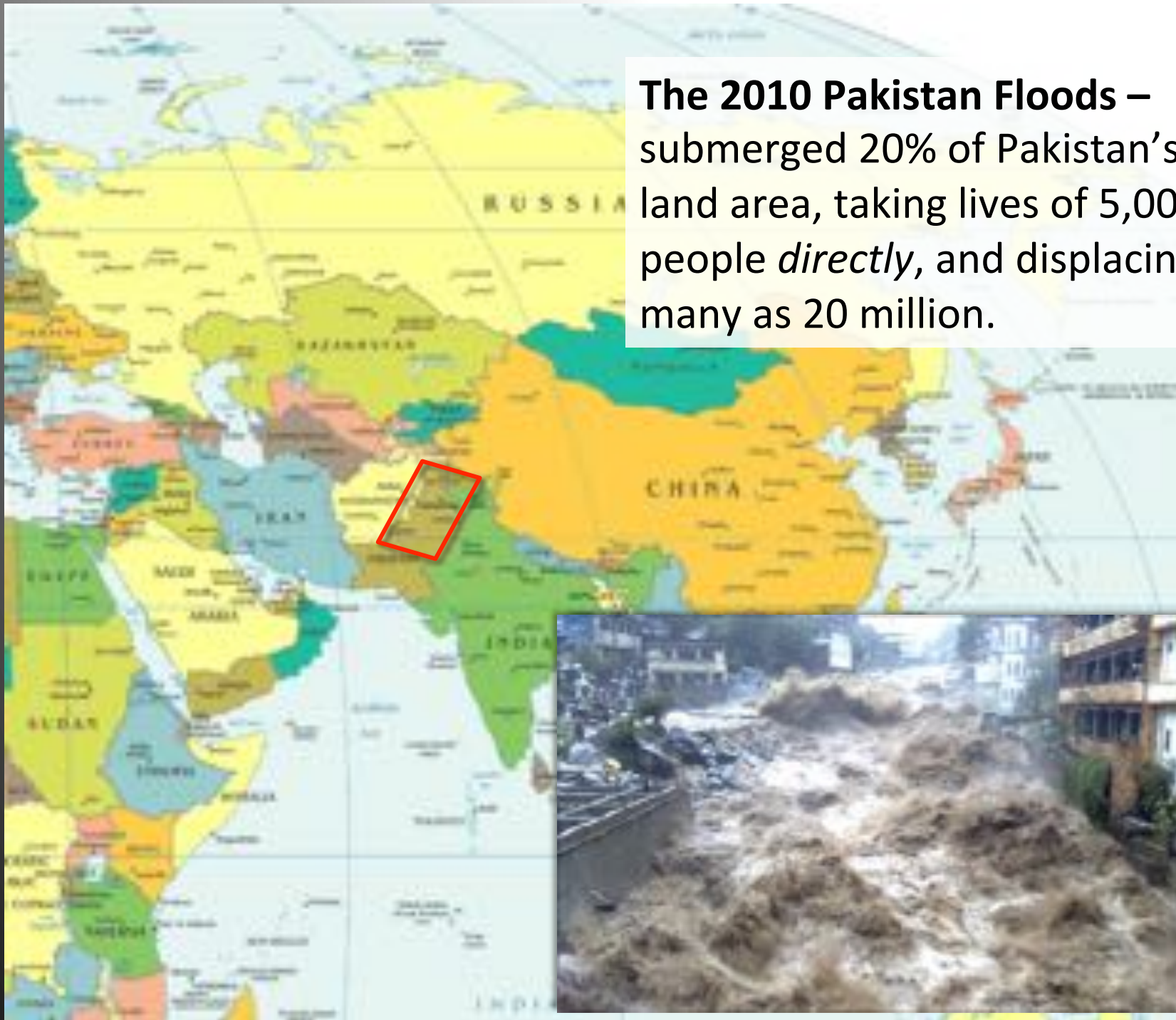
Global warming → more extremes

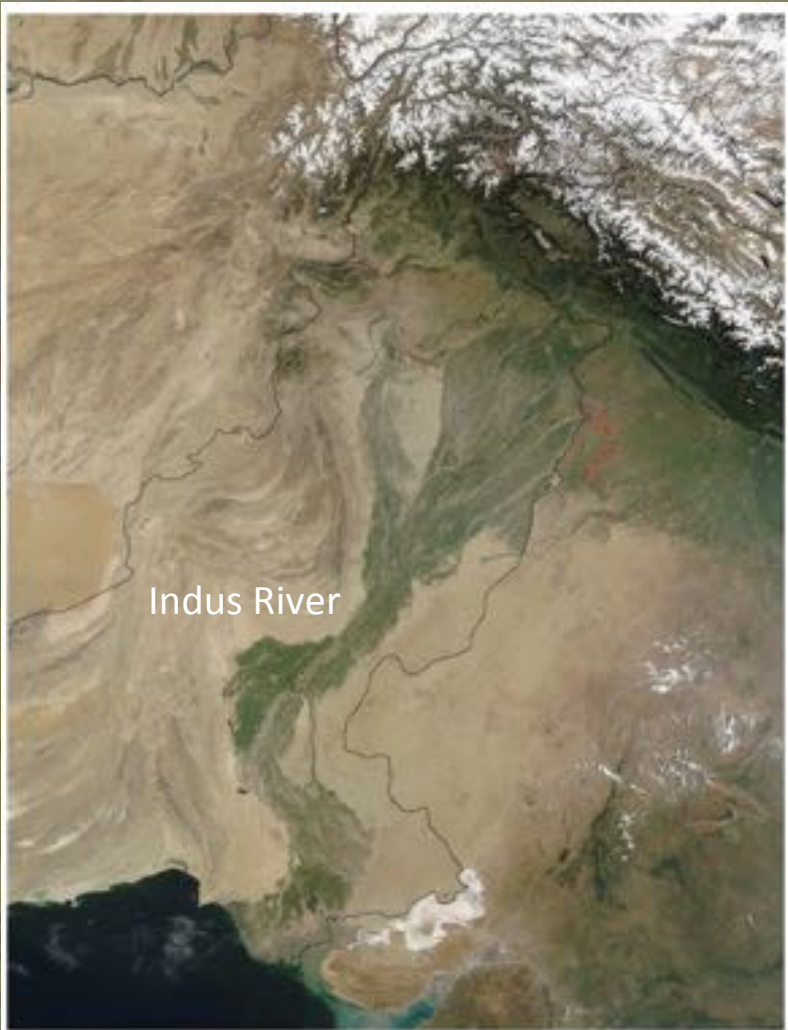
but,

every time when an extreme event occurs...

One event \neq warming !?

The 2010 Pakistan Floods – submerged 20% of Pakistan’s land area, taking lives of 5,000 people *directly*, and displacing as many as 20 million.

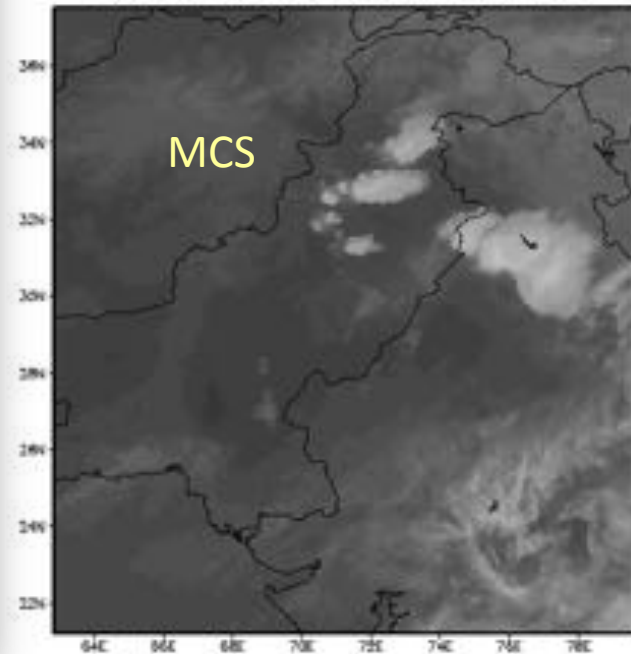




mesoscale convective systems (MCSs)

**3 MCSs → flash floods
(7/12, 7/19, 7/28)**

Global Merged IR (00min00Z12JUL2010)
Created by NASA Goddard GES DISC

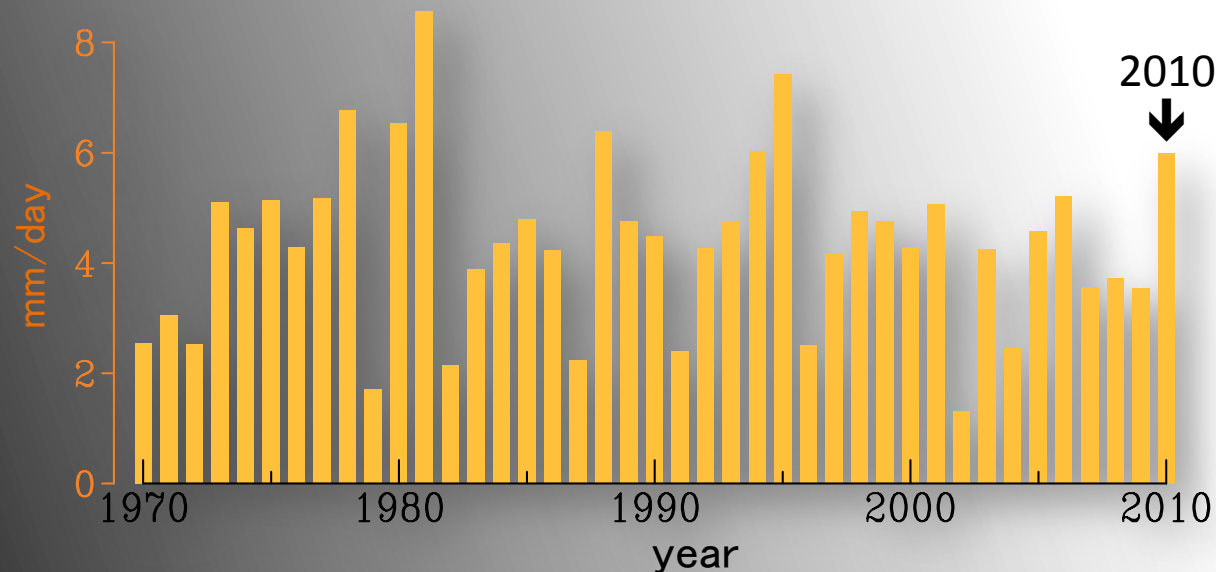


Source: NASA

Puzzles:

1. Total precipitation wasn't record-breaking
2. Has the monsoon extended further inland?
3. Is the flooding linked to climate change?

Mean Jul-Aug rainfall in northern Pakistan (5°x5°)

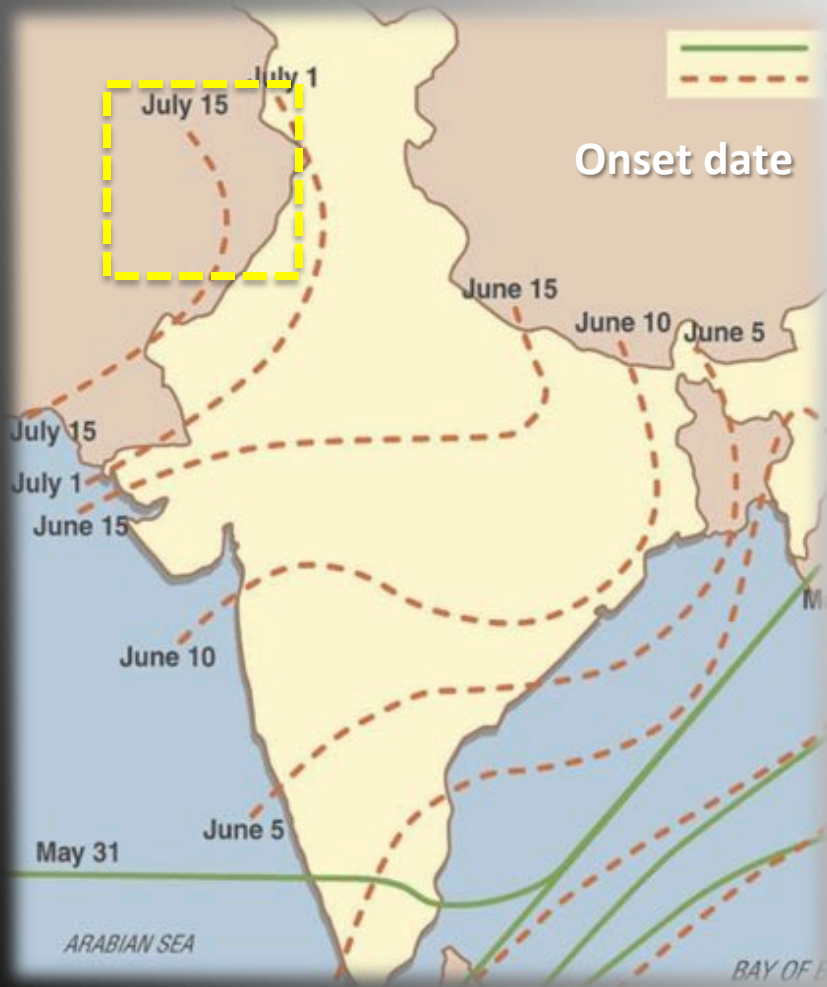


2010

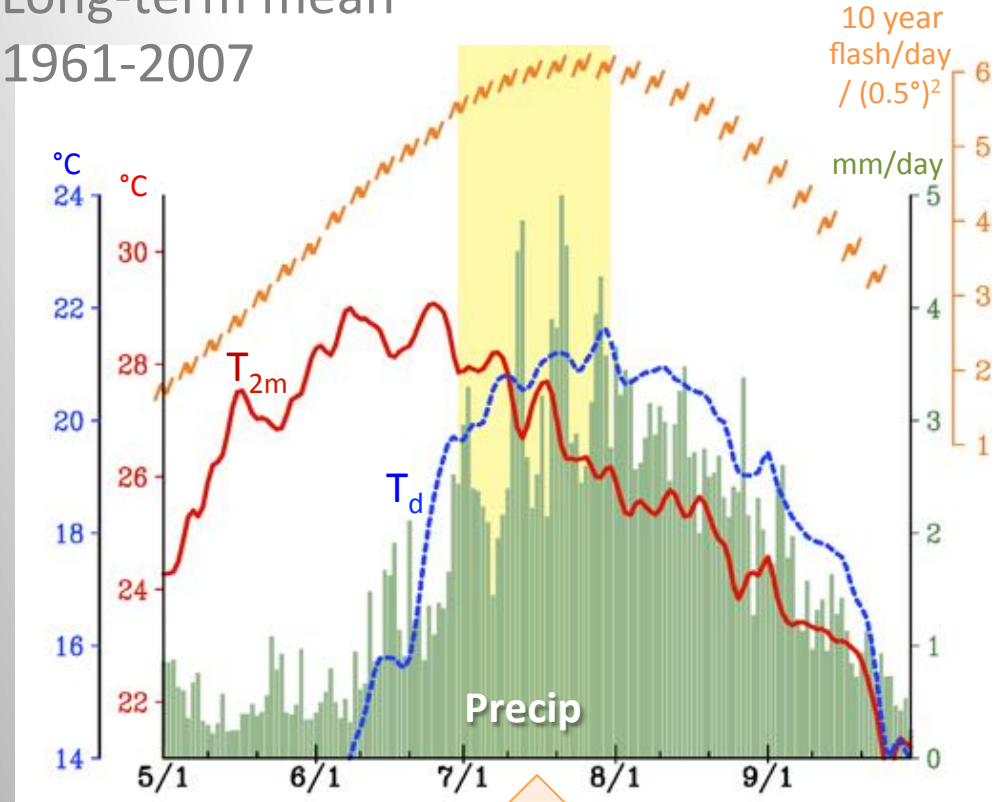
↓
PMD: 2010 seasonal mean ranked only 6th



A 2-stage monsoon perspective

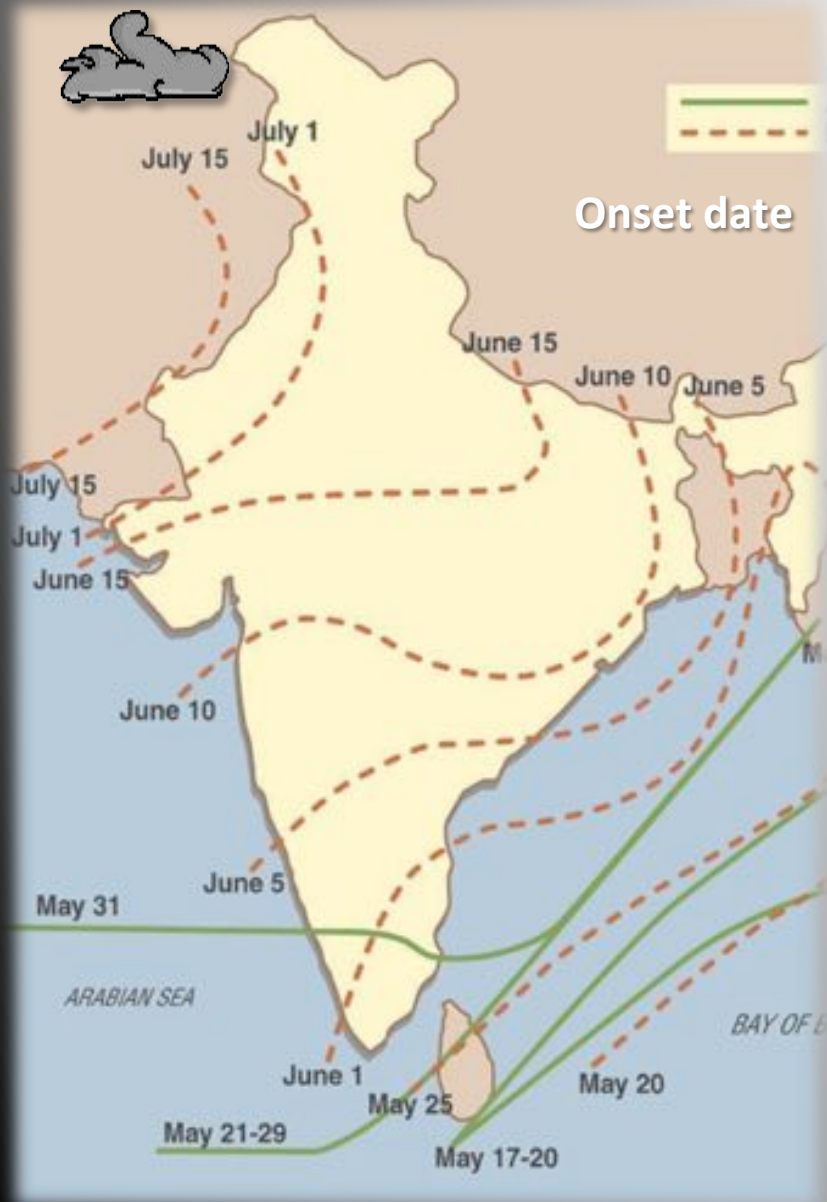


Long-term mean
1961-2007

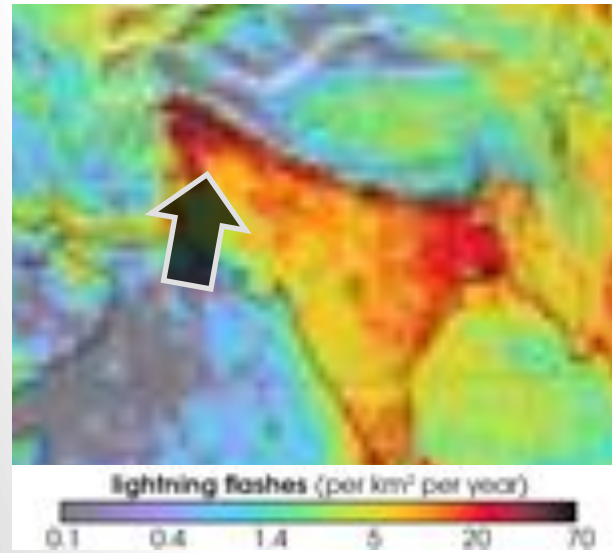


Onset

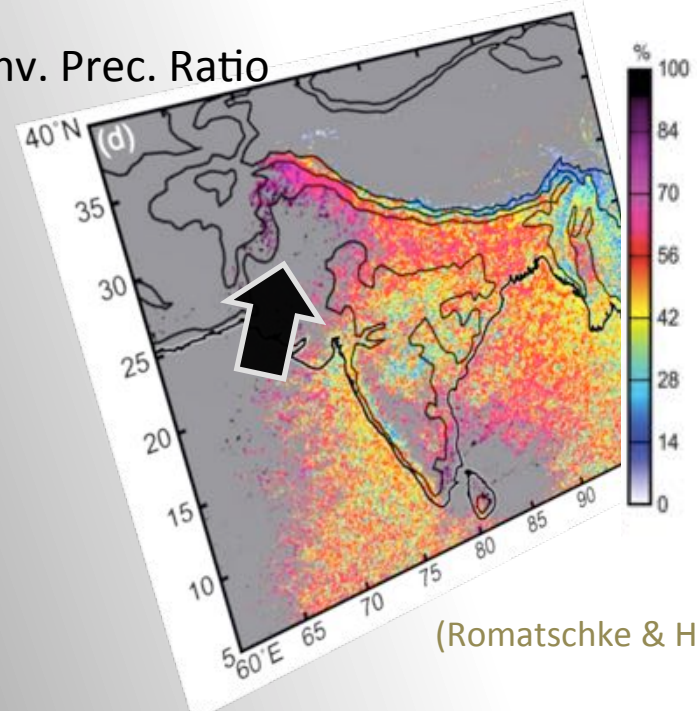
A 2-stage monsoon perspective



Lightning frequency (TRMM LIS)

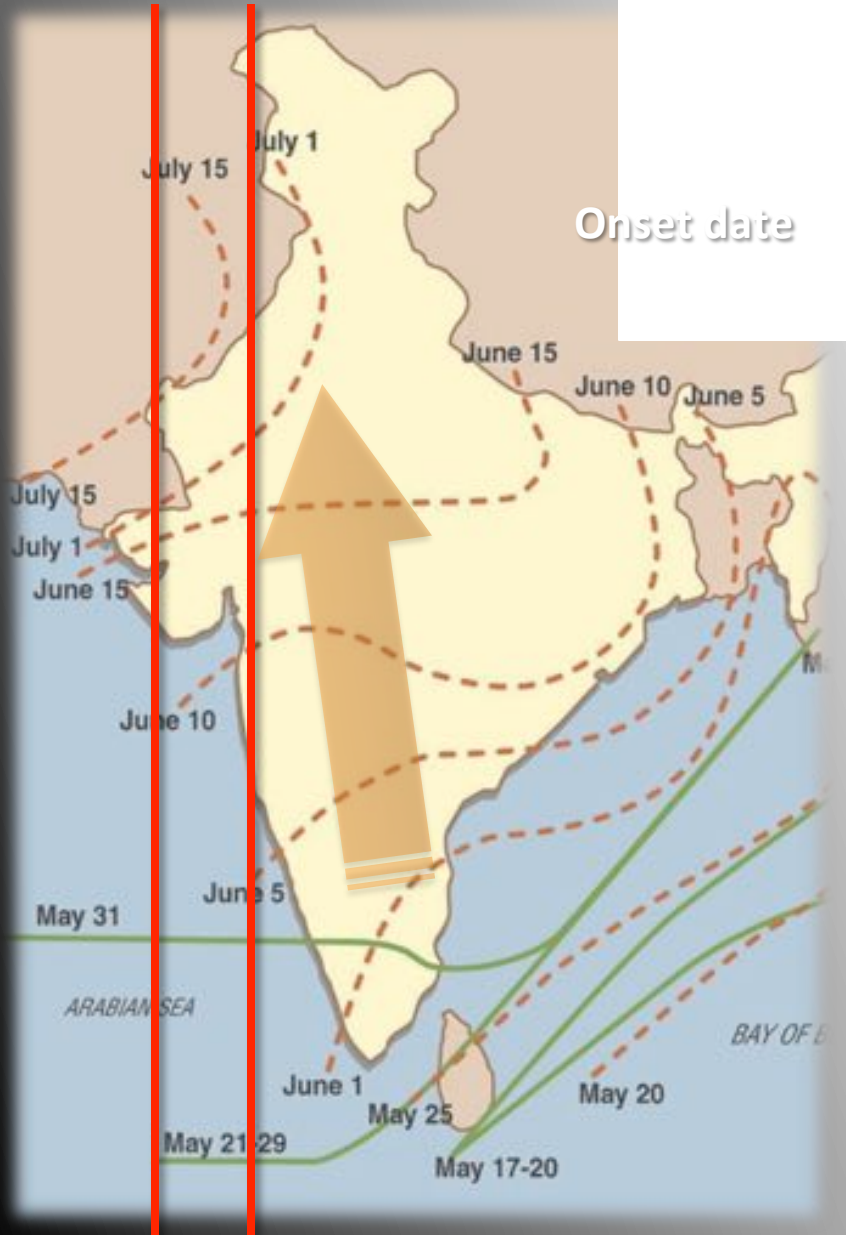


Conv. Prec. Ratio

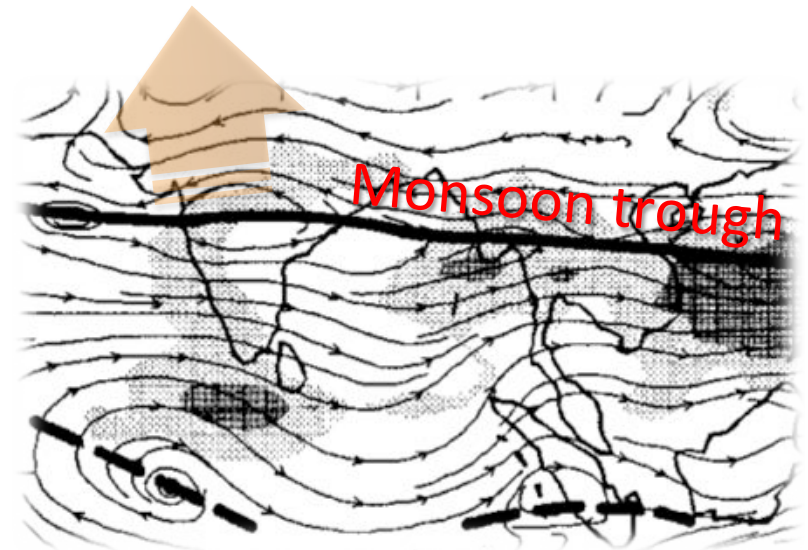


(Romatschke & Houze 2011)

A 2-stage monsoon



Role of the monsoon trough?

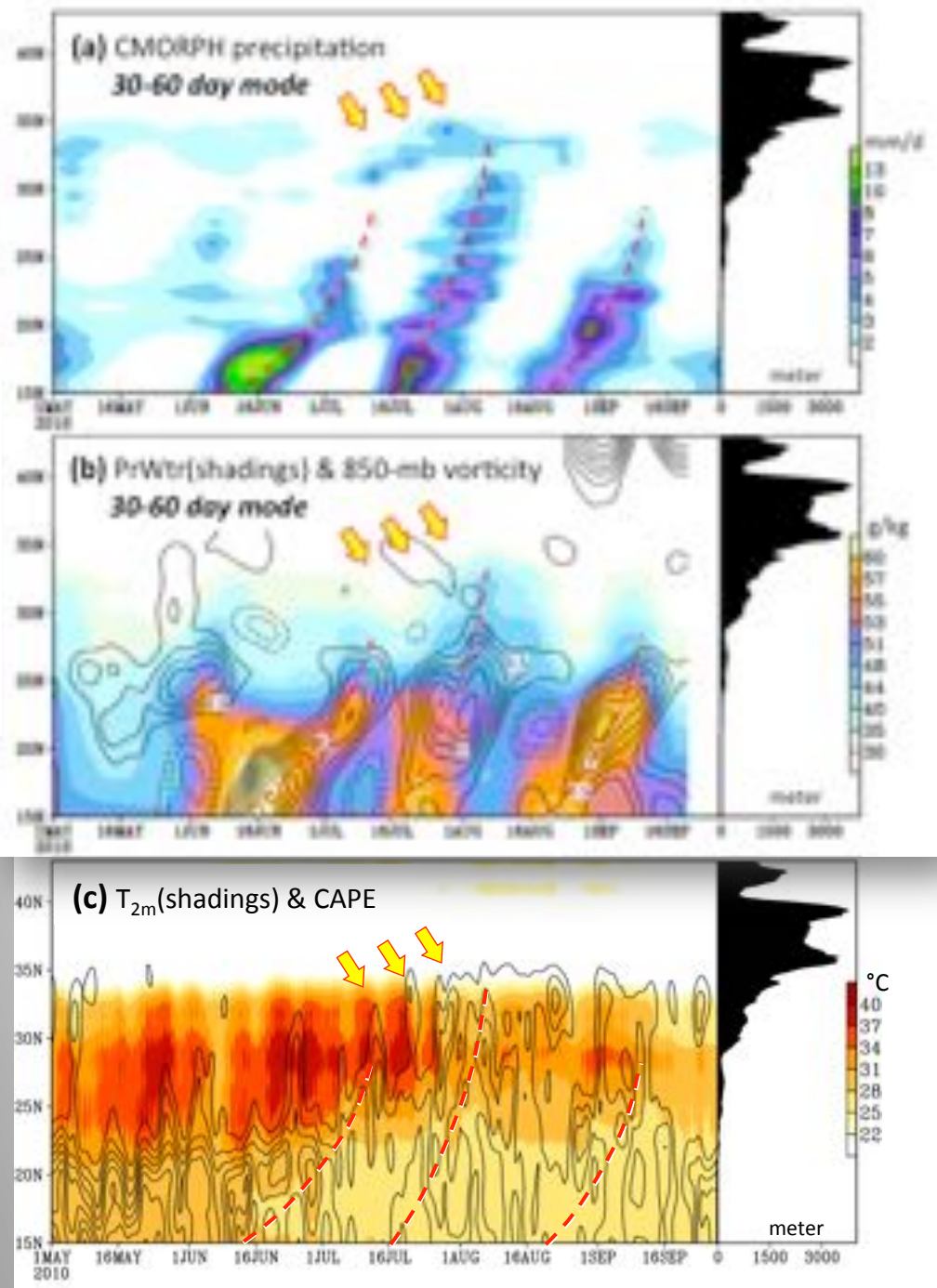


850mb streamlines + OLR

A 2-stage monsoon

2010 →

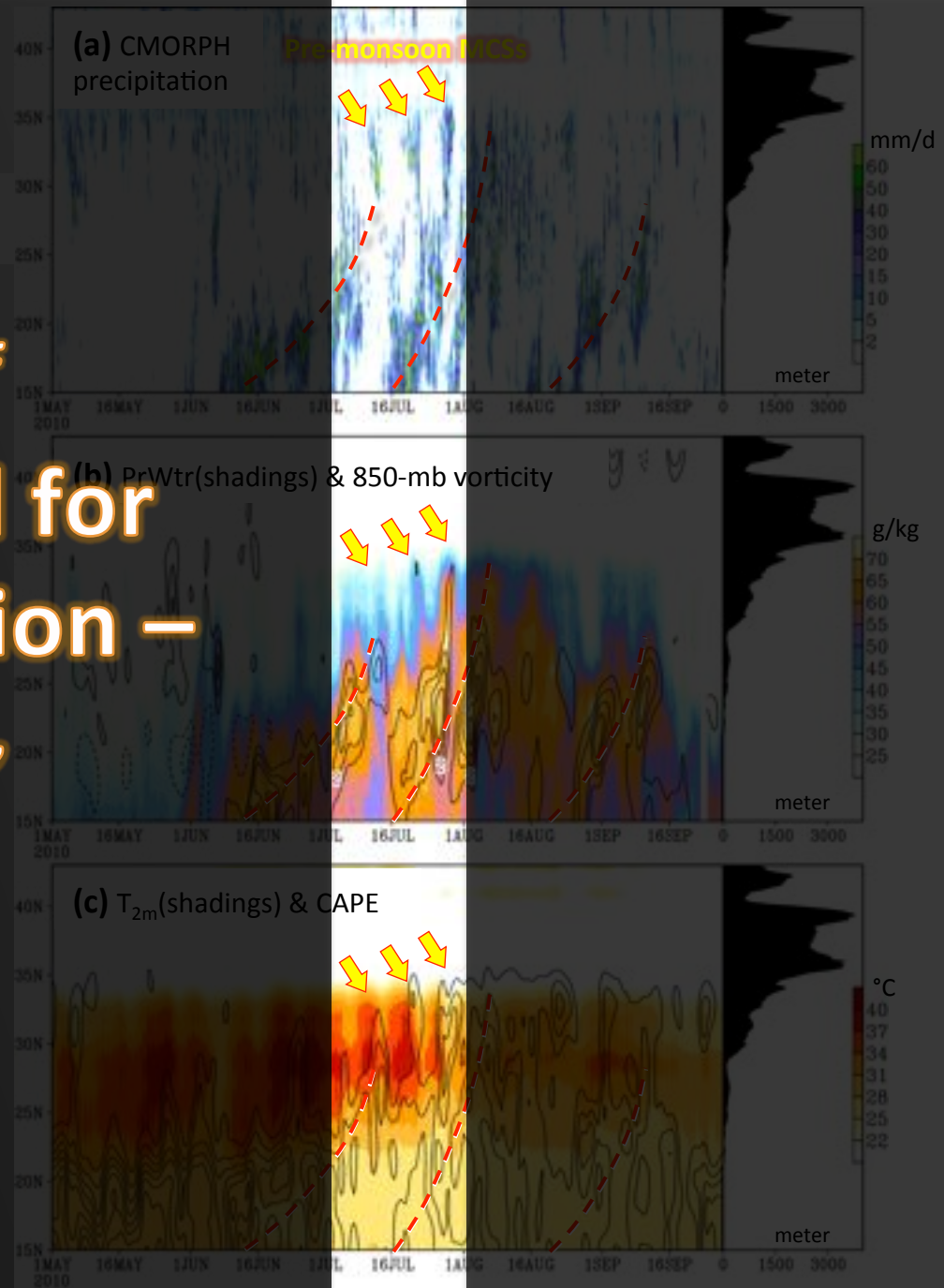
Intraseasonal mode:
30-60 day bandpass
filtered monsoon trough
migration



2010 →

pre-monsoon trough phase (July):

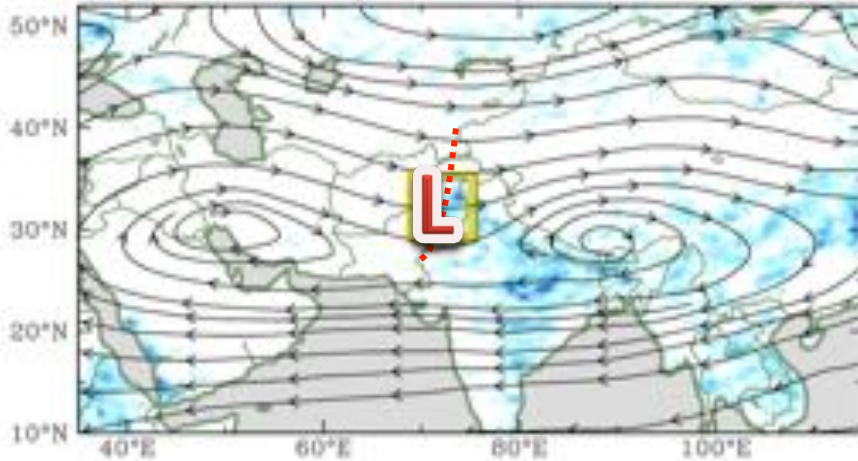
**Strong potential for
intense convection –
instability, moisture,
& lift (disturbances)**



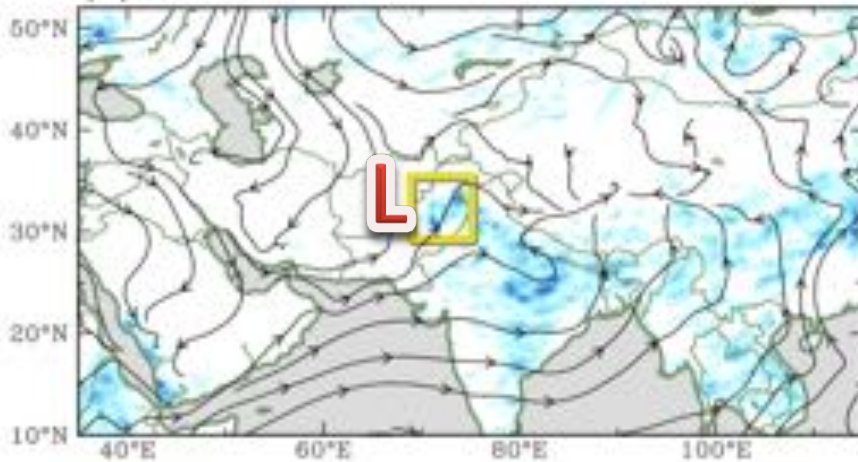
Circulation Dynamics: 2 stages

2010

(a) 250mb 7/10-7/20

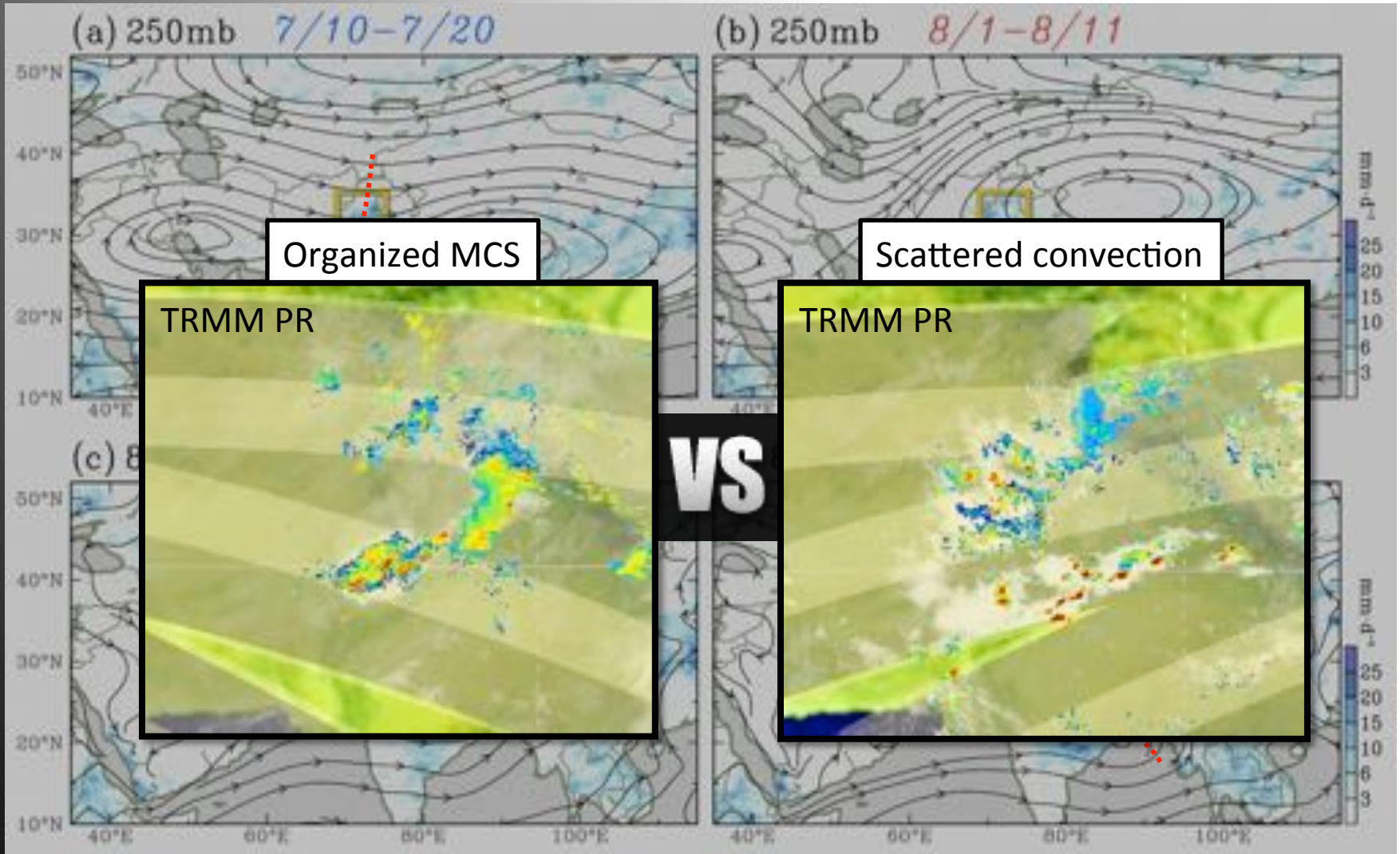


(c) 850mb



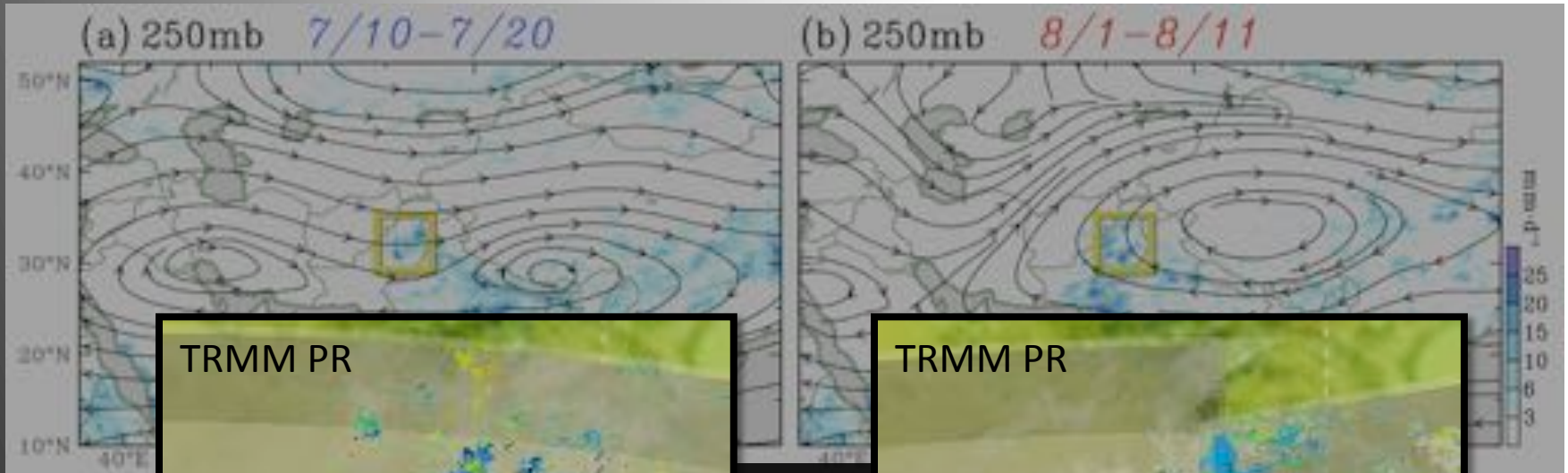
Circulation Dynamics: 2 stages

2010



Circulation Dynamics: 2 stages

2010



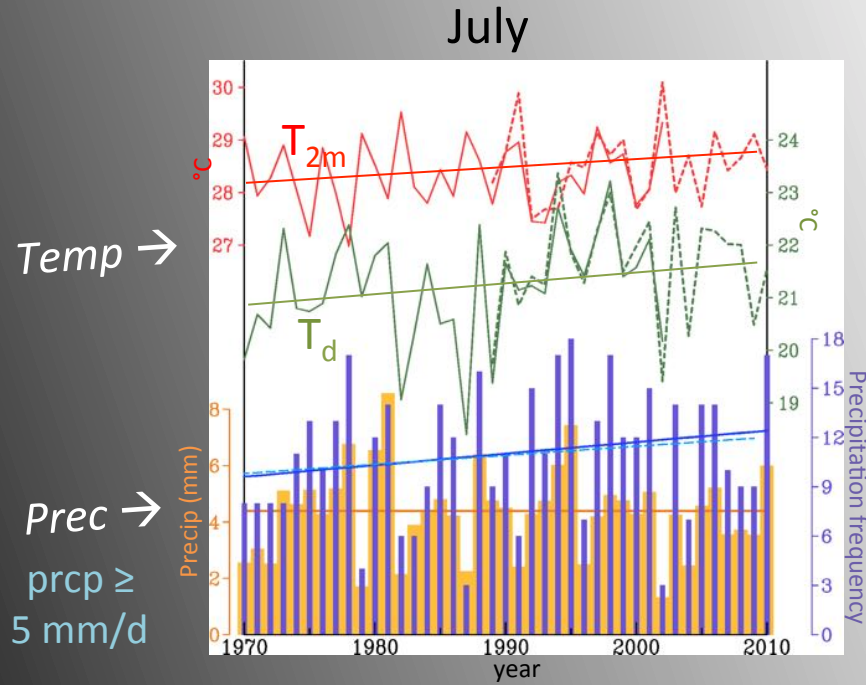
**Pre-monsoon trough:
intense, organized
convective systems
(like in U.S. Midwest)**

VS

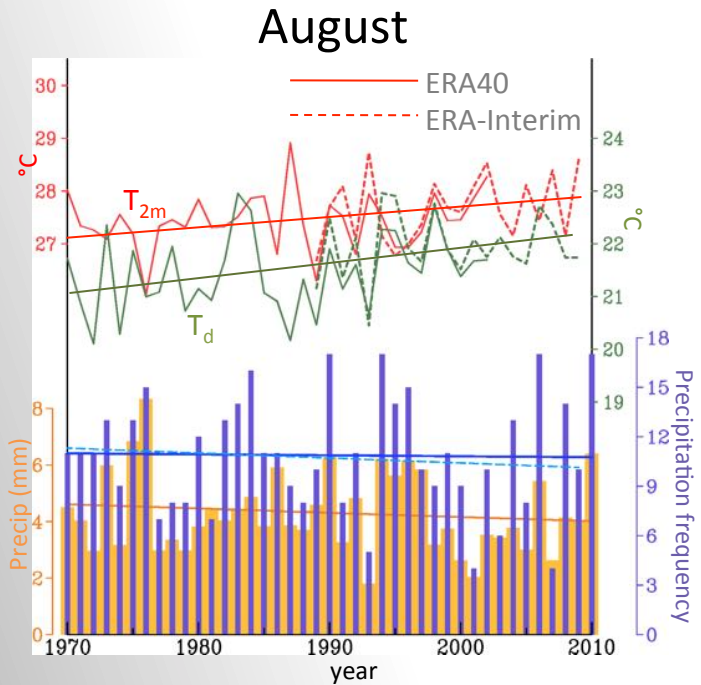


**Mature monsoon:
steady diurnal rains,
less organized, &
less intense**

Climate change signal: 2 stages



Changed
(increasingly convective)



Not changed

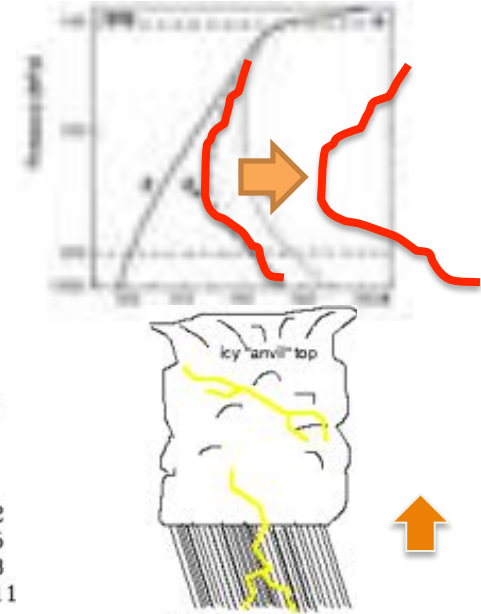
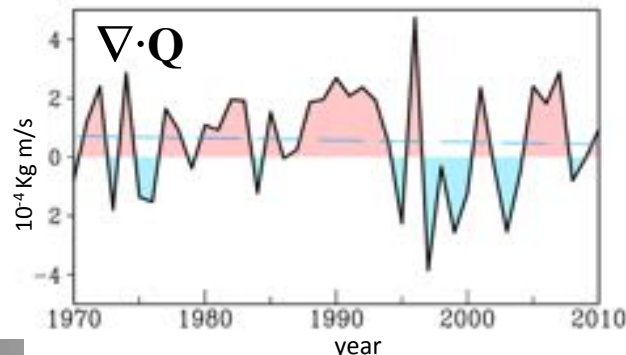
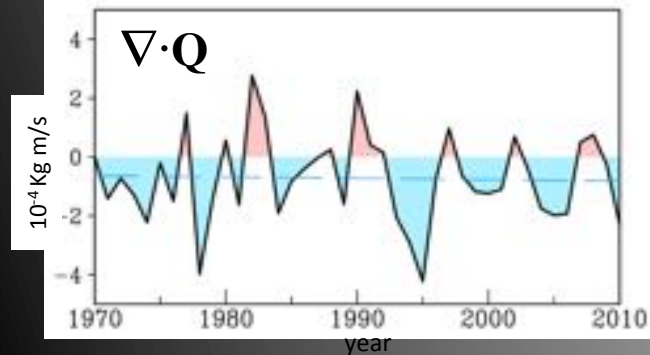
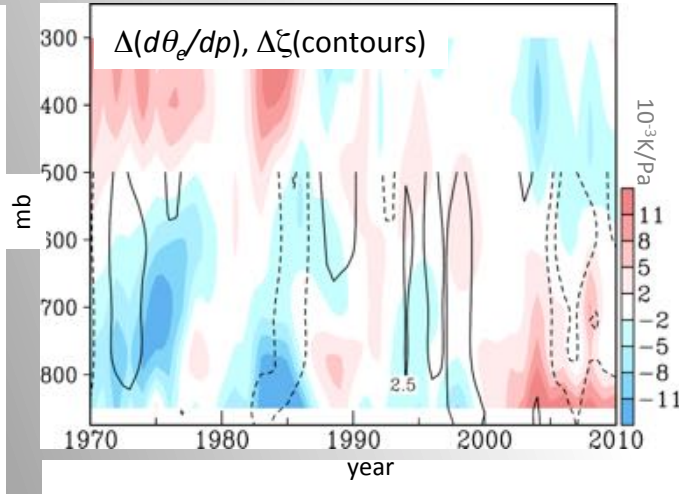
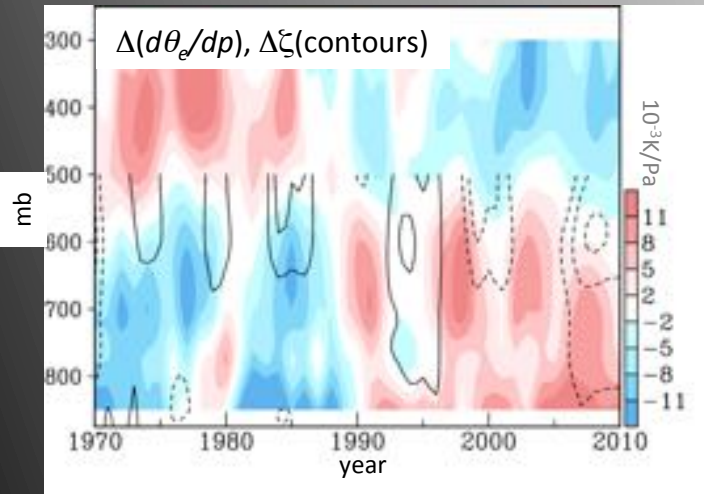
Climate change signal: **Instability**

Equivalent potential temperature $\theta_e = T_e \left(\frac{p_0}{p} \right)^{\frac{R_d}{c_p}} \approx \left(T + \frac{L_v}{c_p} r \right) \left(\frac{p_0}{p} \right)^{\frac{R_d}{c_p}}$

→ conditional instability ($d\theta_e/dp$) →

July

August



← no change in forced moisture convergence.

Warming?

Quantify Climate Change Impact

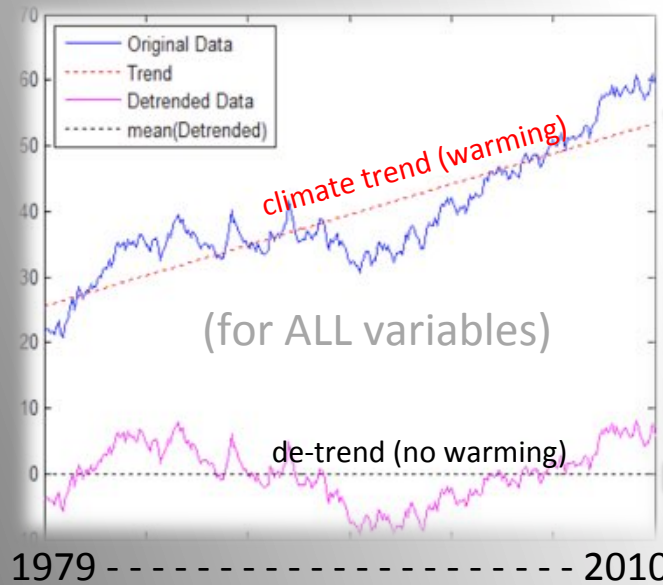
Simulation: Jiming Jin (USU)

Weather Research and Forecasting (WRF)
Advanced WRF v3.1 + NCEP/DOE R-2
(dynamical downscaling approach...)

30 km; optimal CU/MP/PBL



R-2 forcing data: 2 sets



Simulation: 2010 JJA



Control



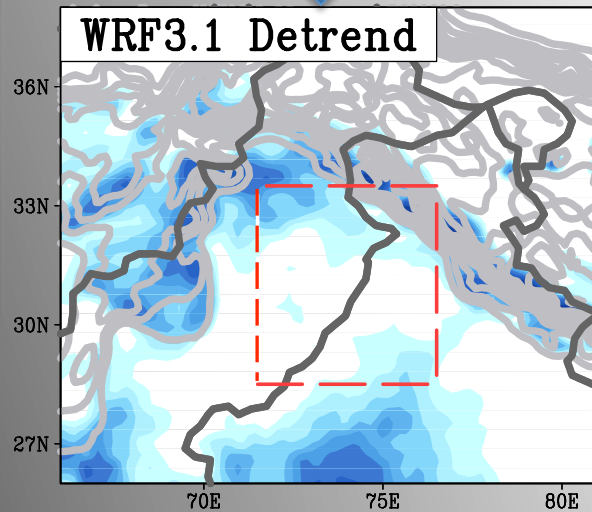
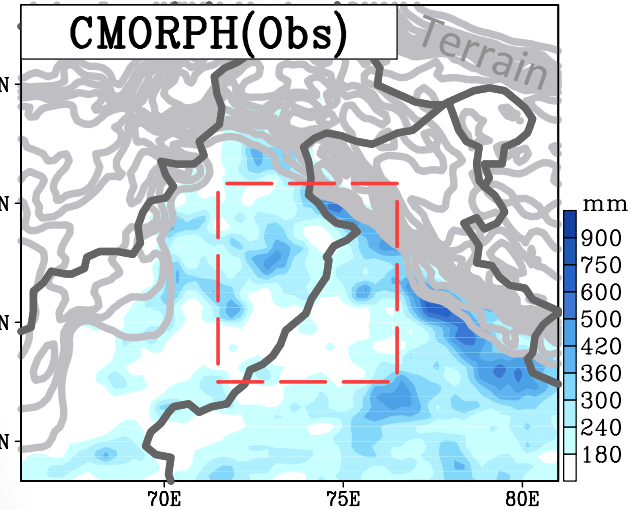
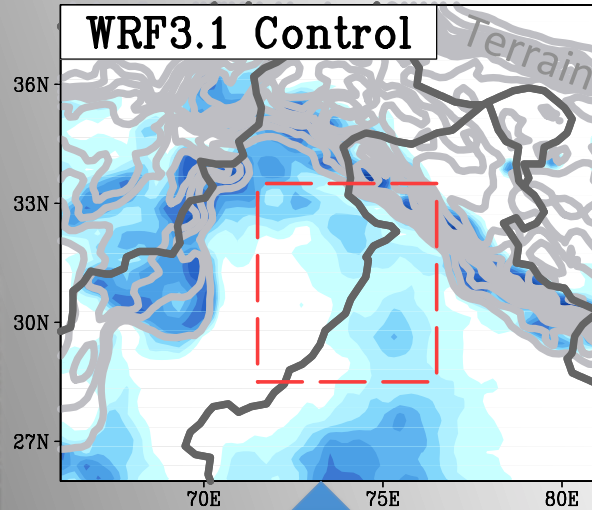
Experiment
(Detrend)

Quantify Climate Change Impact

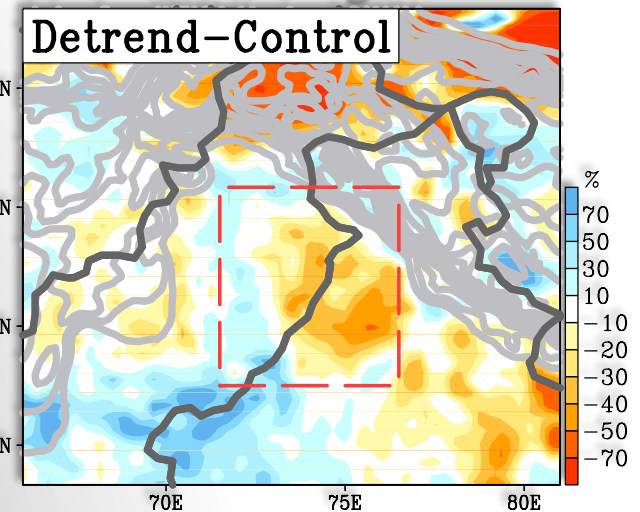
Simulation: Jiming Jin (USU)



Jul-Aug, 2010

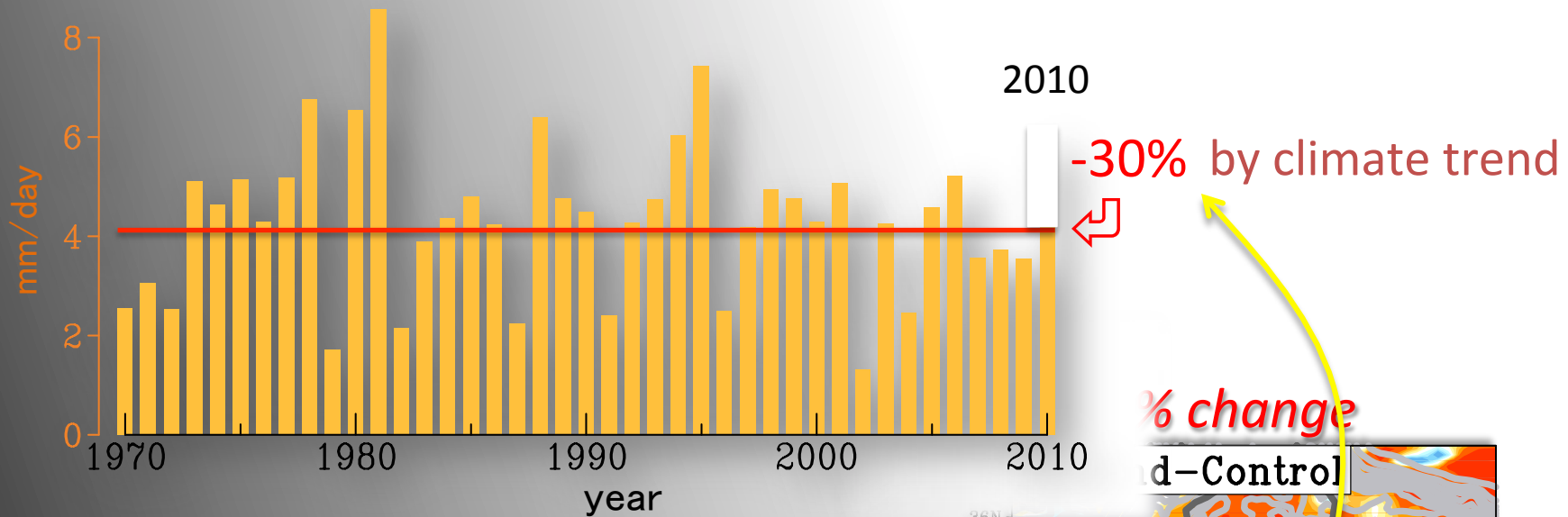


% change

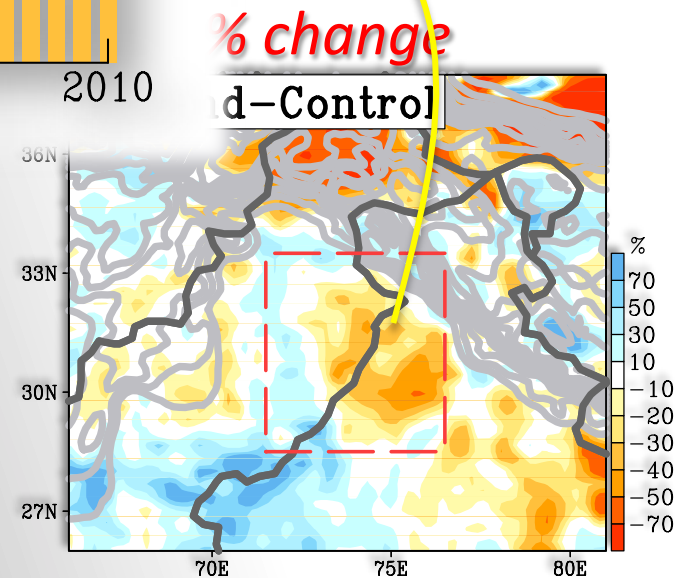


Quantify Climate Change Impact

Mean Jul-Aug rainfall in northern Pakistan

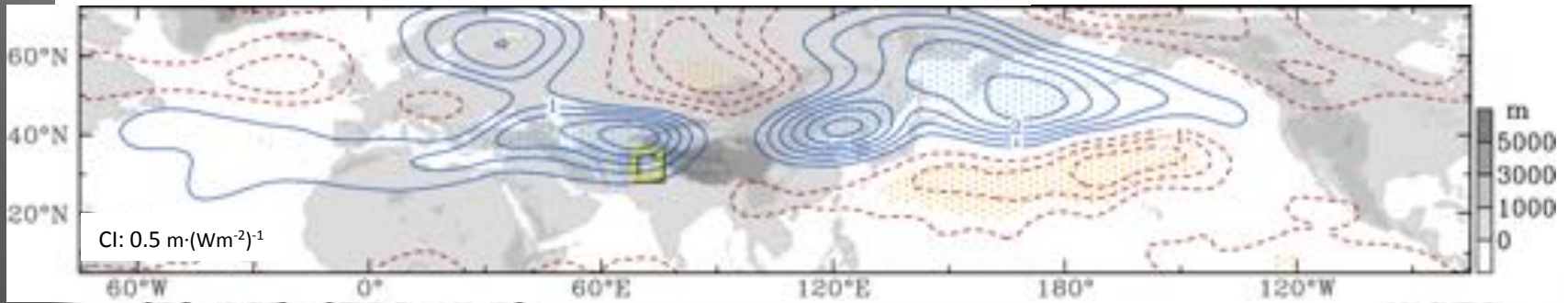


Dynamical downscaling approach suggests 30% contribution from climate trend (i.e. warming)
→ *wouldn't be that extreme...*

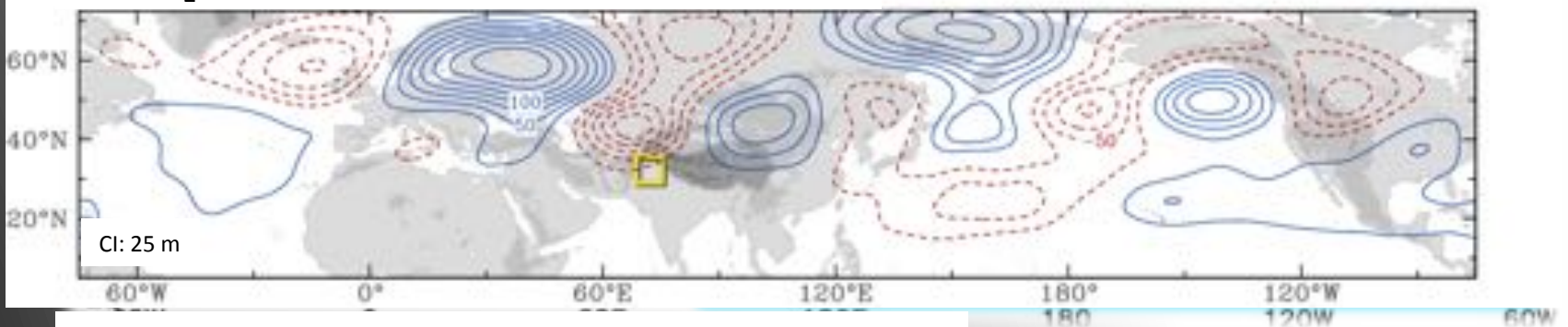


Changing monsoon dynamics – forecast challenge!

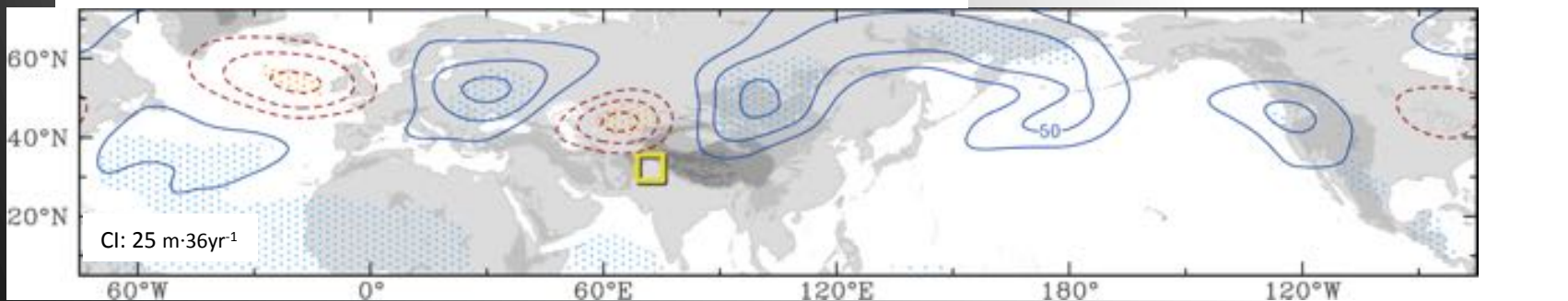
(a) Z(200mb) reg. w/ Δ Precip(□) July 1974-2010



(b) ΔZ_E (200mb) July 2010 (Pakistan flood)



(c) Z(200mb) linear trend July 1974-2009

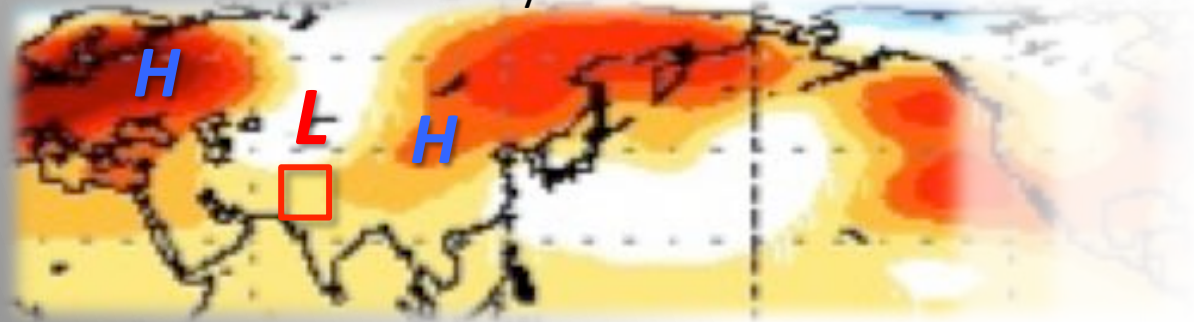


Changing monsoon dynamics

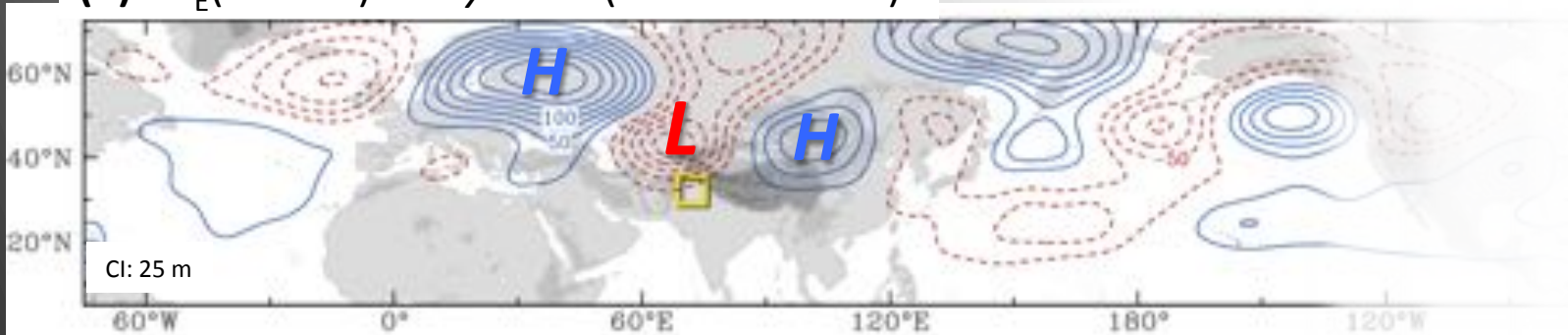
CFS 20-member, last update Jul 12, 2010

CFS 1mo
 $\Delta Z(200\text{mb})$

July 2010 forecast

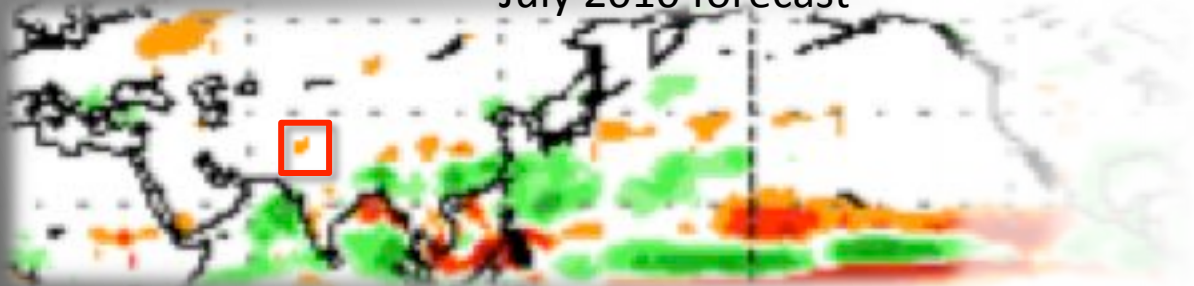


(b) $\Delta Z_E(200\text{mb})$ July 2010 (Pakistan flood)



CFS 1mo
 ΔPrecip

July 2010 forecast



SUMMARY

- Only the pre-monsoon (July) phase has changed (cond. instab.)
- There *are* climate change signals! (warming $\approx 30\%$)
- Increased instability may have modified the monsoon dynamics
→ may hinder monsoon prediction for Pakistan/N. India!



SUMMARY

- There are climate change signals!
- Only the pre-monsoon trough phase is affected
- Increased instability may have modified the monsoon dynamics
 - may hinder monsoon prediction for Pakistan/N. India!

Important question:

- Has this region reached a climate “tipping point”?
 - Need long-term dynamical downscaling exp.
 - Enhance weather-to-climate prediction



THANK YOU!

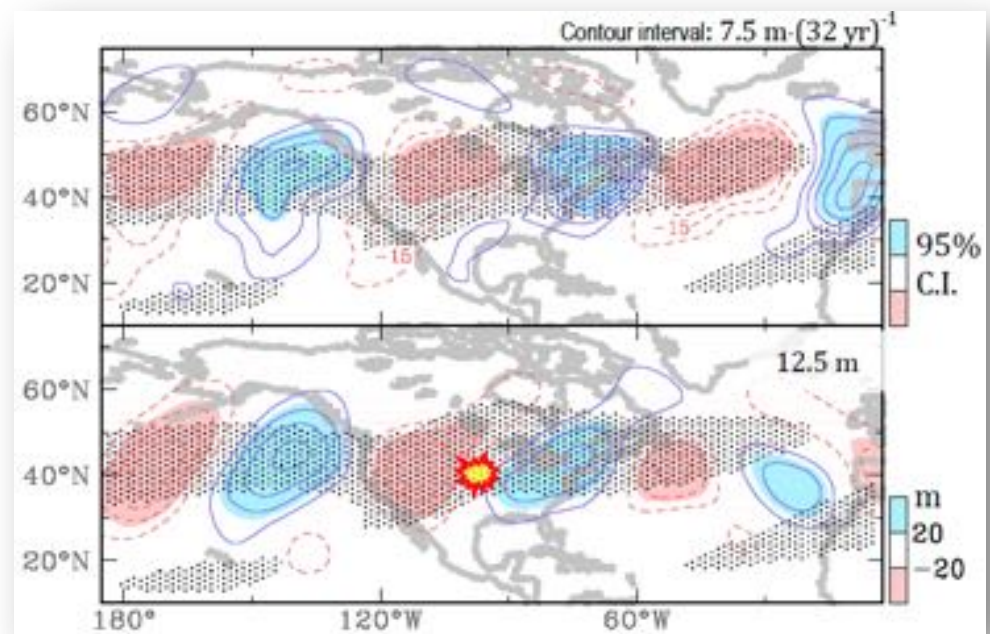
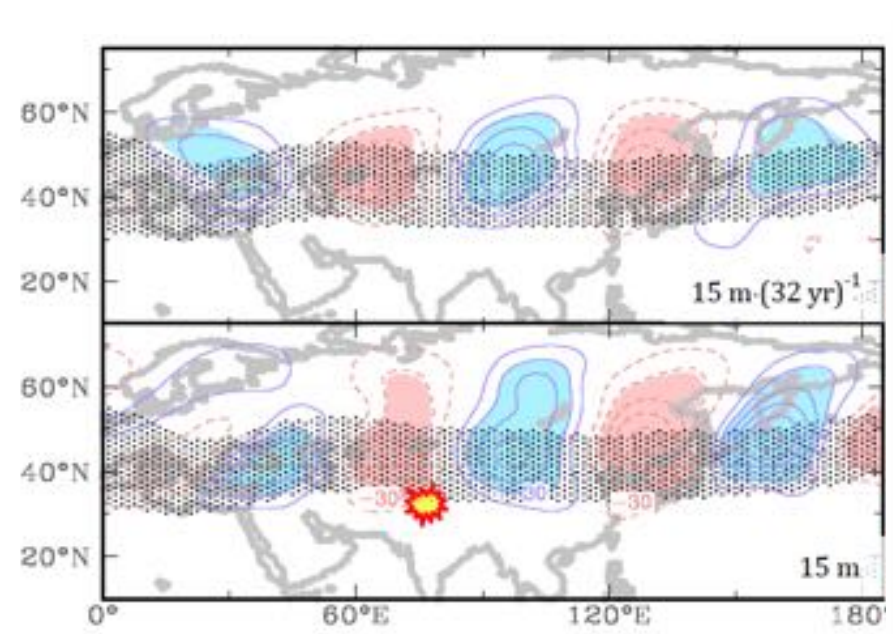
- There are climate change signals!
- Only the pre-monsoon trough phase is affected (so far)
- Increased instability may have modified the monsoon dynamics
 - may decrease the predictive ability for monsoon!

Important question:

- Has this region reached a climate “tipping point”?
 - Long-term dynamical downscaling may answer

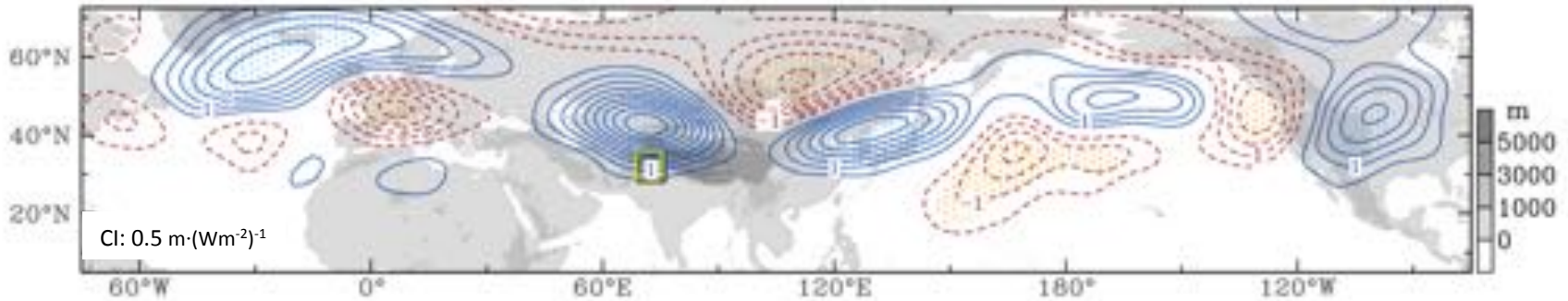


UtahStateUniversity
PLANTS, SOILS & CLIMATE

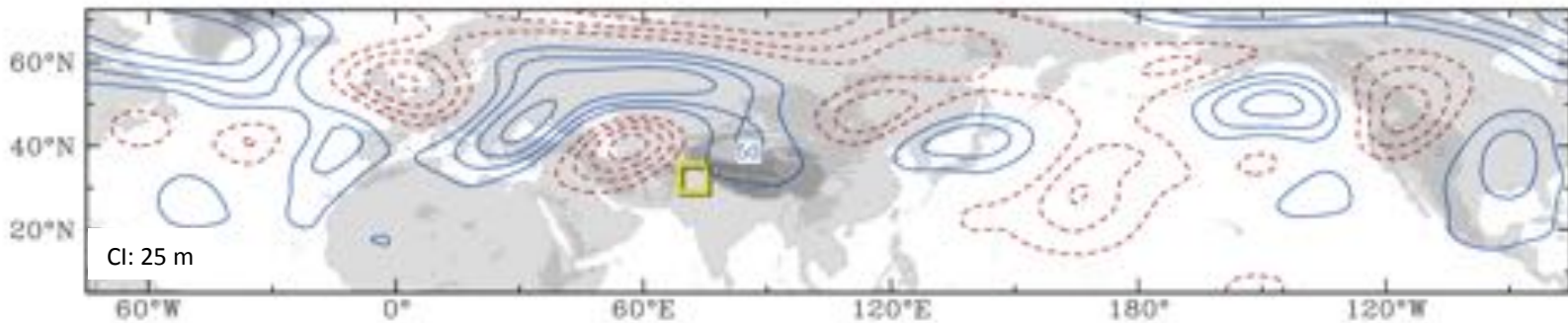


Climate change signal: Circulation pattern

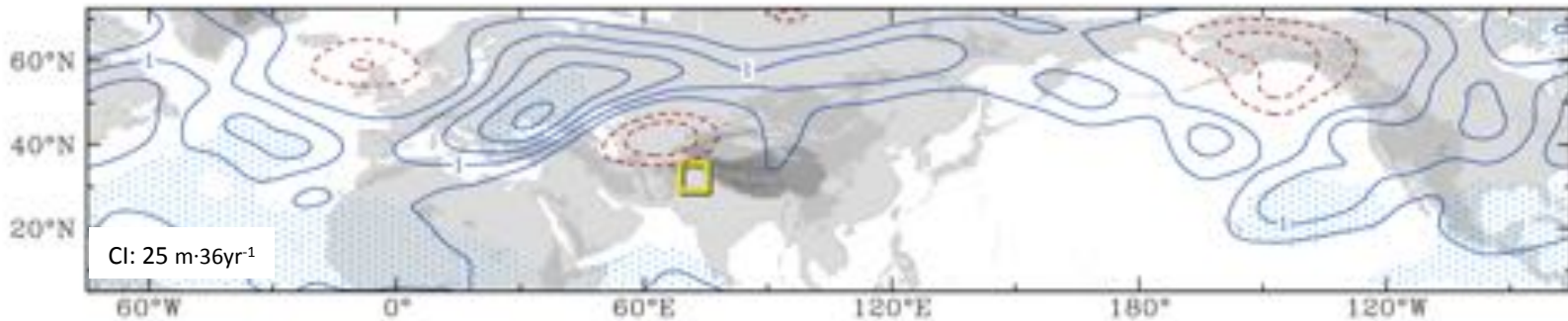
(a) Z(200mb) reg. w/ $(235\text{W}\cdot\text{m}^{-2} - \text{OLR})(\text{N.Pakistan})$ August 1974-2010



(b) $\Delta Z_E(200\text{mb})$ August 2010

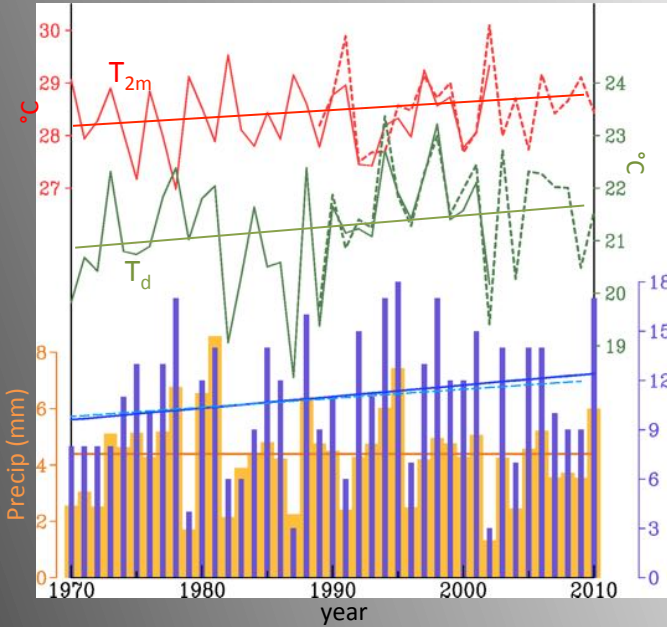


(c) Z(200mb) linear trend August 1974-2009

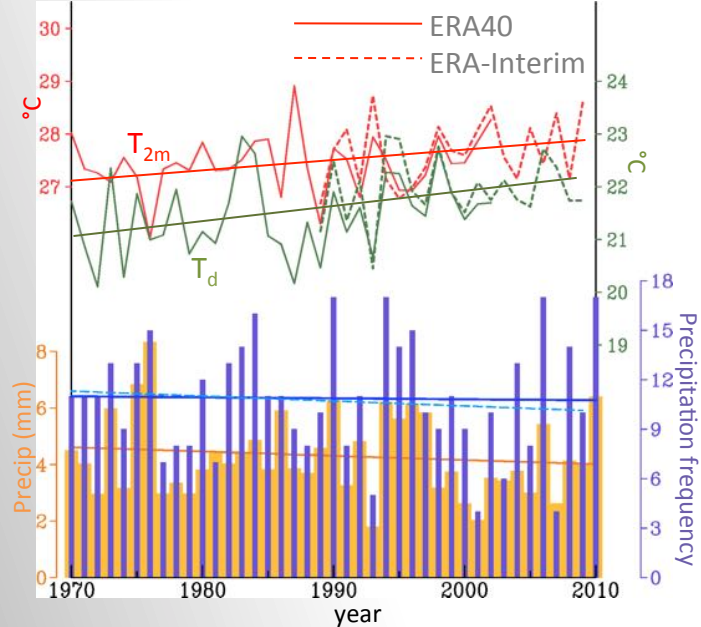


Climate change signal: 2 stages

July

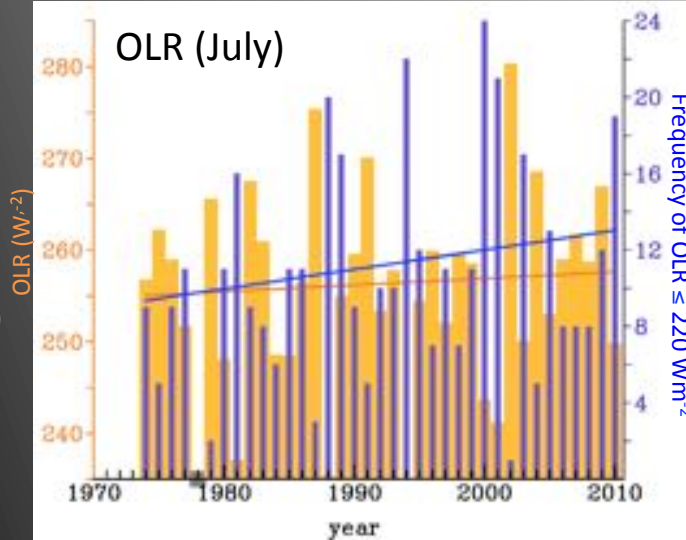


August

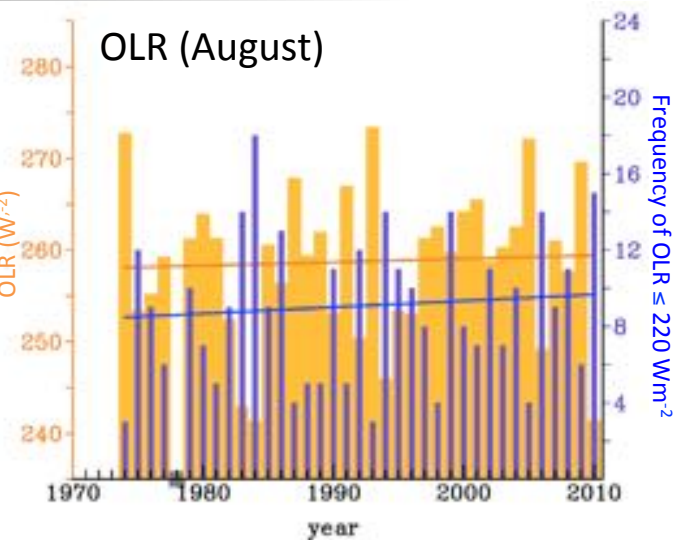


precip \geq
5 mm/day

Outgoing
longwave
radiation
(Satellite)



OLR (August)



OLR \leq
 $215 \text{ W}\cdot\text{m}^{-2}$