Developing a High-Resolution Texas Water and Climate Prediction Model

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WATER RESOURCES RESEARCH, VOL. 47, W05301, doi:10.1029/2010WR010090, 2011

Hyperresolution global land surface modeling: Meeting a grand challenge for monitoring Earth's terrestrial water

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[1] Monitoring Earth's terrestrial water conditions is critically important to many hydrological applications such as global food production; assessing water resources sustainability; and flood, drought, and climate change prediction. These needs have motivated the development of pilot monitoring and prediction systems for terrestrial hydrologic and vegetative states, but to date only at the rather coarse spatial resolutions (~10–100 km) over continental to global domains. Adequately addressing critical water cycle science questions and applications requires systems that are implemented globally at much higher resolutions, on the order of 1 km, resolutions referred to as hyperresolution in the context of global land surface models. This opinion paper sets forth the needs and benefits for a system that would monitor and predict the Earth's terrestrial water, energy, and biogeochemical cycles. We discuss six major challenges in developing a system: improved representation of surface-subsurface interactions due to fine-scale topography and vegetation; improved representation of land-atmospheric interactions and resulting spatial information on soil moisture and evapotranspiration; inclusion of water quality as part of the biogeochemical cycle; representation of human impacts from water management; utilizing massively parallel computer systems and recent computational advances in solving hyperresolution models that will have up to 10^9 unknowns; and developing the required in situ and remote sensing global data sets. We deem the development of a global hyperresolution model for monitoring the terrestrial water, energy, and biogeochemical cycles a "grand challenge" to the community, and we call upon the international hydrologic community and the hydrological science support infrastructure to endorse the effort.

Citation: Wood, E. F., et al. (2011), Hyperresolution global land surface modeling: Meeting a grand challenge for monitoring Earth's terrestrial water, *Water Resour. Res.*, *47*, W05301, doi:10.1029/2010WR010090.

Hyperresolution global land surface modeling: Meeting a grand challenge for monitoring Earth's terrestrial water

An opinion paper by Wood, E. F., et al., 2011, WRR, 47, W05301.

- A grand challenge to the community
- Hyperresolution: O(1 km) globally; O(100 m) continental scales
- Need for hyperresolution: global food production; water resources sustainability; flood, drought, and climate change prediction
- Six major challenges:
- surface-subsurface interactions due to fine-scale topography and vegetation;
- land-atmospheric interactions; soil moisture & evapotranspiration;
- inclusion of water quality as part of the biogeochemical cycle;
- representation of human impacts from water management;
- utilizing massively parallel computer systems in solving 10^9 unknowns; and
- developing the required in situ and remote sensing global data sets.

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Hyperresolution regional land surface modeling for Texas

An opinion presentation proposed today at Water Forum II.

- A grand challenge to the community
- Hyperresolution: O(100 m) CONUS; O(10 m) Texas
- Need for hyperresolution: Texas food production; water resources sustainability; flood, drought, and climate change prediction
- Six major challenges:
- surface-subsurface interactions due to fine-scale topography and vegetation;
- land-atmospheric interactions; soil moisture & evapotranspiration;
- inclusion of water quality as part of the biogeochemical cycle;
- representation of human impacts from water management;
- utilizing massively parallel computer systems in solving 10^9 unknowns; and
- developing the required in situ and remote sensing data sets.

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How to obtain hyperresolution weather data for Texas?

O(10 m) is not feasible; but
O(1 km) is possible.

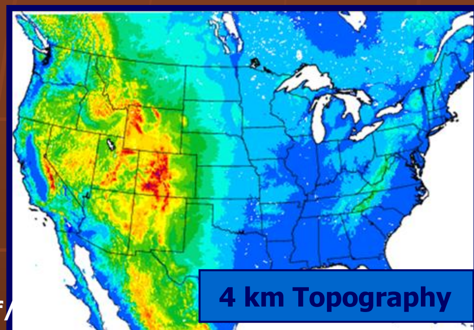
Revolution in Modeling

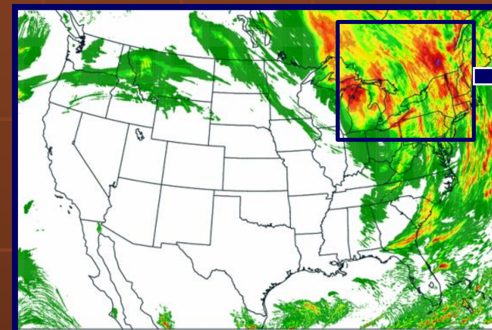
Shuttleworth (2011)

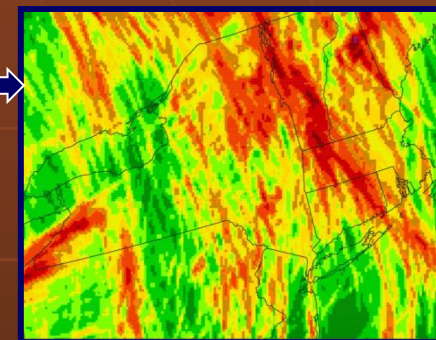
The grid resolution of regional and global models has reduced hugely, and will continue to do so

e.g. 4 km resolution Weather Research and Forecasting (WRF) Model

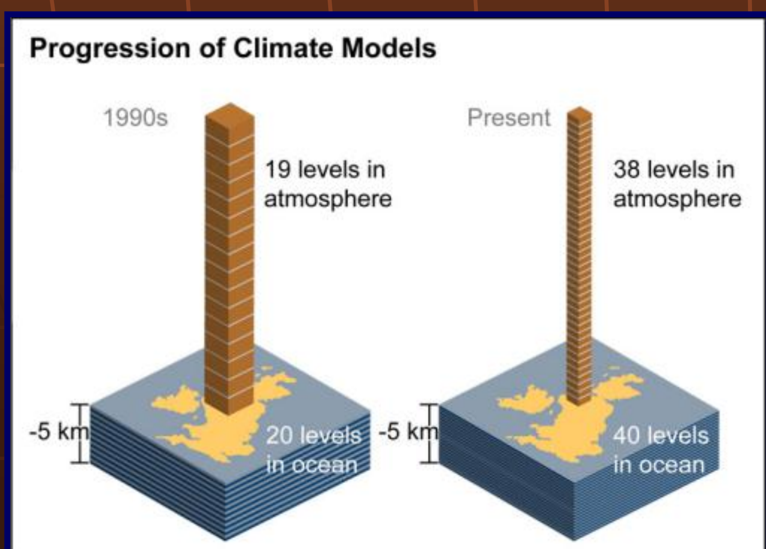
www.nssl.noaa.gov/wrf/



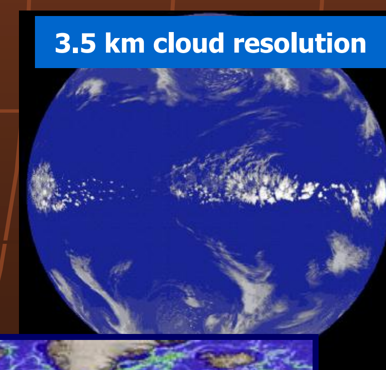


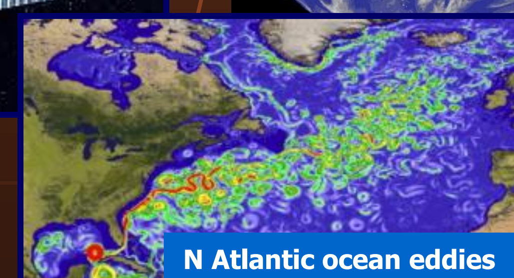


e.g. increasing spatial resolution in Global Models



www.nec.co.jp





High Performance Computing

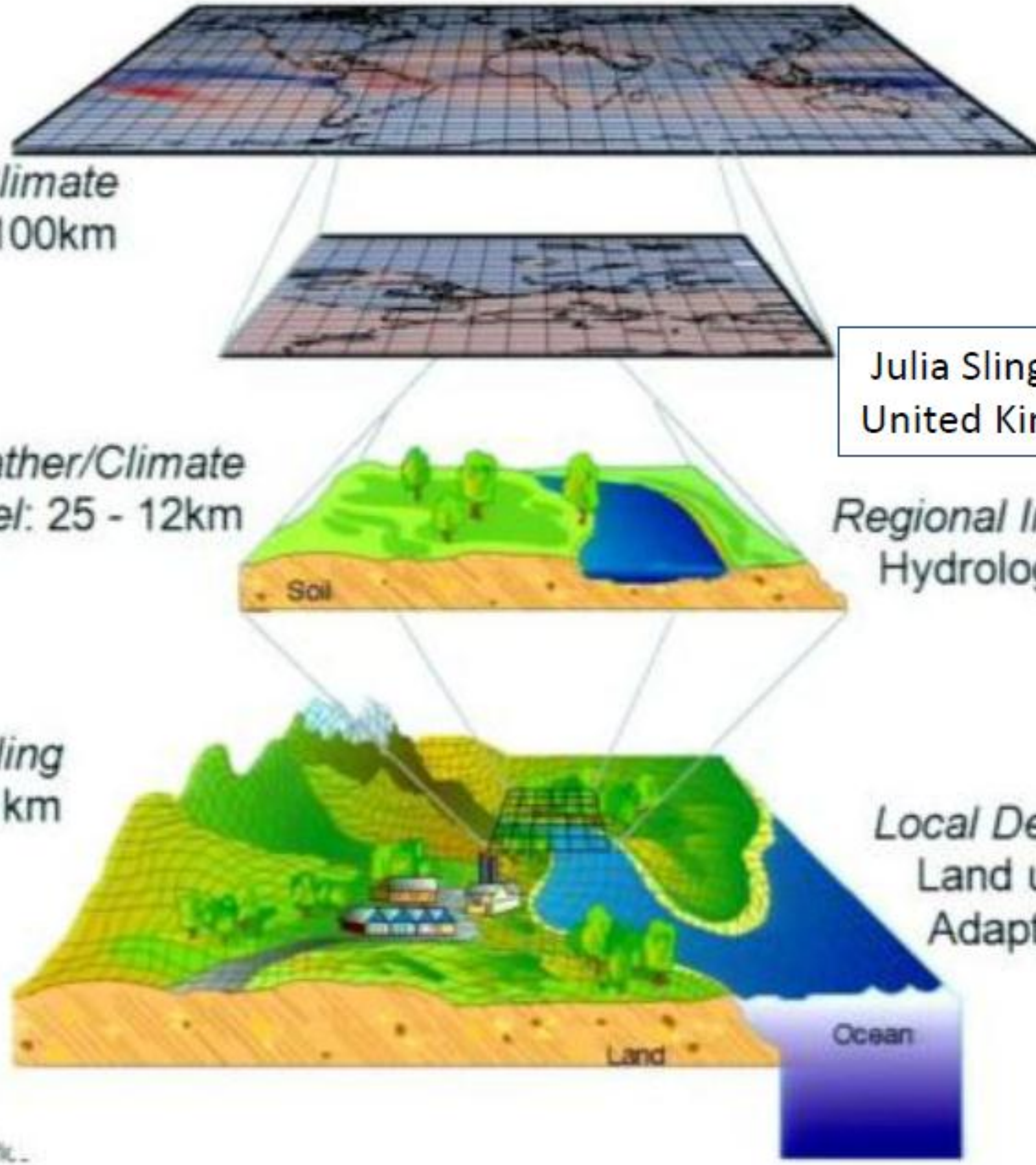
- Petascale [$O(10^{15})$] Computing Architectures
  - Massively parallel supercomputers (10^4–10^5 multi-core processors)

World's "Fastest" Supercomputer in 2013
10 peta math operations per second (**PFlops**)
500,000 processors
Texas Advanced Computing Center, UT-Austin
Stampede
January 2013

World's "Fastest" Supercomputer in 2011
579.4 trillion math operations per second (**TFlops**)
3936 nodes, 62976 core processors
Texas Advanced Computing Center, UT-Austin
Ranger
5/19/2011

Bridging the Gaps and Bridging the Scales

Met Office



Julia Slingo, Chief Scientist
United Kingdom Met Office

While climate projections at O(100 year) timescales are useful, water resource planning also needs climate predictions at O(10 day) to O(1 year) time scales!

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Dynamic Seasonal Hydrologic Forecasts

Step 1: Seasonal climate forecasts: precipitation, temperature, radiation, winds, humidity; coarse spatial resolution, O(100 km)

Step 2: Seasonal climate downscaling: precipitation, temperature, radiation, winds, humidity; fine spatial resolution, O(10–1 km)

Step 3: Seasonal land surface forecasts; soil moisture, evapotranspiration, runoff, water table

Step 4: Seasonal river flow forecasts; river flow

Step 5: Seasonal reservoir forecasts; lake storage

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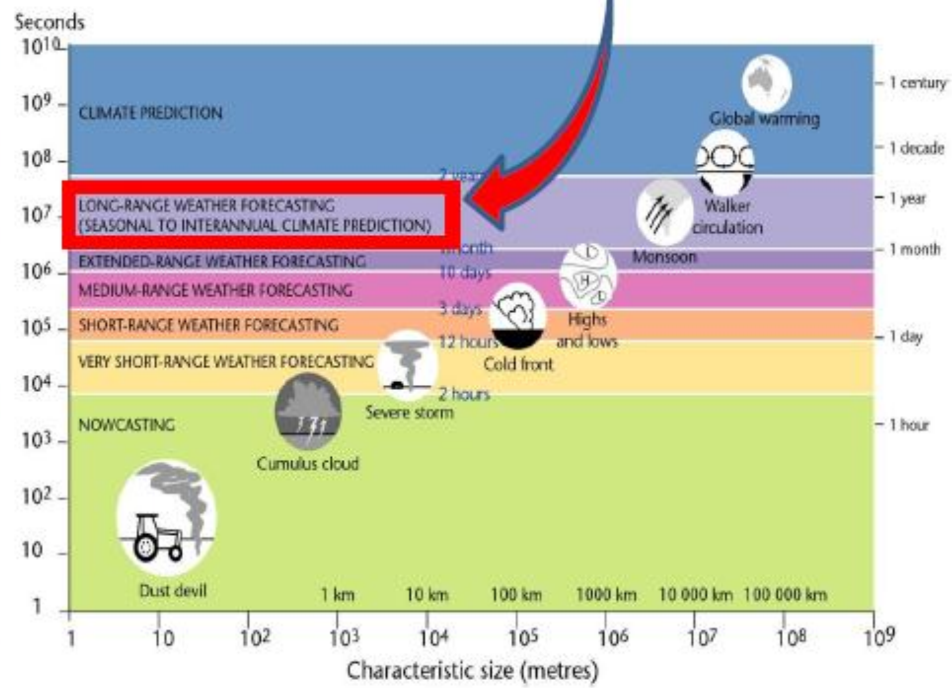
Step1: Seasonal Climate Forecasts

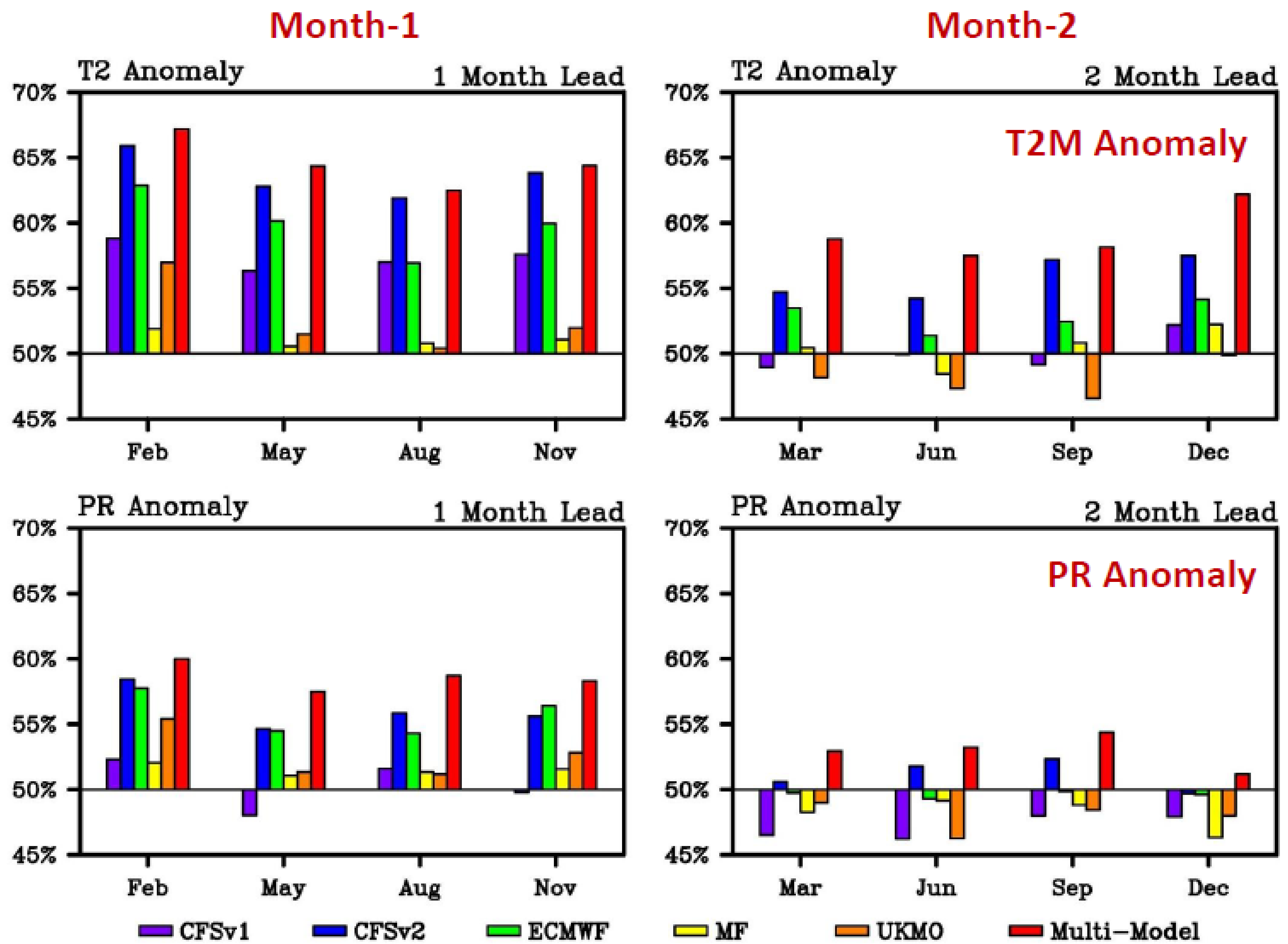
Seasonal forecast: linking climate to weather for a seamless prediction (WWRP+WCRP)

- Seasonal climate anomalies are predictable if there are strong anomalies in the **slowly varying boundary conditions** of SST and land surface conditions.
- **CGCM-based seasonal climate forecast** since 1990s (numerical models, data assimilation, and computing resources).
- Operational seasonal forecast with CGCMs (NCEP, ECMWF, UKMO).



Yuan (2011); Shukla (2009)

Skill of the state-of-art seasonal climate forecast models



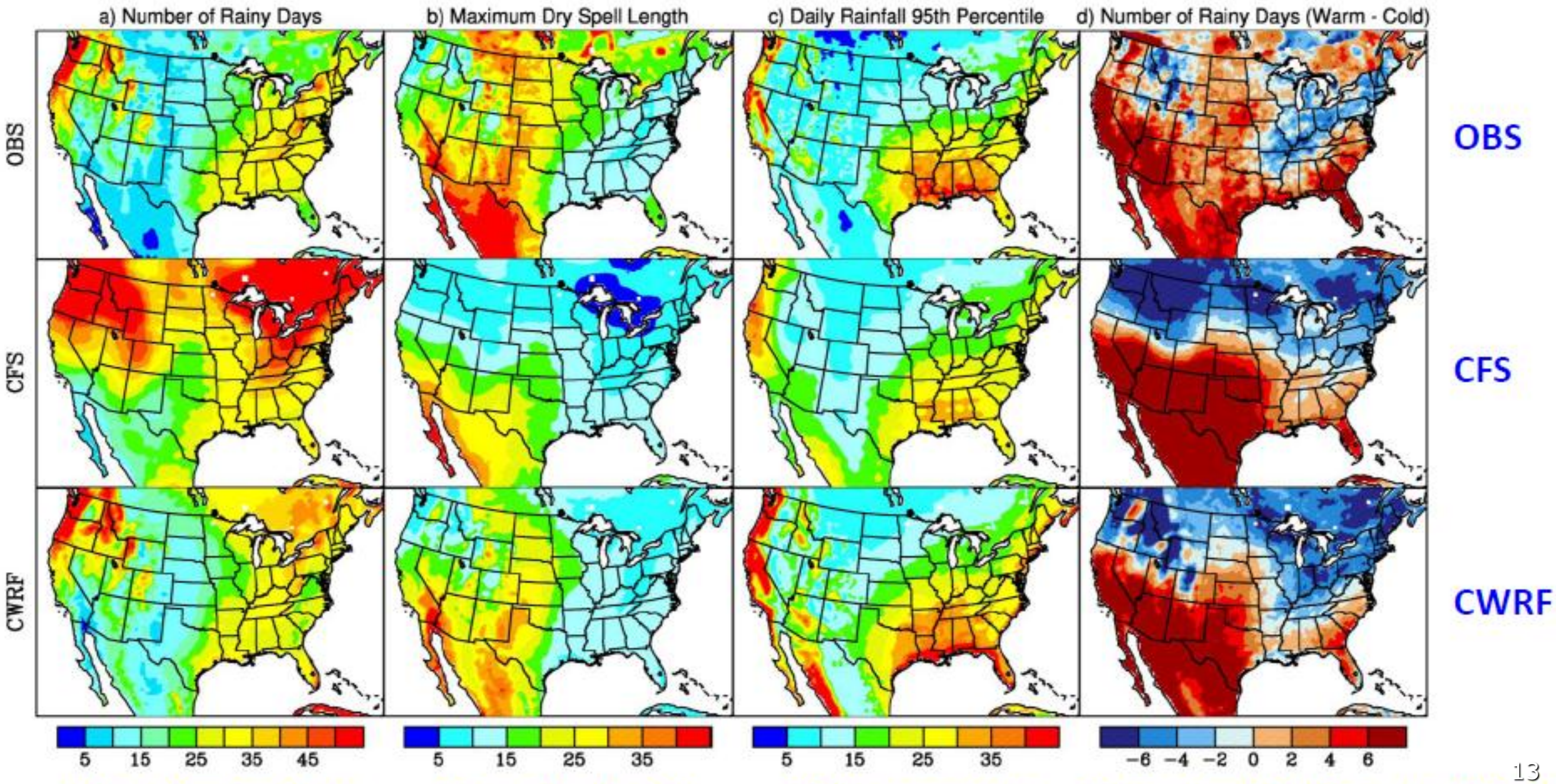
Percentage of positive Ranked Probability Skill Score (RPSS) for global monthly surface air temperature and precipitation anomaly

Yuan et al., *GRL*, 2011

Step 2: Seasonal Climate Dynamic Downscaling

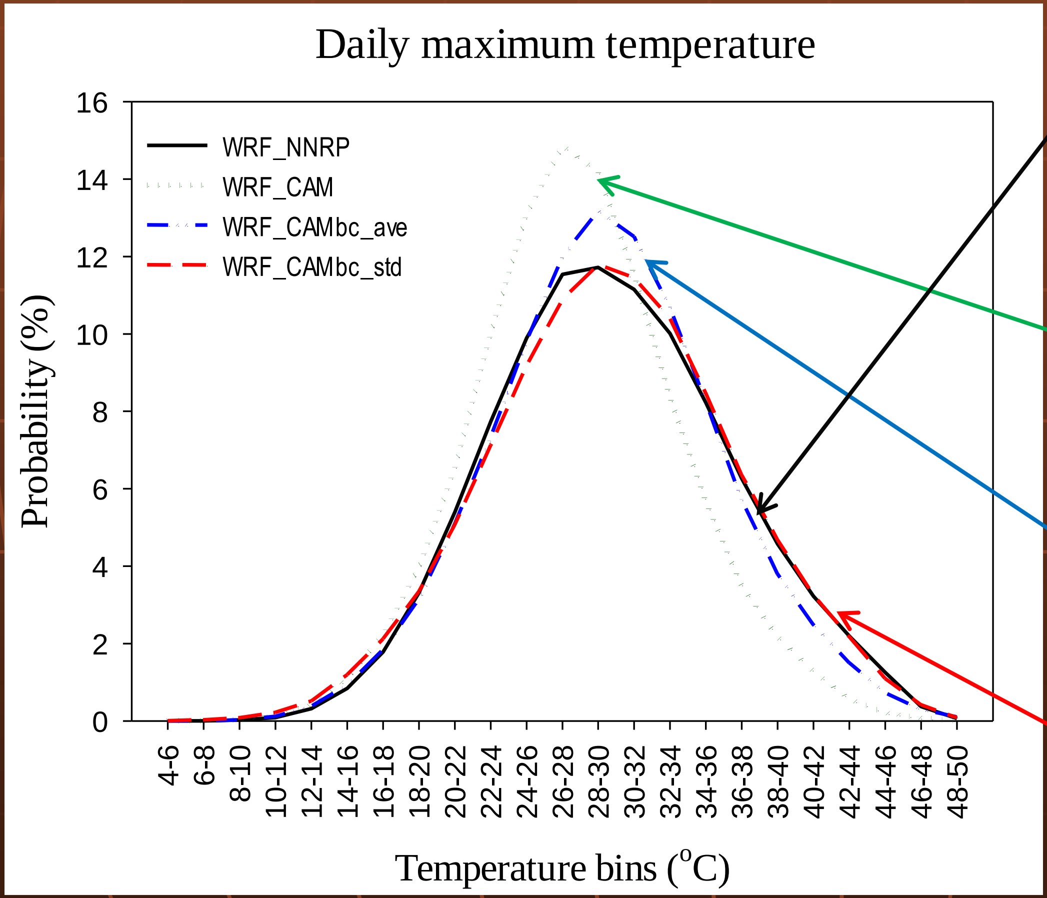
Daily mean precipitation characteristics (JFM)

Yuan and Liang (2011) GRL



No. of rainy days | Max. dry length | 95% percentile | Rainy day (El Niño- La Niña)

Dynamic Downscaling with Bias Correction Improves the PDF of Daily Maximum Temperature in Summer



Black:
WRF simulation driven by NNRP

Green:
WRF simulation driven by GCM output without bias correction

Blue:
With mean value bias correction

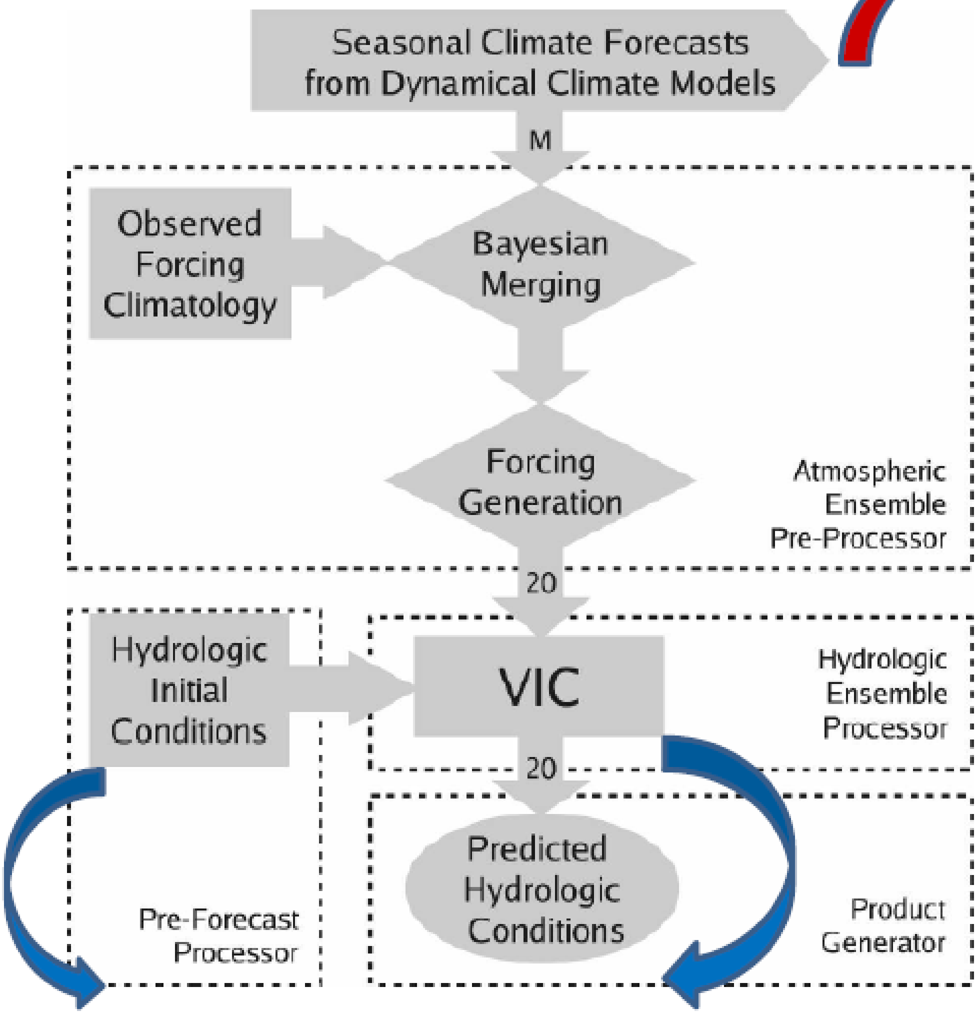
Red:
With mean value and variance bias corrections

The PDF is computed over the central US region (40°–50°N, 100°–85°W) at **60-km** resolution

Xu and Yang (2012)

Seasonal hydrologic forecast system and its uncertainty

Xing Yuan & Eric Wood, Princeton University



Major uncertainty is from climate forecast models: downscaling, ensemble?

Uncertainty from IC: offline simulation, data assimilation

Uncertainty from LSM: parameter calibration and regionalization

CFSv1

NCEP GFS (T62)
GFDL MOM3 (1/3-1°)
OSU LSM

CFSv2

NCEP GFS (T126)
GFDL MOM4 (0.25-0.5°)+Sea ice
NOAH LSM

Upgrading hydrologic forecast system

UT has world-class expertise in

- Understanding and modeling terrestrial hydrological processes & global water cycle
  - Land Model for Climate Prediction
  - Land Model for Weather Forecasts
- Mapping geospatial datasets
- Observing the global water cycle
- High Performance Computing
  - Lonestar
  - Ranger
  - Stampede

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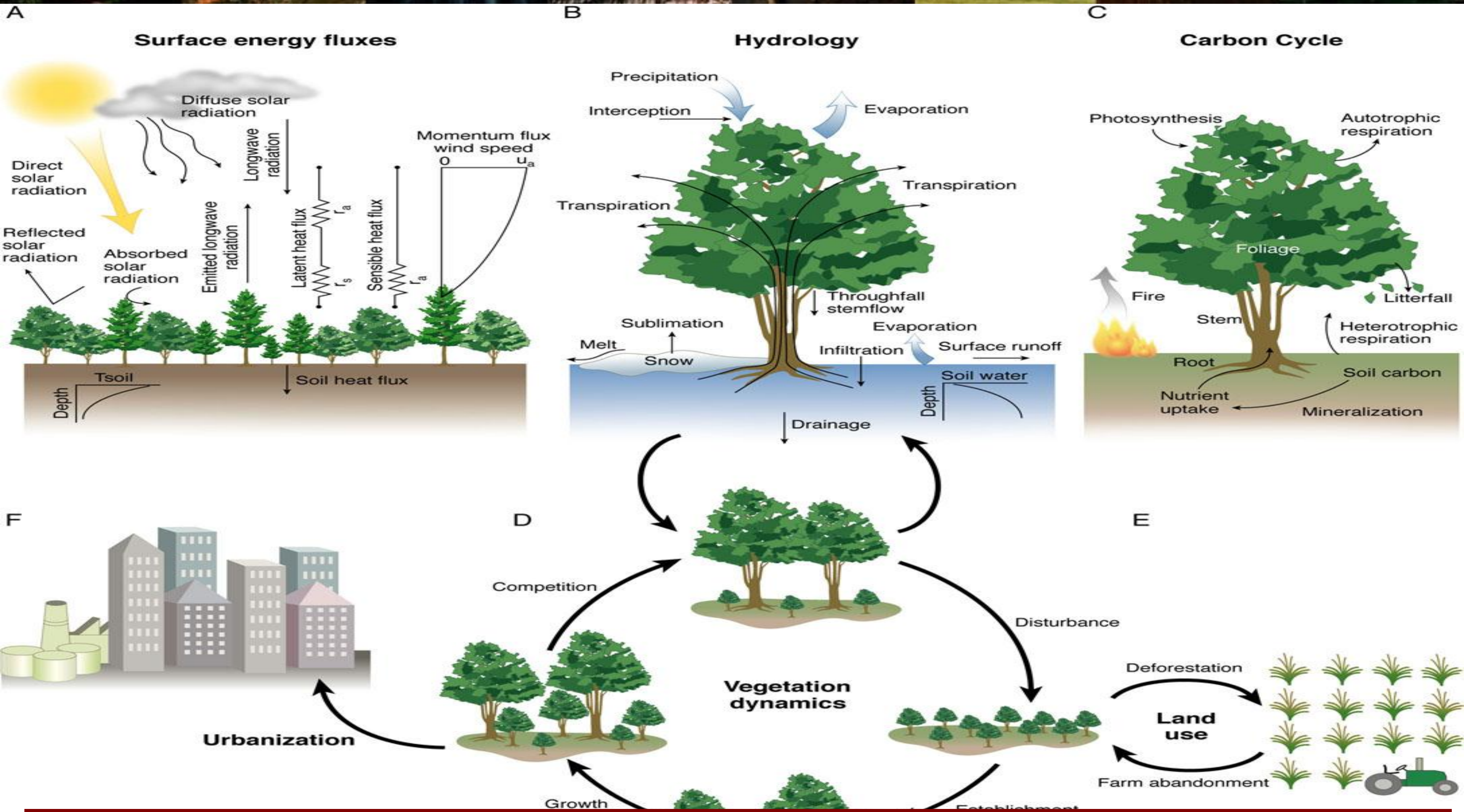
NCAR Community Land Model (CLM4) for Climate Models in 2010



Co-Chairs: David Lawrence (NCAR), Zong-Liang Yang (Univ of Texas at Austin)

Noah-MP Land Model for Weather Forecasts

- **A new paradigm** in land-surface hydrological modeling
- In a broad sense,
  - o Multi-parameterization ≡ Multi-physics ≡ Multi-hypothesis
- **A modular & powerful framework for**
  - o Diagnosing differences
  - o Identifying structural errors
  - o Improving understanding
  - o Enhancing data/model fusion and data assimilation
  - o Facilitating ensemble forecasts and **uncertainty quantification**

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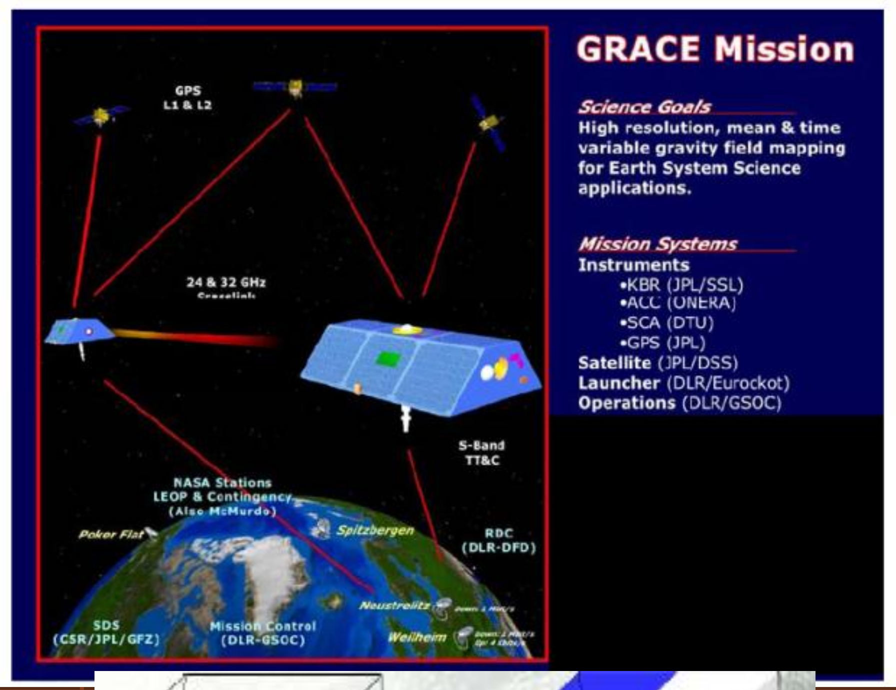
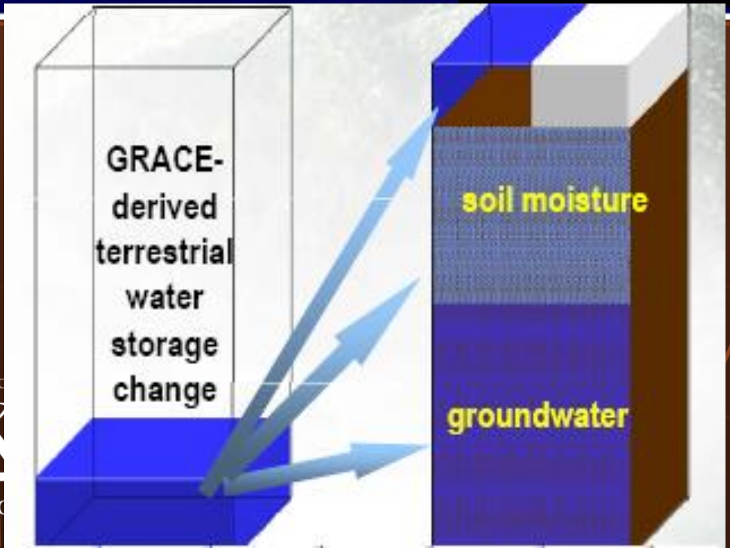
Niu et al. (2011); Yang et al. (2011)

Collaborators: Yang, Niu (UT), Chen (NCAR), Ek (NCEP/NOAA), and others

Gravity Recovery and Climate Experiment (GRACE)

- 10 years of mission operation (Tapley et al., 2004)
- First-time global data of gravity (~100 km, monthly to 10-day)
- Unprecedented accuracy of mass variations
- Allowing a better understanding of the global water cycle





Center for Integrated Earth System Science

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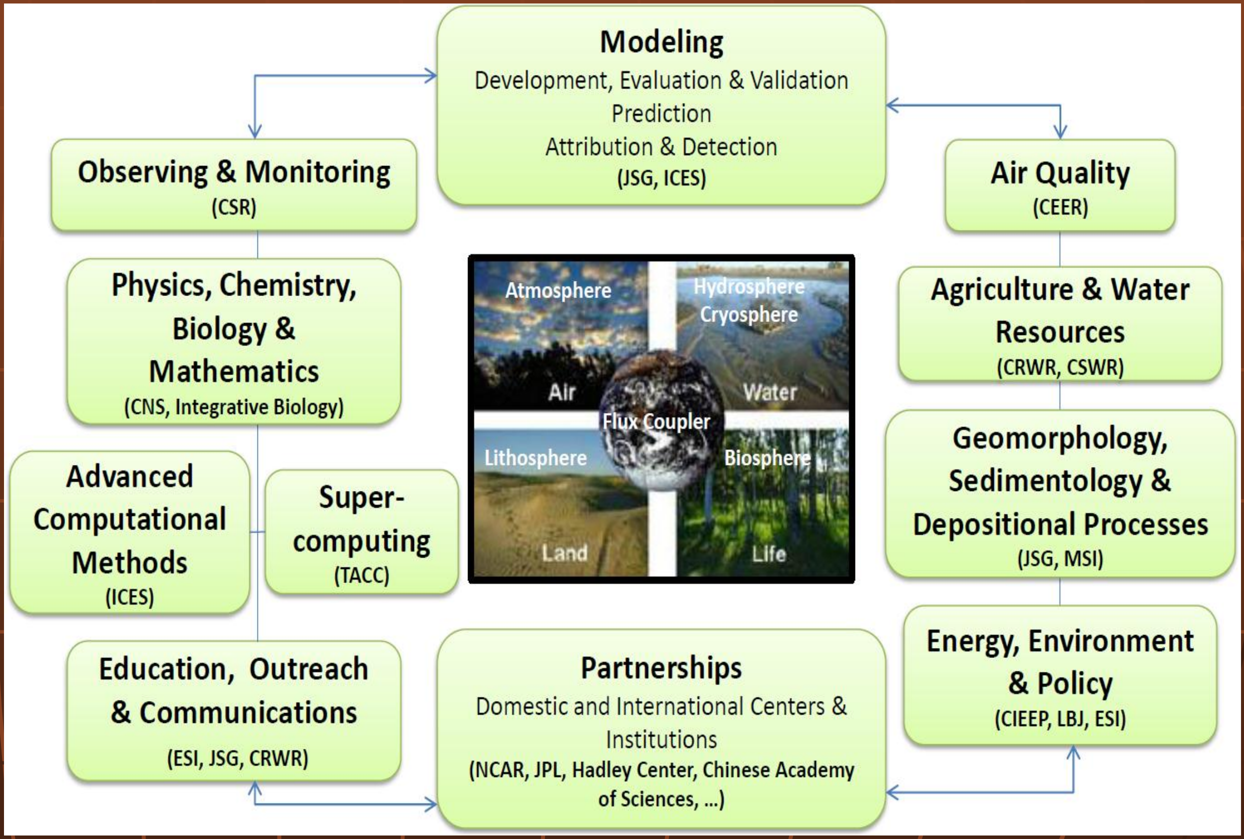
- Formed in August 2011
- Director: Liang Yang
- Associate Director: David Maidment
- A cooperative effort between



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Cockrell School of Engineering

http://www.jsg.utexas.edu/ciess

Summary

- CIESS was formed to integrate UT's expertise in earth system science and collaborate with national/international communities for the betterment of society.
- As high-resolution seasonal to decadal climate and hydrologic forecasts are emerging as a new paradigm for modeling and prediction research, CIESS is positioned to develop an integrated atmosphere–land-surface–river network modeling system, applicable to Texas for water resource applications.

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