State of the Science of Climate Modeling from Global to Regional Scales

Metropolitan Washington Council of Governments
Climate Impacts Symposium
May 21, 2012

Antonio J Busalacchi
Chair, U. Maryland Council on the Environment
Director, Earth System Science Interdisciplinary Center

With thanks to:
Steve Halperin, Sujay Kaushal, Xin-Zhong Liang, Ragu Murtugudde, Da-Lin Zhang

Chair, Joint Scientific Committee,
World Climate Research Programme (WCRP)

Chair, NAS/NRC Board on Atmospheric Sciences and Climate (BASC)

Chair, NOAA Climate Working Group (CWG)

Outline

- International Perspective
- Facts and fiction about downscaling and regional climate modeling
- Multiple stressors and extreme events at regional scales
- Examples of relevant regional climate modeling
- What we can reasonably expect from regional climate models at present and in the near future

Mission & Objectives

- **World Climate Research Programme** supports **climate-related decision making** and planning **adaptation to climate change** by coordinating research required to improve

(1) climate predictions and

(2) our understanding of human influence on climate

"for use in an increasing range of practical applications of direct relevance, benefit and value to society"
(WCRP Strategic Framework 2005-2015).

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ESSP DIVERSITAS IGBP IHDP WCRP

WCRP
World Climate Research Programme

WMO IOC ICSU

WCRP OPEN SCIENCE CONFERENCE

CLIMATE RESEARCH IN SERVICE TO SOCIETY

Monday:	**The Climate System Components and their Interactions**
Tuesday:	**Observation and Analysis of the Climate System**
Wednesday:	**Assessing and Improving Model and Predictive Capabilities**
Thursday:	**Climate Synthesis and Assessments**
Friday:	**Translating Scientific Understanding into Climate Information for Decision Makers**

24–28 October 2011, Denver, Colorado, USA

conference2011.wcrp-climate.org

WCRP World Climate Research Programme

WCRP REPORT

SUMMARY REPORT

A STRATEGY FOR CLIMATE CHANGE STABILIZATION EXPERIMENTS WITH AOGCMs AND ESMs

Aspen Global Change Institute 2006 Session
Earth System Models: The Next Generation

(Aspen, Colorado, July 30–August 5, 2006)

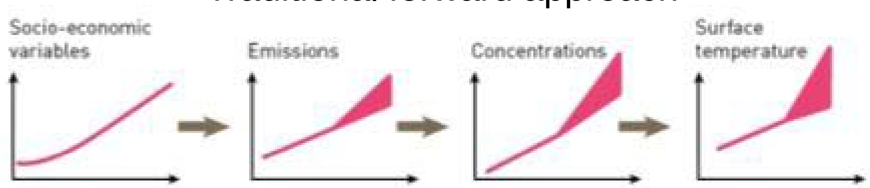
May 2007

WCRP Informal Report N° 3/2007
ICPO Publication N° 112
IGBP Report N° 57

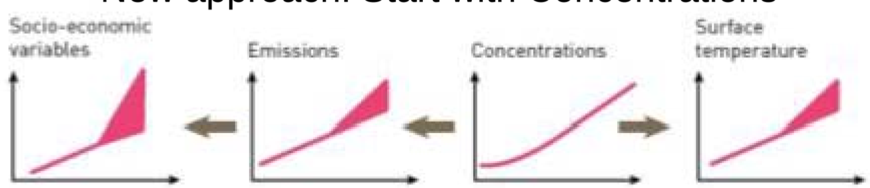
Contributions to IPCC AR5
in collaboration with IGBP

AR5 Scenario Development

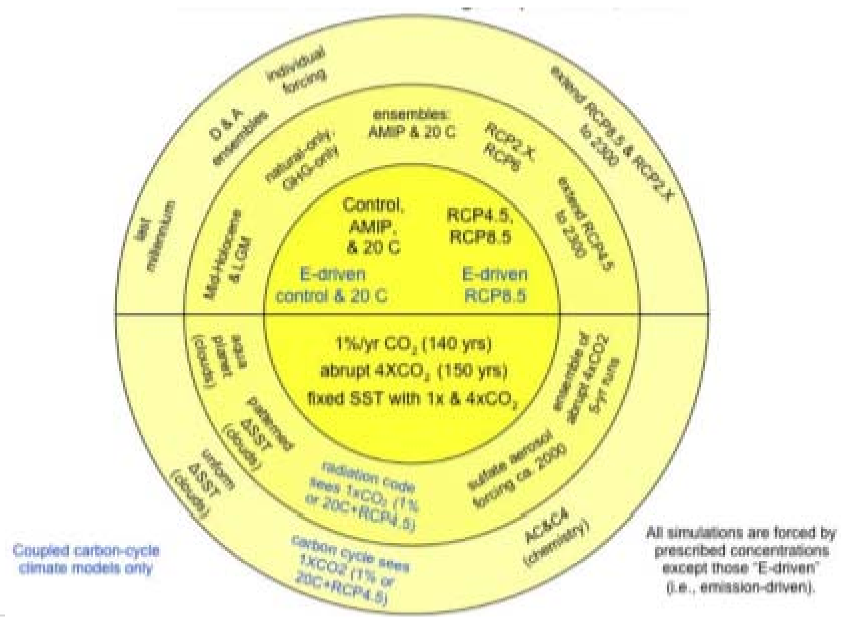
Traditional forward approach



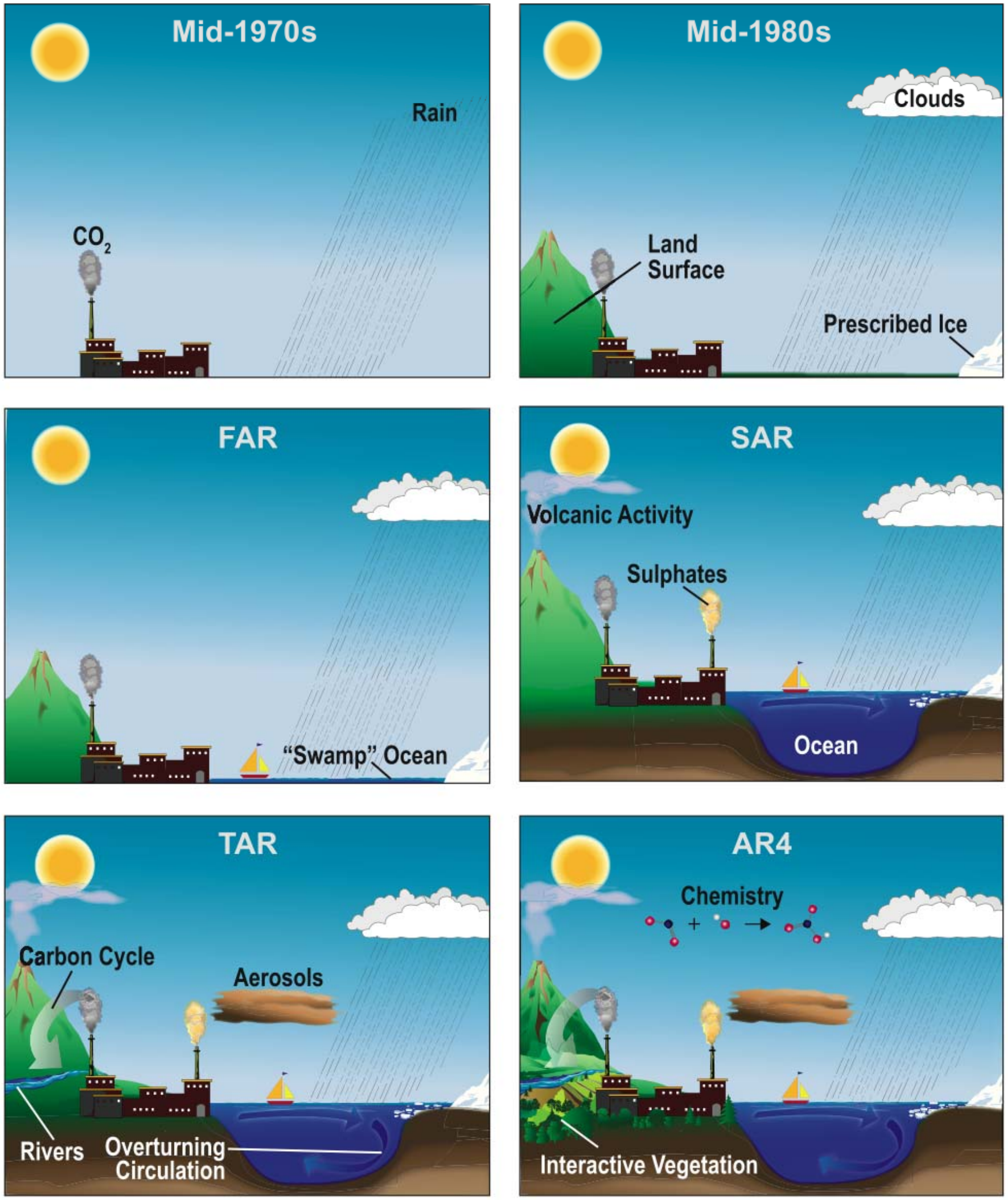
New approach: Start with Concentrations



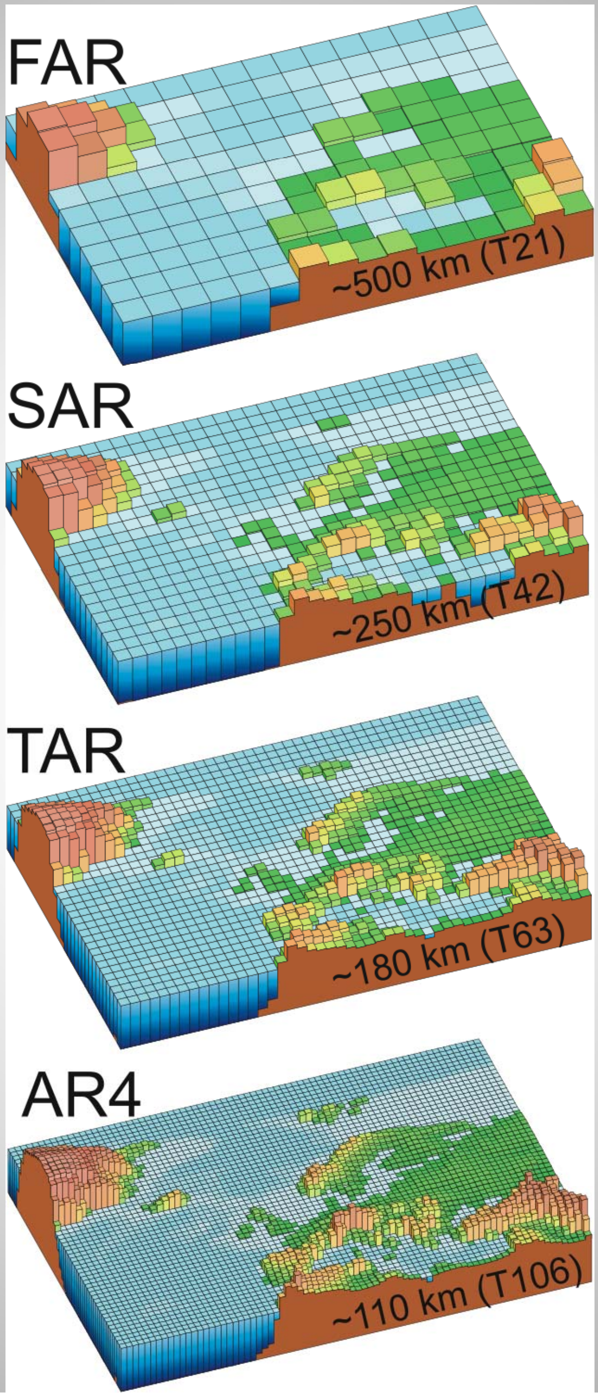
WGCM CMIP5
Decadal + Long-Term Protocols



The World in Global Climate Models



Geographic resolution characteristic of the generations of global climate models used in the IPCC Assessment Reports

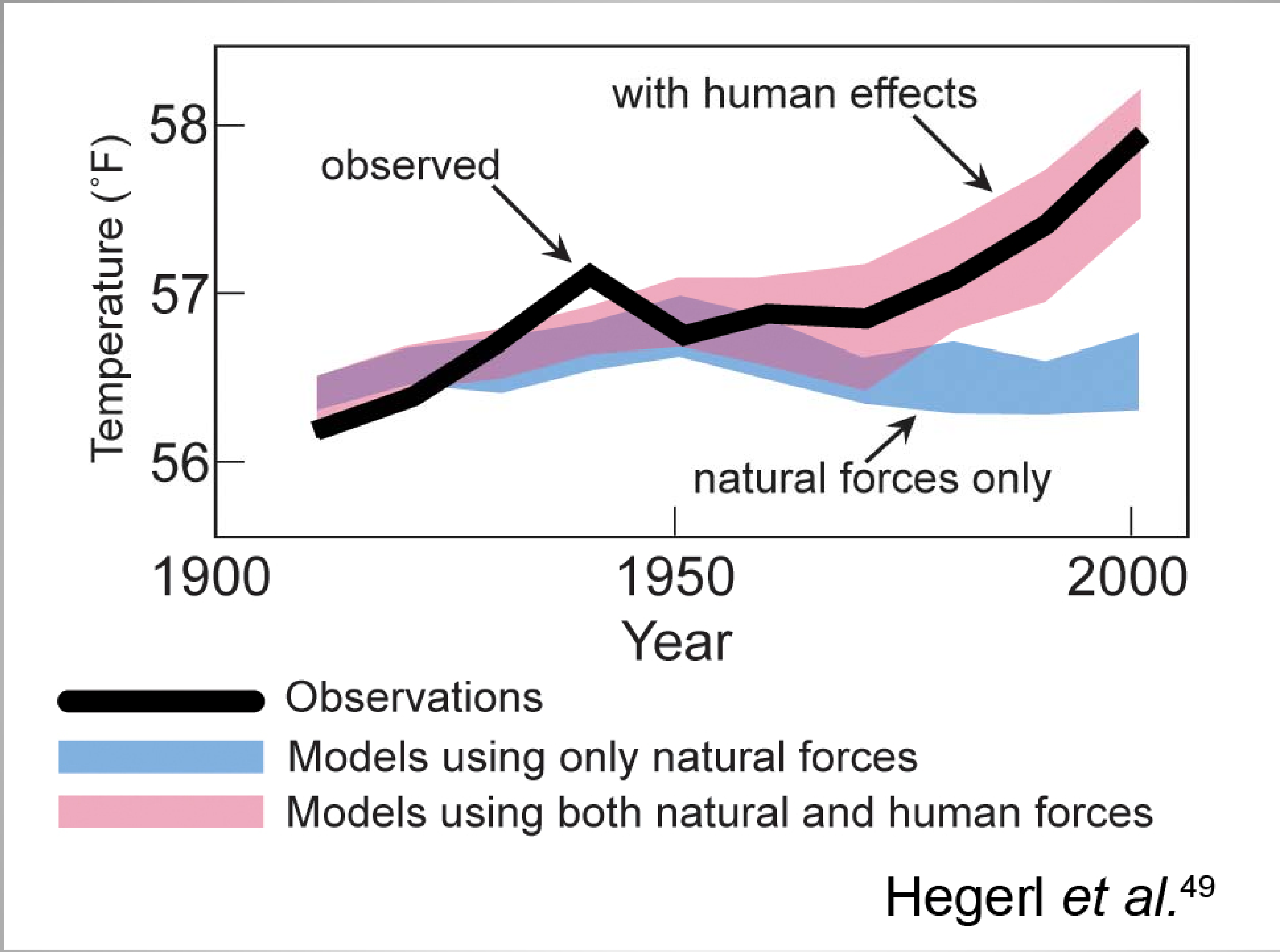


1990

1996

2001

2007



The blue band shows how global average temperatures would have changed due to natural forces, only as simulated by climate models. The red band shows model projections of the effects of human and natural forces combined. The black line shows actual observed global average temperatures. As the blue band indicates, without human influences, temperature over the past century would actually have first warmed and then cooled slightly over recent decades.

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Future Directions: Actionable Science

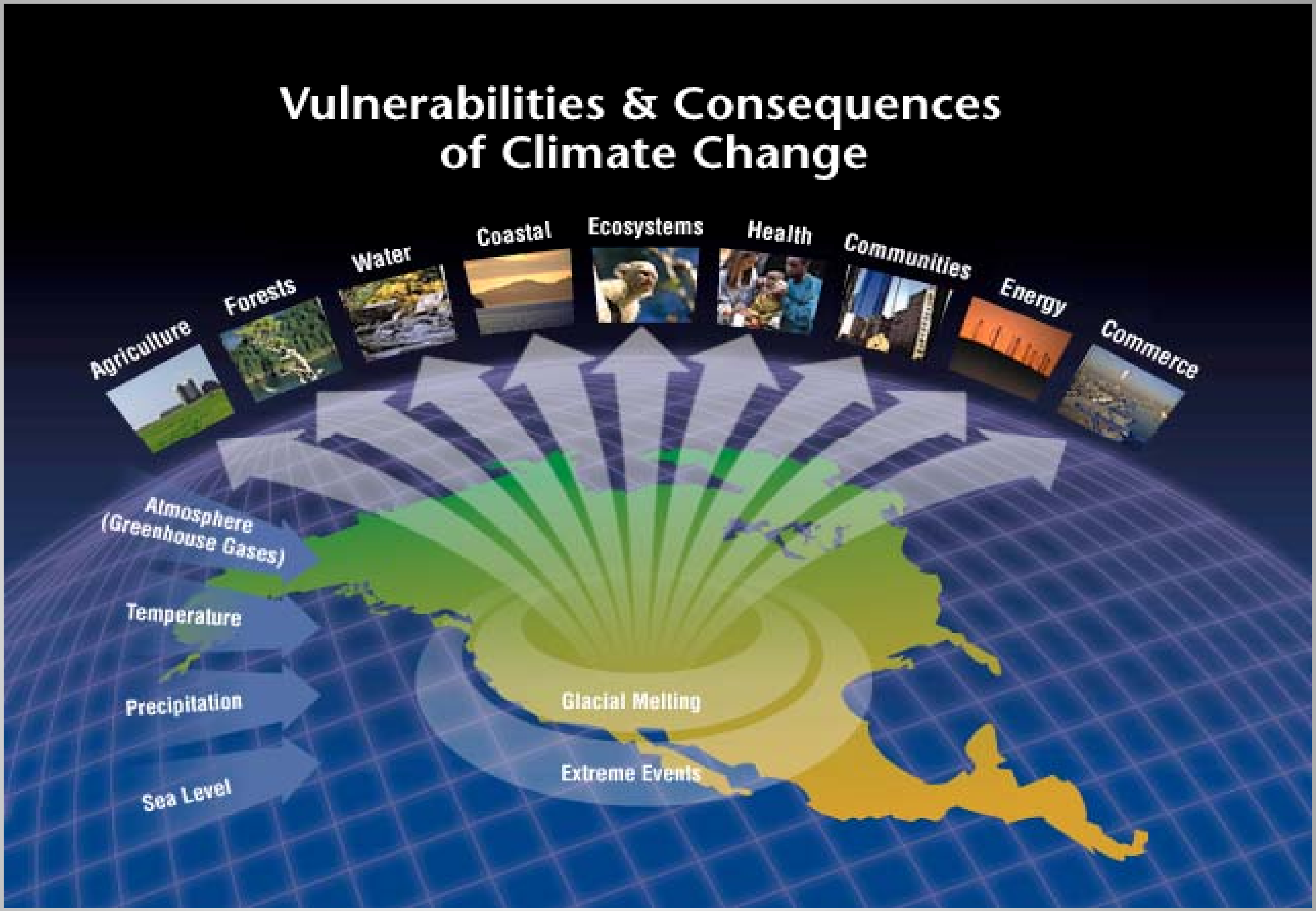
Defined as: data, analysis, and forecasts that are sufficiently predictive, accepted and understandable to support decision-making, including capital investment decision-making.

- World Climate Conference-3, OceanObs '09, ICSU Review and Visioning, acknowledge WCRP past contributions and identify future challenges and opportunities.

- Need for more flexibility/agility to respond to expanding users needs, that includes information:

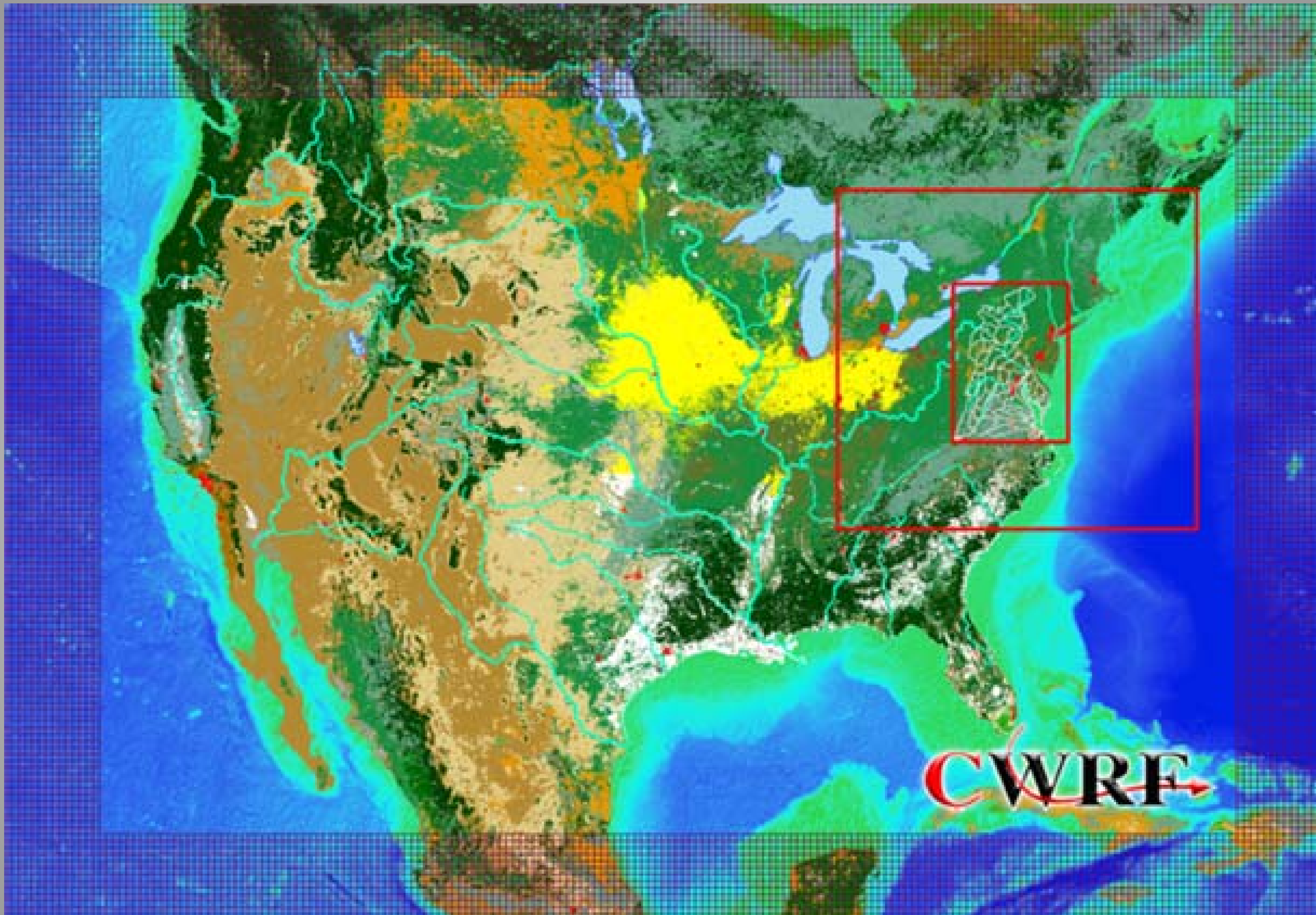
    - At regional scale
    - For key sectors of global economy
    - For adaptation, mitigation and risk management

Grand Challenges: Prediction of the Earth System



GOALS:

- Deliver knowledge to respond to global change
- Engage a new generation of researchers
- Transition to the full range of sciences and humanities



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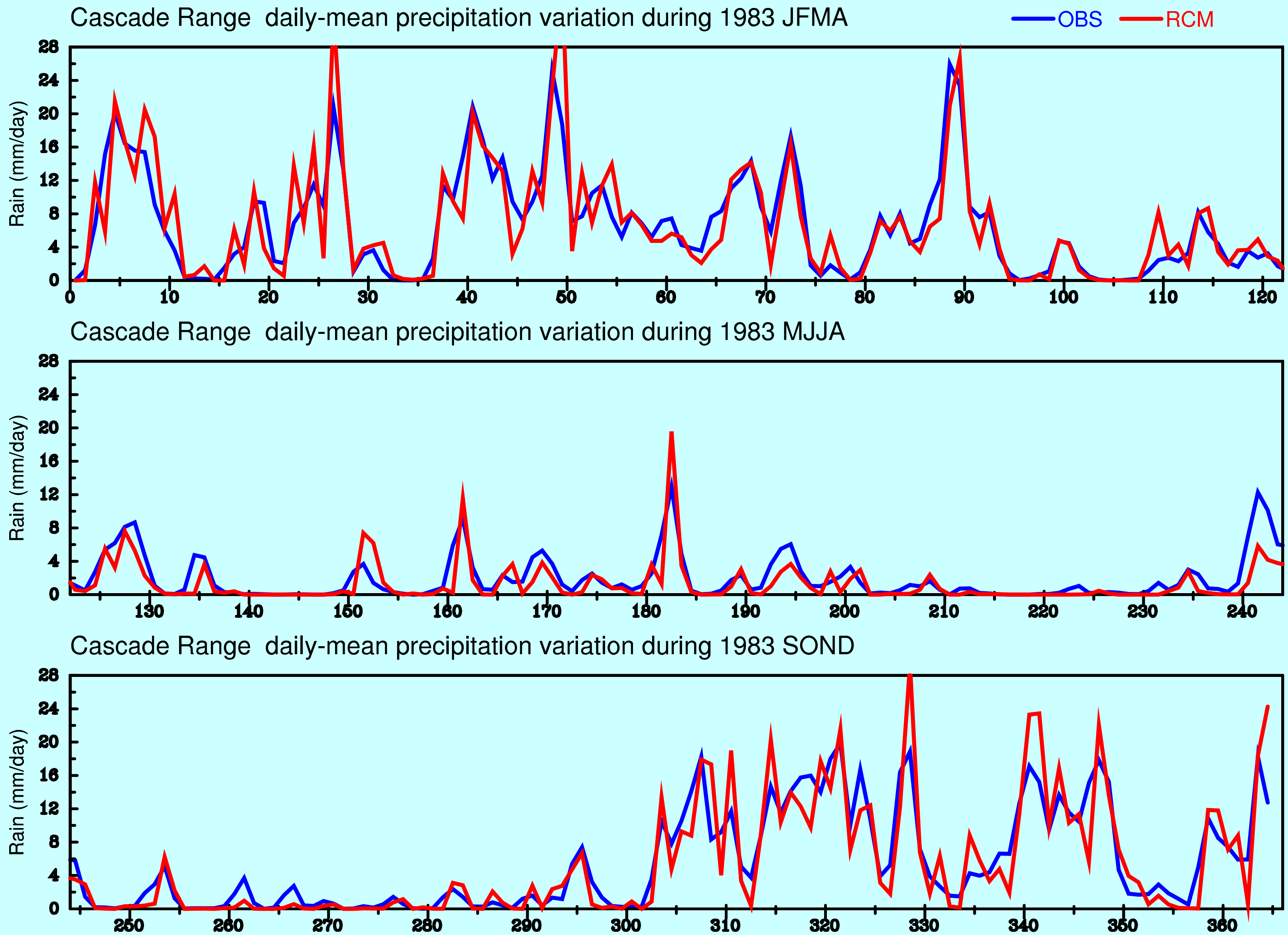
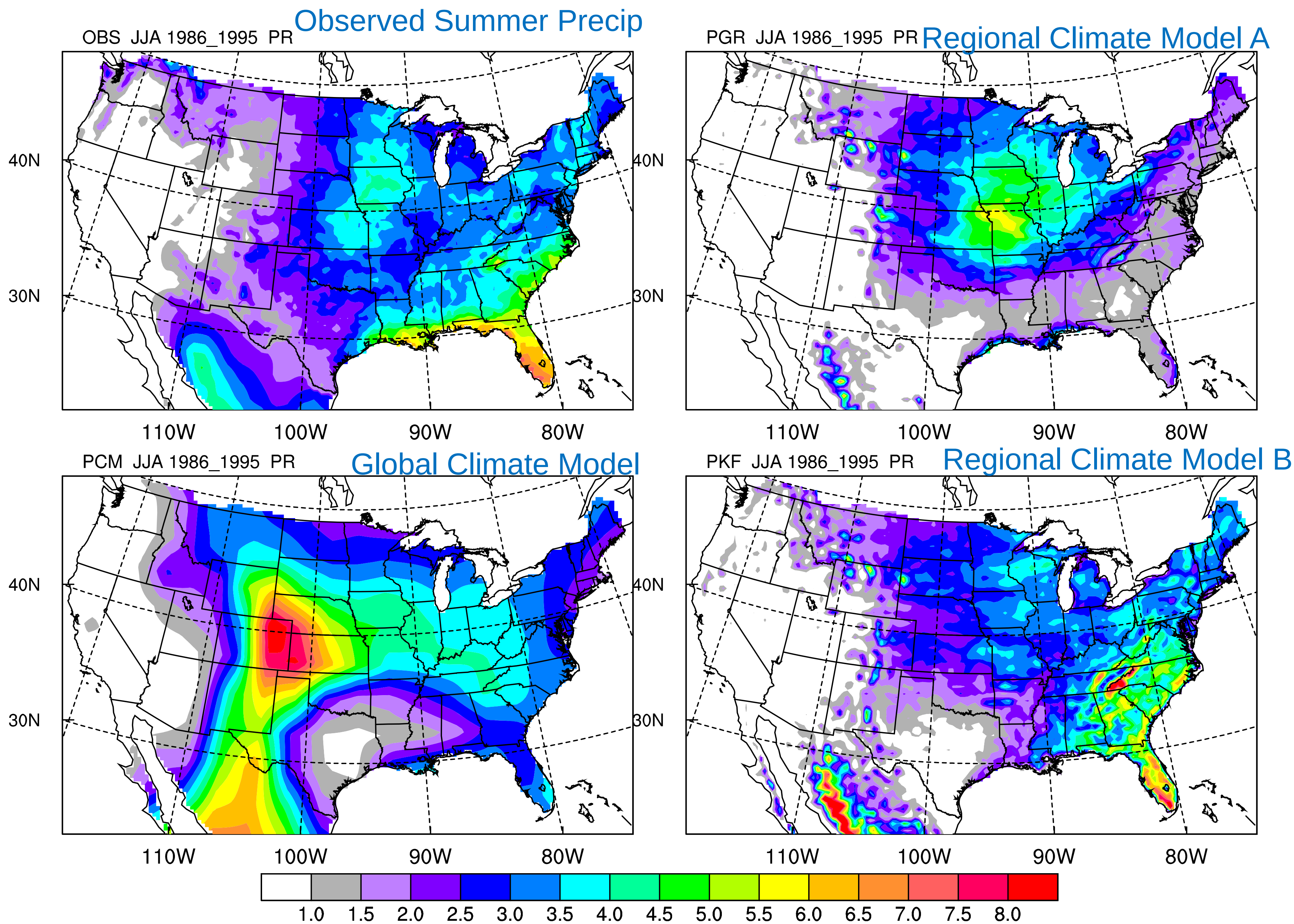
Downscaling Skill: Daily Fluctuations
Role of Orography in the Cascades

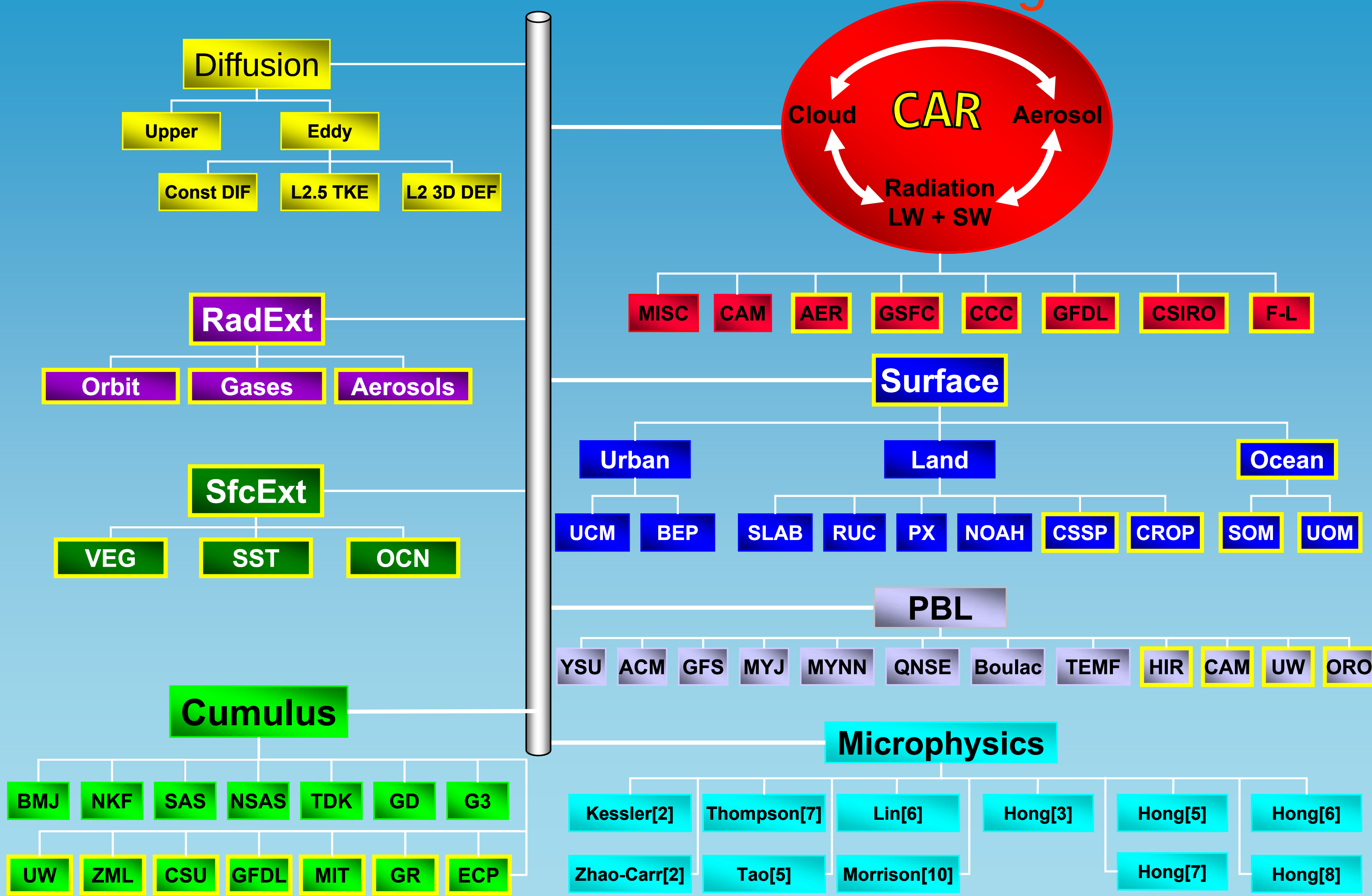


Much More Than That…



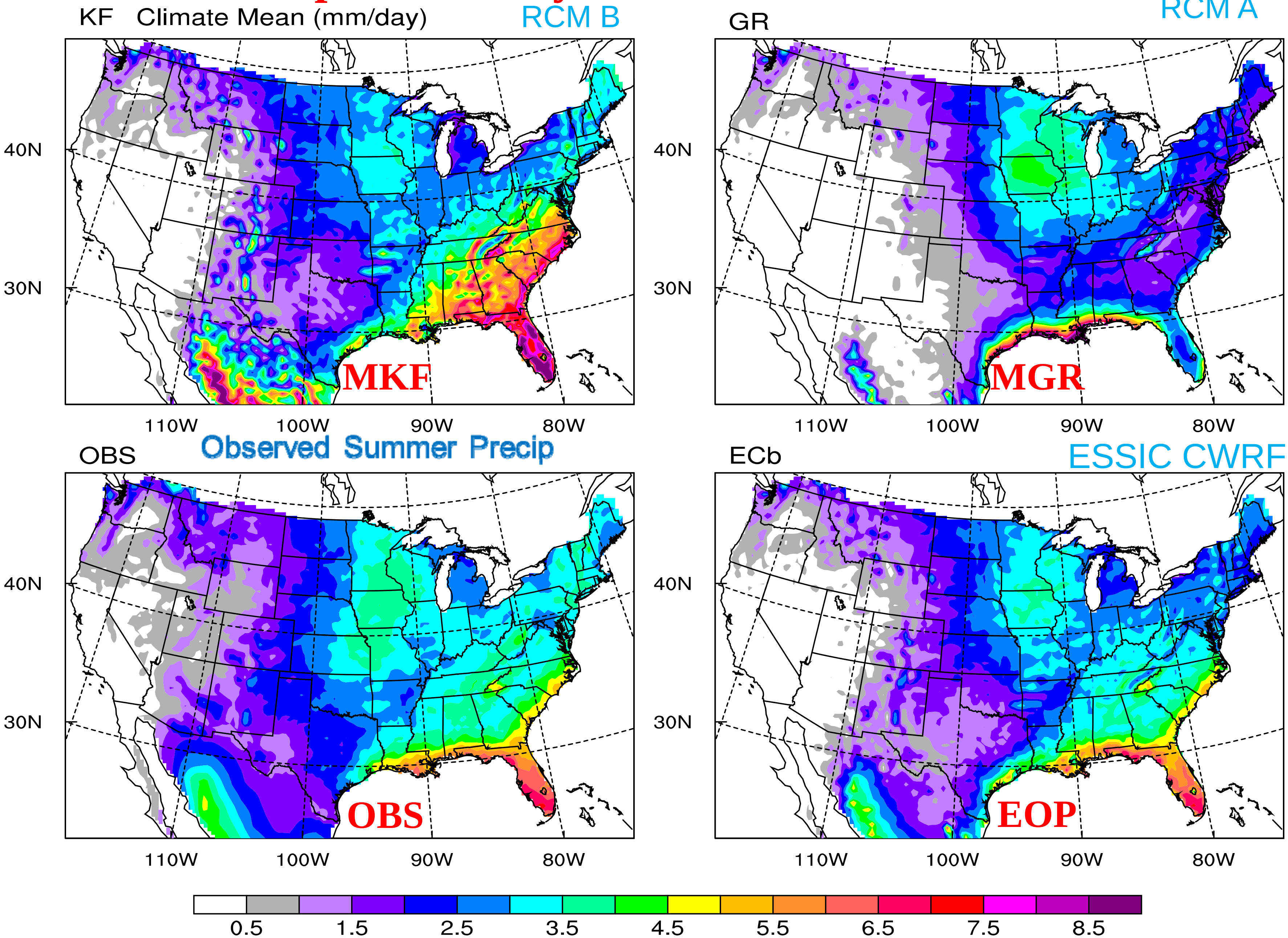
ESSIC CWRF Physics Options

Under Direction of X-Z Liang



http://cwrf.umd.edu

Optimized Physics-Ensemble Prediction

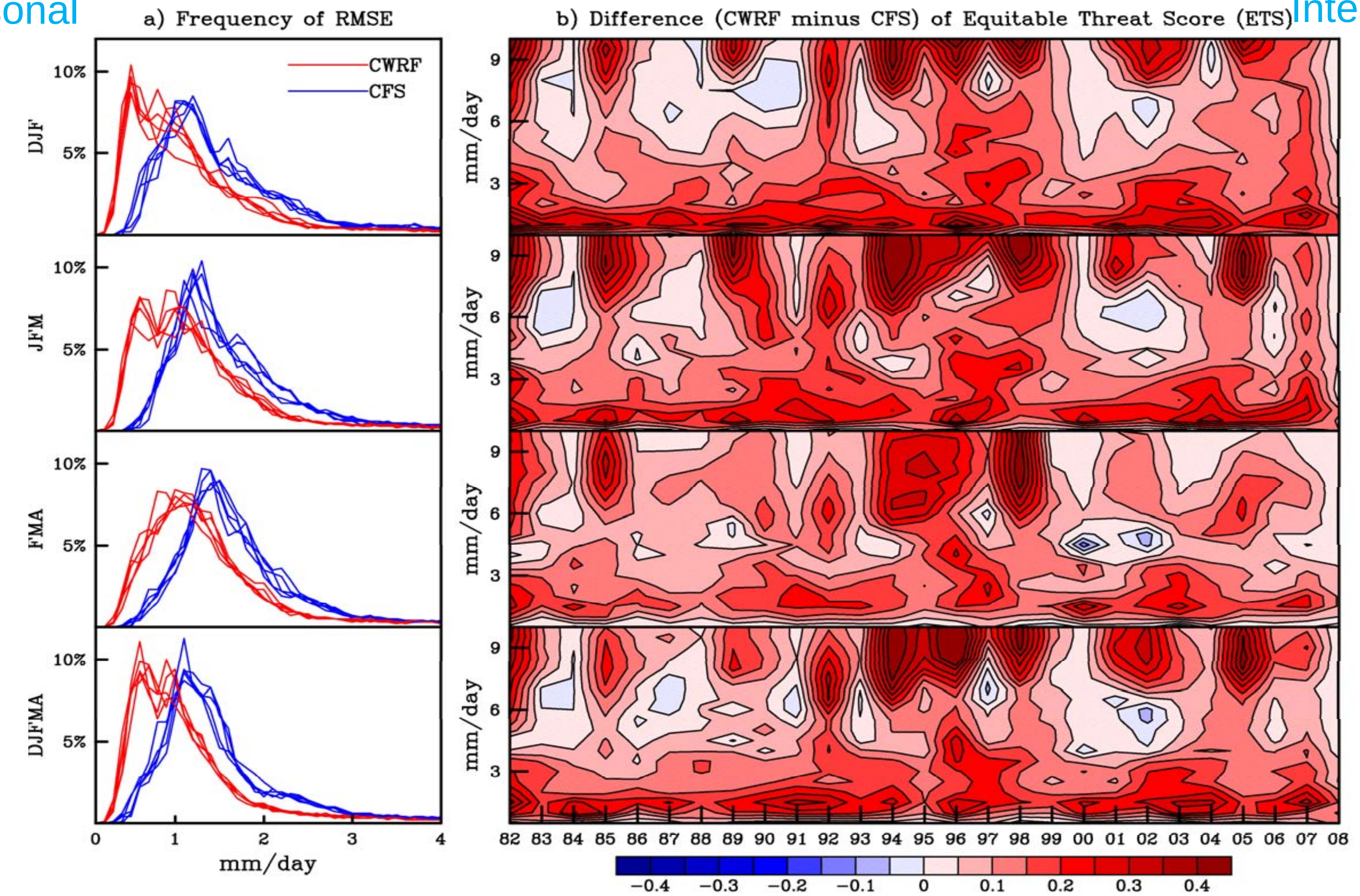


CWRF Improves Seasonal Climate Prediction

Precipitation Errors CWRF vs NOAA Global CFS

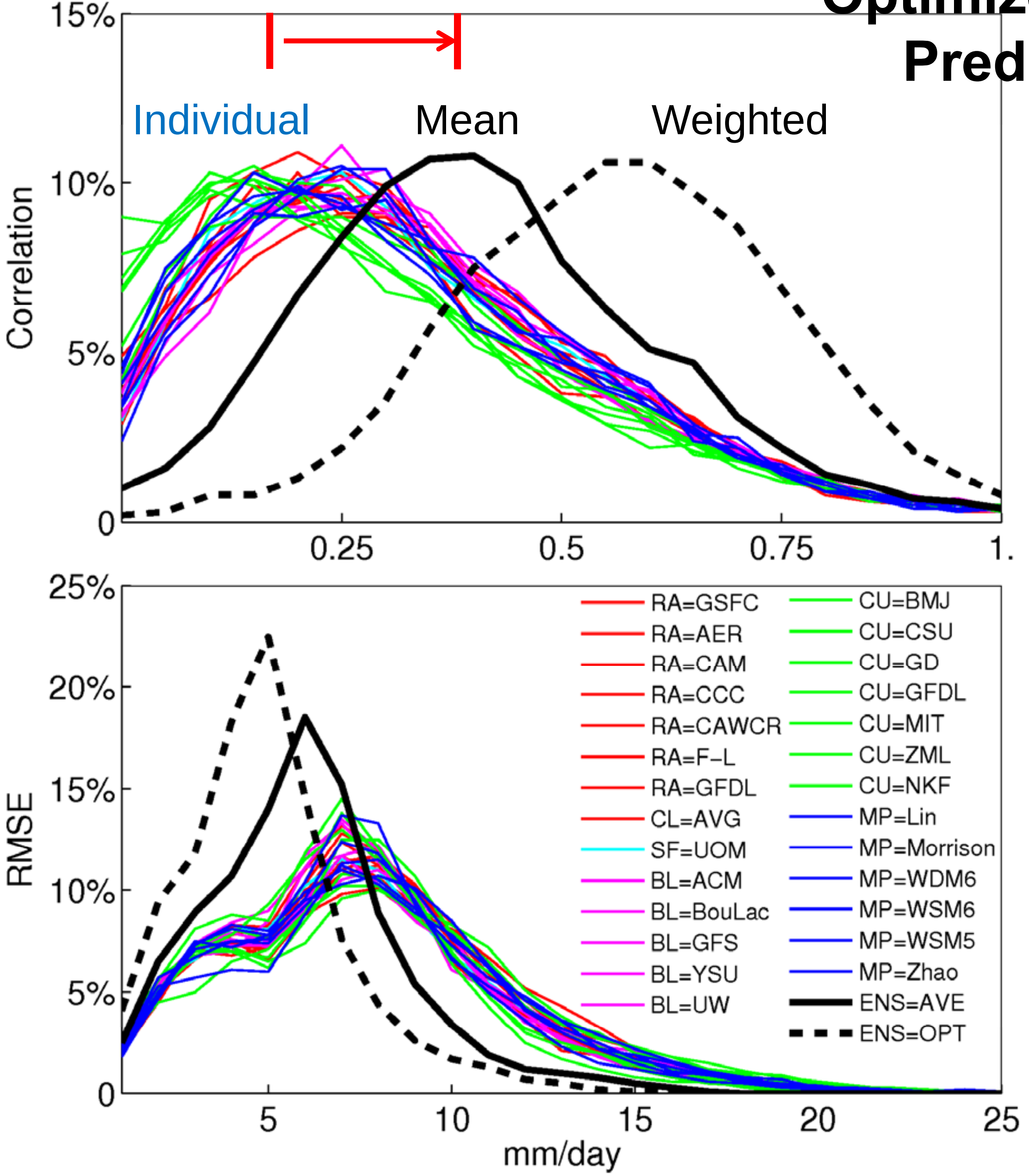
Seasonal

Interannual



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).

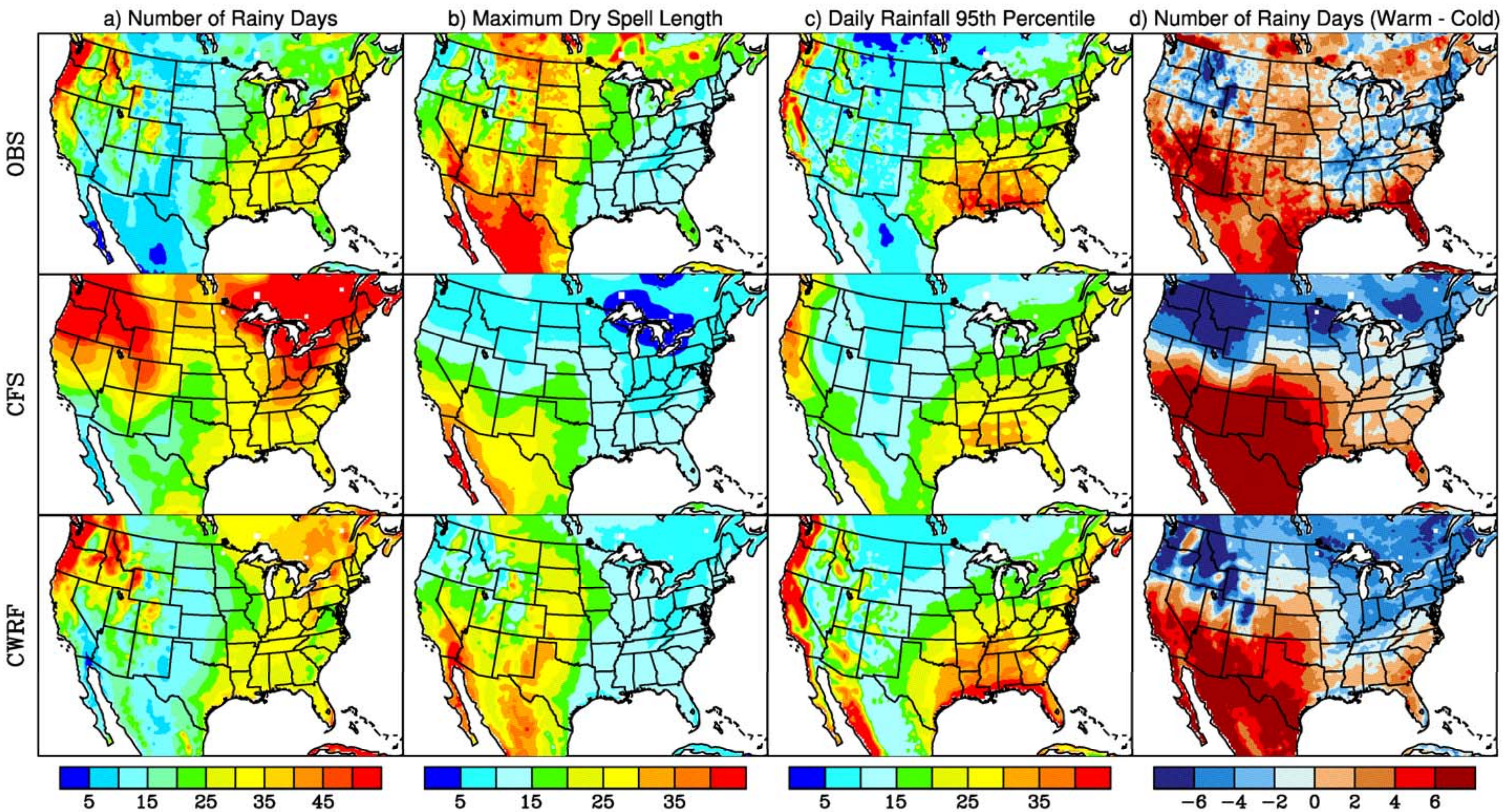
Optimized Physics Ensemble Prediction of Precipitation In summer 1993



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 Downscaling Seasonal Climate Prediction: Extreme Events



Observed (OBS), CFS-predicted, and CWRF-downscaled: **a)** number of rainy days, **b)** maximum dry spell length (day), **c)** daily rainfall 95th percentile (mm/day), and **d)** difference in number of rainy days averaged between the El Niño (warm) and La Niña (cold) events for JFM during 1983-2008.

Why is Baltimore often warmer than Washington, DC?

Hypothesis:

The warmer air and higher ozone concentrations observed in Baltimore results primarily from the enhanced Urban Heat Island effects by upstream urbanization.

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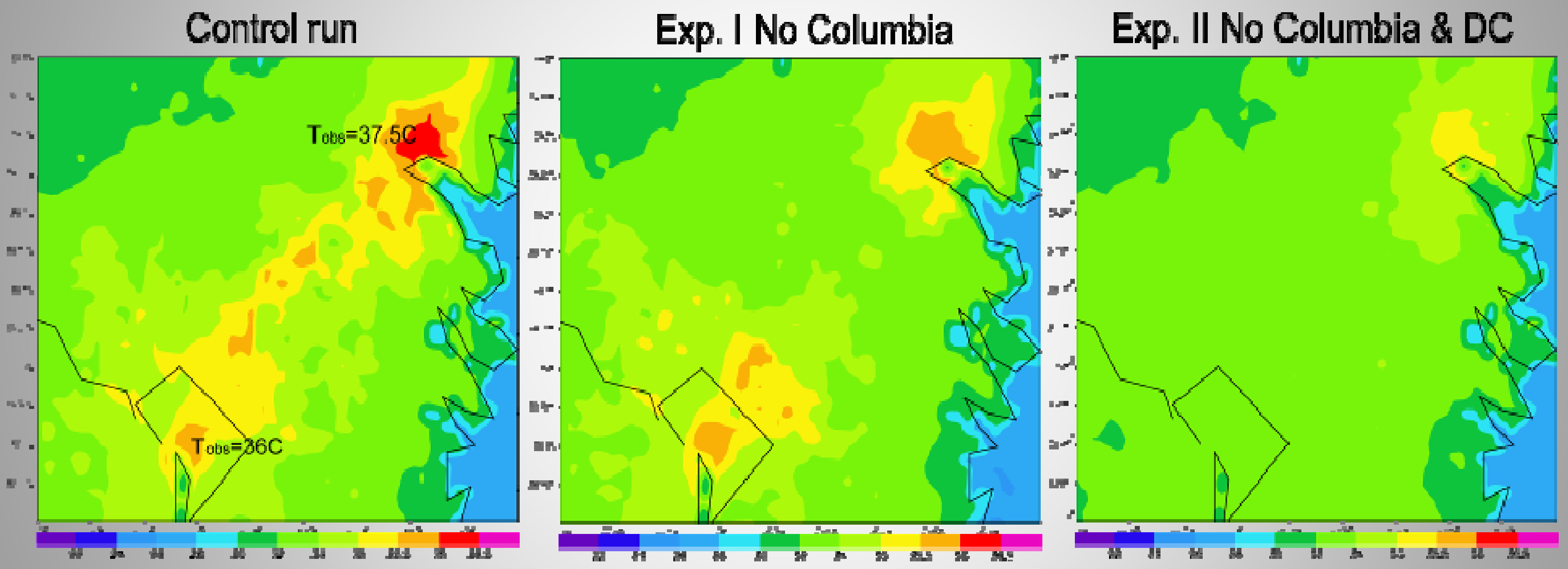
Simulated surface temperatures



Simulated surface temperatures at 15:30 LST 9 July 2007: (a) Control run; (b) No Columbia run; and (c) No upstream urban run.

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Major findings:

- Without the upstream influences, the UHI effects over Baltimore would be 1.25°C colder or reduced by 25%, with a 200-m shallower boundary layer and much less robust "hot plumes".
- The enhanced UHI effects are argued to result from the (nonlocal) thermal advection of warm air upstream, local upward surface heat fluxes and entrainment of the potentially warmer air aloft.

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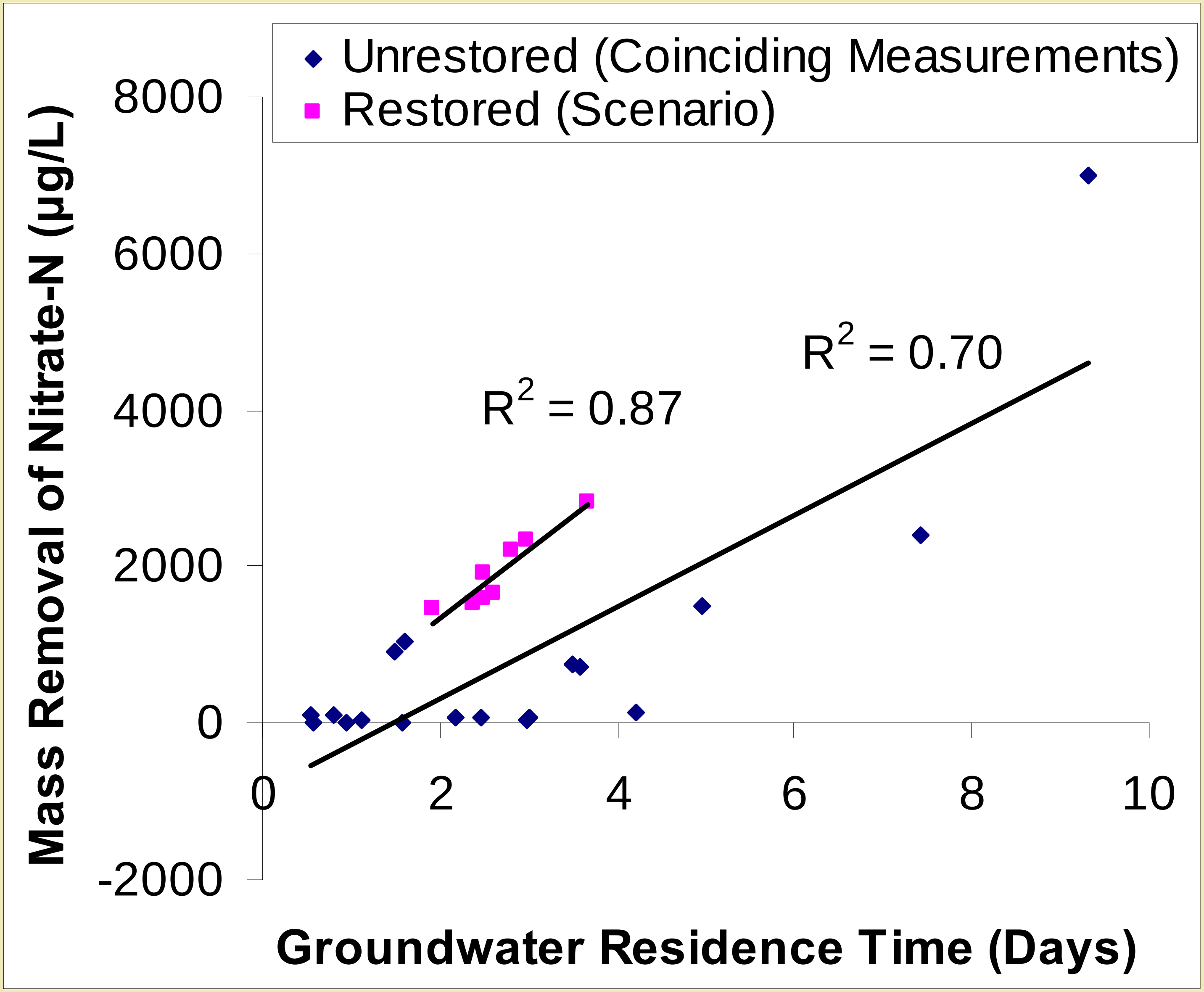
Land Use and Sources of Nitrogen Export





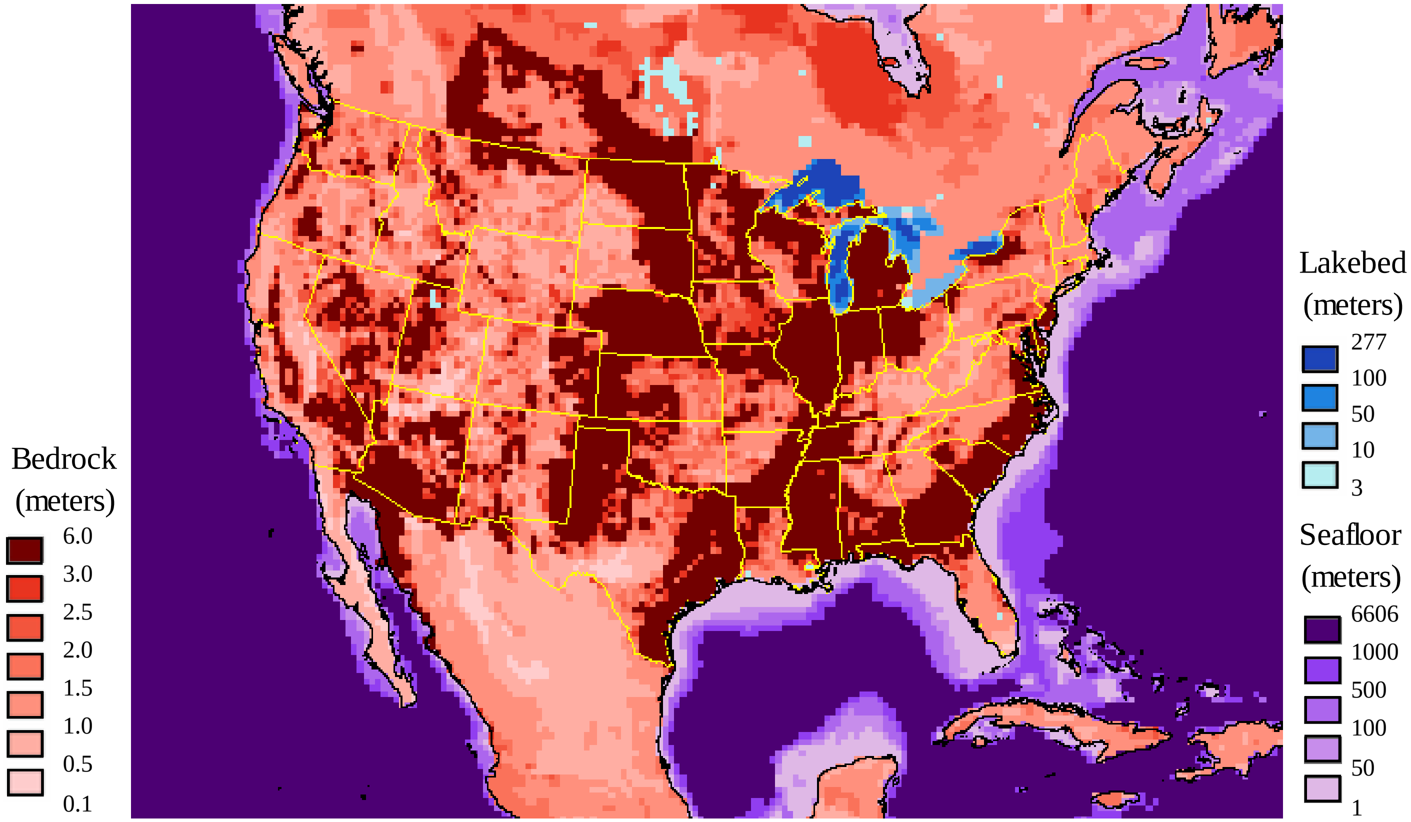
Lesson #2: Hydrologic residence time is important to remove N.



Kaushal et al. (2008), *Ecological Applications*

Demand for Terrestrial Characterization

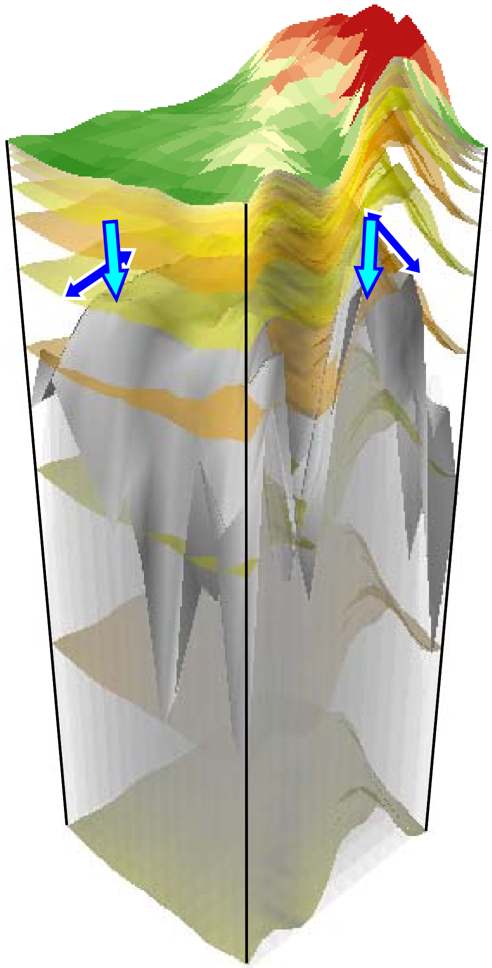
Bedrock, Lakebed or Seafloor Depth (DBED)

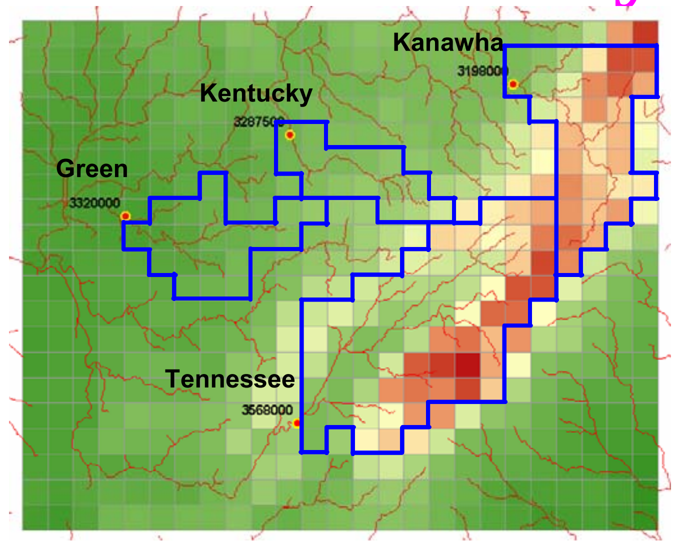


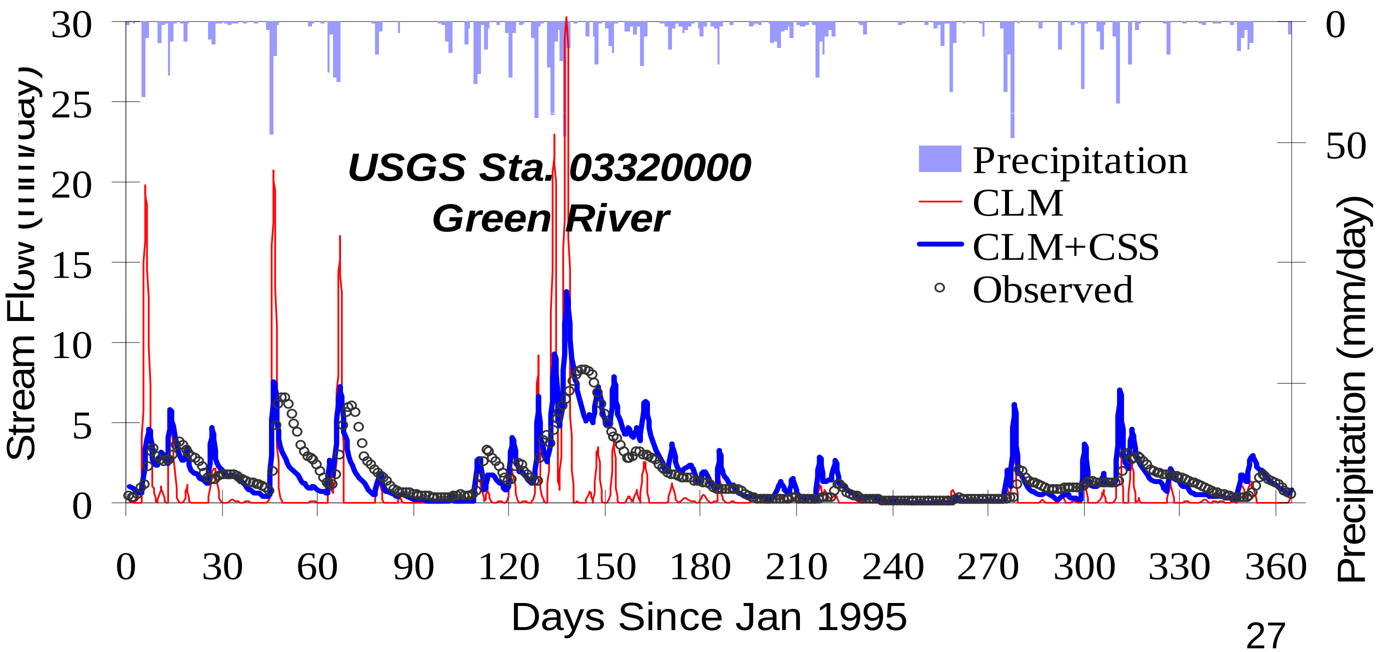
Many key local characteristics are not available and difficult/expensive to measure. Their accurate specification, however, is the base to realize any gain from resolution increase and physics improvement.

Liang, X.-Z., H. Choi, K.E. Kunkel, Y. Dai, E. Joseph, J.X.L. Wang, and P. Kumar, 2005: Surface boundary conditions for mesoscale regional climate models. *Earth Interactions*, **9**, 1-28.

CWRF Terrestrial Hydrology

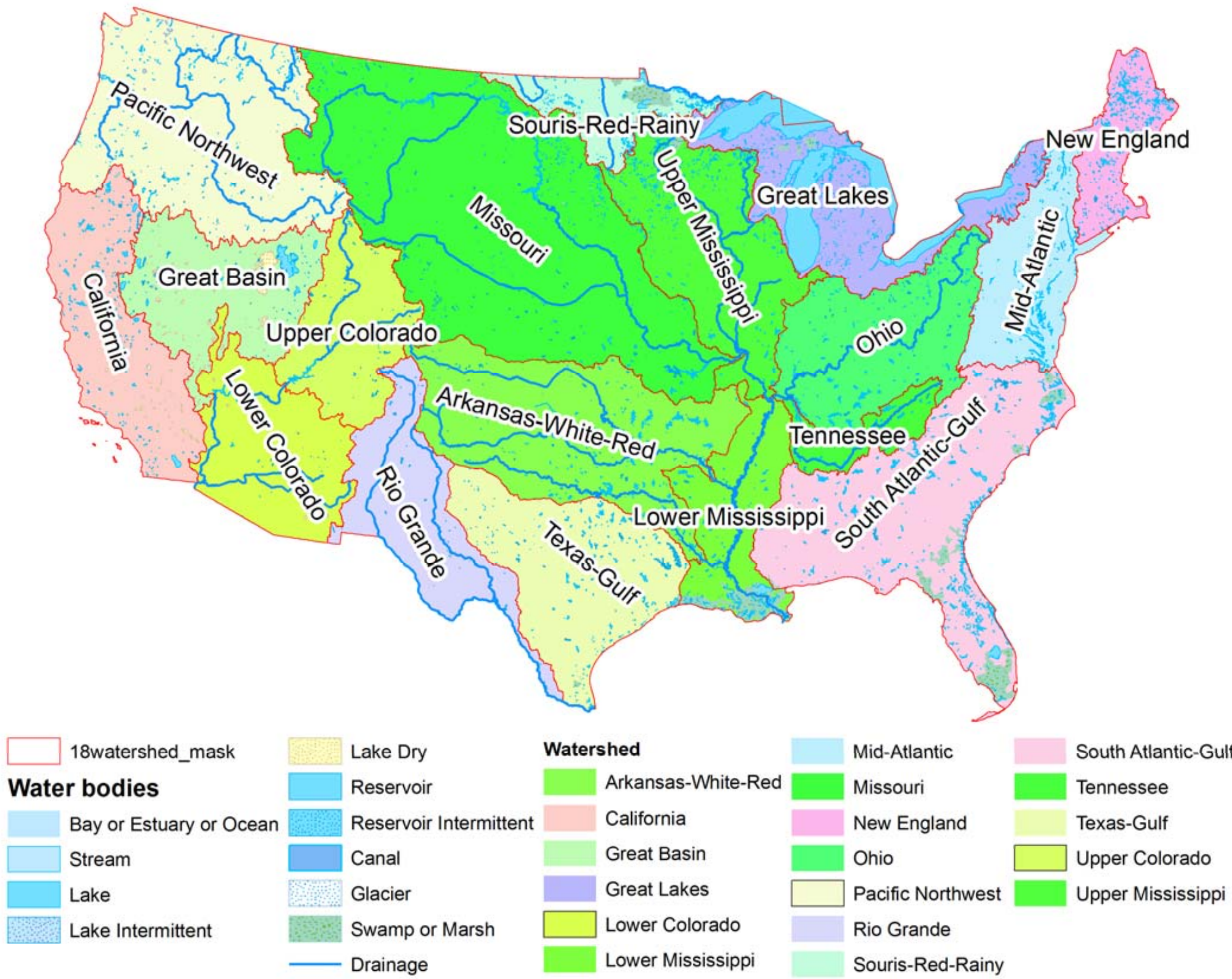




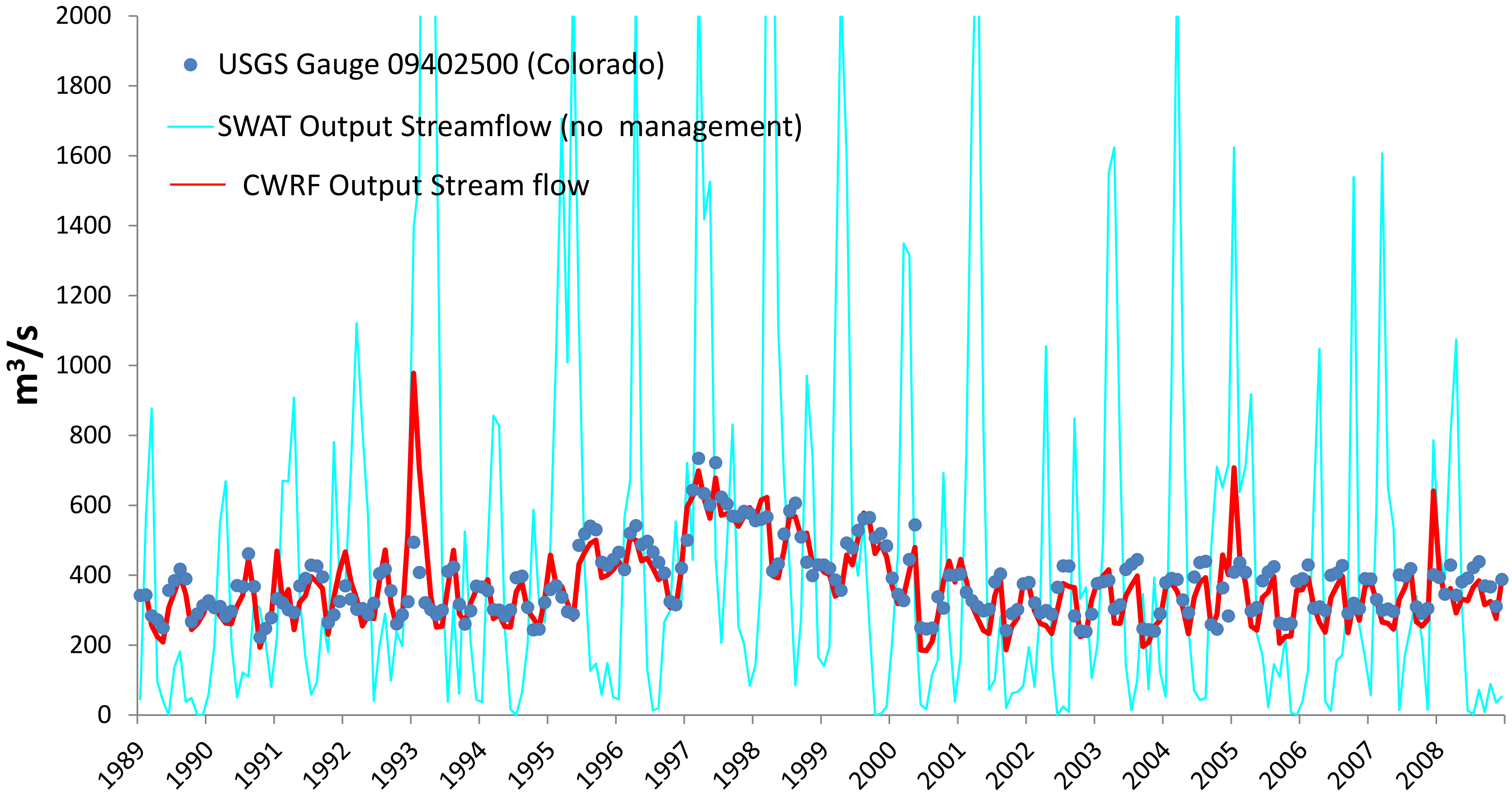


Choi 2006; Choi et al. 2007; Choi and Liang 2010; Yuan and Liang 2010; Liang et al. 2010d

18 USA Water Resources Regions



Reservoir Management Critical to Streamflow Prediction



Chesapeake Bay Forecast System

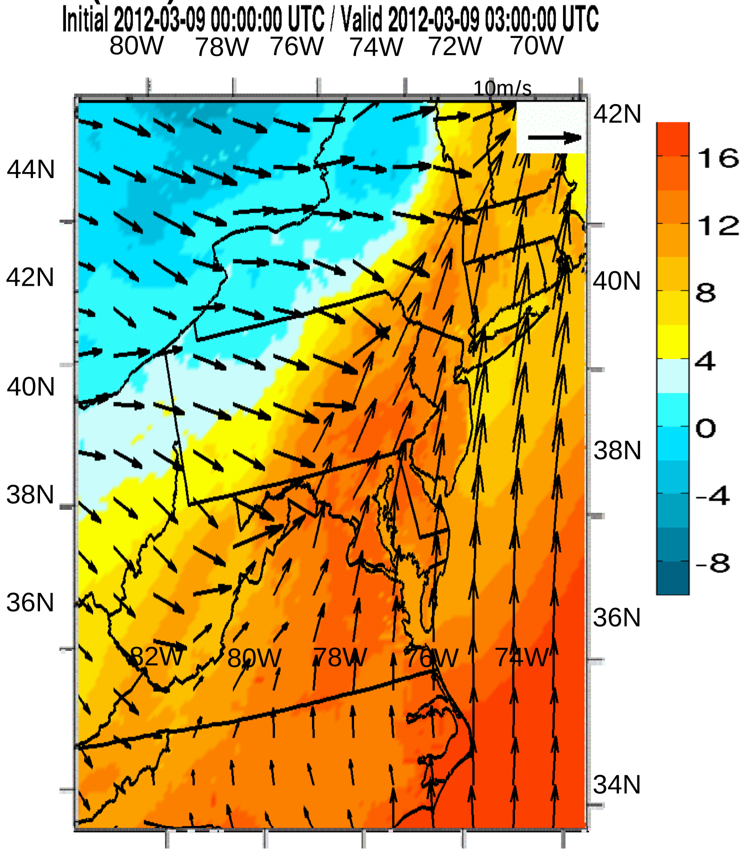
- **Objective:** Develop a fully integrated model of the Chesapeake Bay and its air and watershed
- **Purpose:**
  - Near-Real Time Applications: Nowcasting and forecasting of the Bay circulation, ecosystem, pathogens, harmful algal blooms, waves and inundation.
  - Climate Projections: Estimating effect of climate change, between now and 2050, on the health of the Bay and its watershed.
  - Provide a decision making tool for users

SeaWiFS true-color image of Mid-Atlantic Region from April 12, 1998.

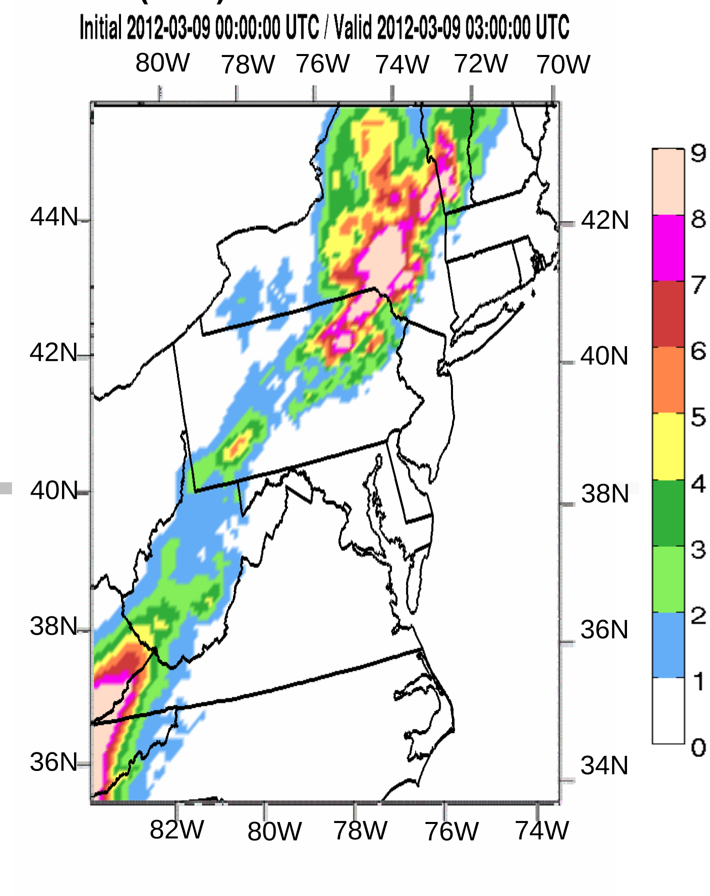
Image provided by the SeaWiFS Project, NASA/Goddard Space Flight Center and ORBIMAGE

WRF 14 Days Forecasts from 2012/03/09

2-m Air Temperature (°C) with 10-m winds(m/s)



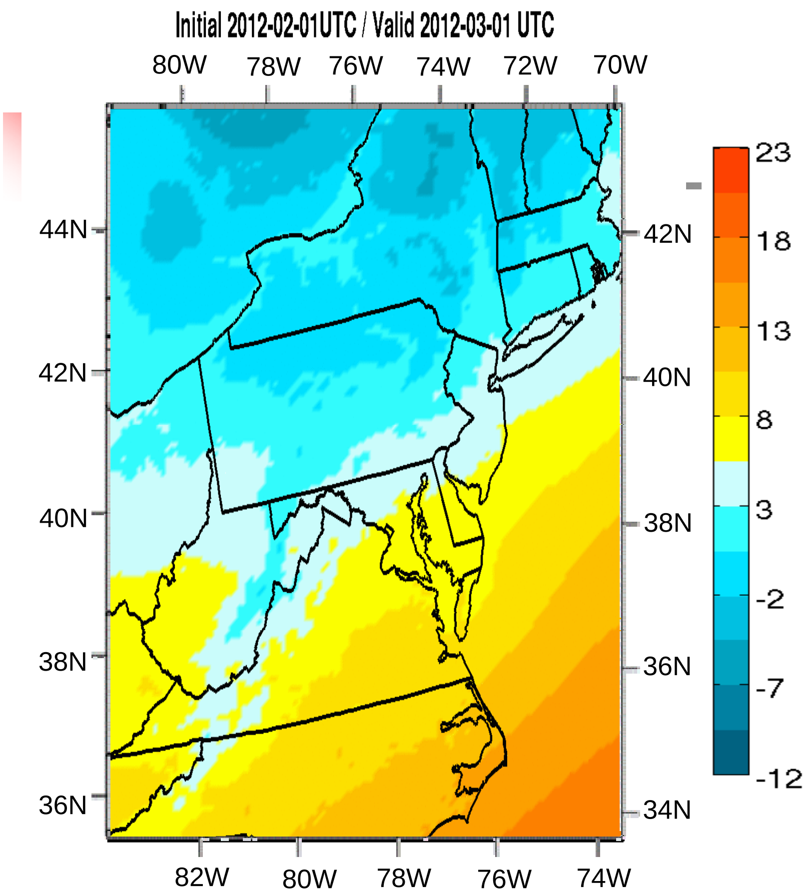
3-hr Precipitation (mm)



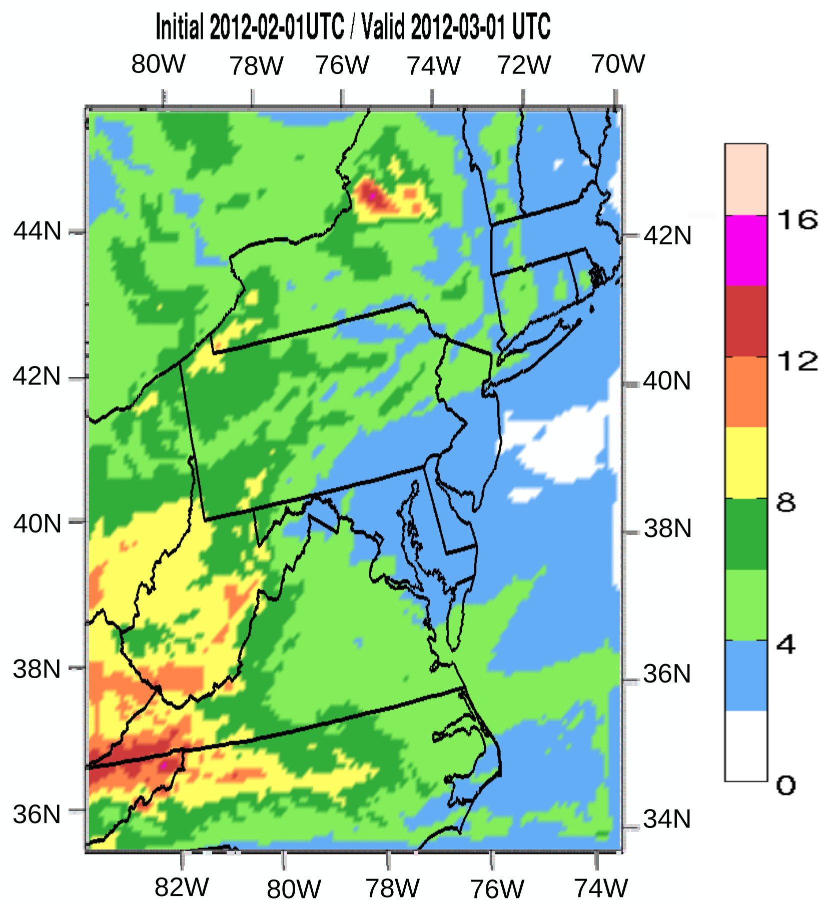
20-member ensemble mean forecast of temperatures, winds, and precipitation for 00UTC 18 February – 06 UTC 4 March 2012.

WRF Seasonal Forecasting from 2012/03/01-05/31

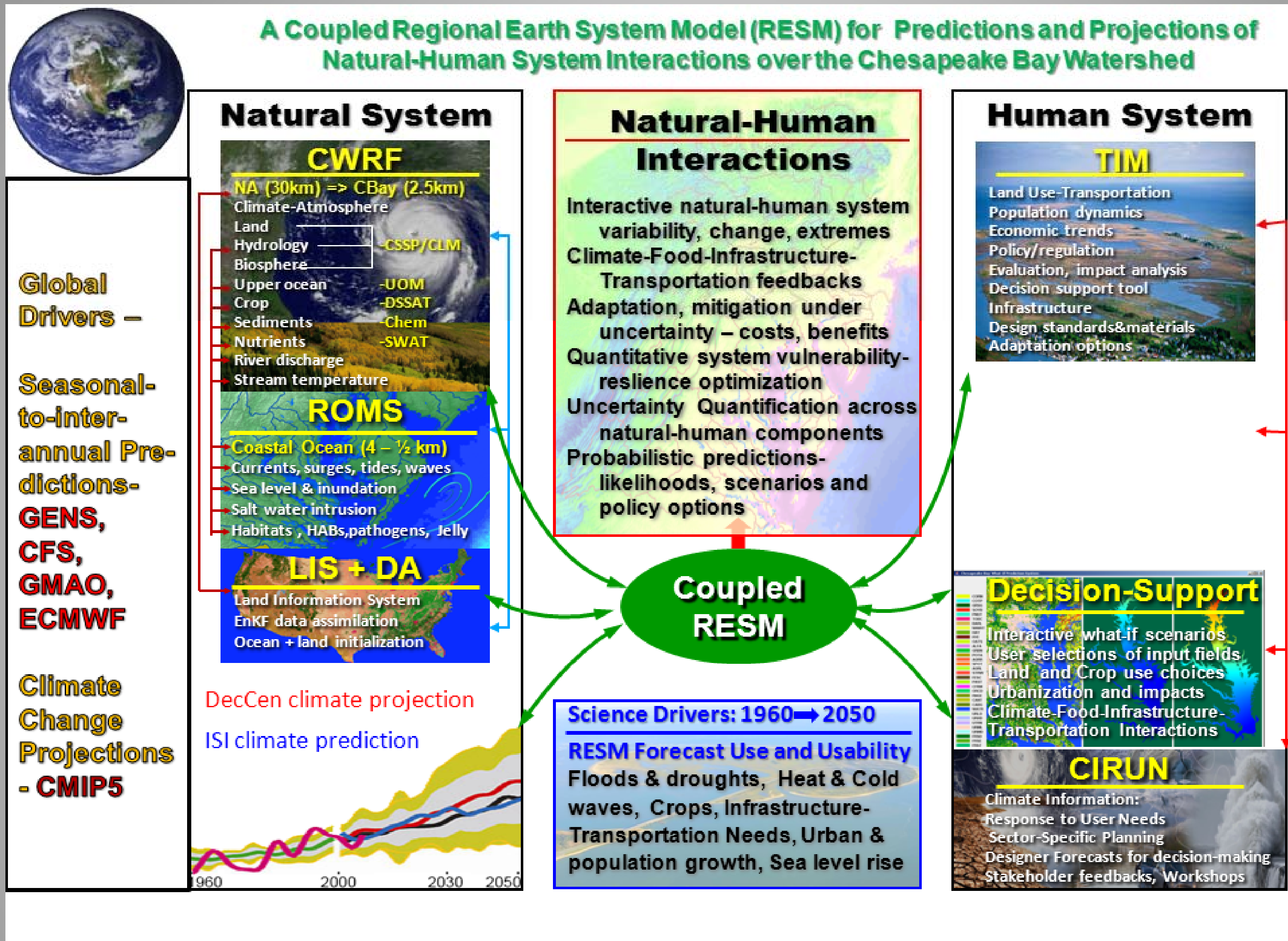
Daily Mean 2-m Air Temperature (°C)



Daily Mean Rain (mm)



Temperatures and precipitation for March – May 2012. This is based on downscaling 15 members of the ECHAM4.5 GCM forecast with WRF.



Regional Earth System Model (RESM) framework for predictions and projections of natural-human system interactions over the Chesapeake Bay watershed. The Natural System is represented by CWRF and is fully coupled with transportation-infrastructure and vulnerability-resilience models. Predictions and projections from days to decades will be delivered to users from various sectors.

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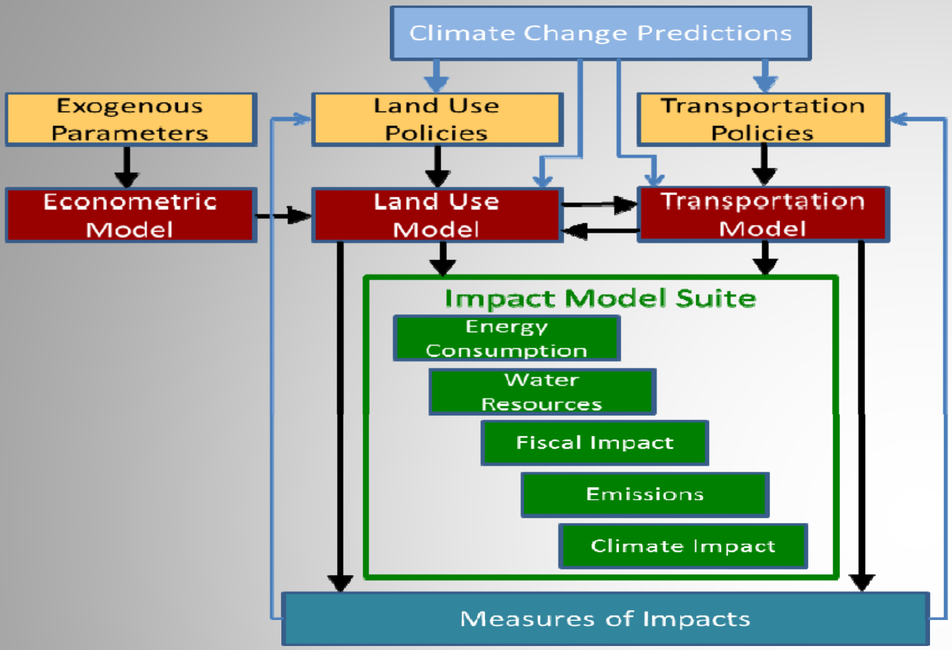
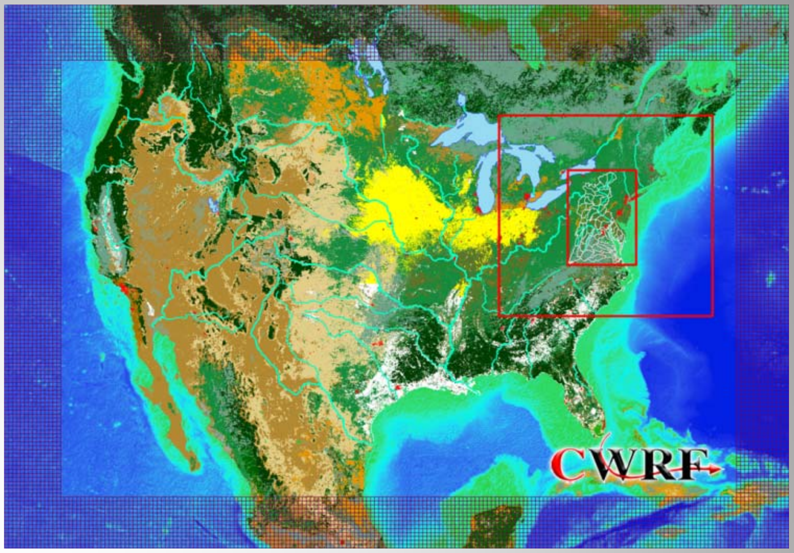
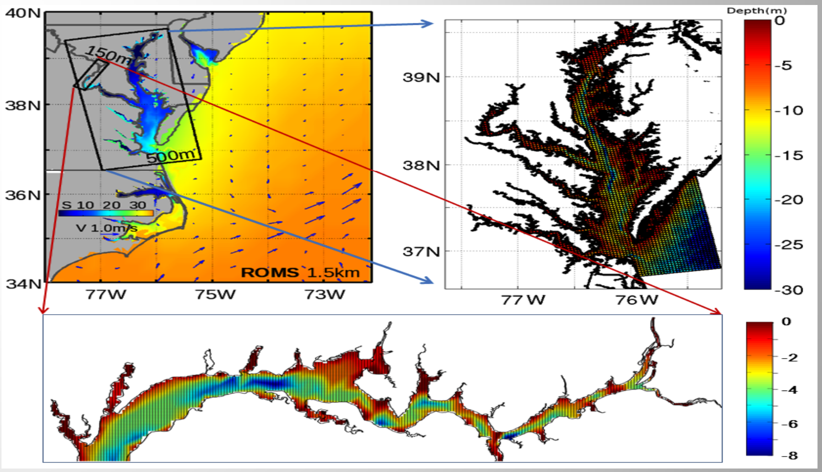
Multiple Stressors







A state-of-the-art model to represent the human system components of land use, transportation, and infrastructure that are being coupled to the natural system model CWRF. Together with the Vulnerability-Resilience Indicator Model, the RESM is a comprehensive prediction-projection model with natural-human system interactions.

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Summary

- Stakeholders require **actionable** climate information on regional scales from seasons to decades in the future to support sound investment and policy decisions

Actionable Information ESSIC could provide as established in the peer reviewed literature :

Hydrology

- For any given area 20 miles square in the US we can for the next 30 years predict/project the following, with quantified uncertainty:
  - Number of rainy days, dry spell lengths
  - Number of heavy rainfall events above given thresholds
  - Frequency and magnitude of floods and droughts
  - Streamflows along major rivers
  - Water levels in major reservoirs under the current management or future scenario

Storm Surges

- We can estimate with reasonable error bounds the potential maximum storm surge at any location on the Chesapeake Bay watershed over the next 30 years.
  - We can also estimate the likelihood of storm surges at lower levels.
  - We can also provide the probable locations for inundation of streets in cities and towns for a given level of surge, and the means to display this visually using digital elevation maps of cities where these exist.
  - A GIS-based navigation tool to track street-by-street water levels could also be developed above and beyond simple scenarios

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Summary

Crops

- For any given area 20 miles square in the US we can for the next 30 years predict/project the following, with quantified uncertainty:
    - Prediction (a season in advance) of yields for 30 major crops (corn, soybean, wheat, cotton…)
    - Projection of future yields for these crops under climate change
    - Prediction/projection of water need for irrigation
    - Prediction/projection of probability of early spring arrival/warming and cold surges
    - Prediction/projection of change in water availability and quality
    - Prediction/projection of probability of floods and droughts

Energy

- For any given area 20 miles square in the US we can for the next 30 years predict/project the following, with quantified uncertainty:
    - Number of days/yr when winds are below and above given thresholds
    - Number of days/yr when solar energy are below and above given thresholds
    - Number of days/yr when extreme events would endanger power lines
    - Number of days for cooling and heating needs
    - Frequency and magnitude of heat waves
    - Availability of water

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