The Changing Monsoon Extremes and Dynamics: Example in Pakistan

S.-Y. Simon Wang[^1], R. Davies[^1], W.-R. Huang[^2], and R. Gillies[^1]

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 ≠ 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)

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°)

PMD: 2010 seasonal mean ranked only 6th

Data: APHRODITE (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation)
A 2-stage monsoon perspective

Long-term mean 1961-2007

Onset date

Onset

10 year flash/day / (0.5°)^2

Precip
A 2-stage monsoon perspective

Lightning frequency (TRMM LIS)

Conv. Prec. Ratio

(Romatschke & Houze 2011)
A 2-stage monsoon

Role of the monsoon trough?
A 2-stage monsoon

**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
Circulation Dynamics: 2 stages

2010

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

(b) 250mb 8/1-8/11

Organized MCS

Scattered convection

TRMM PR

VS

TRMM PR
Circulation Dynamics: 2 stages

2010

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

(b) 250mb 8/1-8/11

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

Mature monsoon: steady diurnal rains, less organized, & less intense
Climate change signal: **2 stages**

**July**
- Temp $T_{2m}$
- Precip $(mm)$

**August**
- Temp $T_{2m}$
- Precip $(mm)$

**Temp $\rightarrow$**

**Prec $\rightarrow$**

$prcp \geq 5 \text{ mm/d}$

*Changed* (increasingly convective)

*Not changed*

Data: APHRODITE (P) & ERA40/Interim (Ts)
Climate change signal: **Instability**

Equivalent potential temperature

→ conditional instability \( \frac{d\theta_e}{dp} \) →

**July**

\[ \Delta(d\theta_e/dp), \Deltaζ(\text{contours}) \]

\[ \nabla \cdot Q \]

**August**

\[ \Delta(d\theta_e/dp), \Deltaζ(\text{contours}) \]

\[ \nabla \cdot Q \]

\( \leftarrow \) no change in forced moisture convergence.

Warming?
Quantify Climate Change Impact

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)

1979 - - - - - - - - - - - - - - - - - - - - - - - - 2010

climate trend (warming)
de-trend (no warming)
Quantify Climate Change Impact

Simulation: Jiming Jin (USU)
Dynamical downscaling approach suggests 30% contribution from climate trend (i.e. warming) → wouldn’t be *that* extreme...
Changing monsoon dynamics – forecast challenge!

(a) $Z(200\text{mb})$ reg. w/ $\Delta\text{Precip}(\square)$ July 1974-2010

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

(c) $Z(200\text{mb})$ linear trend July 1974-2009
Changing monsoon dynamics

CFS 20-member, last update Jul 12, 2010

CFS 1mo
ΔZ(200mb)

July 2010 forecast

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

Cl: 25 m

CFS 1mo
ΔPrecip

July 2010 forecast
• Only the pre-monsoon (July) phase has changed (cond. instab.)
• There *are* climate change signals! (warming ≈ 30%)
• Increased instability may have modified the monsoon dynamics
  → may hinder monsoon prediction for Pakistan/N. India!
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
• 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
Climate change signal: Circulation pattern

(a) $Z(200\text{mb})$ 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) $Z(200\text{mb})$ linear trend  
August 1974-2009
Climate change signal: 2 stages

July

August

precip ≥ 5 mm/day

OLR ≤ 215 W/m²