

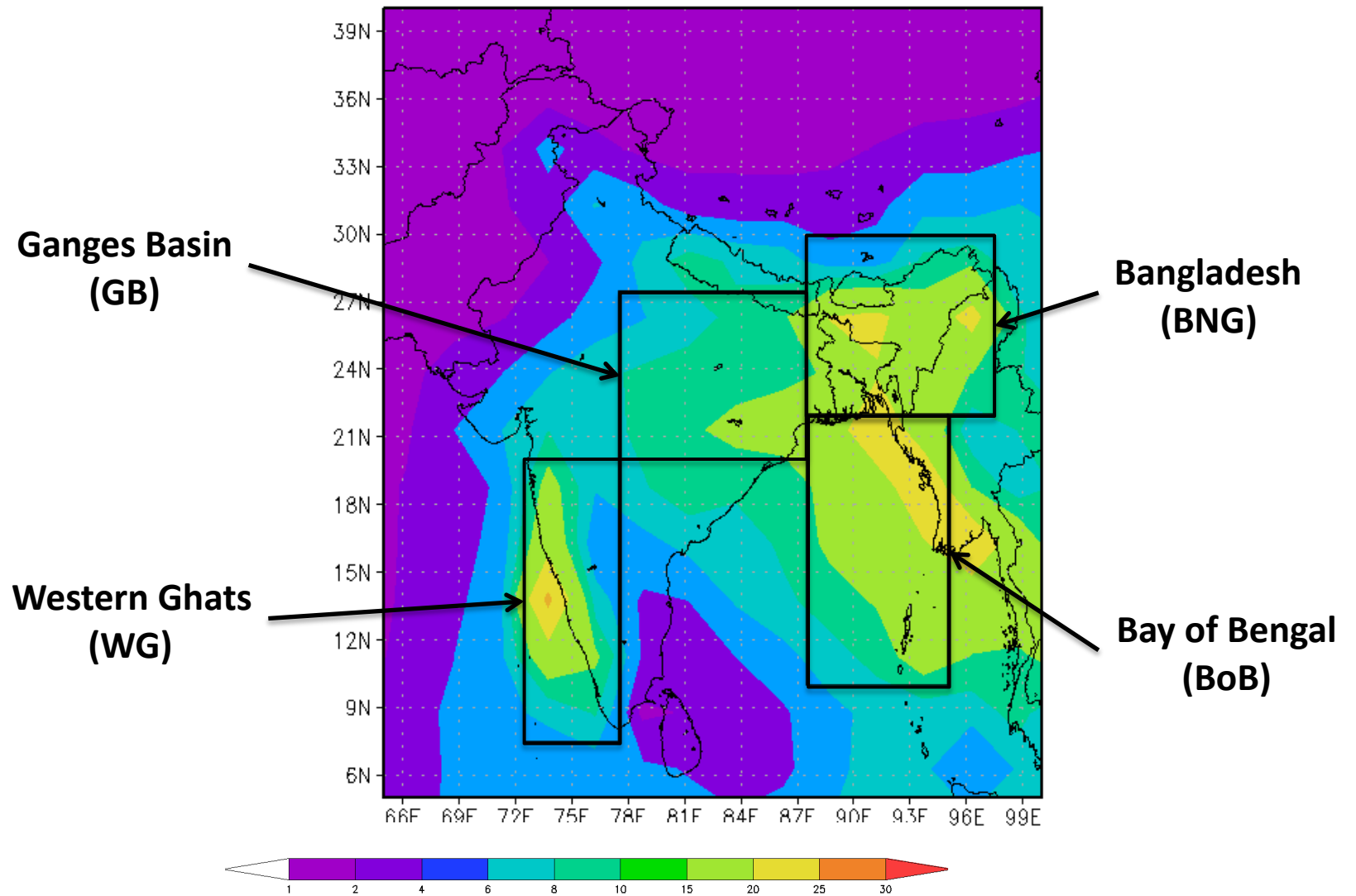
# Regional Structure of the Indian Monsoon in Observations, Reanalysis, and Simulations

**Benjamin A. Cash (COLA)**

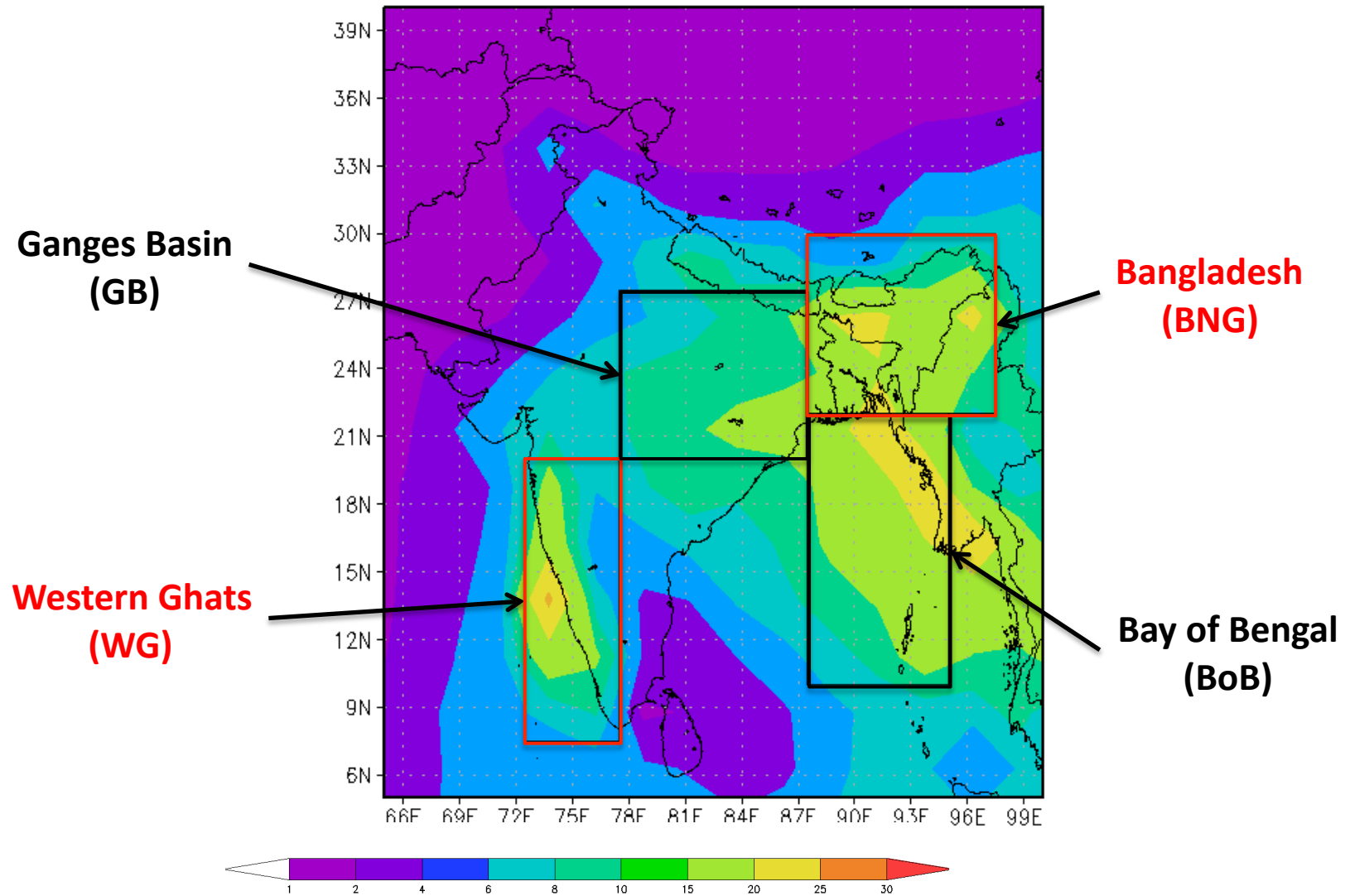
*Many thanks to Jim Kinter*

- Why focus on the Indian Monsoon?
  - Dominant mode of seasonal to interannual variability in the climate system
  - Directly affects the lives and livelihood of billions of people
- Why focus on the regional structure?
  - Large scale representations (All-India Rainfall) give no information on regional rainfall totals
  - Regional variations in monsoon rainfall directly impact agriculture, water quality, disease transmission...
  - Leads to confusion when discussing relationships between “the” monsoon and remote forcing
- Why consider multiple representations?
  - Results may be sensitive to the choice of product
  - Reanalysis and simulation allow for different analyses than merged precip products, but do we trust them?

# 1979-2009 JJAS Rainfall (GPCP)



# 1979-2009 JJAS Rainfall (GPCP)



# Data Sources

- Objective analyses of precipitation

- **GPCP** (Merged Gauge-Satellite)

- 1979-2009 <http://www.gewex.org/gpcp.html>

- **CMAP** (Merged Gauge-Satellite)

- 1979-2009 e.g. <http://www.esrl.noaa.gov/psd/data/gridded/data.cmap.html>

- **Chen** (Gauge only)

- 1948-2009 (Chen et al., 2002: Global Land Precipitation: A 50-yr Monthly Analysis Based on Gauge Observations, *J. Hydrometeor.*, **3**, 249-266)

- Reanalysis

- **NCEP CFSR**

- 1979-2009 <http://cfs.ncep.noaa.gov/cfsr/> (Saha et al., 2010: The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Meteor. Soc.*, **91**, 1015–1057)

- **NASA MERRA**

- 1979-present <https://gmao.gsfc.nasa.gov/merra/intro.php>

- **ECMWF ERA-Interim**

- 1979-2009 <http://www.ecmwf.int/products/data/archive/descriptions/ei/index.html>

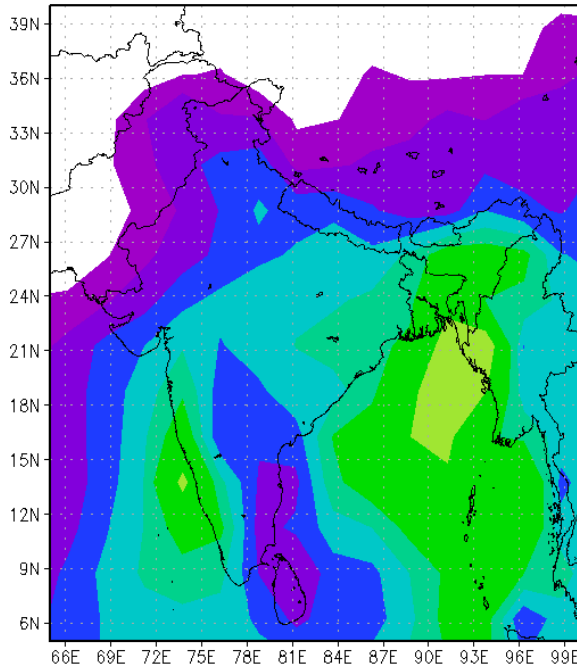
- Simulations

- **IFS Athena**

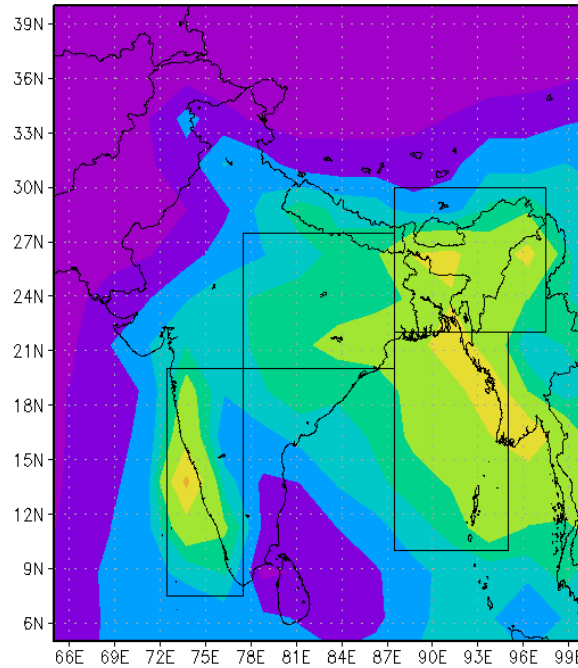
- 1961-2007 <http://wxmaps.org/athena/home/>

- 16 km AGCM forced with observed SST

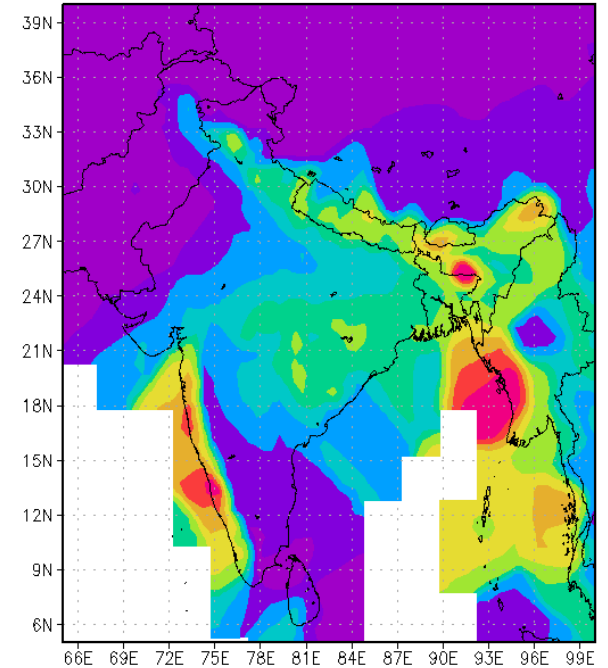
# 1979-2009 JJAS Mean Rainfall



**CMAP**



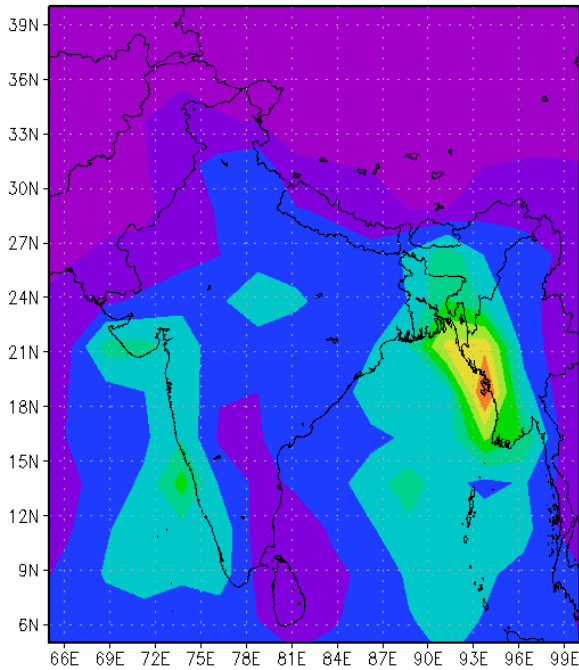
**GPCP**



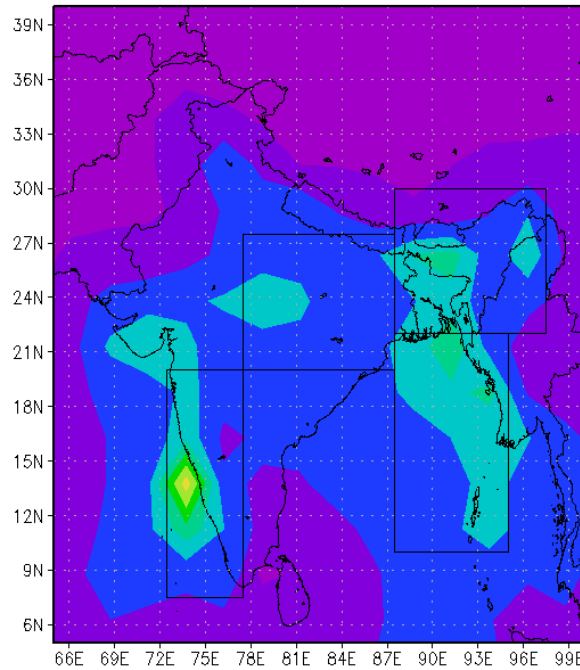
**Chen et al.**



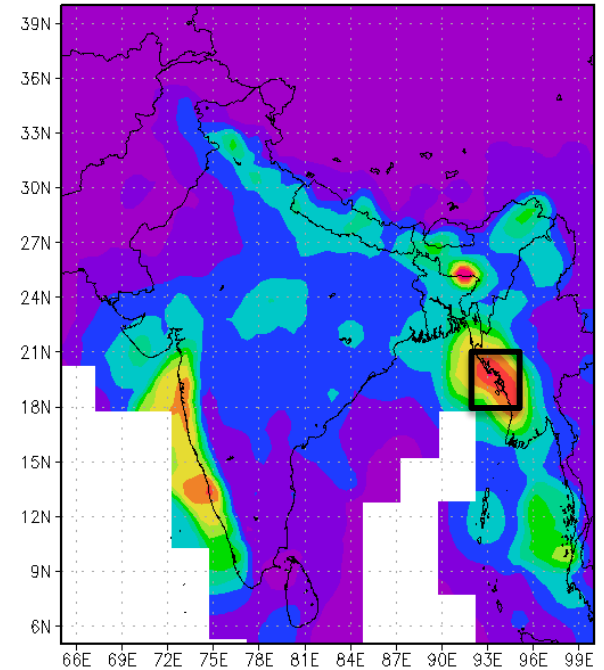
# 1979-2009 JJAS Rainfall St. Dev.



CMAP



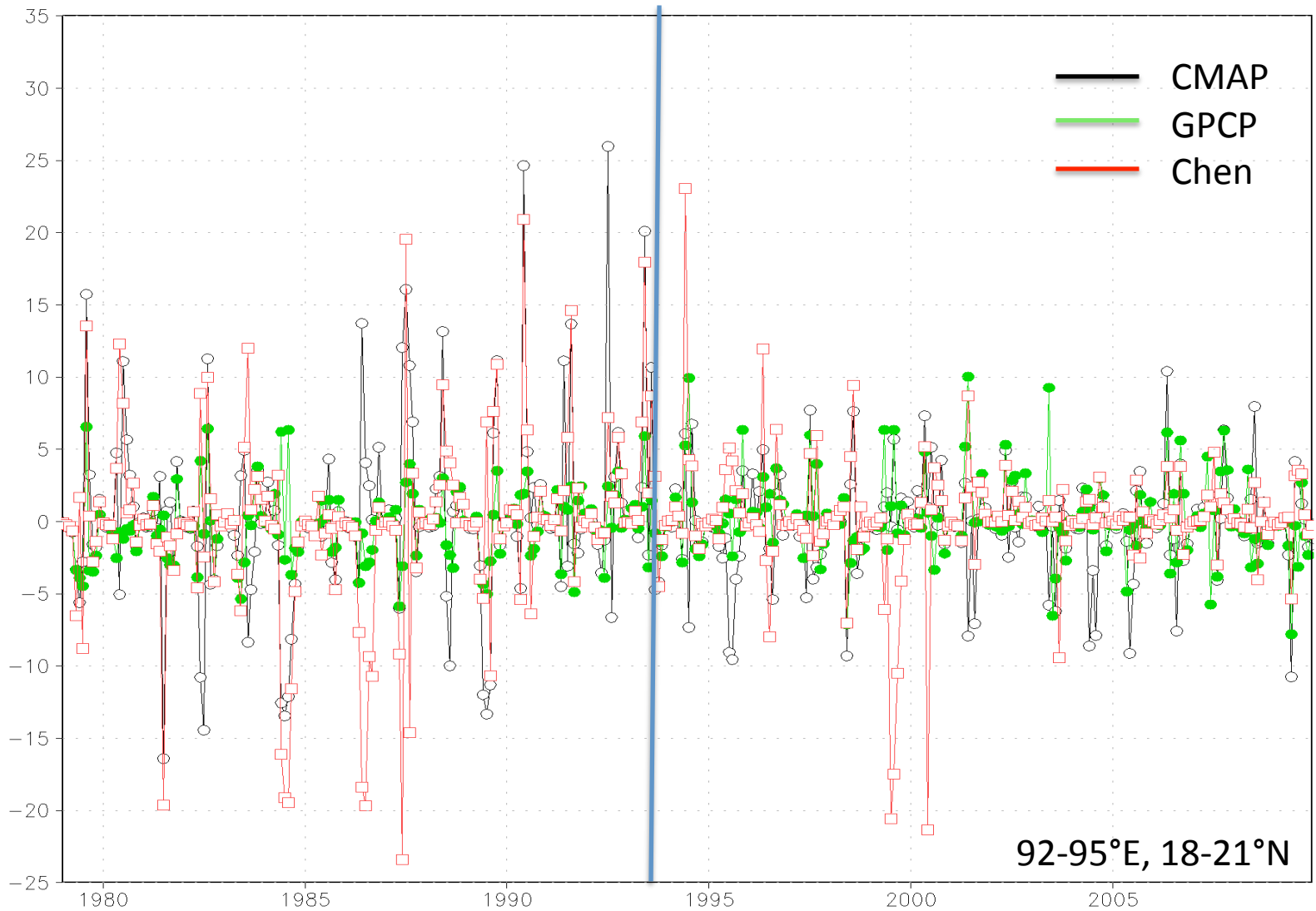
GPCP



Chen et al.

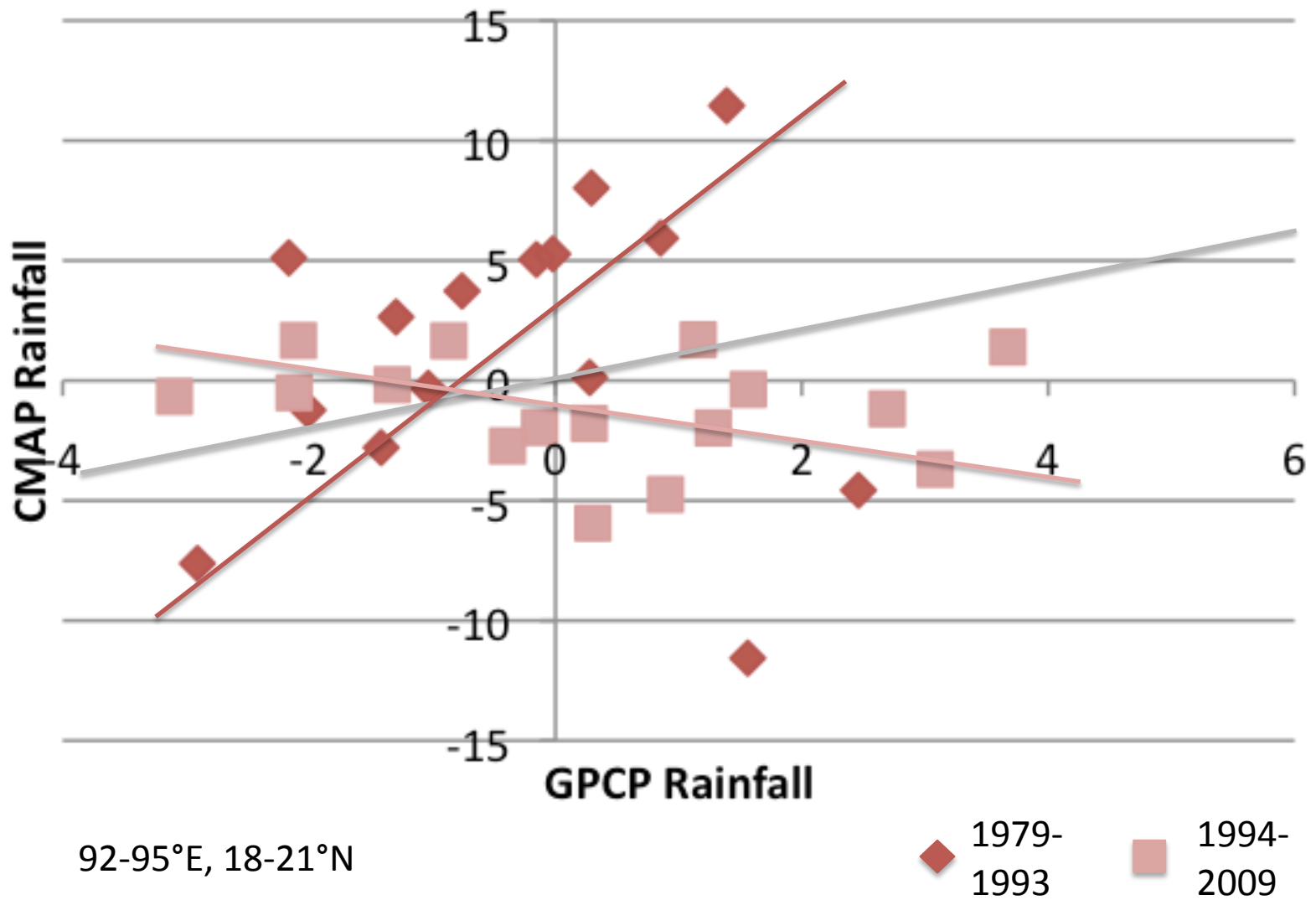


# Myanmar Rainfall

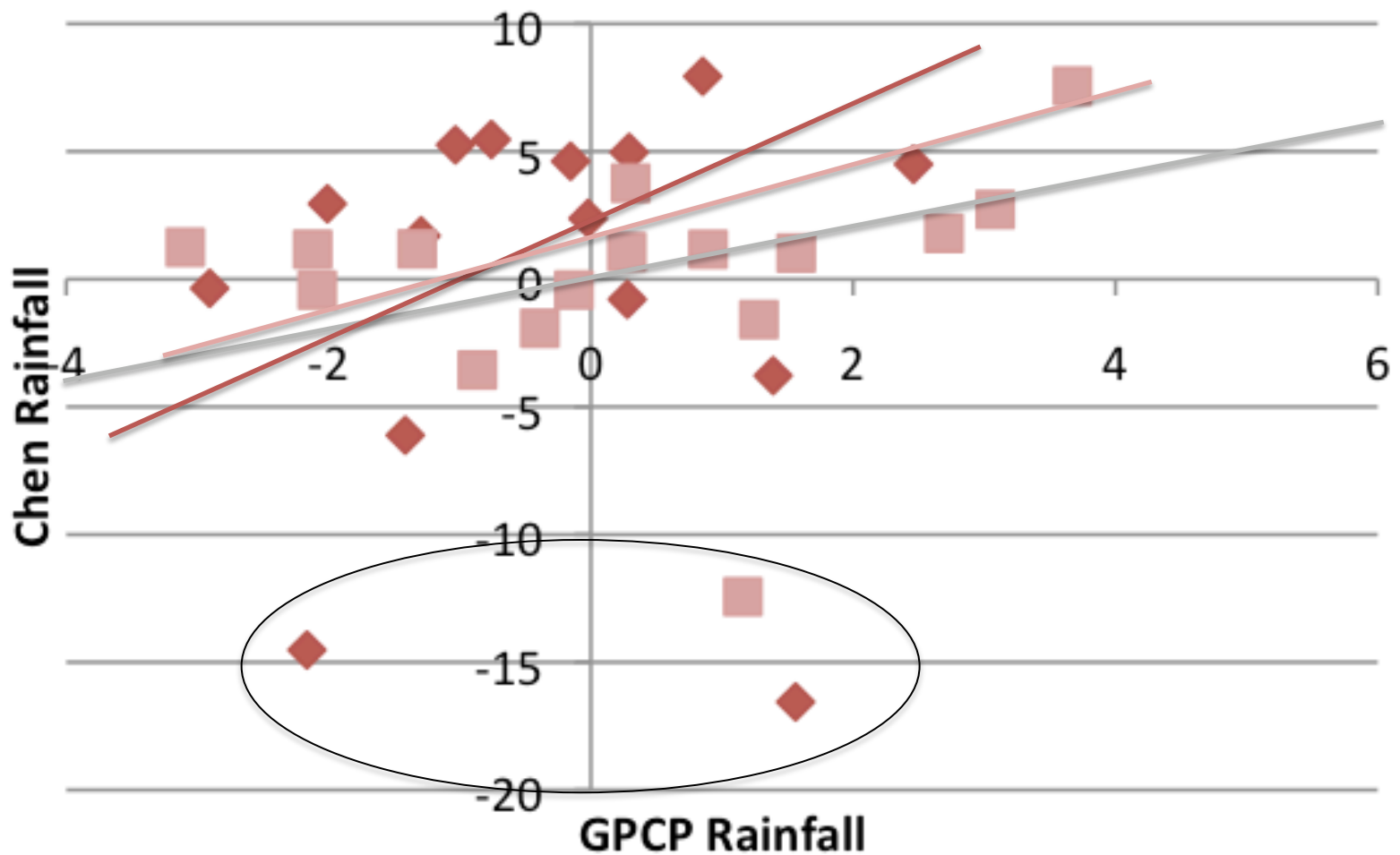




# Myanmar Rainfall Comparison



# Myanmar Rainfall Comparison



92-95°E, 18-21°N

◆ 1979-1993  
■ 1994-2009

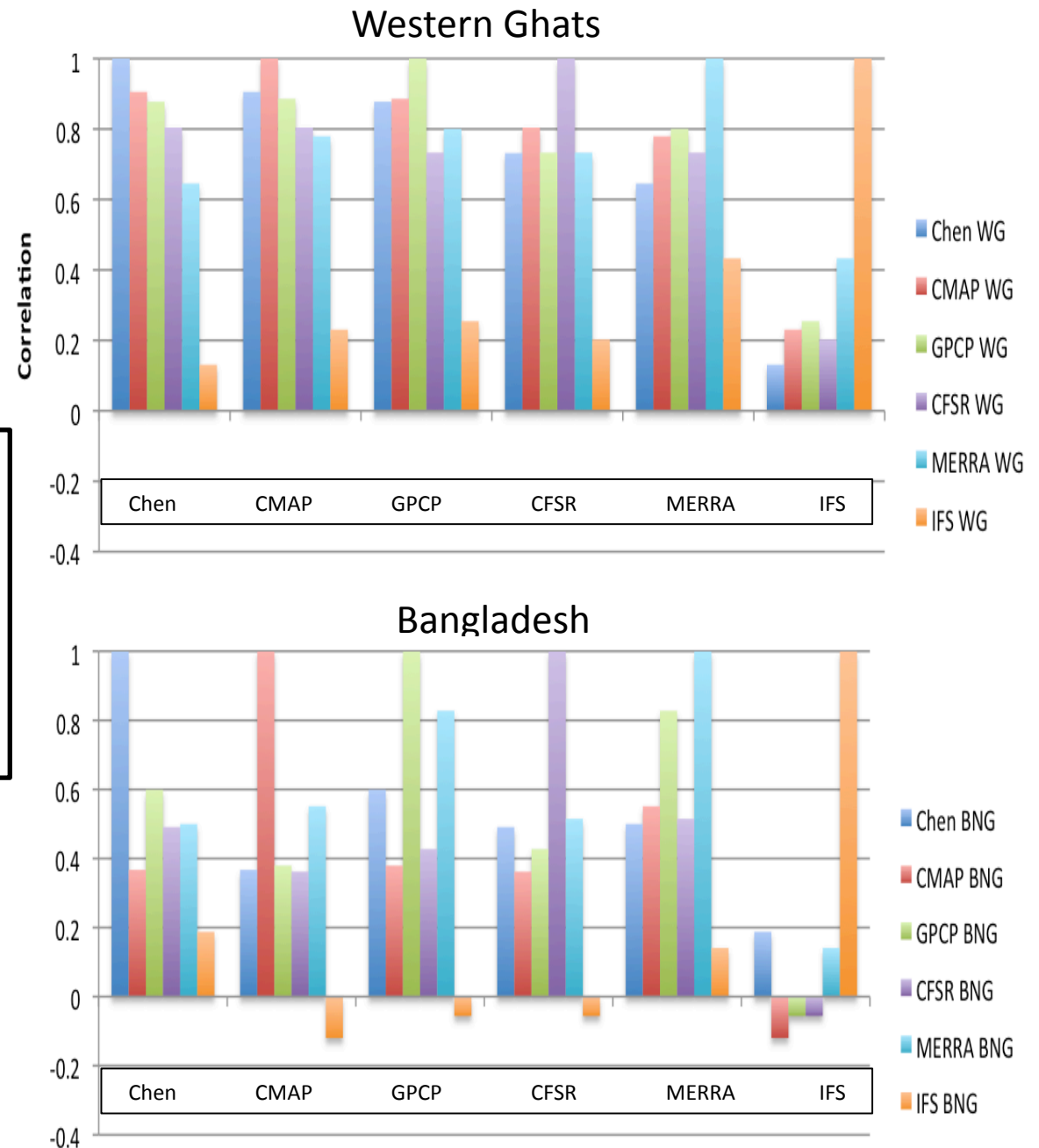
# What's Going On?

- There is an abrupt change in the CMAP data between 1993 and 1994, reducing its overall variability.
- Slope of relationship with GPCP also changes sign?
- Variability in Chen data generally exceeds that of GPCP, but uniformly over period
- Gauge availability and quality vary greatly by time period in SE Asia
- Differences likely due to specific gauges included, but difficult to be certain

*Many thanks to Phil Arkin and Pingping Xie*

# Correlation Between Rainfall Products

- Rainfall index calculated for each rainfall product
- Correlated with indices for each other product

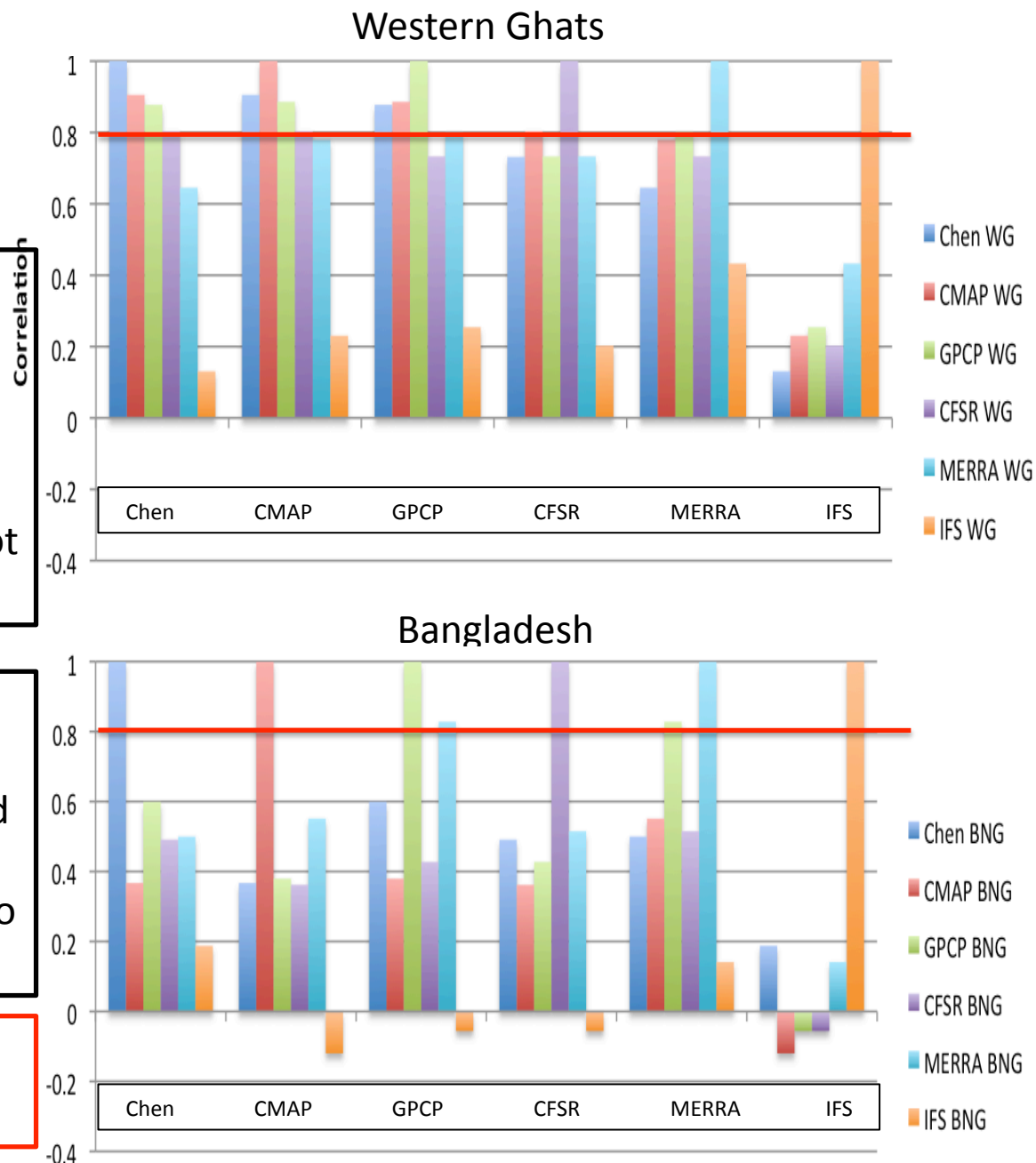


# Correlation Between Rainfall Products

- Good agreement for Western Ghats
- Stronger agreement for observational products
- Simulations are clear outlier – do not capture interannual variability

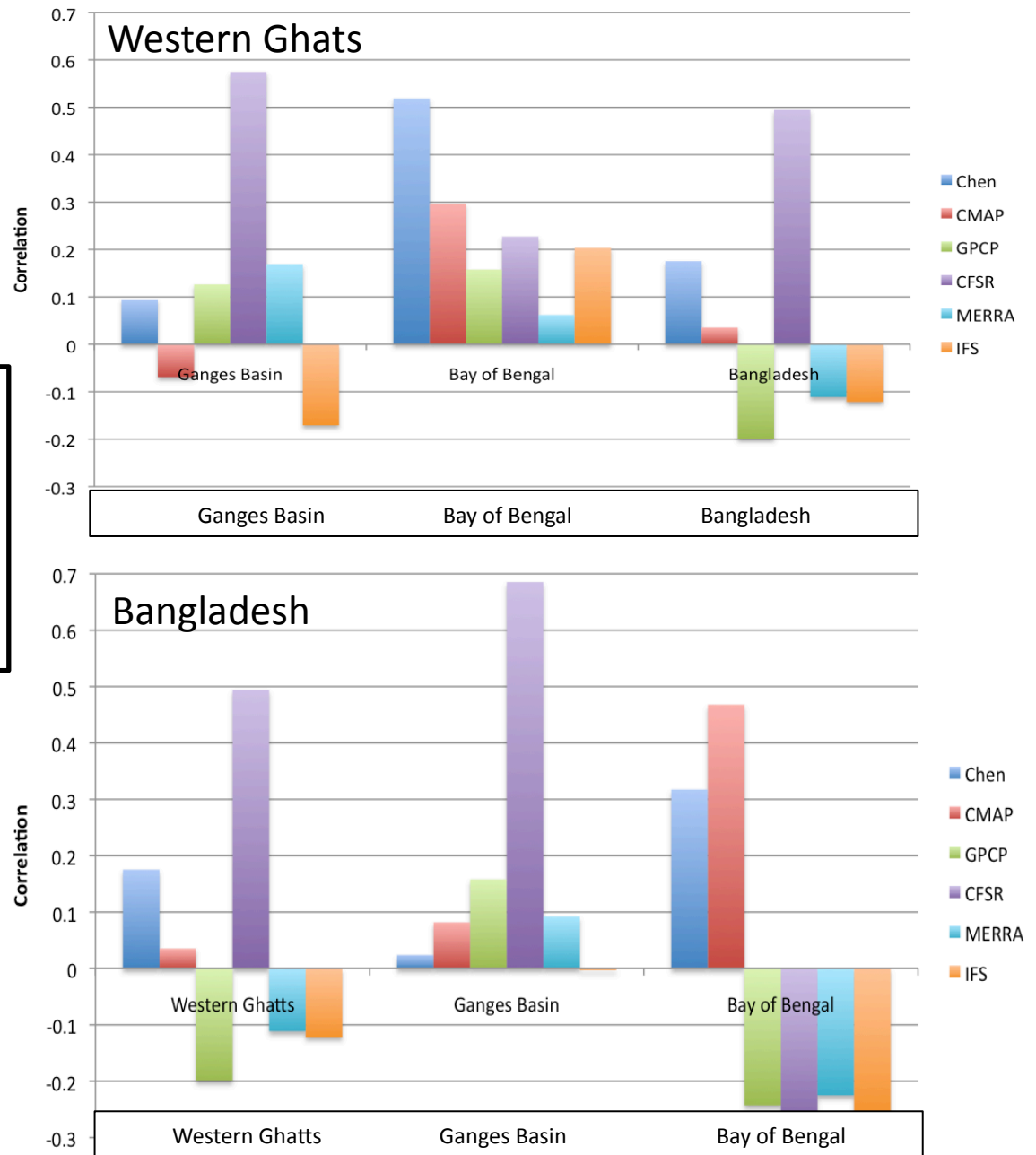
- Poor agreement for Bangladesh
- MERRA and GPCP closely correlated
- Simulations remain clear outlier – do not capture interannual variability

**Strong regional dependence of product uncertainty**



# Correlation Between Regions

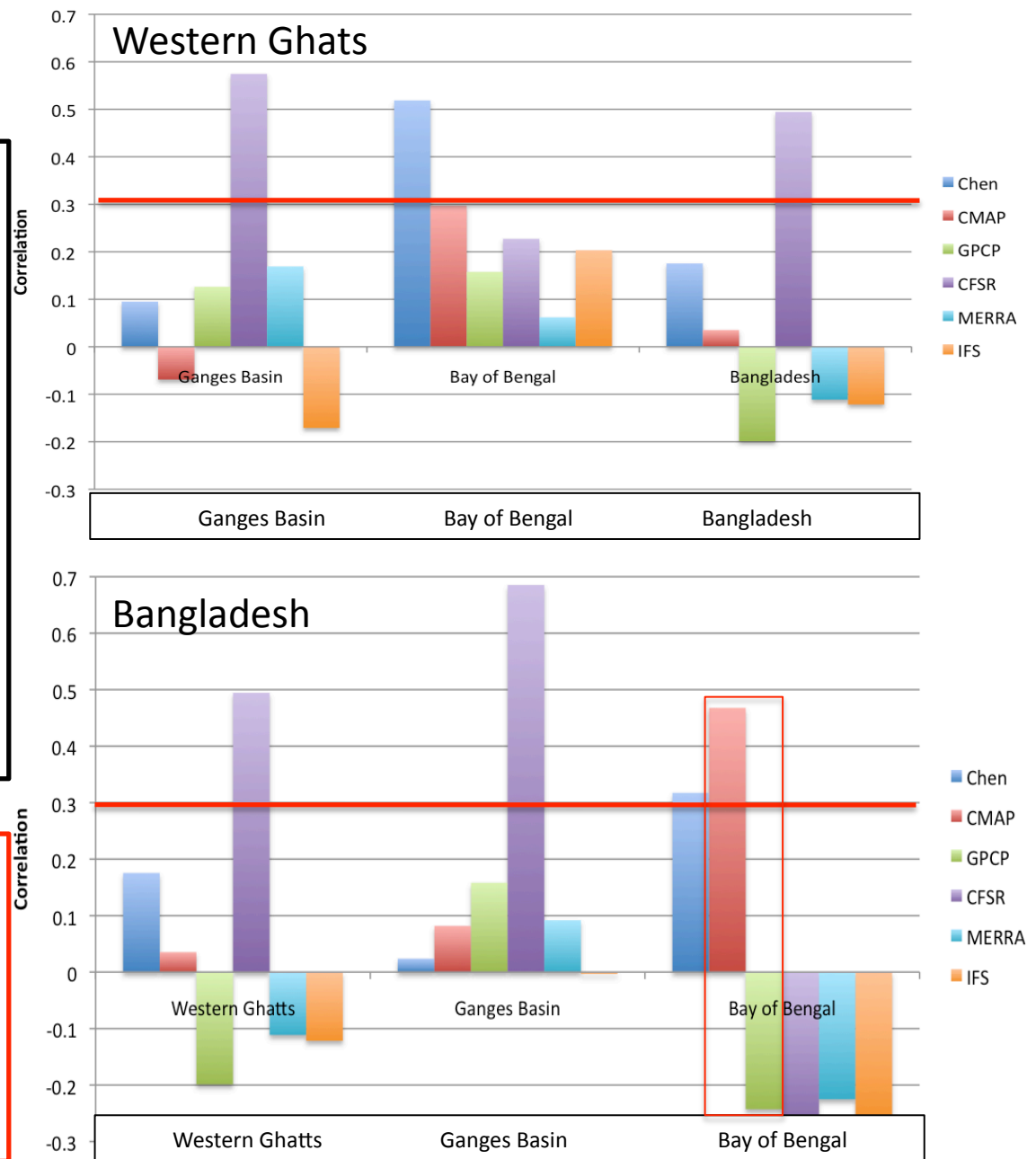
- Rainfall index calculated for each region
- Correlated with indices for each other region



# Correlation Between Regions

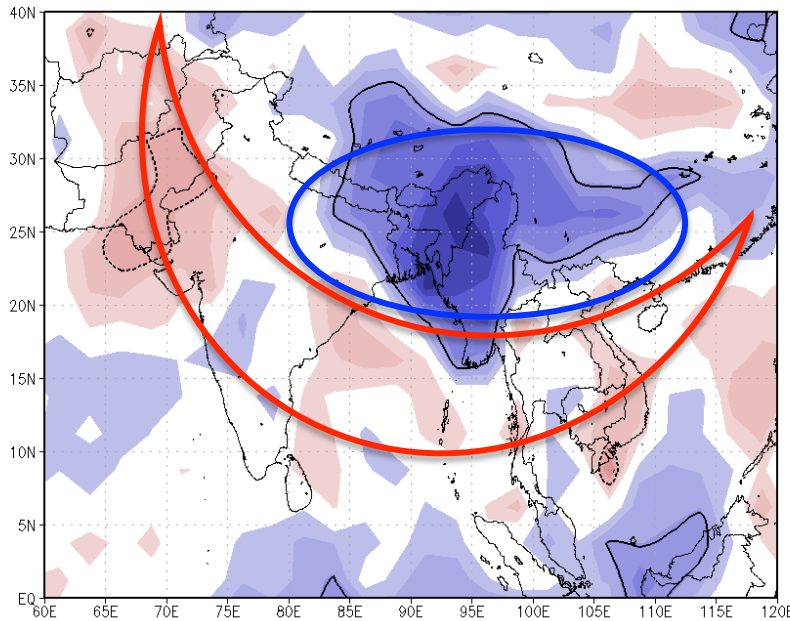
- Correlations between regions are weak for most products ( $< 0.3$ )
- CFSR is a clear outlier, with strong positive correlations between most regions
- IFS is NOT an outlier in this metric
- CMAP and GPCP disagree on the sign of the correlation between Bay of Bengal and Bangladesh regions

- Regions are generally independent
- Results can be sensitive to product
- Simulations more accurate than some reanalyses

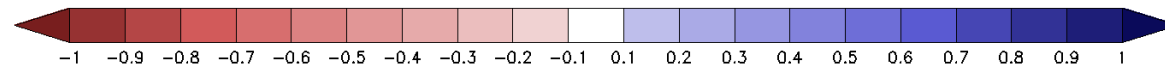
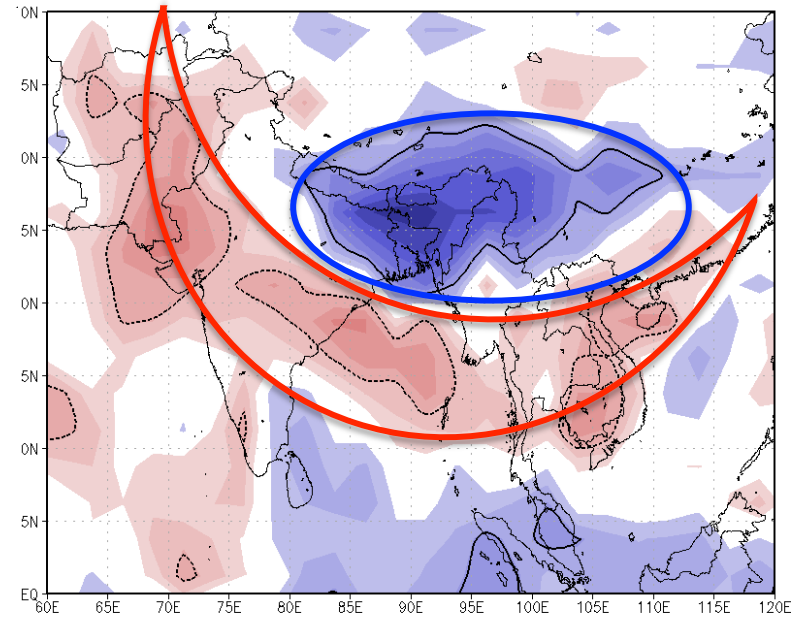


# Regional JJAS Rainfall Correlations

## BNG - CMAP



## BNG - GPCP

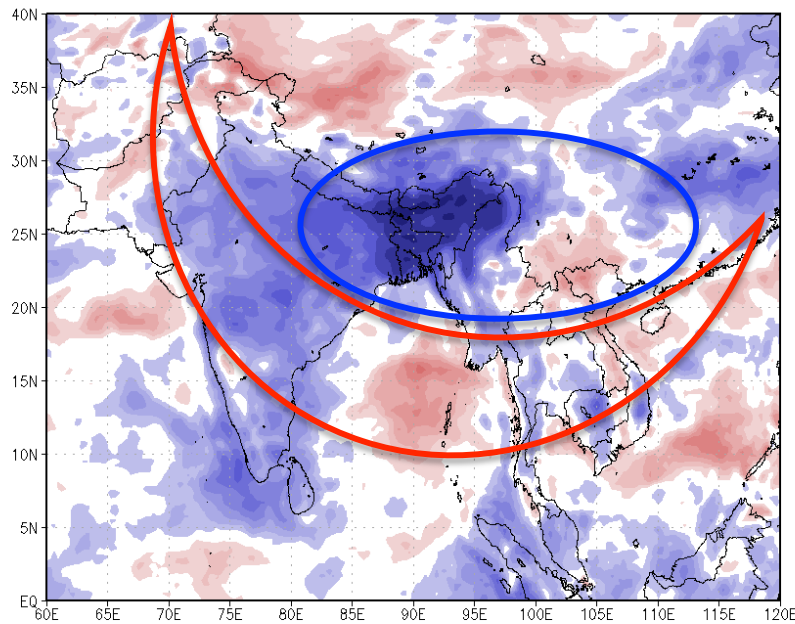


CMAP BNG precipitation includes all of Myanmar  
BNG and BOB almost uncorrelated in GPCP

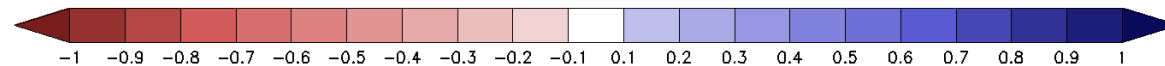
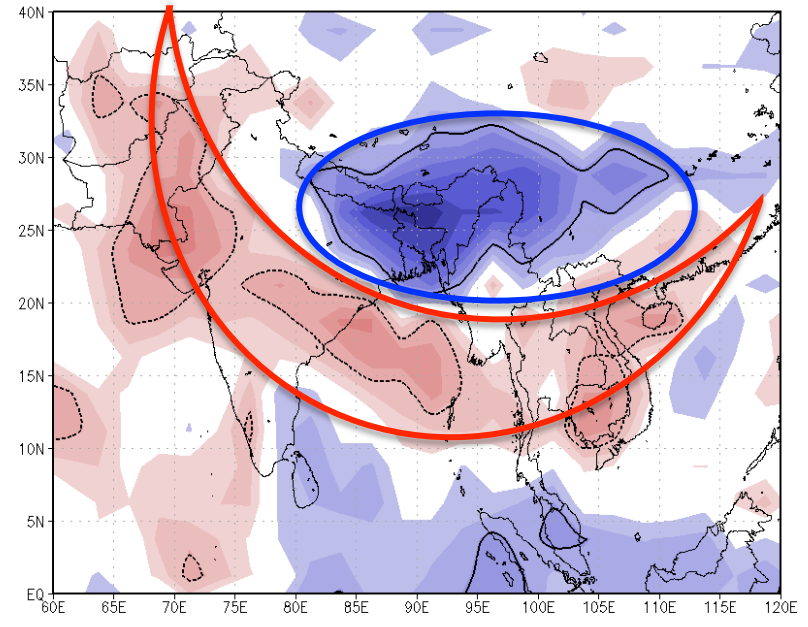


# Regional JJAS Rainfall Correlations

## BNG - CFSR



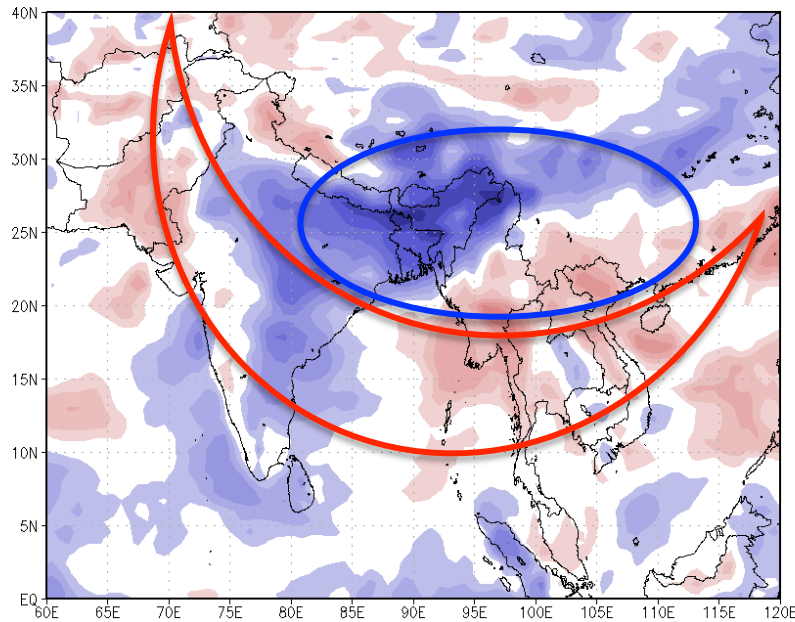
## BNG - GPCP



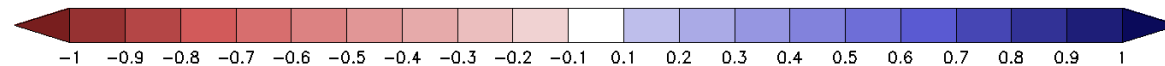
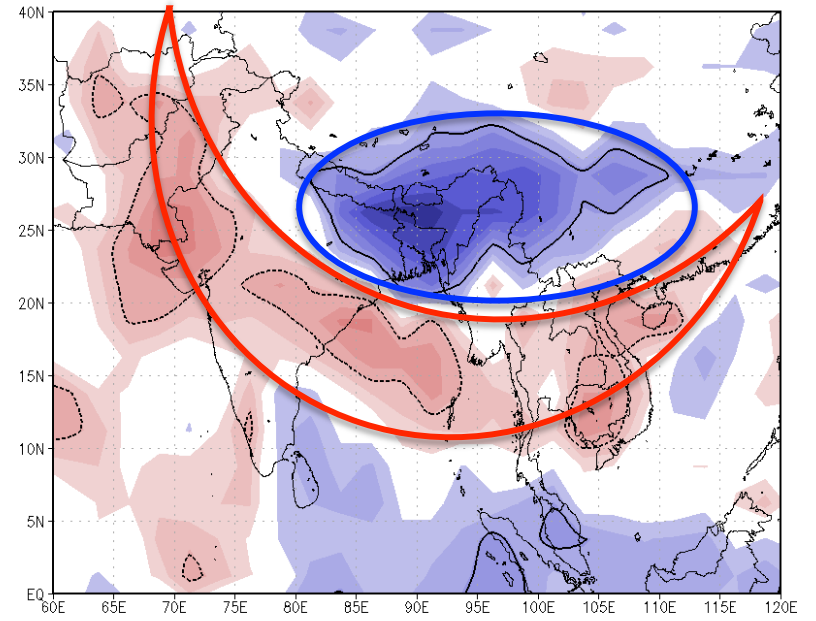
**CFSR BNG precipitation strongly correlated with rainfall across entire region**

# Regional JJAS Rainfall Correlations

## BNG – ERA/I



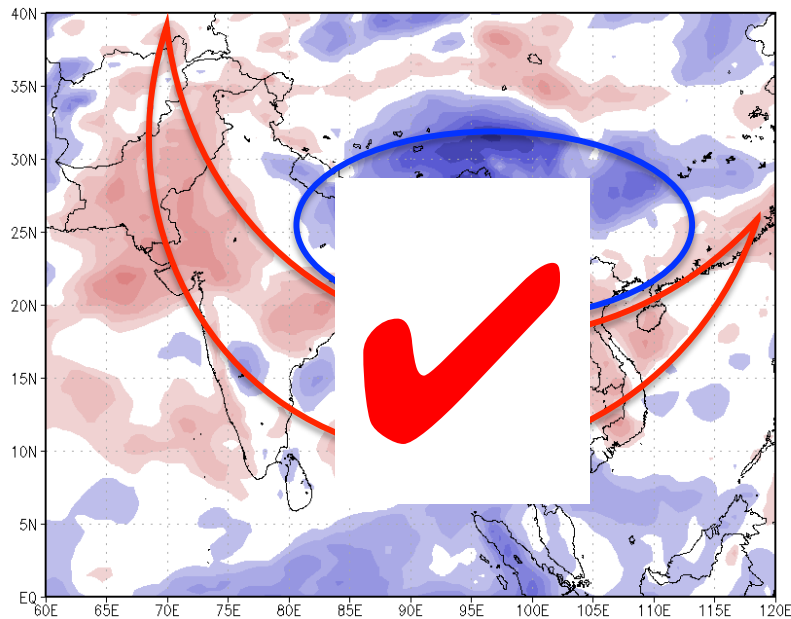
## BNG - GPCP



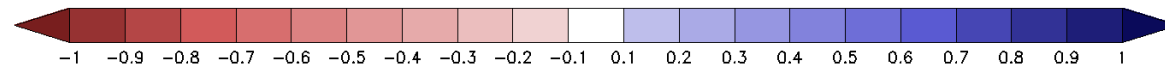
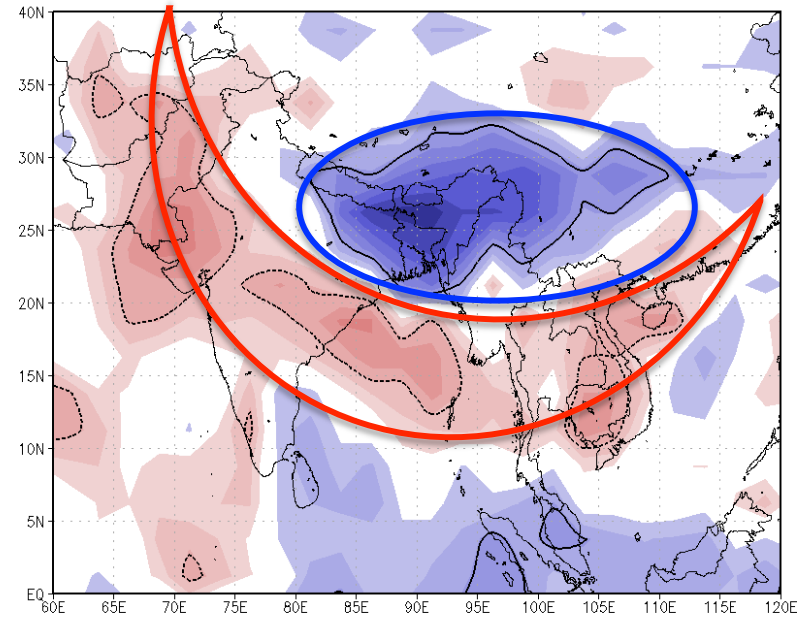
ERA/I BNG precipitation also broadly correlated across Ganges Basin

# Regional JJAS Rainfall Correlations

## BNG - MERRA



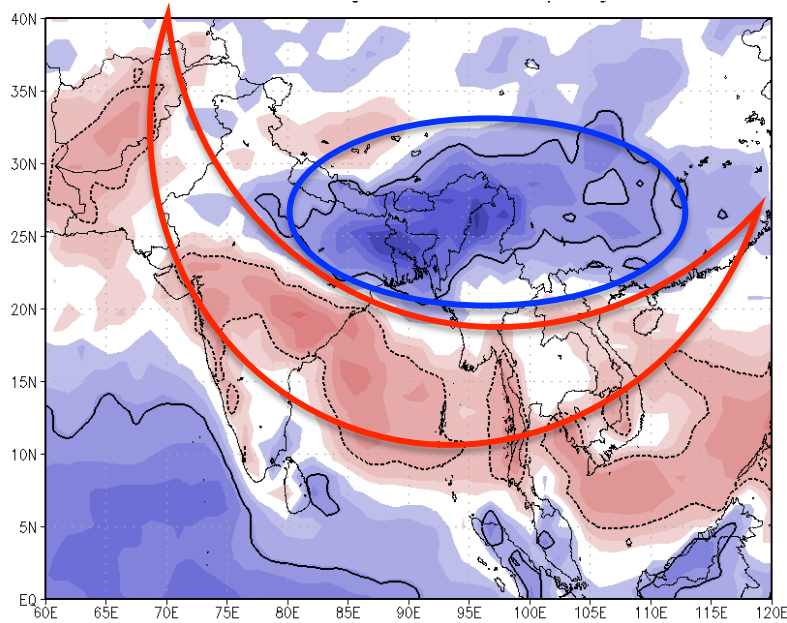
## BNG - GPCP



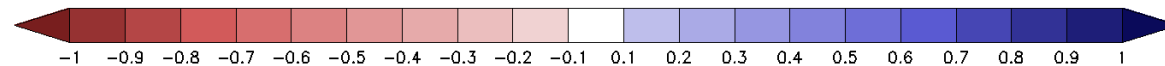
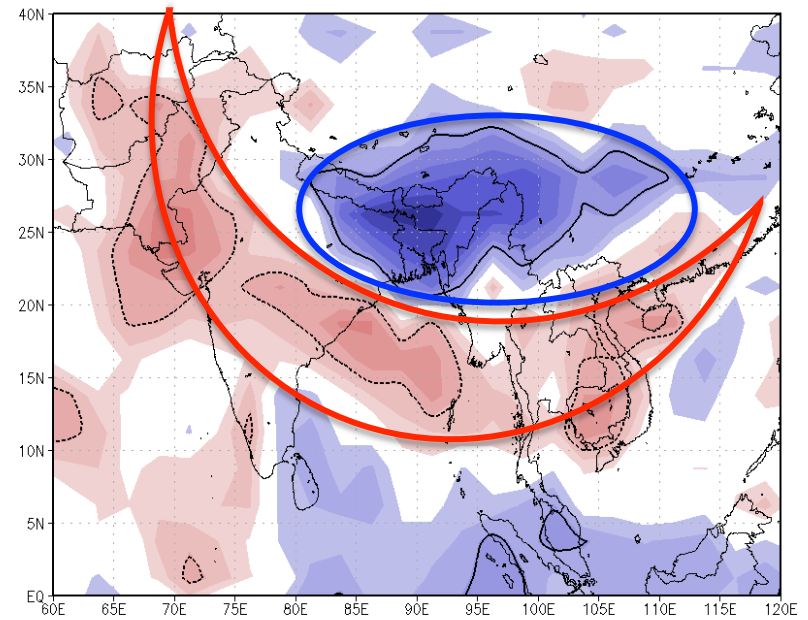
MERRA matches GPCP almost perfectly

# Regional JJAS Rainfall Correlations

## BNG - IFS



## BNG - GPCP



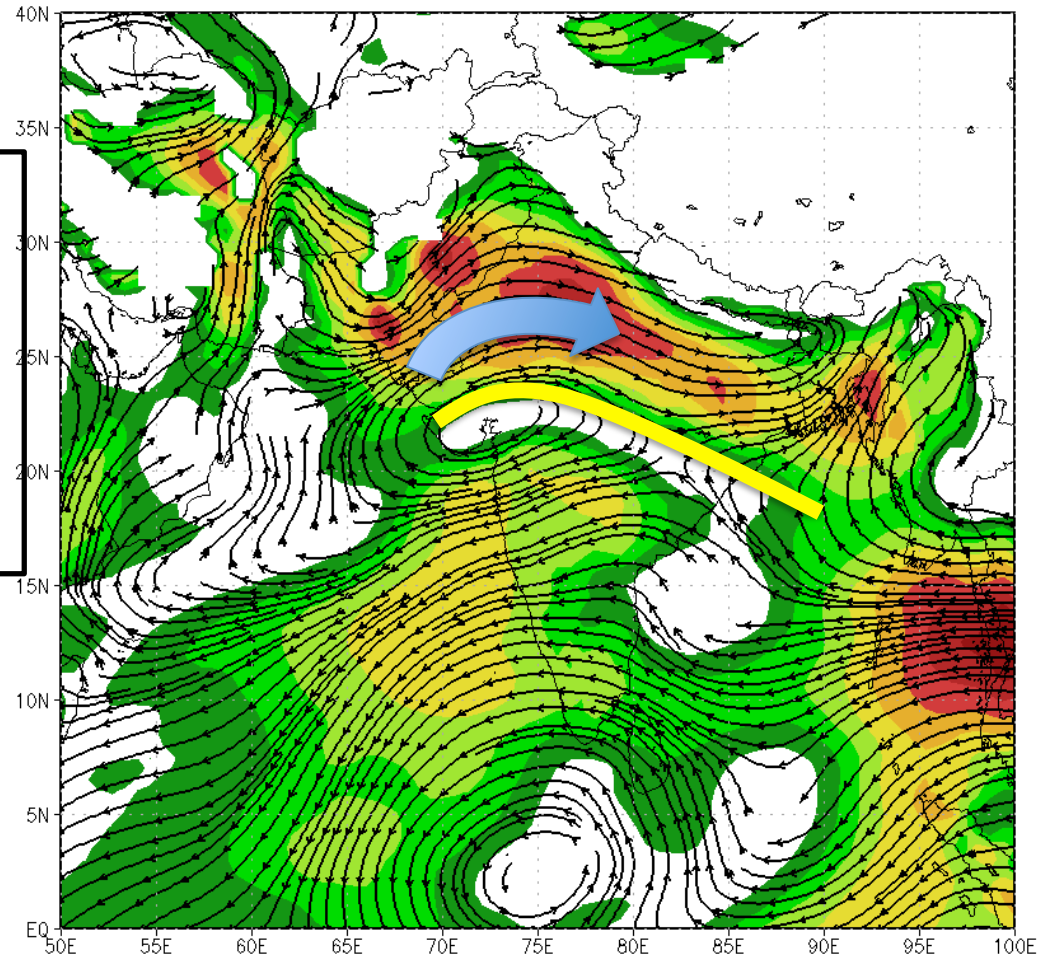
**IFS BNG precipitation closer to GPCP in structure than CFSR/ERA-I/CMAP**

# 850 hPa Circulation Regression

BNG: MERRA winds regressed on MERRA precip

Enhanced BNG precipitation due to enhanced flow along foothills of Tibetan Plateau

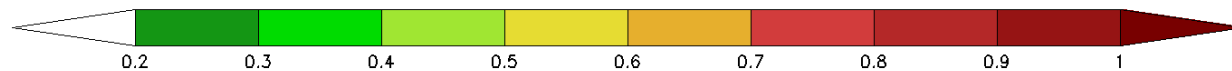
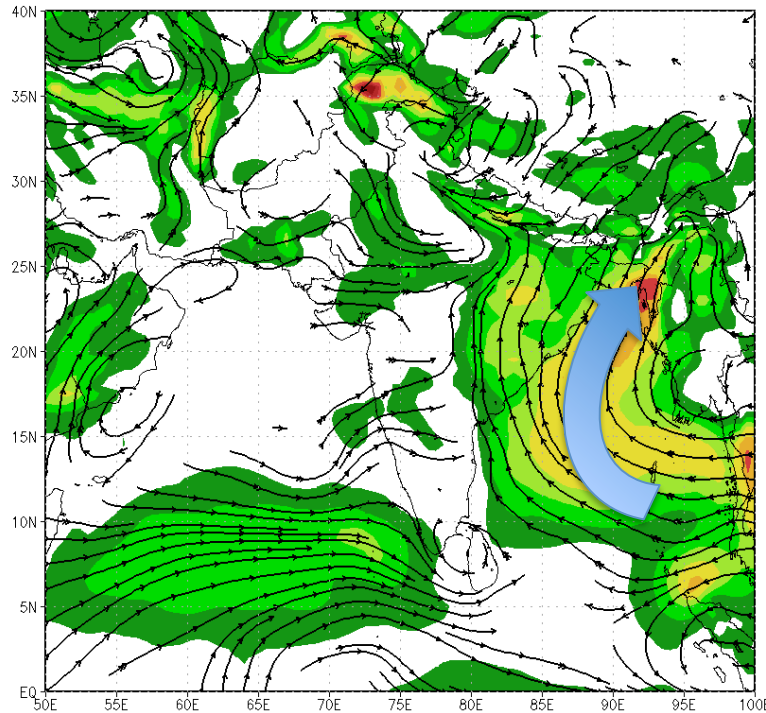
Similar to mechanism identified previously using pacemaker version of COLA AGCM





# 850 hPa Circulation Regression

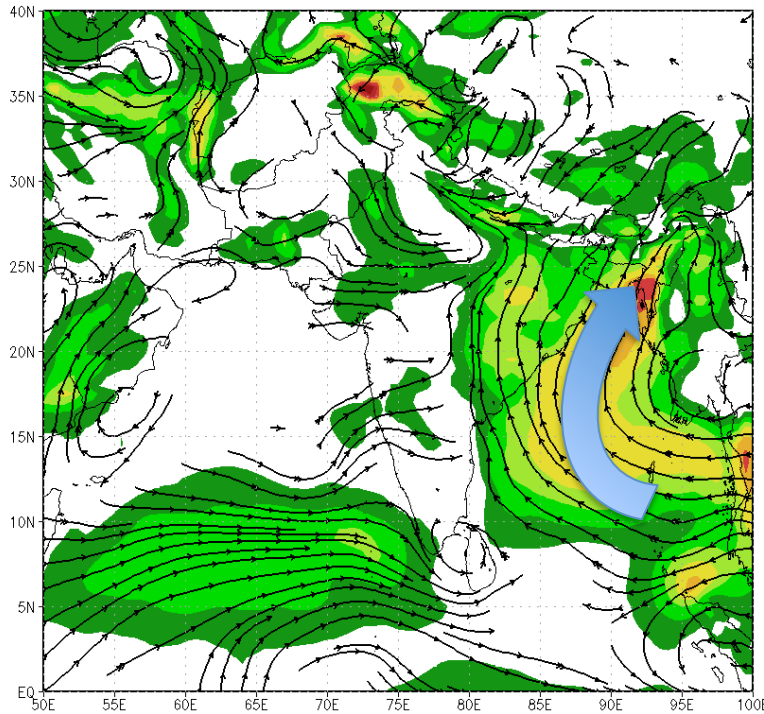
**BNG: CFSR winds regressed on  
CFSR precip**



1979-2009

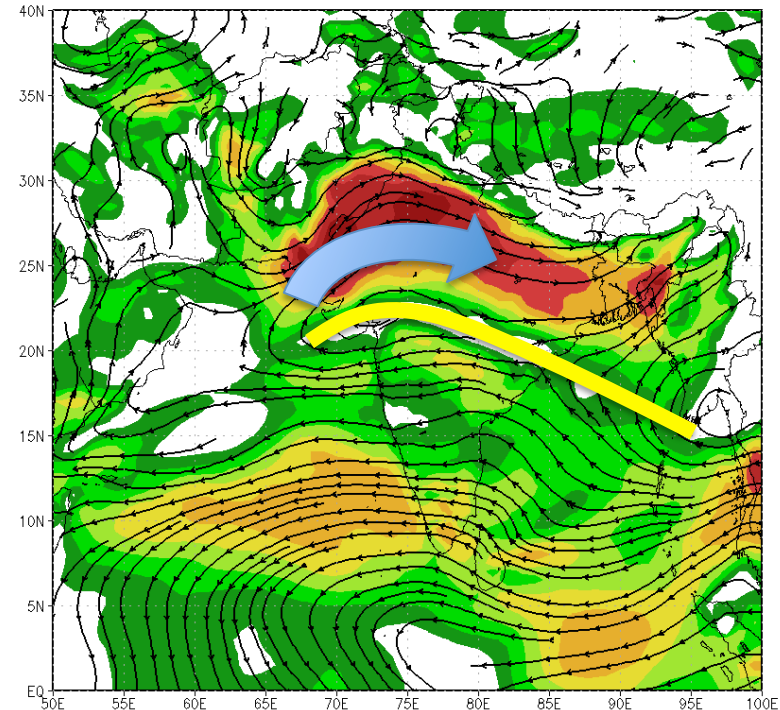
# 850 hPa Circulation Regression

**BNG: CFSR winds regressed on CFSR precip**



1979-2009

**BNG: CFSR winds regressed on GPCP precip**

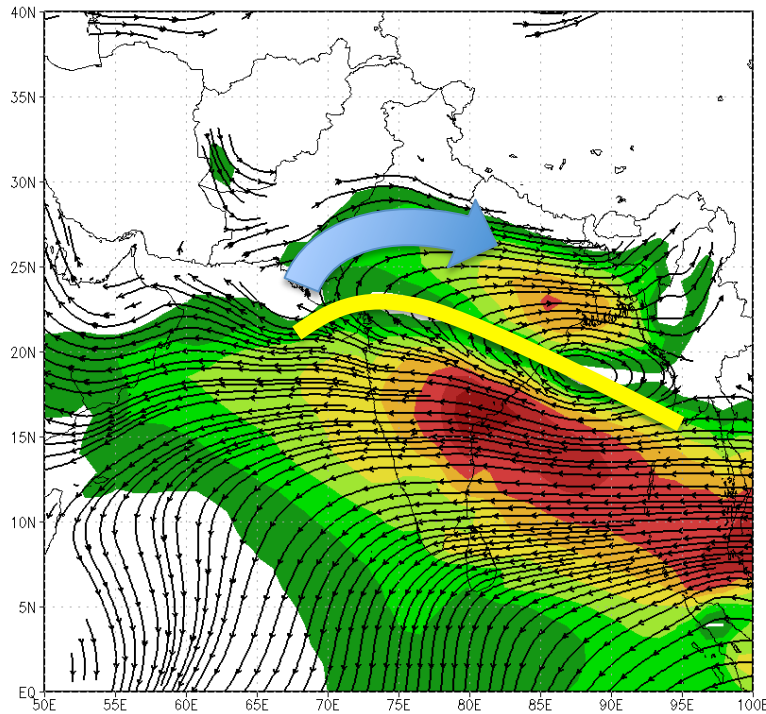


1979-2009

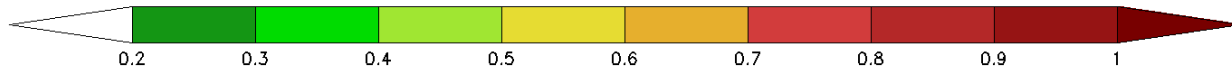
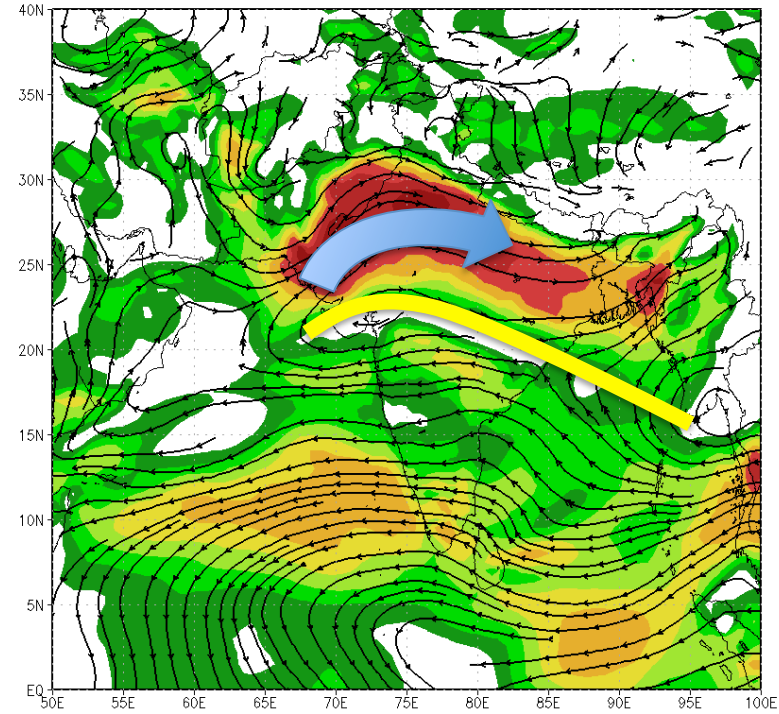
CFSR BNG precipitation associated with northward flow off Bay of Bengal  
Regressing against GPCP precipitation recovers pattern from MERRA

# 850 hPa Circulation Regression

**BNG: IFS winds regressed on IFS precip**



**BNG: CFSR winds regressed on GPCP precip**



1961-2007

1979-2009

IFS BNG circulation matches that of MERRA and CFSR/GPCP  
Simulations are accurate proxy for observed rainfall and circulation structure



# Summary

- Significant disagreements among observational estimates of monsoon rainfall structure
  - Largely due to data-sparse regions such as Myanmar and Bangladesh
- Significant disagreements among reanalyzed estimates of monsoon rainfall structure
  - CFSR and ERA-I overestimate spatial correlation extent
  - MERRA rainfall structure is indistinguishable from GPCP/CMAP
- Observed products generally show distinct, independent centers of rainfall variability
  - expansion of previous studies beyond India
- Significant differences among estimates of anomalous monsoon circulation
  - Northward flow from Bay of Bengal: CFSR and ERA-I
  - Eastward flow along Tibetan Plateau: MERRA and IFS
- Regressing against observed precipitation unifies estimated circulation
  - CFSR/ERA-I circulation patterns improved by regressing against observed precip
  - Erroneous precip is being driven by correct winds
- Models can be more faithful to the best observational estimates than reanalysis!
  - IFS rainfall and circulation structure indistinguishable from GPCP/MERRA
  - Reliable tool for diagnosing structure and circulation patterns... but not totals