An Overview of NRCM Research and Lessons Learned

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With NCAR MMM/CGD scientists, students (U. Miami, Georgia Tech), and visitors (CMA and Taiwan)

The NRCM effort was initiated in 2003 to develop regional climate modeling capability in WRF

- Downscaling
  - Address regional climate variability and change
- Process study
  - Understand regional earth system processes
- Upscaling
  - Address large scale biases in global models

Model Development

- Goal: To maintain a single version of WRF for weather and climate research

- Implementation of CCSM physics:
  - CAM radiation (WRF2.2)
  - CLM land surface model (WRF3)
  - Neale and Richter cumulus scheme (WRF3)
  - Morrison microphysics (WRF3)

- Generalize WRF framework for climate simulations (WRF2.2 and WRF3):
  - Updating of SST, sea ice, vegetation fraction, surface albedo
  - Diagnostic variables (e.g., ISCCP simulator, total/clear sky radiative fluxes, accumulated fluxes)
  - Cloud fraction used in radiative transfer
  - Sea surface skin temperature based on Zeng and Beljaars
  - Channel implementation (specified N-S, periodic E-W)

Model Development

- Preprocessor: Generate WRF inputs from GCM outputs (in WRF3)

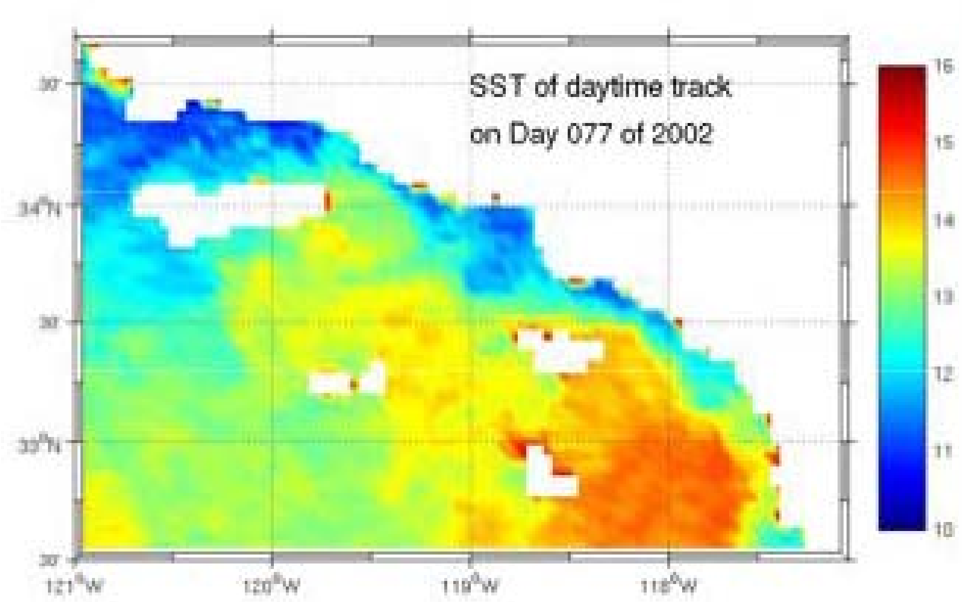
- Community efforts:
  - Coupling WRF and ROMS (UCLA)
  - Development of WRF-CHEM (NOAA, PNNL, and others)
  - Development of global WRF in WRF3 (Caltech/NCAR)

- Established WRF RCM working group to coordinate community efforts

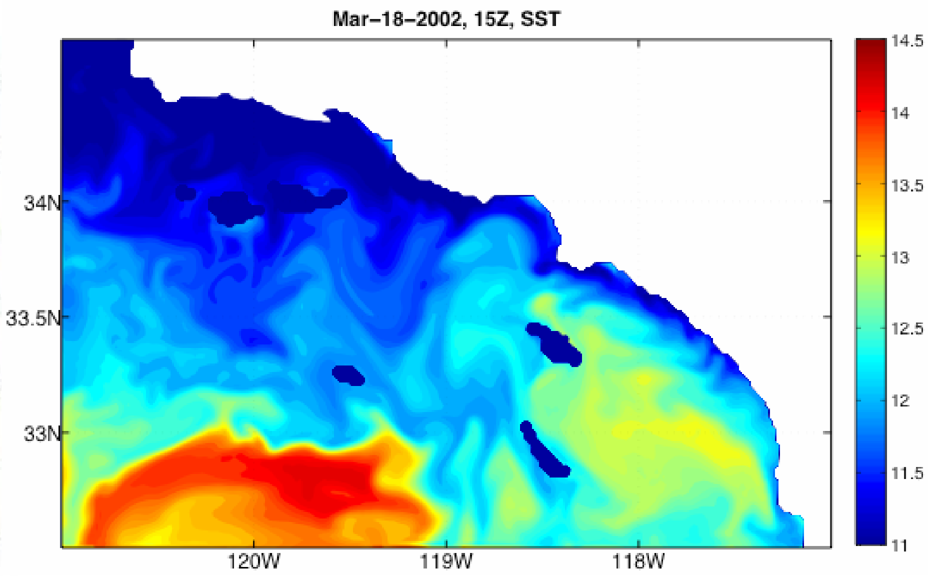
- Organized a RCM workshop in 2005 and identified three areas for model development and research (BAMS 2006):
  - Regional earth system modeling
  - High resolution modeling
  - Upscaling

WRF-ROMS Simulation of an Upwelling Event in Southern California

SST from the Pathfinder satellite on March 18, 2002



WRF-ROMS simulation on March 18, 2002 (WRF applied at 6 km and ROMS applied at 2 km resolution)



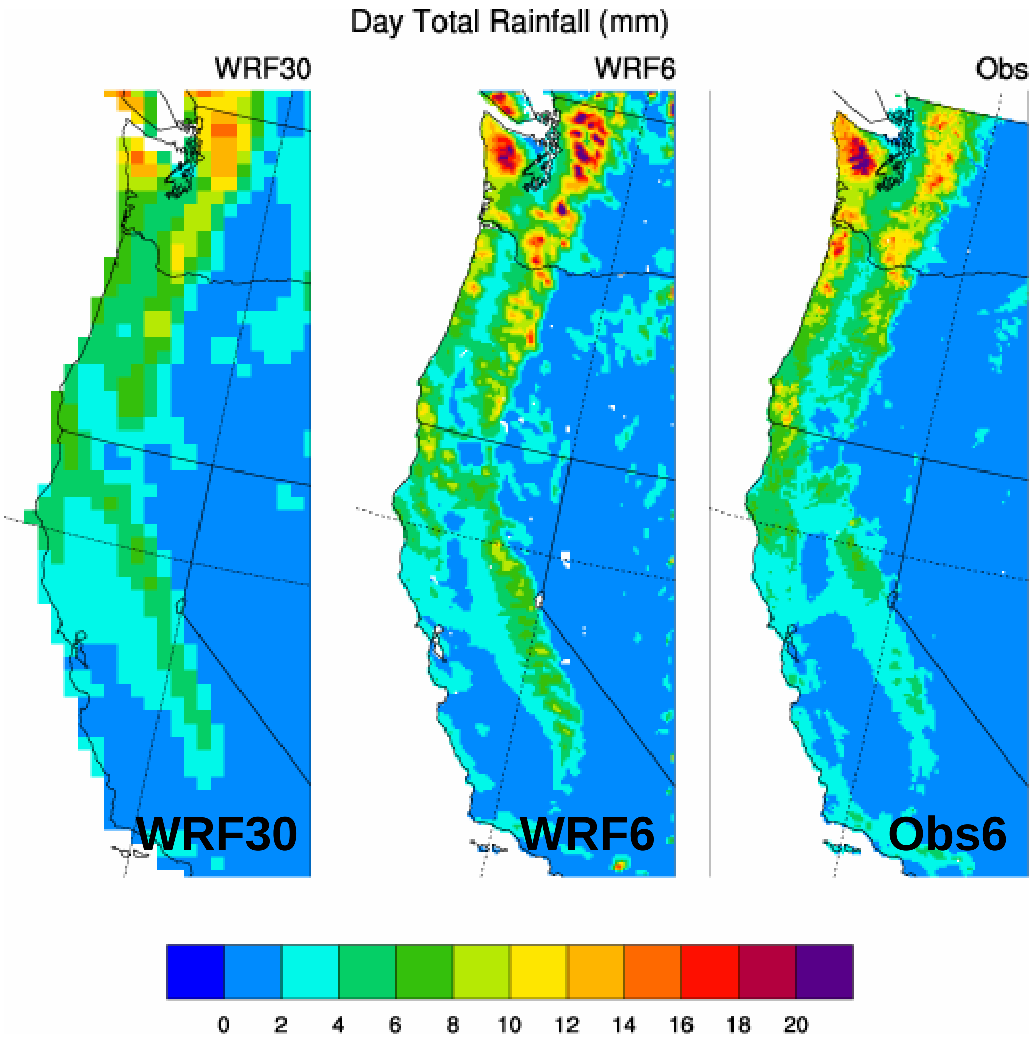
Source: Alex Hall and Jim McWilliams

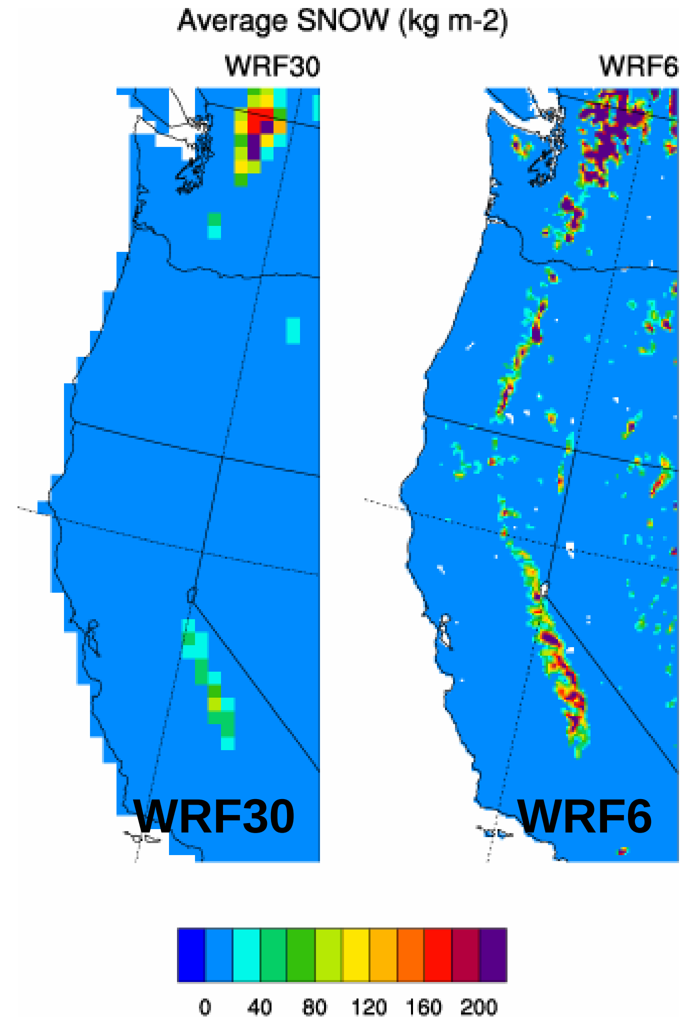
Outline

- Downscaling experiments
  - Western US
  - North America
  - NARCCAP
- Tropical channel experiments
  - Large scale circulation
  - Tropical modes
  - East Asian monsoon

Downscaling: Western US

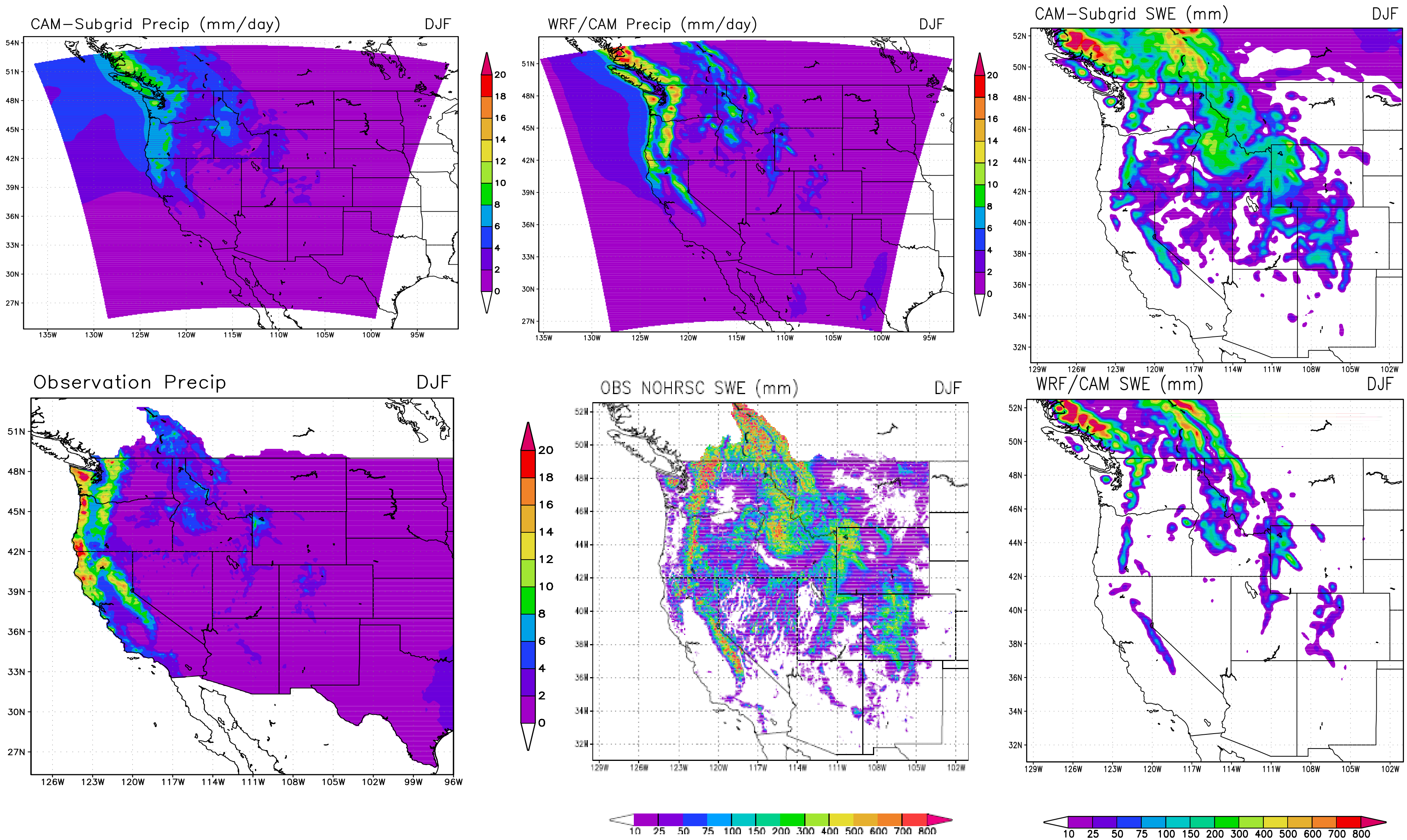
- Wet bias increases with increasing spatial resolution
- Wet bias not very sensitive to cloud microphysics
- Low bias in snowpack using the NOAH LSM with a snow emissivity of 0.9





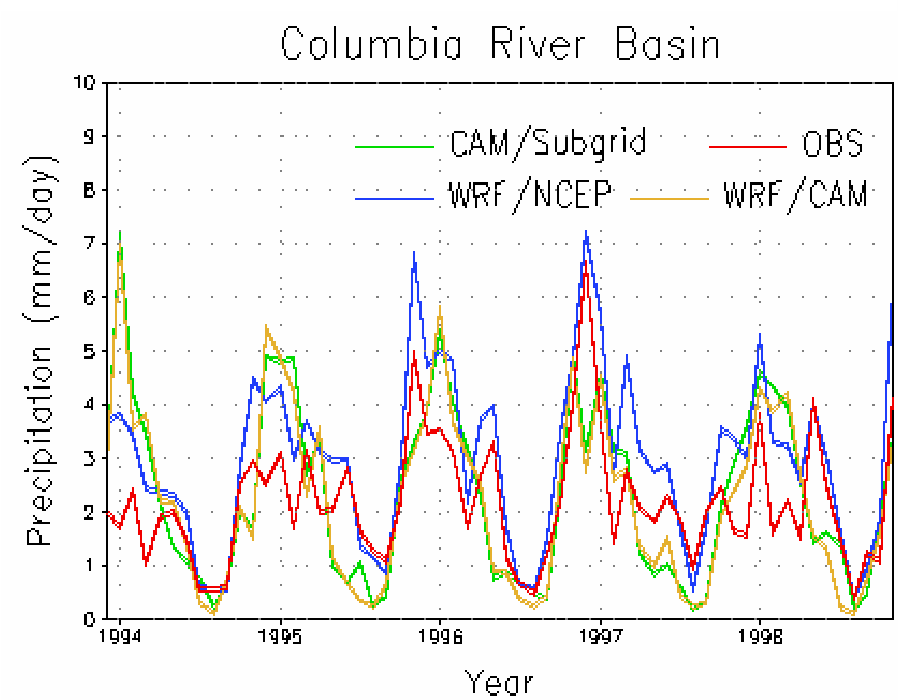
Downscaling: Western US

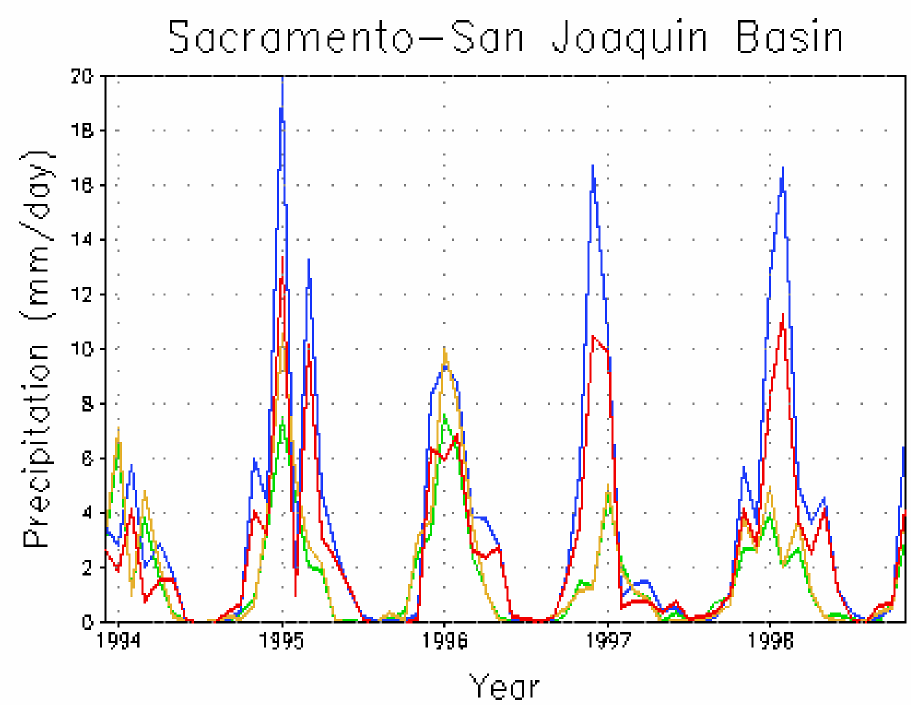
- When driven by CAM boundary conditions, WRF produced more realistic features of rain bands in the coastal mountains
- The CAM-subgrid simulation produced better snowpack



Downscaling: Western US

- In the cold season regime over large areas, P simply reflects the large scale moisture convergence
- When driven by global reanalysis, RCM almost always has higher large scale moisture convergence
- When driven by CAM, WRF preserves the large scale moisture convergence of CAM
- Without data assimilation, would global reanalysis produce much higher moisture convergence over land based on its moisture flux from the Pacific Ocean?

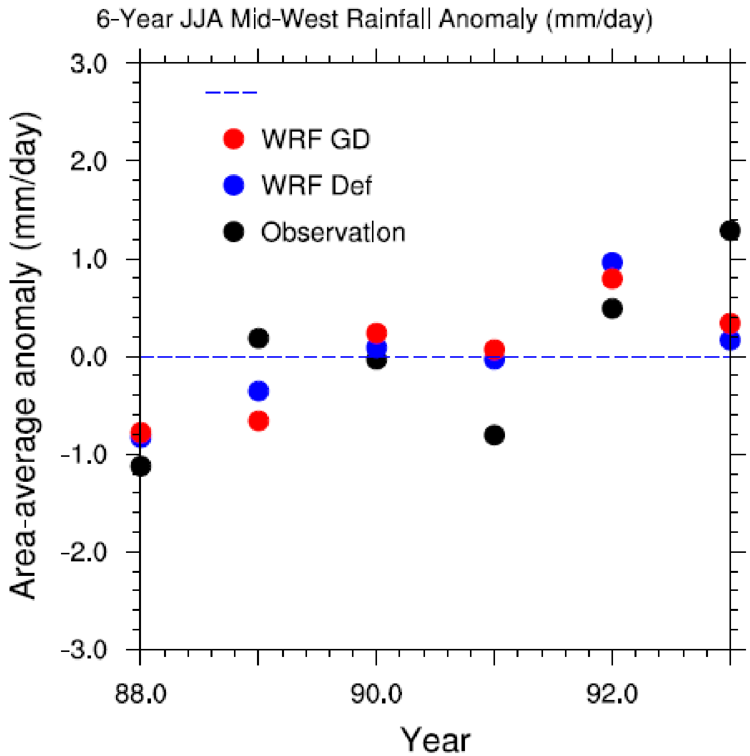




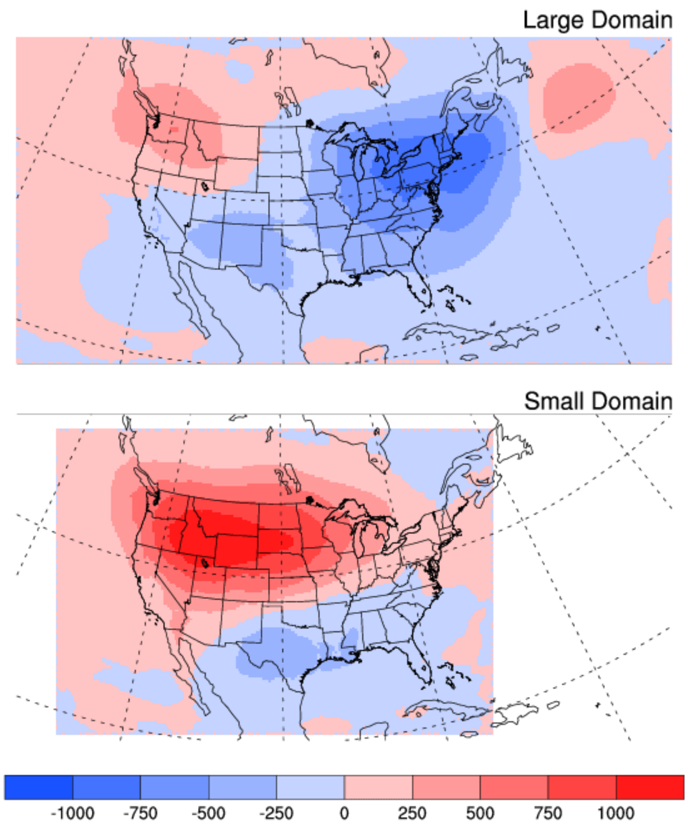
Downscaling: North America

- Investigated biases in warm season precipitation and its interannual variations in the central US
- GD produces more rainfall than KF, but does not improve simulation of interannual variability
- Large scale bias masks the interannual variations in large scale circulation, and hence precipitation

JJA rainfall anomaly in the Midwest



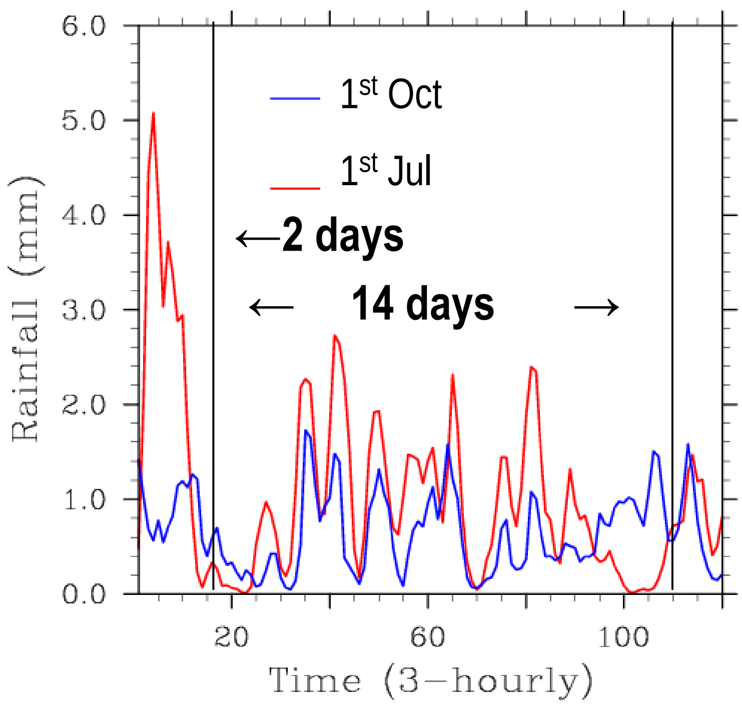
Error in 300mb height



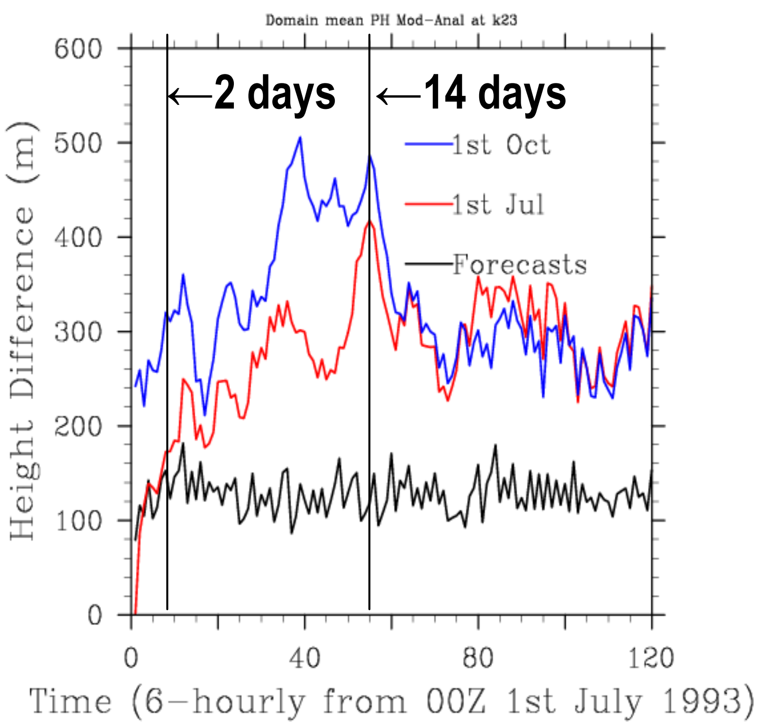
Downscaling: North America

- Error growth:
  - Fast adjustment of 2 days
  - Slow adjustment of 14 days before reaching an equilibrium

Flood Region Rainfall



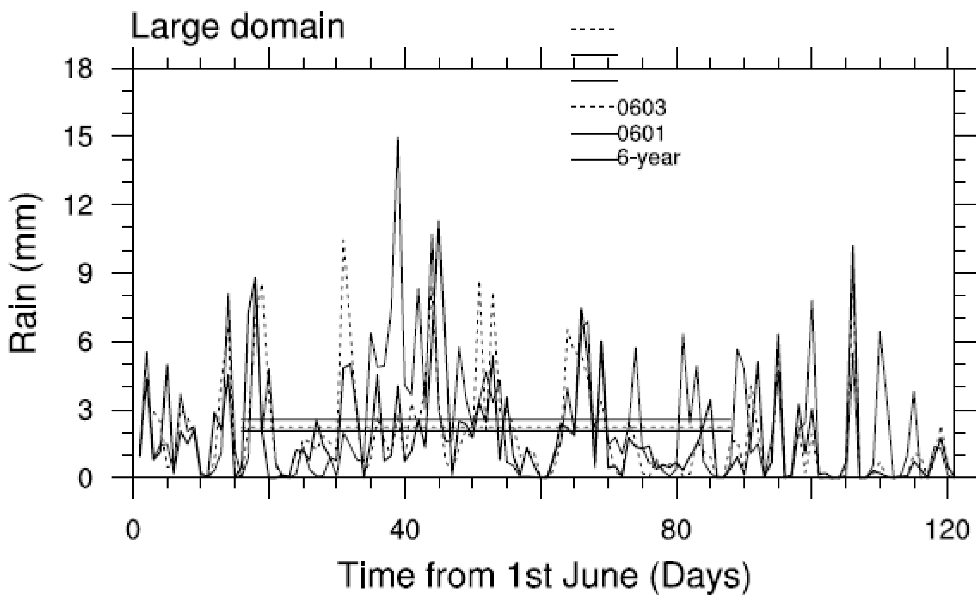
Domain Mean 500mb Height



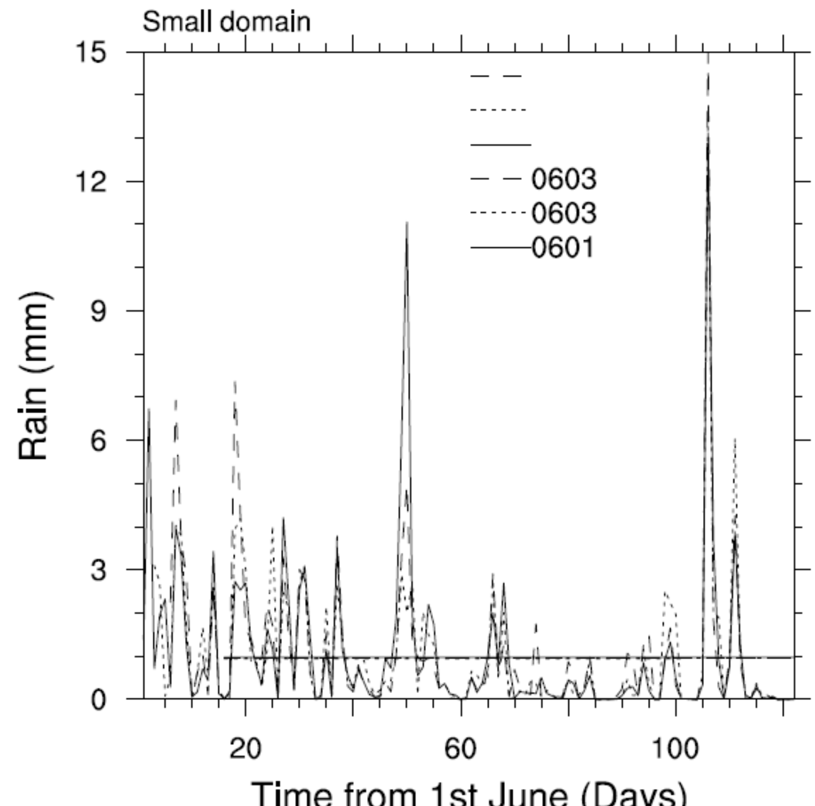
Downscaling: North America

- Impacts of internal model variability (IMV) for the large domain can be as large as impacts due to physics or domain sizes
- Implications for testing physics parameterizations

Effects of IMV in a large domain

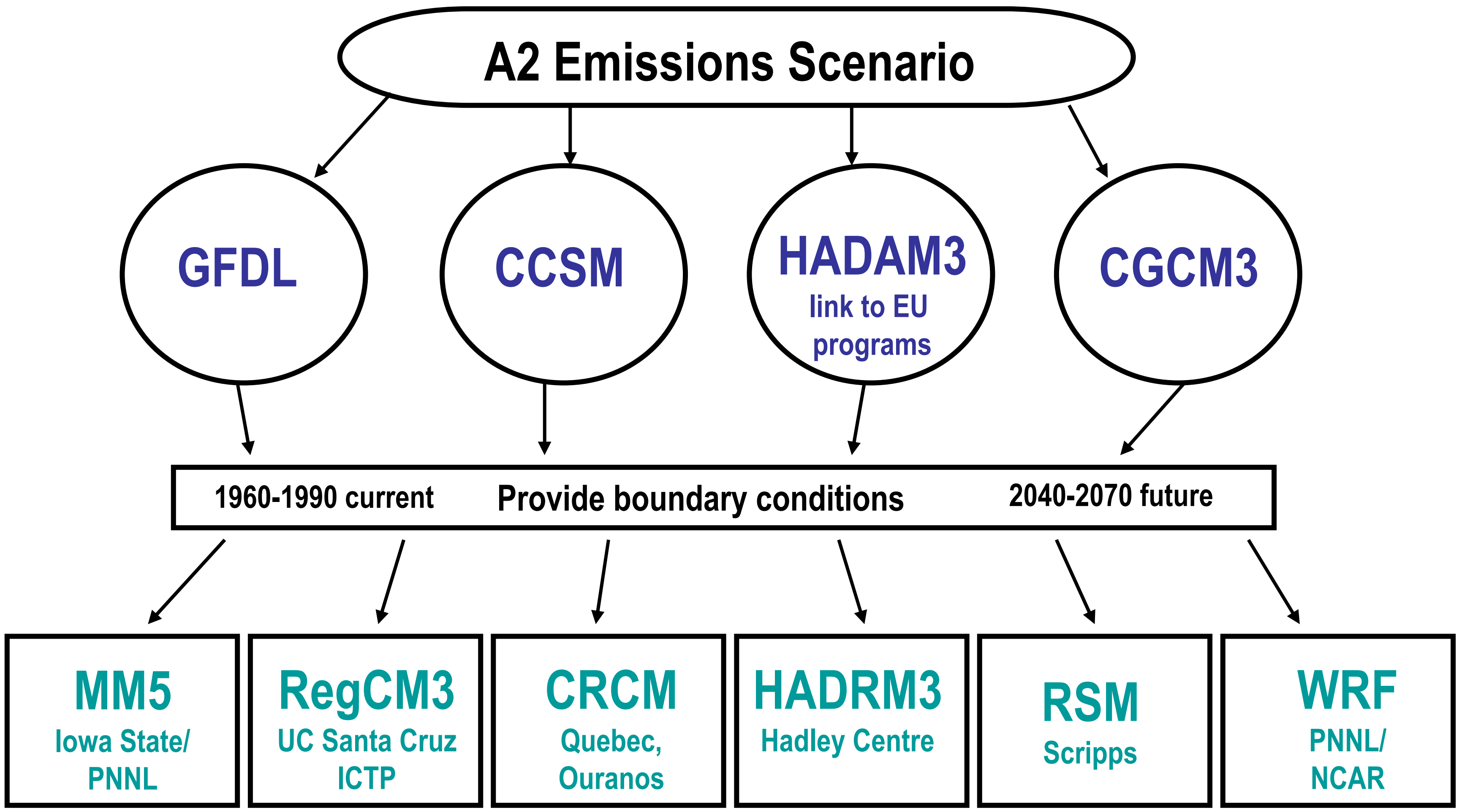


Effects of IMV in a small domain



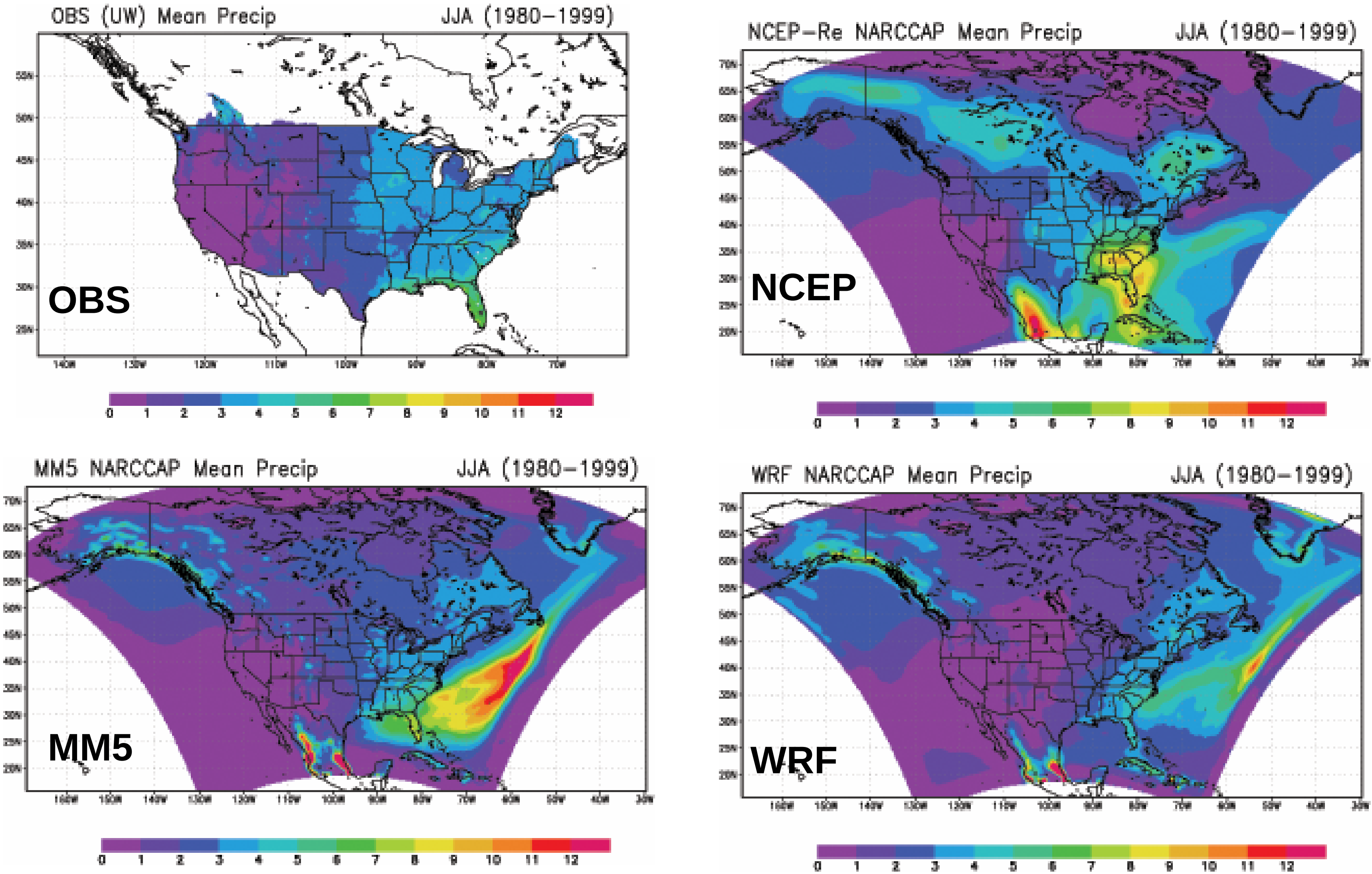
North American Regional Climate Change Assessment Program (NARCCAP)

- Develop multiple regional climate change scenarios for North America
- Quantify uncertainties in climate model projections

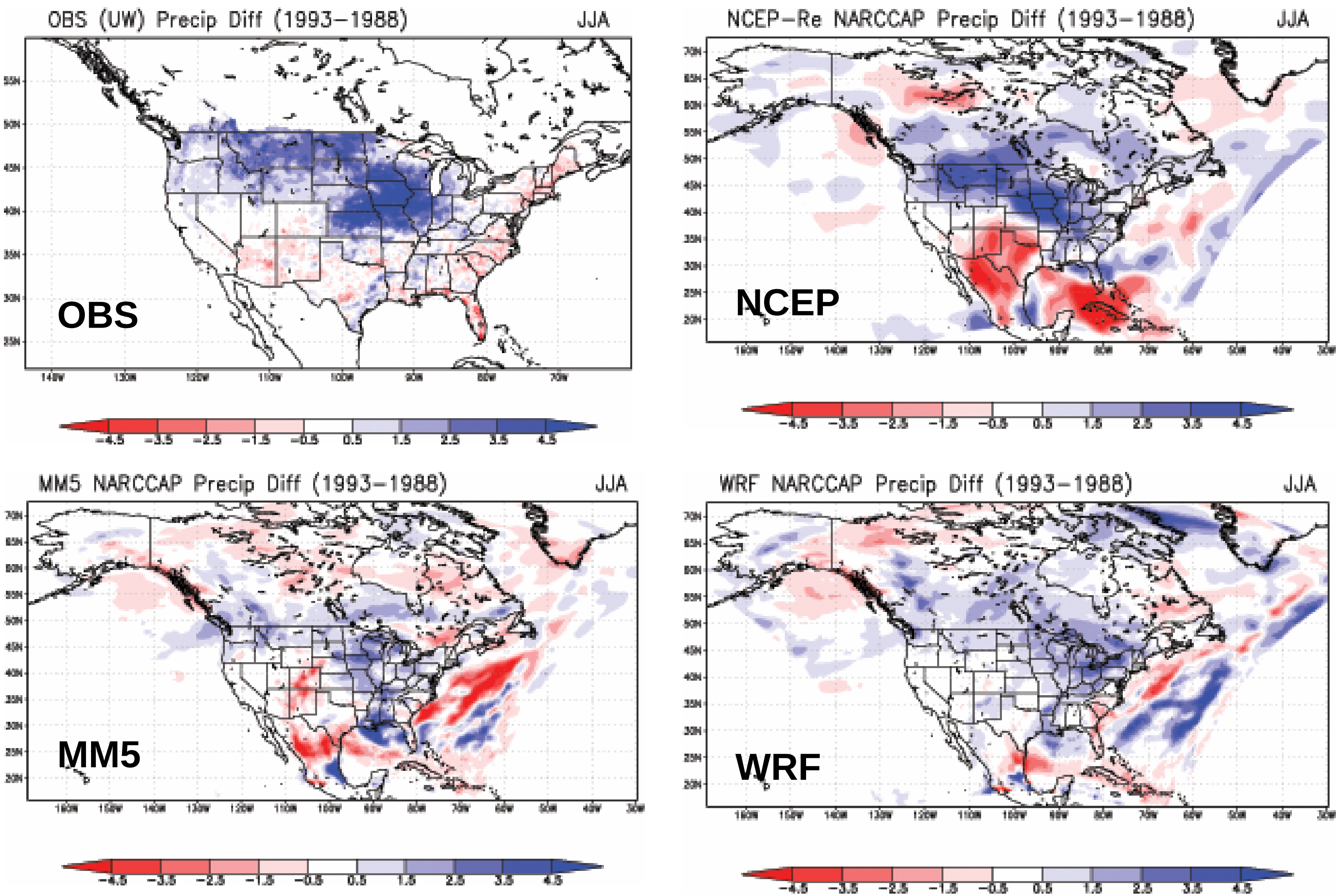


JJA Mean Precipitation

Regional simulations driven by NCEP/NCAR global reanalysis for 25 years at 50 km spatial resolution

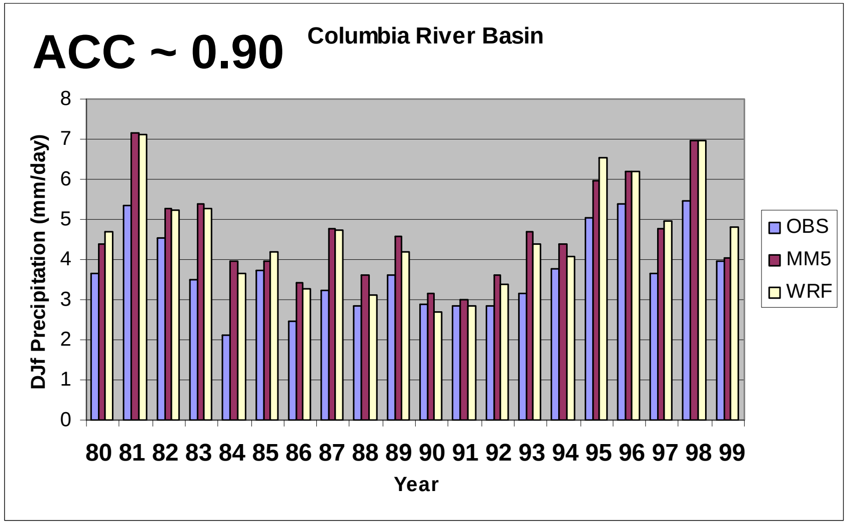


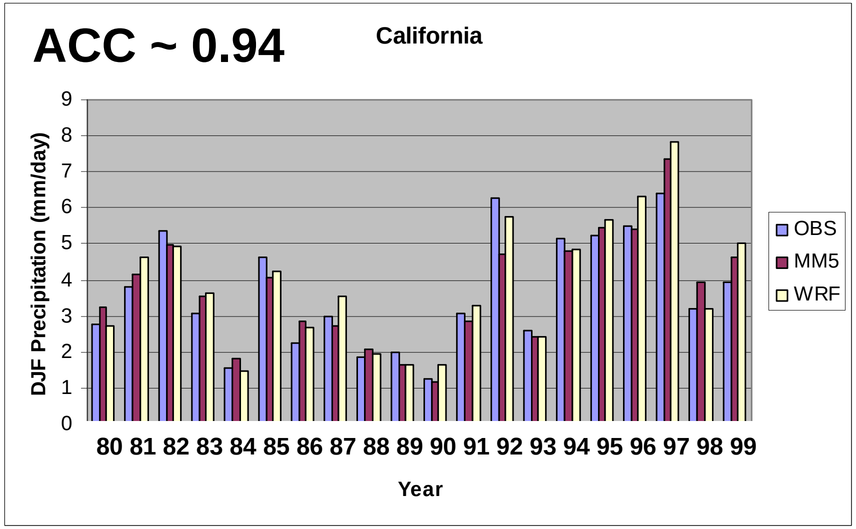
JJA Precipitation Anomaly (1993 – 1988)

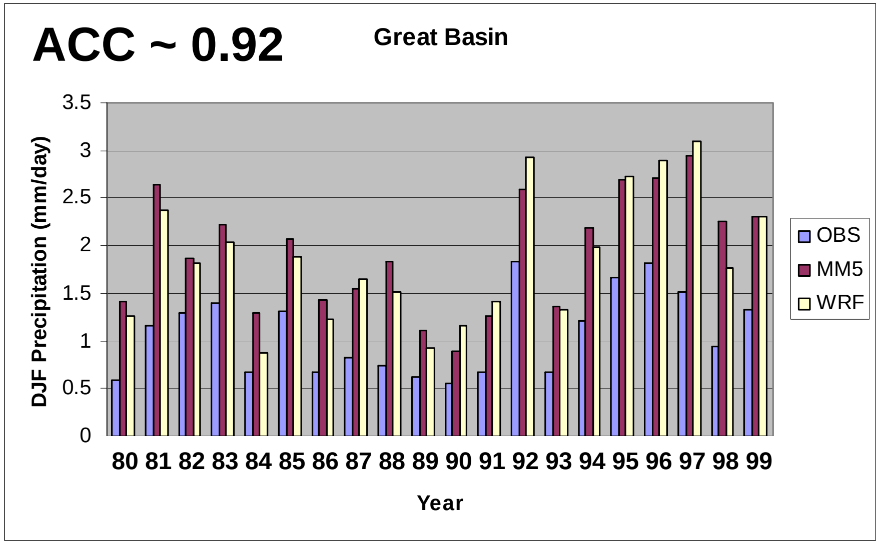


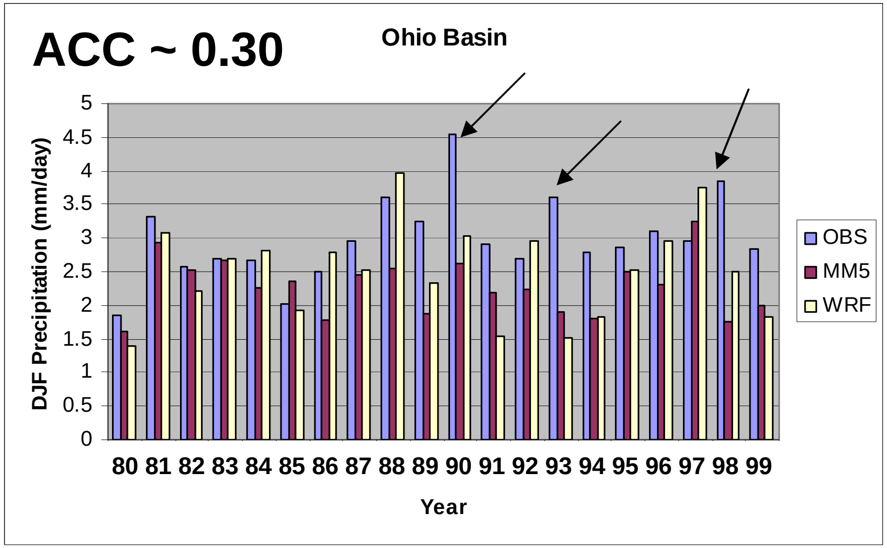
Cold Season Variability

WRF and MM5 have similar skill in capturing cold season variability





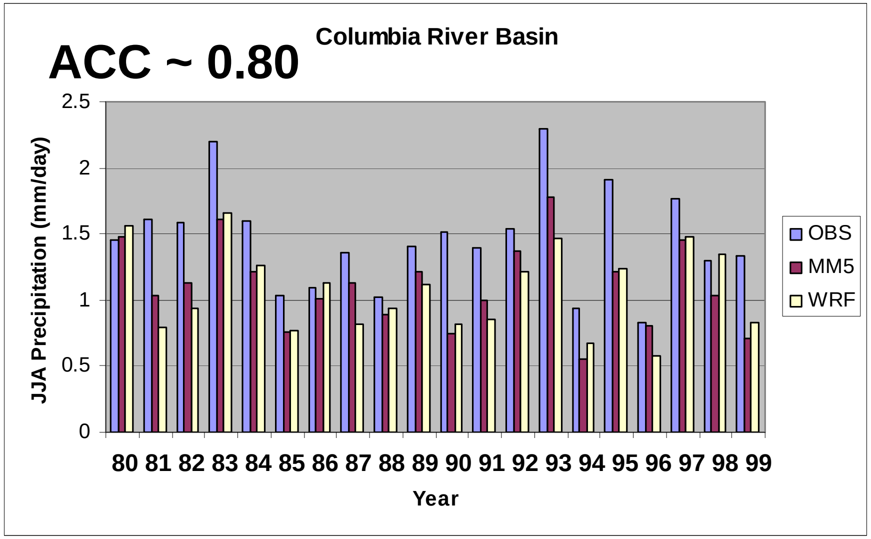


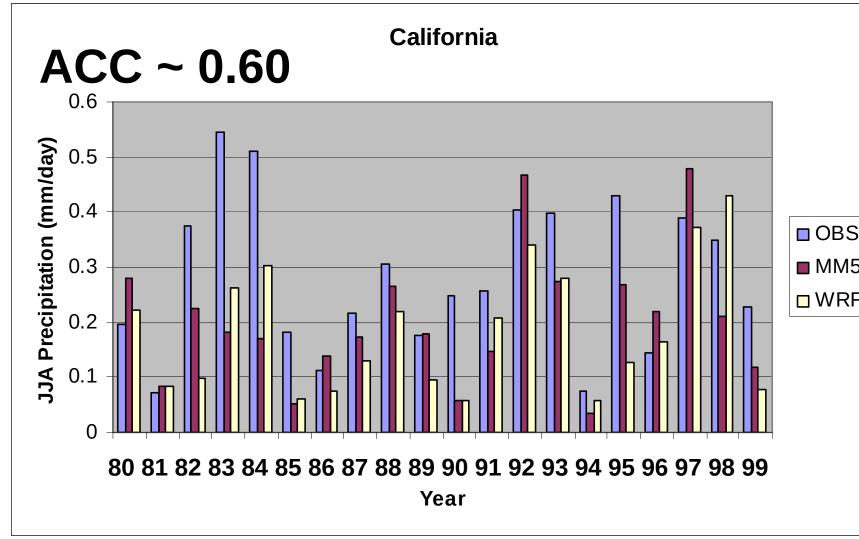


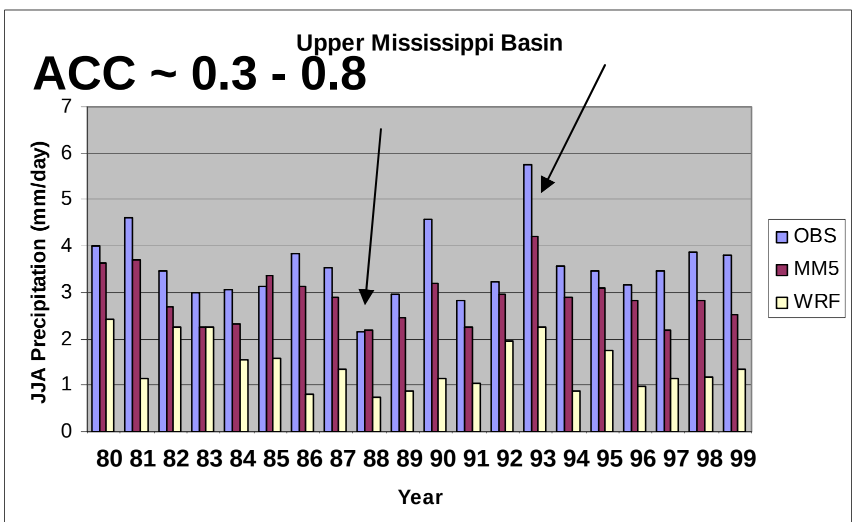
ACC ~ 0.60 in NCEP

Warm Season Variability

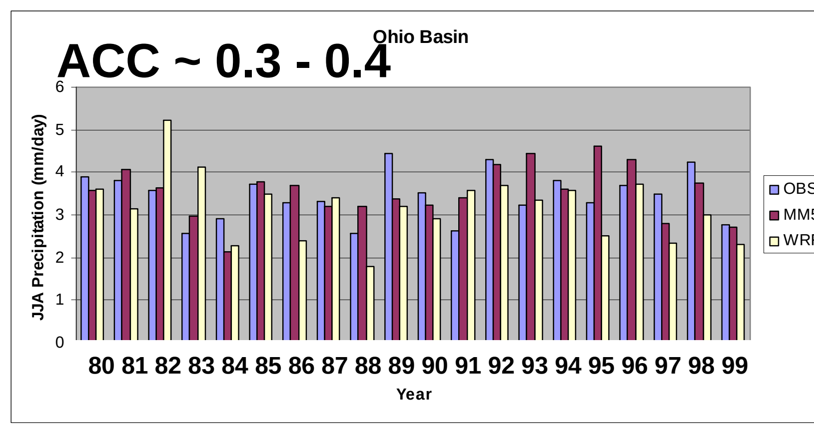
Larger differences between WRF and MM5 skill in capturing warm season variability; differences traced to new vs old KF scheme







ACC ~ 0.60 in NCEP

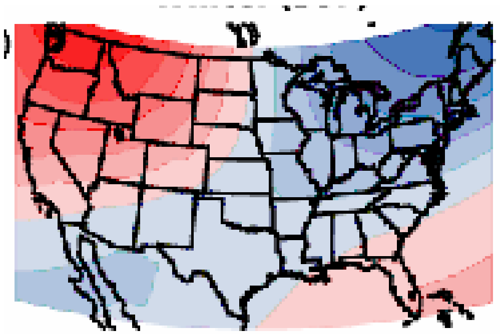


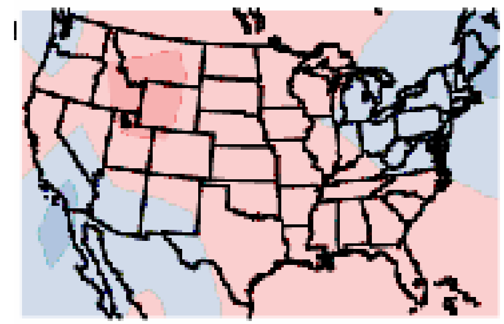
ACC ~ 0.17 in NCEP

Impacts of large scale circulation biases

Anomalous 500-hPa height during winter

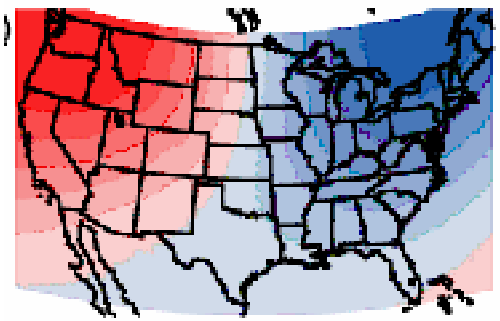
NARR



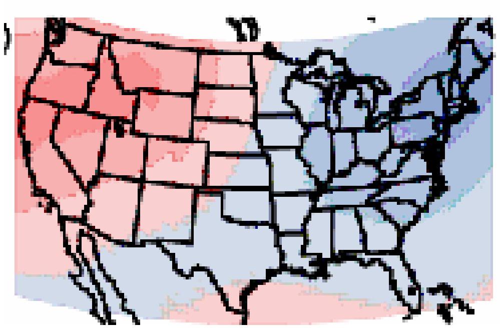


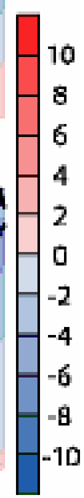
GCM
(GISS R15)

RCM
driven by
NRA



RCM
driven by
GCM





Using a large domain, RCM may correct some large scale biases from the lateral boundary conditions, but successful downscaling requires improvement in GCM simulations and better understanding of regional processes

What Have We Learned?

- When applied at horizontal resolution of 10 – 40 km, WRF has similar performance compared to MM5 for both cold season and warm season precipitation in the US

- Interannual variations of precipitation are well captured in the cold season regime (e.g., western US where ACC > 0.9), but less so in the warm season regime (e.g., central US where ACC is between 0.2 – 0.5)

- Need further investigations of the source of large scale biases that limit skill in simulating interannual variability in the summer:

  - physics parameterizations

  - boundary treatment

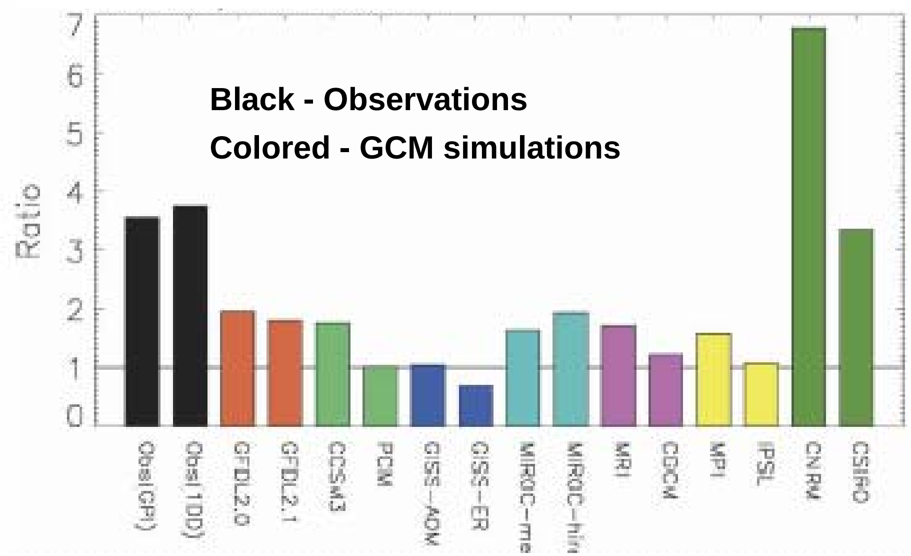
  - errors in the lateral boundary conditions (over the oceans)

- Need to assess advantages and disadvantages of evaluating RCMs and their physics parameterizations using global reanalysis versus global climate simulations

Process Study and Upscaling

- Convective latent heat release in the tropics modulates the large-scale circulations and excites tropical modes that influence both the tropical and extra-tropical climates
- Most GCMs exhibit large tropical biases, including simulations of the ITCZ, tropical modes, diurnal cycle, and hurricanes
- The lack of scale interactions in GCMs could be the most critical factor responsible for the tropical biases
- Will two-way coupling of WRF and CAM in “hot spots” help address tropical biases in GCMs?

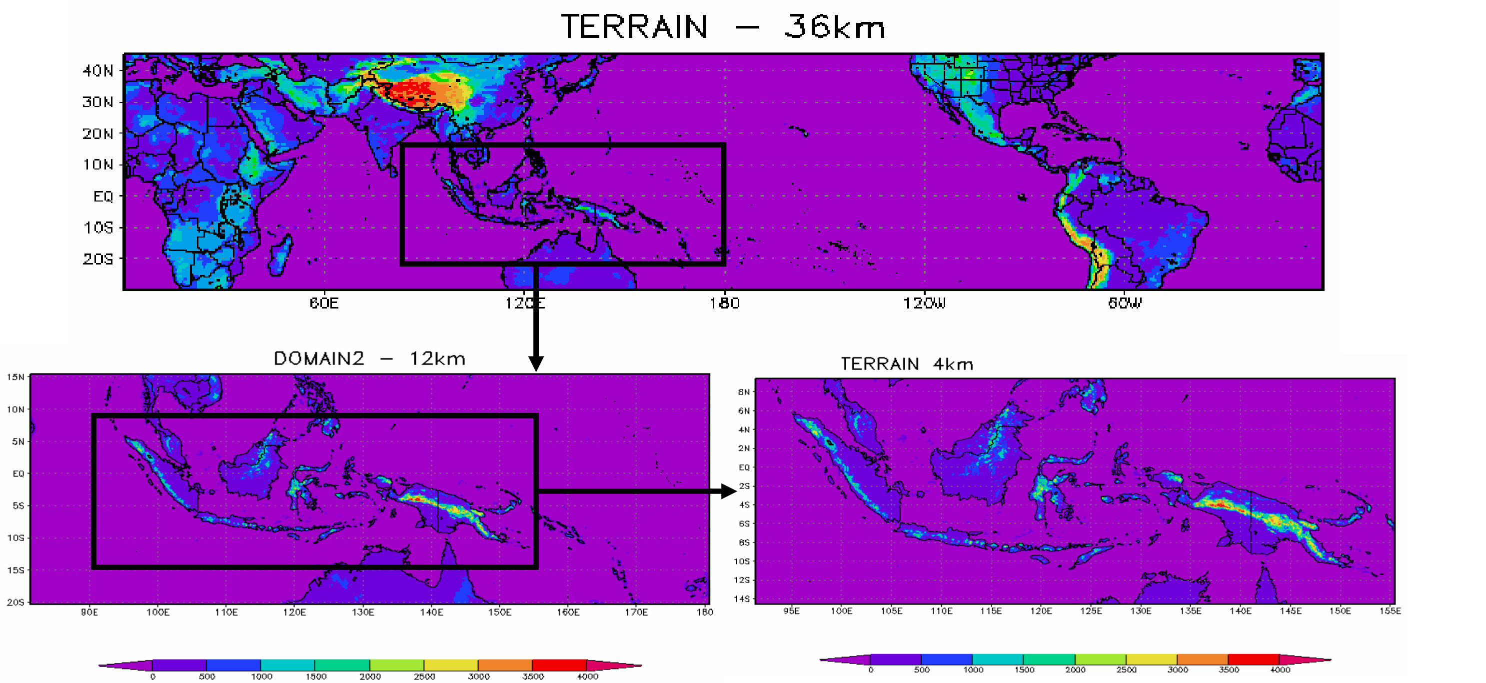
Eastward vs westward MJO variance in the Indian Ocean (Lin et al. 2006)



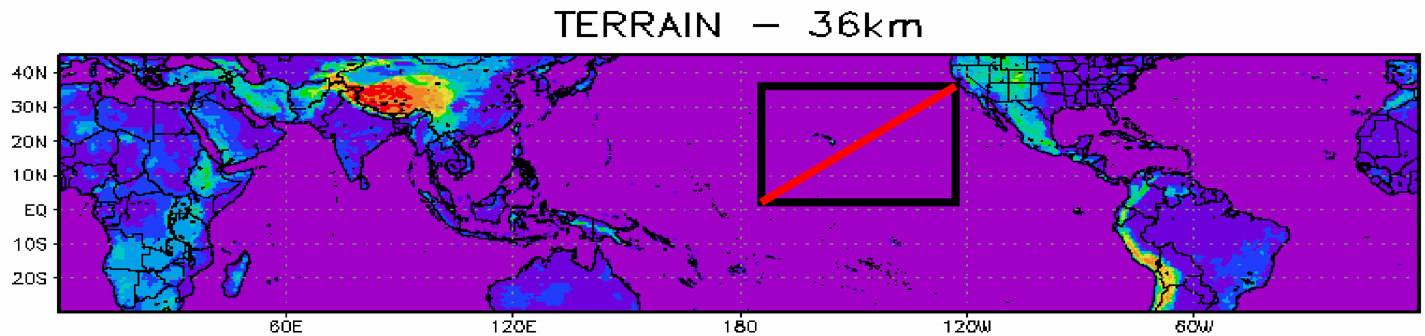
WRF Tropical Channel Simulations

- WRF has been configured as a tropical channel at 36 km resolution to simulate tropical phenomena
- A cloud resolving nest at 4 km resolution is embedded over the Pacific warm pool - the heat engine of the tropics - to investigate tropical convection and its upscaled effects
- Simulations were performed on the NCAR Bluevista and NASA LCF Columbia using 132 to 496 processors for 5 years each

Tropical channel configuration



Large Scale Circulation Features

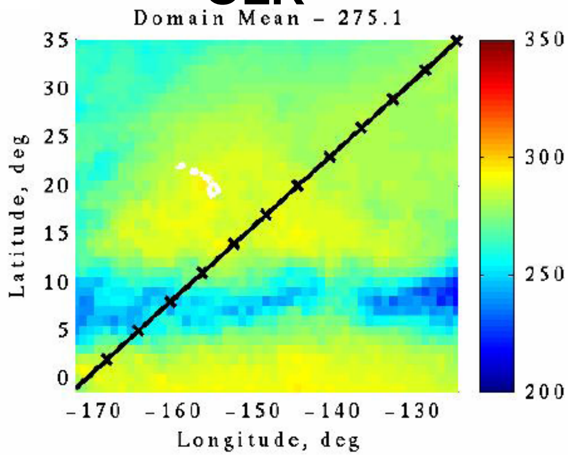


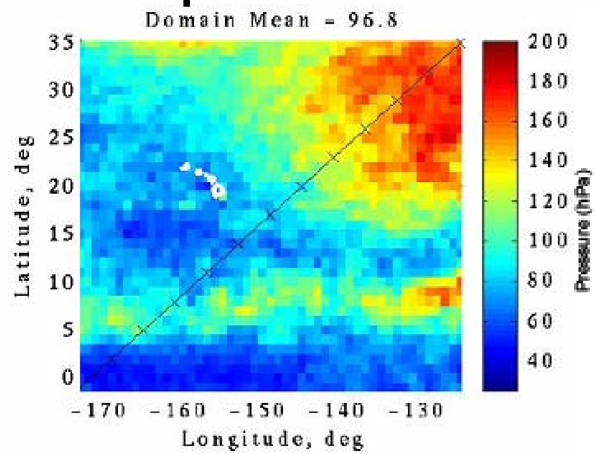
OLR

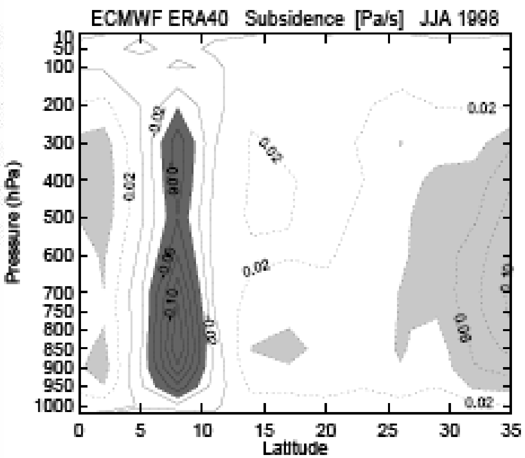
Upward SW

Upward motion

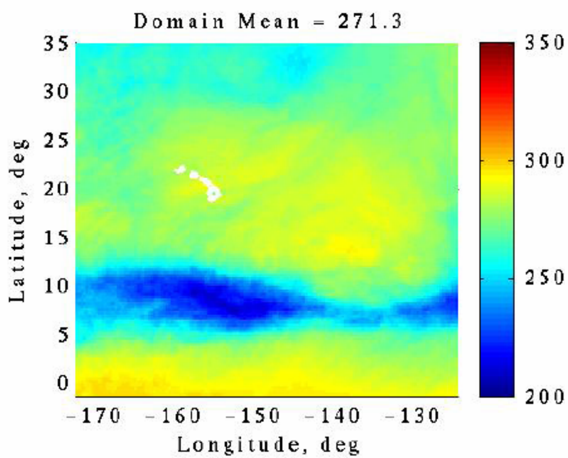
OBS

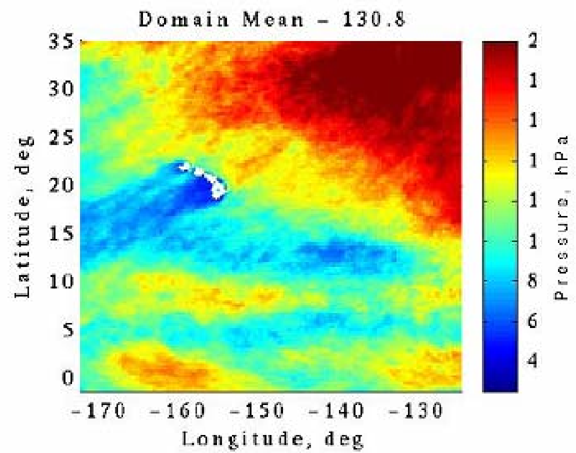


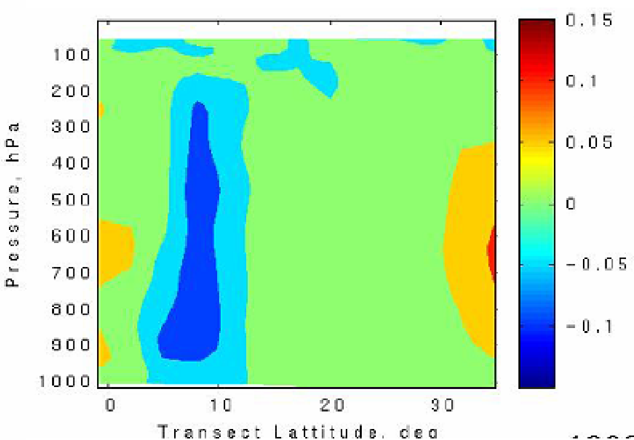




NRCM



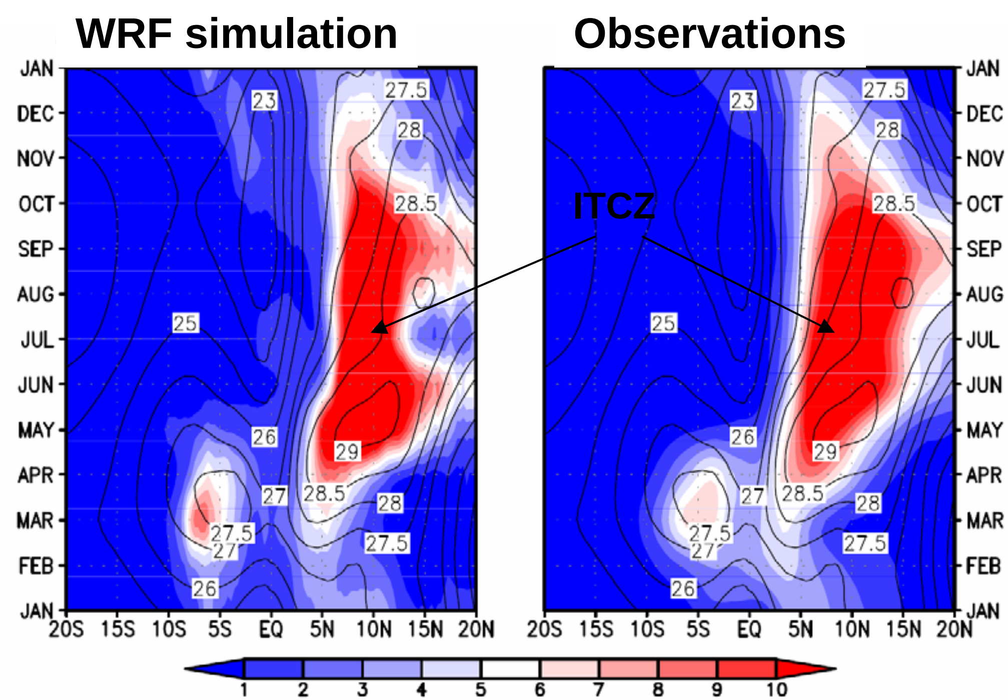




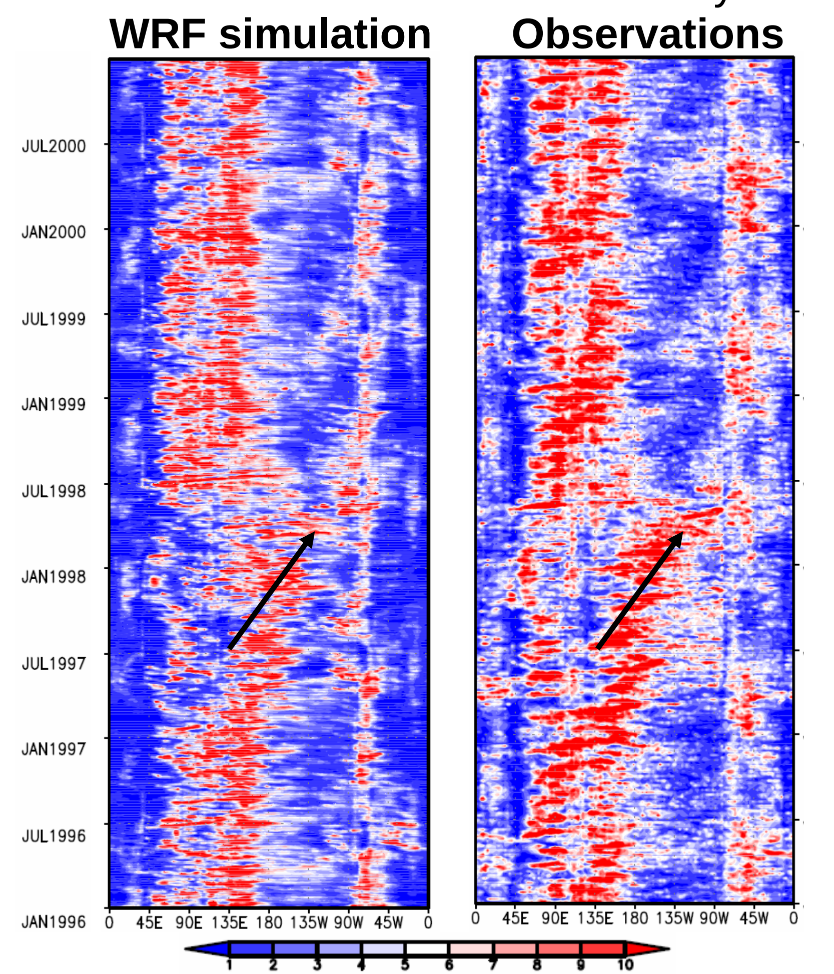
Large Scale Circulation Features

- The simulation shows some realistic climate features of the tropics, including the ITCZ and precipitation response to ENSO forcing

Seasonal evolution of the ITCZ well simulated over the eastern Pacific (90-120W)



Precipitation averaged over 10S to 10N: Rainfall shifted eastward in response to the 1997 El Nino SST anomaly

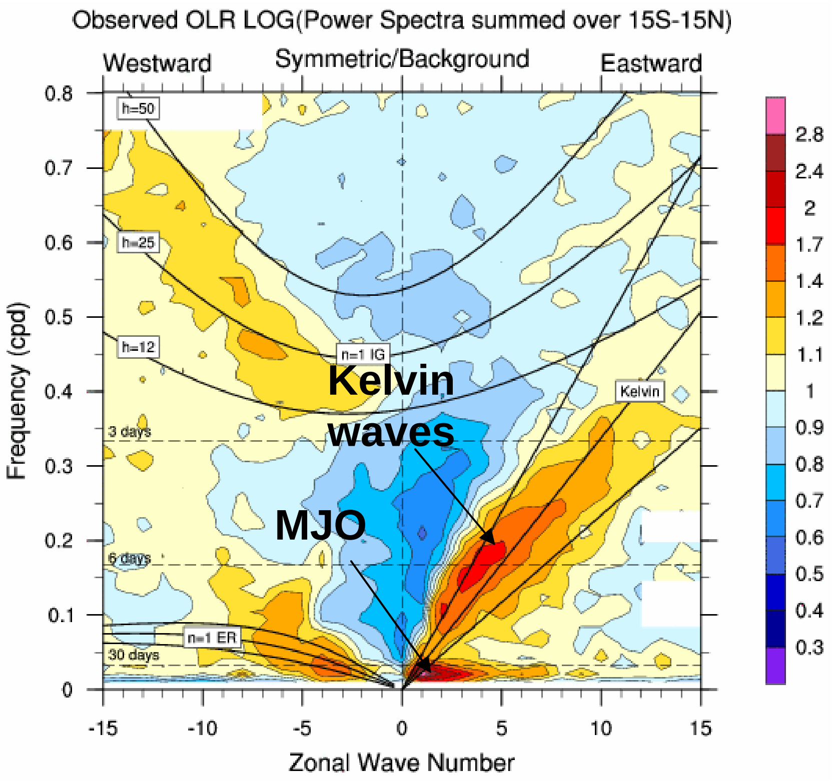


Source: Ray Pallav

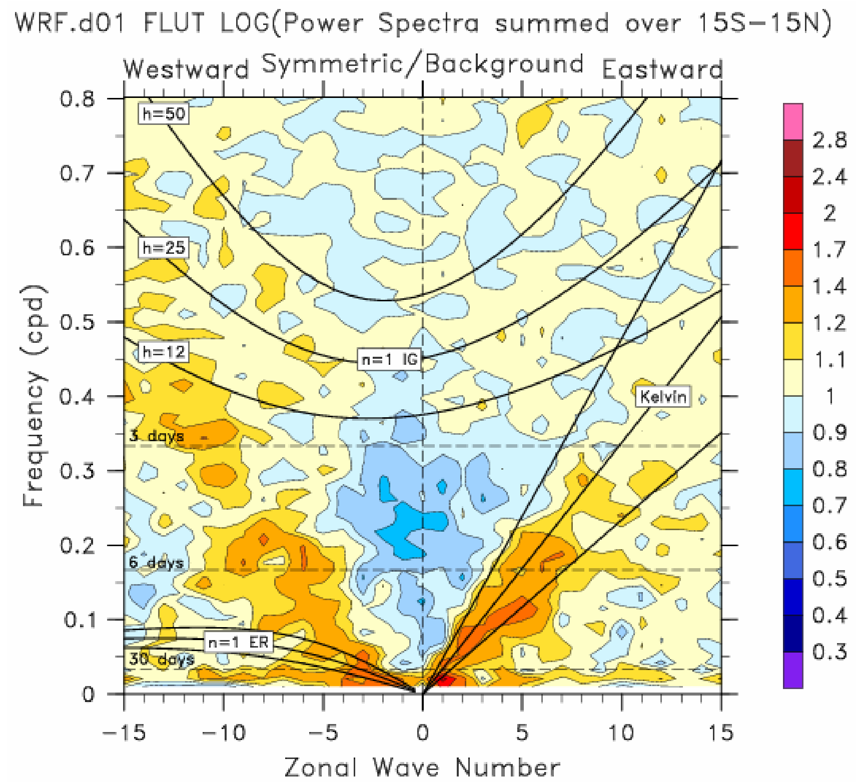
Tropical Modes

- WRF reasonably captured various tropical modes, including the eastward traveling Kelvin waves and MJO

Observed power spectra



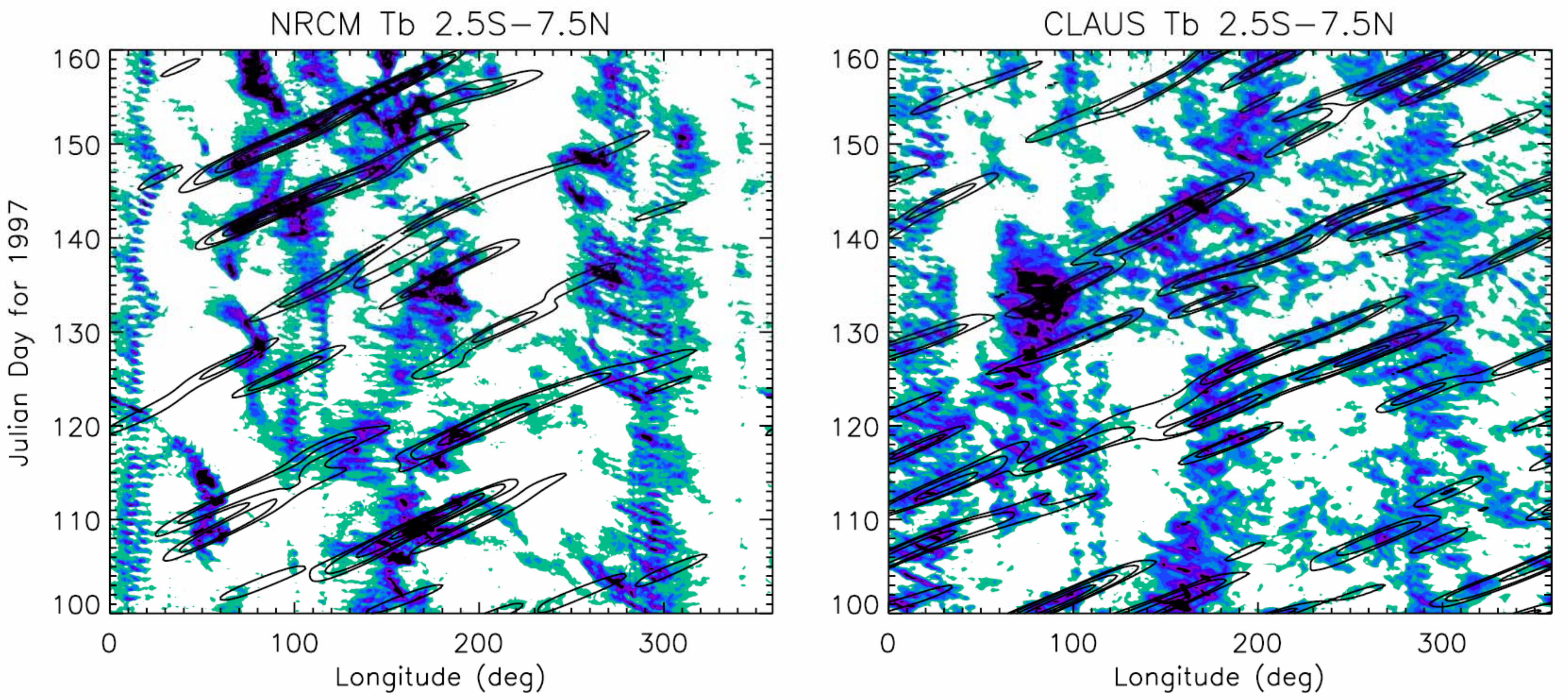
Simulated power spectra



Source: Julie Caron

Tropical Modes

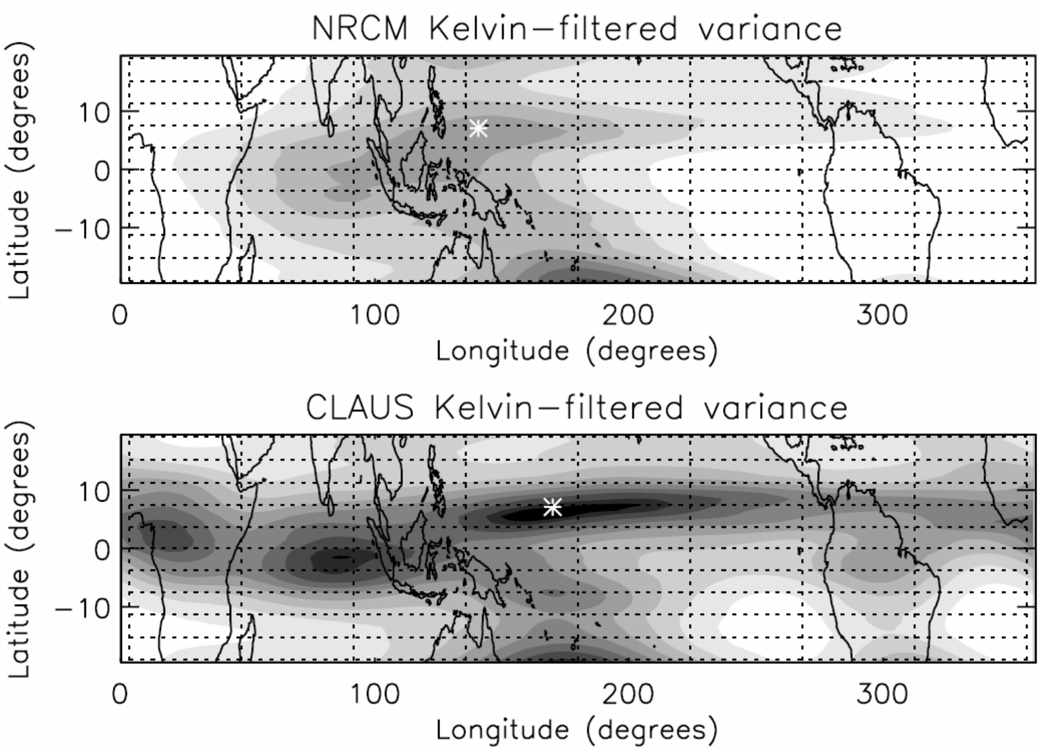
- More organized eastward propagating tropical waves in the observations over the India Ocean, South America, and West Africa

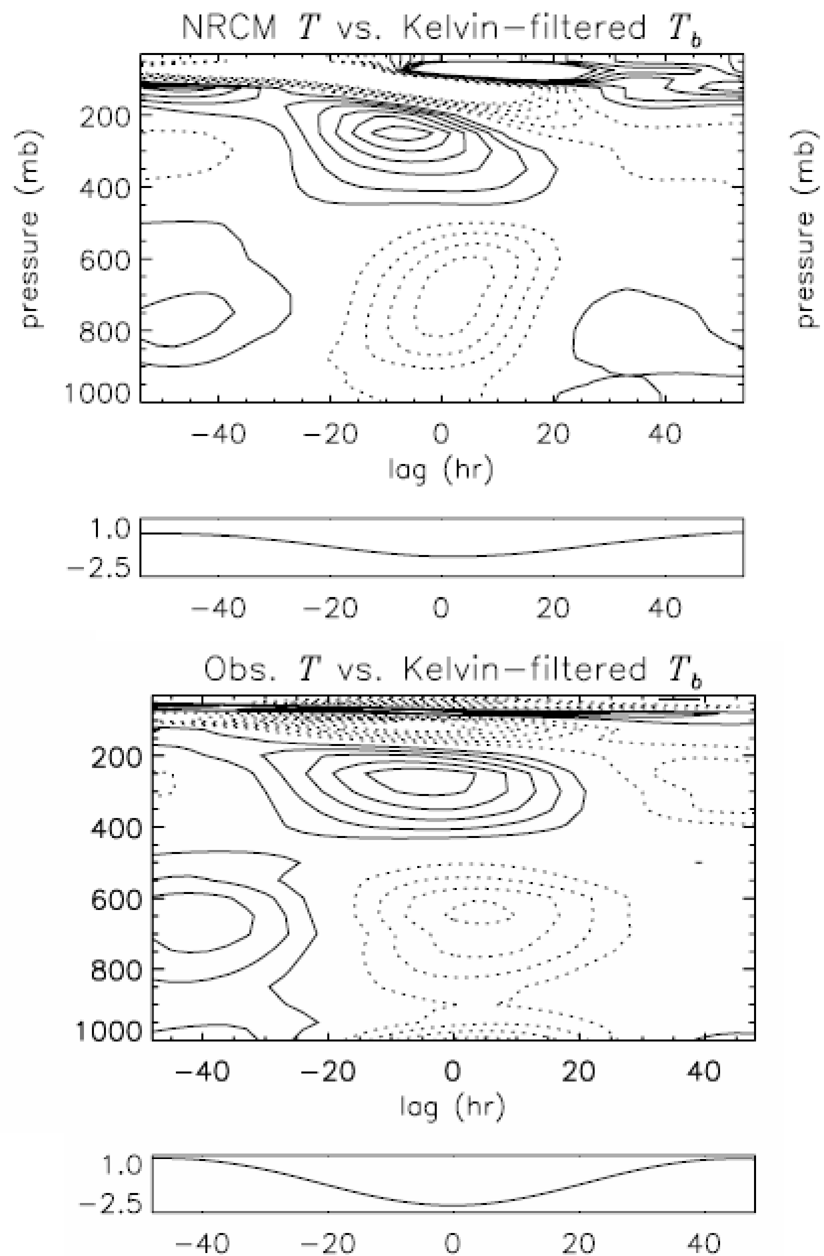


Source: Stefan Tulich

Kelvin Wave Variance and Structure

- Low Kelvin wave variance in the deep tropics
- Simulated realistic structures of Kelvin waves



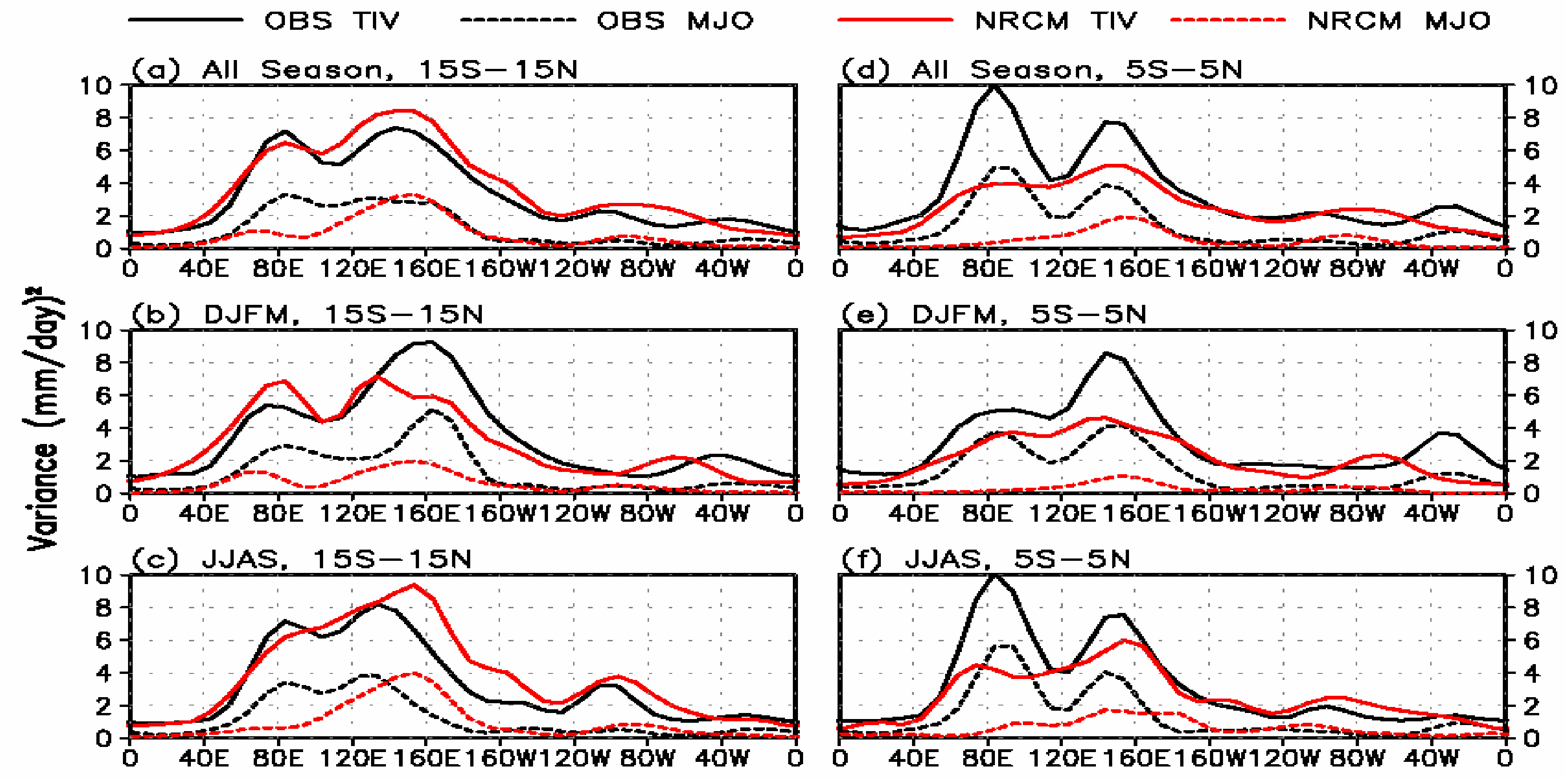


Source: Stefan Tulich

MJO Variance

- Insufficient TIV (total intraseasonal variance) and MJO variance in the deep tropics, particularly over the Indian Ocean

MJO variance and Total Intraseasonal Variance (TIV) of precipitation

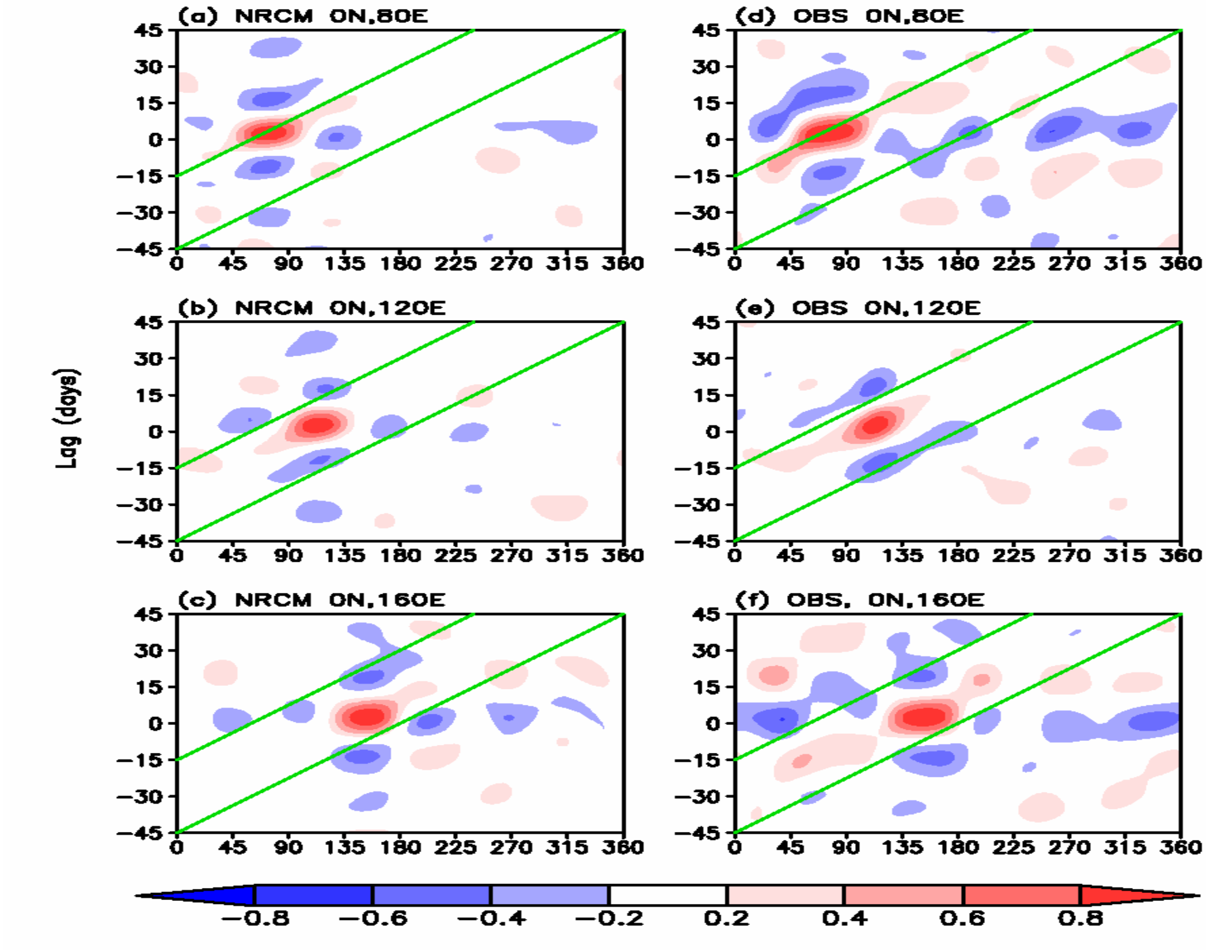


Source: Ray Pallav

MJO Propagation

- MJO propagation speed fairly well captured by model

Lag-correlation of 20-90 day precipitation

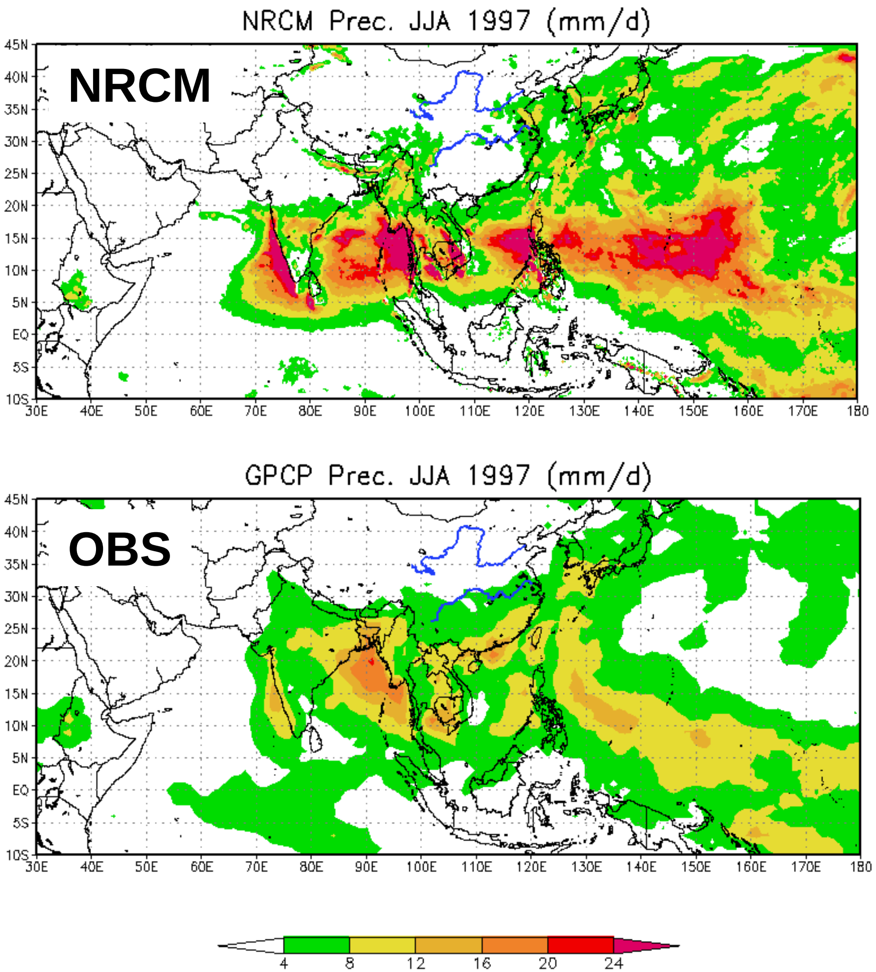


Source: Ray Pallav

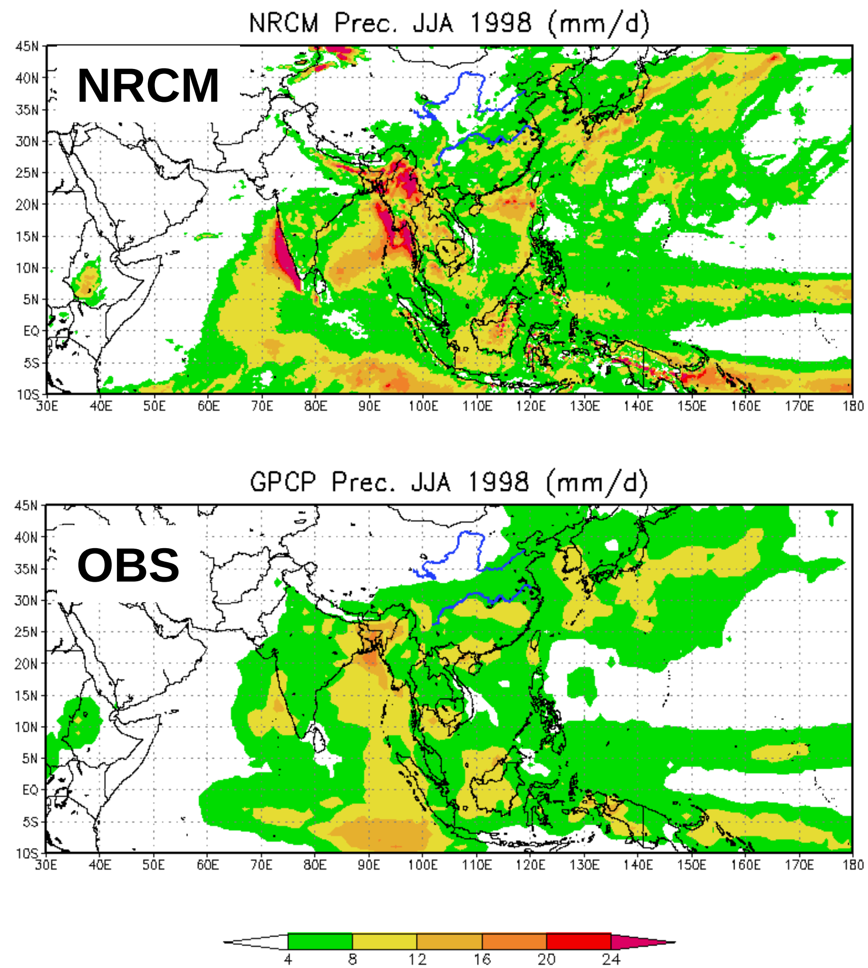
East Asian Monsoon

- Generally there are dry biases in the summer monsoon rainfall in East Asia, except for 1998

Summer Rainfall 1997



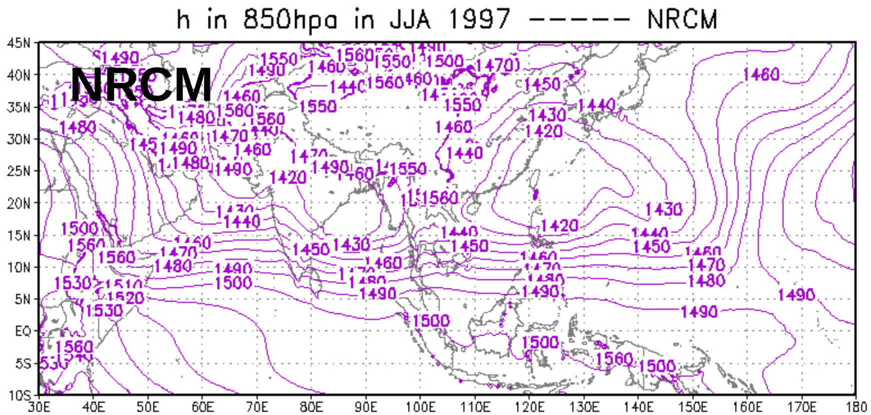
Summer Rainfall 1998

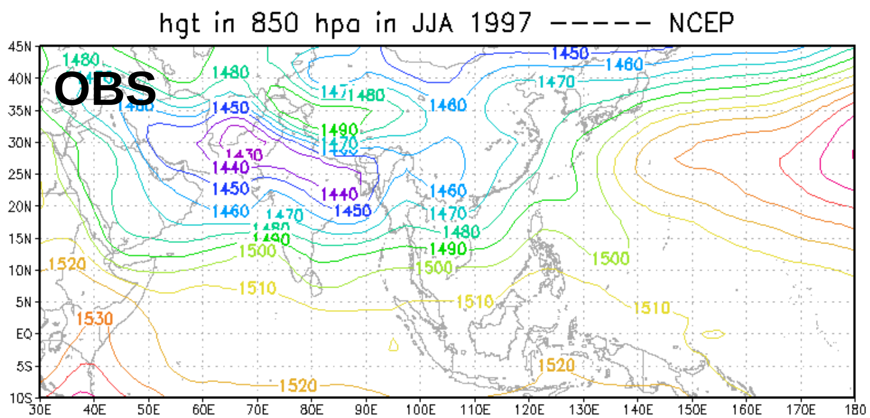


East Asian Monsoon

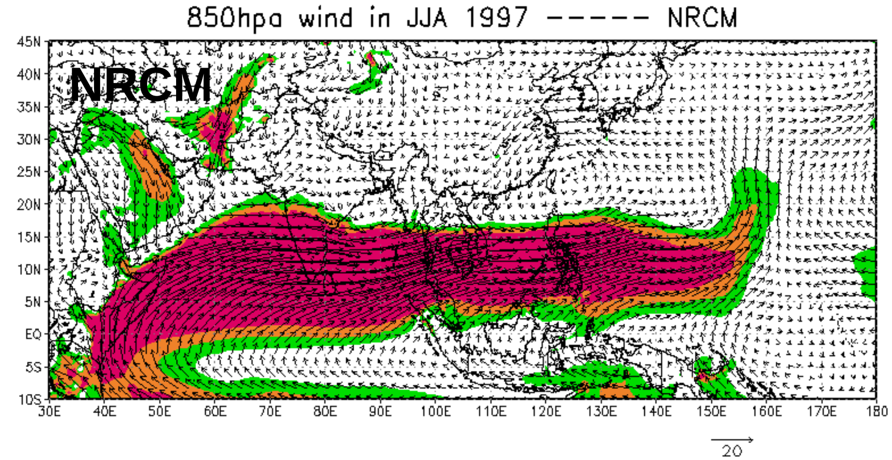
- 1997: West Pacific Subtropical High pushed further east, low pressure in the South China Sea, northeasterly flow in eastern China, southwesterly monsoonal flow never reaches China

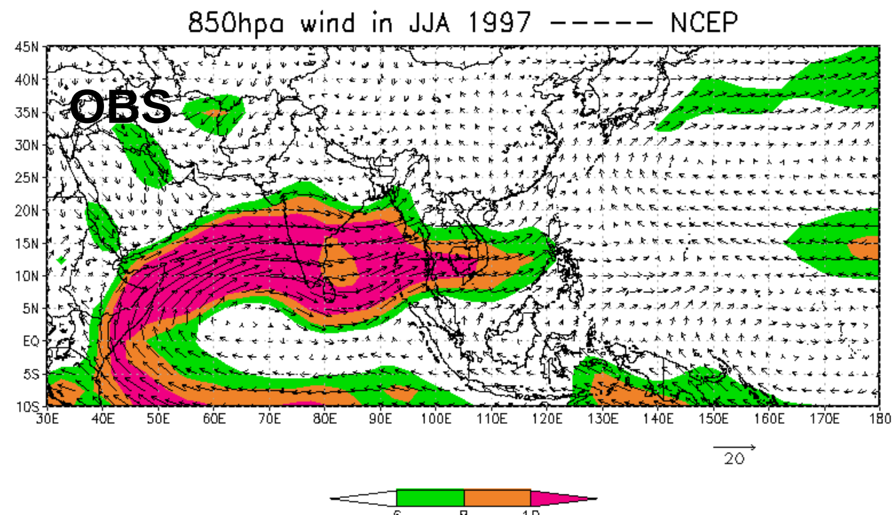
850 mb Height 1997





850 mb Winds 1997

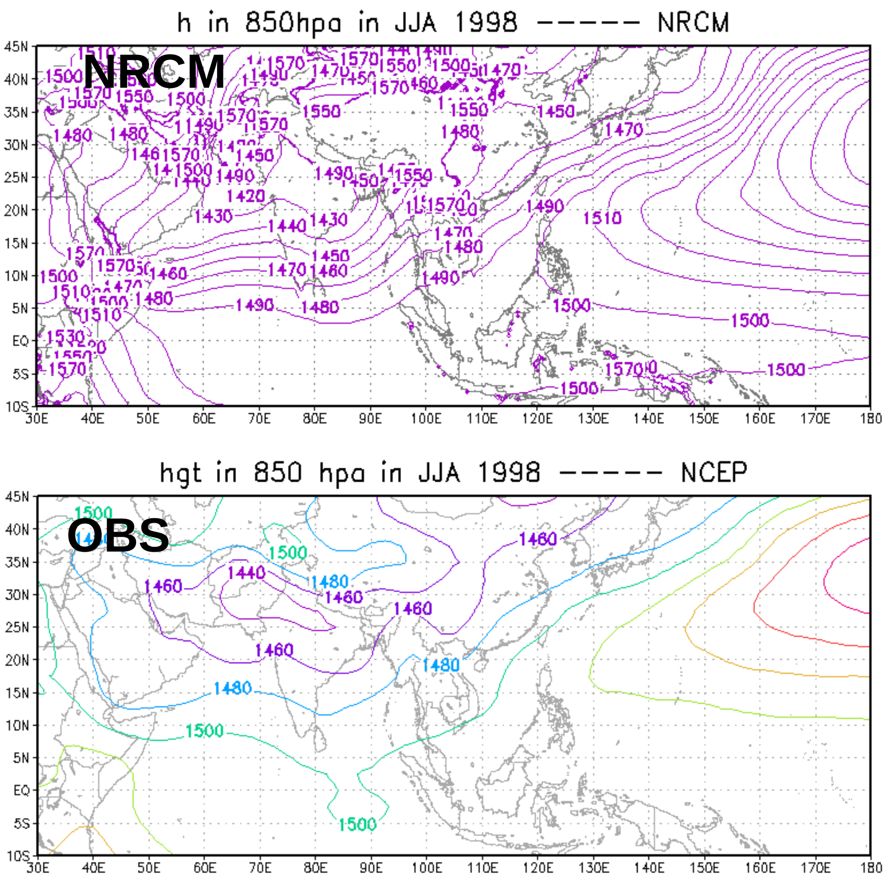




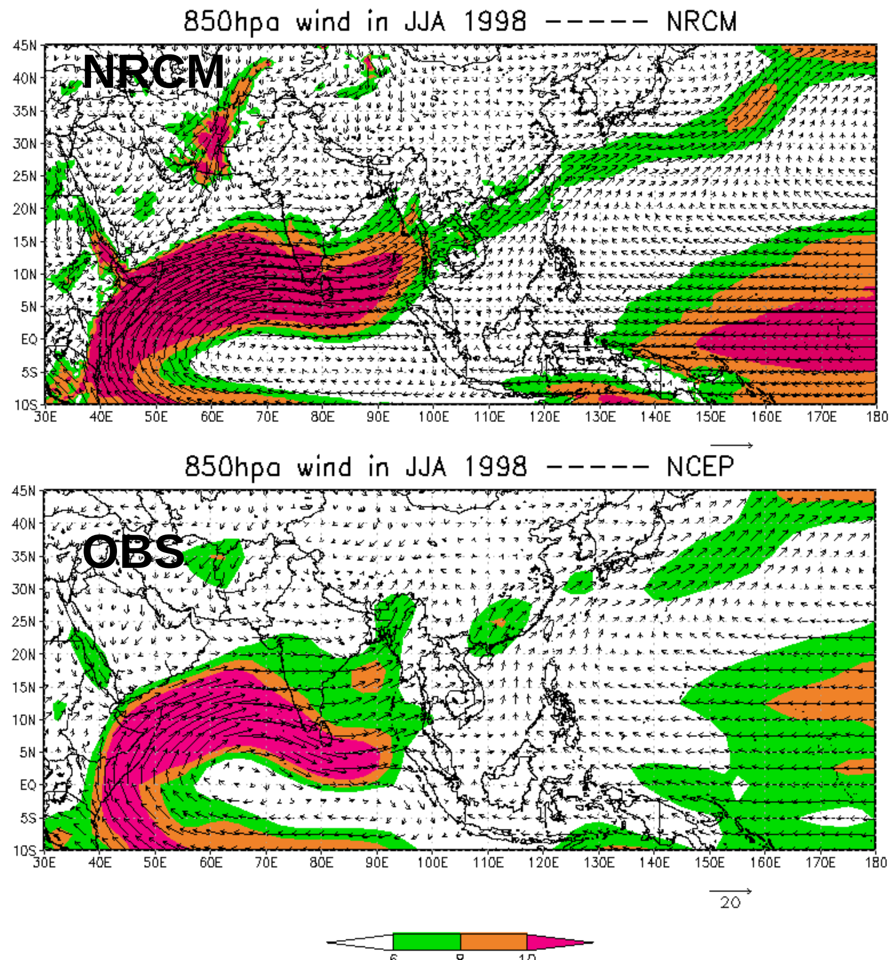
East Asian Monsoon

- 1998: West Pacific Subtropical High has reasonable strength and location, southwesterly monsoonal flow brings abundant moisture to China

850 mb Height 1998

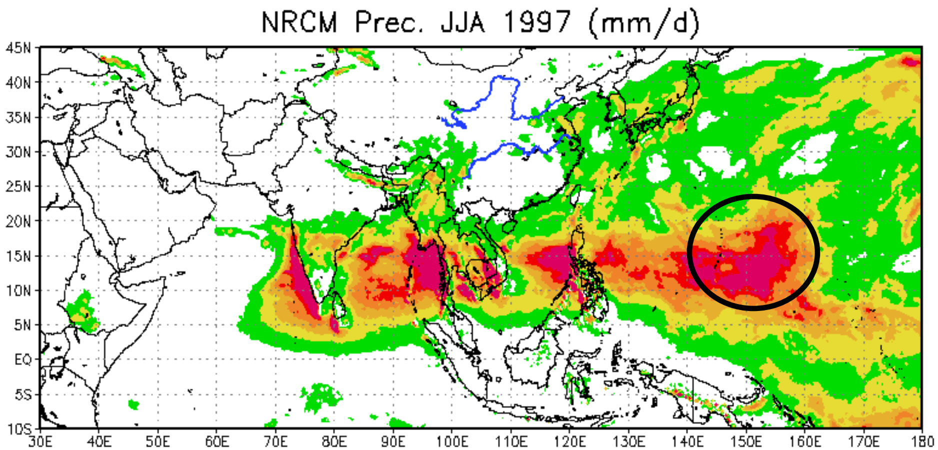


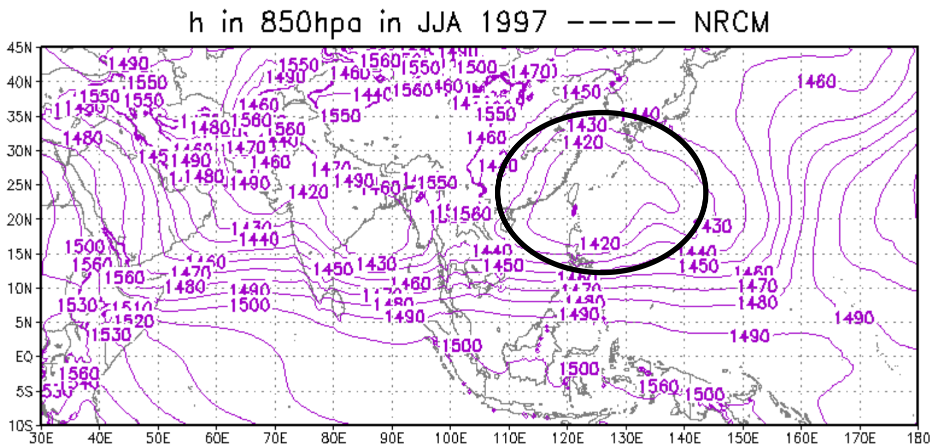
850 mb Winds 1998



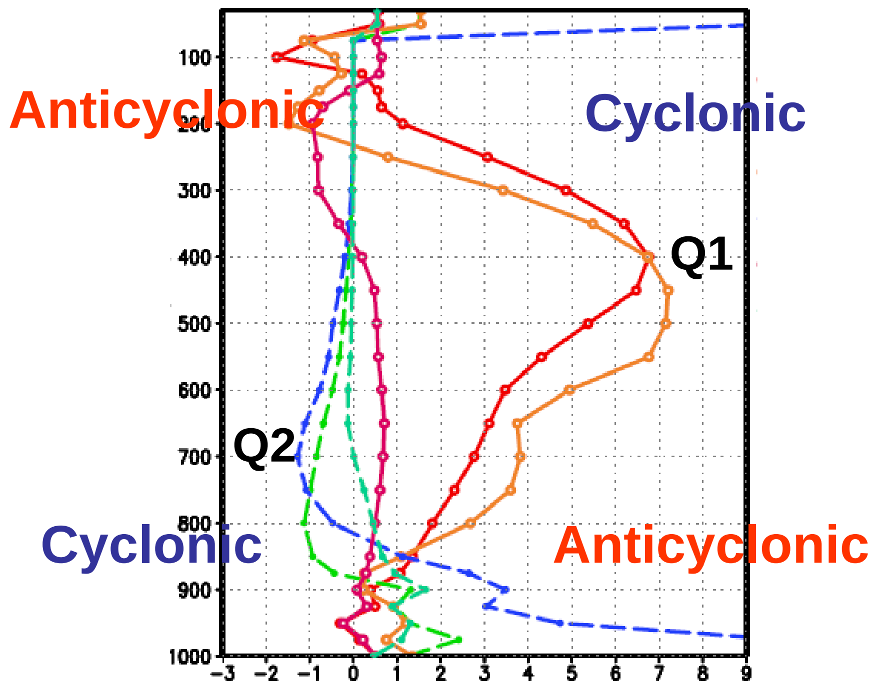
Dynamical Response to Diabatic Heating

- The low pressure at 850 mb west of the intense convective center is likely a dynamical response to the convective heating that maximizes near 400 – 500 mb





Q1/Q2 in the western Pacific



Liu et al. 2001; 2003

Sensitivity Experiments

- What makes 1997 bad and 1998 good?
- Initialize NRCM model with new initial condition from NCEP/NCAR reanalysis
- Change the cumulus parameterization scheme from Kain-Fritsch to Betts-Miller scheme
- Remove cumulus parameterization (explicit only)
- Replace the 1997 SST by 1998 SST, but still using 1997 lateral boundary conditions
- Repeat the simulations from 1 May 1997 (from the continuous NRCM 36-km run) and integrate for four months

Sensitivity Experiments

- The 98SST experiment has the largest impacts, reducing wet biases in the western Pacific, and improving monsoon rainfall in China

OBS

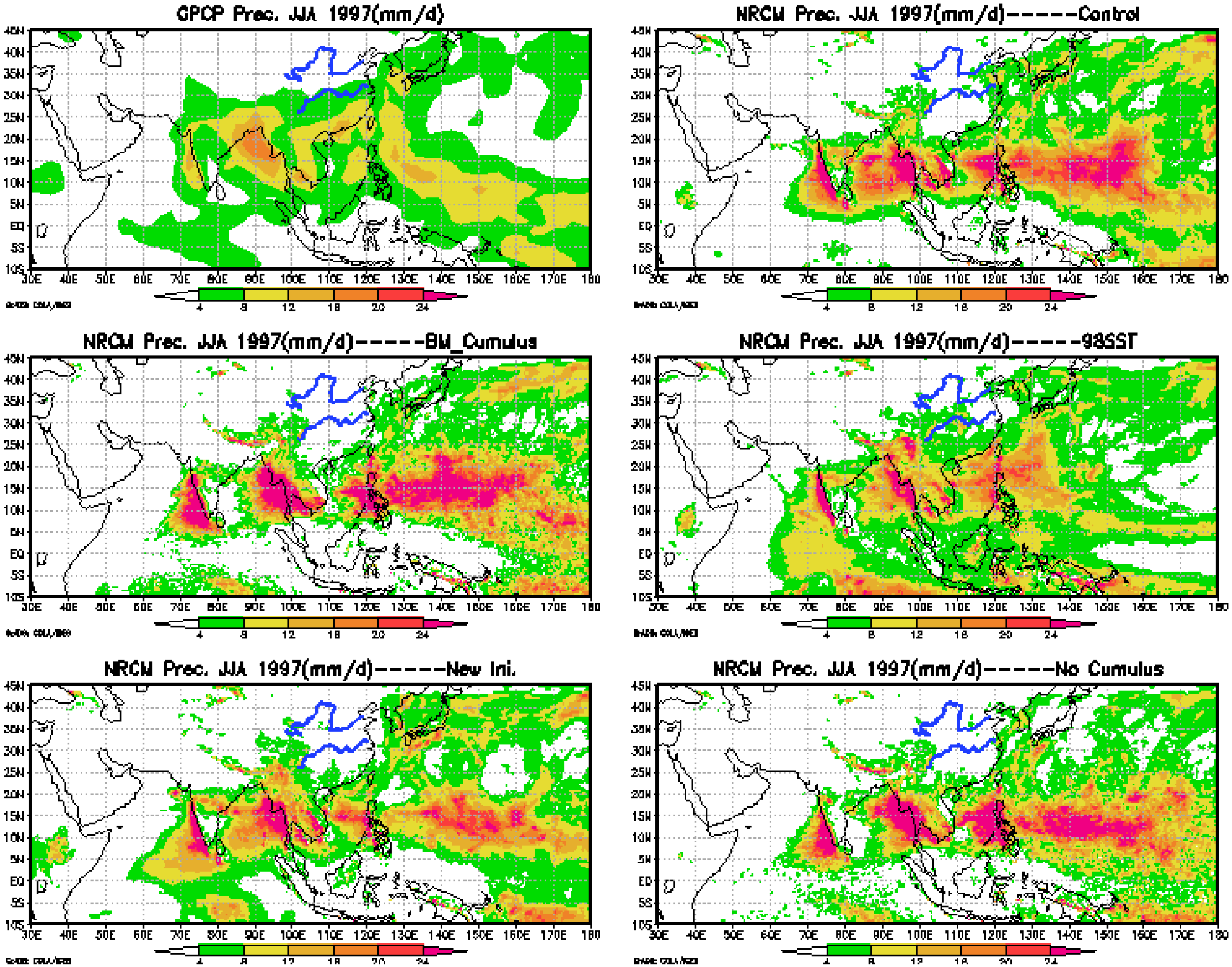
Control

BM

98SST

New IC

No Cumulus



Sensitivity Experiments

- The 98SST experiment has better simulation of the monsoon circulation

OBS

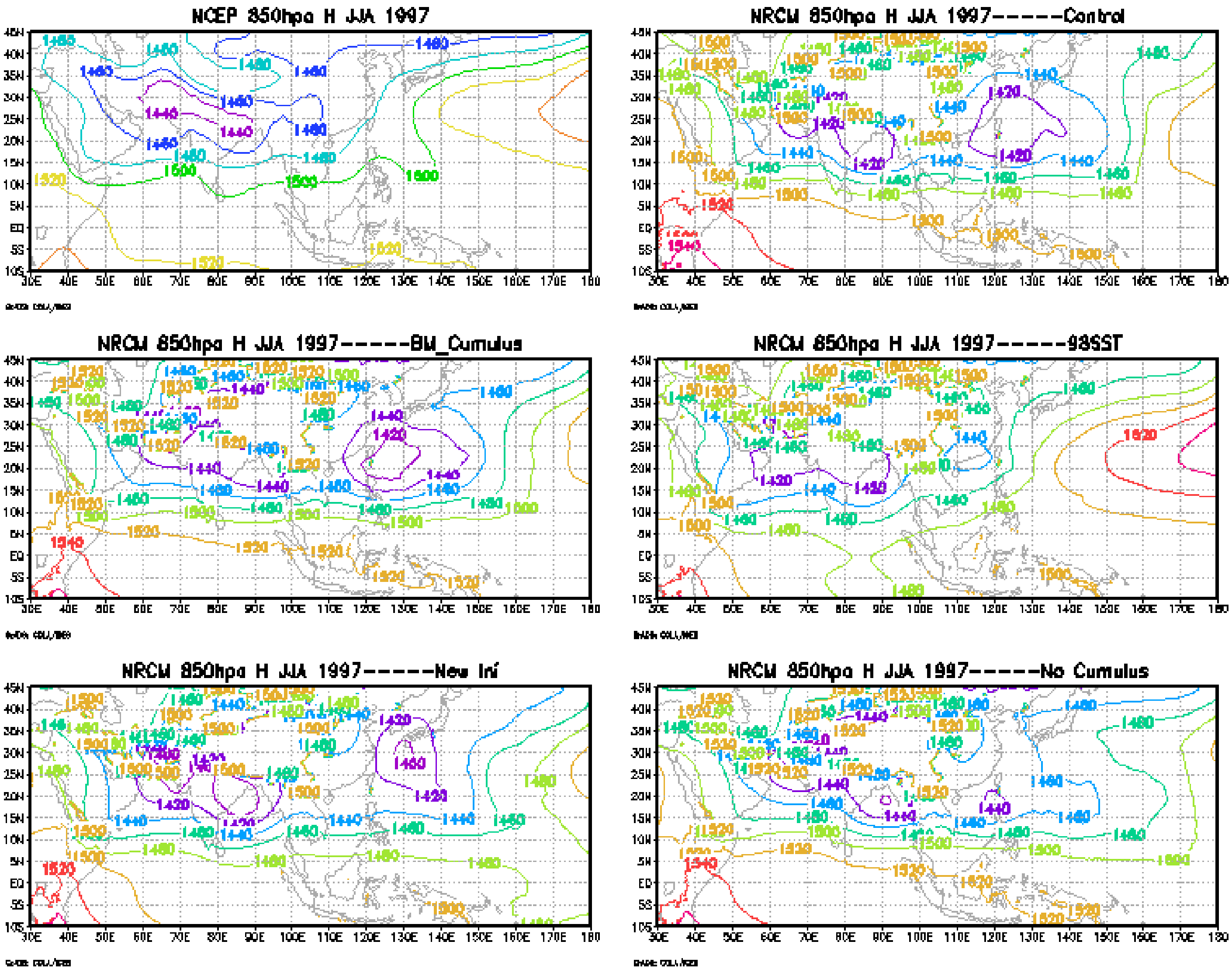
Control

BM

98SST

New IC

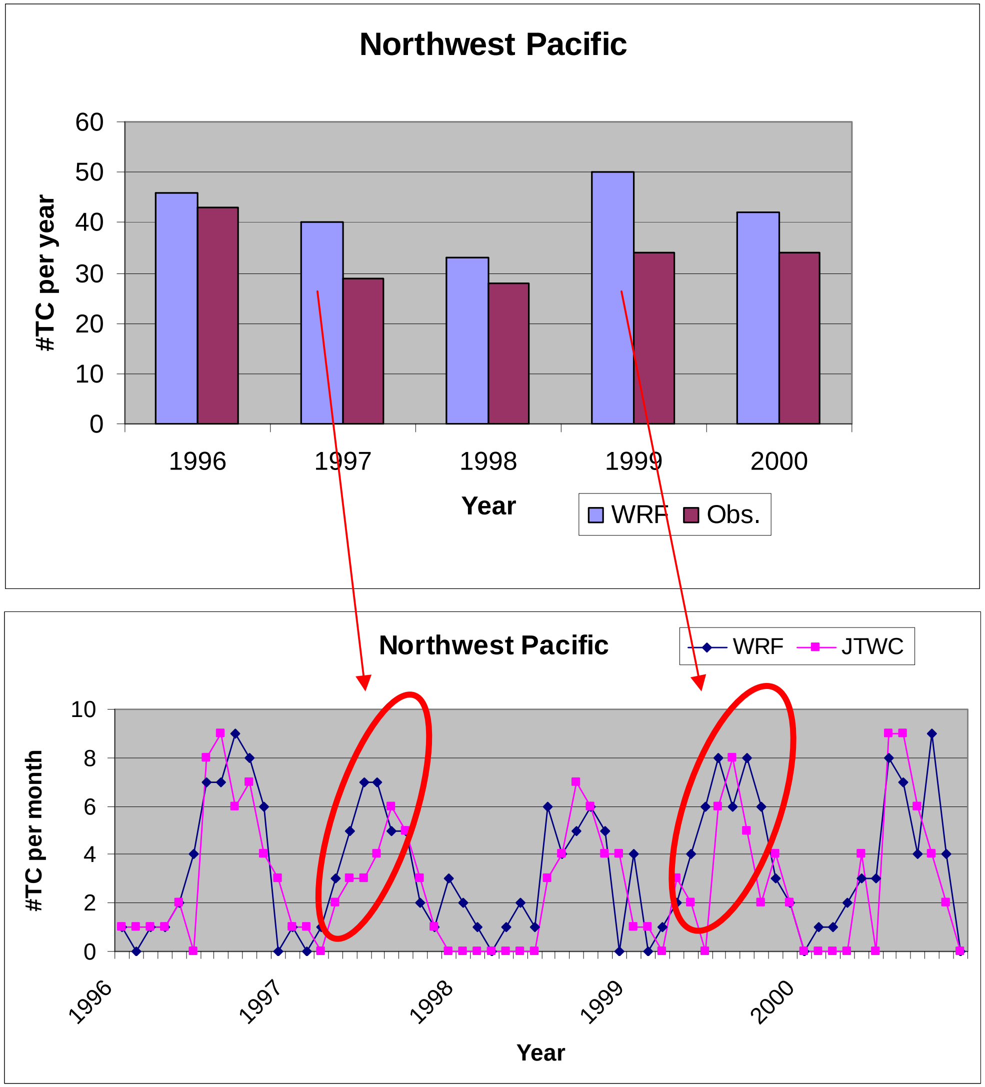
No Cumulus



Implications

- SST has profound influence on tropical convection in the model
- In the large tropical channel domain, SST exerts stronger influence than lateral boundary conditions
- The influence of initial conditions can last 1-2 months in the large channel domain
- Change in convection schemes (KF, BM) has little impacts
- Are we missing some important feedback mechanisms (e.g., air-sea interactions, cloud-radiation feedbacks)?

Poor Monsoon Circulation and Tropical Cyclone Simulation



- The number of simulated tropical cyclones are too high for 1997 and 1999, particularly in the early seasons from April to July

- Poor monsoon circulation leads to poor TC simulation, or poor TC simulation partly responsible for the convection biases and poor circulation?

Source: Suzuki

What Have We Learned?

- WRF captured some basic large scale circulation features in the tropics such as the seasonal migration of ITCZ, TOA cloud forcing, and transition from stratocumulus to deep convection in the East Pacific transect
- In the large tropical channel, the simulation is more strongly controlled by SST than lateral boundary conditions, though results show some sensitivity to the location of the southern boundary, particularly over the South Indian Ocean
- Some features of MJO and Kelvin waves are well simulated, but the simulation generally lacks intraseasonal variability in the deep tropics, with less organized eastward propagation

What Have We Learned?

- Larger biases are found over the Indian Ocean and western Pacific where convection responds too strongly to warm SST; biases in diabatic heating have negative impacts on the monsoon circulation, which also correlates with poor simulation of tropical cyclones

- In the tropical channel at 36 km spatial resolution, parameterized convection continues to present challenge in simulating tropical convection

- Lack of air-sea interactions could also be an important factor contributing to the biases in tropical convection and tropical modes?

- The impacts of the cloud resolving (4 km) nest over the warm pool have not been addressed

Future Directions

- WRF has become a very flexible modeling framework; it can be configured as limited area model, tropical channel model, and global model, with one-way and two-way nesting capability going down to the cloud resolving scale

- Downscaling at higher spatial resolution

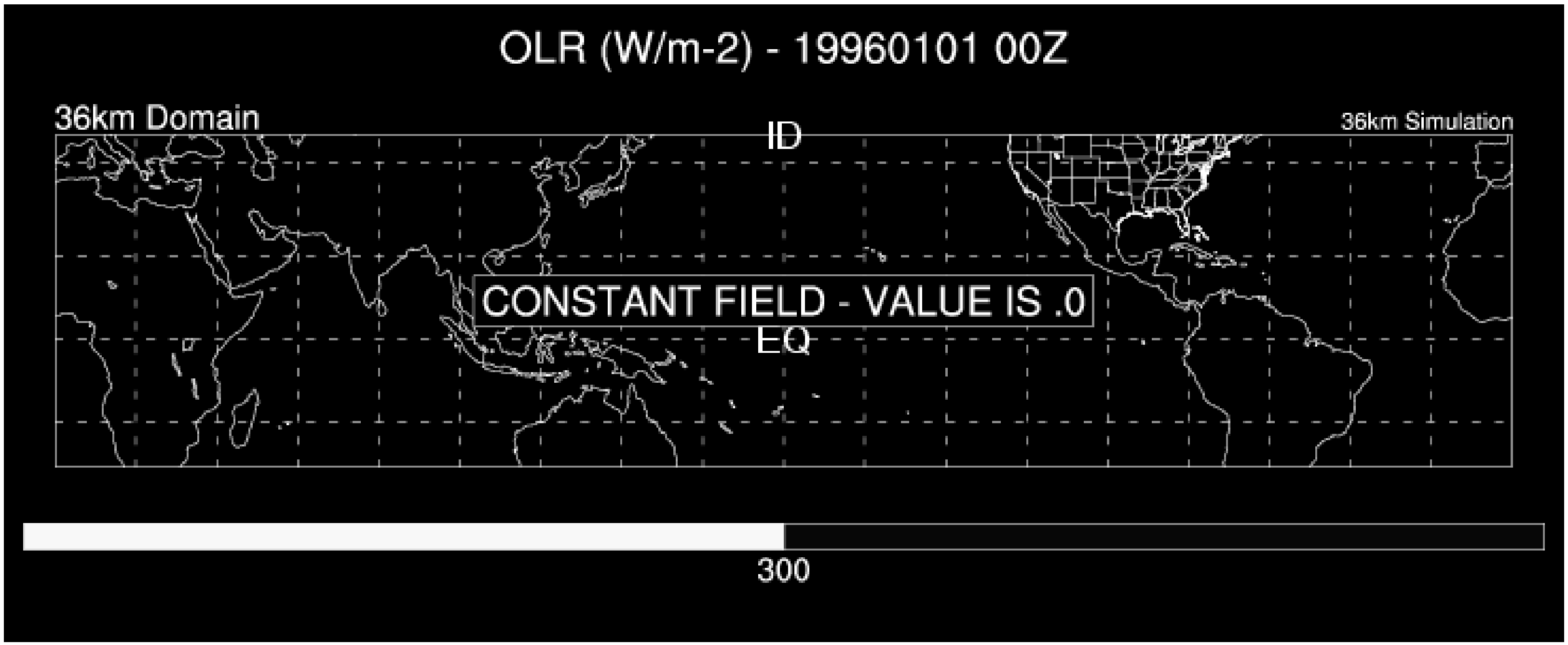
- WRF can be used to investigate scale-interactions

- WRF can be used to test and develop physics parameterizations for global cloud resolving models and assess potential impacts of global cloud resolving modeling

- With earth system components, WRF can be a useful tool to understand regional earth system processes, allowing model parameterizations to be evaluated using measurements highly influenced by local conditions

- WRF/ROMS can be embedded 2-way within global modeling systems to simulate regional processes and upscaled effects

Questions?



OLR (W/m-2) - 19960101 00Z
36km Domain
36km Simulation
ID
CONSTANT FIELD - VALUE IS .0
EQ
300