Monsoon and climate variability in South Asia and Bangladesh: ongoing work and ideas

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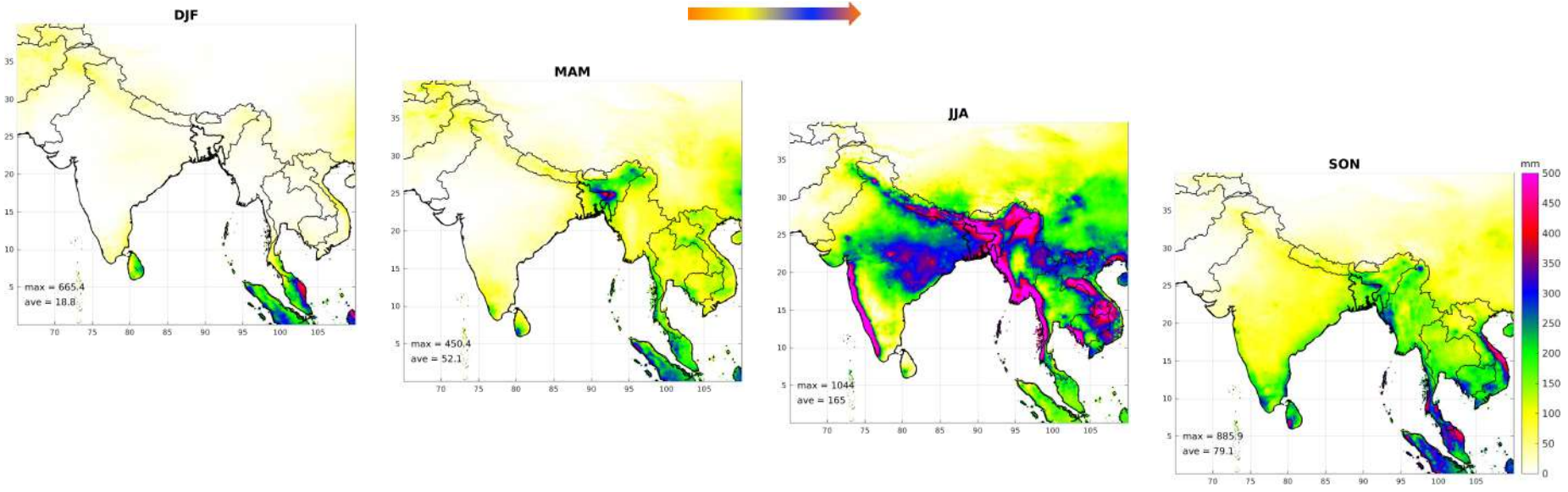
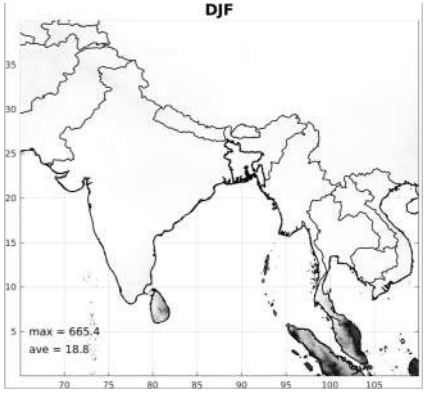
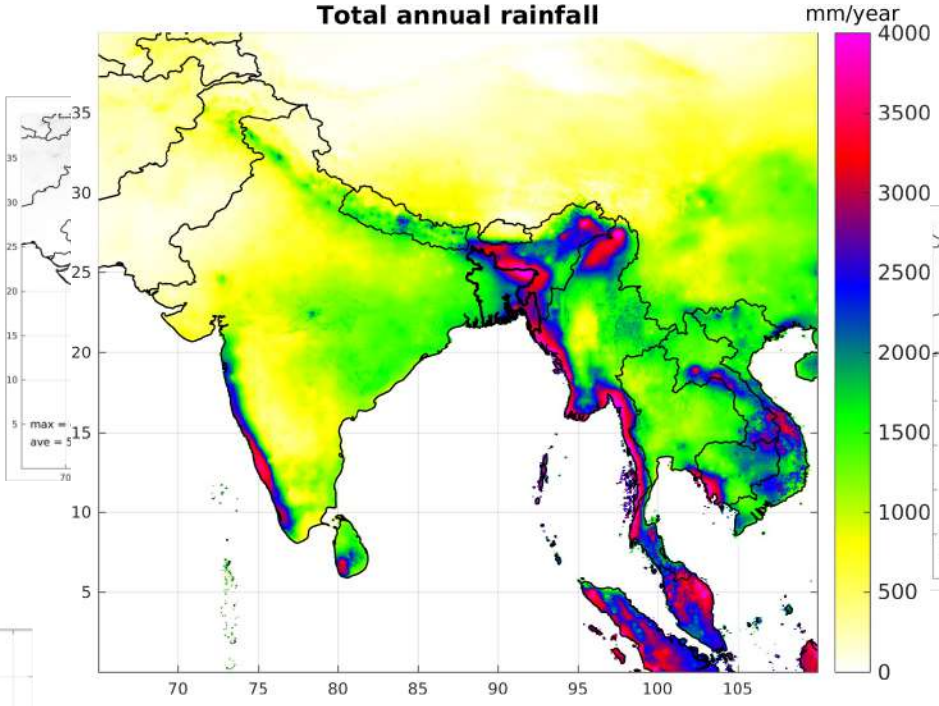
Outline

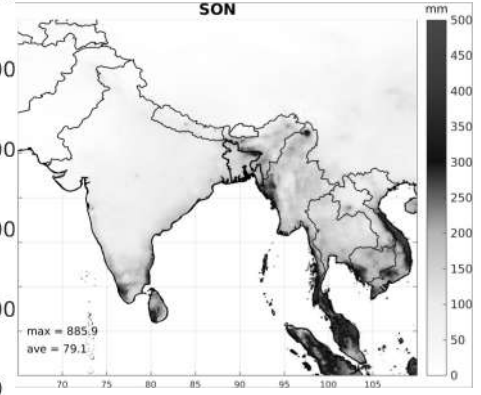
- Climate variability
- Scales
- Datasets available
- Importance
- Examples:
  - Large scales monsoon dynamics
  - Local scale in Bangladesh
  - Predictability: onset, heavy rainfall events, dry spells
  - Linkage with crop models
- Future ideas

Annual cycle of precipitation

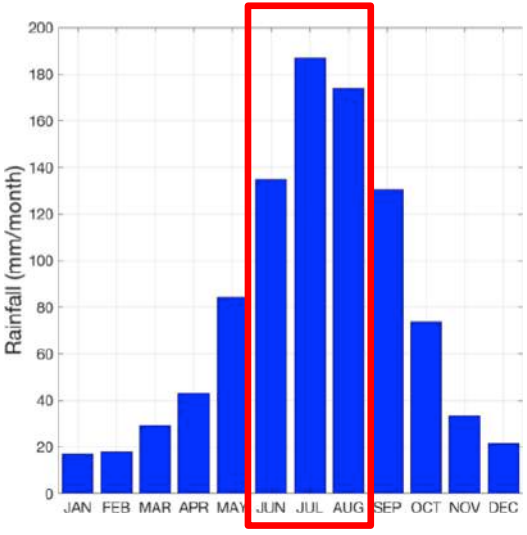




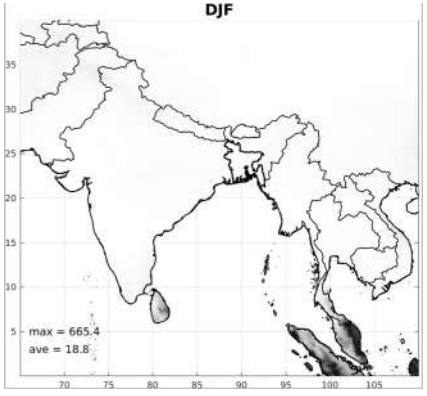


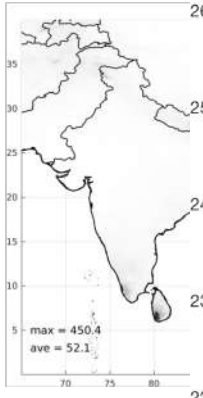


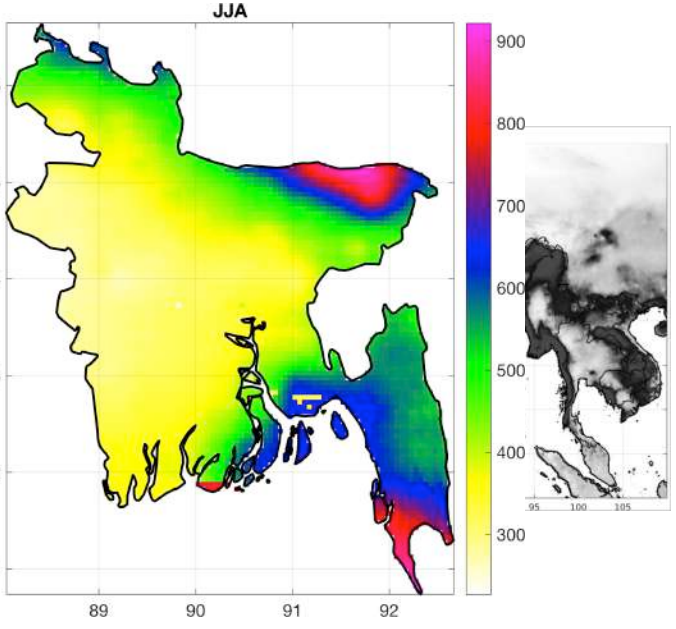
South Asia

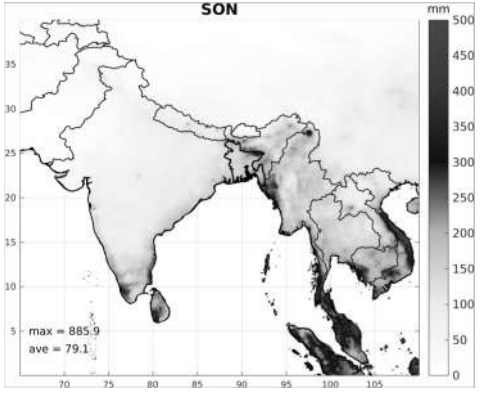


- **Summer** monsoon season
- JJA **~52%** annual precipitation
- Source of water for ***Kharif*** crops

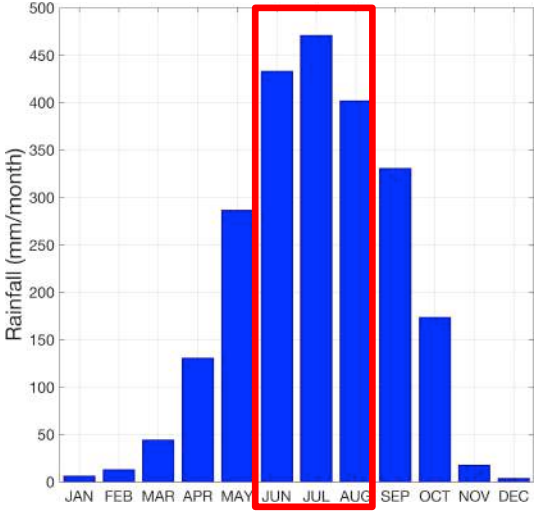




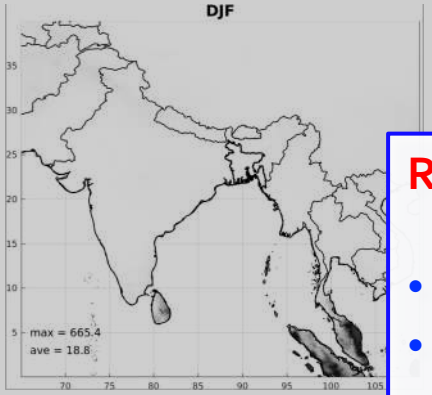


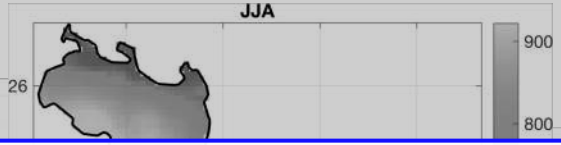


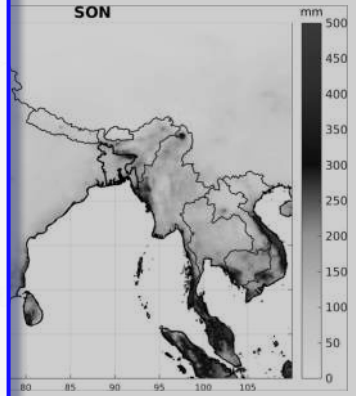
Bangladesh



- **Summer** monsoon season
- JJA **~56%** annual precipitation
- Source of water for ***Kharif*** crops



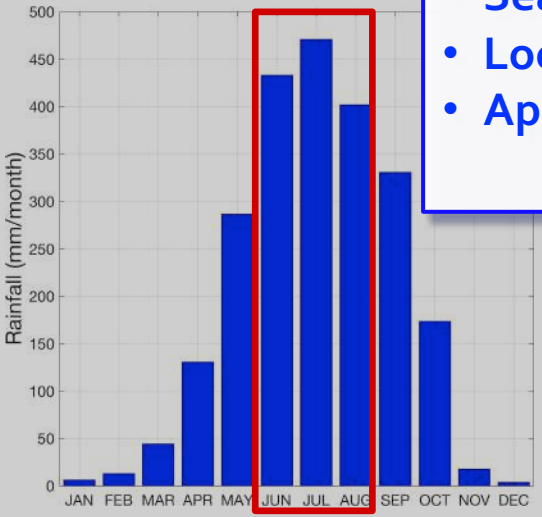




Research questions:

- Seasonal to Interannual variability
- Variability in monsoon timing?
- Future projections?
- Implications for agriculture?
- Large scale forcing, covariability?
- Seasonal and sub-seasonal predictability?
- Local impacts and strategies?
- Appropriate data available?

Bangladesh

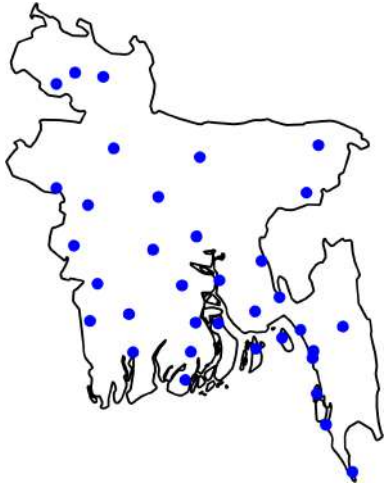


- **Summer** monsoon season
- JJA **~56%** annual precipitation
- Source of water for ***Kharif*** crops

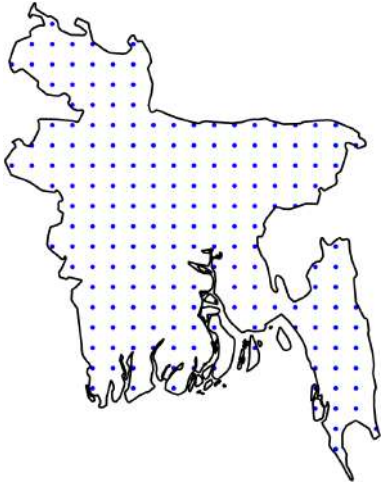
Multiple datasets

- 35 BMD stations: observational reference
- Period 1981 – 2017 (variable)
- Gridded climate products
  - Satellite, ground observations, reanalysis
- Model outputs
  - GCMs, RCGs (CORDEX)
- Satellite products
  - NDVI3g, LAI3g, BNU LAI, MODIS
- Gridded crop yields, phenology, area
- Crop modeling

BMD stations

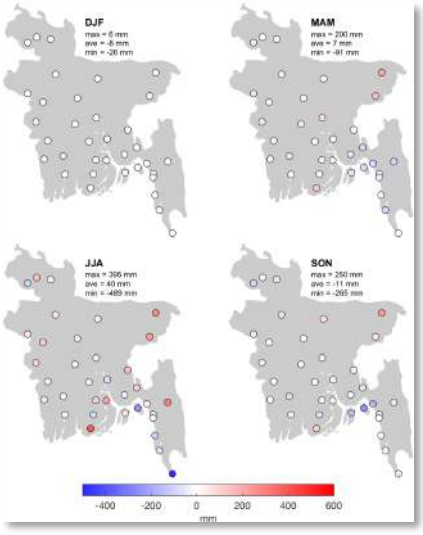


0.25º x 0.25º gridded products

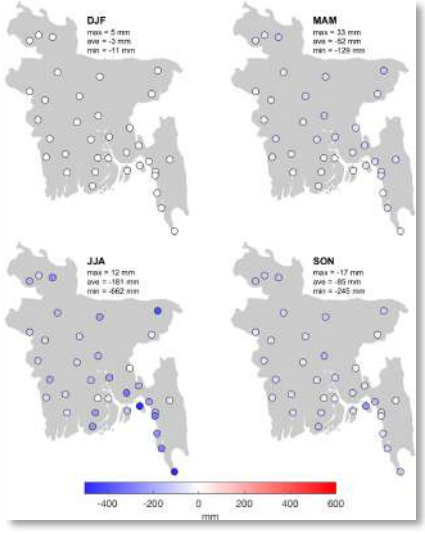


Seasonal Bias

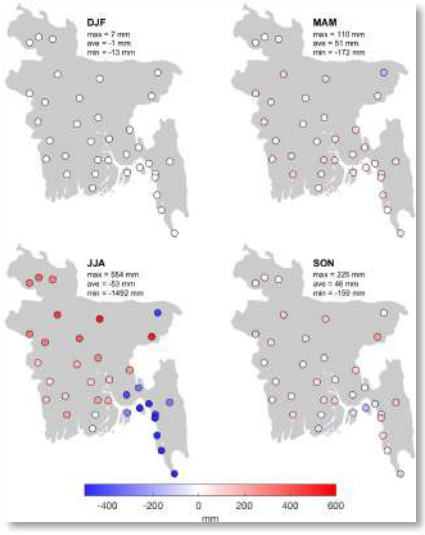
CHIRPS (1981-2017)



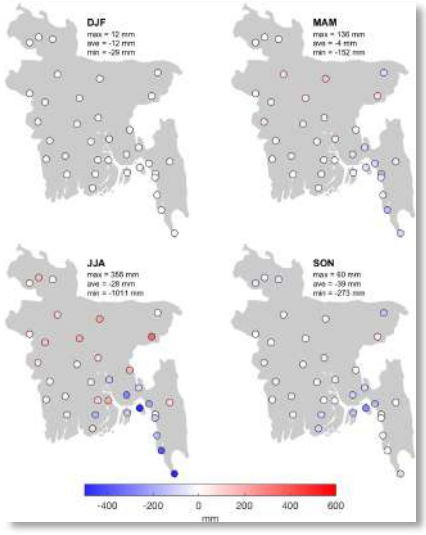
APHRODITE (1981-2007)

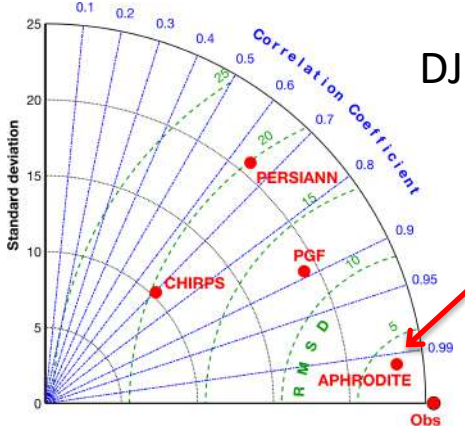


PERSIANN (1983-2017)

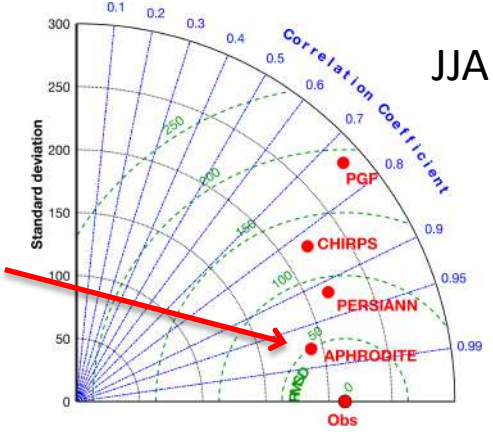


PGFv3 (1981-2016)

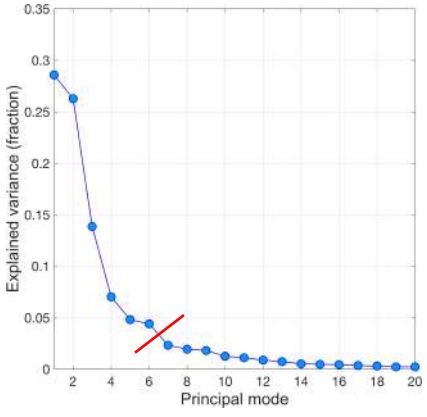




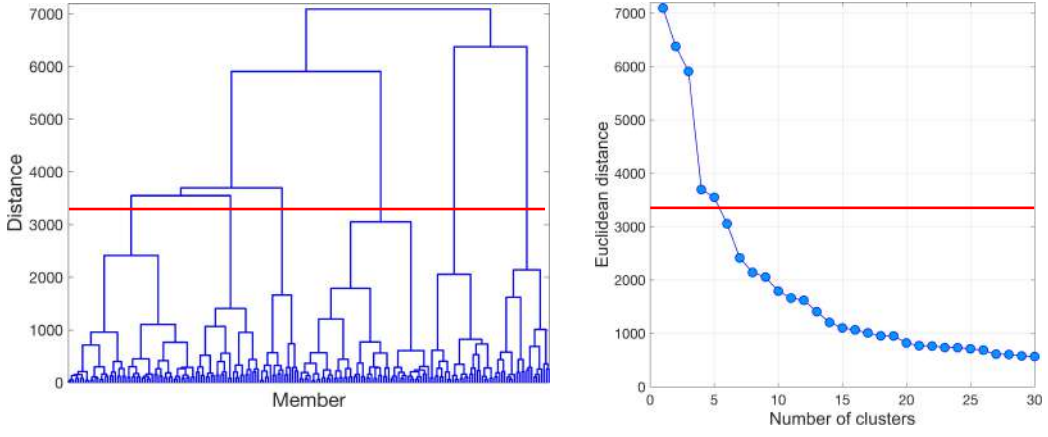
Best global performance



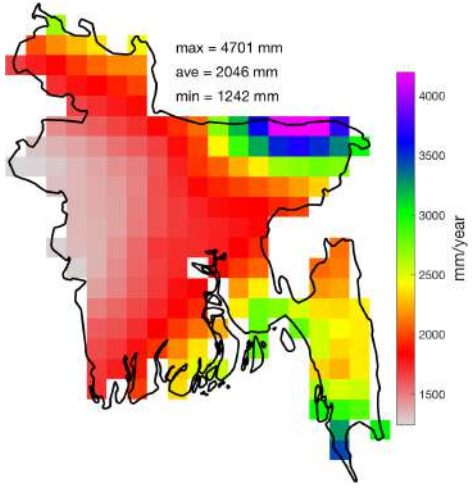
6 PCs retained for clustering



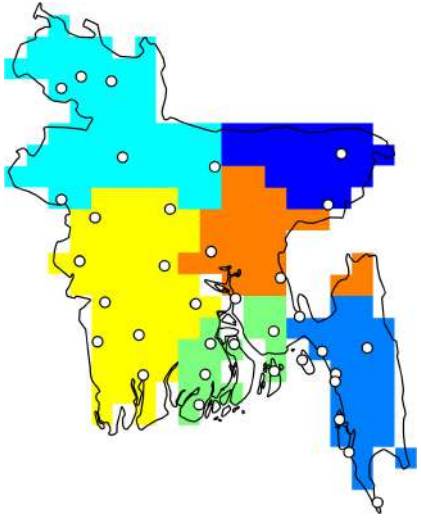
6 clusters selected
Based on explainded variance and experience



Annual APHRODITE precipitation

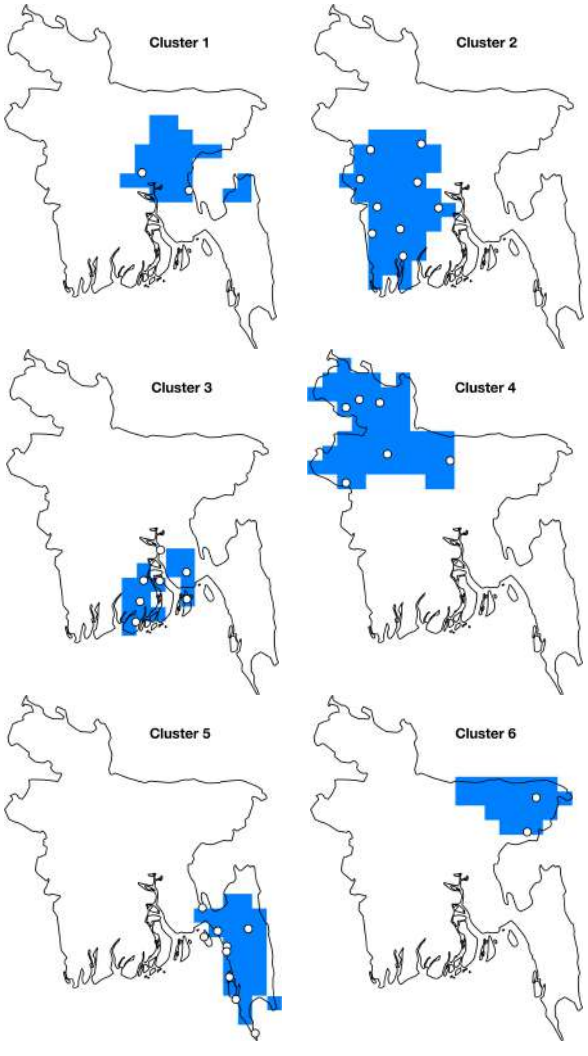


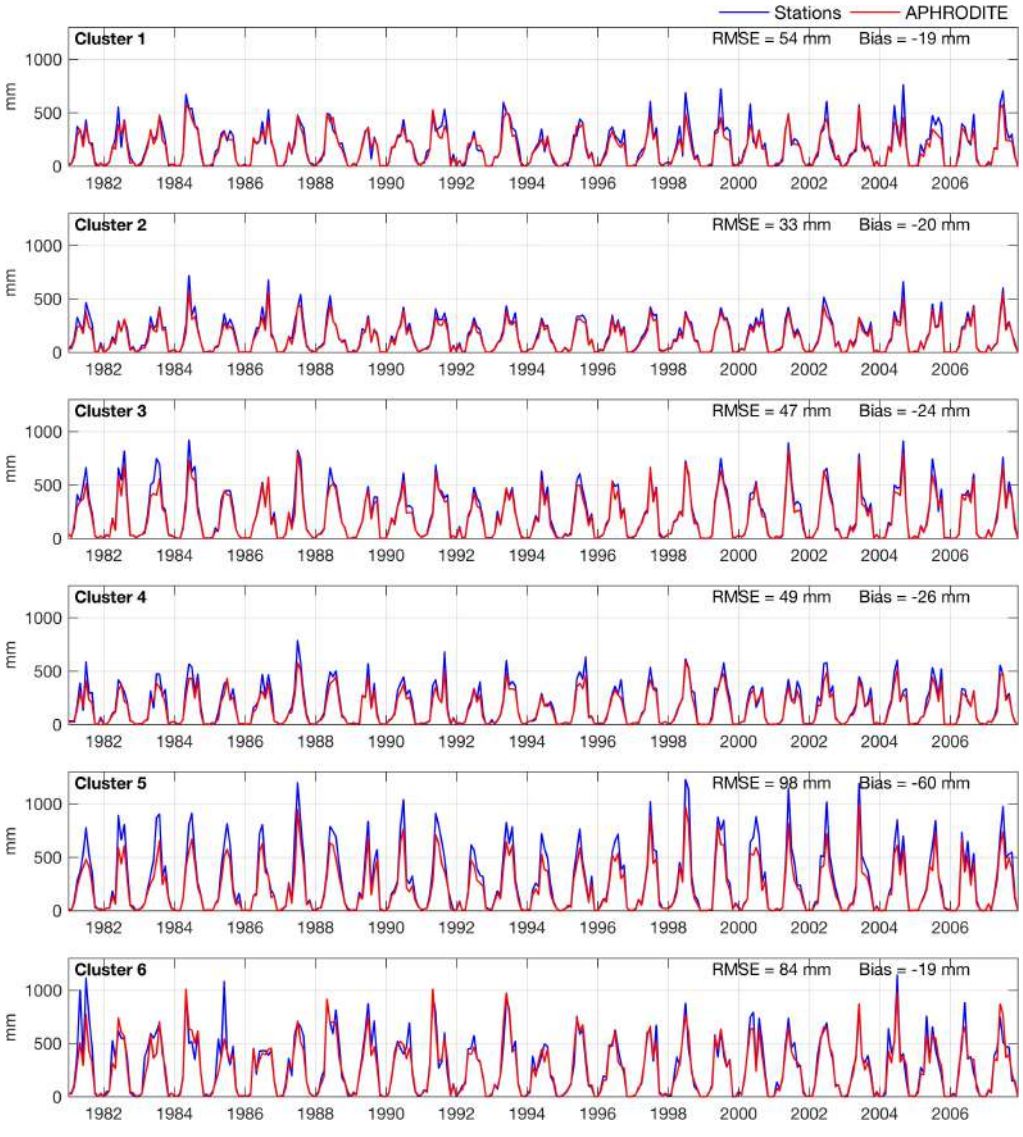
Spatial distribution of APHRODITE groups and stations



At least 1 station
in each cluster

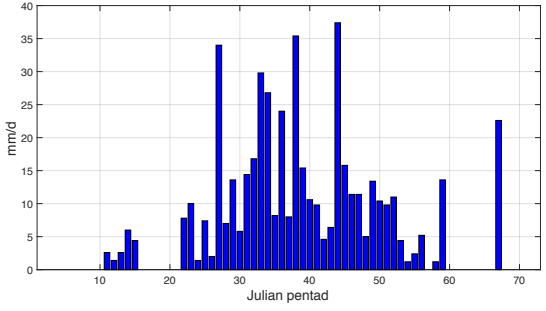
Monthly rainfall



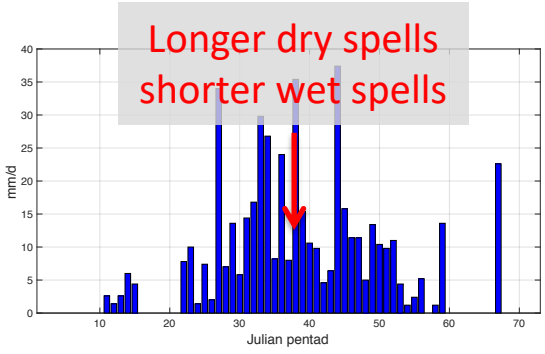


Monsoon season precipitation

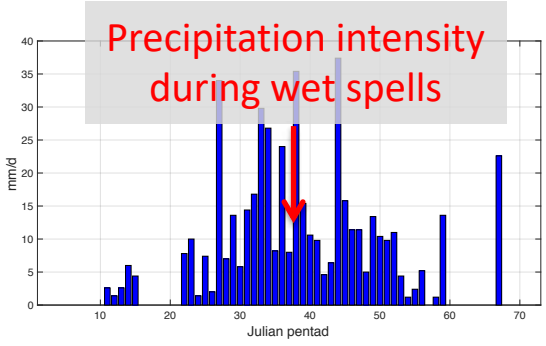
Seasonal variability



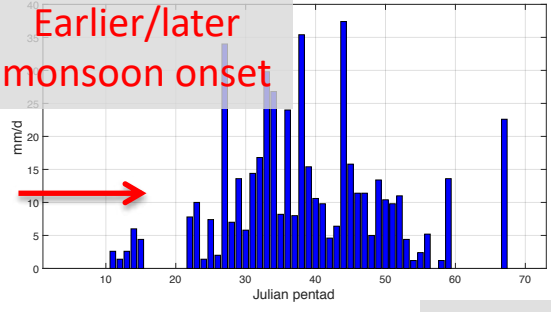
Longer dry spells
shorter wet spells



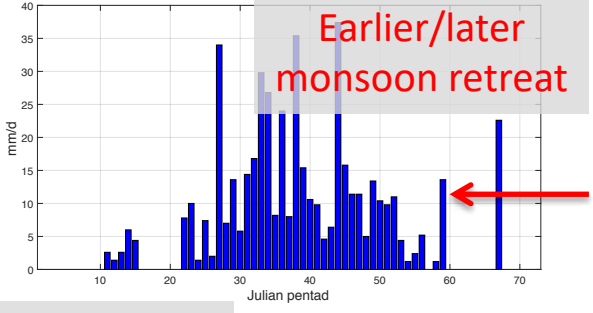
Precipitation intensity
during wet spells



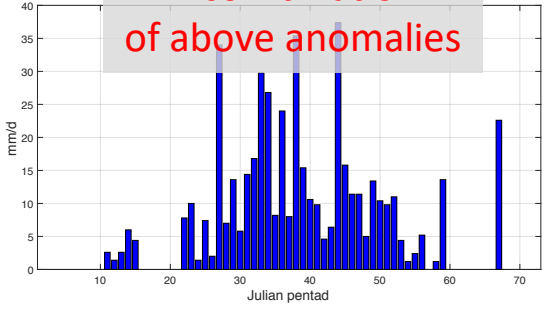
Earlier/later
monsoon onset



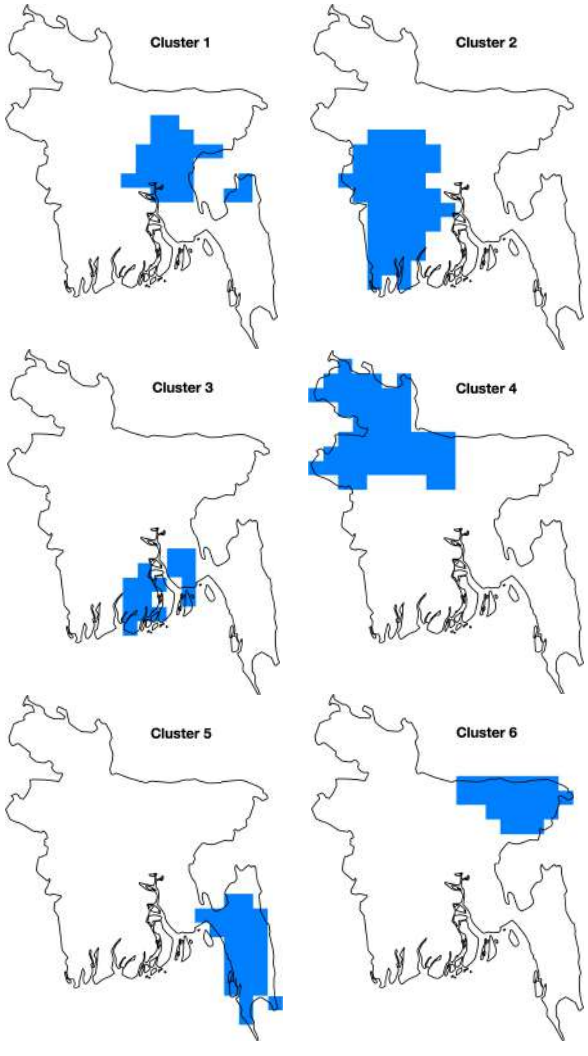
Earlier/later
monsoon retreat

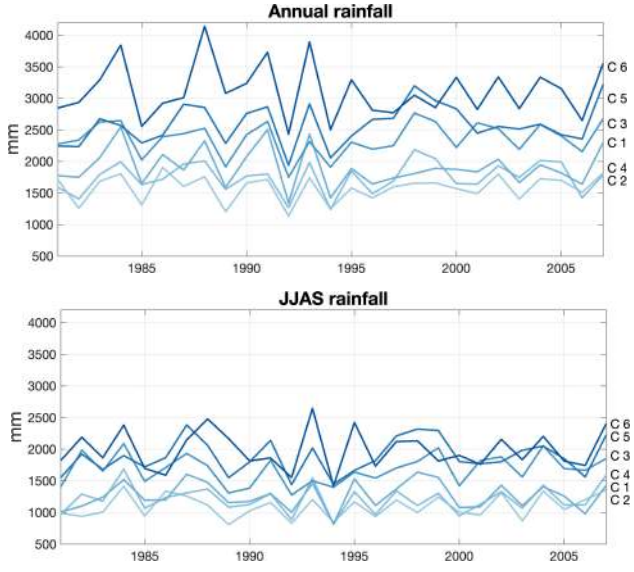


A combination
of above anomalies

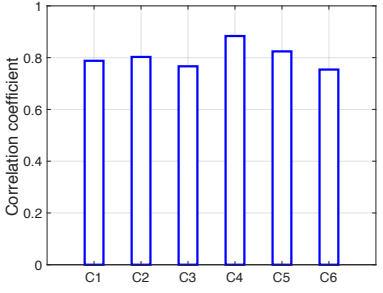


Monthly rainfall: JJAS climatology



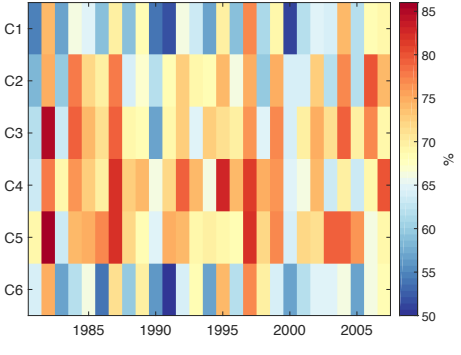


High correlation

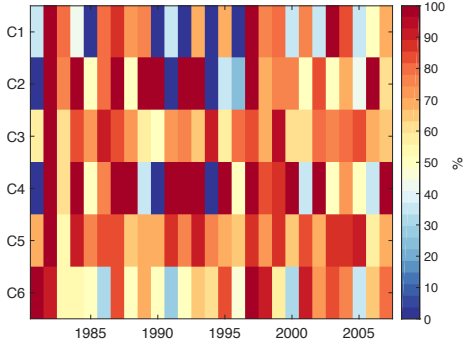


Subseasonal metrics

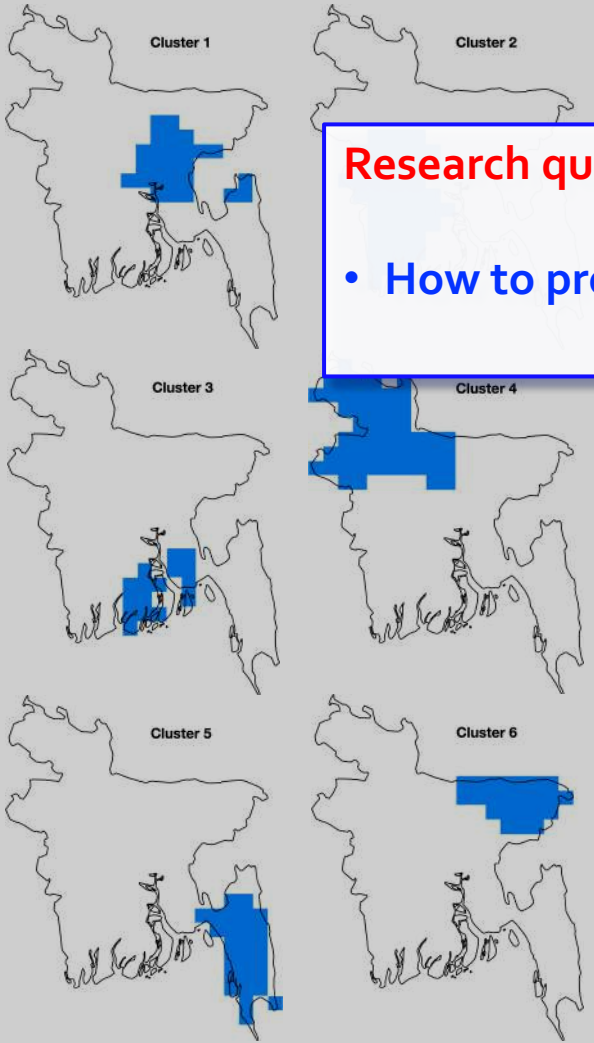
% annual rainfall

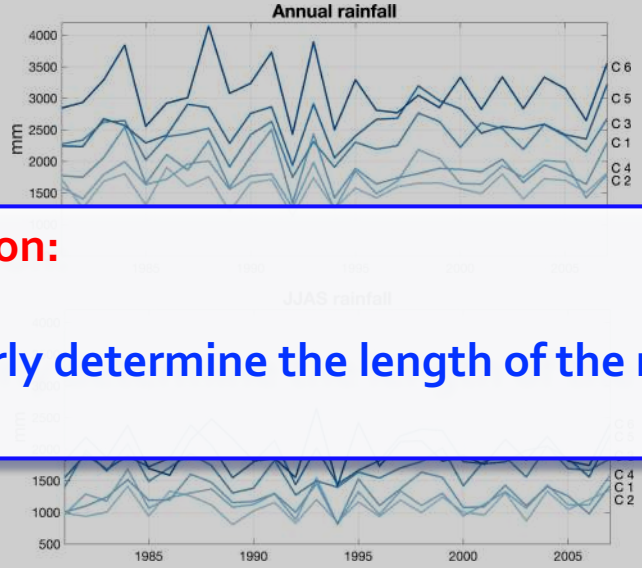


% heavy rainfall events



Monthly rainfall: JJAS climatology

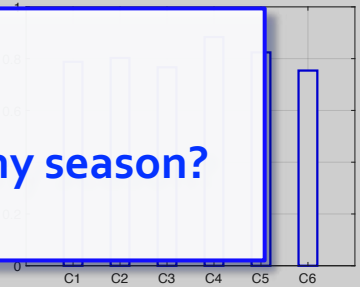




Research question:

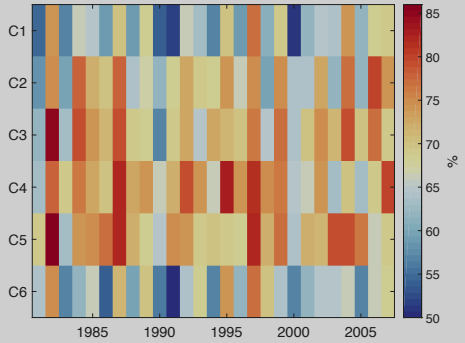
- **How to properly determine the length of the rainy season?**

High correlation

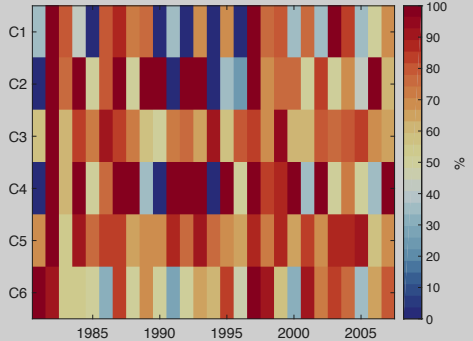


Subseasonal metrics

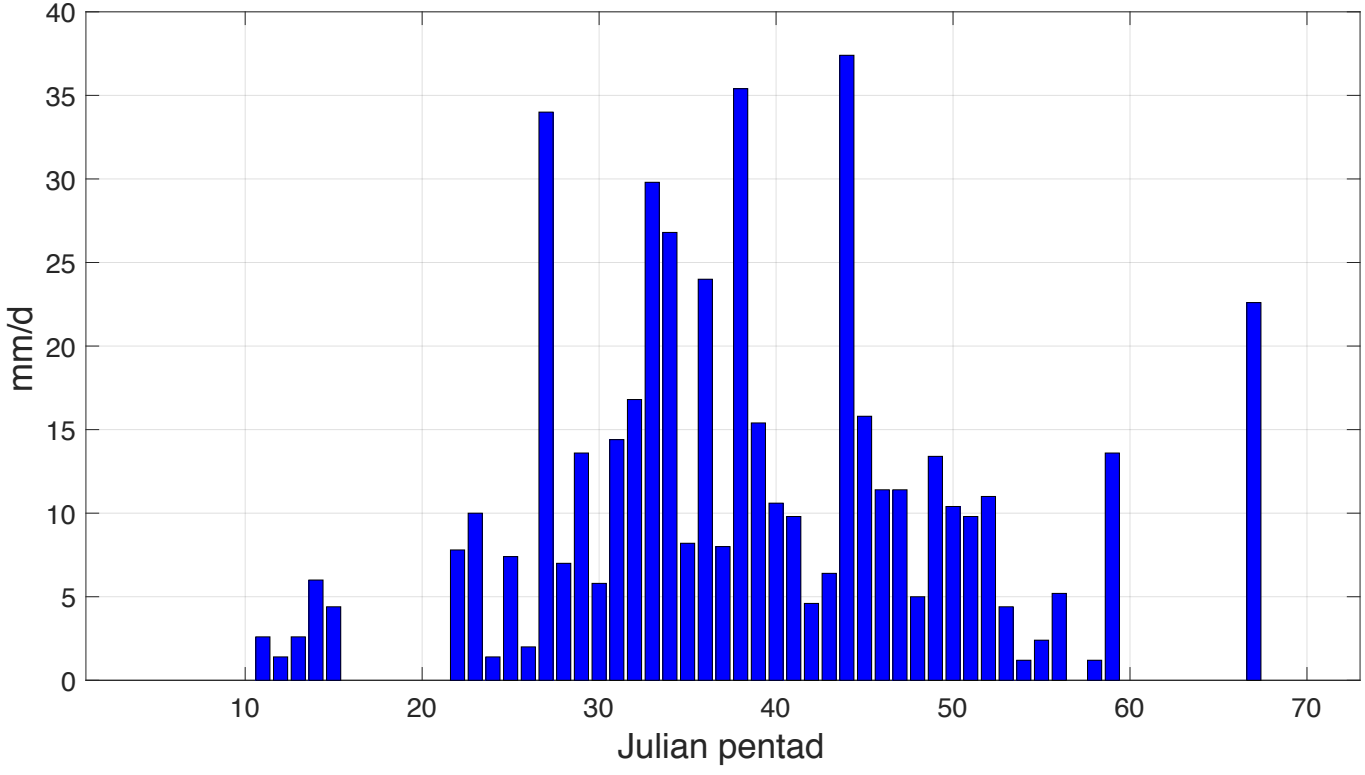
% annual rainfall



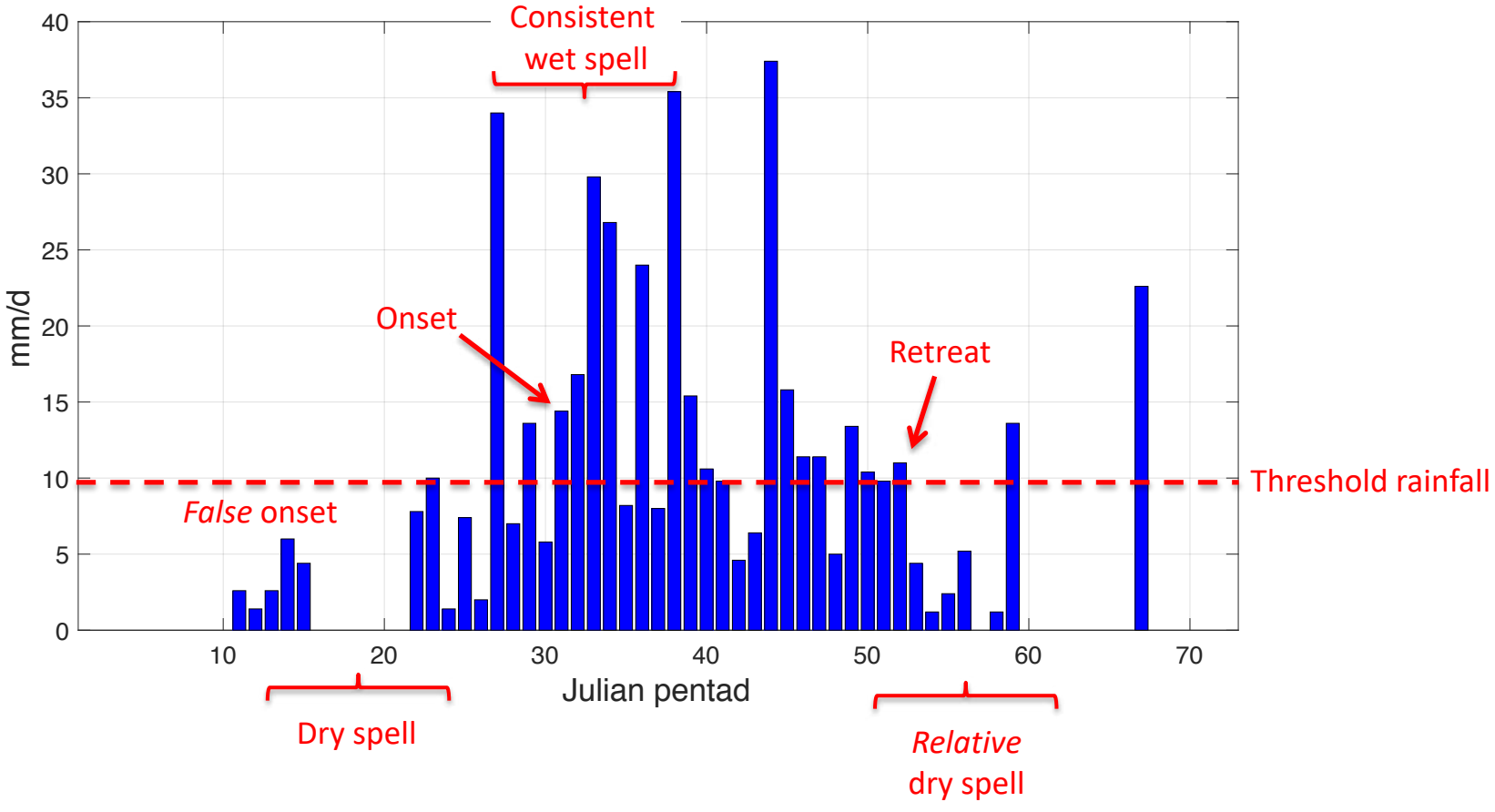
% heavy rainfall events



A typical year in Bangladesh



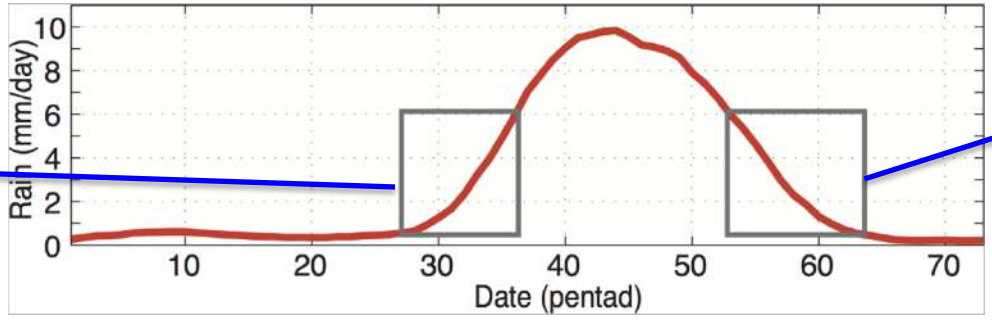
A typical year in Bangladesh



Monsoon onset withdrawal definition

Integrated Onset Matrix

1 1 0 1 0 1
1 1 1 0 1 0
1 1 1 0 0 1
1 1 0 0 1 1
1 1 0 1 1 0
1 1 0 1 1 1
1 1 1 0 1 1
1 1 1 1 0 0
1 1 1 1 0 1
1 1 1 1 1 0
1 1 1 1 1 1



Integrated Withdrawal Matrix

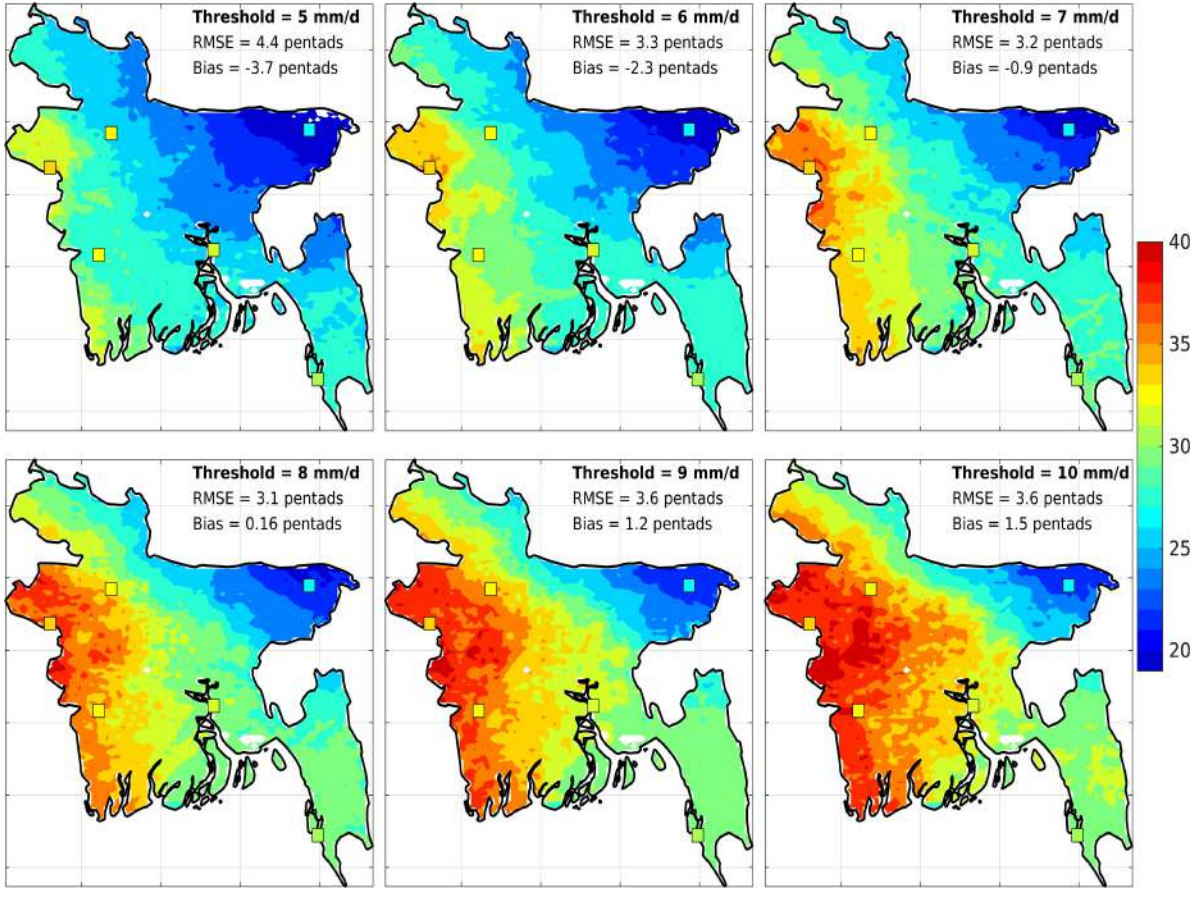
1 0 1 1 0 0
1 0 1 0 1 0
1 1 0 1 0 0
1 1 0 0 1 0
1 1 1 1 0 0
1 0 1 1 1 0
1 0 1 0 1 1
1 0 1 1 0 1
1 1 0 1 1 0
1 1 0 0 1 1
1 1 0 1 0 1
1 1 1 0 1 0
1 1 1 0 0 1
1 1 1 1 1 0
1 0 1 1 1 1
1 1 0 1 1 1
1 1 1 0 1 1
1 1 1 1 0 1
1 1 1 1 1 1

- Monsoon onset and withdrawal
- Monsoon parameter: threshold pentad precipitation
- Pentad binary time series
- 1 = rainfall higher than threshold

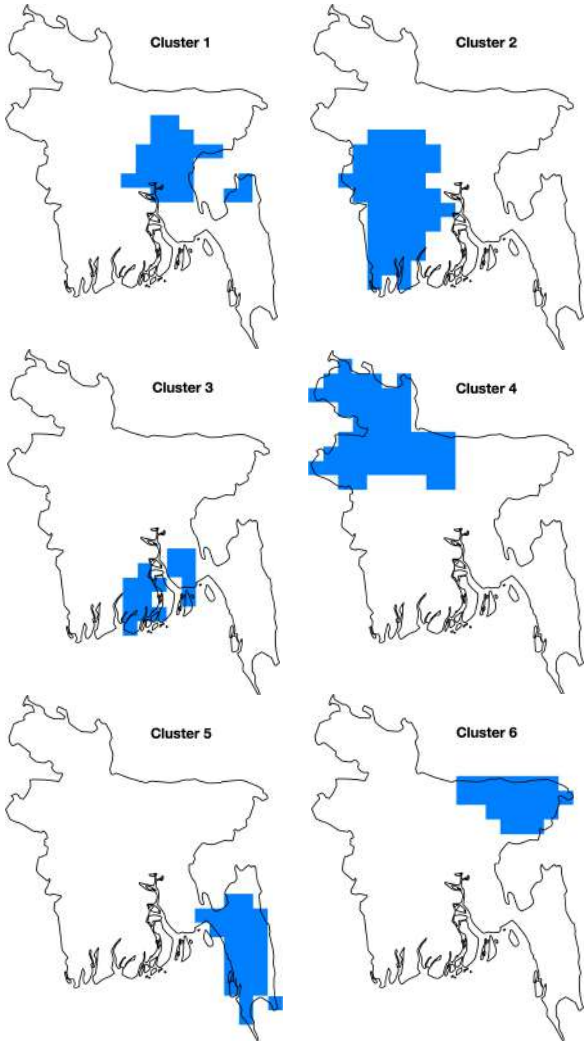
Stiller-Reeve et al., 2014

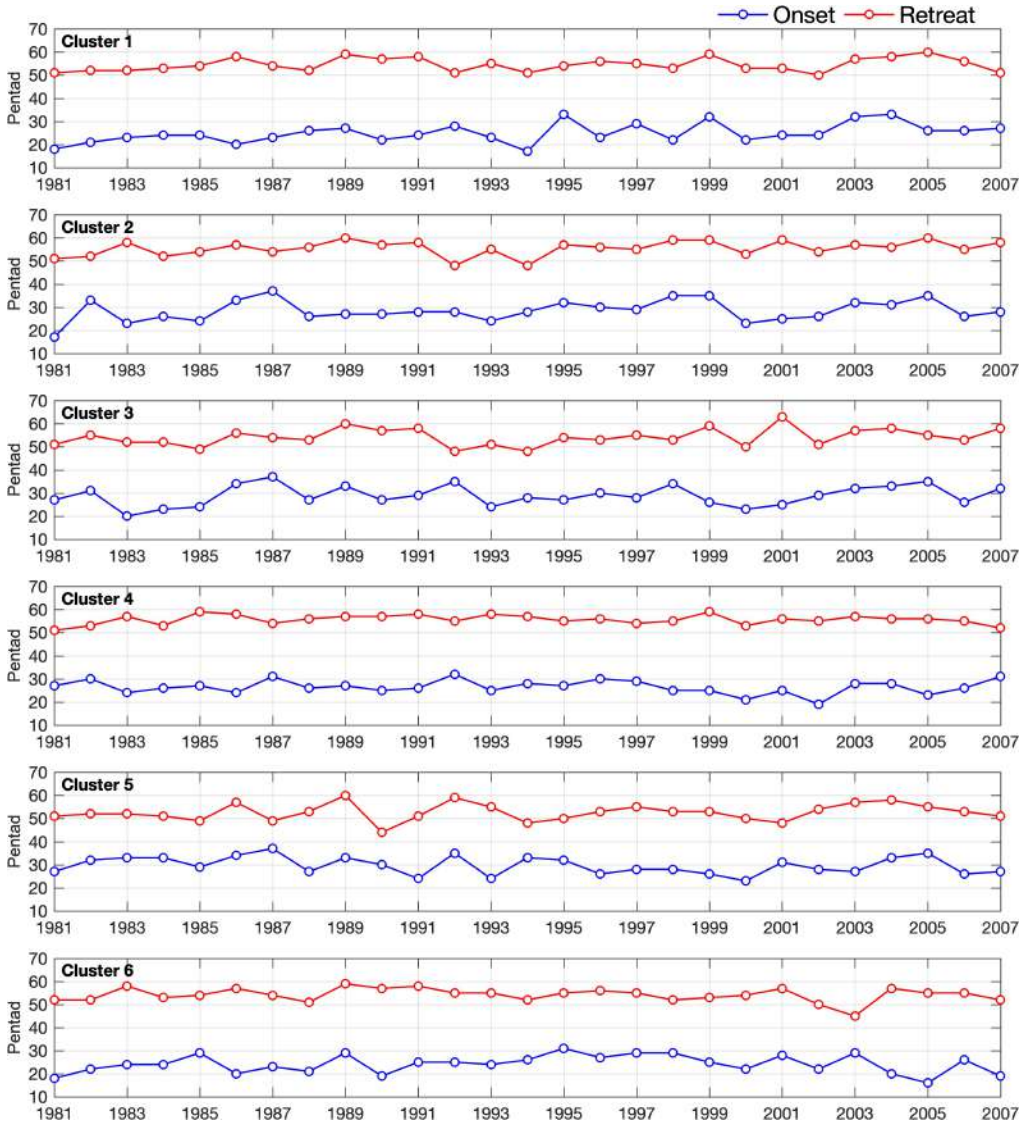
Monsoon onset withdrawal definition

Spatial pattern for different rainfall thresholds

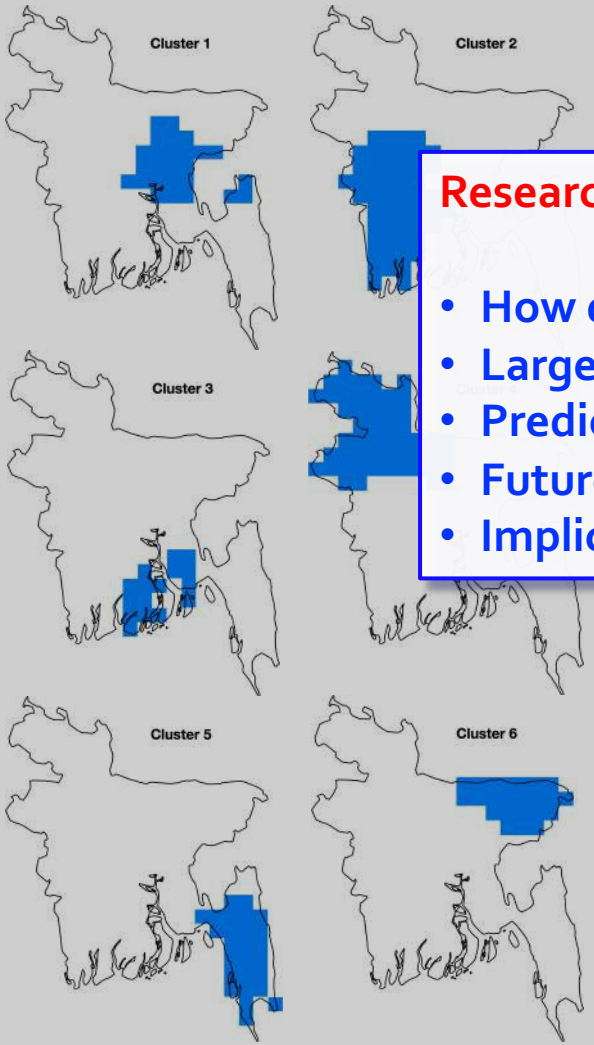


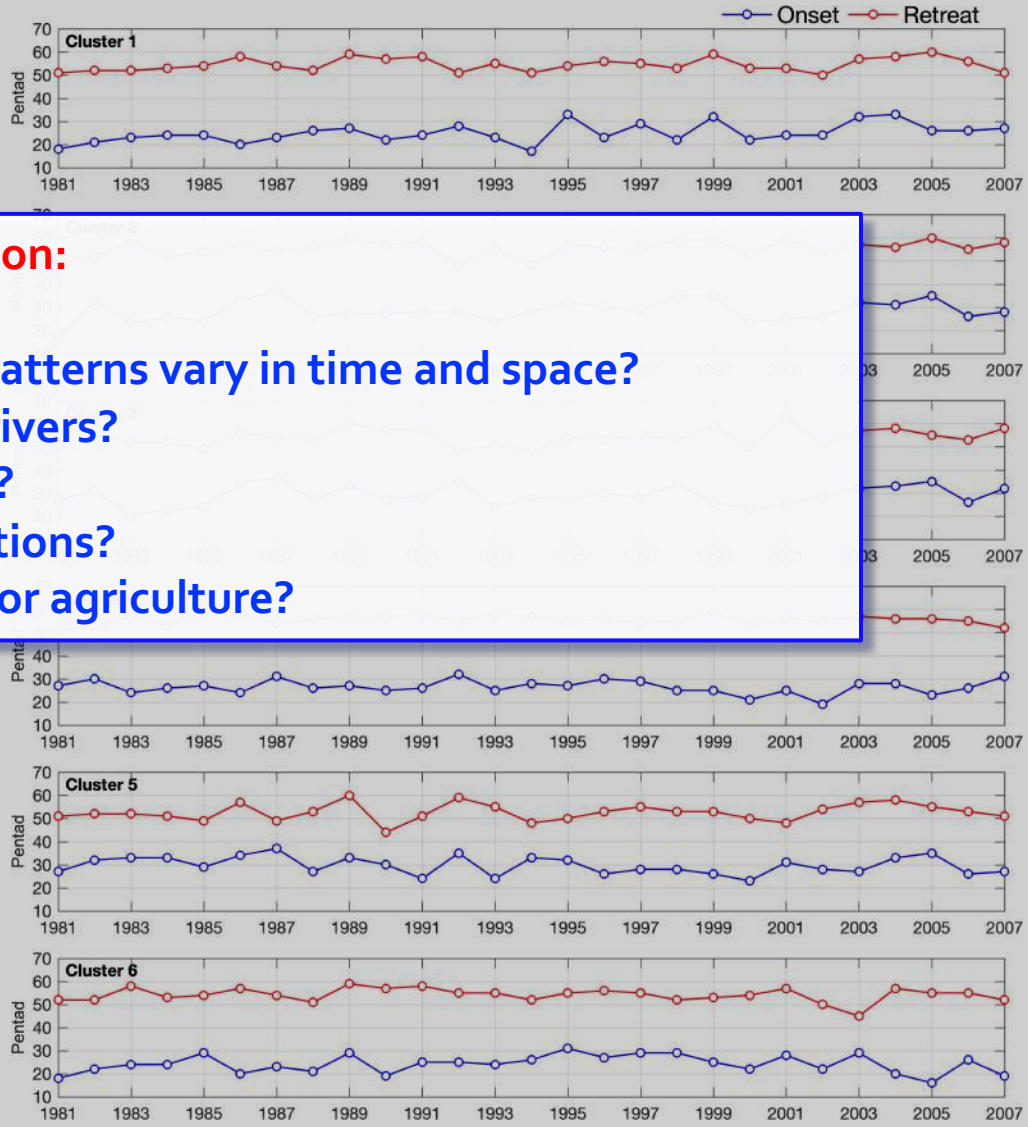
Monsoon onset and retreat





Monsoon onset and retreat





Research question:

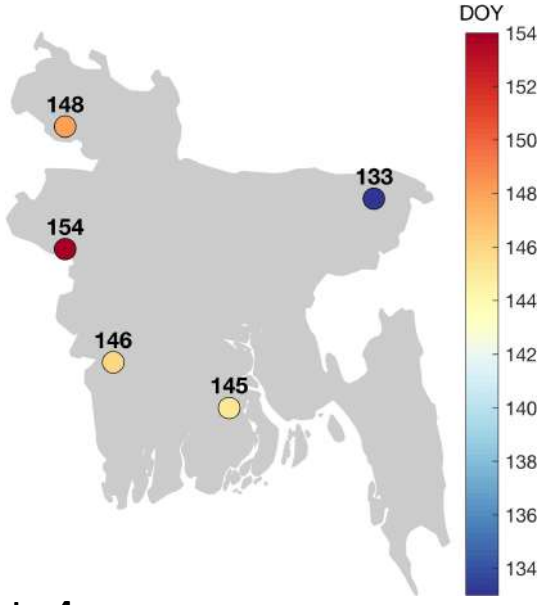
- How do this patterns vary in time and space?
- Large scale drivers?
- Predictability?
- Future projections?
- Implications for agriculture?

Monsoon onset definition for crop modeling

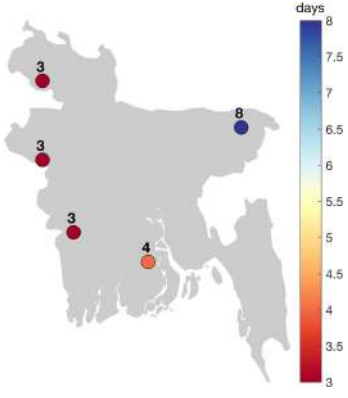
Parameters for Marteau *et al.* definition of monsoon onset

Calculated from May 1 to October 31

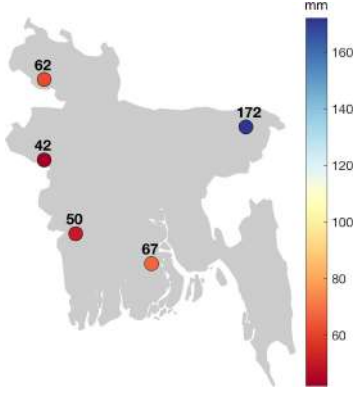
1. The duration of the initial wet spell
2. The amount of rainfall received during the initial wet spell
3. The length of post-onset dry spell to avoid false starts of the
4. The maximum amount of rainfall received during the post-onset dry spell



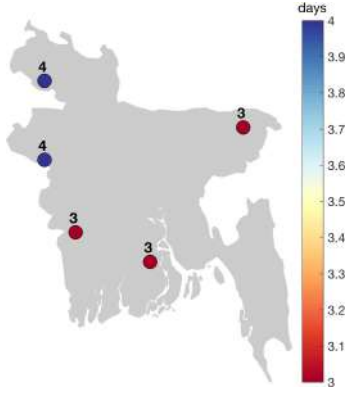
Parameter 1:
Duration of initial wet spell



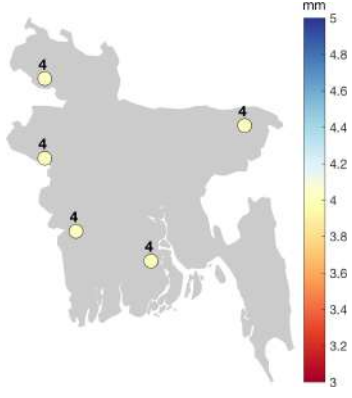
Parameter 2:
Rainfall amount of initial wet spell



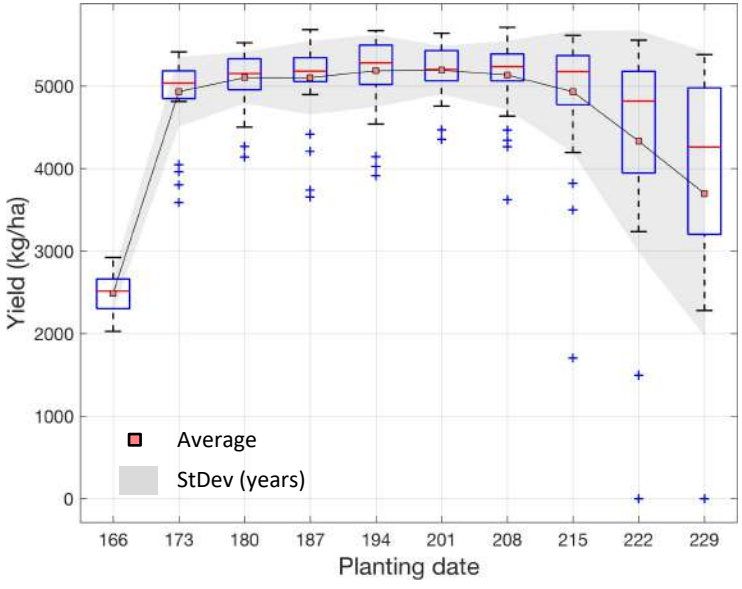
Parameter 3:
Duration of post onset dry spell



Parameter 4:
Rainfall amount of post onset dry spell



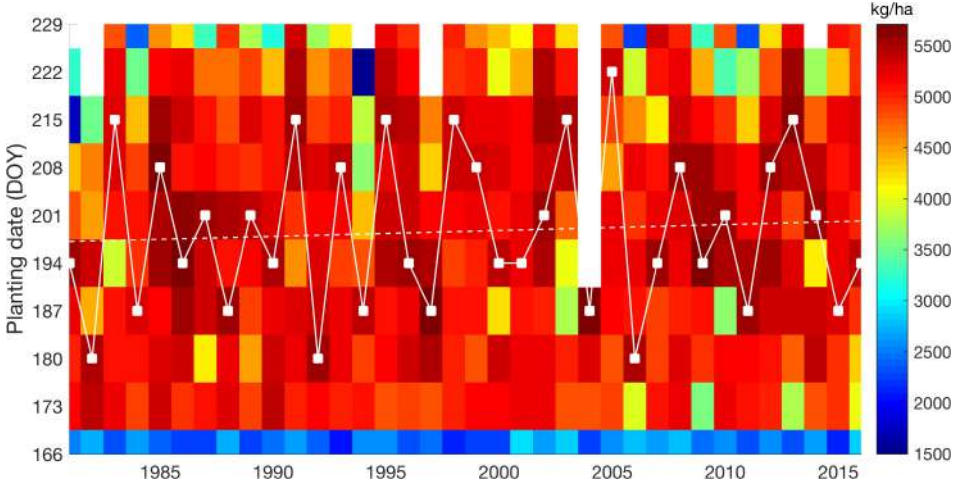
Rice yields and planting date (1981-2016)



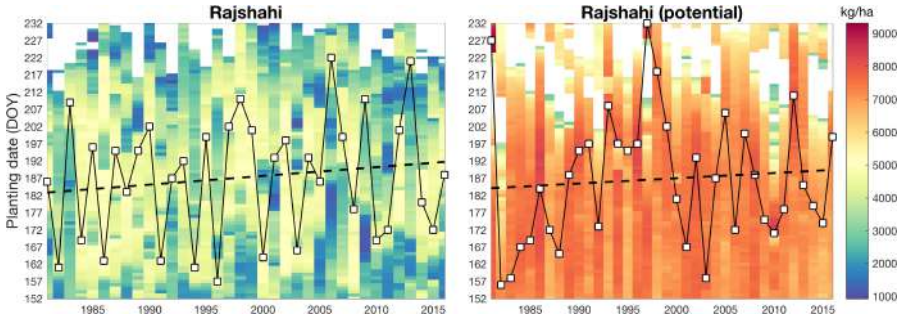
- Stable yield since planting date DOY 173
- High variability after planting date DOY 215

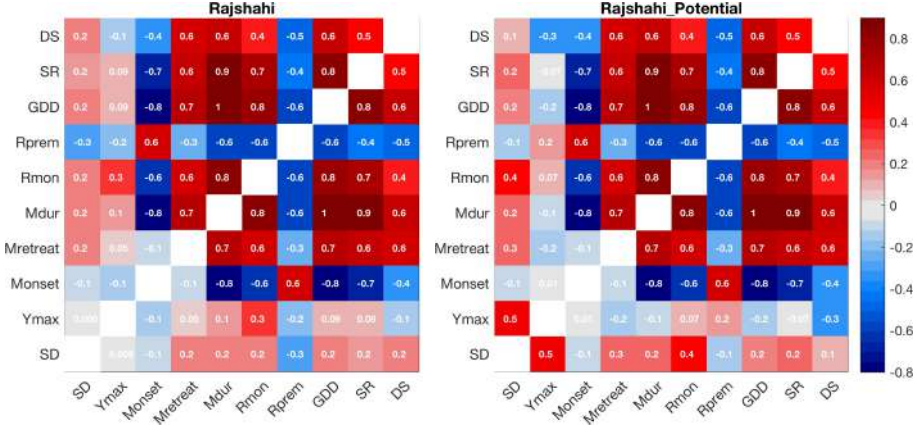
- High interannual fluctuation
- Possible connection with climate?

Planting date of maximum yield

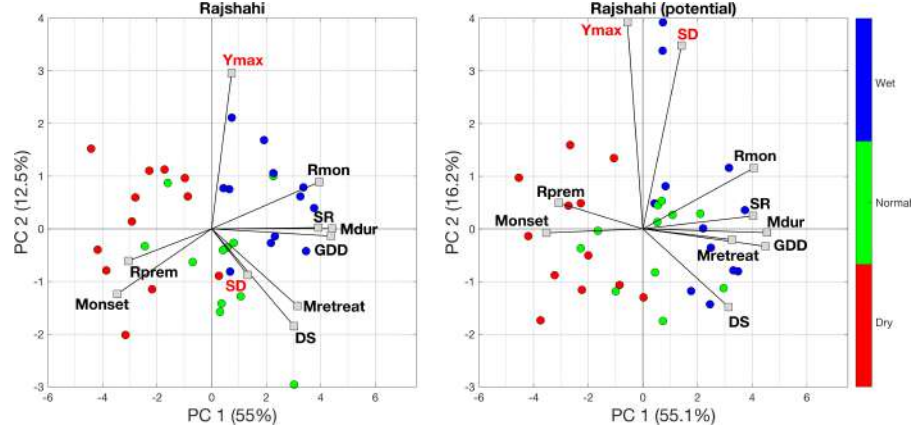


“Real” vs “potential” rice yields



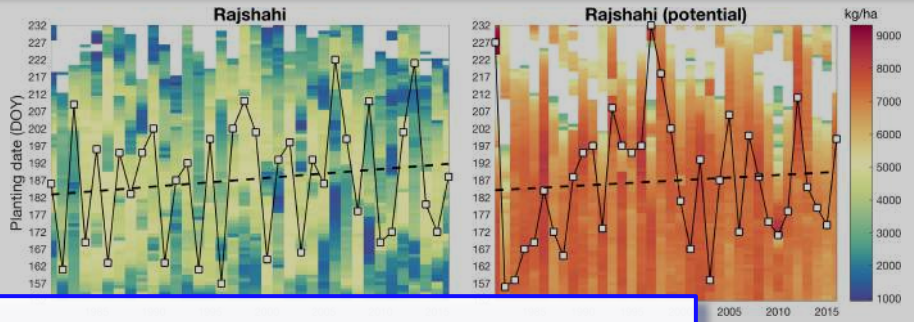


Correlation matrix with climate variables



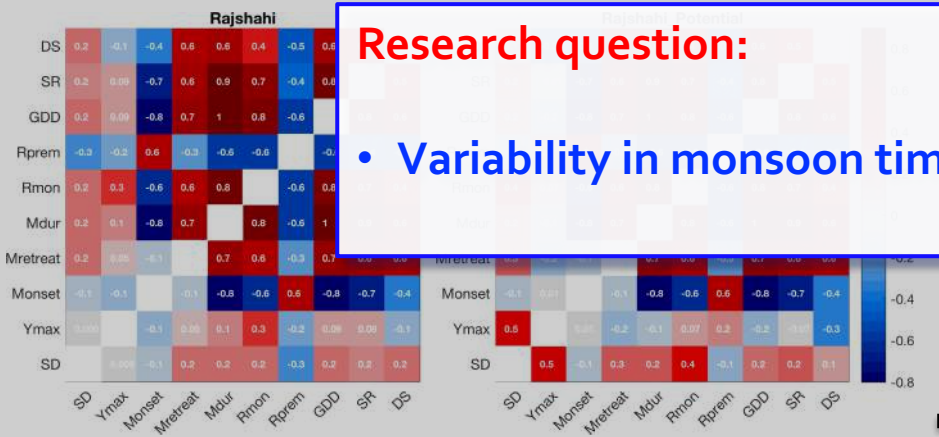
Relationship between variables in time

- Higher yields for “potential” model configuration
- Positive trend in both cases

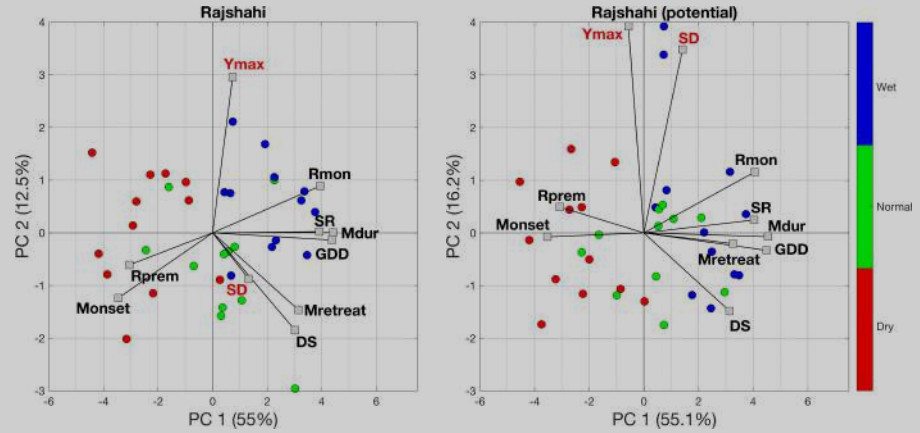


Research question:

- **Variability in monsoon timing and subseasonal metrics?**

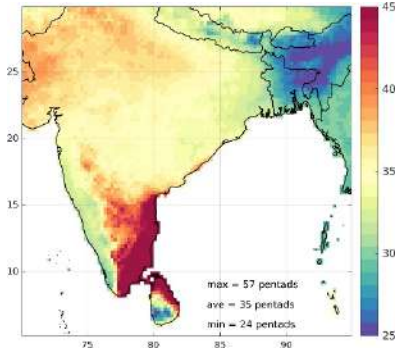


- Higher correlations between SD/Ymax and climate in the *potential* case
- Expected correlations between anomalies of climate metrics, strong in some cases
- Ymax correlates with SD in the *potential* case
- Higher correlation between SD and Rmon

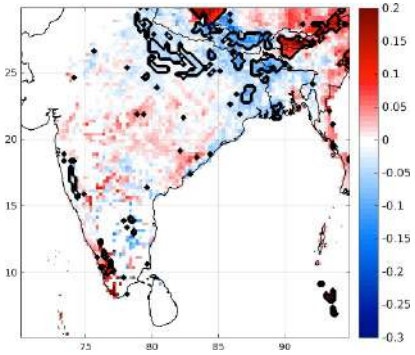


- Well differentiated rain categories (colored dots) and climate: e.g. Variables concentrate in wet years
- Potential case: higher association with climate anomalies

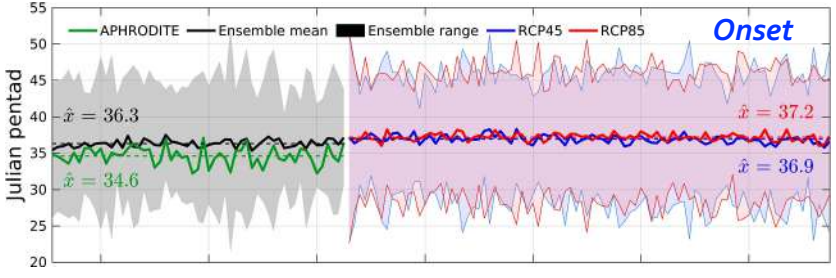
Average onset



Trend

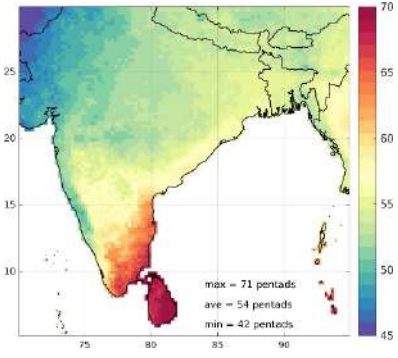


- East-West monsoon progression
- Earlier NE Bangladesh
- Late onset SE India
- Significant trends over some regions

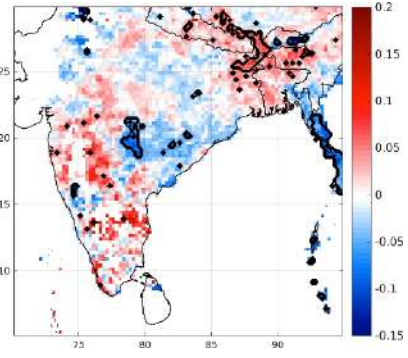


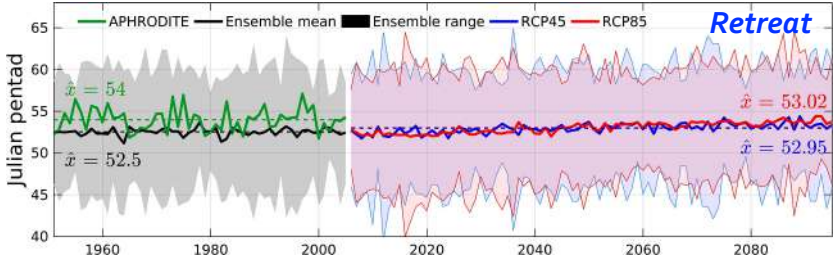
- Earlier in NW India and NW Bangladesh
- Late in SE India
- General WE progression
- Significant trends over some regions

Average retreat



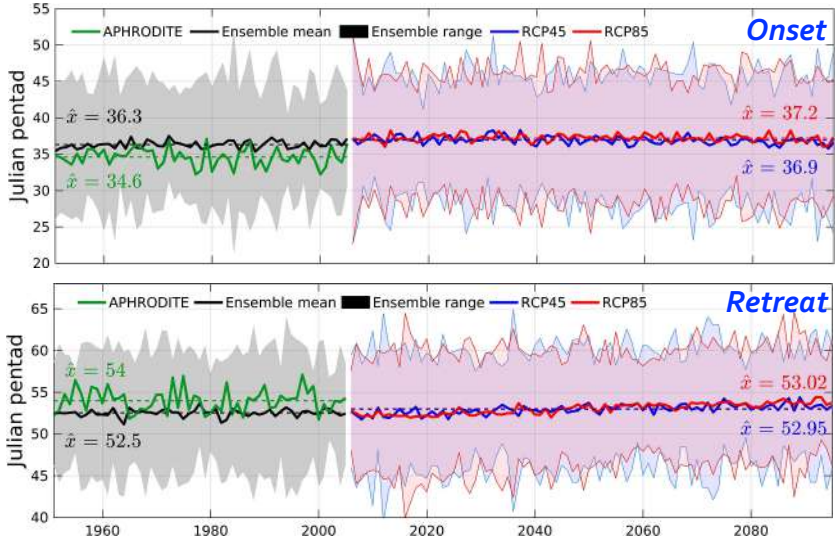
Trend





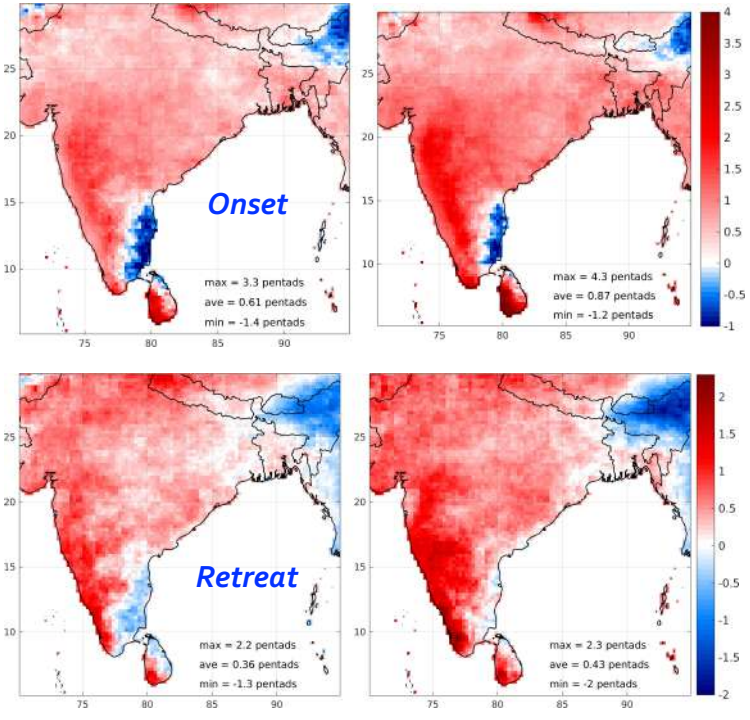
APHRODITE 1950-2005

Historical variability and future projections: 21 CMIP5 GCMs

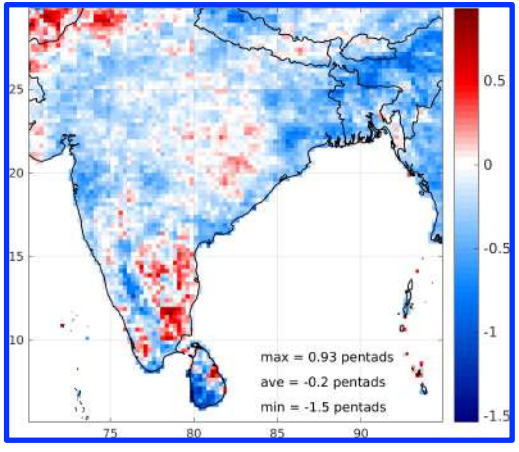


RCP45 *minus* historical

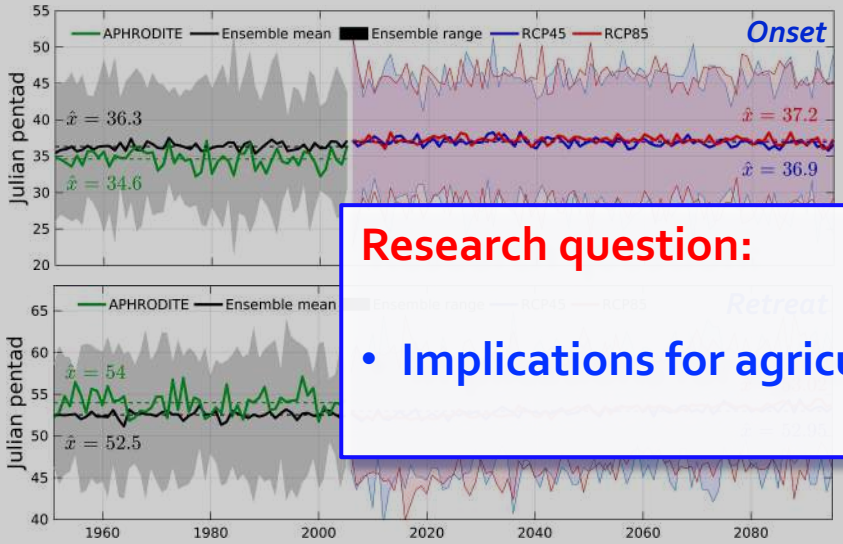
RCP85 *minus* historical



Net shortening in monsoon season



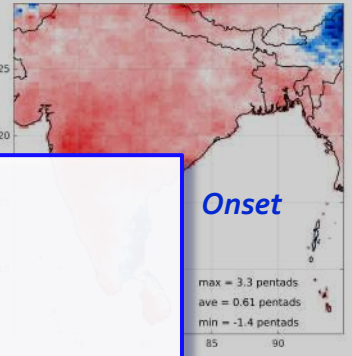
Historical variability and future projections: 21 CMIP5 GCMs

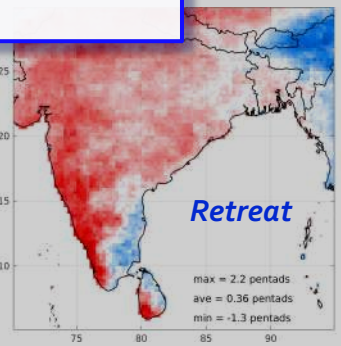


Research question:

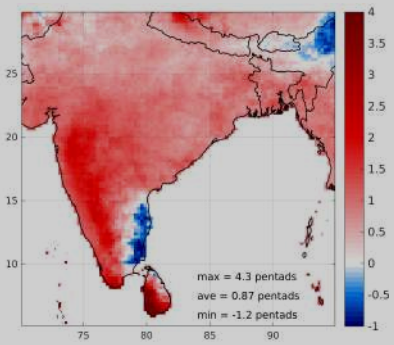
- **Implications for agriculture?**

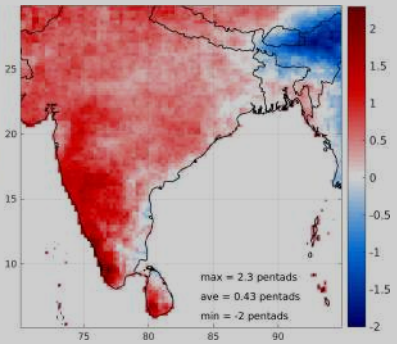
RCP45 *minus* historical



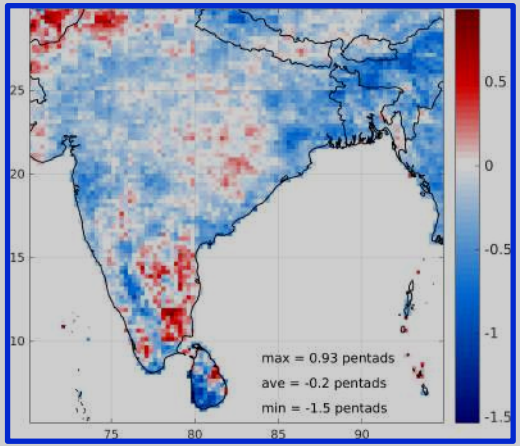


RCP85 *minus* historical





Net shortening in monsoon season



Sensitivity of rainfed rice yields to historical and projected monsoon precipitation and temperature over South Asia

Data

- NASA NEX GDDP downscaled (0.25º x 0.25º) CMIP5 21 GCMs
  - Daily rainfall, maximum and minimum temperature
  - Historical period 1950-2005
  - RCP45 and RCP85 2006-2095
- Gridded rainfed rice annual yields (Lizumi et al., 2017*)
  - 1961-2006
  - Bilinearly interpolated from 0.5º x 0.5º to 0.25º x 0.25º
- Princeton Global Meteorological Forcing (0.25º x 0.25º)
  - Daily rainfall, maximum and minimum temperature
- Reference rice planting date from RiceAtlas product (Laborte et al., 2017**)
- Monsoon-derived rice planting date (Mathison et al, 2018)

Sensitivity of rainfed rice yields to historical and projected monsoon precipitation and temperature over South Asia

Selected climate explanatory variables

Timing:

- Monsoon onset
- Monsoon retreat
- Monsoon-derived rice planting date

From planting date to monsoon retreat

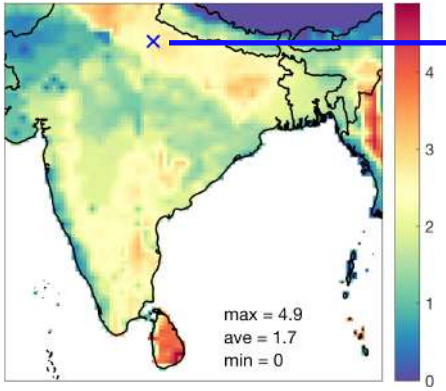
- Monsoon total precipitation
- Growing degree days
- Number of dry spells (rainfall < 1 mm, 5 or more days)
- Number of warm days (Tmax > 35ºC)
- Number of warm nights (Tmin > 28ºC)
- Length of the growing season

Modeled historical and future projections

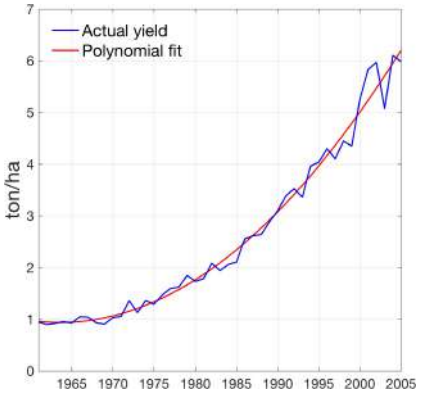
- Annual rice yields

Rice yield anomalies: statistical crop modeling

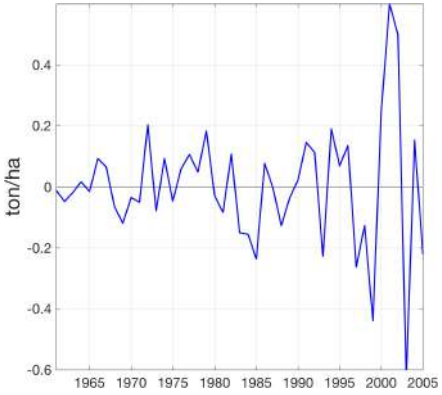
Lizumi et al. rice yields product (1961-2005)



For every grid cell



Yield anomalies



$$Y_{i,j,gcm} = \alpha_{i,j,gcm} + \beta_{i,j,gcm}\boldsymbol{Climate}_{i,j,gcm} + \delta_{i,j,gcm}\boldsymbol{Int}_{i,j,gcm} + \epsilon_{i,j,gcm}$$

Where, for every grid cell *i,j* and model (*gcm*)

$Y_{i,j,gcm}$: simulated rice yield anomalies

$\alpha_{i,j,gcm}$, $\beta_{i,j,gcm}$ and $\delta_{i,j,gcm}$: regression coefficients

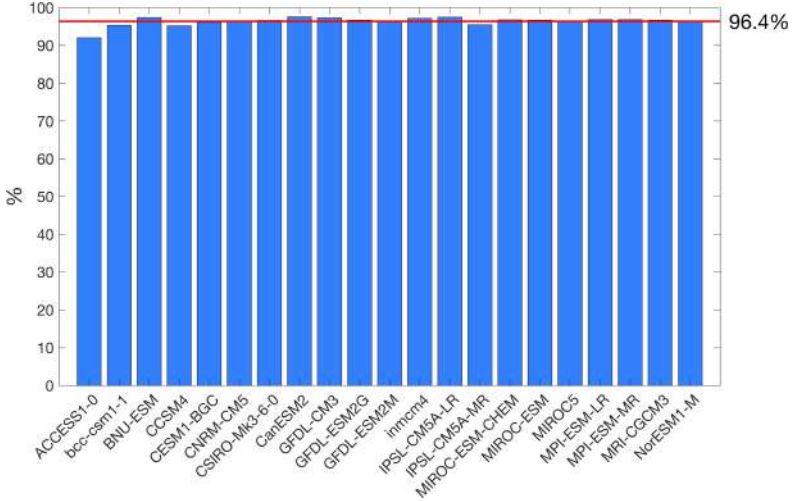
$\epsilon_{i,j,gcm}$: error term

Climate: vector of seasonal climate and derived variables (planting date, monsoon onset , monsoon retreat, monsoon rainfall, GDD, warm days, warm nights, dry spells)

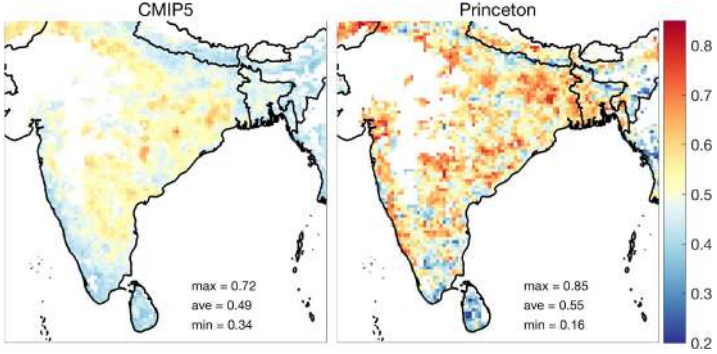
Int: vector of interaction terms (monsoon onset × GDD; monsoon rainfall × GDD, monsoon retreat × GDD, dry spell × GDD, monsoon rainfall × warm days, monsoon rainfall × warm nights)

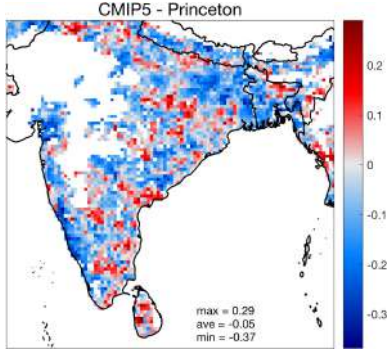
Rice yield anomalies: CMIP5 models, 1950-2005

Percentage of grid cells with significant correlation (*p* value <= 0.05) between observed and simulated rice yield anomalies for CMIP5 models

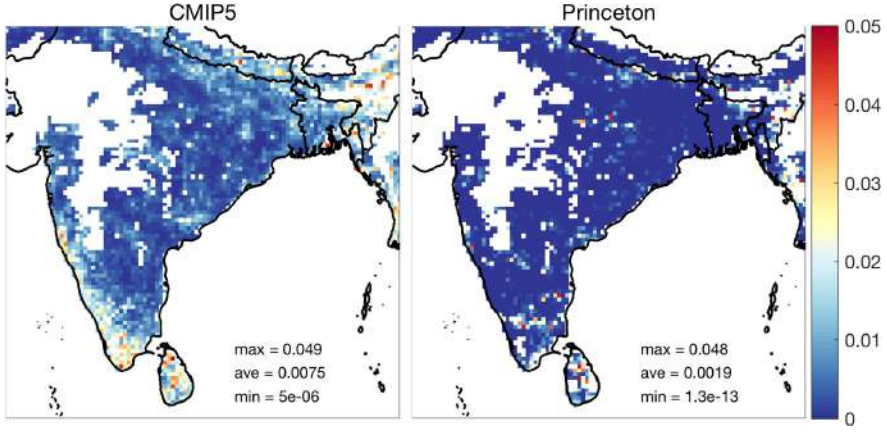


Average correlation between simulated and observed yield anomalies



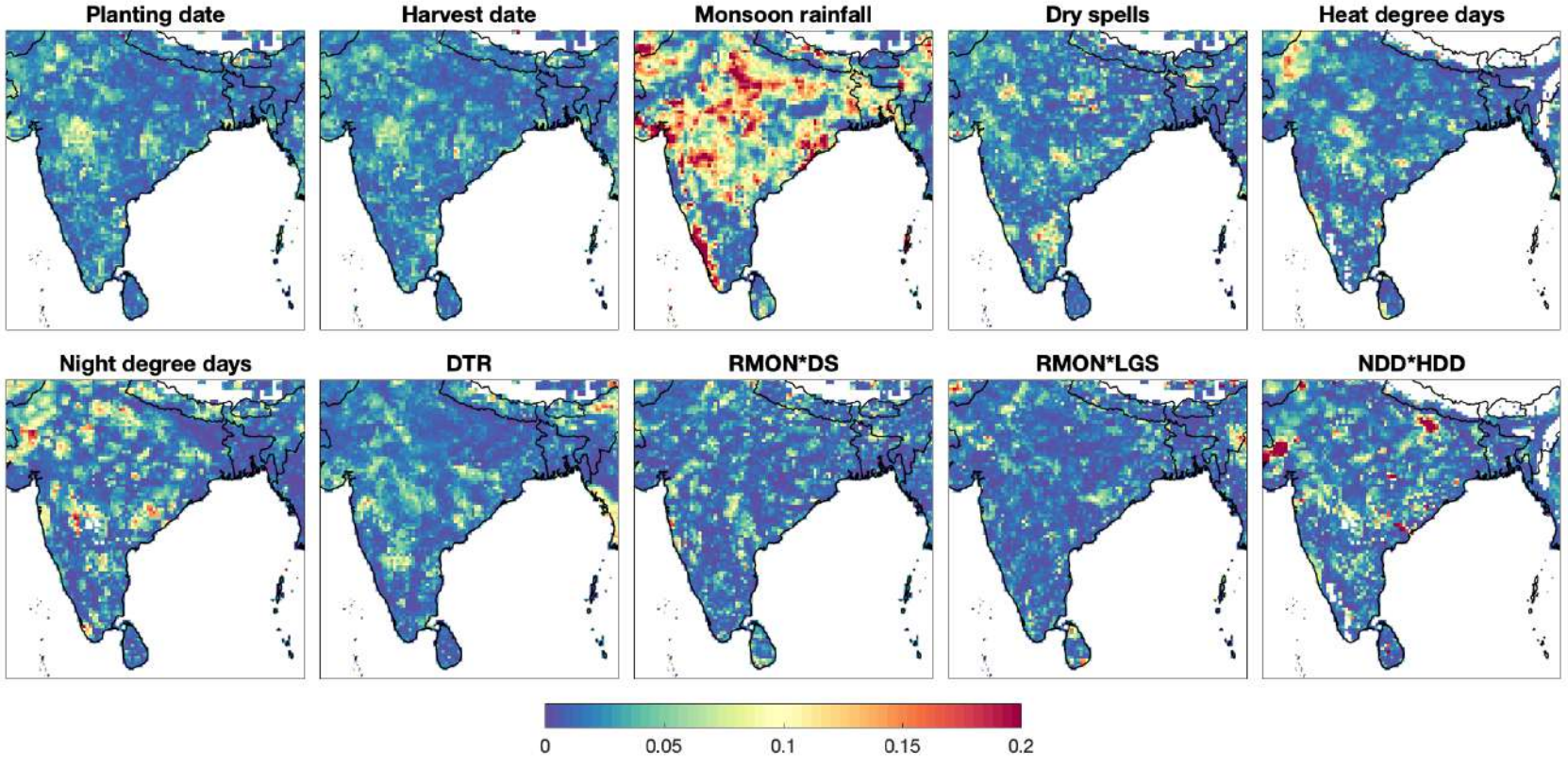


Average *p* value (significant)



Rice yield anomalies: Princeton GMF, 1950-2005

Dominance analysis to determine the relative importance (fraction) of the predictors of rice yields anomalies



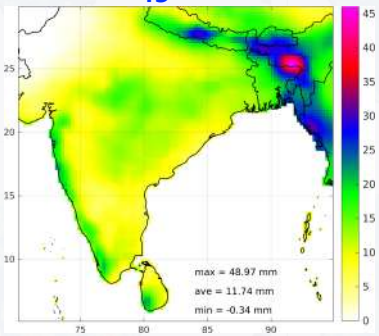
Rice yield anomalies: Princeton GMF, 1950-2005

Domi

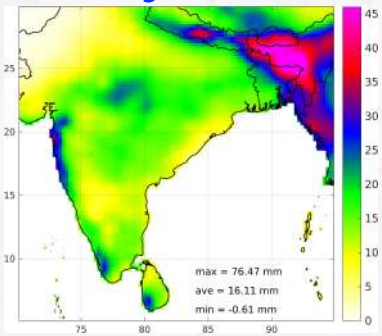
Research question:

- Future projections?
- Rainfall v/s temperature according to climate trends

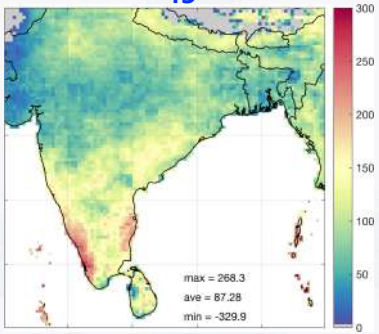
ΔR RCP45



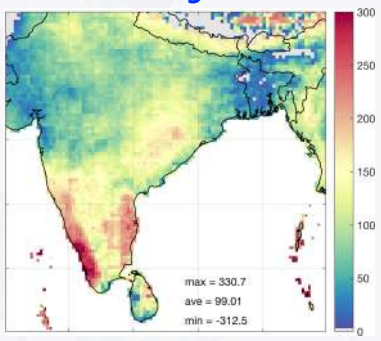
ΔR RCP85



ΔGDD RCP45



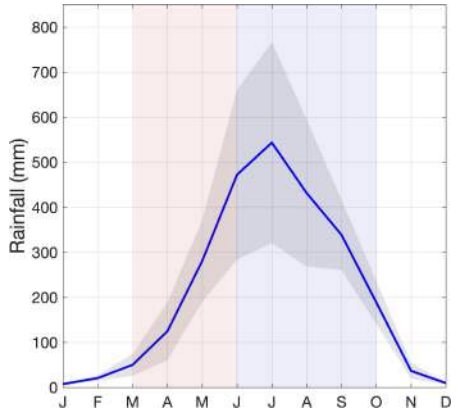
ΔGDD RCP85



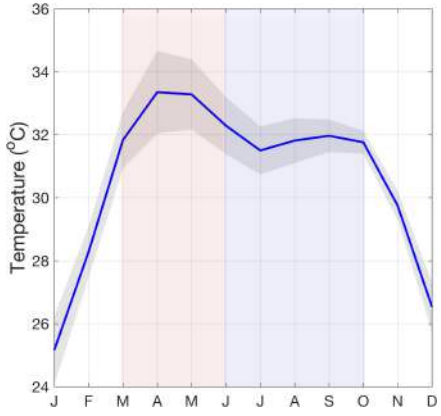
Understanding climate variability in bangladesh: precipitation and temperature

Mean annual cycle and standard deviation

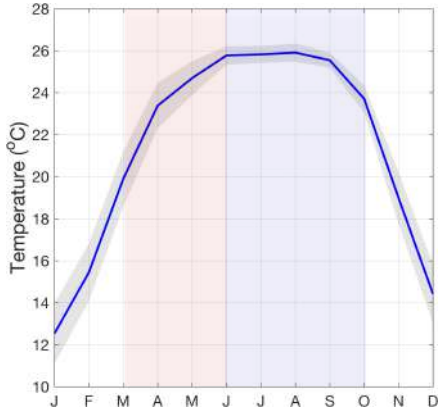
Precipitation



Maximum temperature



Minimum temperature



Precipitation:

- MMA: strong increase in rainfall
- JJAS: peak in July

Maximum temperature:

- MAM: maximum precipitation
- Surface heating interrupted by cloudiness and surface wetness
- JJAS: decrease and then stable
    - Deacreasing incoming energy and precipitation

Minimum temperature:

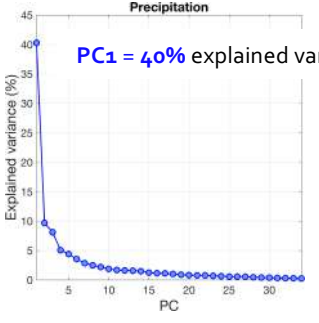
- MAM: slight increase
- JJAS: stable values
- *Typical* annual cycle
- Diurnal vs nocturnal processes

Climate - circulation covariability and sources of predictability in Bangladesh

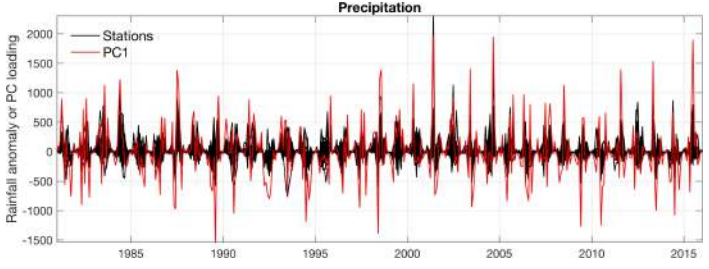
Principal Component Analysis to monthly anomalies

PC1 to be used for subsequent analysis

EOF1: spatial structure of PC1



PC1 = 40% explained variance



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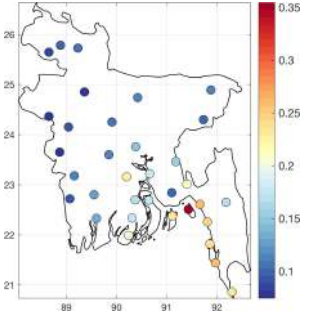
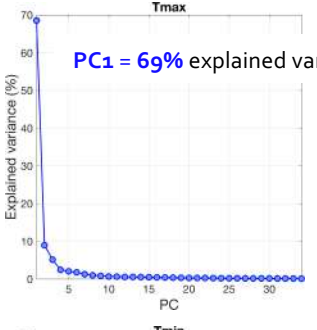
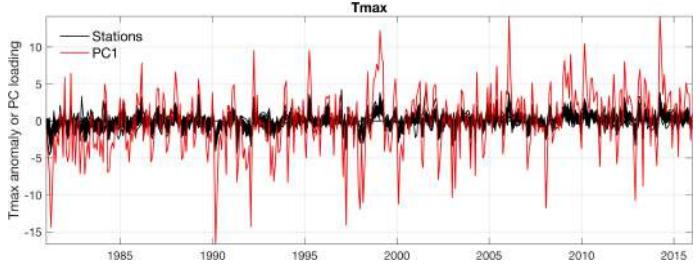




PC1 = 69% explained variance



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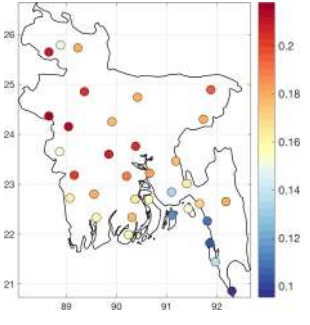
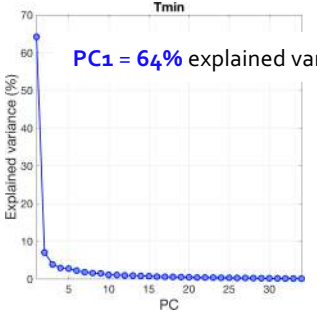
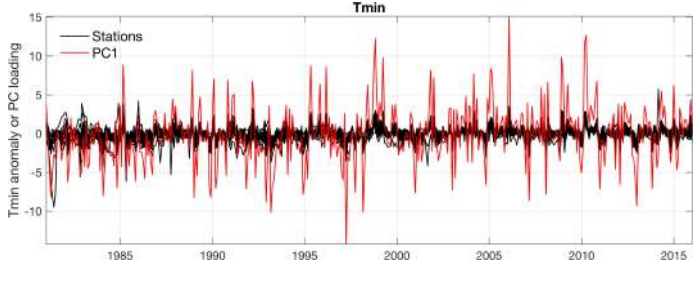




PC1 = 64% explained variance



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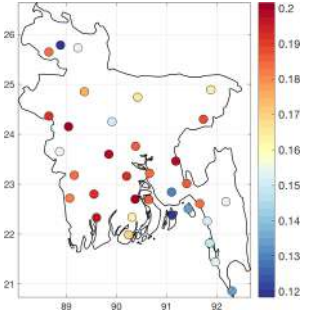
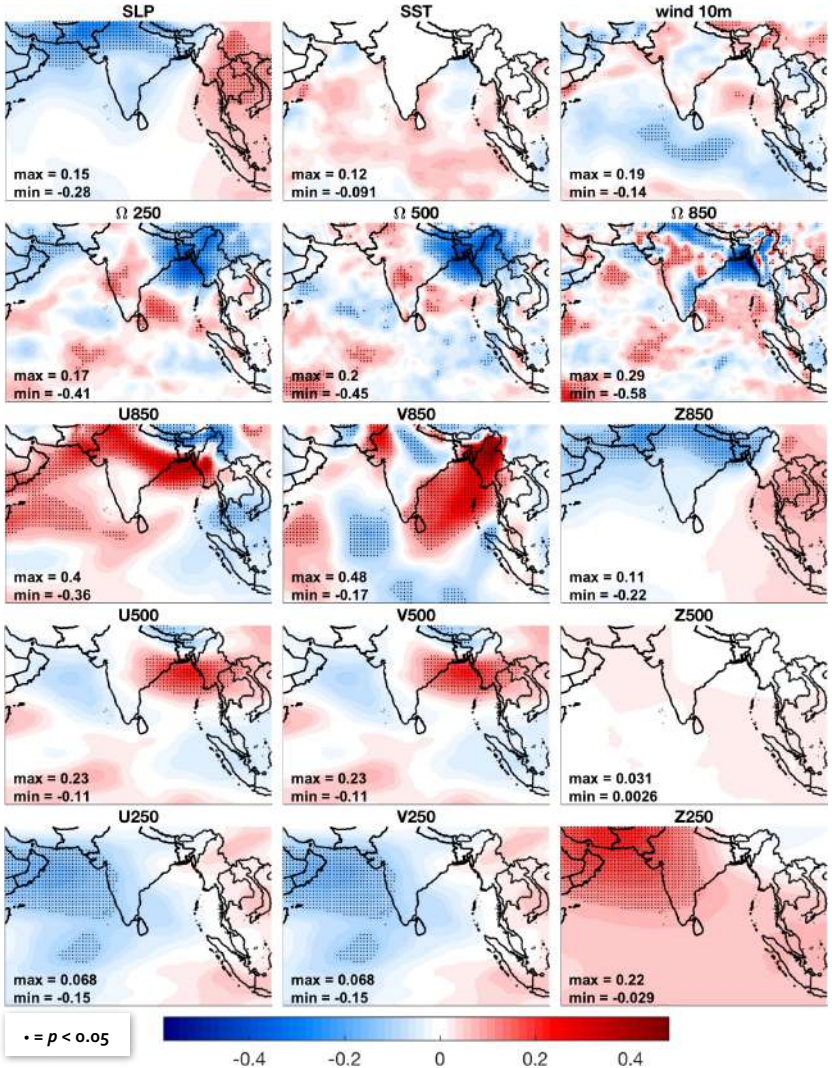


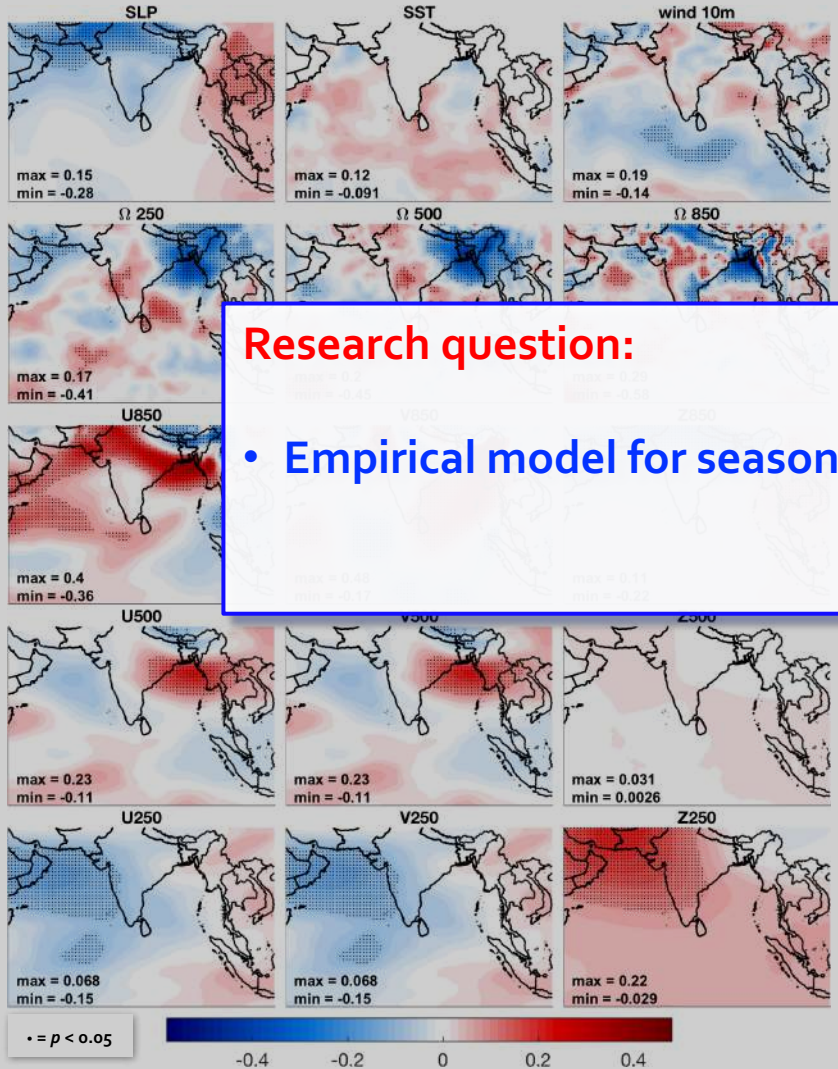


SLP: sea level pressure; H500: geopotential height 500 hPa; Ω500: vertical pressure velocity 500 hPa; UZ: zonal wind at Z = 850, 500 and 250 hPa; VZ: meridional wind at Z = 850, 500 and 250 hPa; QZ: specific humidity at 850, 500 and 250 hPa

Precipitation and circulation anomalies

Point-to-point correlation between **synoptic** fields and **PC1**

- **Significant (*medium*) correlations/covariability**
- **Main large scale factors explaining climate in Bangladesh**
  - **Pressure velocity**
  - **Zonal and meridional wind**
  - **Geopotential height**



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Precipitation and circulation anomalies

Research question:

- **Empirical model for seasonal climate prediction in Bangladesh?**

Point-to-point correlation between synoptic fields and **PC1**

- Main large scale factors explaining climate variability in Bangladesh
  - Pressure velocity
  - Zonal and meridional wind
  - Geopotential height

Collaboration

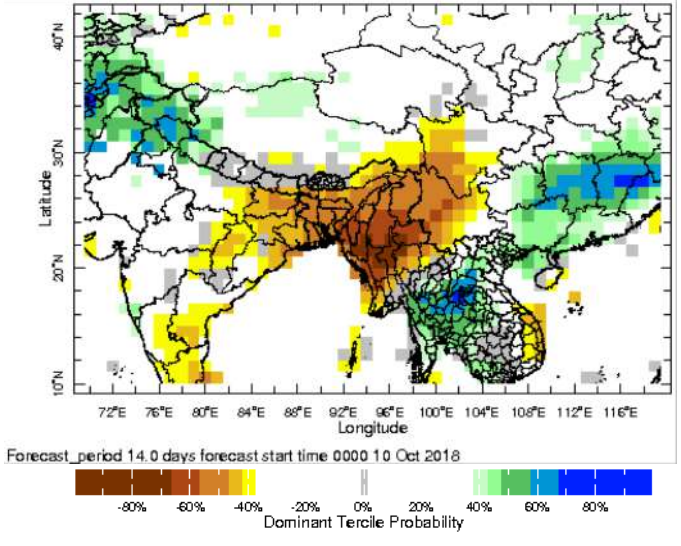
North American Multi-Model Ensemble (NMME)

Dynamical forecast

- Seasonal forecasting: monsoon rainfall and sub-seasonal relevant climate metrics

NOAA MME Dynamical forecast

- Sub-seasonal forecasting (~1 month): monsoon onset predictability



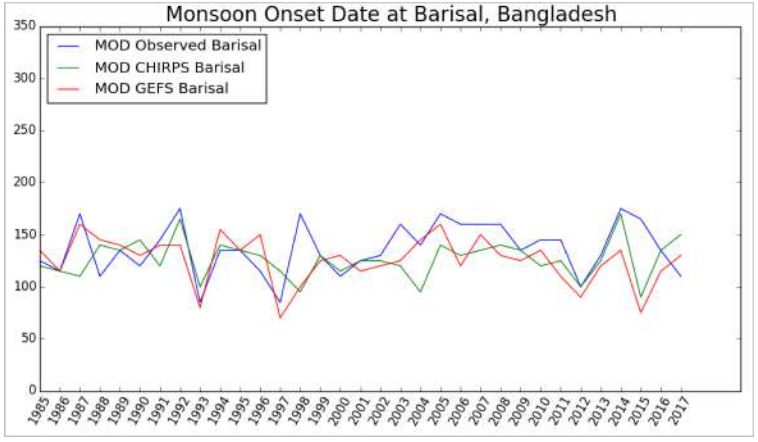
CIMMYT
International Maize and Wheat Improvement Center

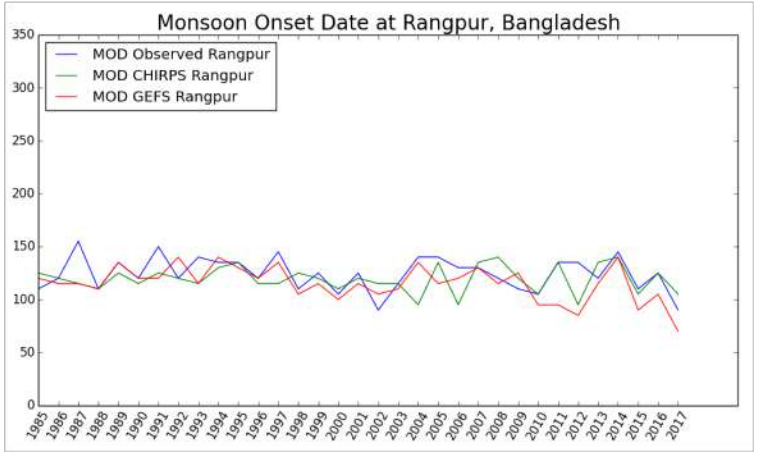
IRI International Research Institute for Climate and Society
Earth Institute | Columbia University

Collaboration

GEFS-CHIRPS sub-seasonal forecast for Bangladesh

- 21 models, 16-days forecast, every 6 hours
- Monsoon onset predictability





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