# Regional Climate-Weather Research and Forecasting (CWRF) Model Development & Application


**Xin-Zhong Liang**

**Department of Atmosphere & Ocean Science**
**Earth System Science Interdisciplinary Center**
**University of Maryland, College Park**


2011 May 17

National Weather Service
Environmental Modeling Center

# Collaboration with NOAA

**Julian X.L. Wang** (Air Resource Laboratory)

**Vernon Morris, Everette Joseph, Tsann-Wang Yu** (NCAS/Howard University)

**We Moved**

**Earth System Model (EaSM) Research & Development Laboratory**

**ESSIC, University of Maryland**

# Collaboration Began in 1999

- **Climate, Air Quality and Impact Modeling System (CAQIMS)**
  – predict climate & air quality variations at scales crucial to human activities and natural resources
- **Regional Climate Impact & Air Quality Experiments (CIAQEX)**
  – downscale GCM climate simulations
  – simulate the surface ozone and particle levels
  – perform scenario experiments on regional scales

# Collaboration Expands

- Sustained supercomputing supports
- Research grant awards
  - Orographic effect (2004-2007)
  - North American monsoon (2000-2003)
  - Vegetation deep-root effect (2006-2009)
  - Seasonal climate prediction (2008-2011)
  - Ensemble prediction optimization (2008-2011)
  - Cloud-radiation interaction (NCAS, 2000-2006)
  - CWRF physics development (NCAS, 2006-2011)
- U.S.-China Bilateral Activities
  - Visiting scientists assisting model development

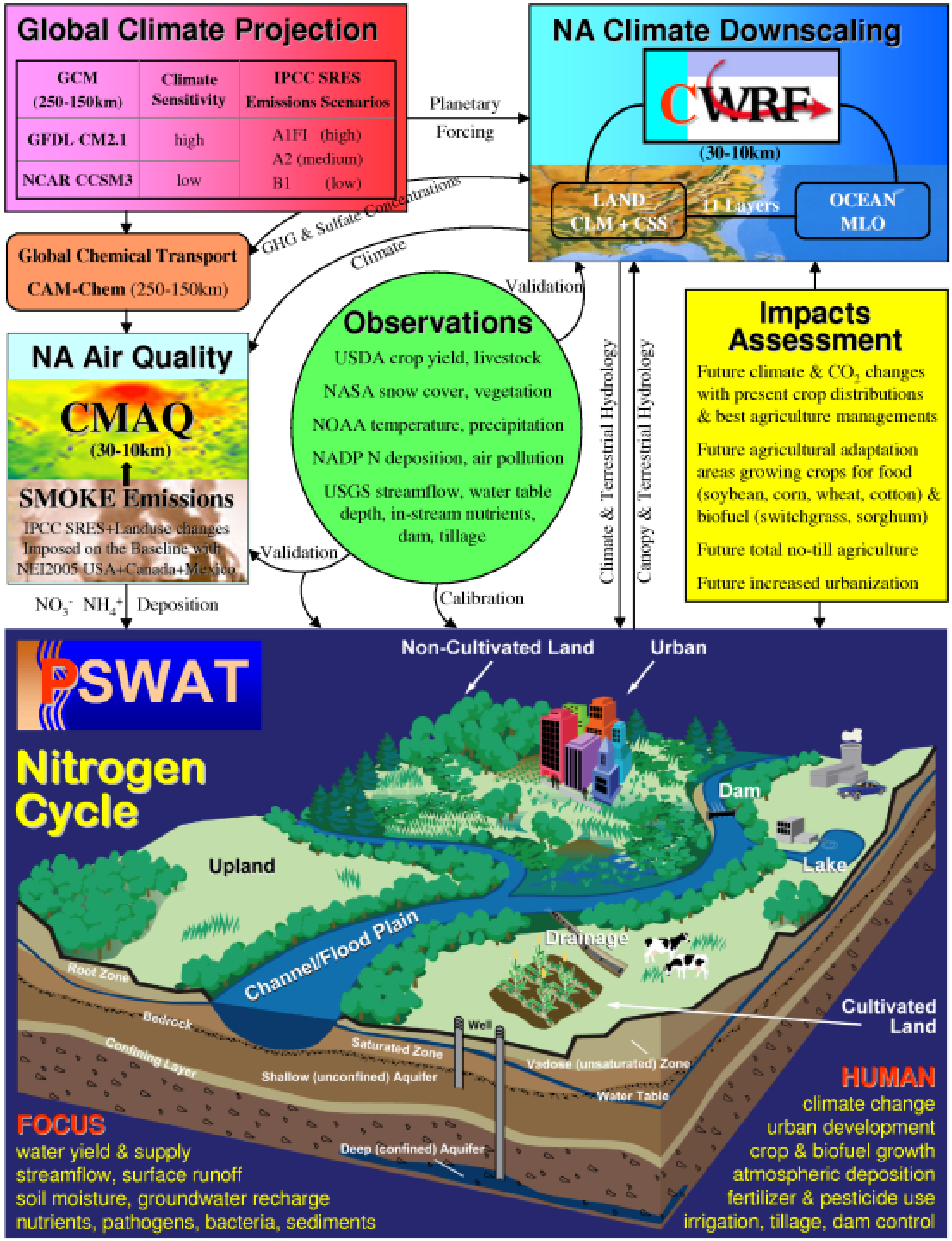
EPA STAR
2003-2011

FOCUS

Consolidate
$O_3$

Elaborate
PM

Explore
Hg




EPA STAR
2009-2012

FOCUS

Nutrients

Pathogens

Bacteria

Sediments

Agriculture

Urban

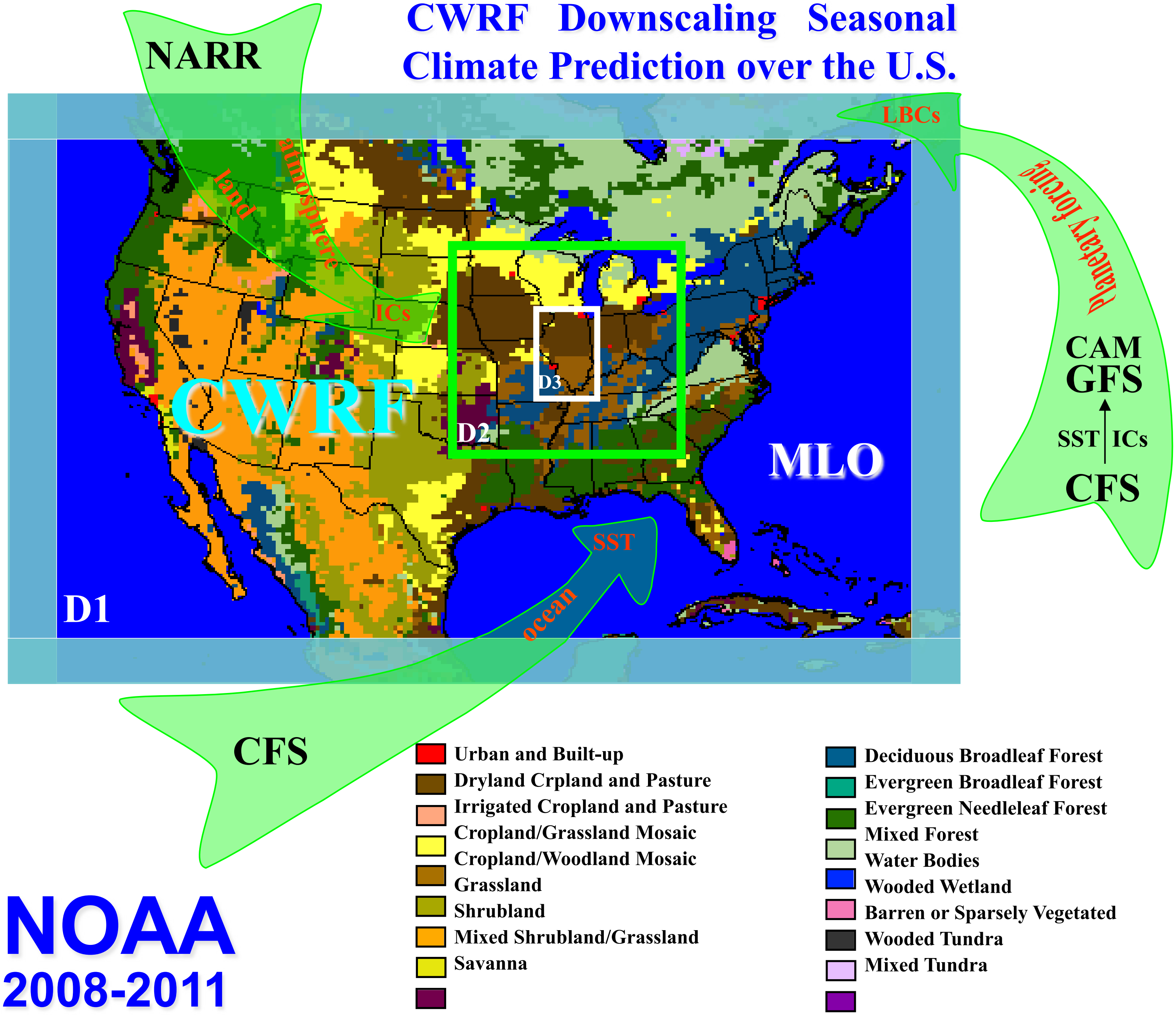
# EaSM R&D Thrusts

- System Integration & Improvement
  - Physical schemes; research => operation
- Seasonal-Interannual Ensemble Prediction
  - Ensemble optimization; data assimilation
- Climate Change & Impacts Projection
  - Quantify & narrow uncertainty range
- Interactive Climate-Human System
  - Adaptation, Mitigation, Policy & Decision Making

# Outline

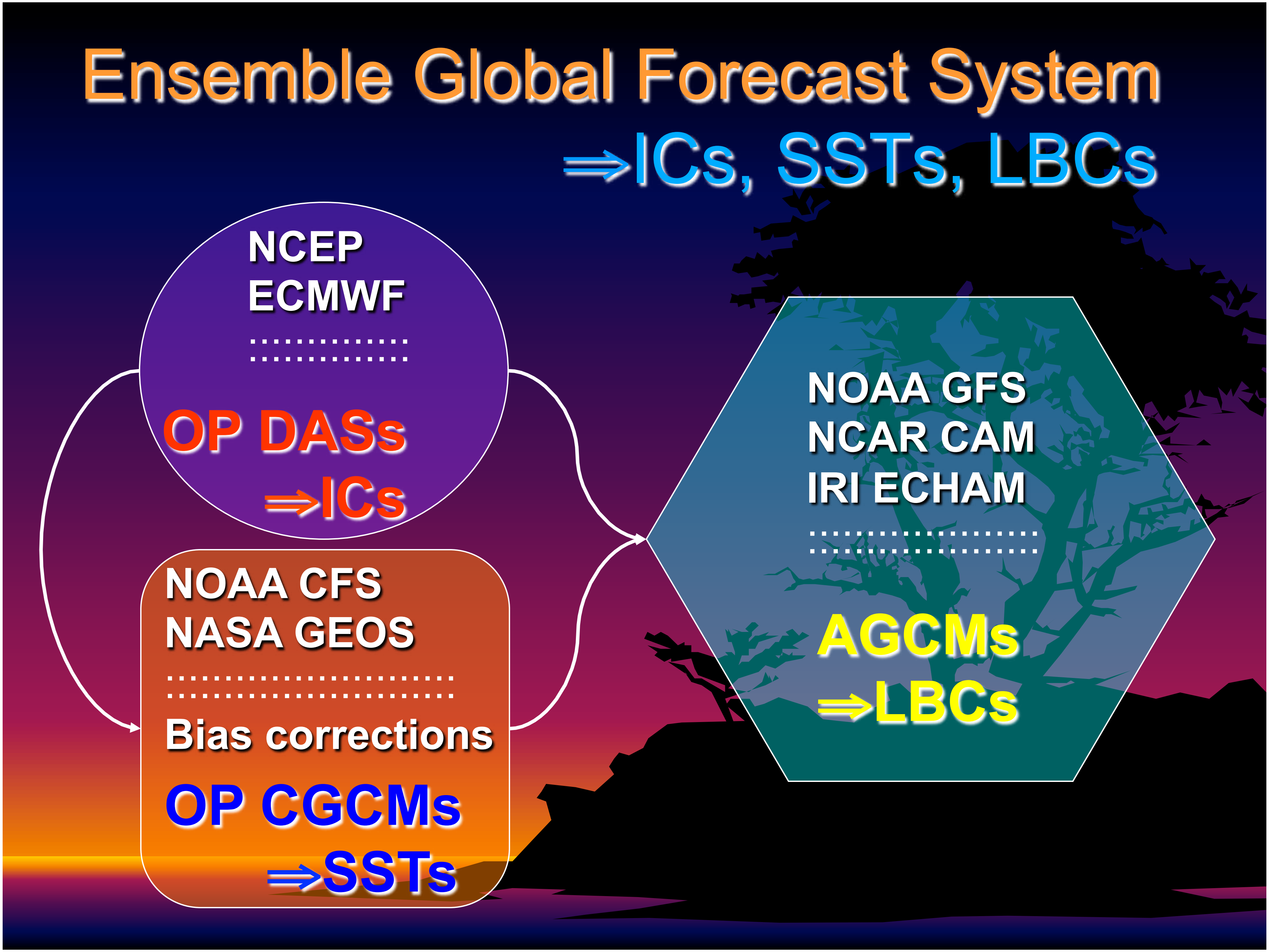
- What is RCM – the EaSM core?
- What are values added by RCM downscaling?
- What are CWRF advances over other RCMs?
- What are needed to make a credible RCM run?
- What challenges face RCM development?
  - Scale dependence
  - Physics configuration selection
  - Optimized physics ensemble
  - System uncertainty

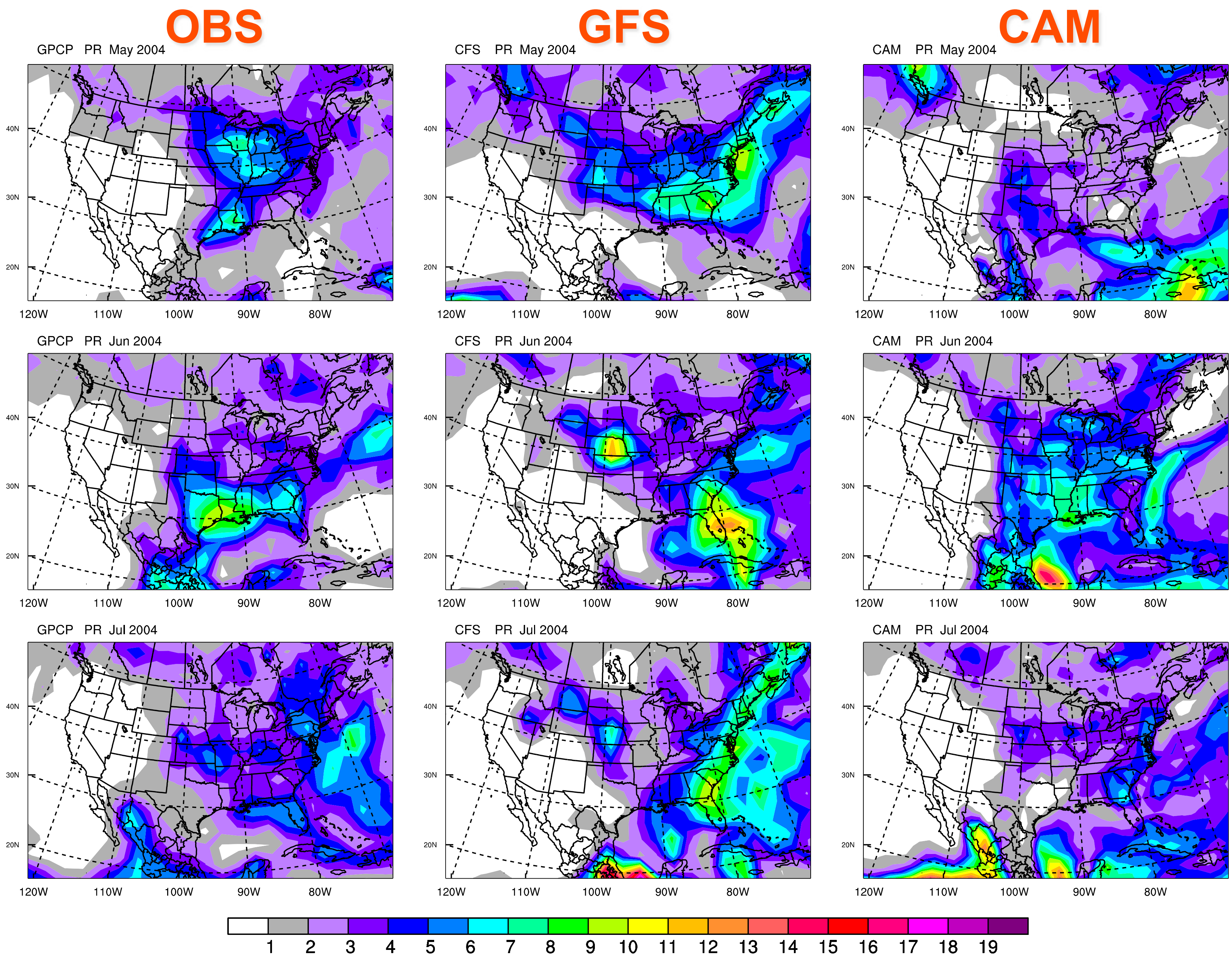
# CWRF Downscaling Seasonal Climate Prediction over the U.S.

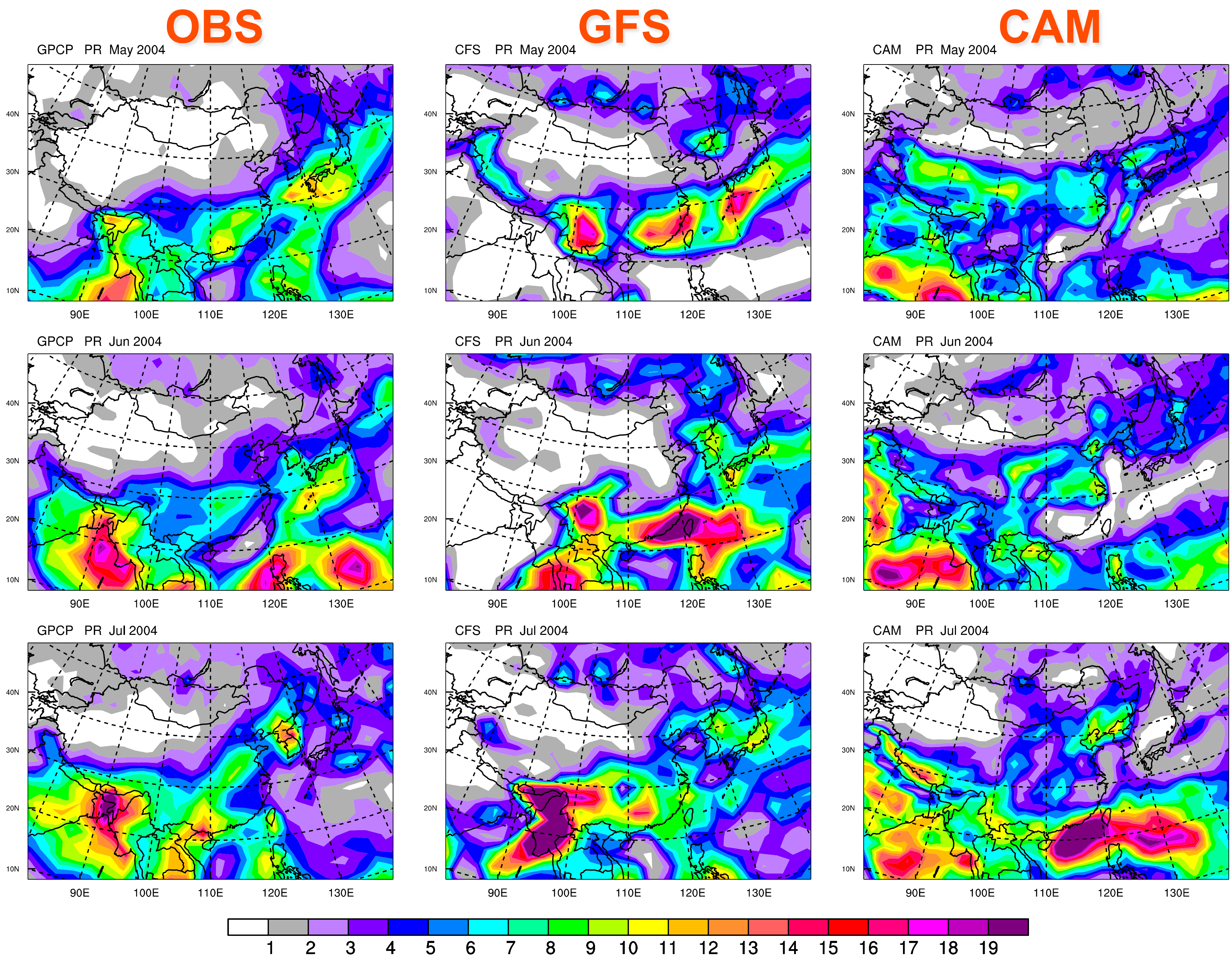



**NOAA**

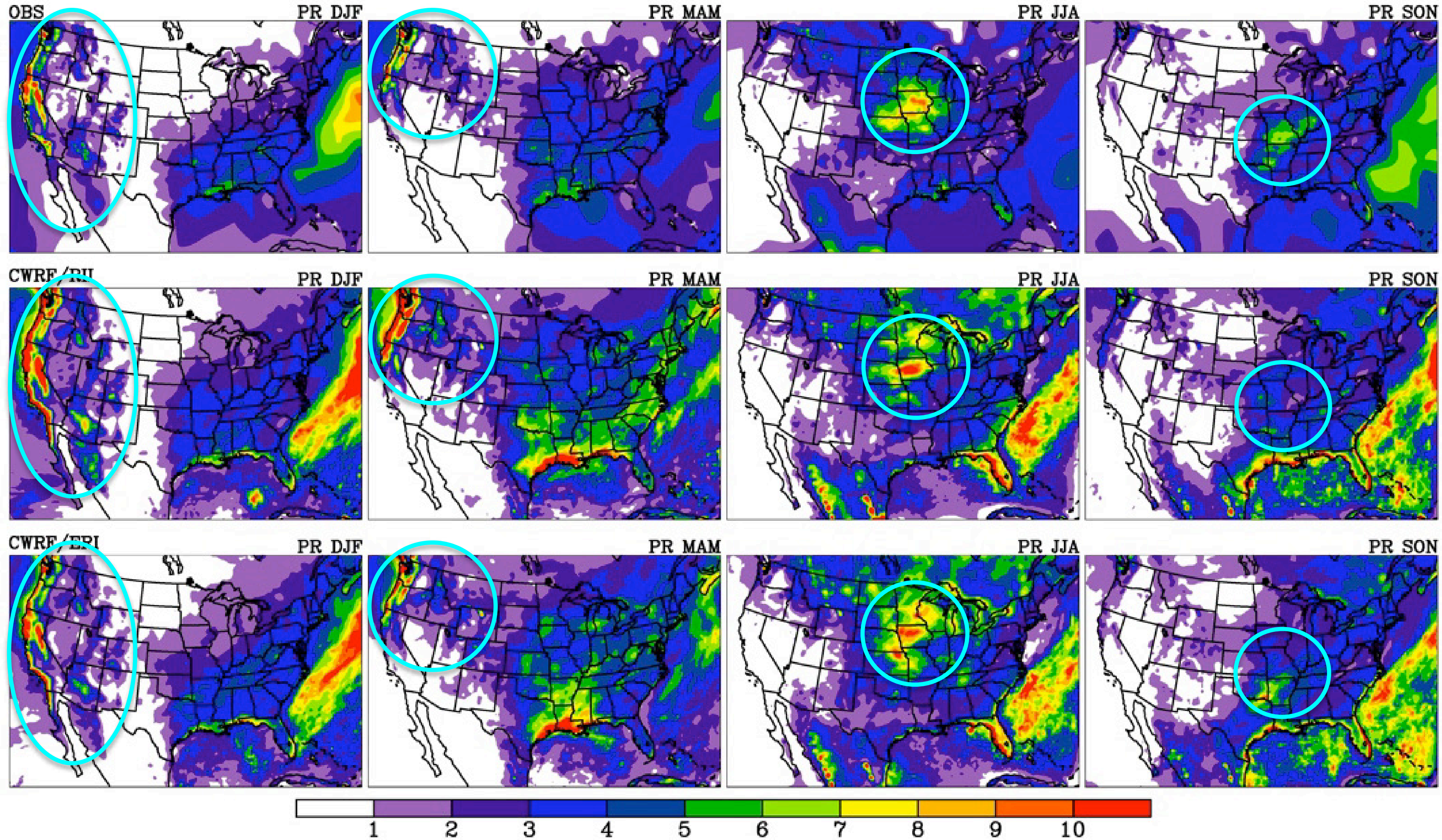
**2008-2011**


Ensemble Global Forecast System
⇒ICs, SSTs, LBCs
NCEP
ECMWF
OP DASs
⇒ICs
NOAA CFS
NASA GEOS
Bias corrections
OP CGCMs
⇒SSTs
NOAA GFS
NCAR CAM
IRI ECHAM
AGCMs
⇒LBCs


OBS
GFS
CAM
GPCP PR May 2004
CFS PR May 2004
CAM PR May 2004
GPCP PR Jun 2004
CFS PR Jun 2004
CAM PR Jun 2004
GPCP PR Jul 2004
CFS PR Jul 2004
CAM PR Jul 2004
40N
30N
20N
120W
110W
100W
90W
80W
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19


OBS
GFS
CAM
GPCP PR May 2004
CFS PR May 2004
CAM PR May 2004
GPCP PR Jun 2004
CFS PR Jun 2004
CAM PR Jun 2004
GPCP PR Jul 2004
CFS PR Jul 2004
CAM PR Jul 2004
40N
30N
20N
10N
90E
100E
110E
120E
130E
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

# NCEP/AMIP II vs ECMWF-Interim Reanalysis



# CWRF

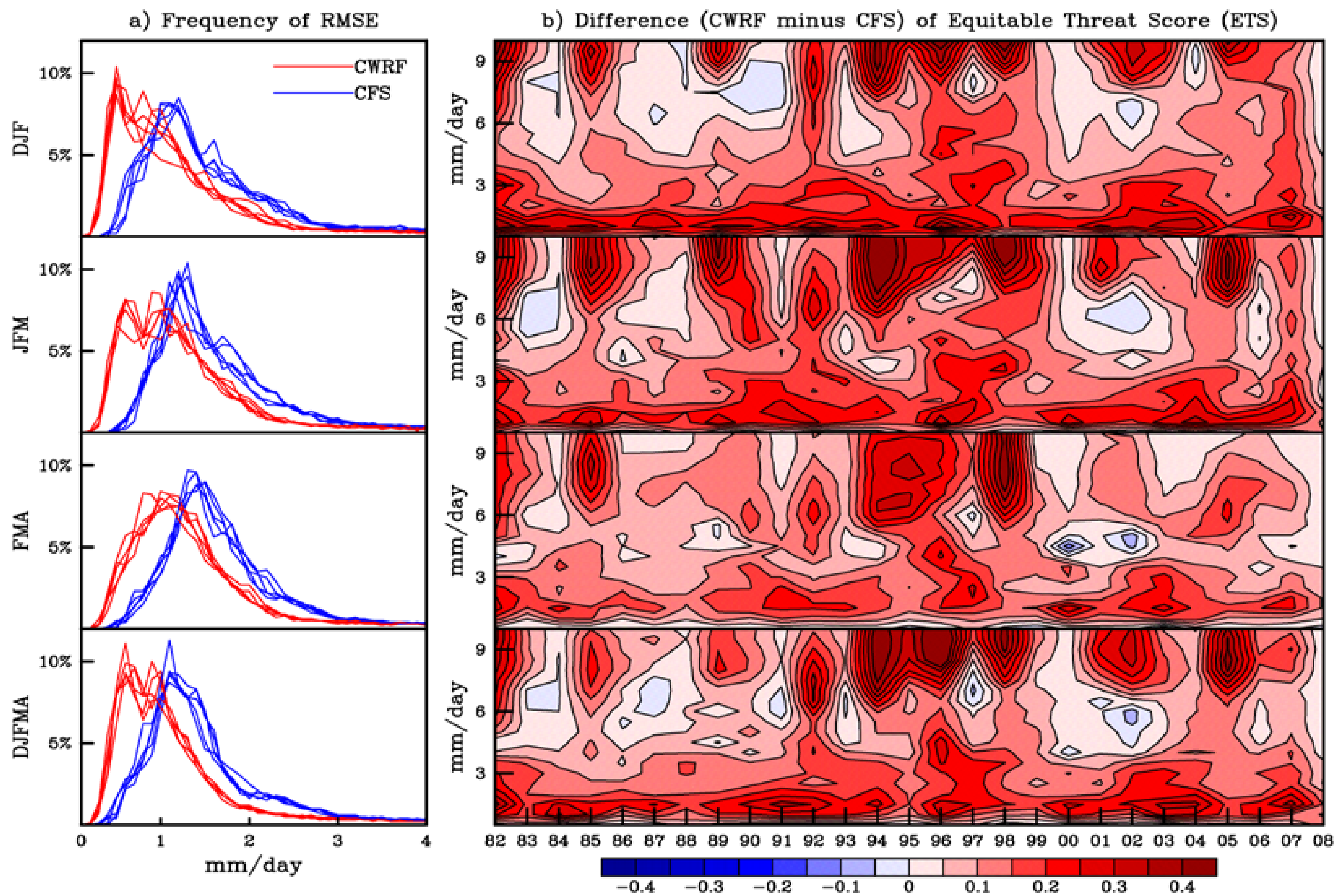
## Seasonal-Interannual Climate Prediction

Nested with NOAA Operational

CFS

Yuan, X., and X.-Z. Liang, 2011: Improving cold season precipitation prediction by the nested CWRF-CFS system. *Geophys. Res. Lett.,* **38**, L02706, doi:10.1029/2010GL046104 .

# CWRF Improves Seasonal Climate Prediction




**a)** Spatial frequency distributions of root mean square errors (*RMSE*, mm/day) predicted by the CFS and downscaled by the CWRF and **b)** CWRF minus CFS differences in the equitable threat score (*ETS*) for seasonal mean precipitation interannual variations. The statistics are based on all land grids over the entire inner domain for DJF, JFM, FMA, and DJFMA from the 5 realizations during 1982-2008. *From* Yuan and Liang 2011 (GRL).

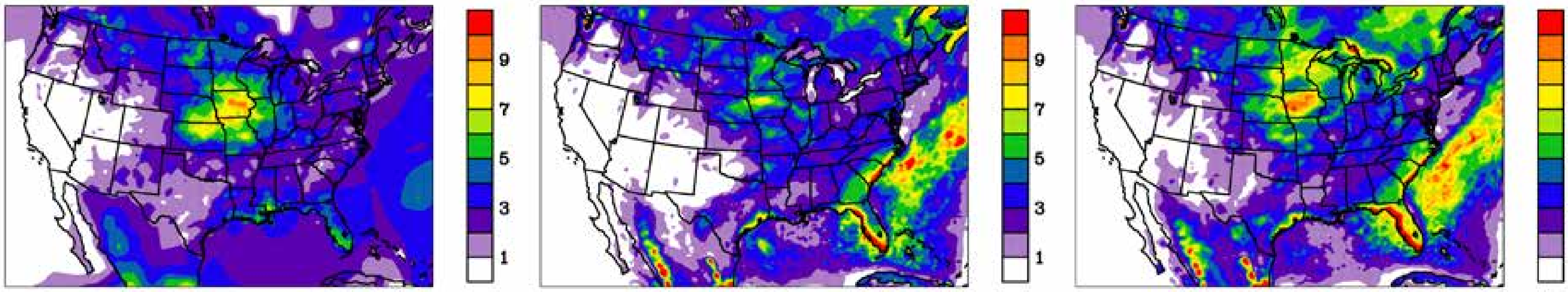
# Recent Advances
## Comparing with Other RCMs

Ability to reproduce observations

- All driven by the same reanalysis
- Result comparison on
    - Seasonal variations
    - Interannual anomalies
    - Extreme events

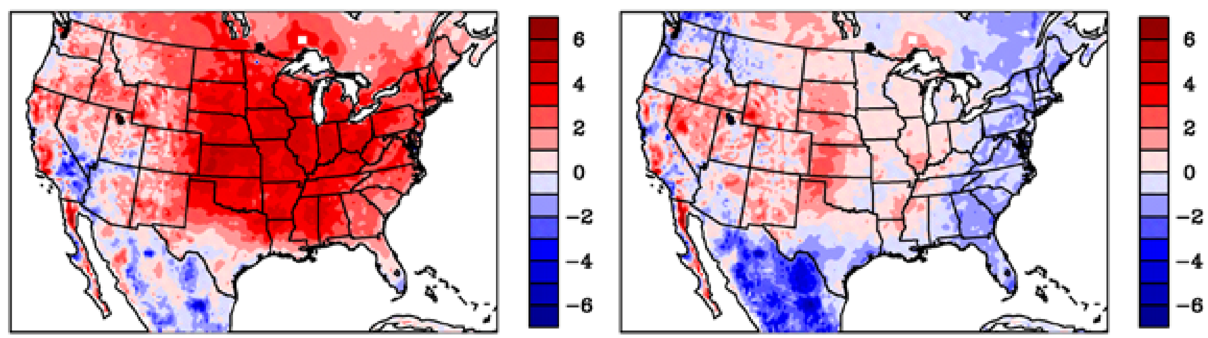
## Rainfall (summer 1993)

OBS NOAH CSSP

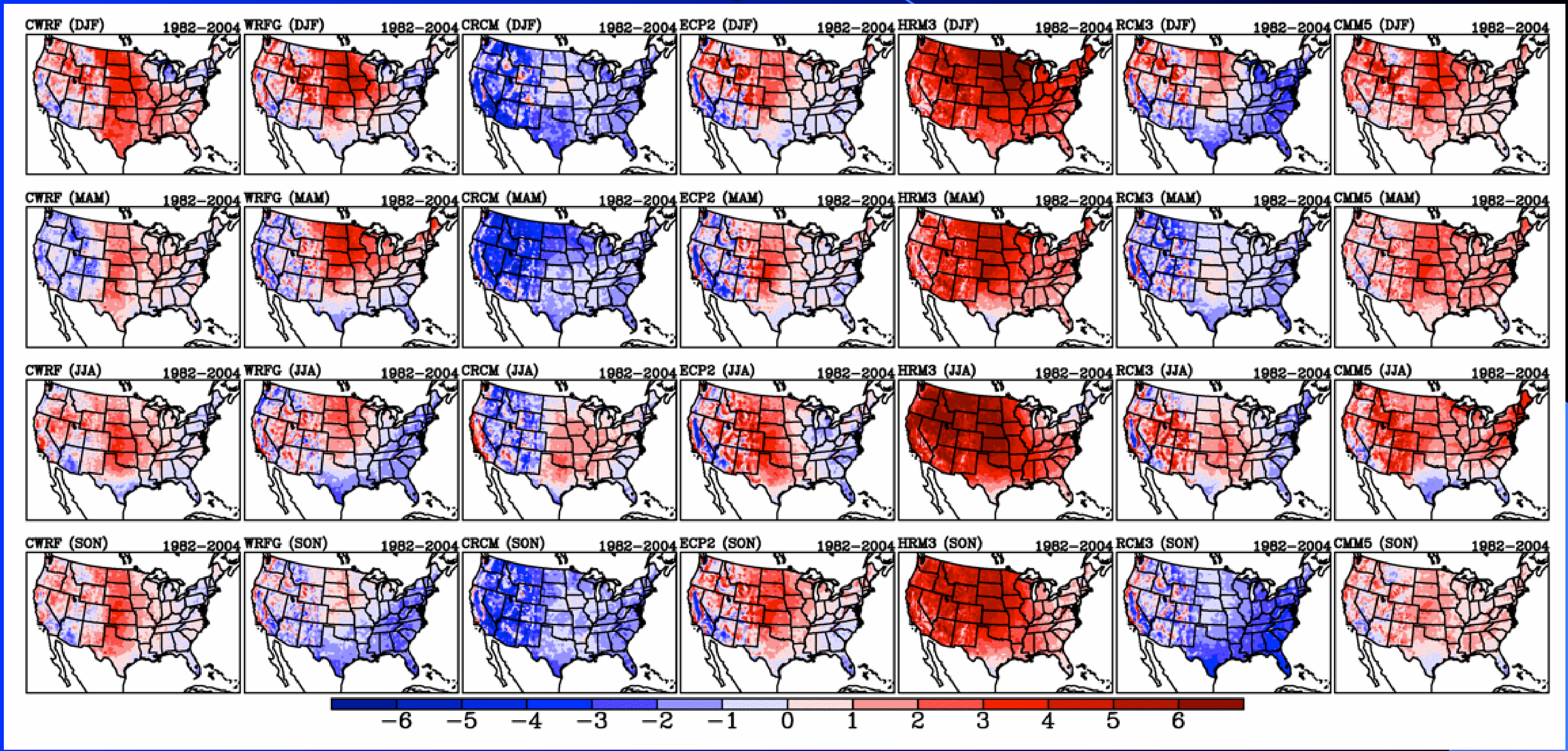



## T2m Bias (summer 1993)

**CWRF has made significant improvements.**

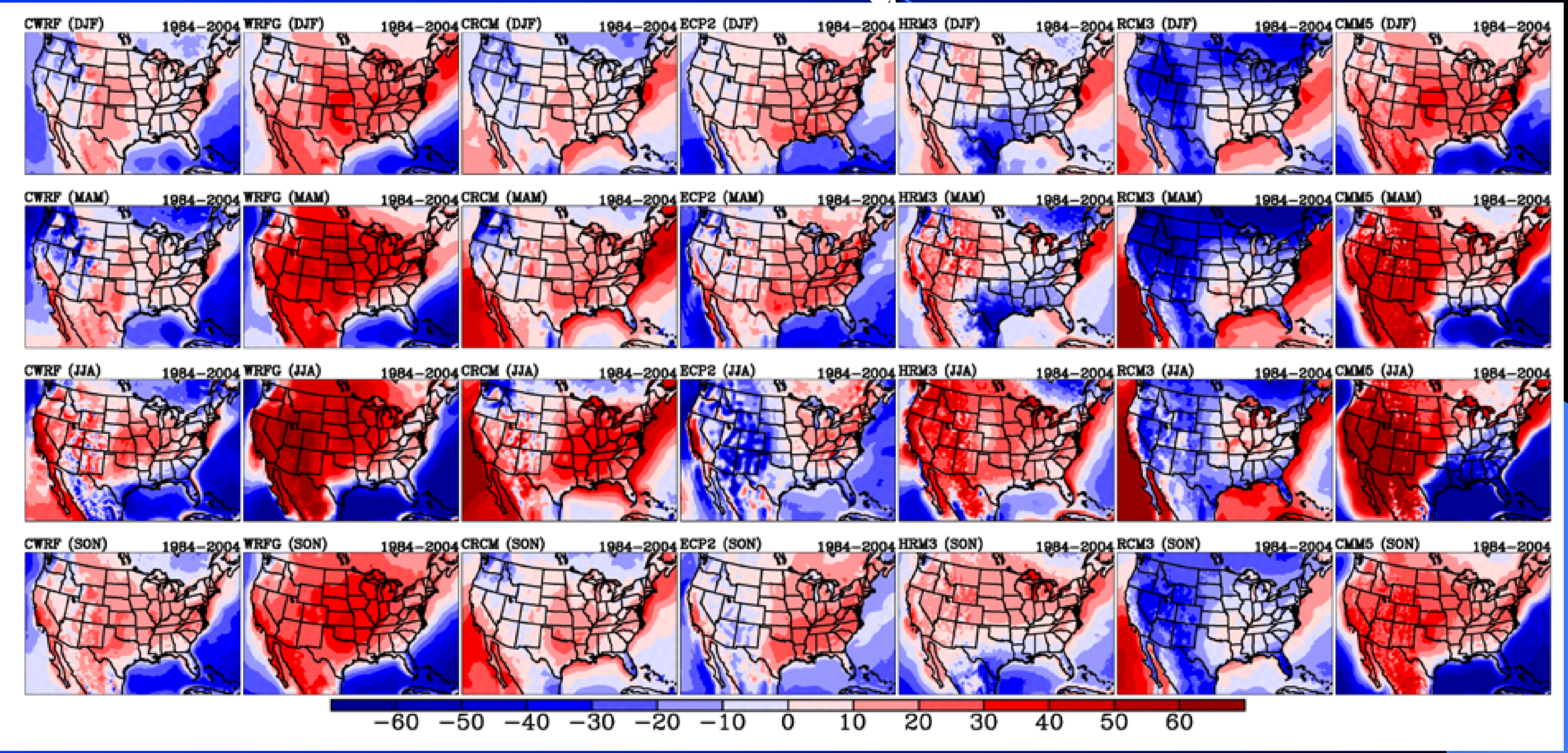


# Surface Temperature Biases




All driven by NCEP/DOE AMIP II Reanalysis

# Surface $SW_d$ Biases

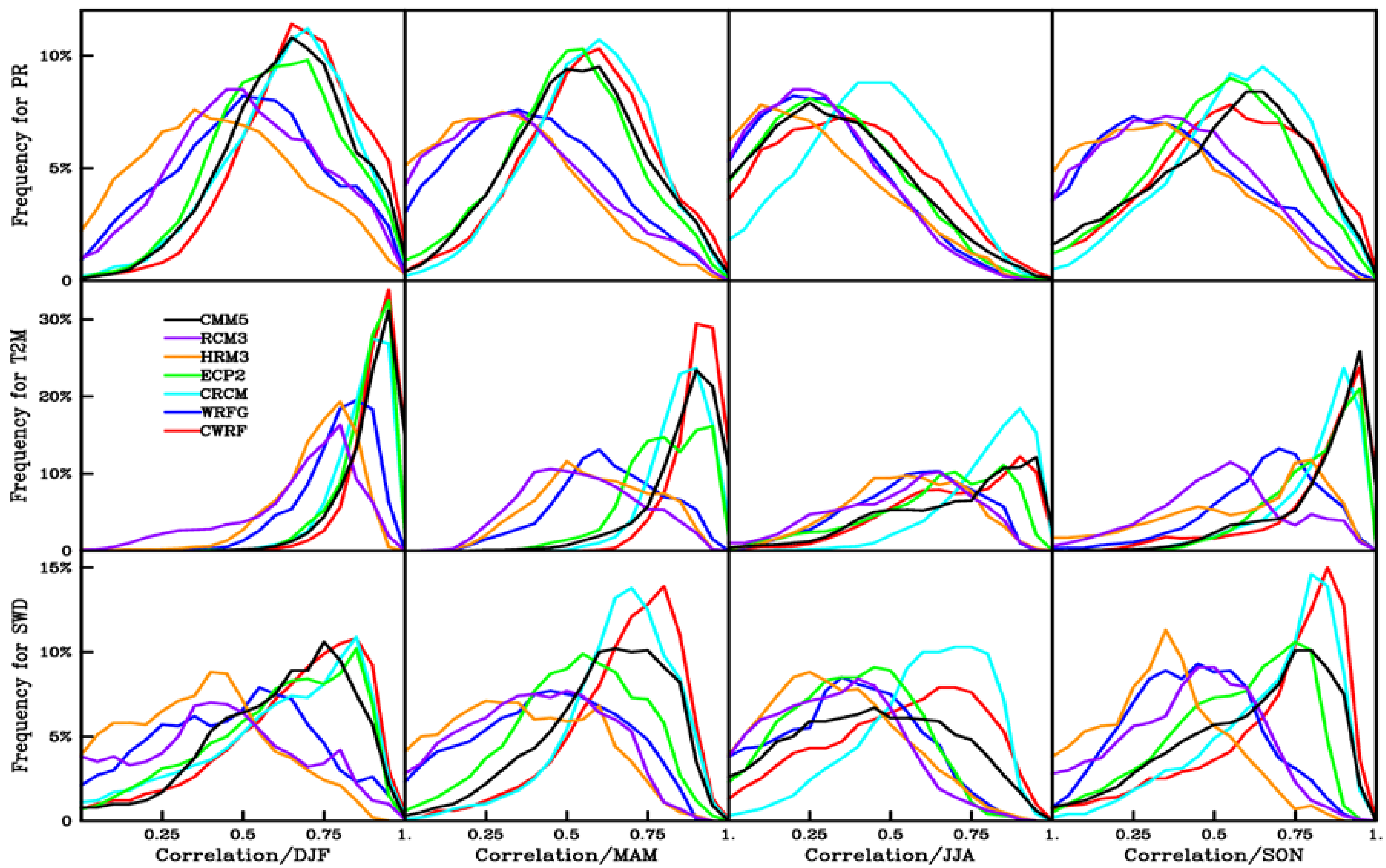



All driven by NCEP/DOE AMIP II Reanalysis

# Understanding Biases

- WRFG & CMM5: SWd are too large,
  while T2m biases are relatively small
- HRM3: SWd is quite realistic,
  while T2m is substantially overestimated
- CRCM: SWd is fairly realistic,
  but T2m has notable cold biases
- RCM3: SWd is substantially underestimated,
  yet T2m is reasonable
- CWRF: SWd and T2m both are quite realistic
- Conclusion: SWd seems not the dominant factor that cause T2m biases; the latter may largely result from deficiencies in the water cycle.

# Interannual CORR over USA



# Why Do RCM Results Differ?

- Domain: U.S. + Adjacent for CWRF & CMM5,
  Extended North America for NARCCAP
- Resolution: 30 km for CWRF & CMM5,
  50 km for all other NARCCAP RCMs
- Forcing: linear-exp relaxation in buffer zones of
  14 (CWRF, CMM5), 10 (WRFG) grids
  linear relaxation in 4 grids (MM5I, HRM3)
  domain spectral nudging (ECP2, CRCM)
  NARCCAP IA correlations differ largely
  due to the strength of forcing integrated
- Physics: CWRF is much better than CMM5,
  being identical in all other settings
  Different dynamics may also contribute

# Physics Representation

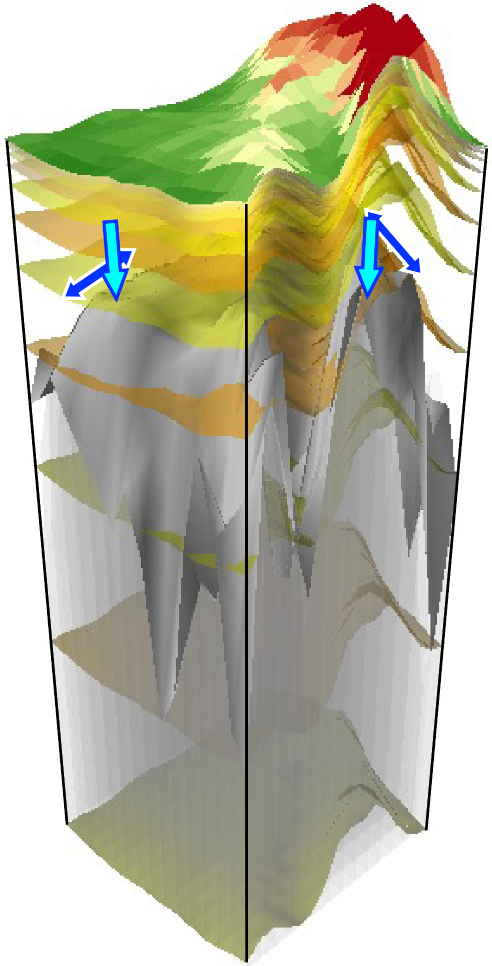
## Evaluating Skill under Correct Forcing Conditions

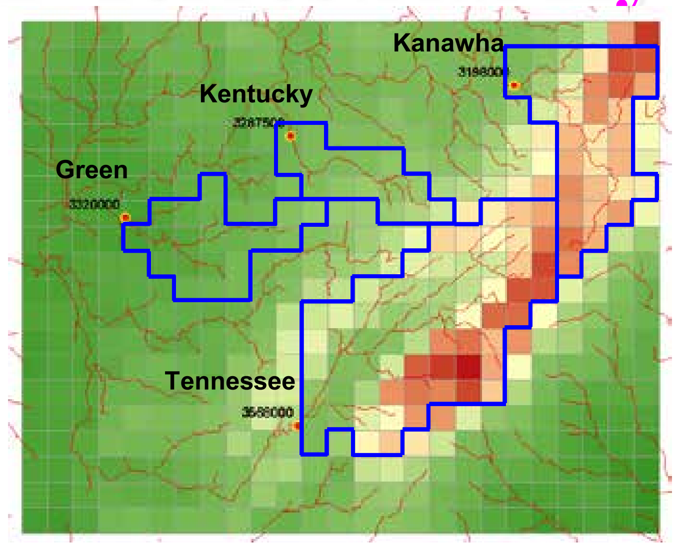
# Scale Dependence

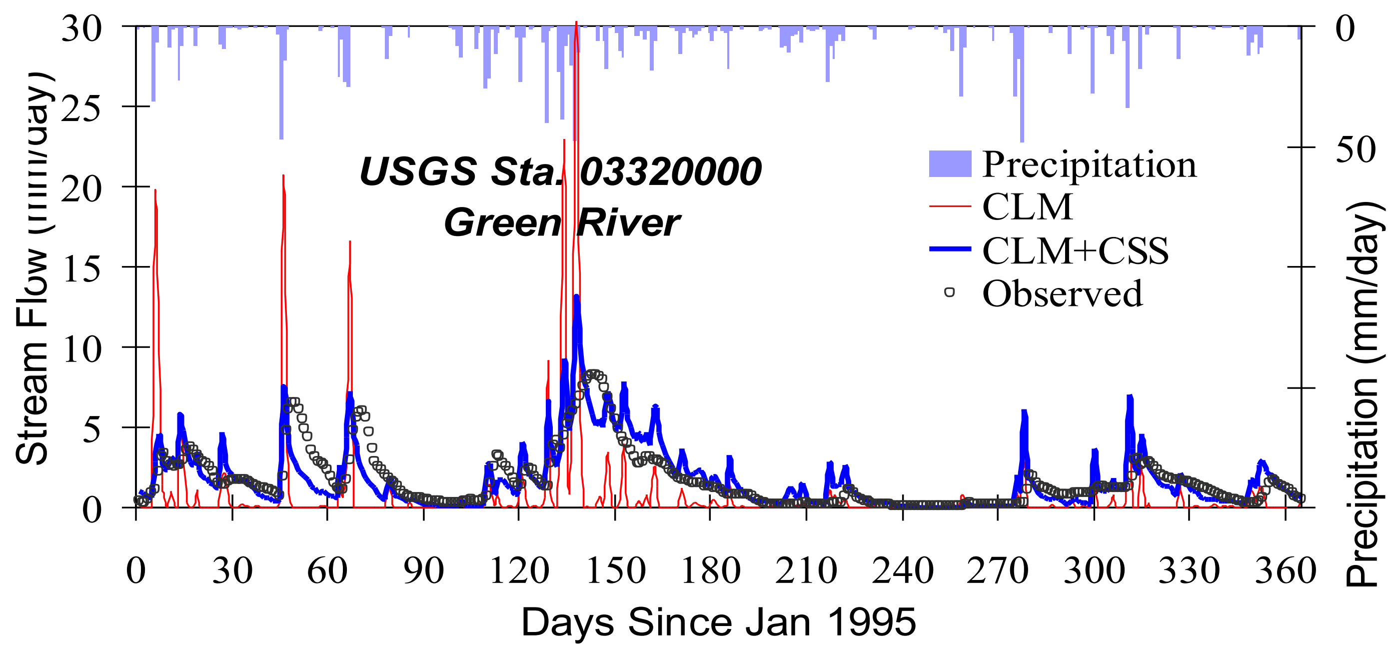
Model physics representation and predictive skill depend on spatial scale

*Challenging*

# CWRF Terrestrial Hydrology

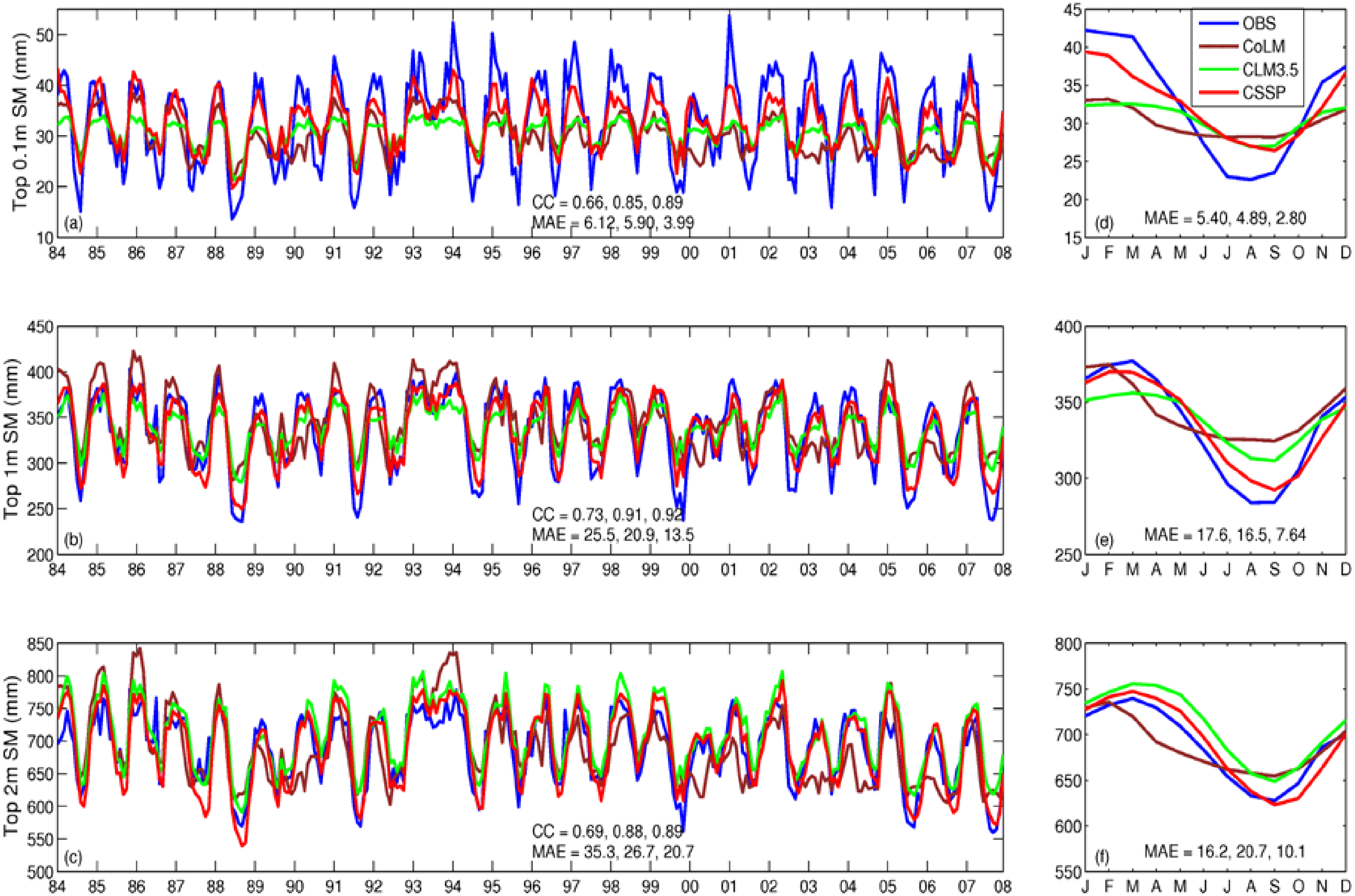





Choi 2006; Choi et al. 2007; Choi and Liang 2010; Yuan and Liang 2010; Liang et al. 2010d

# Illinois Soil Moisture Simulations Driven by NARR




Yuan and Liang 2011 (J. Hydrometeorology)

# CWRF

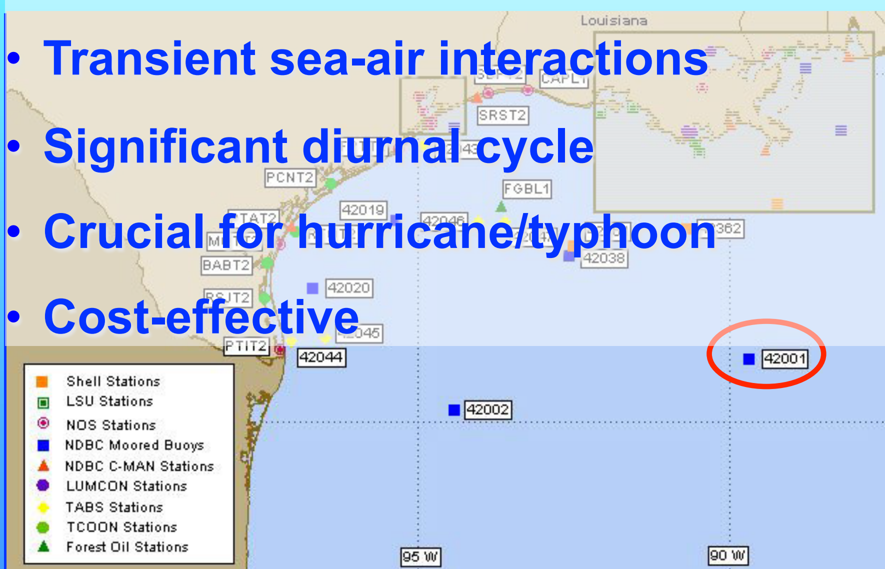
## Climate-Ocean Interaction

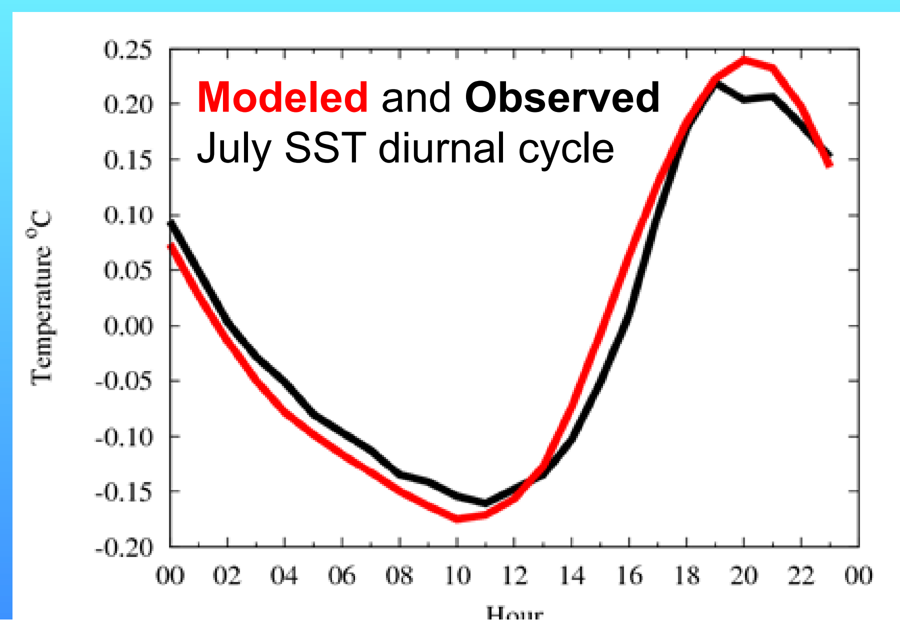
Multilevel Upper Ocean Model

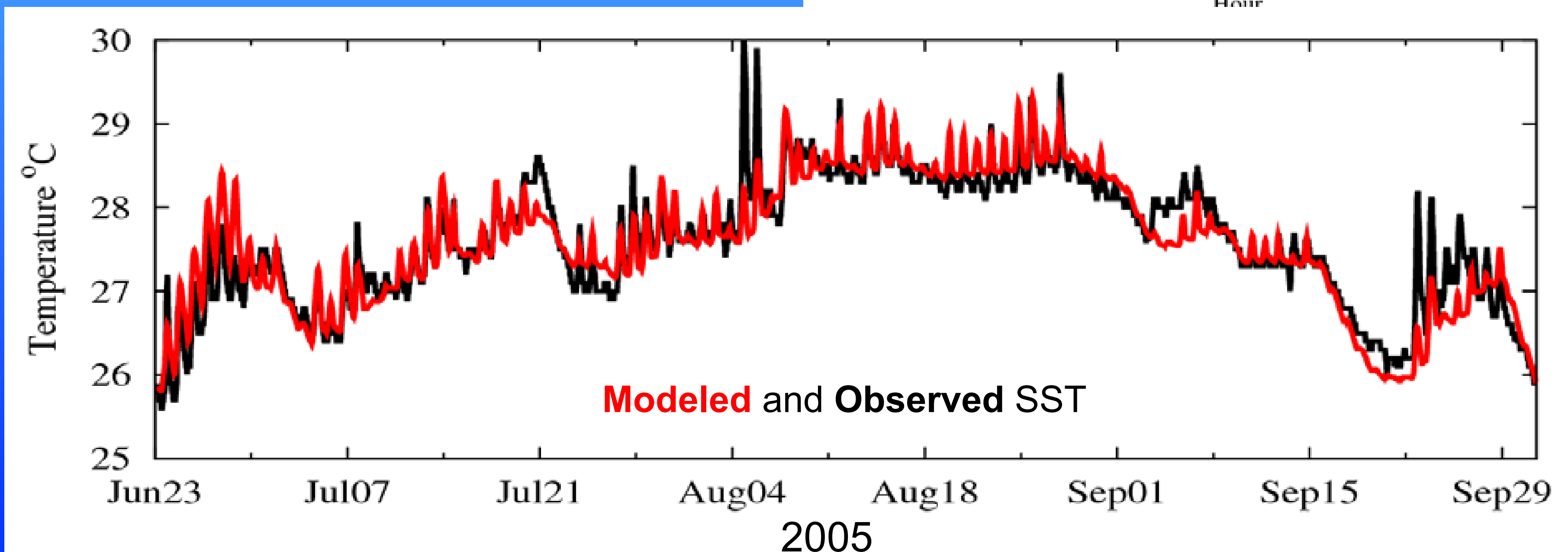
UOM

# CWRF MLO (upper 300m ocean)

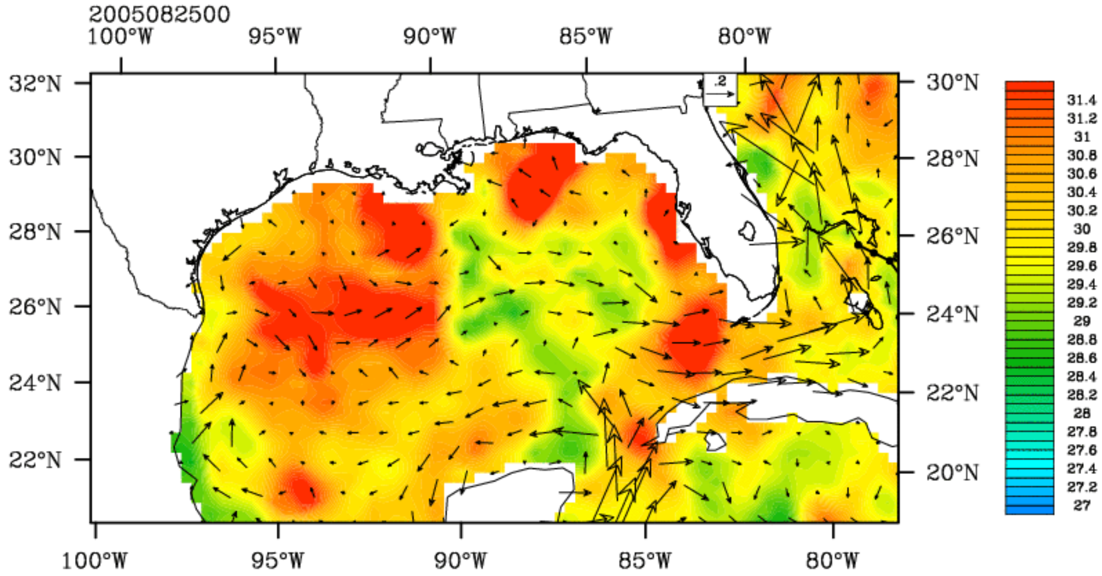
- Transient sea-air interactions
- Significant diurnal cycle
- Crucial for hurricane/typhoon
- Cost-effective



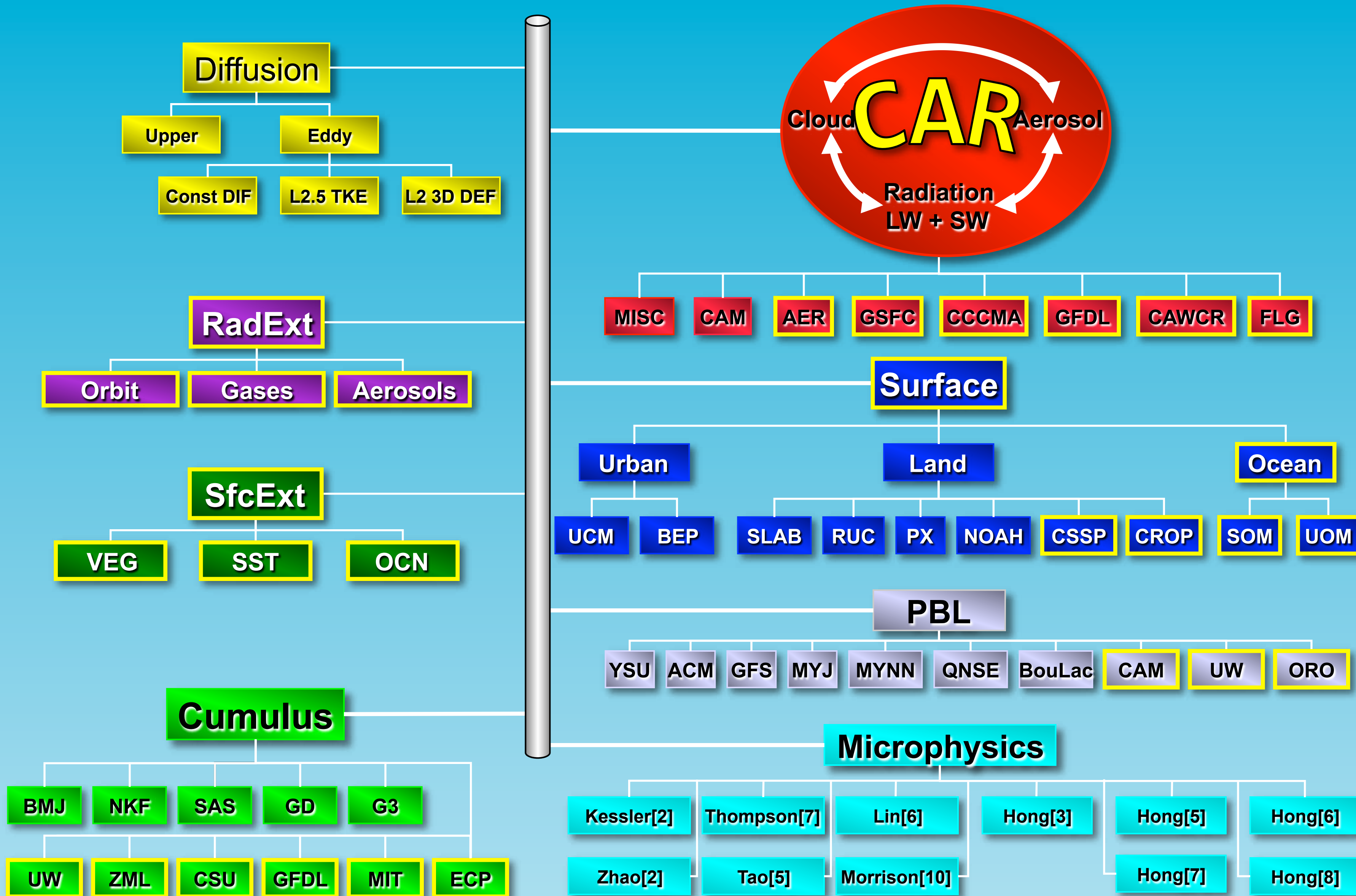
# Hurricane Katrina August 23-30, 2005



# PHYSICS CONFIGURATION

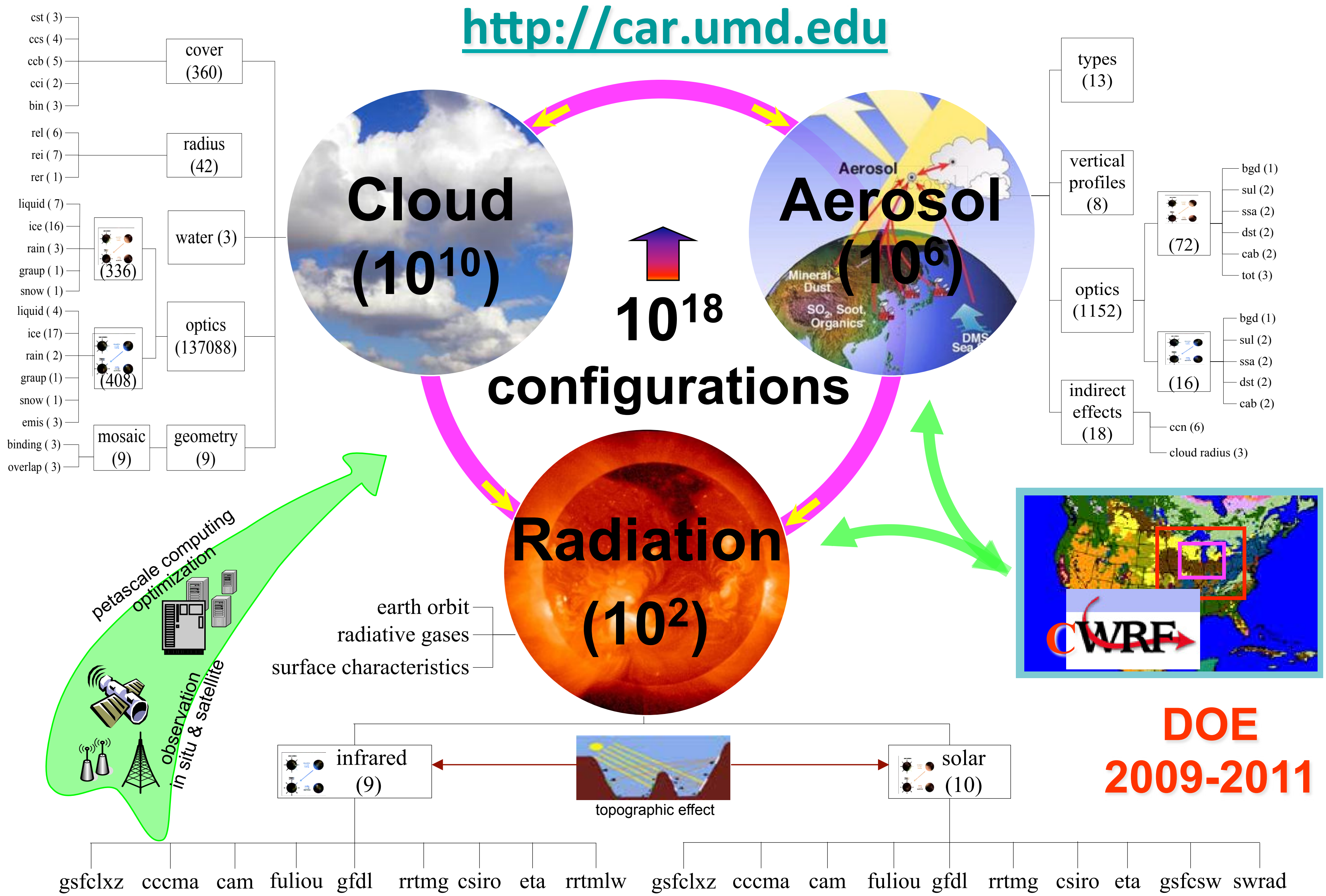
SELECTING OPTIMAL PARAMETERIZATION SCHEMES

# CWRF Physics Options

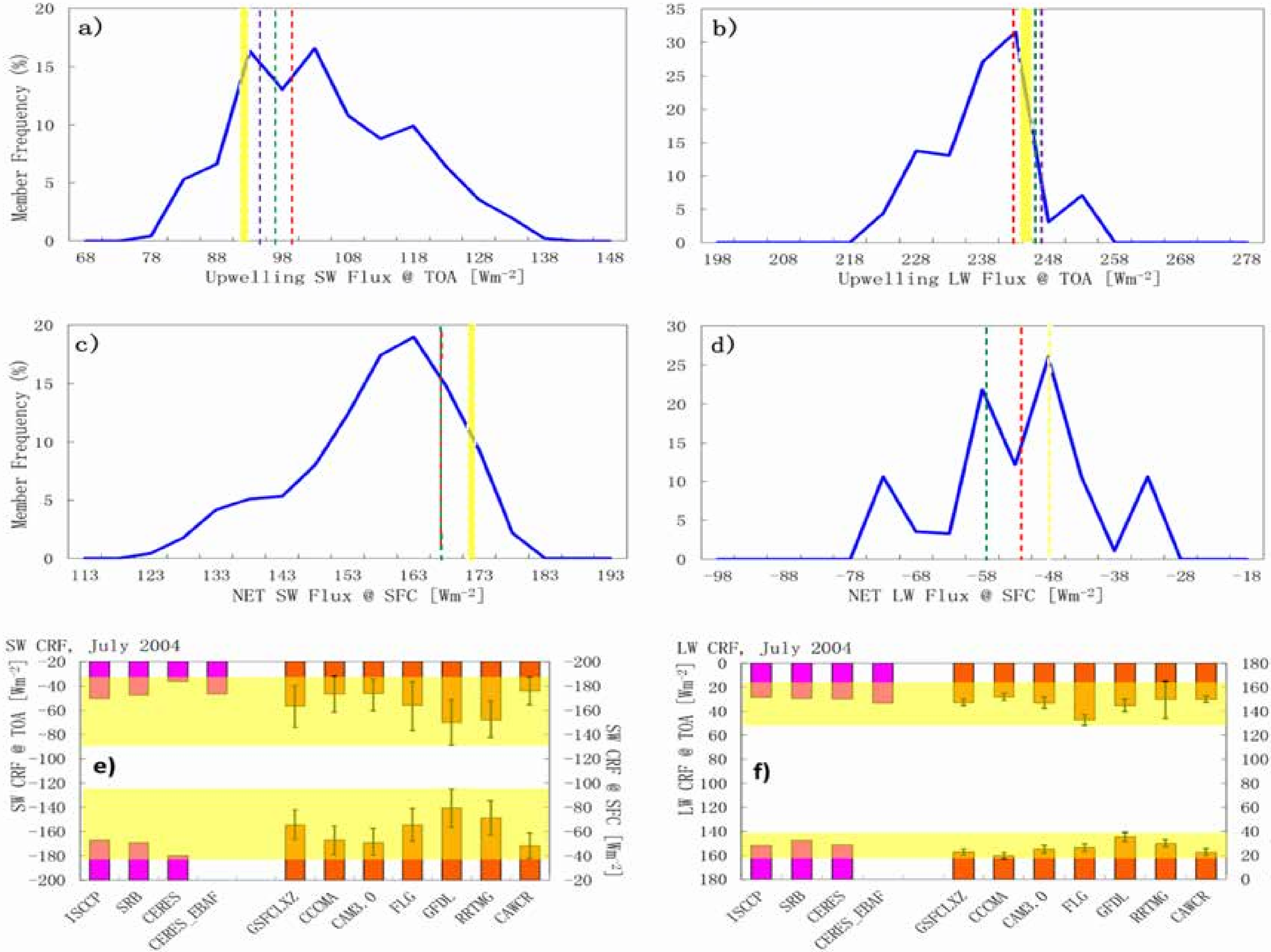



http://cwrf.umd.edu

# Cloud-Aerosol-Radiation Ensemble Model



# CAR Ensemble Flux Frequency Distribution

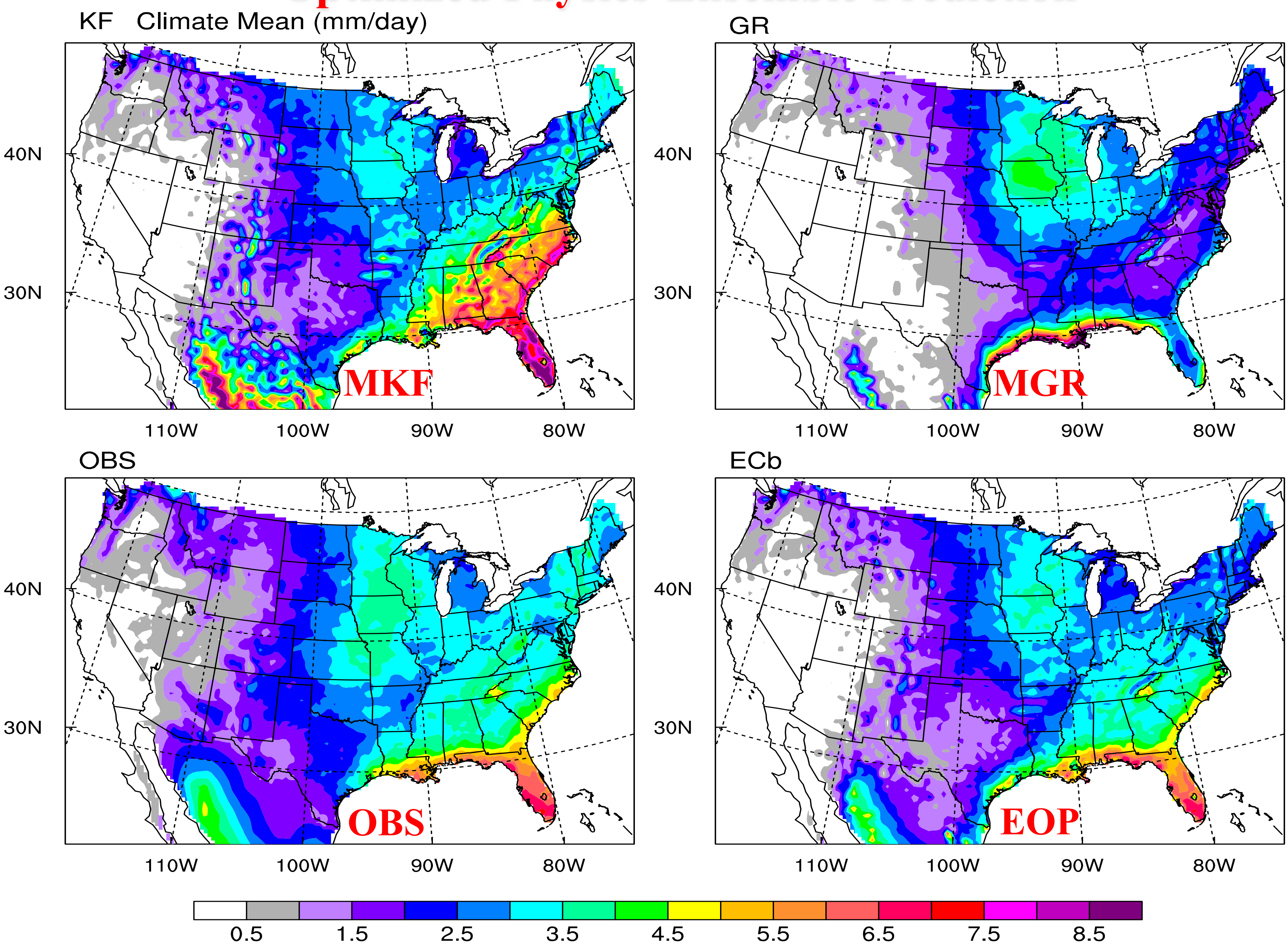


# Optimized Physics Ensemble

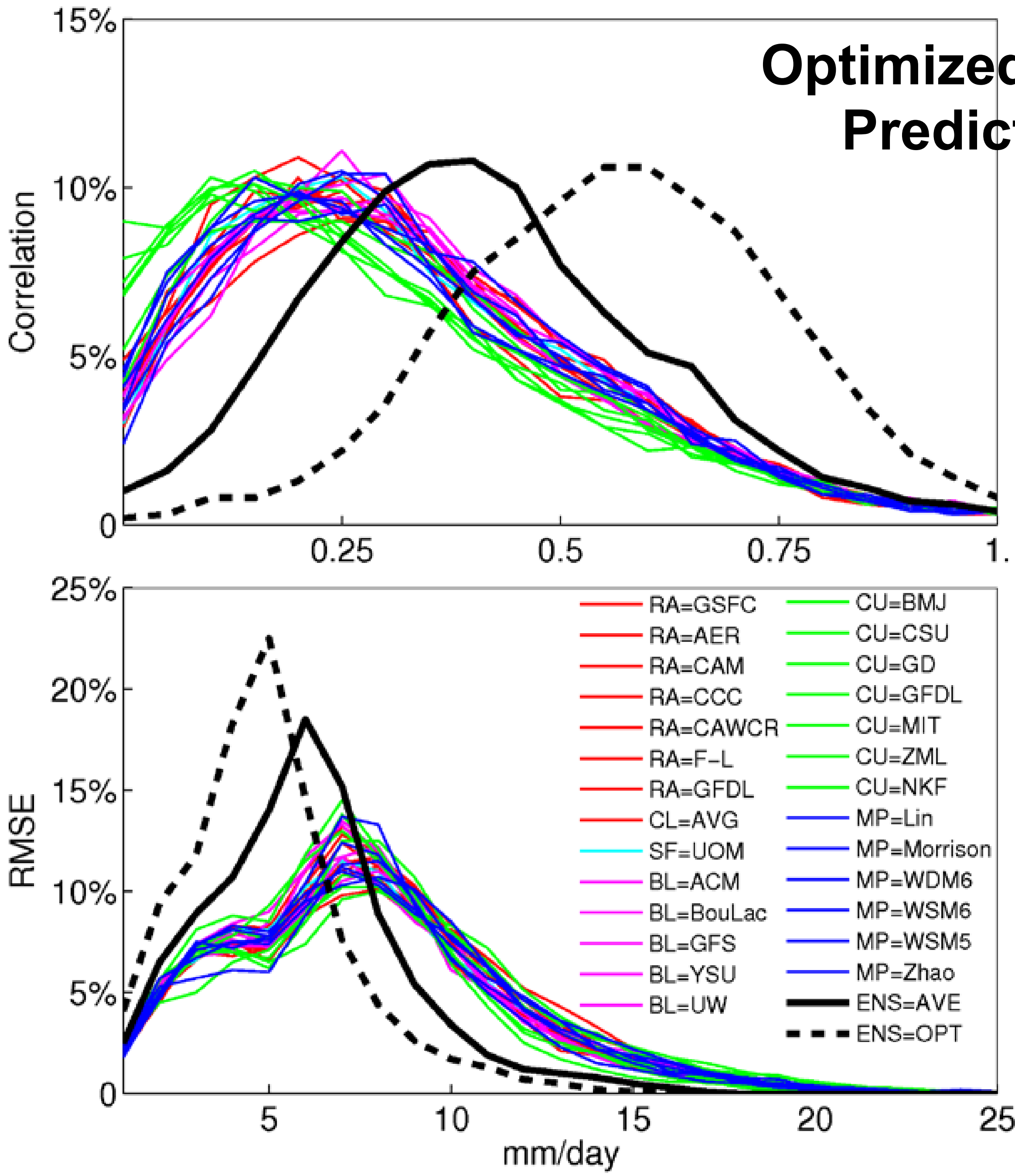
**Increasing predictive skill**

**Quantifying uncertainty**

# Optimized Physics-Ensemble Prediction



# Optimized Physics Ensemble Prediction of Precipitation In summer 1993




**The physics ensemble mean substantially increases the skill score over individual configurations, and there exists a large room to further enhance that skill through intelligent optimization.**

Spatial frequency distributions of correlations (*top*) and rms errors (*bottom*) between CWRF and observed daily mean rainfall variations in summer 1993. Each line depicts a specific configuration in group of the five key physical processes (*color*). The ensemble result (ENS) is the average of all runs with equal (Ave) or optimal (OPT) weights, shown as *black solid* or *dashed* line.

# CWRF improves predictions at regional-local scales

- CWRF includes advanced physics schemes crucial to climate
- CWRF couples essential components directly linking to impacts
- CWRF builds upon a super ensemble of alternative physics schemes for skill optimization and uncertainty quantification
- CWRF has greater capability & better skill than CMM5, WRF…
- CWRF downscaling improves CFS precipitation predictions