

# **How Well Can We Simulate the Regional Hydrological Cycle and Its Sensitivity to Climate Change?**

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# Question

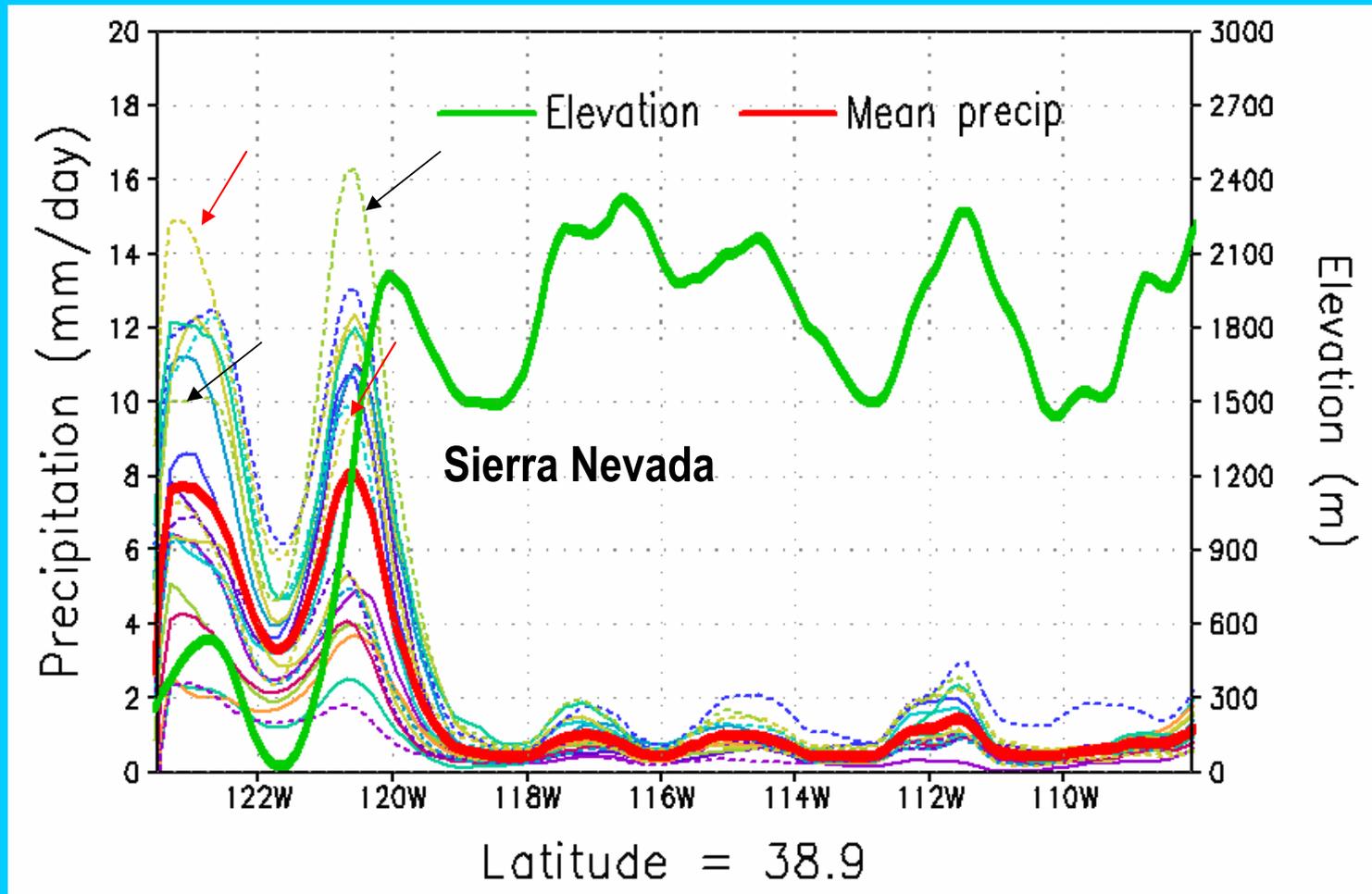
- At what level of resolution (speciation, spatial, and temporal) and accuracy do BC emissions inventory uncertainties become significantly less important than uncertainties due to other climate model inputs and formulation when estimating both global climate forcing effects and impacts on regional hydrological cycles?

# What is the challenge?

- Precipitation is the major driver of land surface hydrology that governs water resources; yet it is the most uncertain part of the hydrological cycle
- Globally, precipitation (P) is balanced by evaporation (E), i.e.,  $P = E = 2.8 \text{ mm/day}$ ; but regionally  $P - E$  varies significantly
- Partition of  $P - E$ : soil moisture, snowpack, runoff
- Challenge: Large temporal variability, large spatial variability, the extreme matters – floods/droughts

# Interannual Variability (CA)

DJF

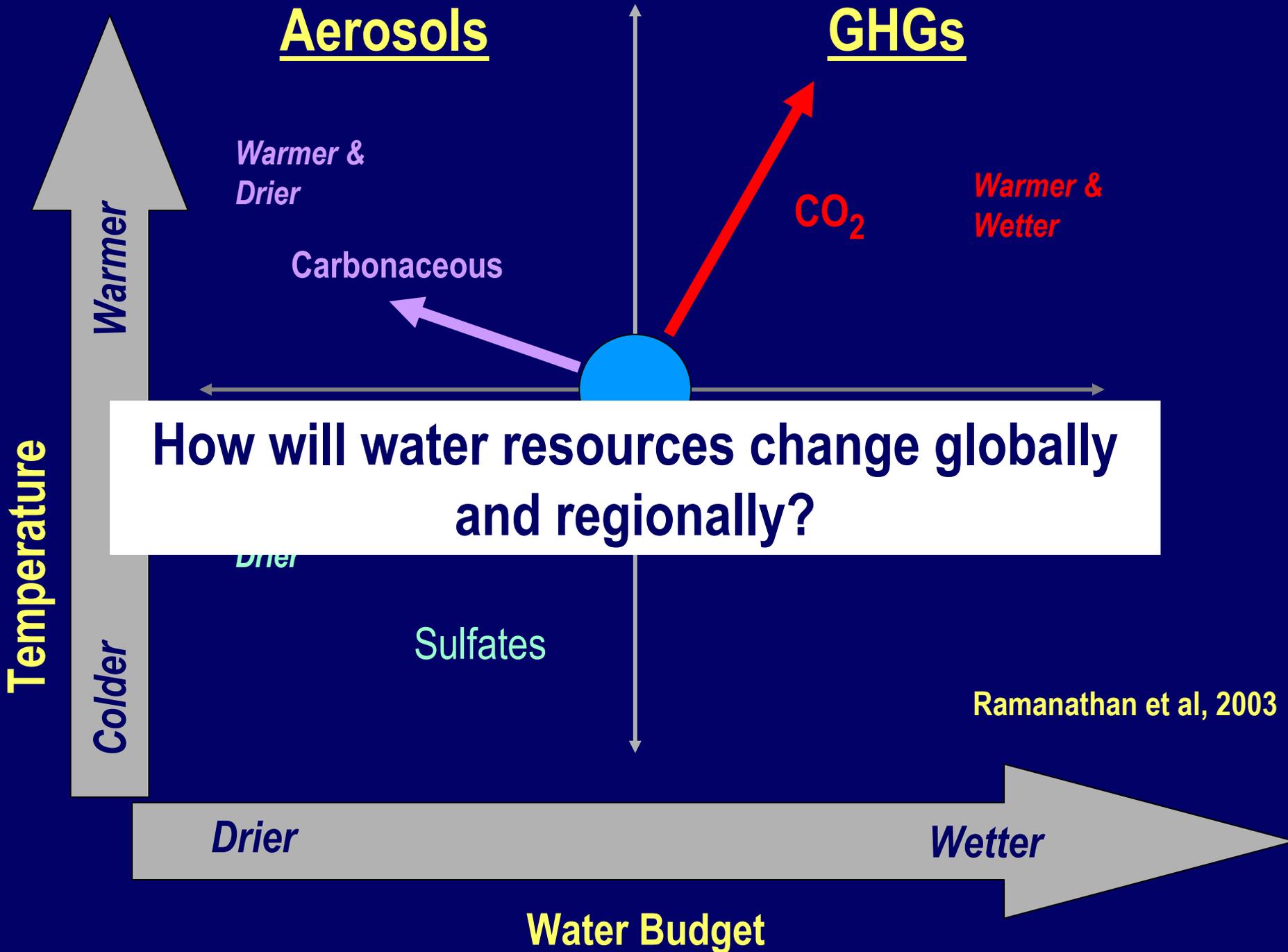


# What Controls Precipitation?

- In most regions, local evaporation contributes no more than 30% of moisture for  $P$ , so  $P$  is largely controlled by atmospheric moisture flux
- Large scale moisture transport is governed by circulation induced by heat sources and sinks (e.g., land-sea contrast, elevated heat source of large topographic barriers)
- Not all moisture flowing through produces precipitation; need rising motion to produce condensation (e.g., extratropical storms, orographic forcing, mesoscale convective storms, turbulence)
- Cloud microphysics has large control on precipitation characteristics

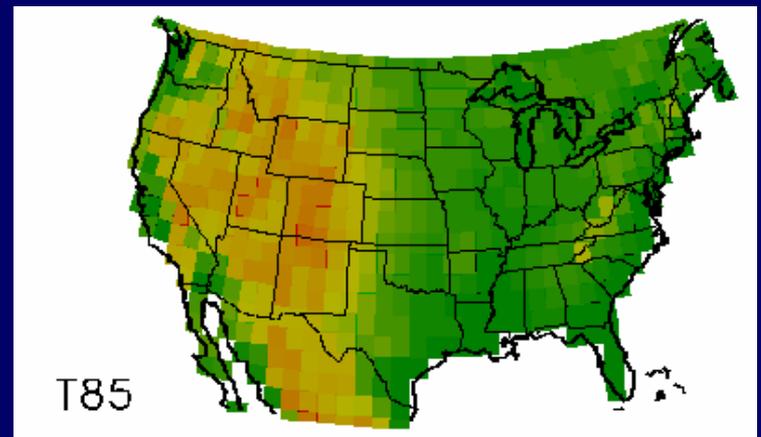
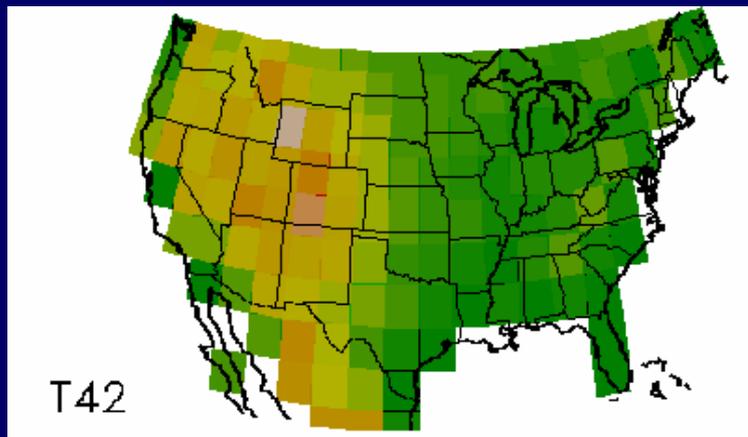
# How will the Global Hydrological Cycle Be Affected by Climate Change?

- Greenhouse warming increases evaporation (Clausius-Clapeyron equation); increased evaporation increases precipitation ( $P = E$  globally)
- Global mean land average rainfall has decreased by 2.33% per °C since the 1950s despite warmer temperature (Hulme et al. 1998)
- Fossil fuel BC emissions have increased by about a factor of 2.5 since the 1950s
- Increase in BC and other aerosols reduces surface solar radiation ( $R$ ), reduced  $R$  must be balanced by reduced  $E$ ; decrease  $E$  leads to decrease  $P$

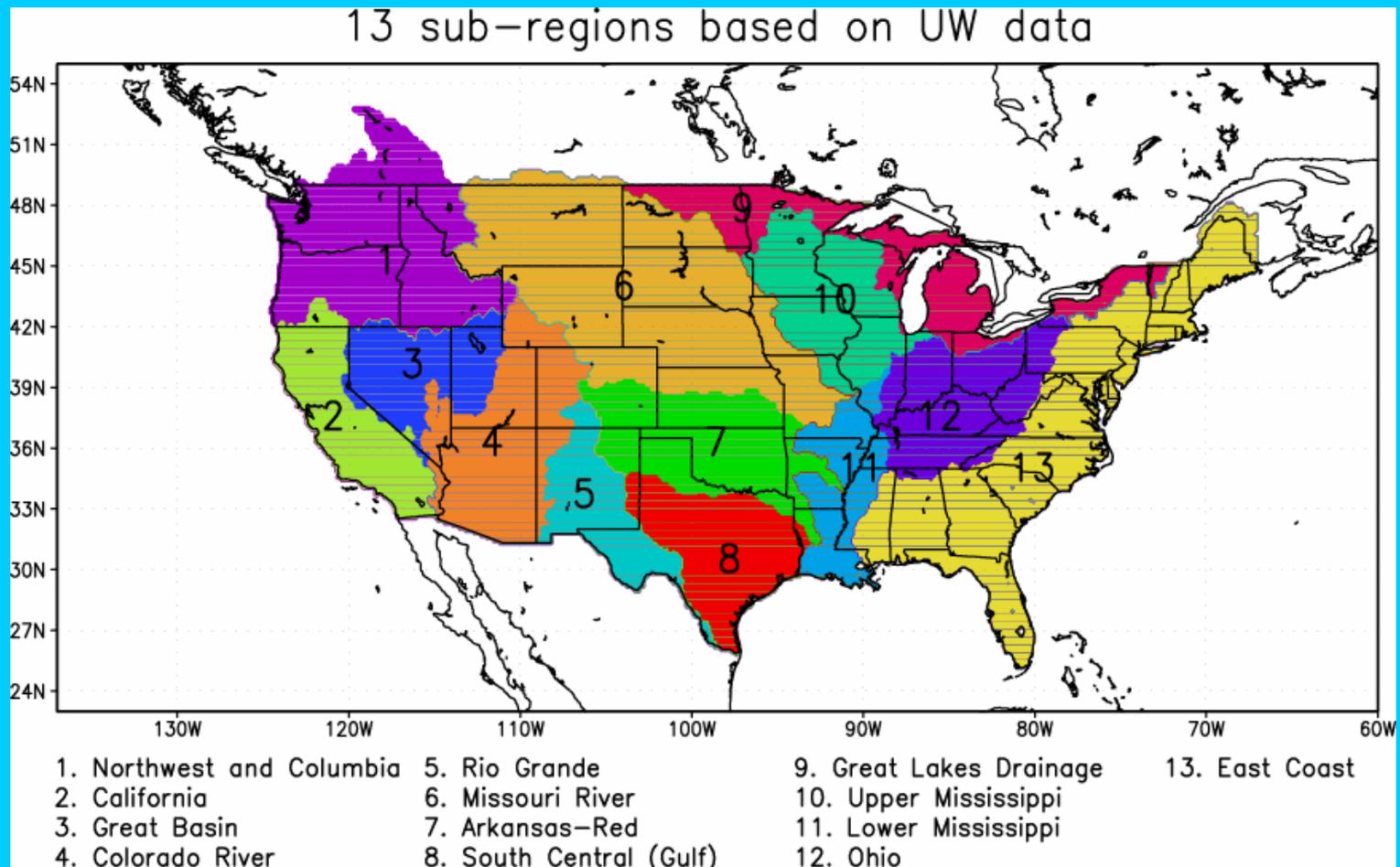


# Some Issues in Climate Modeling

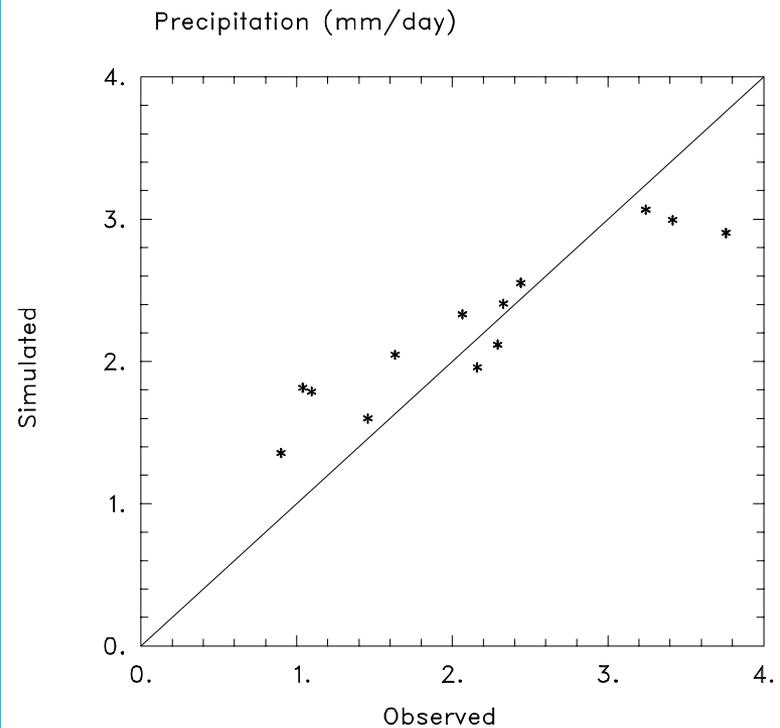
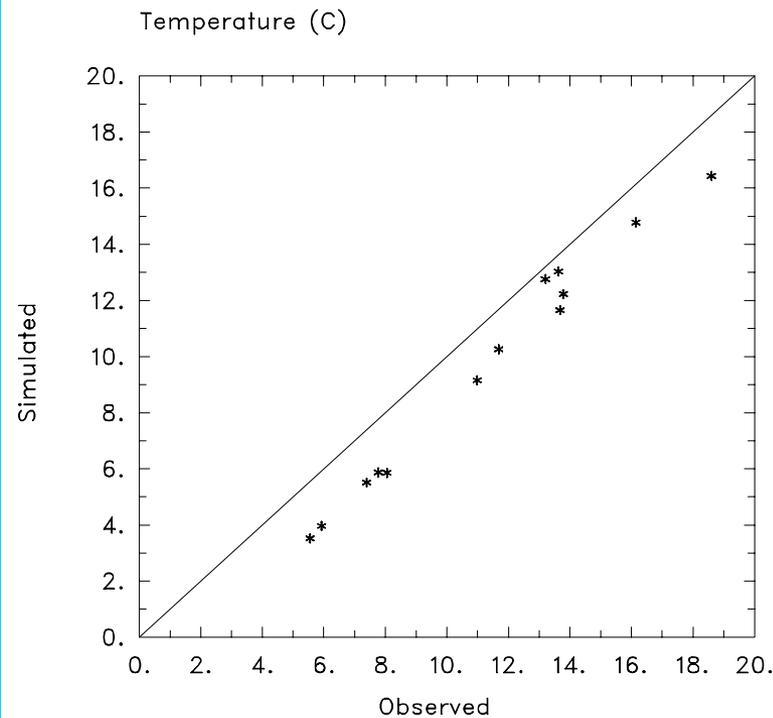
- Climate models are used to sort out the various forcing and response and for making predictions
- To estimate GHG and air pollution effects on regional hydrological cycle, spatial heterogeneity in aerosol forcing and hydrological response must be addressed



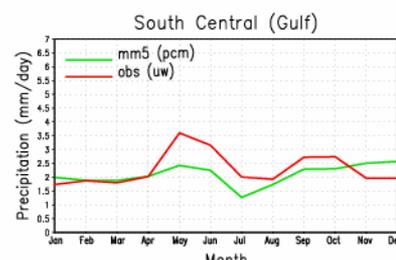
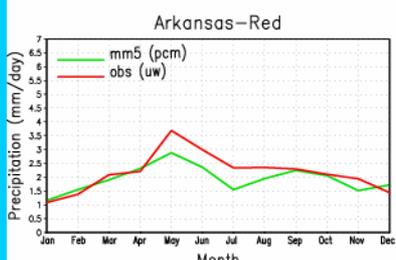
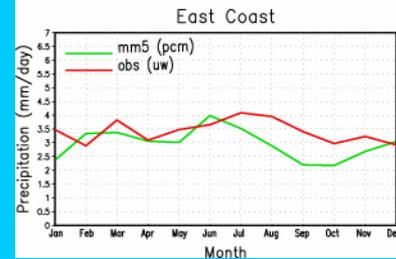
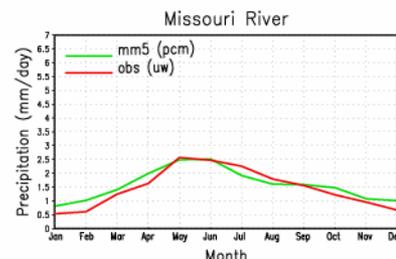
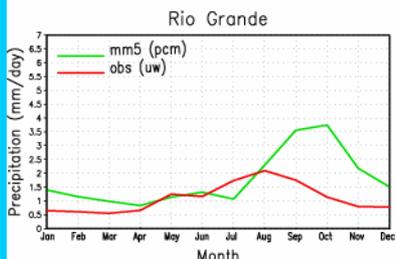
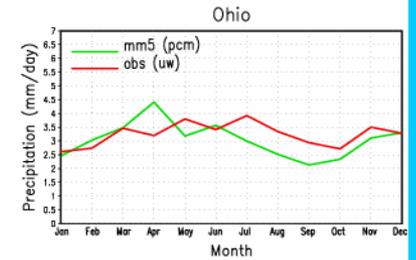
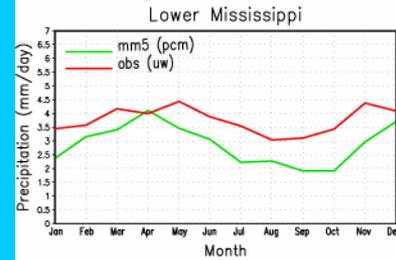
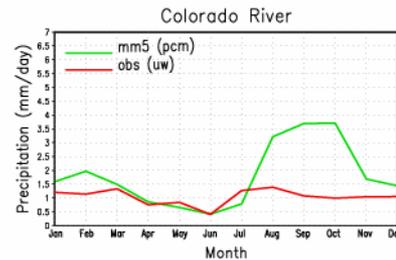
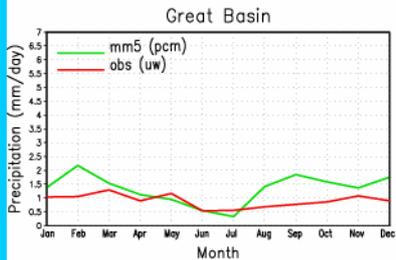
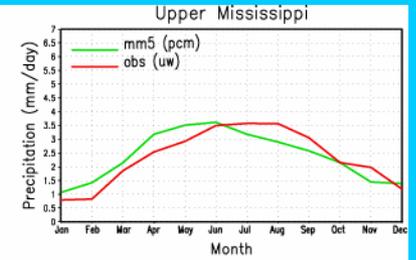
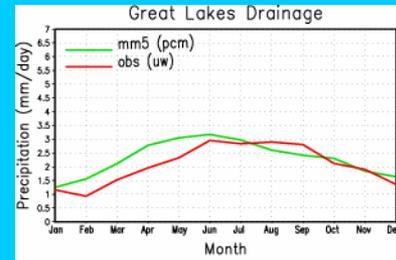
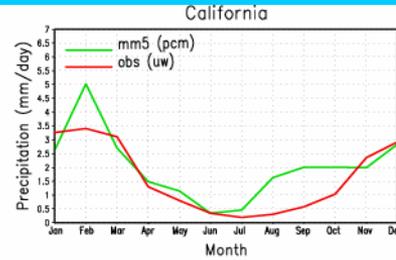
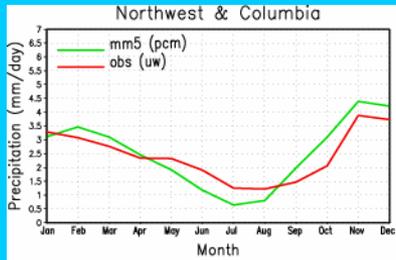
# How Well Can We Simulate Regional Precipitation?



# Regional Climate Model Driven By GCM: Annual Mean Temperature and Precipitation

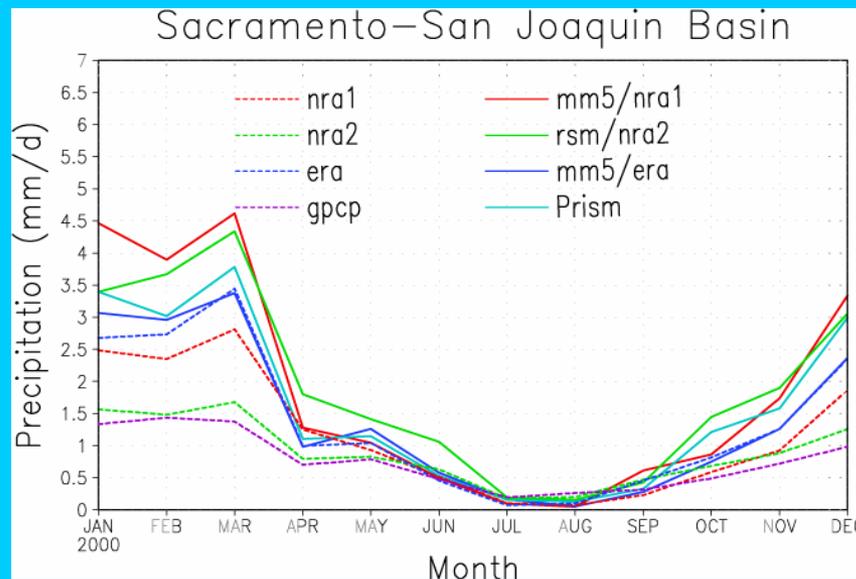
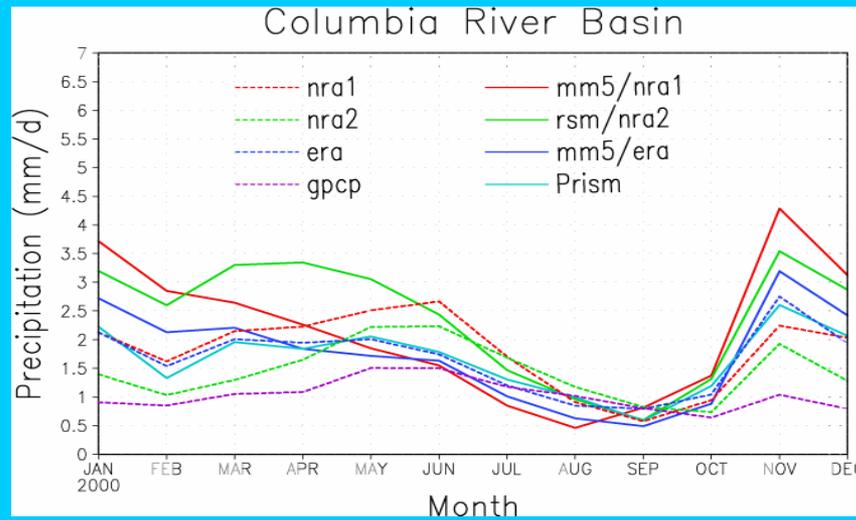


# Seasonal Cycle

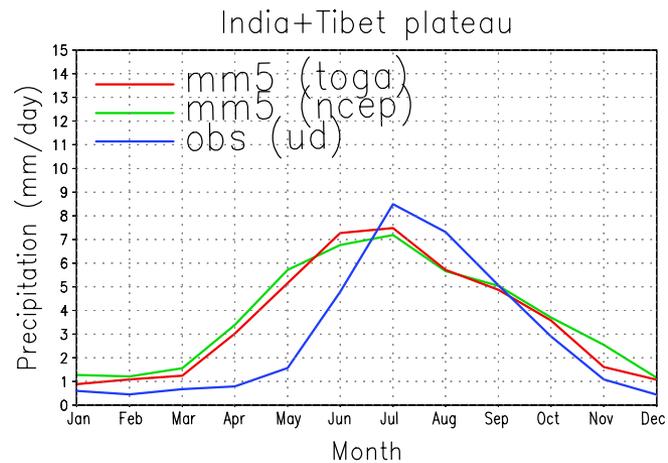
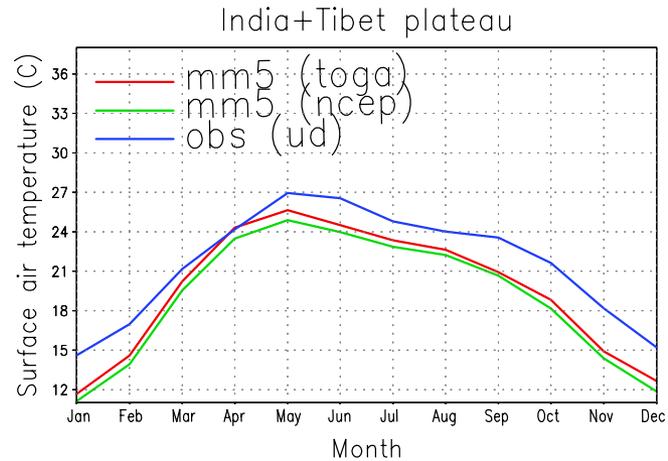




# Sensitivity to Boundary Conditions and Model Formulations

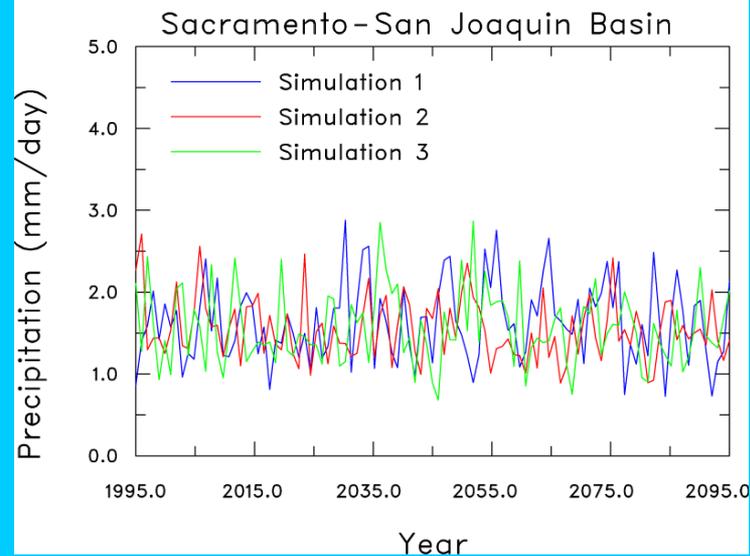
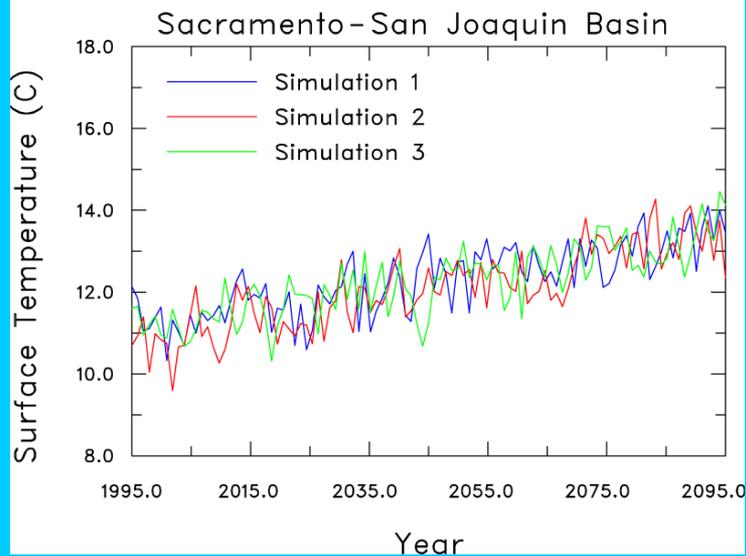
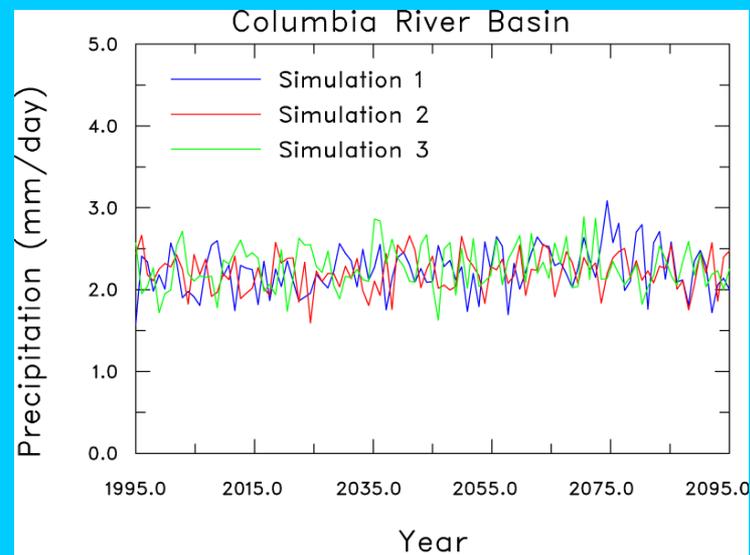
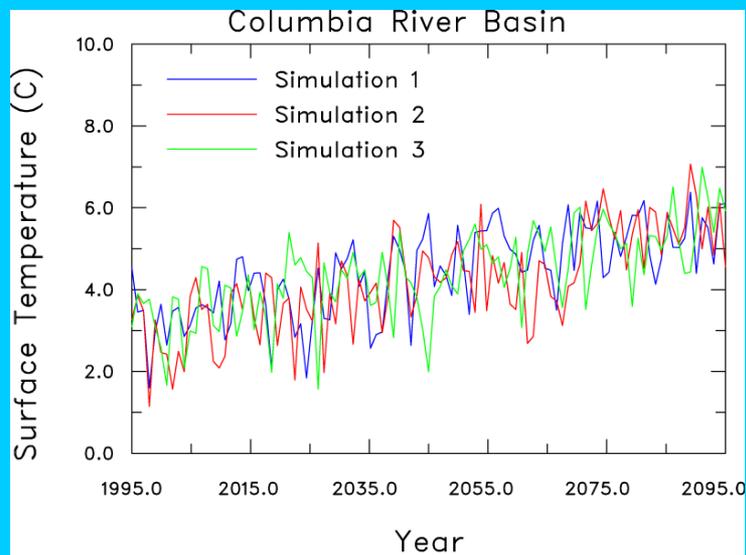


# Sensitivity is Regime Dependent



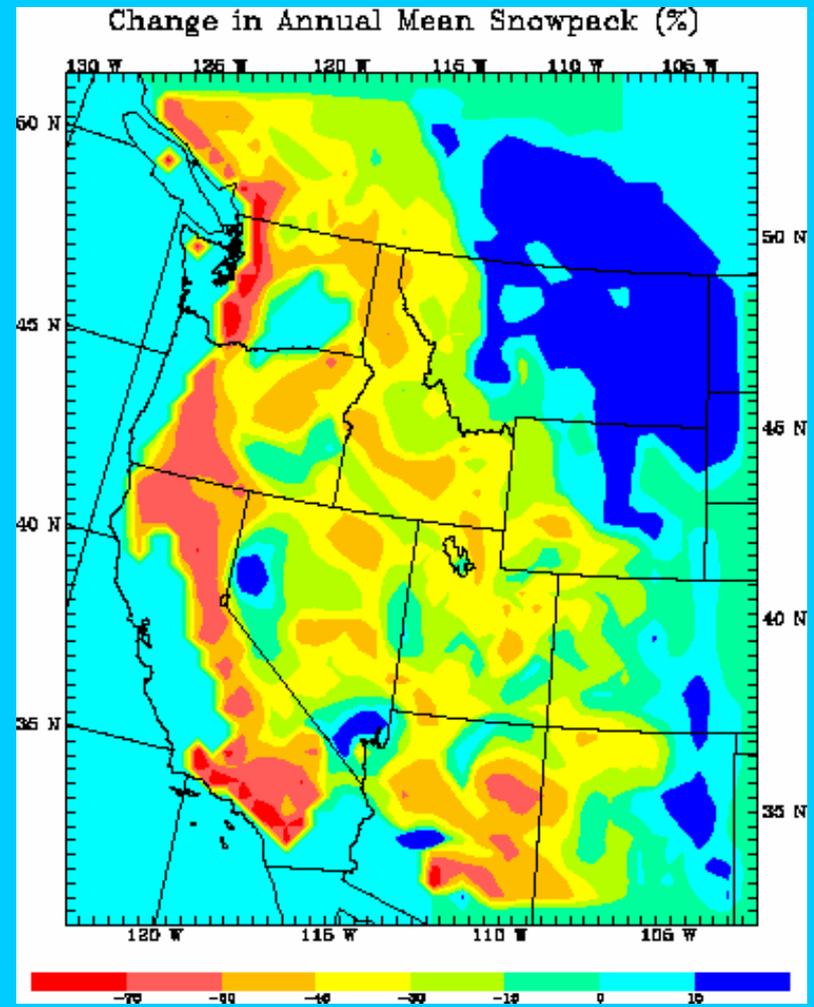
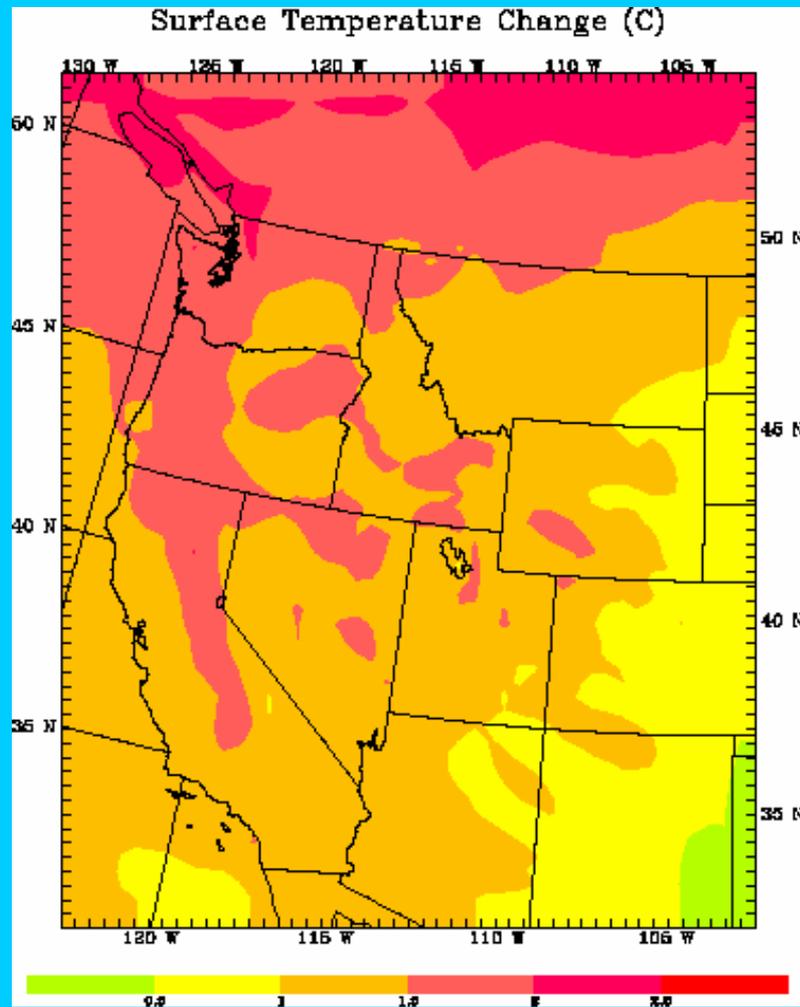
**How Much Confidence Can We Have  
in Projecting Changes in Regional  
Hydrological Cycles?**

# An Ensemble of Future Climate Conditions Simulated by a GCM



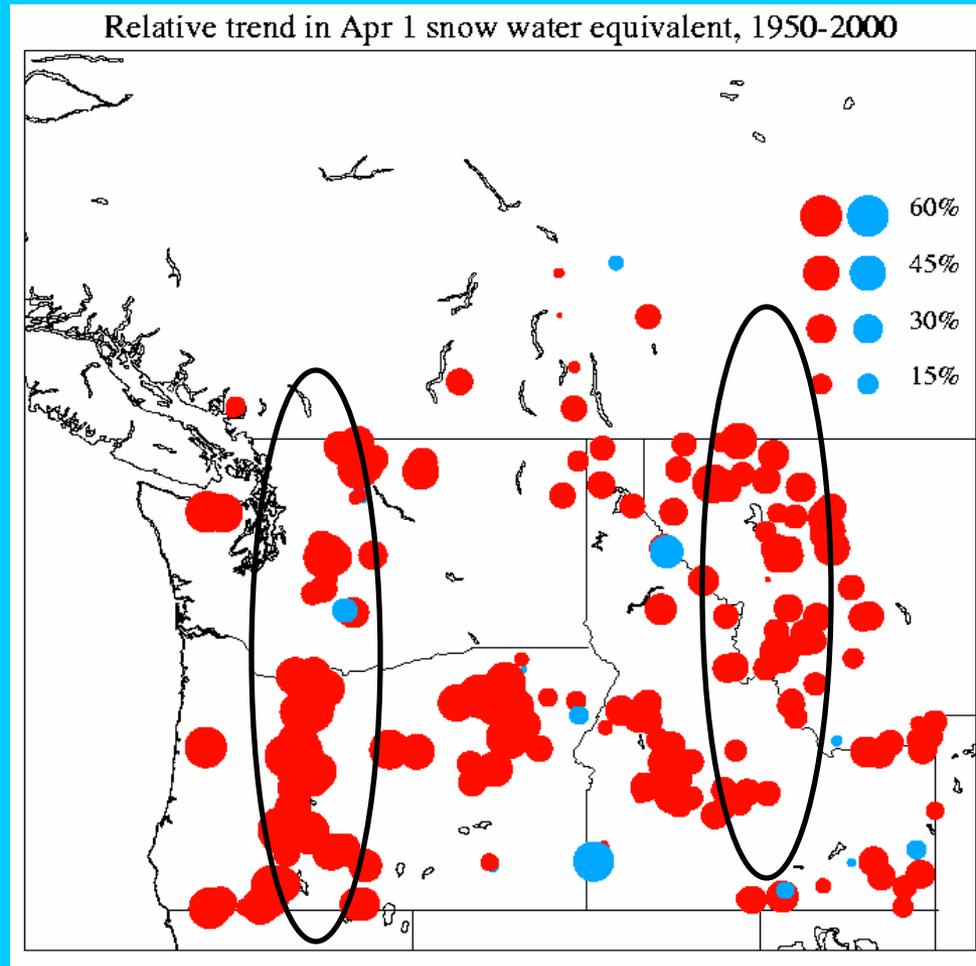
# Snowpack Changes

Lead to significant changes in streamflow affecting hydropower production, irrigation, flood control, and fish protection

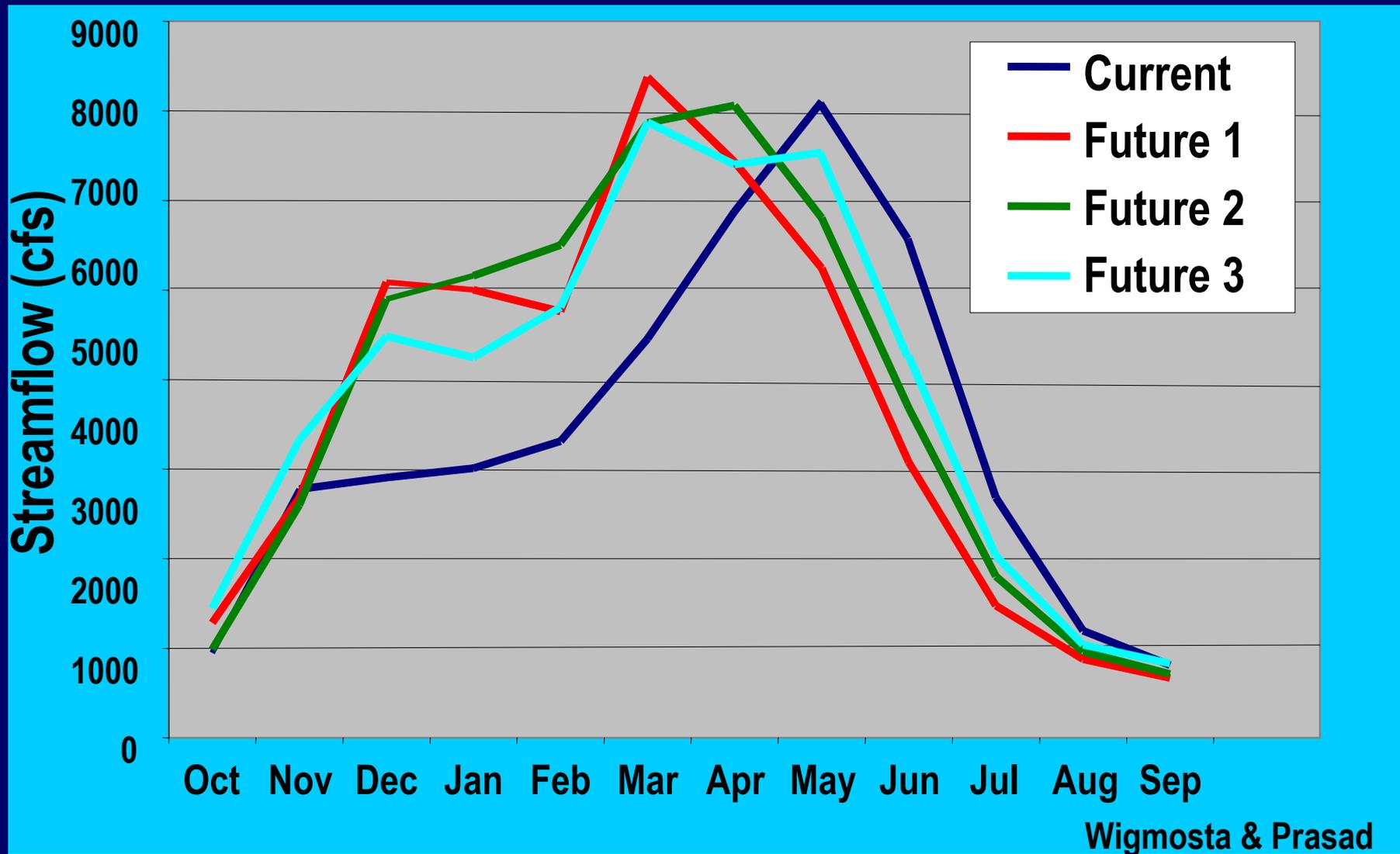


(Leung et al. Climatic Change 2004)

# Trends in April 1 SWE, 1950-2000

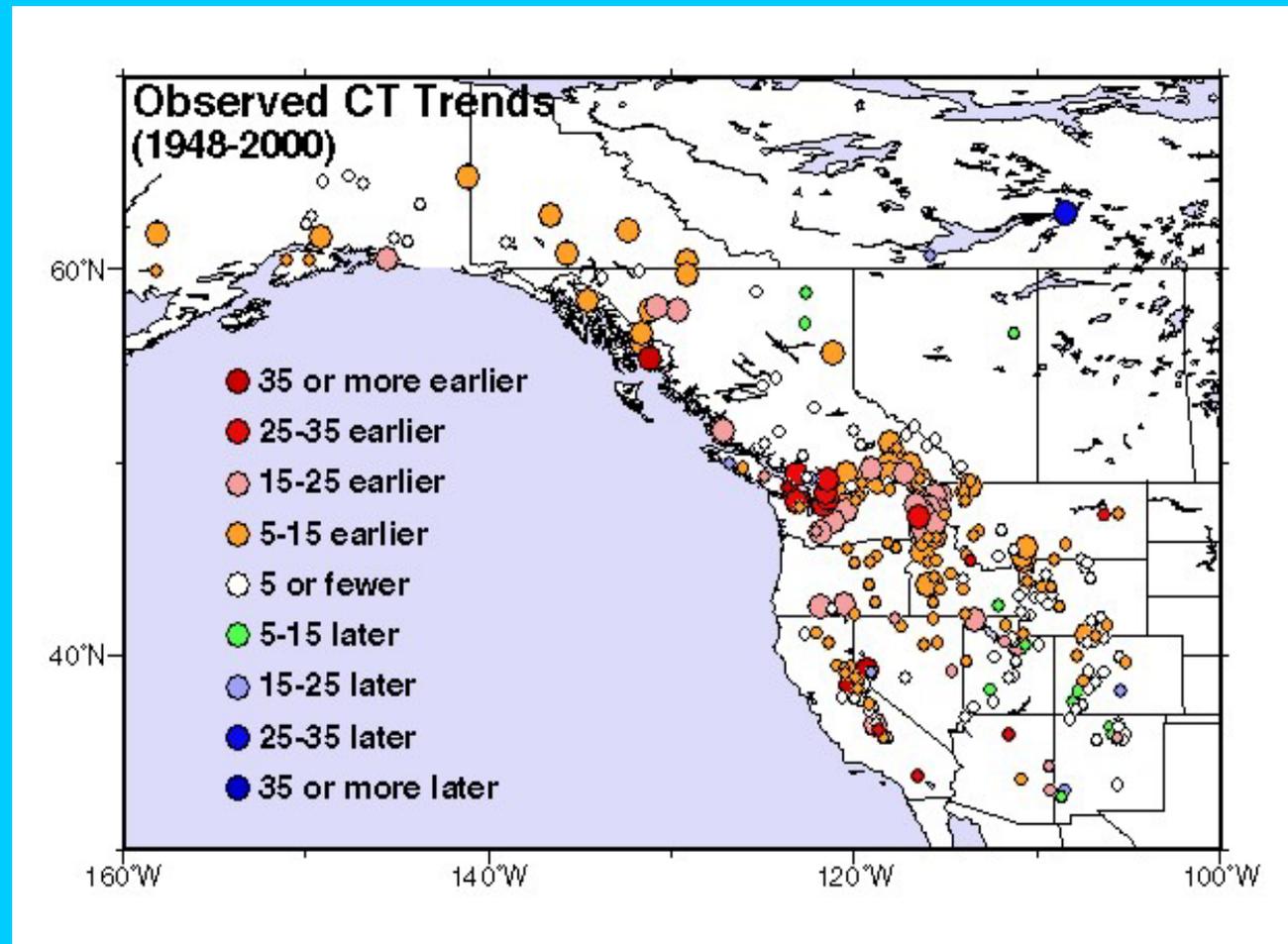


# Current and Future Streamflow in the Yakima River Basin



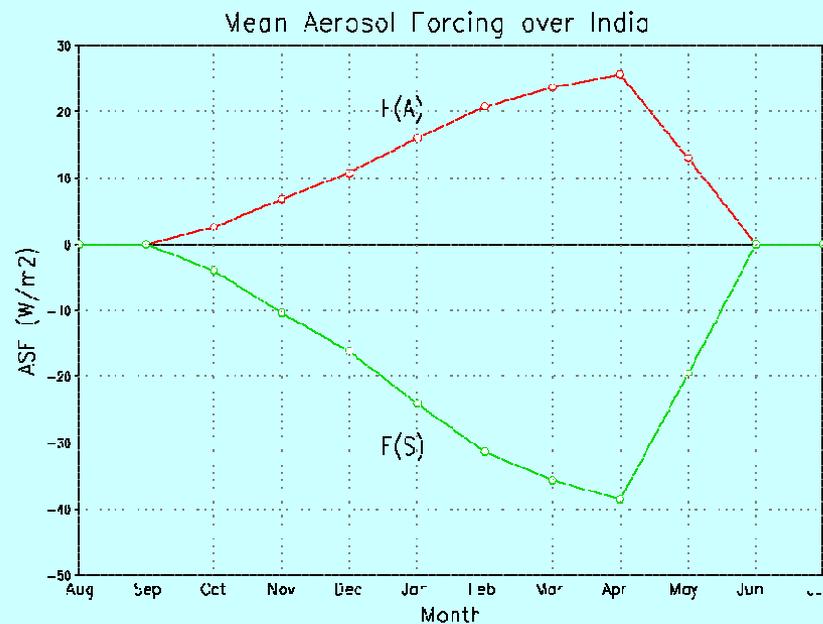
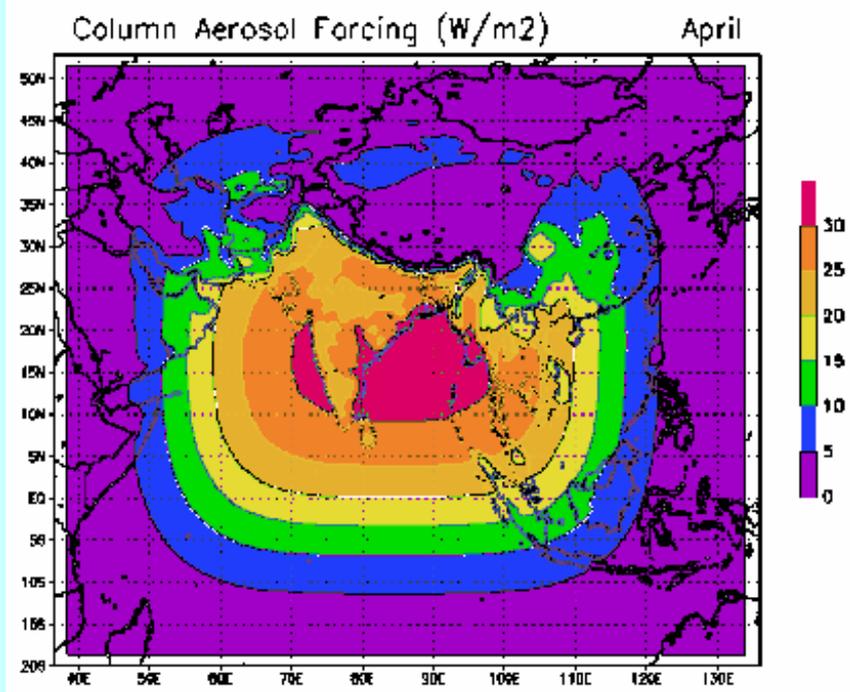
# Snowmelt flows have been starting earlier

“Center Timing”  
of many  
snowmelt  
watersheds  
has advanced  
by 1-4 weeks  
earlier across  
the West during  
last 3 decades



# Aerosol Effects on Regional Climate in South Asia

Two 10 years RCM simulations driven by the NCEP/NCAR reanalysis were performed with and without INDEOX forcing



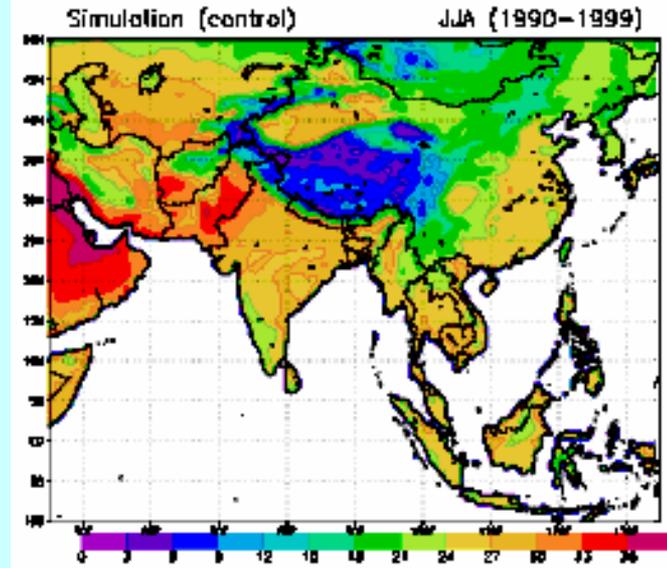
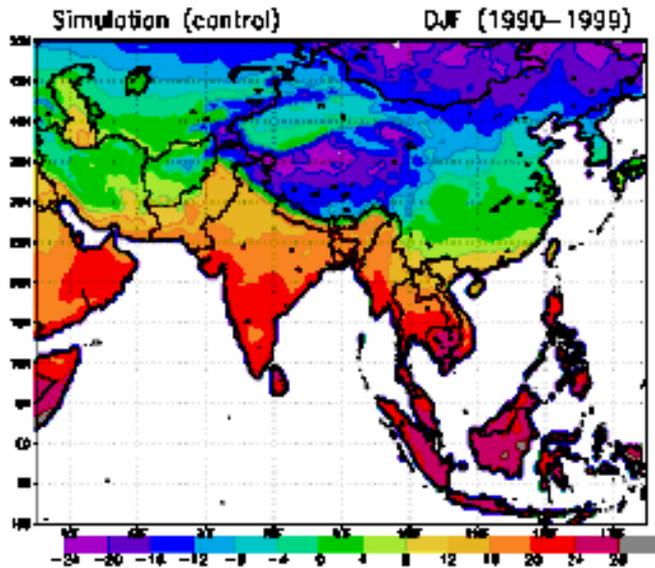
(Chung et al. 2003)

# Observed and Simulated Temperature

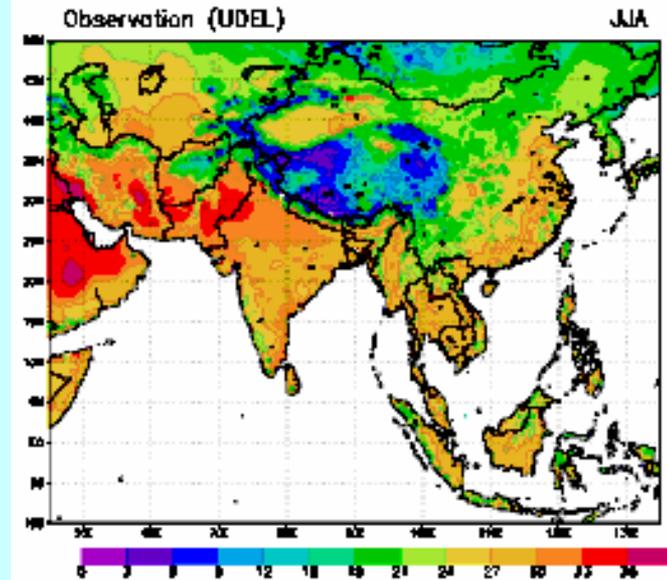
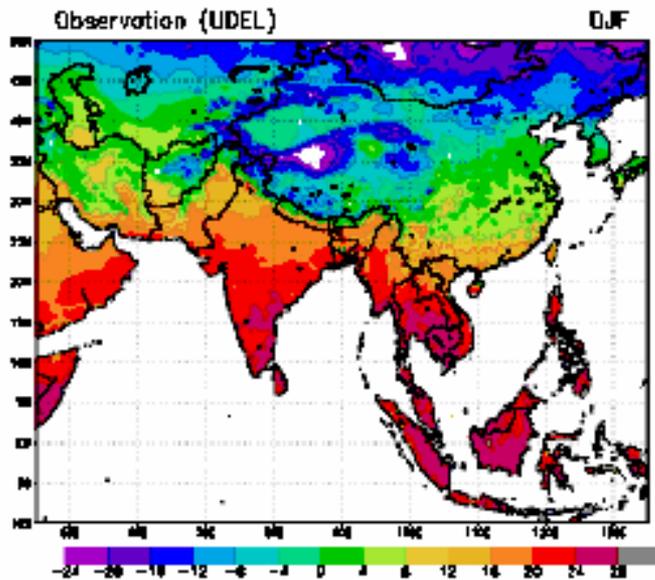
DJF

JJA

Simulated



Observed

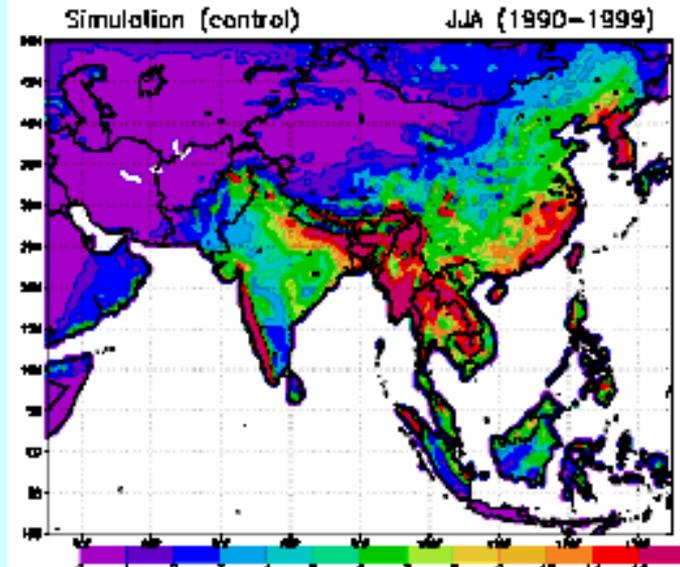
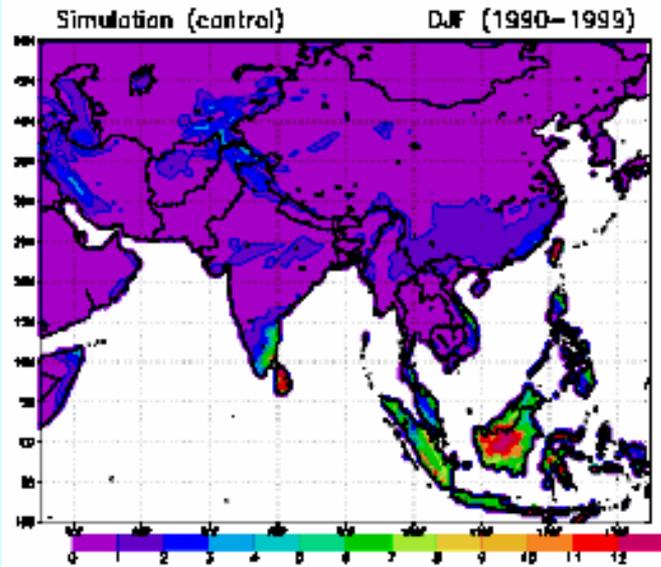


# Observed and Simulated Precipitation

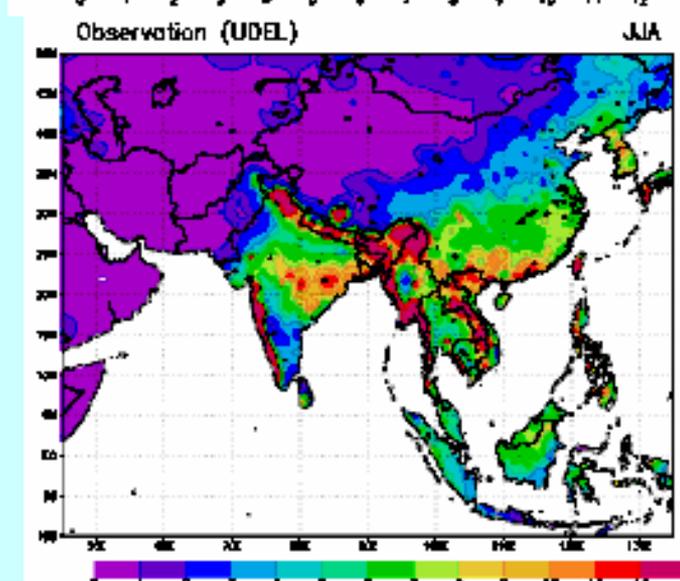
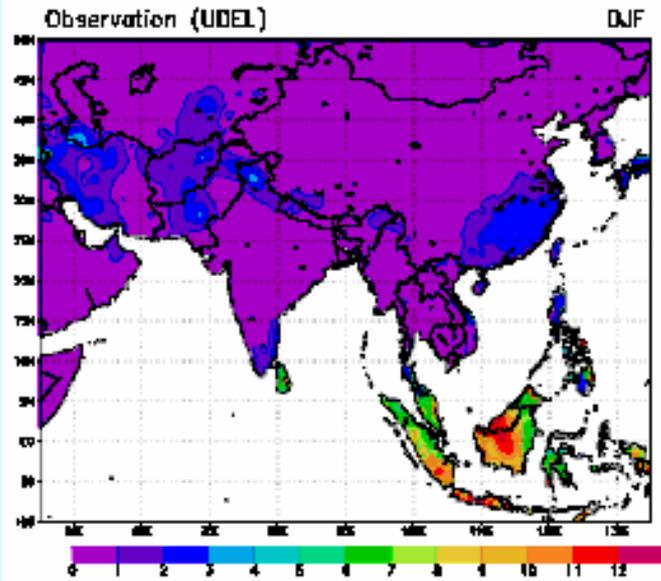
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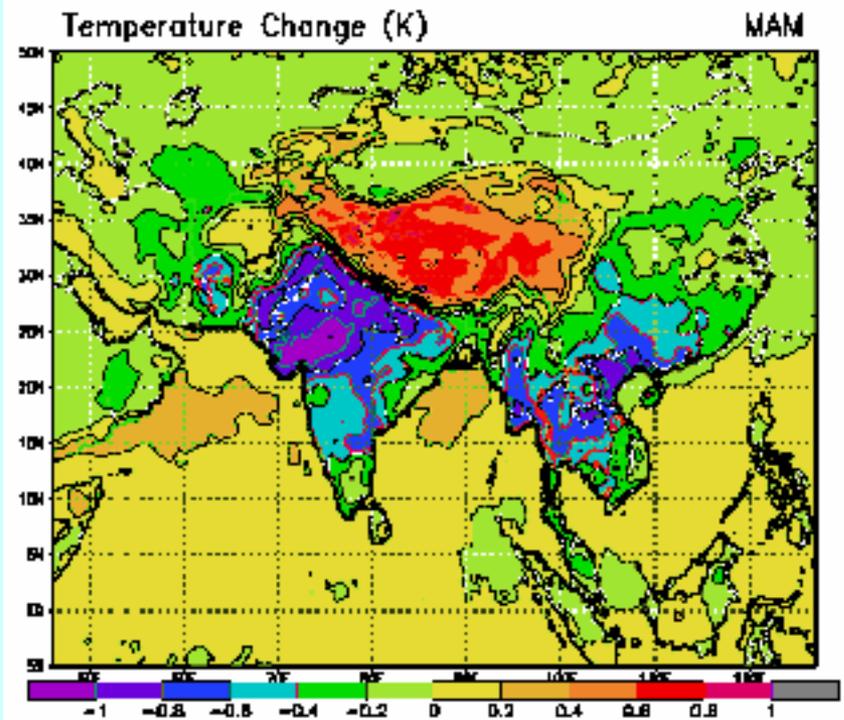
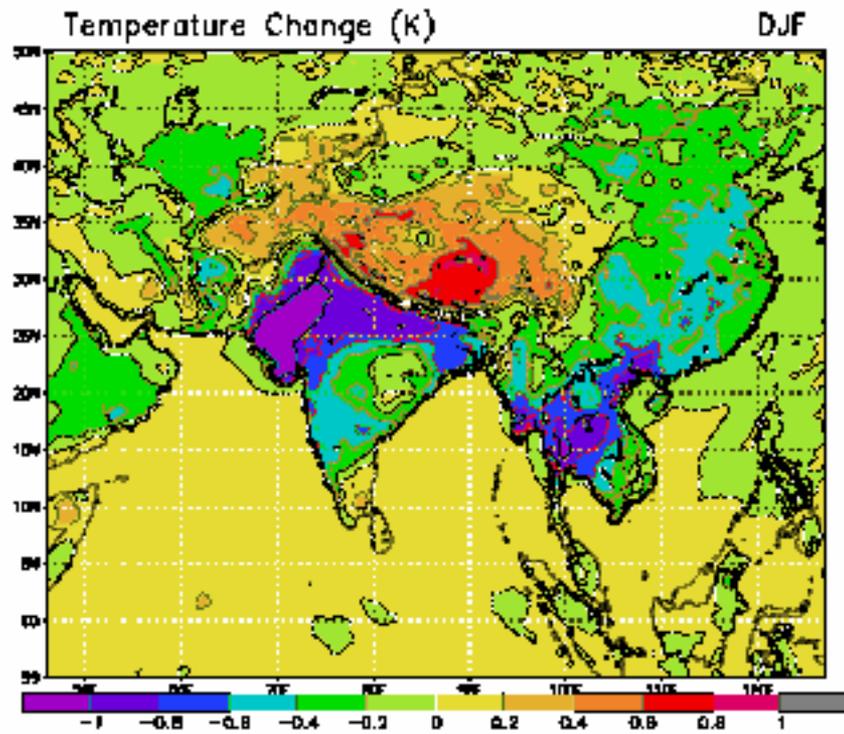
Simulated



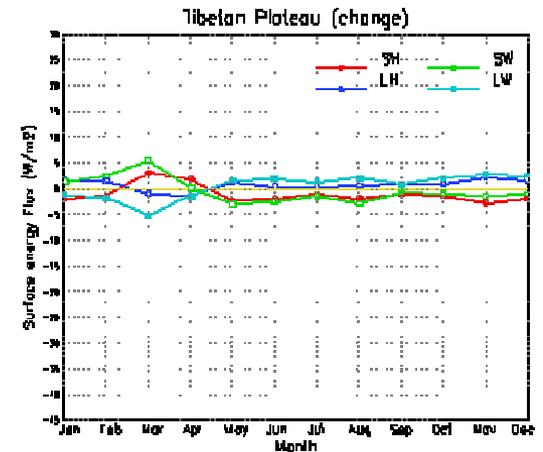
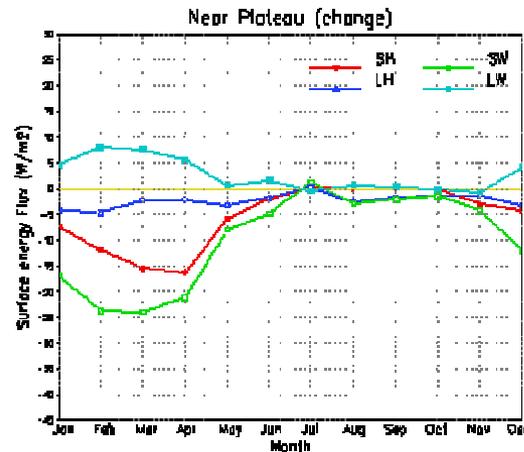
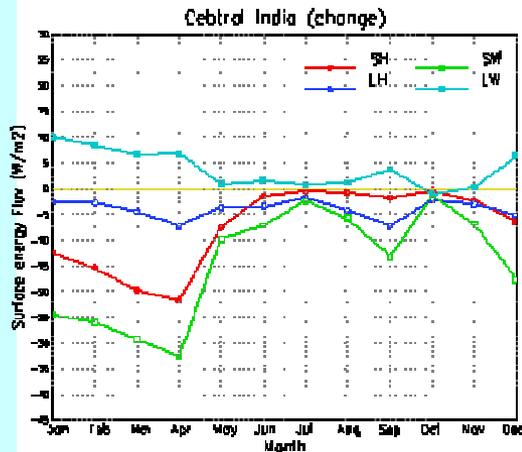
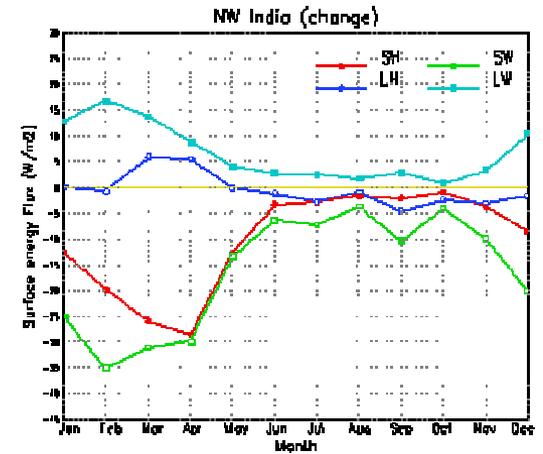
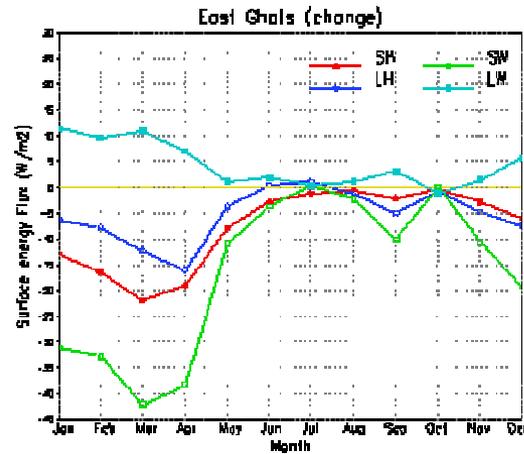
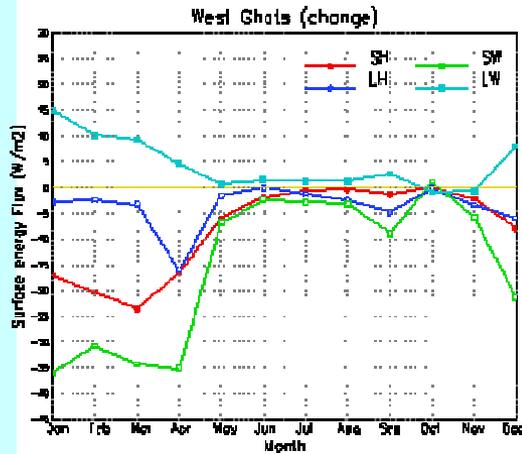
Observed



# Change in T

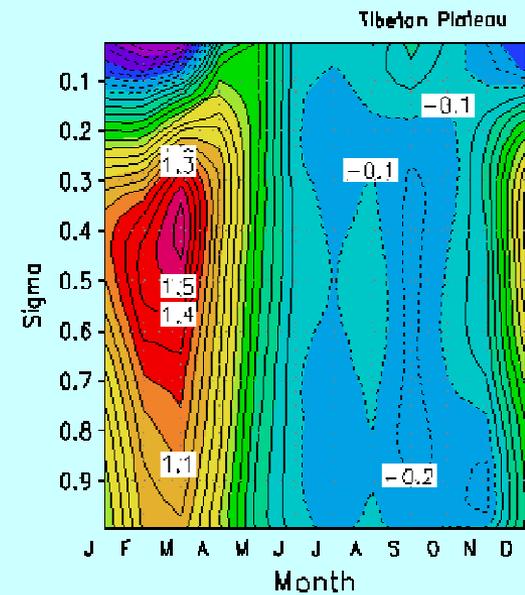
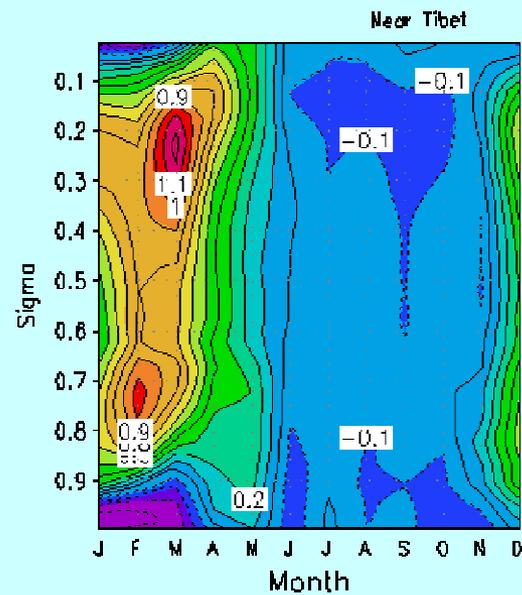
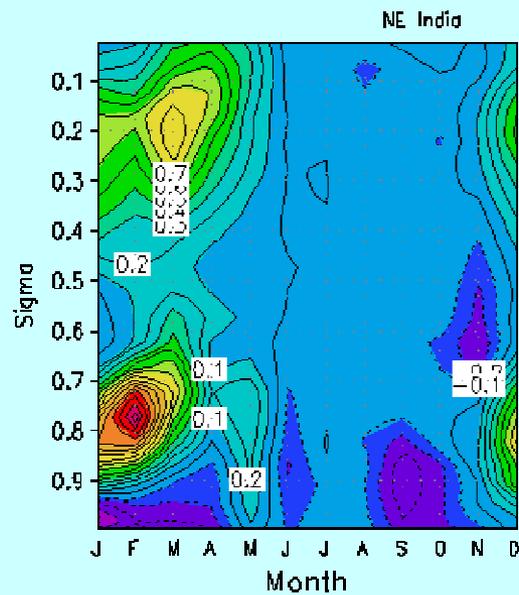
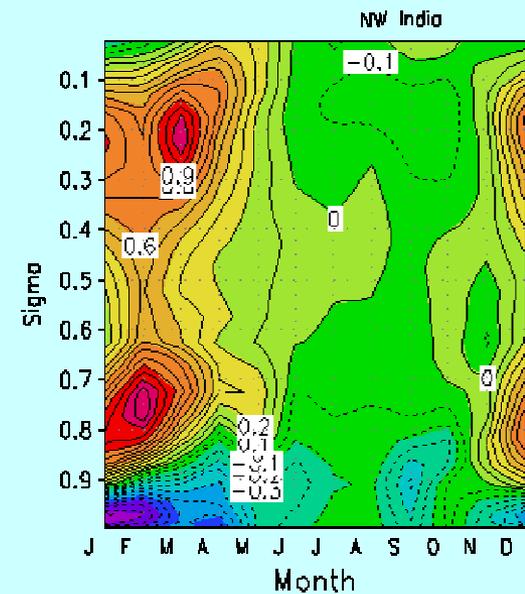
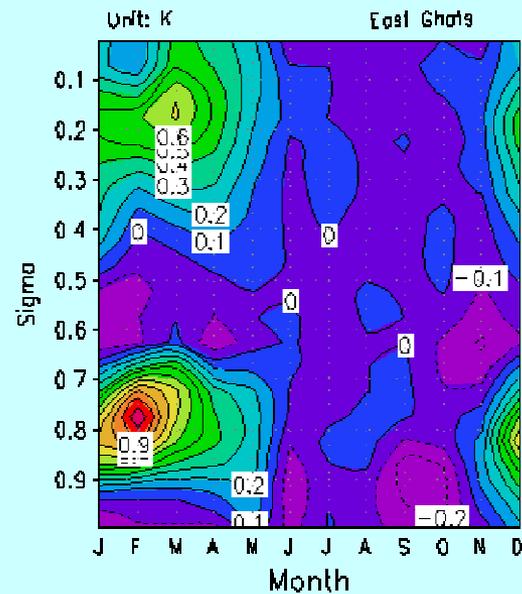
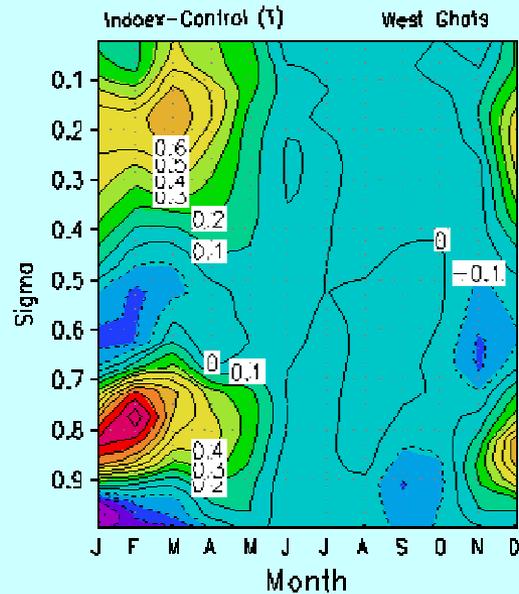


# Change in Sfc Energy Budgets

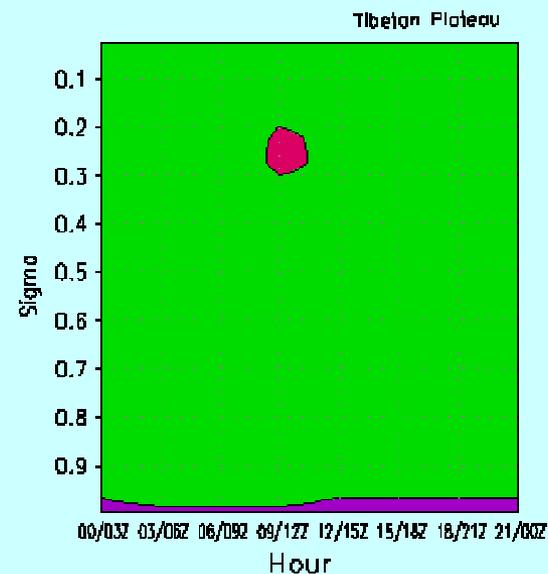
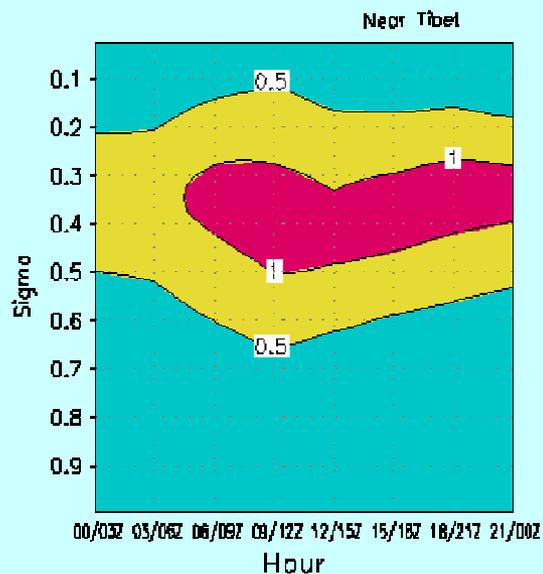
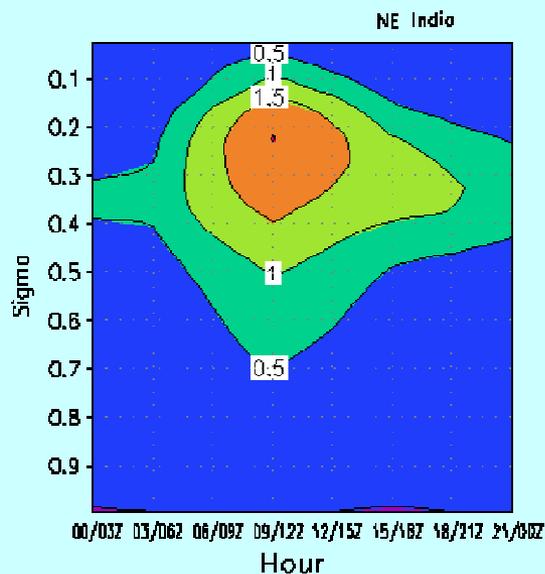
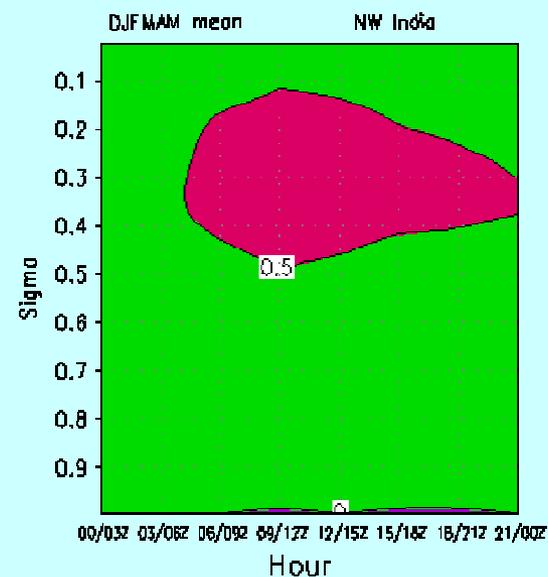
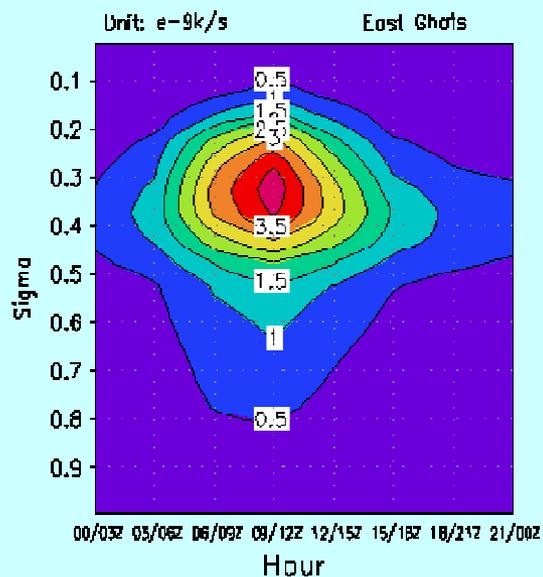
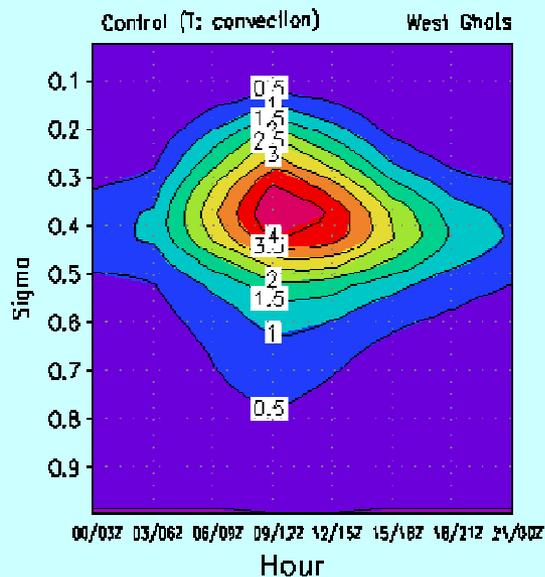


SW/LW – downward (+); SH/LH – upward (+)

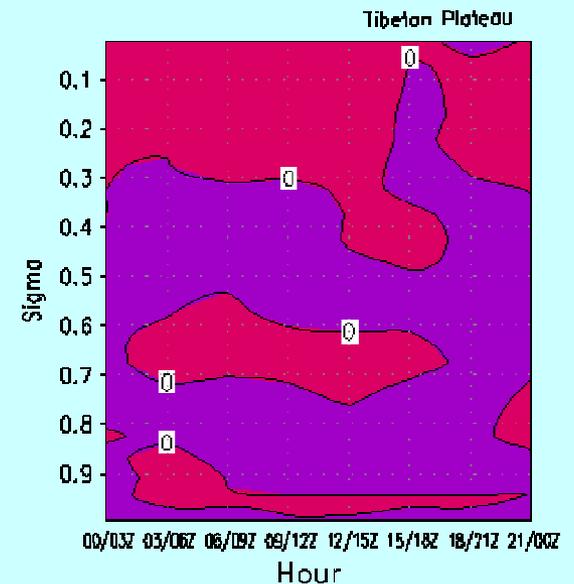
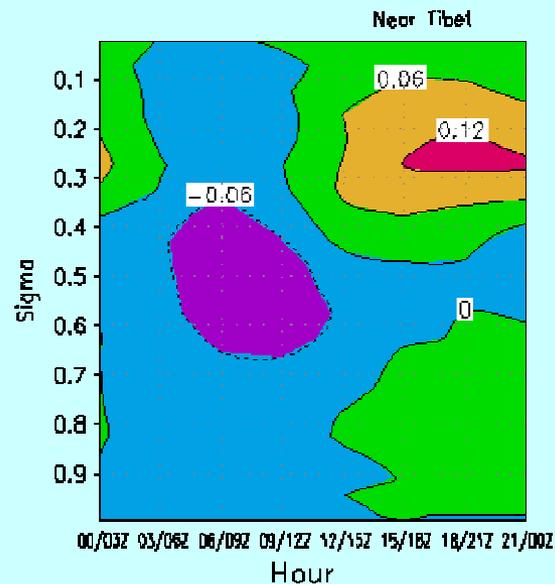
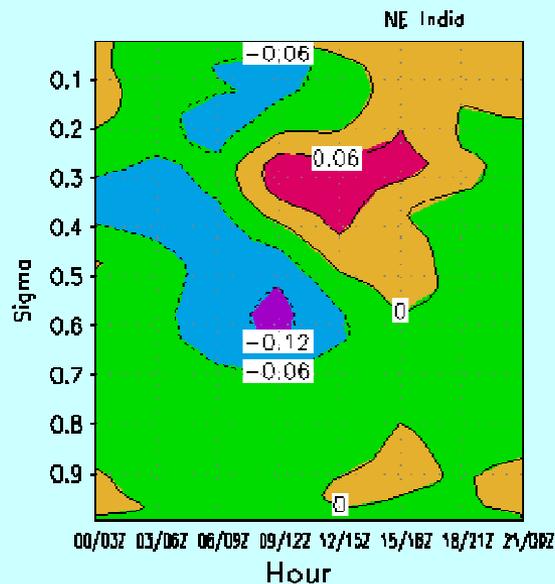
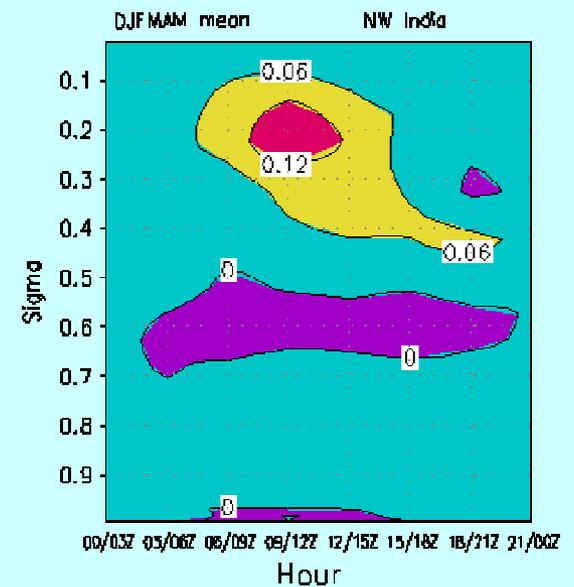
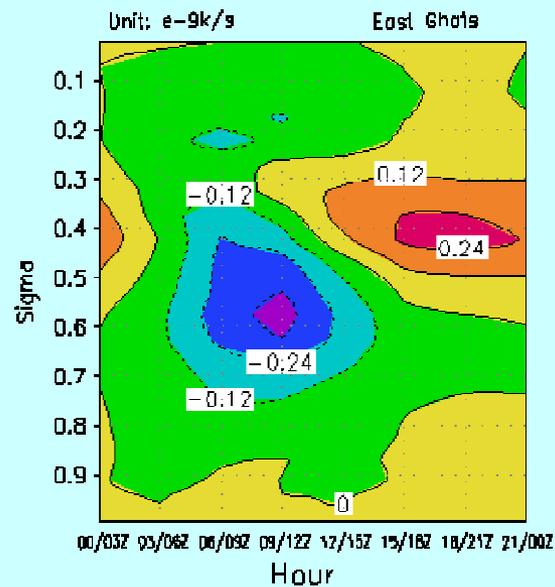
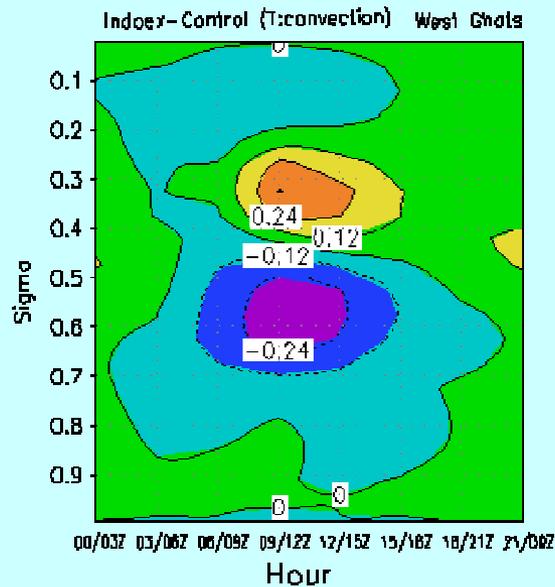
# Change in T



# Convective T Tendency

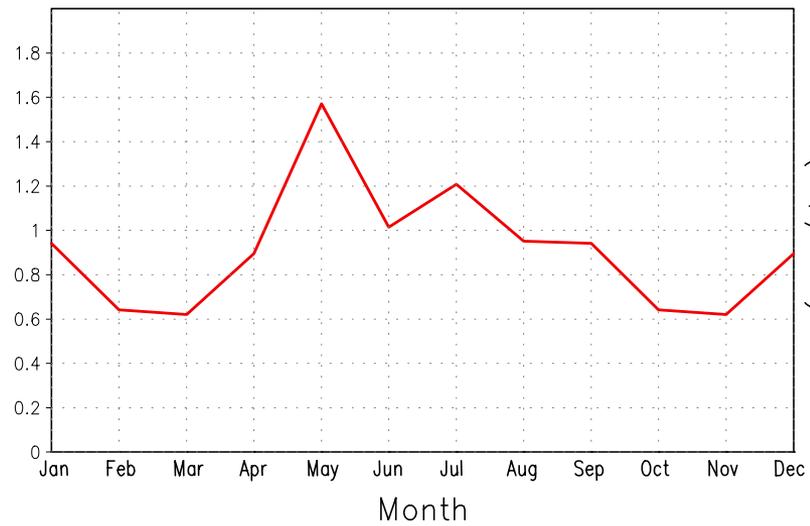


# Change in Convective T Tendency

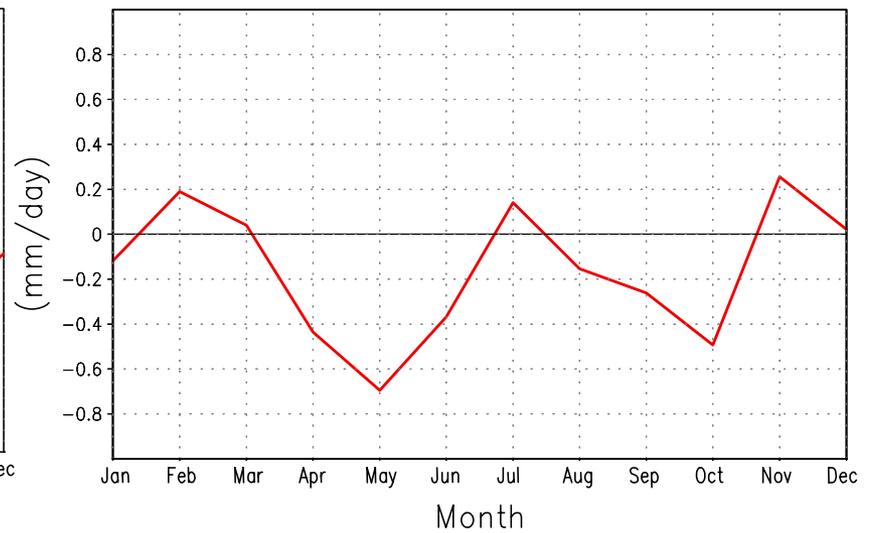


# Signal vs Noise

S.D. of Precipitation



Precipitation Change



# Summary

- Large spatial and temporal variability of precipitation presents a great challenge in simulating the regional hydrological cycle
- RCMs can improve simulation of land surface hydrology (seasonal mean, rain rates)
- Regional simulations are sensitive to lateral boundary conditions and model physics
- Robust hydrological response may be found as a result of threshold and/or positive feedback effects

# Summary

- Impacts of BC on regional hydrological cycle are likely smaller than model bias
- Model bias can have large impacts on estimating hydrological response
- Until we find coherent and robust signals, model uncertainty will likely dominate over uncertainty in BC emission in simulating hydrological response
- How is uncertainty in temperature and precipitation signals related to uncertainty in BC emission? How much change in water cycle can we tell by temperature signal alone?