# Asian Summer Monsoon Changes in CMIP5 Models and Observations

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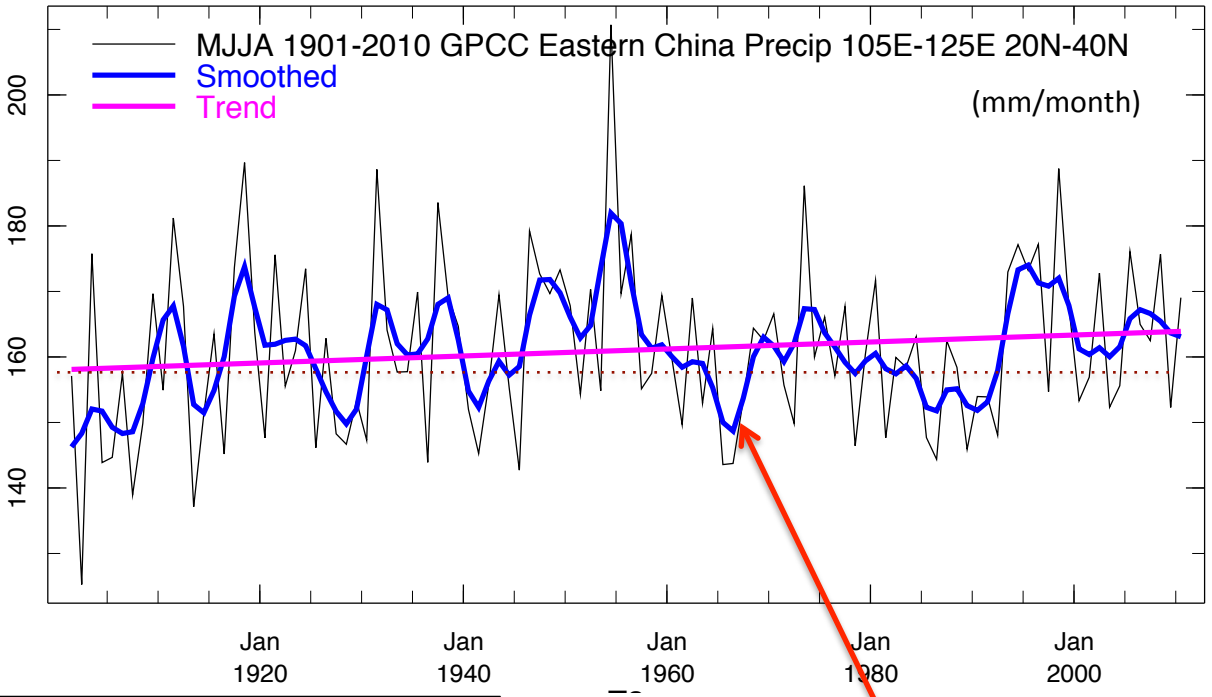
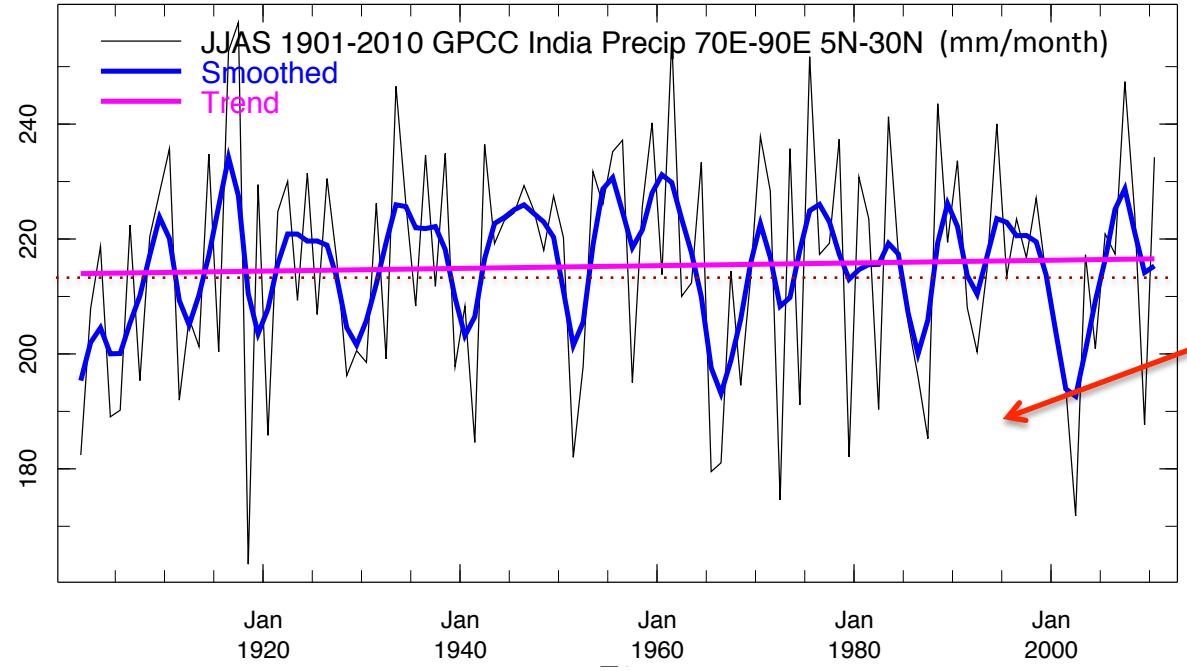
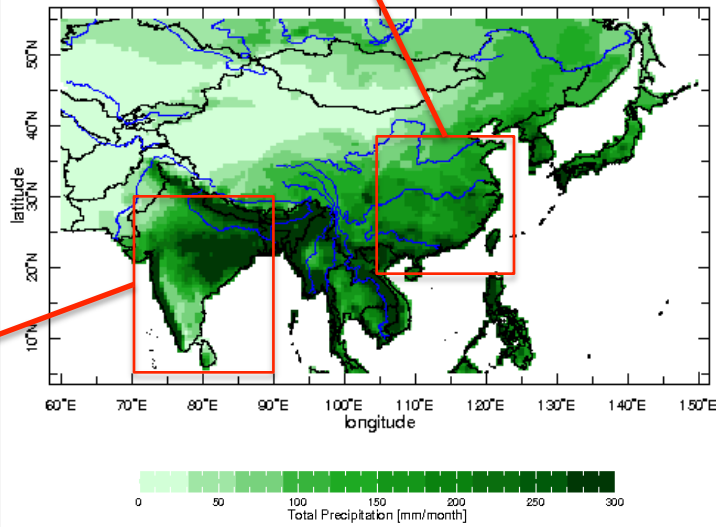
# Observed Asian Monsoon Variability and Change GPCC 1901-2010

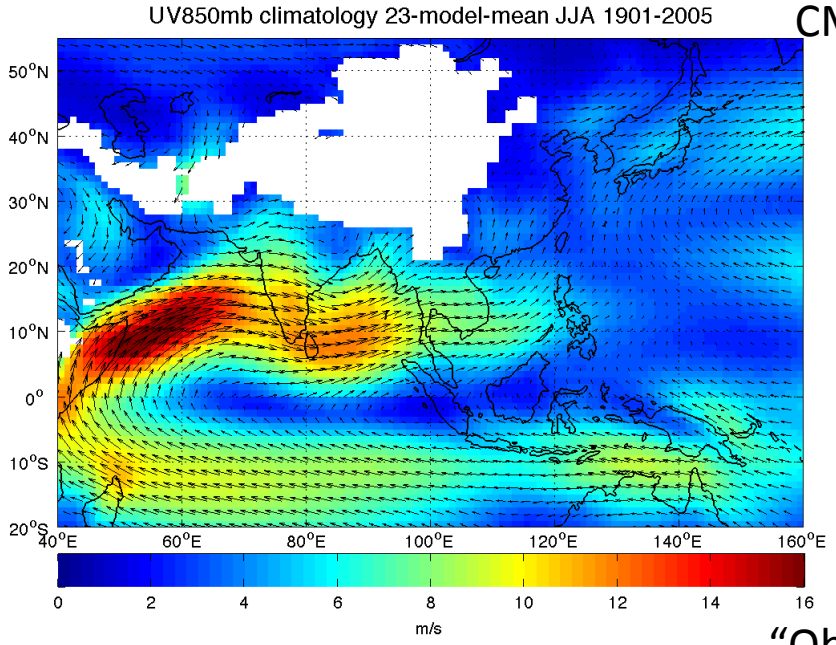
- There is a slight positive trend over the past 110 years in both India and Eastern China
- Llarge interannual and decadal variations
- Are there any detectable anthropogenic signals?



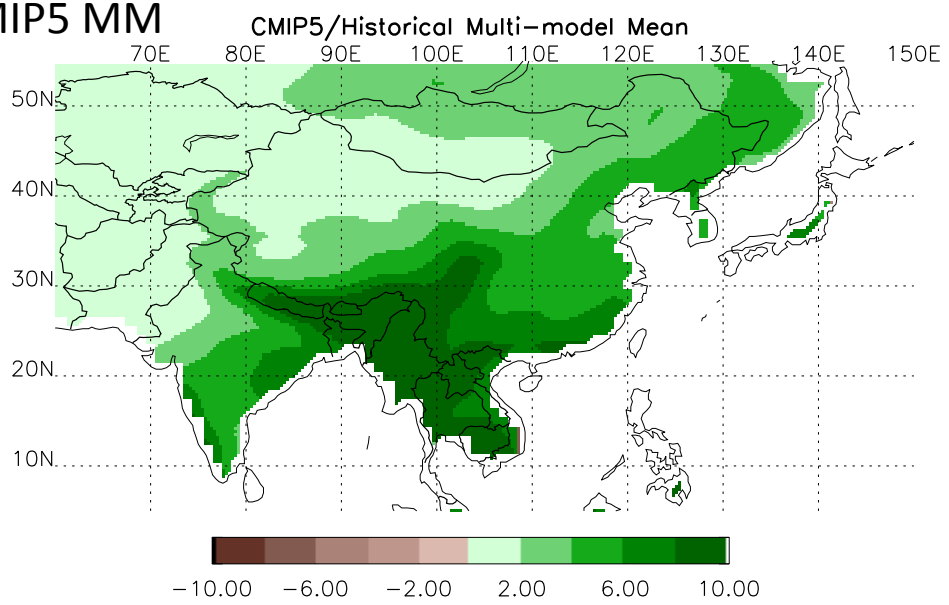



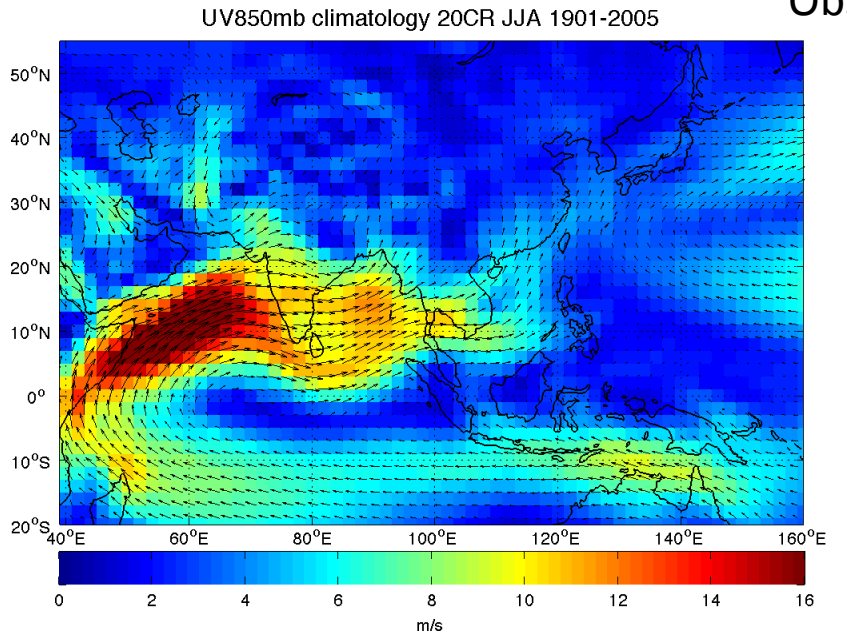
# CMIP5 Model Simulation of the Asian Monsoon

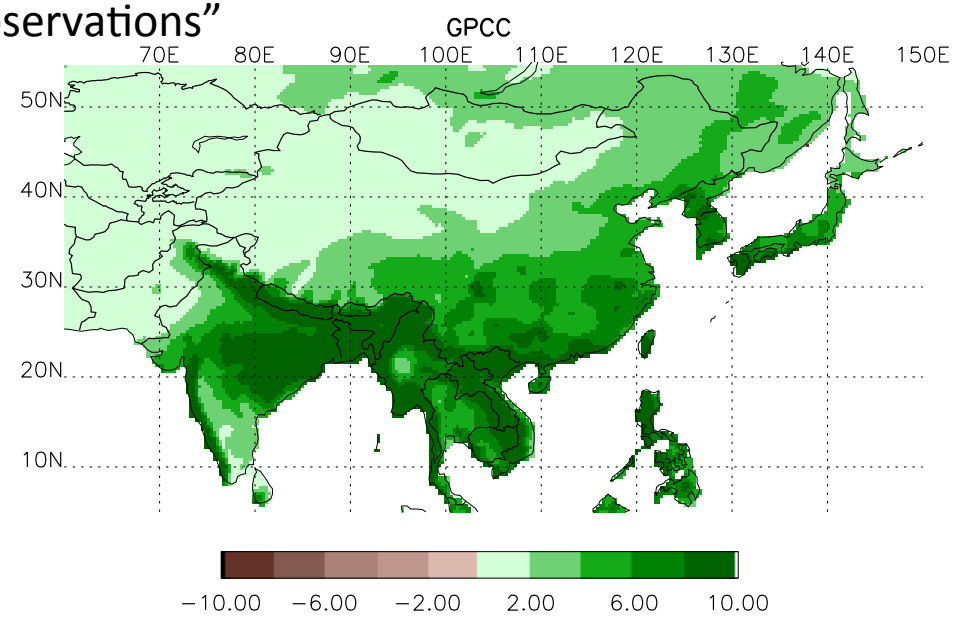



CMIP5 MM

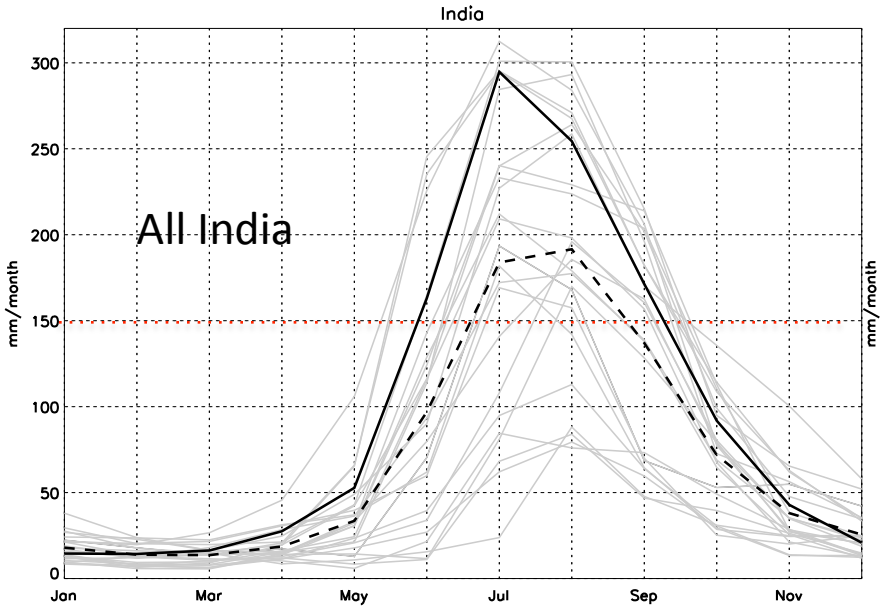


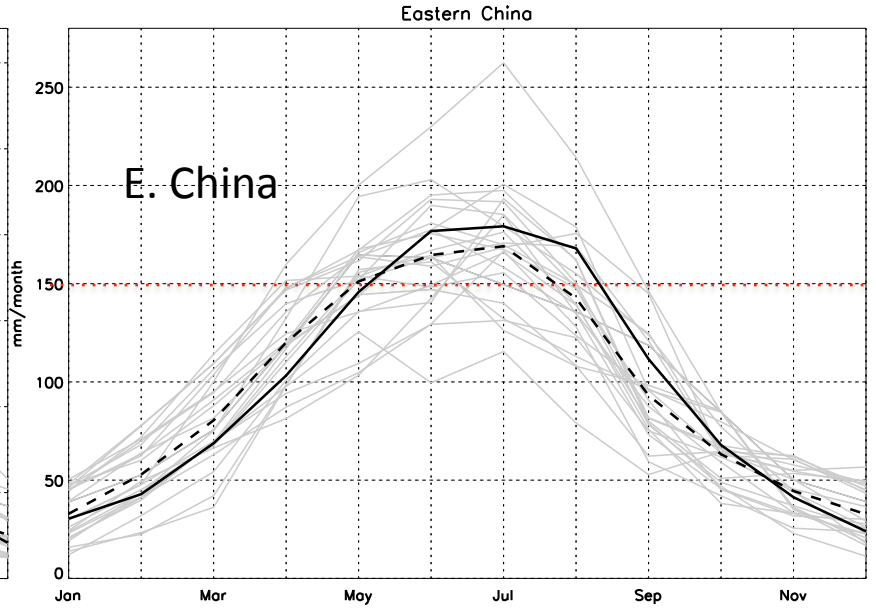

"Observations"



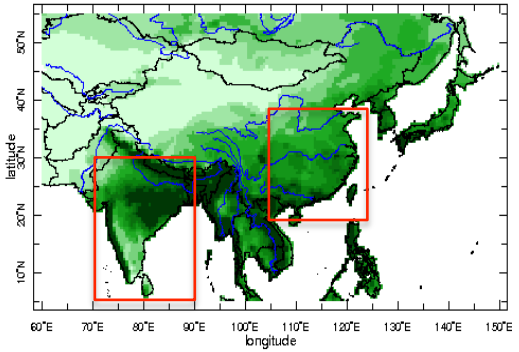



# CLIMATOLOGICAL MEAN SEASONAL CYCLE OF INDIAN AND EASTERN CHINA MONSOONS
# GPCC vs. MODELS (1950-2000)

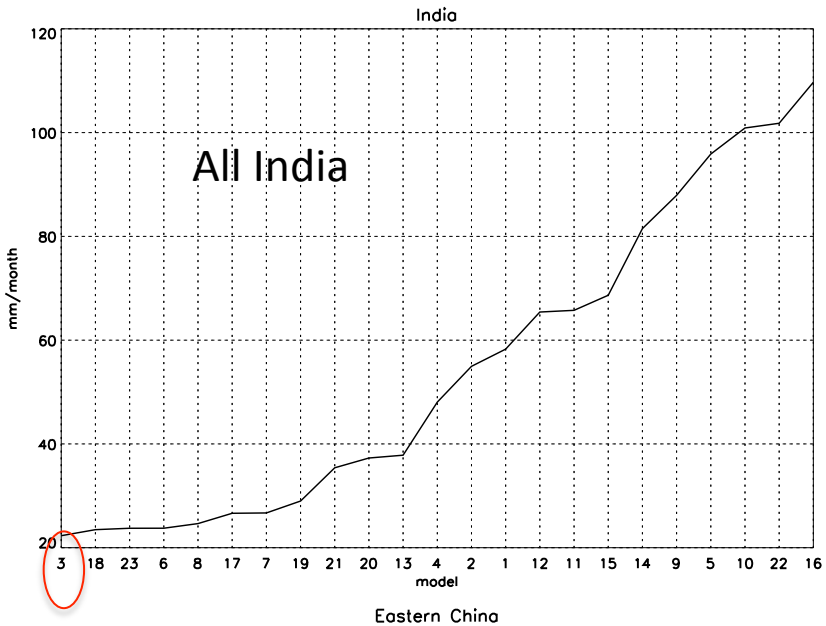


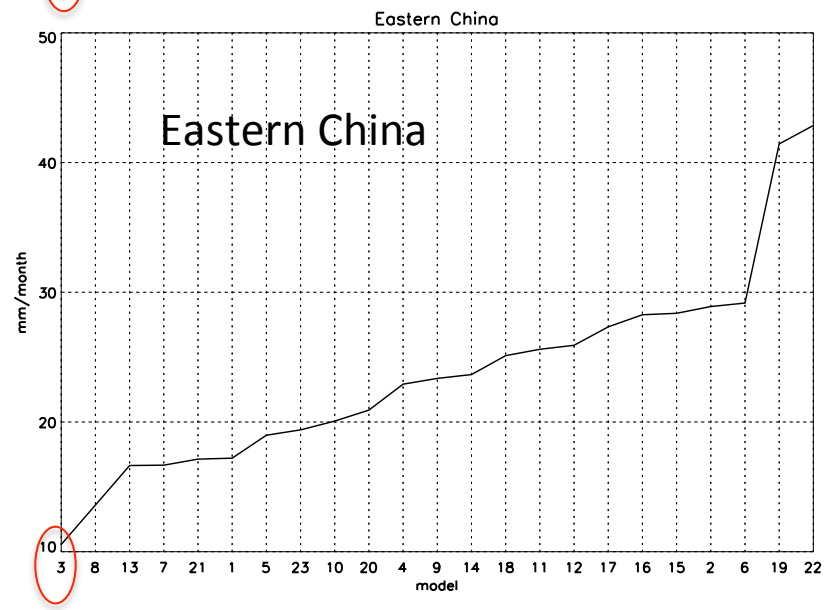




Solid line: GPCC
Thin lines: Individual CMIP5 model simulation
Dashed line: CMIP5 multi-model mean (23 models)



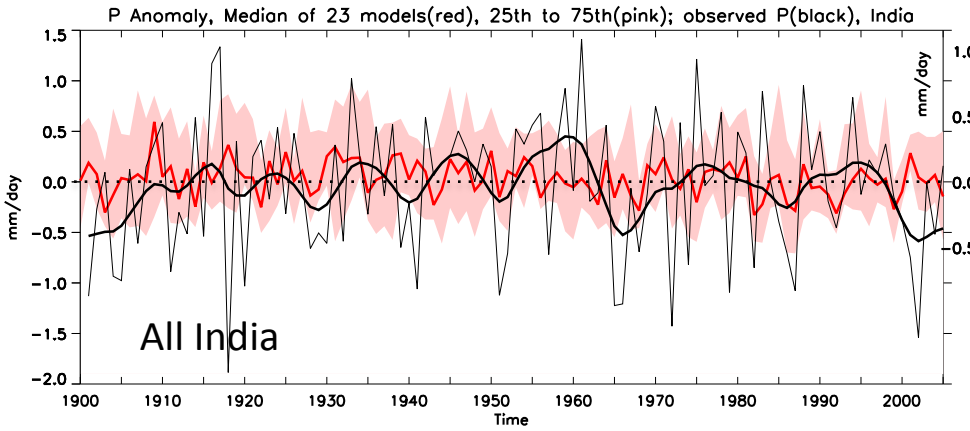
# RMS of precipitation climatology between CMIP5 Models and GPCC (1950-2000)

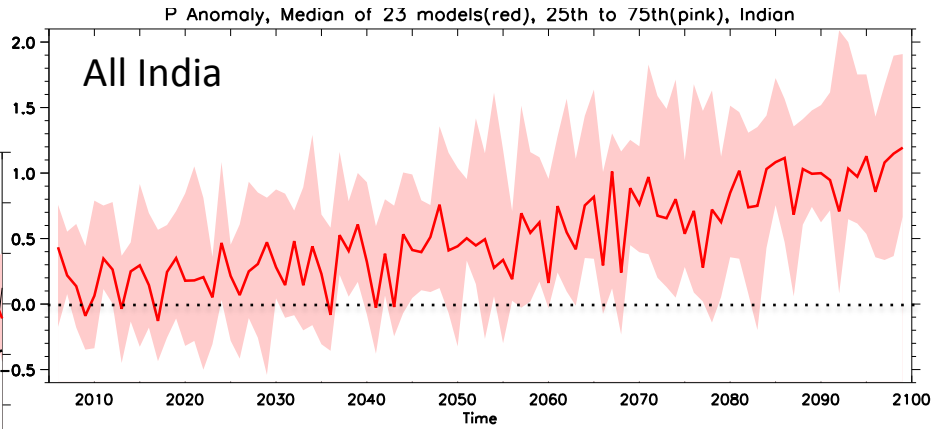


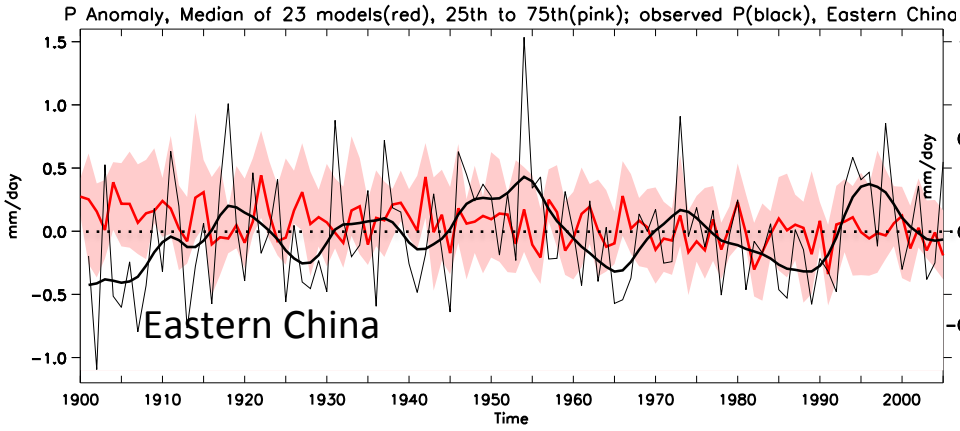



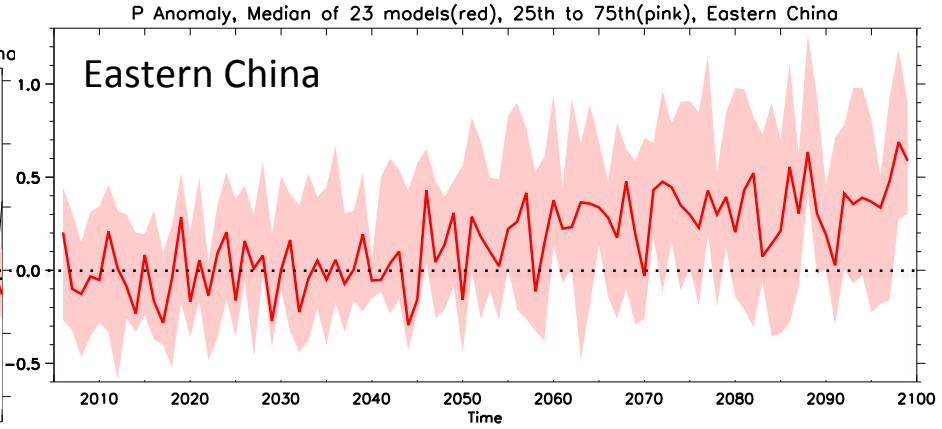

| number | CMIP5 Models |
|---|---|
| 1 | bcc-csm1-1 |
| 2 | CanESM2 |
| 3 | CCSM4 |
| 4 | CNRM-CM5 |
| 5 | CSIRO-Mk3-6-0 |
| 6 | GFDL-CM3 |
| 7 | GFDL-ESM2G |
| 8 | GFDL-ESM2M |
| 9 | GISS-E2-H |
| 10 | GISS-E2-R |
| 11 | HadGEM2-CC |
| 12 | HadGEM2-ES |
| 13 | inmcm4 |
| 14 | IPSL-CM5A-LR |
| 15 | IPSL-CM5A-MR |
| 16 | IPSL-CM5B-LR |
| 17 | MIROC-ESM |
| 18 | MIROC-ESM-CHEM |
| 19 | MIROC5 |
| 20 | MPI-ESM-LR |
| 21 | MPI-ESM-MR |
| 22 | MRI-CGCM3 |
| 23 | NorESM1-M |

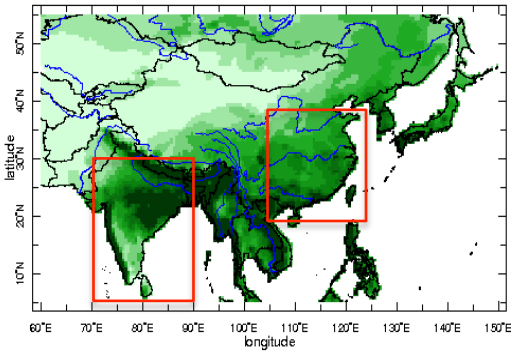
# Monsoon Rainfall Variability and Change: CMIP5 Models vs. GPCC



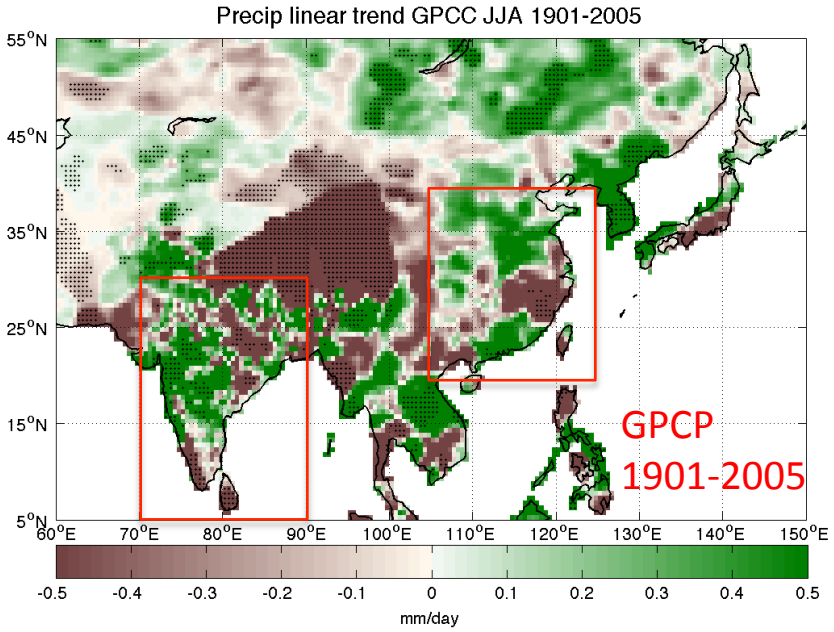



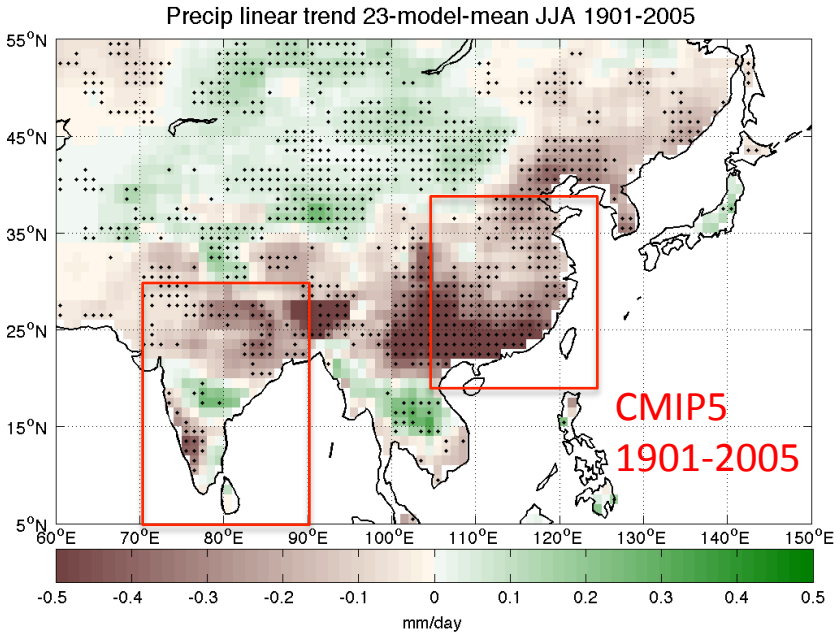



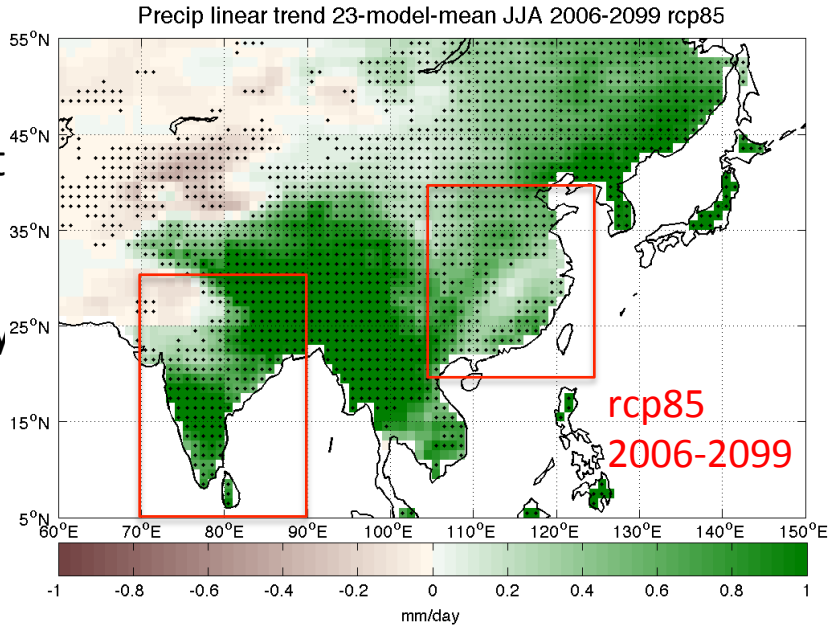

- Anomaly: with respect to 1950-2000 average
- Think (thick) black line: seasonal mean (low-pass filtered) GPCC precip
- Red Line: Median of 23 models, seasonal mean
- Red Shading: 25% - 75% model range

# Monsoon Rainfall Linear Trend




- There are spatial inhomogeneity in the monsoon rainfall trends
- Observed trends show a mixed signal, but mostly increases in rainfall, however, CMIP5 models indicate a generally drying trend for the historical period, particularly in Eastern China
- Future scenario simulation indicates a generally enhanced rainfall over the entire Asian monsoon region.



# Questions:

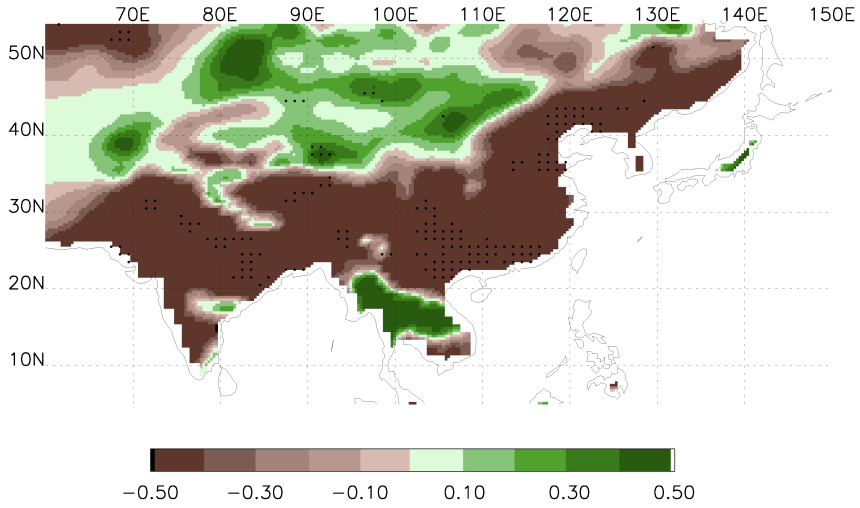
- Is linear trend a good representation of the externally forced trend in monsoon rainfall?
- What could be the mechanisms for the different trends in CMIP5 models for the historical and the future simulations?
- Are there ways to extract the forced signal from observations?

# Signal-to-Noise Maximizing EOF Analysis (Ting et al., 2009) to Identify the Forced Monsoon Rainfall Change

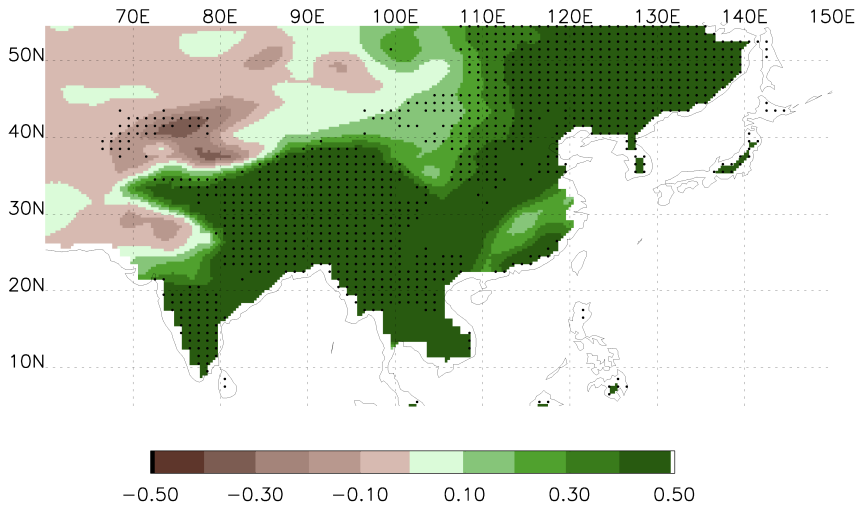
- Allen and Smith, 1997; Venzke et al., 1999; Chang et al., 2000
- Apply EOF analysis to deviations from ensemble average to determine the spatial structure of the internal modes of variability
- Apply a spatial pre-whitening transformation based on the internal EOFs to remove the spatial correlations in the internal atmospheric variability (i.e., "climate noise") contained in the ensemble average
- Apply EOF analysis to pre-whitened ensemble mean Asian monsoon rainfall to obtain the forced patterns

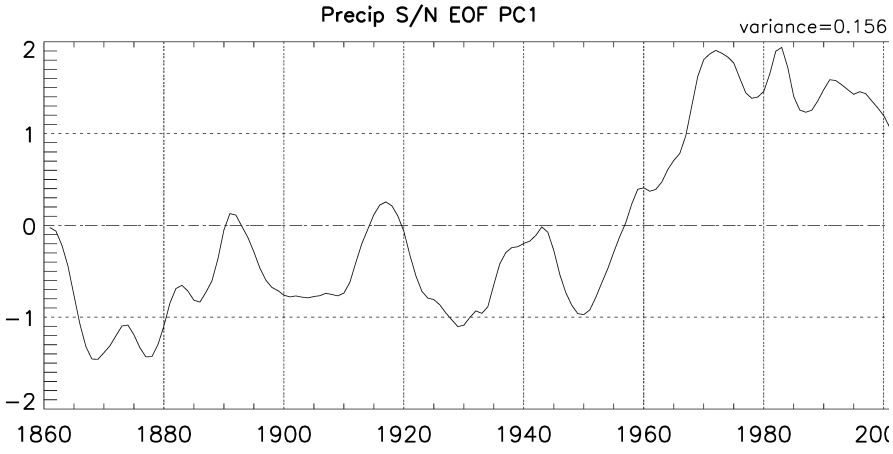
# S/N Maximizing EOF1 and PC1

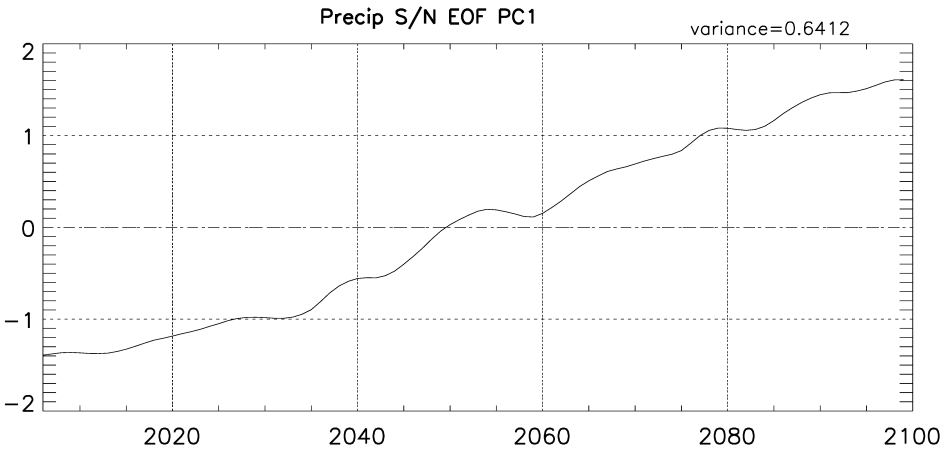
CMIP5/Historical




CMIP5/rcp85



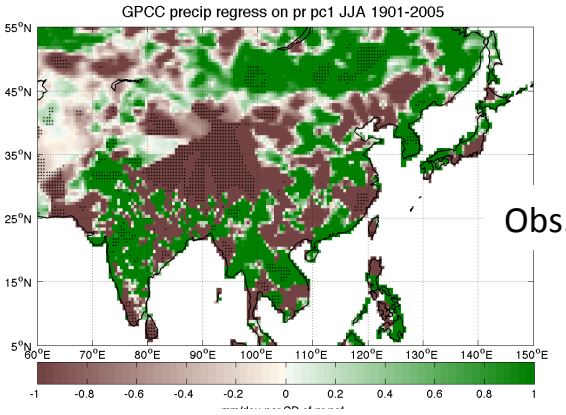



# Precip and SST regression to S/N PC1 of Monsoon Rainfall

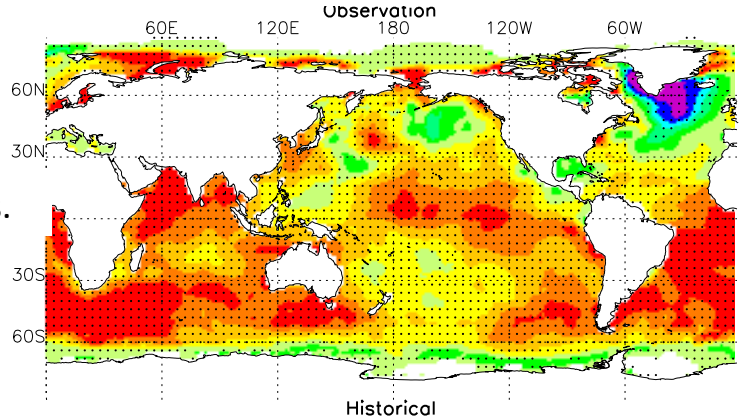
- Global SST pattern resembles that of global warming
- Observed monsoon shows a general increases in seasonal rainfall amount
- CMIP5 historical simulation, however, shows reduced rainfall throughout most of the region
- In rcp85 future, the Asian monsoon enhances everywhere
- Why the difference?

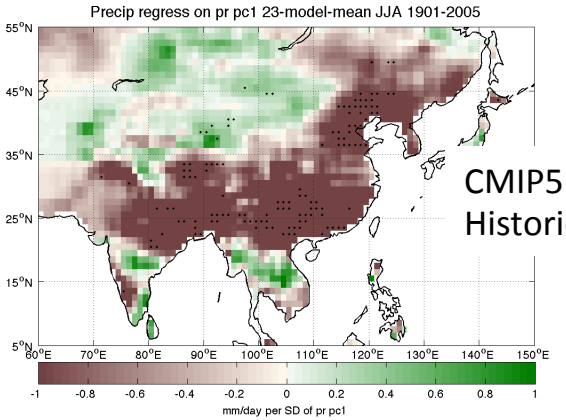
Precip

SST

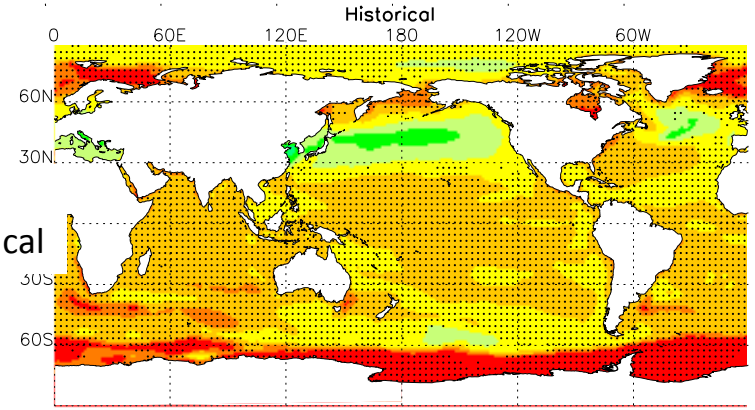


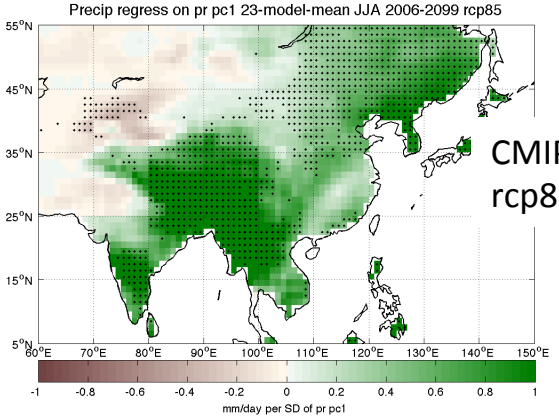

Obs.



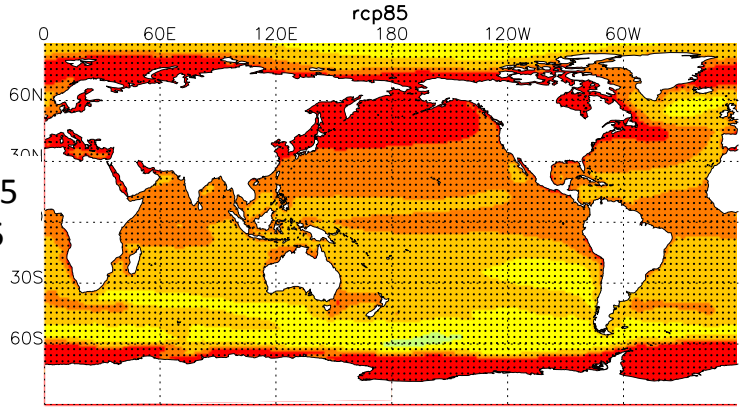



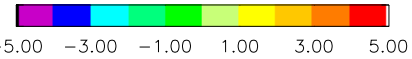

CMIP5 Historical



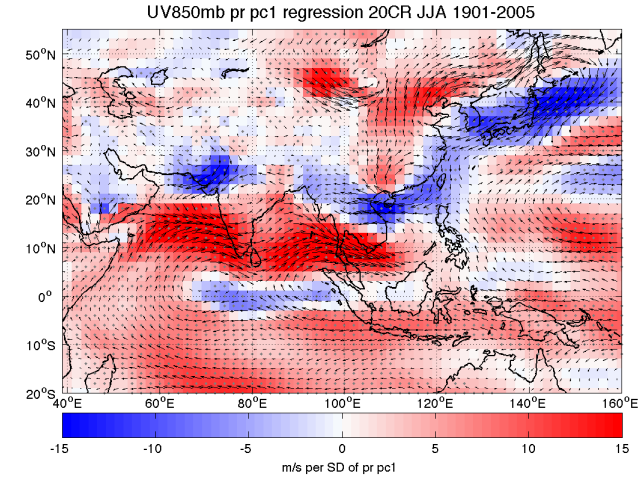



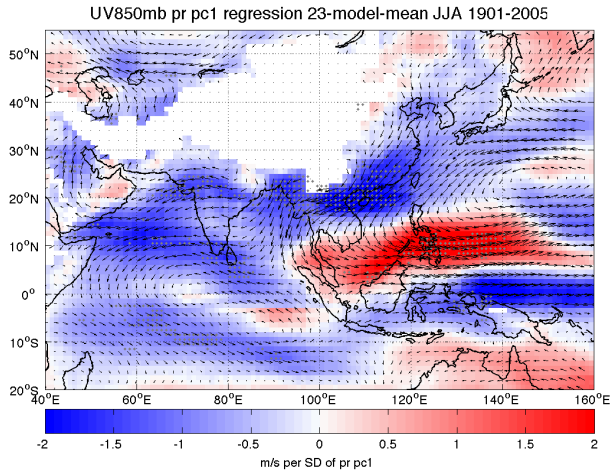

CMIP5 rcp85

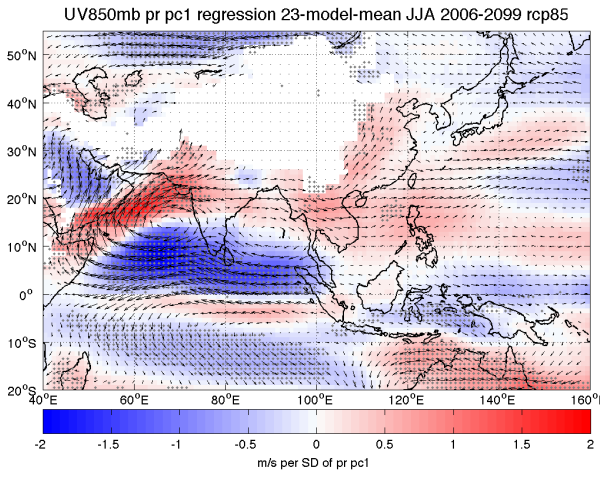


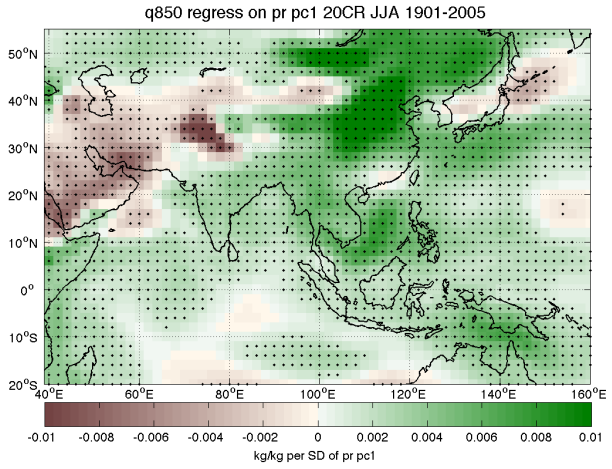



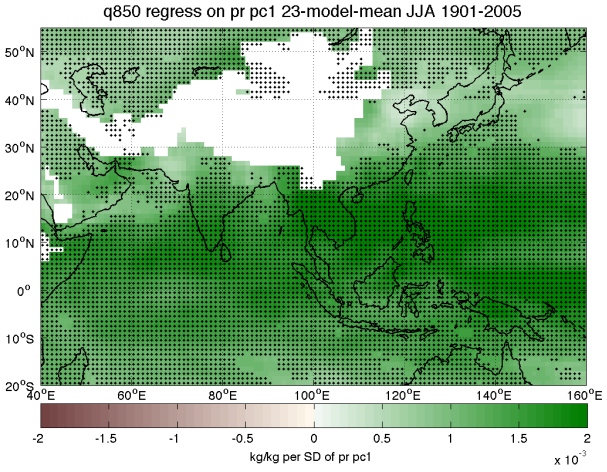
# Regression onto S/N PC1 for observations and CMIP5 Models 850 mb wind (top panels) and specific humidity (lower panels)

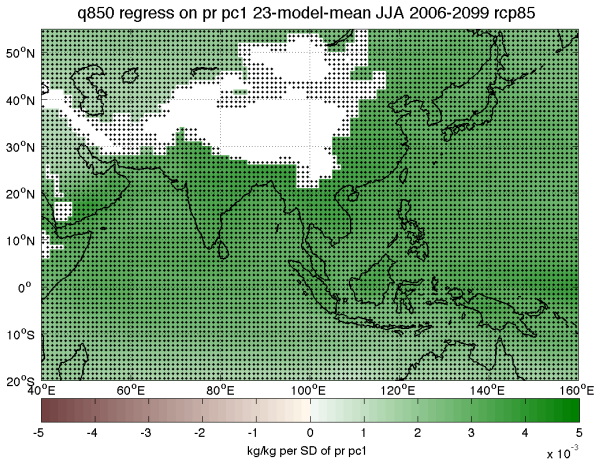



20 C Renanlysis
1901-2005

CMIP5 Historical
1901-2005

CMIP5 rcp85
2005-2099

# Summary

- In 20$^{th}$ Century reanalysis, the forced signal is associated with strengthened monsoon circulation and increased moisture in the atmosphere during the historical period
- In CMIP5 historical simulations, however, the monsoon circulation is greatly weakened while the moisture content in the atmosphere increased everywhere
- In the future (rcp85 scenario), the monsoon circulation is reduced and moisture content greatly increased in the atmosphere. The increases in the amount of moisture in the atmosphere may have dominated over the reduction in monsoon circulation.
- What causes the discrepancies between model and observations?
- Aerosol forcing?