An Integrated Approach for Predicting Nutrient Transports from the Land to the Ocean

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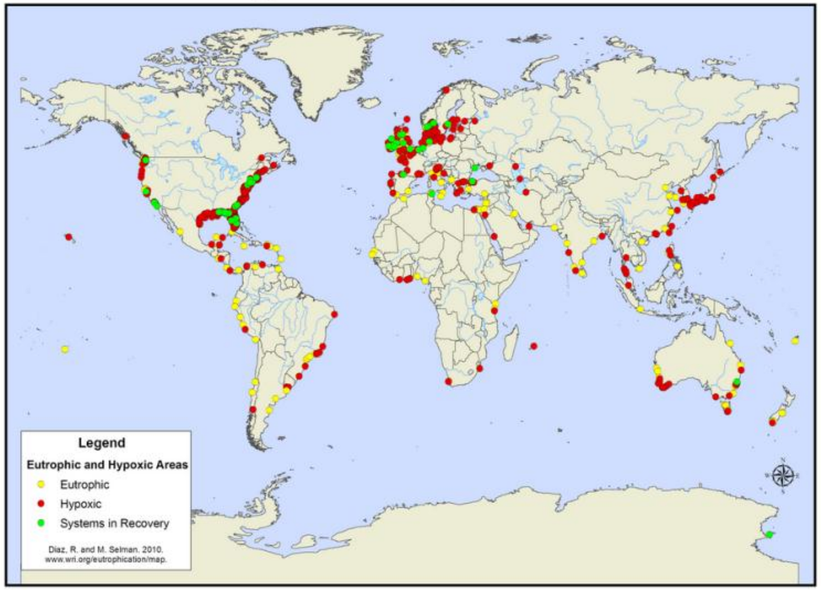
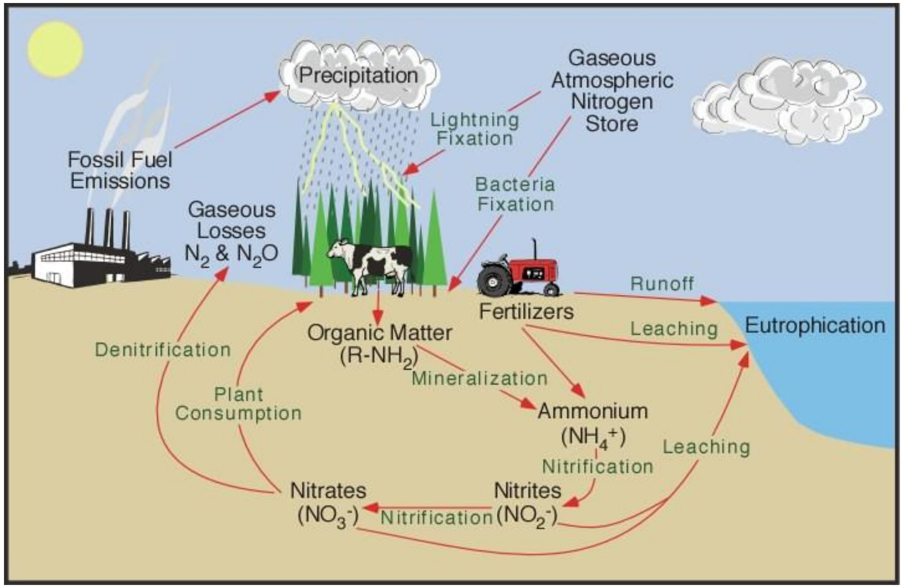
Issues in Riverine Nutrient Export Research

- Lacking integrated climate, extreme weather, land surface, river flow, biogeochemistry, and ecological models

World Hypoxic and Eutrophic Coastal Areas

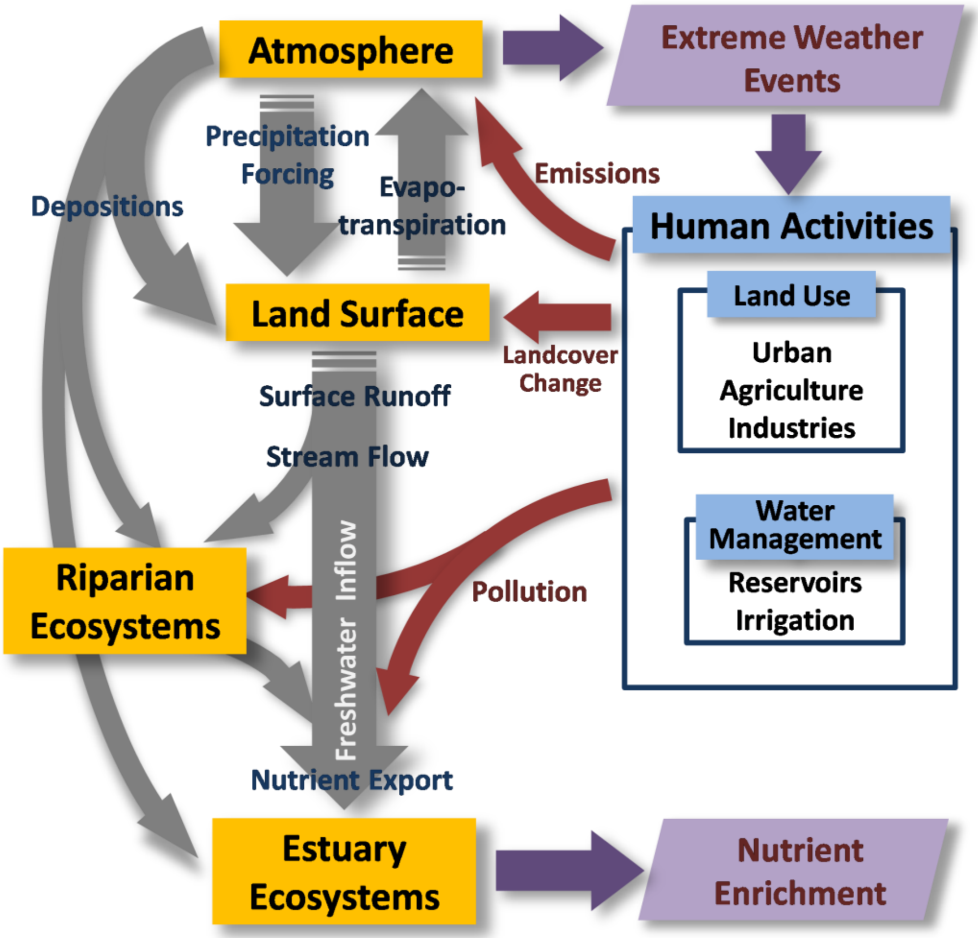




http://www.wri.org/map/world-hypoxic-and-eutrophic-coastal-areas

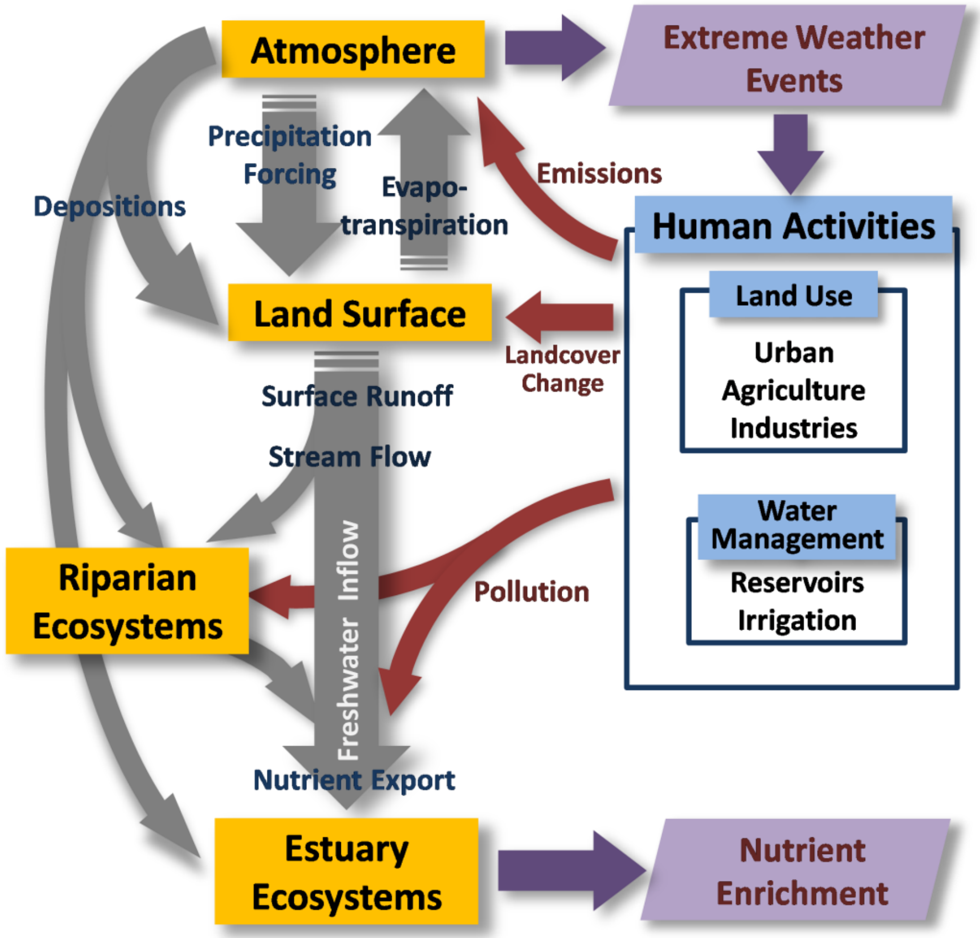
How do we deal with these issues?

- Develop an integrated approach
  - United States NASA Interdisciplinary Research in Earth Science (IDS)

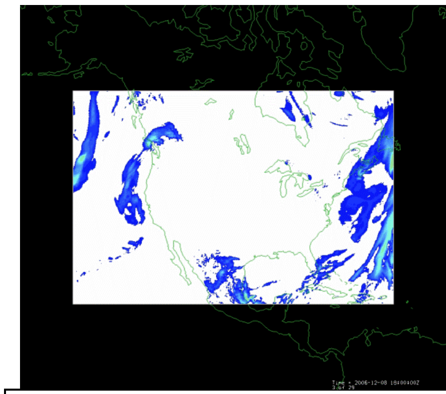


Integrated Approach

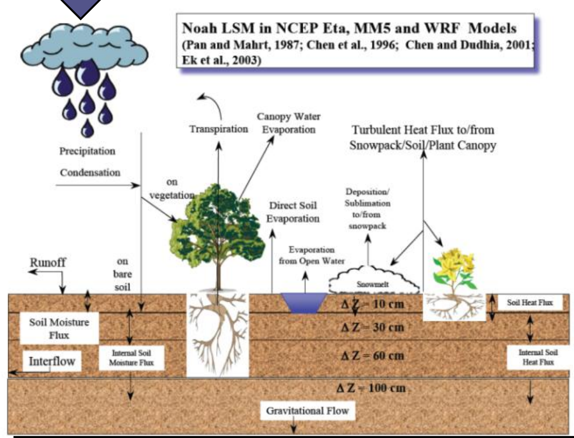
- Global Climate Model
  - (CESM)
- Regional Forecast Model
  - (WRF)
- Land Surface Model
  - (Noah-MP)
- River Flow Model
  - (RAPID)
- Simple estuary model



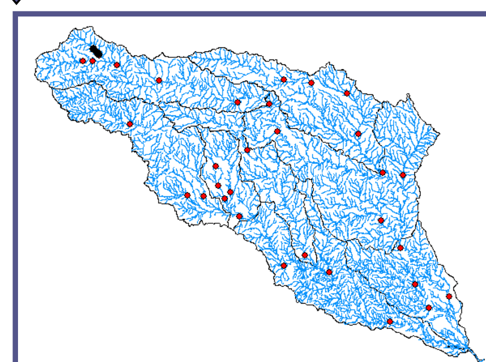
Framework for calculation



Atmospheric Model or Dataset



Land Surface Model

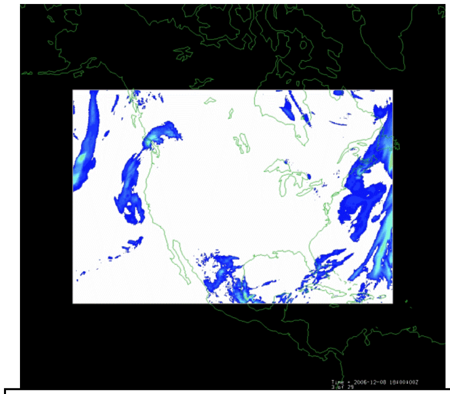


Vector River Network - High-Performance Computing River Network Model

Modeling across spatial and temporal scales:
Global → Regional→ Watershed→ Coastal

Current and future: interannual to hourly

Framework for calculation

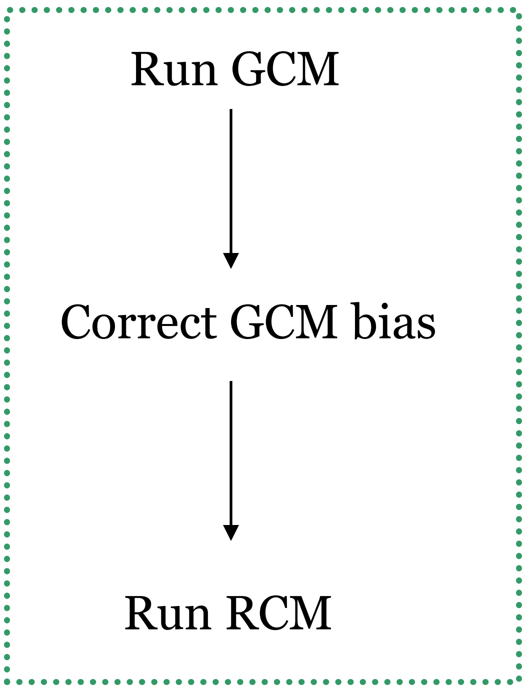


Atmospheric Model or Dataset

Modeling across spatial and temporal scales:
Global → Regional

The New Dynamic Downscaling (NDD) method

- Central Idea
  - Correct climatological mean bias in GCM outputs



Methodology of GCM bias correction

$$CAM = \overline{CAM} + CAM'$$

$$NNRP = \overline{NNRP} + NNRP'$$

- Bias correction 1:

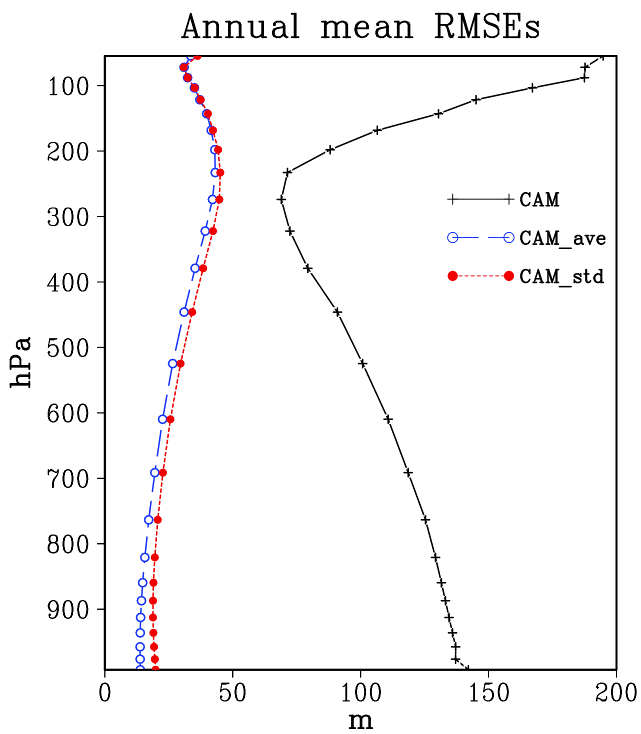
$$CAMbc1 = \overline{NNRP} + CAM'$$

- Bias correction 2:

D: standard deviation

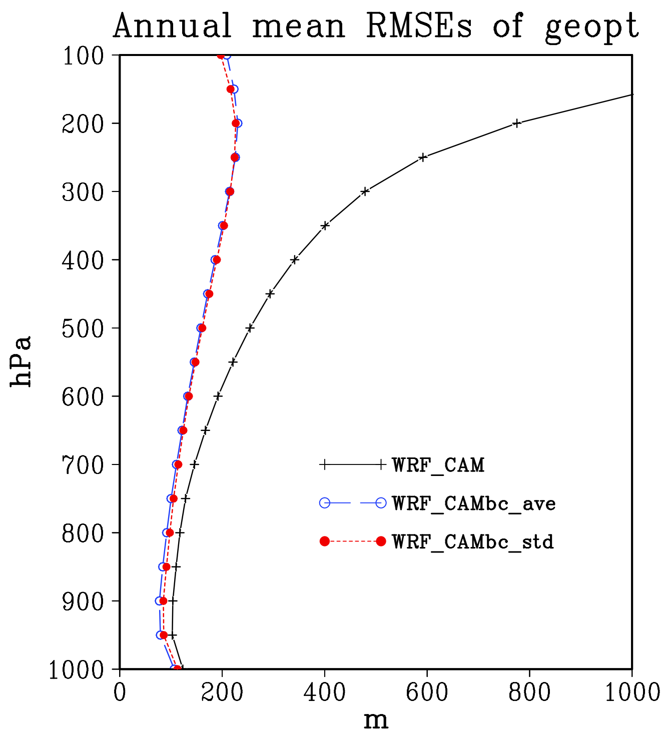
$$CAMbc2 = \overline{NNRP} + CAM' \cdot \frac{D_{NNRP}}{D_{CAM}}$$

Annual mean RMSEs in GCM and RCM



RMSE in GCM

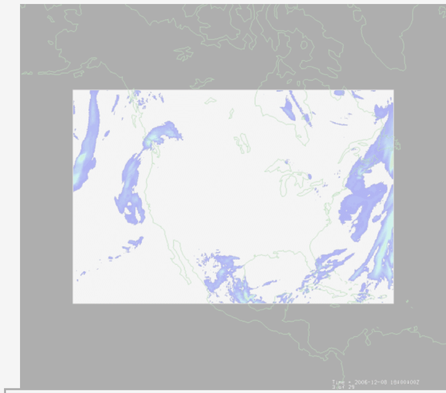
Before downscaling



RMSE in RCM

After downscaling

Framework for calculation



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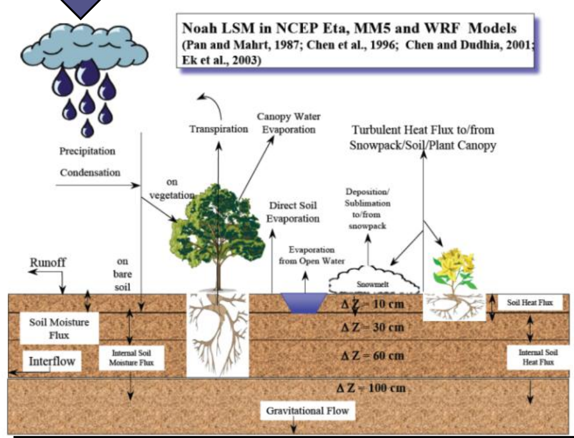
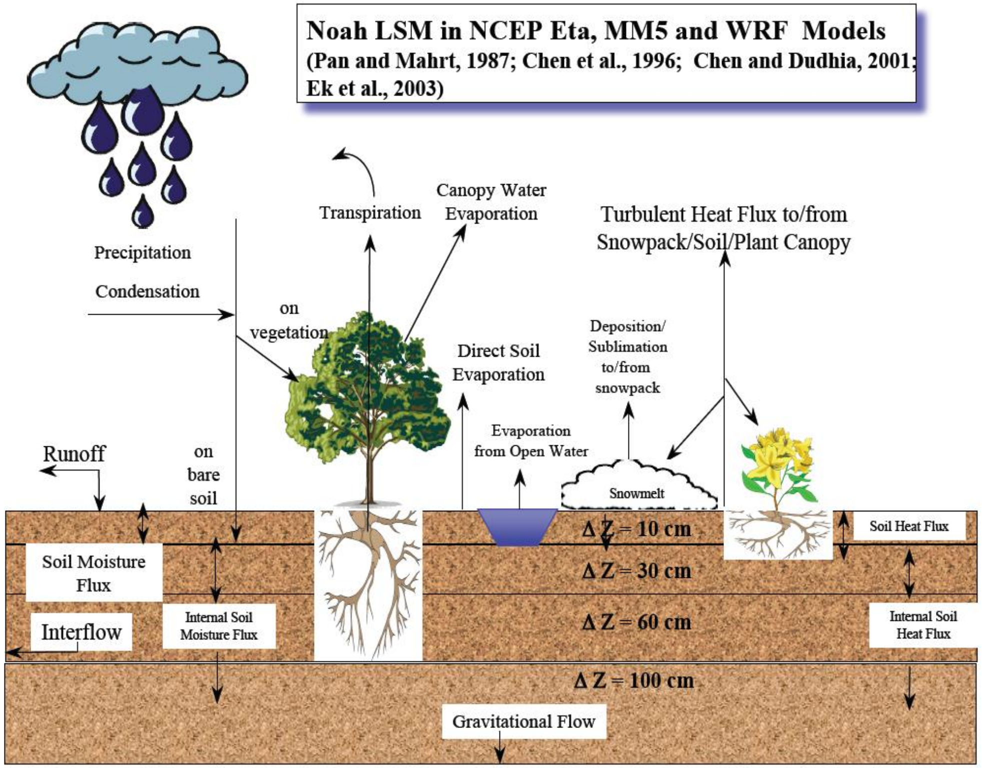


Land Surface Model

Modeling across spatial and temporal scales:

Global → Regional→ Watershed

Noah land surface model with multi-physics options



Noah LSM with multi-physics options

1. **Leaf area index (prescribed; predicted)**
2. **Turbulent transfer (Noah; NCAR LSM)**
3. **Soil moisture stress factor for transpiration (Noah; BATS; CLM)**
4. **Canopy stomatal resistance (Jarvis; Ball-Berry)**
5. **Snow surface albedo (BATS; CLASS)**
6. **Frozen soil permeability (Noah; Niu and Yang, 2006)**
7. **Supercooled liquid water (Noah; Niu and Yang, 2006)**
8. **Radiation transfer:**
   - **Modified two-stream:**
     - **Gap = F (3D structure; solar zenith angle; ...) ≤ 1-GVF**
   - **Two-stream applied to the entire grid cell: Gap = 0**
   - **Two-stream applied to fractional vegetated area: Gap = 1-GVF**
9. **Partitioning of precipitation to snowfall and rainfall (CLM; Noah)**
10. **Runoff and groundwater:**
    - **TOPMODEL with groundwater**
    - **TOPMODEL with an equilibrium water table(Chen&Kumar,2001)**
    - **Original Noah scheme**
    - **BATS surface runoff and free drainage**

More to be added

Niu et al. (2011)

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

Maximum Number of Combinations

1. **Leaf area index (prescribed; predicted) 2**
2. **Turbulent transfer (Noah; NCAR LSM) 2**
3. **Soil moisture stress factor for transpiration (Noah; BATS; CLM) 4**
4. **Canopy stomatal resistance (Jarvis; Ball-Berry) 2**
5. **Snow surface albedo (BATS; CLASS) 2**
6. **Frozen soil permeability (Noah; Niu and Yang, 2006) 2**
7. **Supercooled liquid water (Noah; Niu and Yang, 2006) 2**
8. **Radiation transfer: 3**
   - **Modified two-stream:**
     - **Gap = F (3D structure; solar zenith angle; ...) ≤ 1-GVF**
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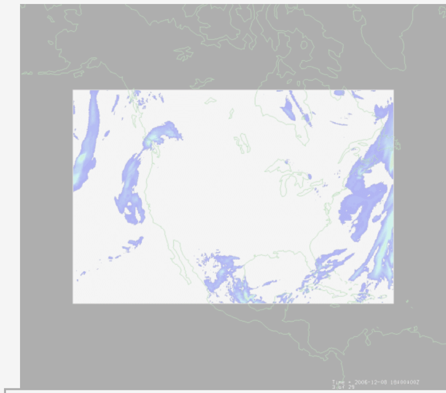
9. **Partitioning of precipitation to snowfall and rainfall (CLM; Noah)2**
10. **Runoff and groundwater: 4**
    - **TOPMODEL with groundwater**
    - **TOPMODEL with an equilibrium water table(Chen&Kumar,2001)**
    - **Original Noah scheme**
    - **BATS surface runoff and free drainage**

2 x 2 x 3 x 2 x 2 x 2 x 2 x 3 x 2 x 4 = 4608 combinations

Process understanding, probabilistic forecasting, quantifying uncertainties

Framework for calculation



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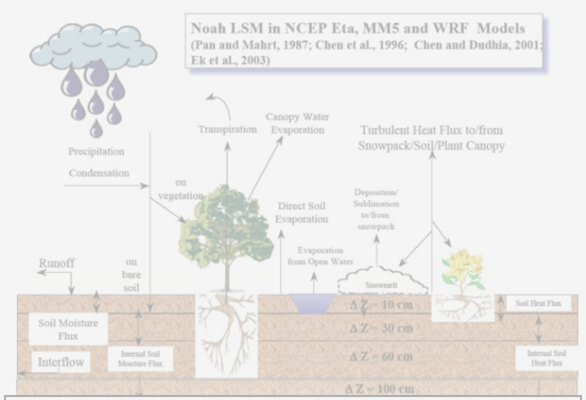
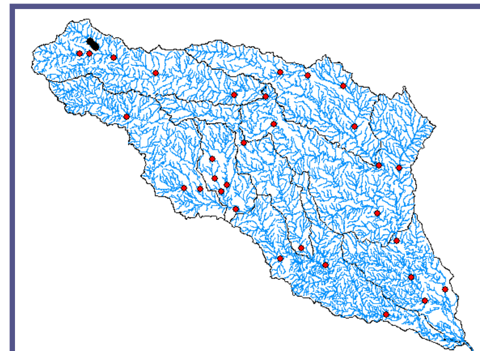


Land Surface Model



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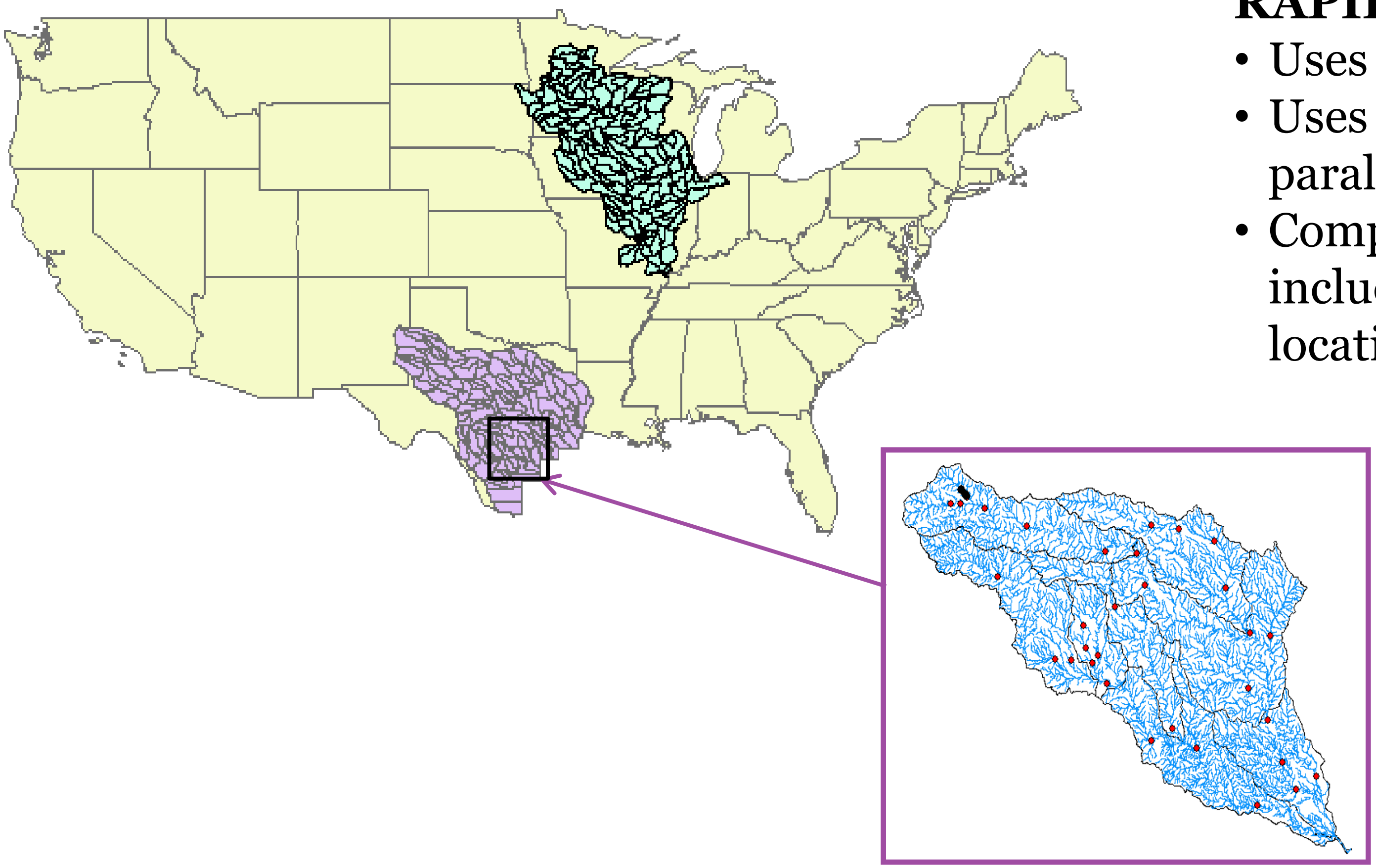
River network modeling



RAPID

- Uses mapped rivers
- Uses high-performance parallel computing
- Computes everywhere including ungaged locations

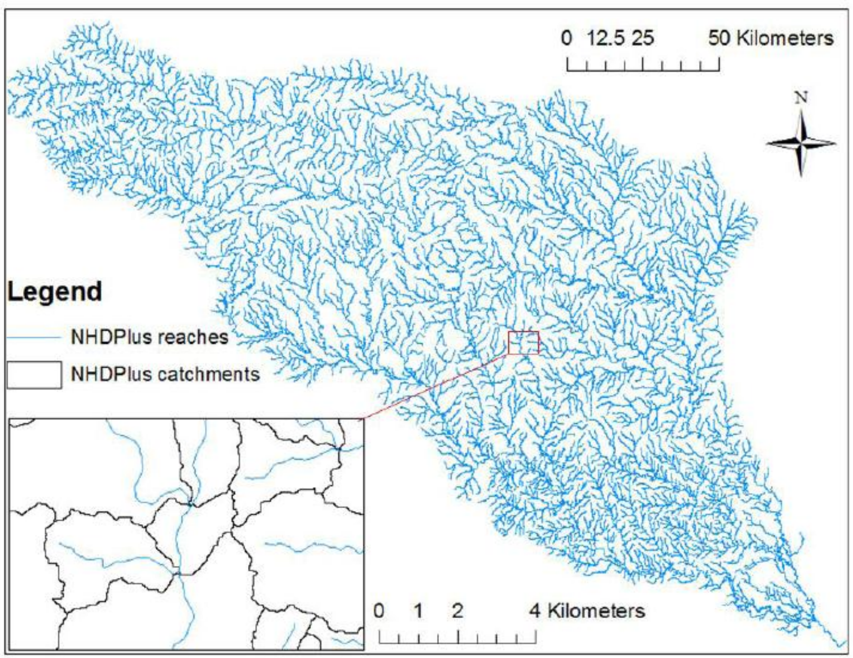
River Network Model: RAPID

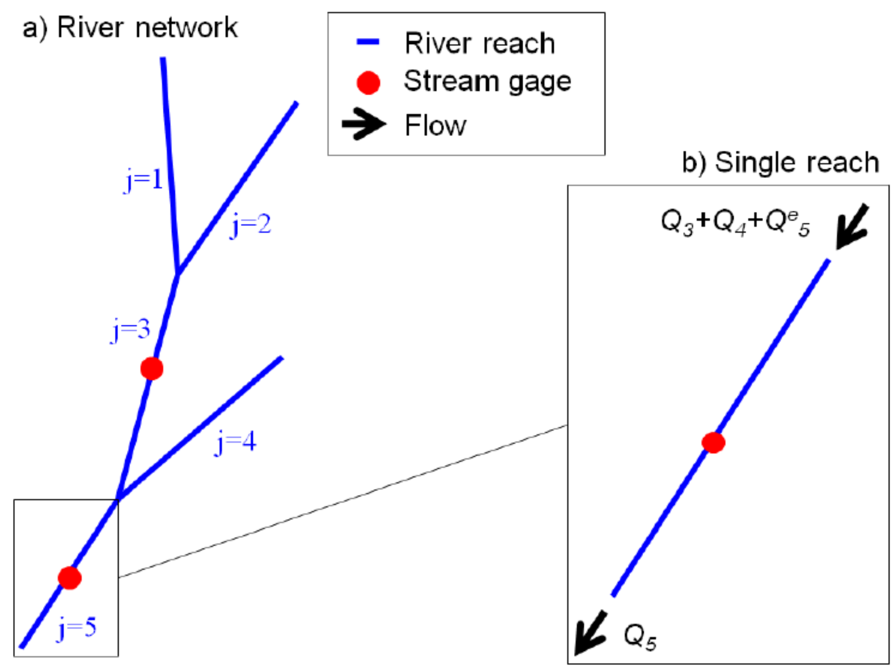
Routing Application for Parallel computatIon of Discharge

Based on Muskingum Method

$$(\mathbf{I}-\mathbf{C}_1\cdot\mathbf{N})\cdot\mathbf{Q}(t+\Delta t)=\mathbf{C}_1\cdot\mathbf{Q}^e(t)+\mathbf{C}_2\cdot\left[\mathbf{N}\cdot\mathbf{Q}(t)+\mathbf{Q}^e(t)\right]+\mathbf{C}_3\cdot\mathbf{Q}(t)$$

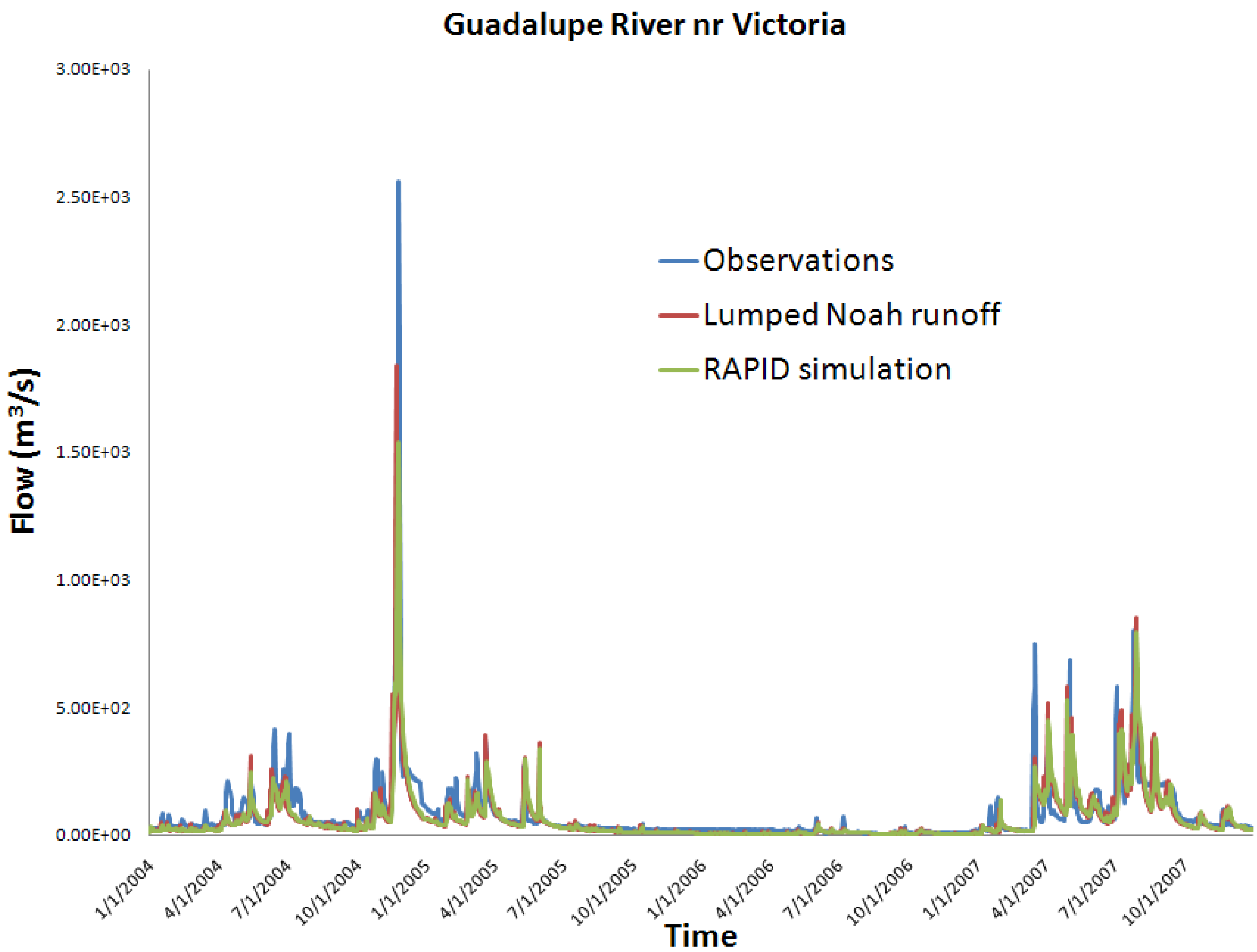
$$\mathbf{V}(t+\Delta t)=\mathbf{V}(t)+\left[\mathbf{N}\cdot\mathbf{Q}(t)+\mathbf{Q}^e(t)\right]\cdot\Delta t-\mathbf{Q}(t)\cdot\Delta t$$



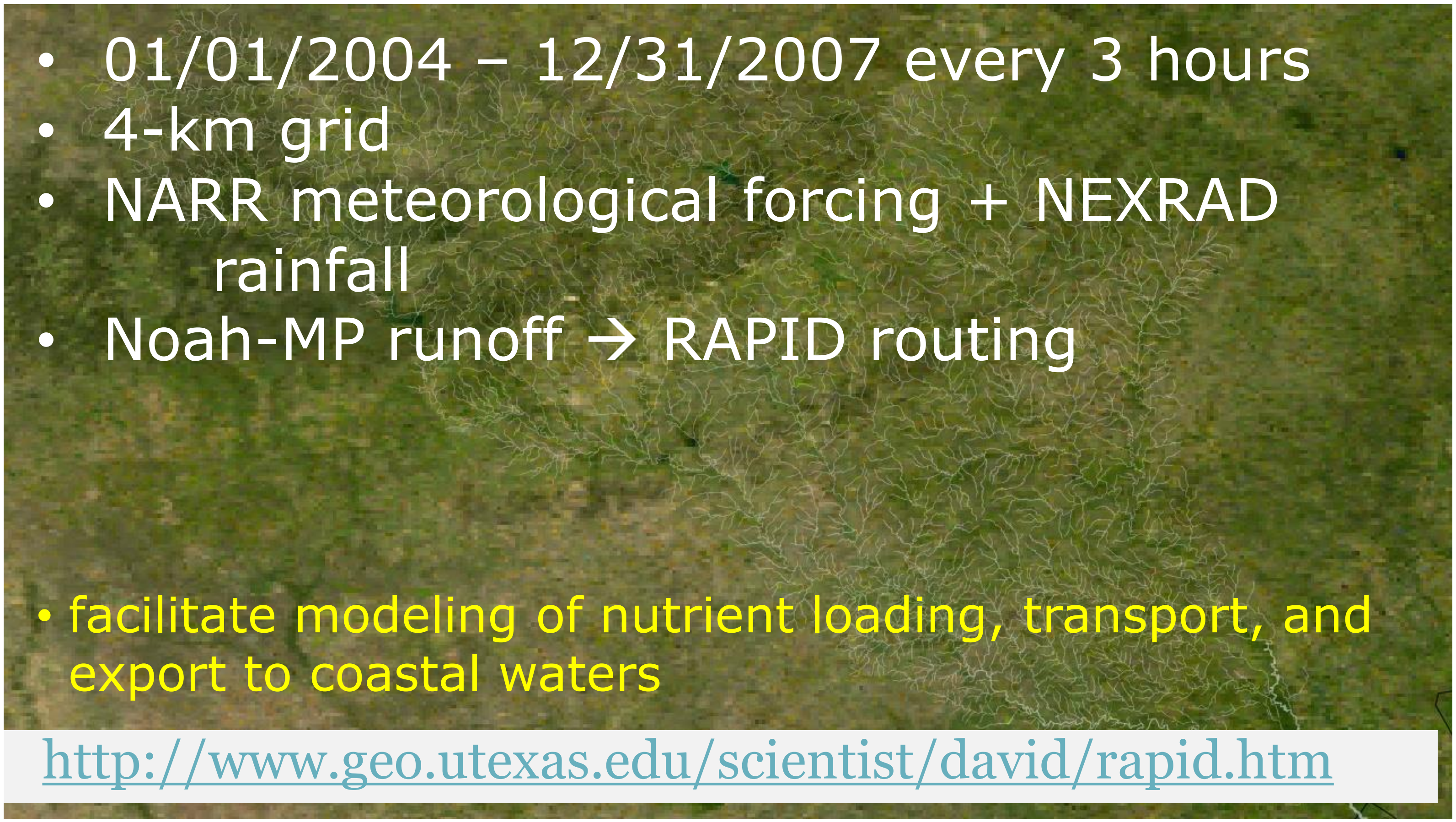


David et al. (2011)

RAPID and Noah-MP Performance Results



Texas Rivers Draining to the Gulf of Mexico



- 01/01/2004 – 12/31/2007 every 3 hours
- 4-km grid
- NARR meteorological forcing + NEXRAD rainfall
- Noah-MP runoff → RAPID routing

- facilitate modeling of nutrient loading, transport, and export to coastal waters

http://www.geo.utexas.edu/scientist/david/rapid.htm

Thanks to Cedric David, Bryan Hong, David Maidment, Ben Hodges, Ahmad Tavakoly, and Adam Kubach of Texas Advanced Computing Center

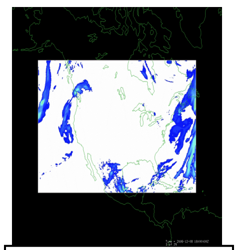
(David et al., 2011, HP, JHM)

RAPID Routing model

- adapted to large scale basin with high spatial resolution
- few parameters, inversion process included
- numerical efficiency (parallel computation)

Application in the Guadalupe river, Texas
River network based on NHDplus

Framework; what is missing?



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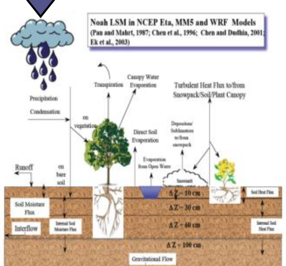
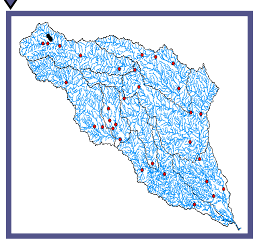


Land Surface Model



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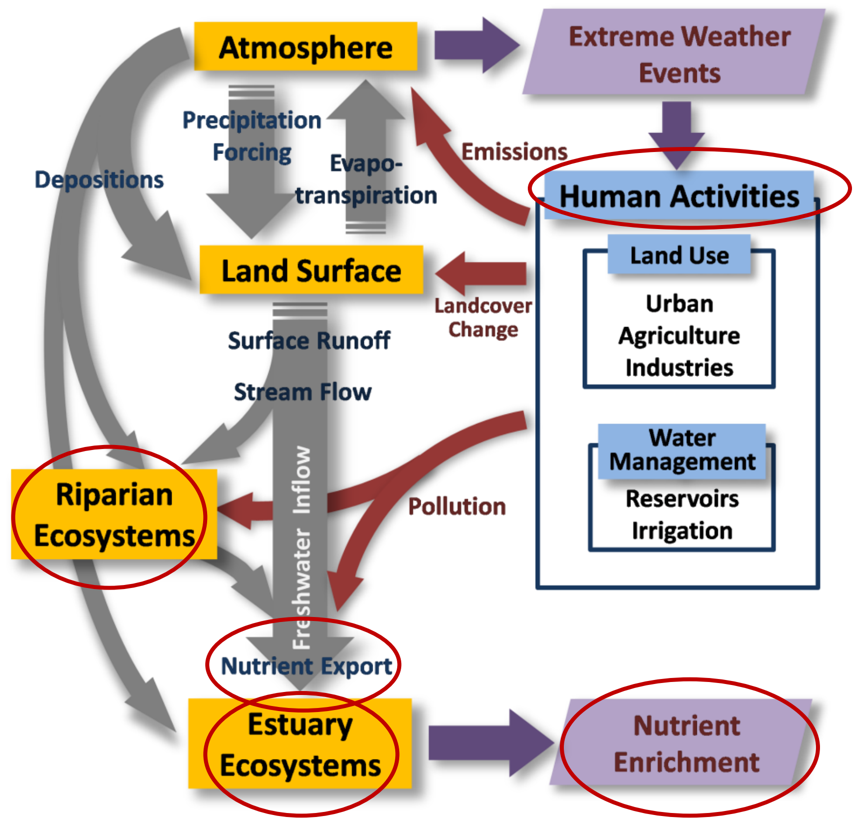
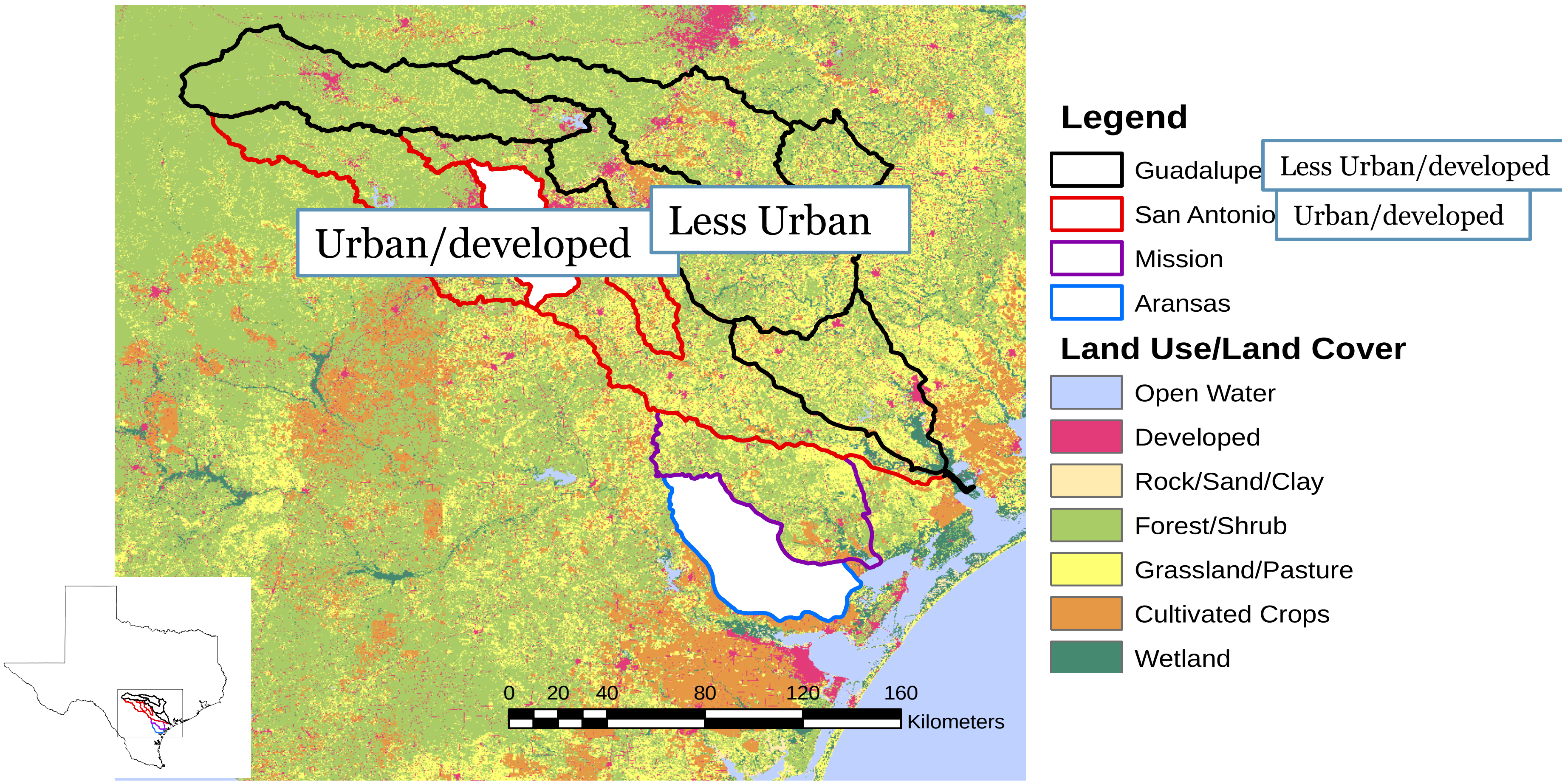


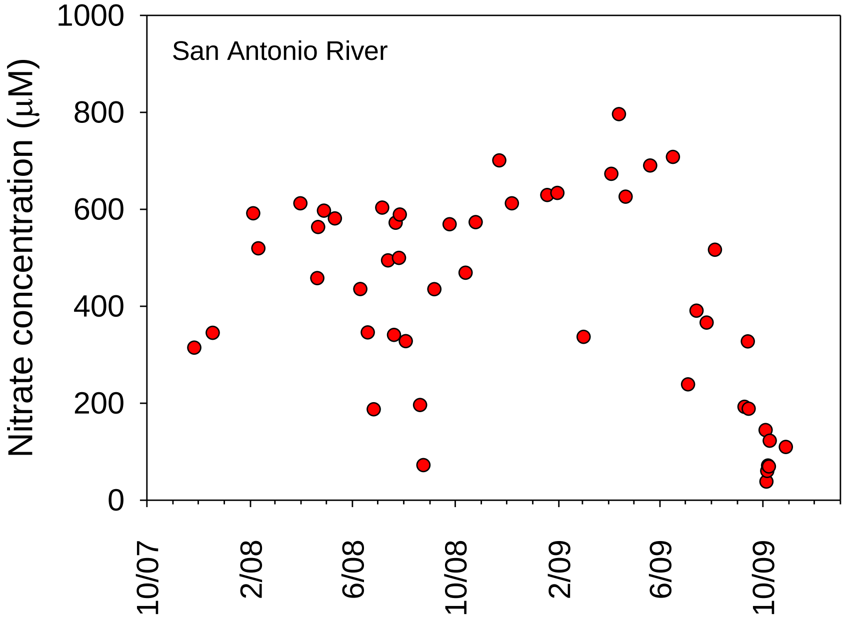
San Antonio, Guadalupe, Mission, and Aransas Rivers

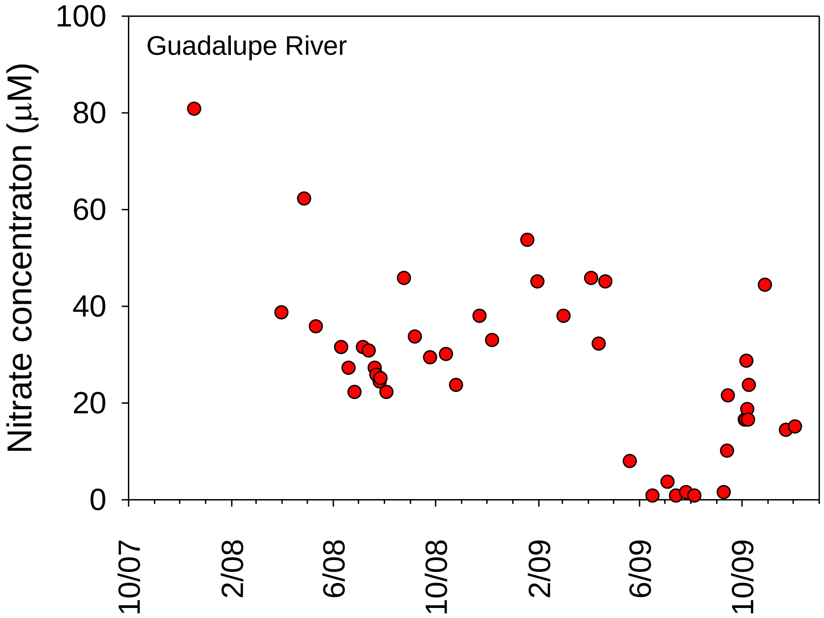


Observations and Chemistry Sampling

- Sampling targeted to high flow events
  - potential for high nutrient export
- Stream Gauge data:
  - Taken from Texas Commission of Environmental Quality (TCEQ)
    - Gauge data collected at constant time step
  - Taken from University of Texas Marine Science Institute (UTMSI)
    - Gauge data collected during high flow events

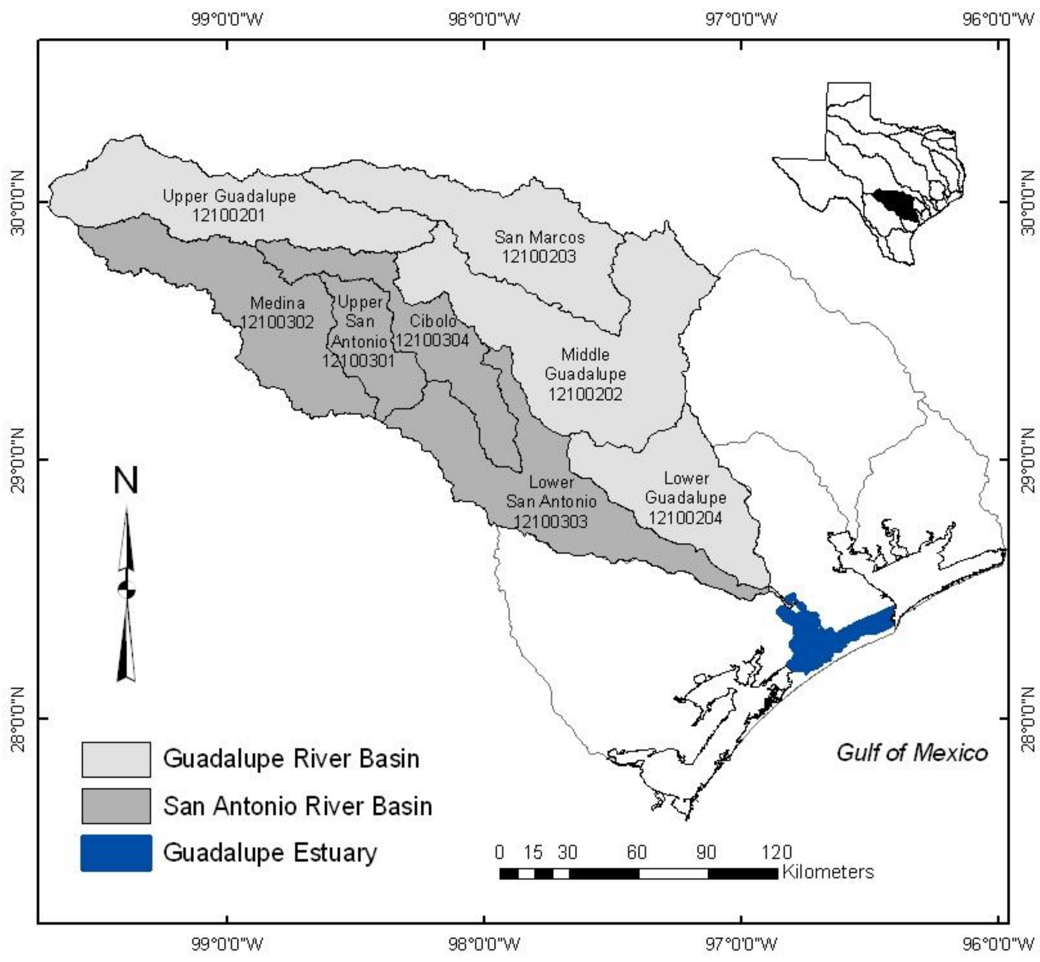
Stream Gauge Nitrate Concentration: Urban vs. Less Urban





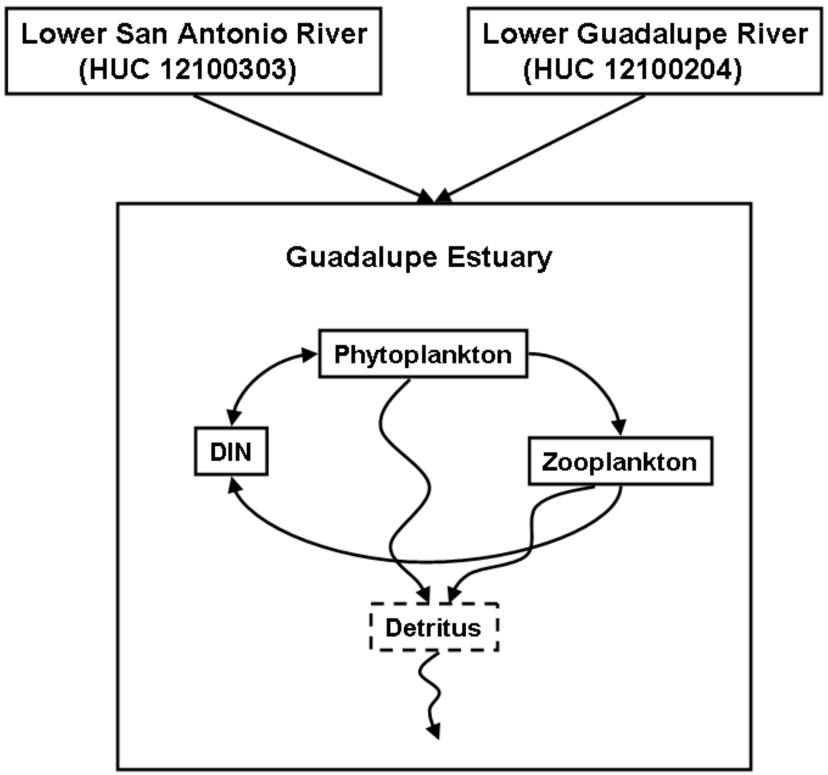
- Urban/Developed Location
- Less Urban Location

Estuary Model Nutrient Transport Study



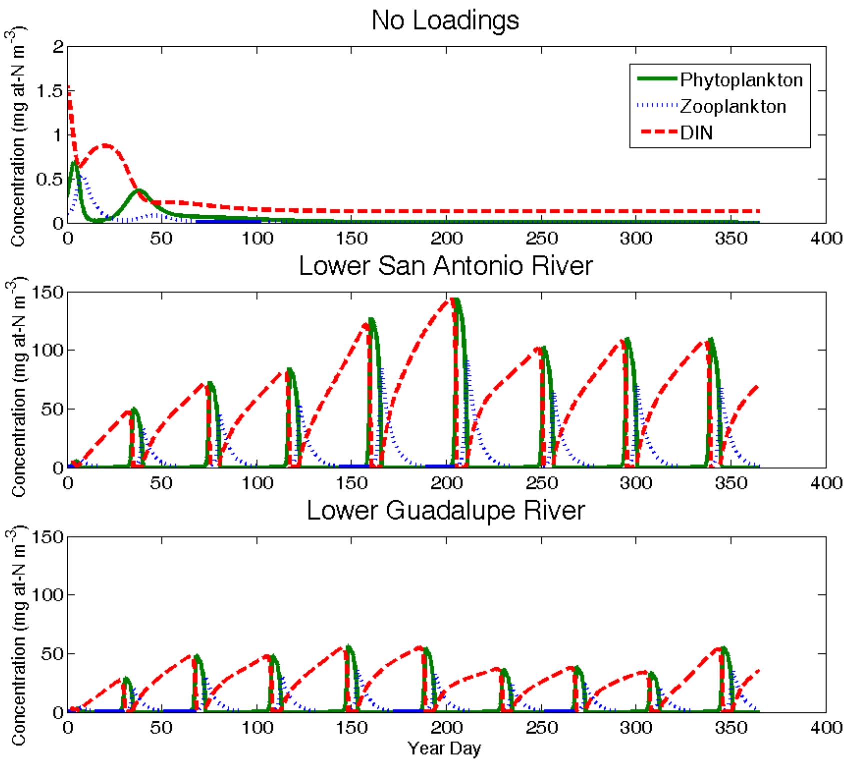
- Same River Basins
  - Guadalupe (Less Urban)
  - San Antonio (Urban/developed)
- Four HUCs in each basin
- Guadalupe Estuary
  - Centrally located along Texas coast
  - Microtidal
  - Small bay area but large watershed relative to other Texas systems

Generic Ecosystem Model (3 components with 2 boundary conditions)



- Mass-balance model
- Two boundaries: LGRW & LSRW
- Three components: Nutrient (DIN) –Phytoplankton – Zooplankton
- Re-mineralization and implicit sinking (or horizontal exchange) were assumed to be 50%, respectively
- Δ=1 hr & RK 4th order scheme

Generic Ecosystem Model Results



- No Loadings (both boundary conditions shut down)
- Lower San Antonio River (Urban/developed region)
- Lower Guadalupe River (Less Urban Region)

Source: Arismendez et al. (2009) Ecol. Informatics 4: 243-253

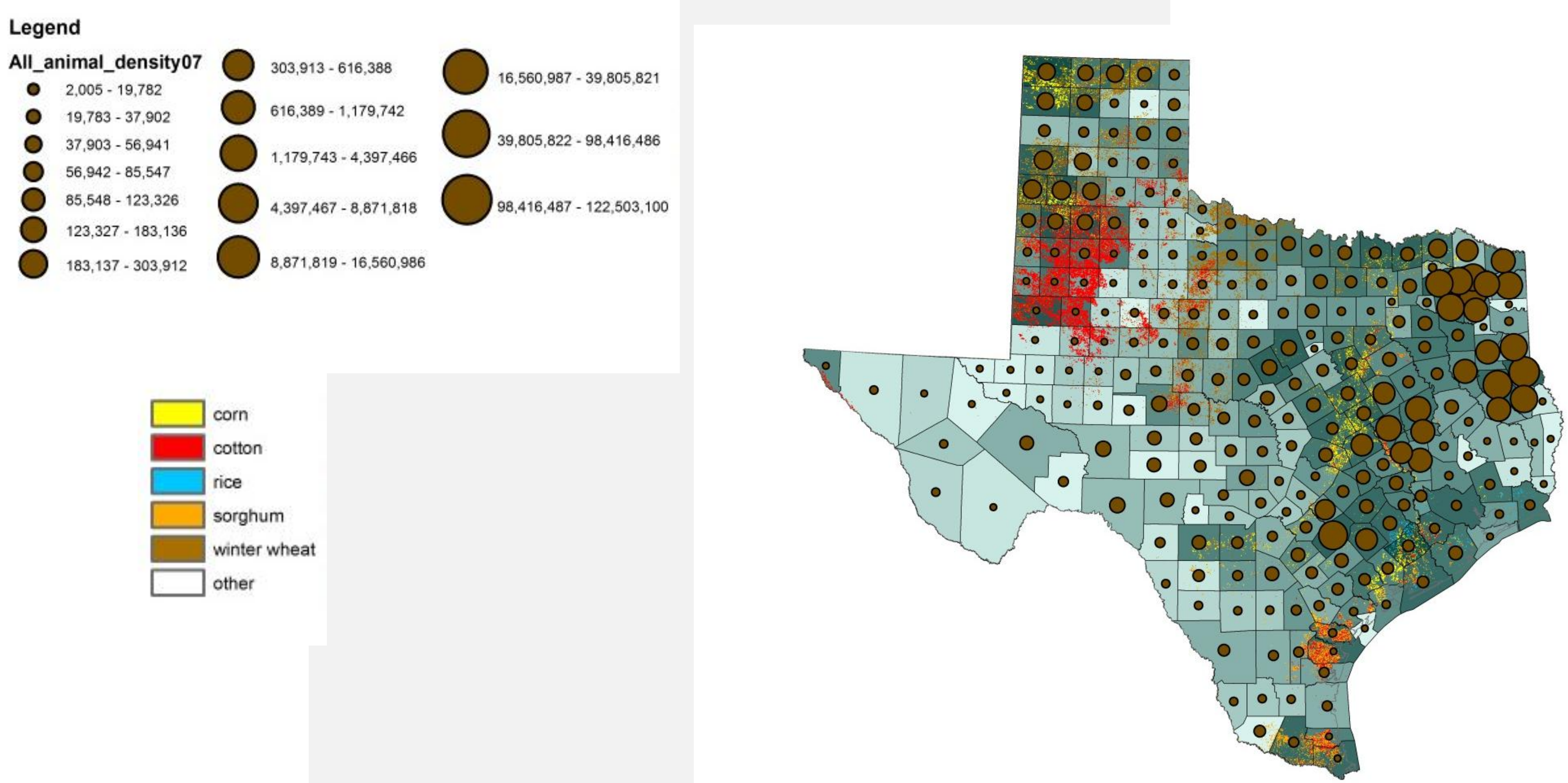
Generic Ecosystem Model Conclusions and Discussion

- Estuary response differs with respect to varying nutrient concentrations.
- Lower San Antonio River (Urban/developed region) is delivering more nutrients and driving greater ranges of ecological response than the Lower Guadalupe River (Less Urban region).
- Increases in nutrient concentrations due to human alterations of the landscape may result in future eutrophic conditions in the Guadalupe Estuary.

Improving on Nutrient Loading

- Developing a Comprehensive Nitrogen Budget for Texas
  - Agriculture Sources
    - Crop fixation, Livestock, and Fertilizer application
  - Atmospheric
    - Dry and wet deposition

Quantification of Sources

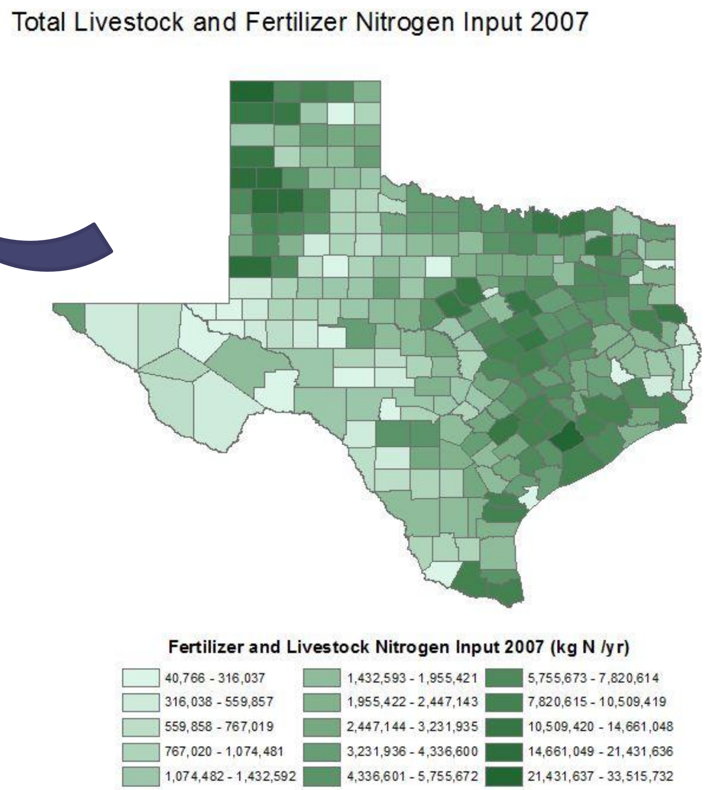


Conclusions

- Predicting nutrient transport from land to coast requires an integrated approach
- Improvement of atmosphere, land, and river flow modeling has lead to better prediction of nutrient fluxes
- Understanding the full pathways of nutrients, with enhanced modeling techniques, will lead to better understanding of sources and solutions

Future Work

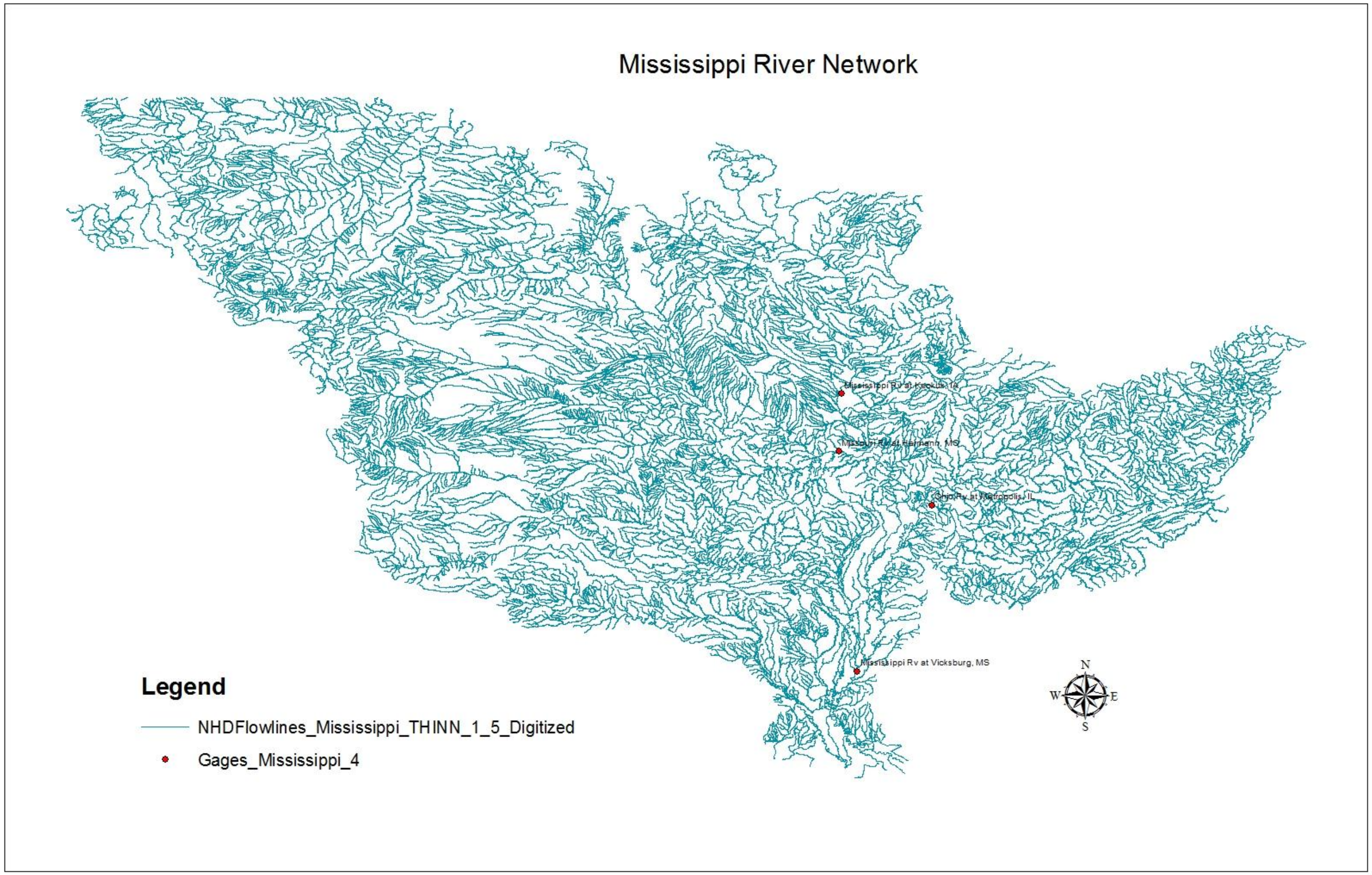
- Land Surface model with leaching (Noah-MP), coupled with regional weather model (WRF)



RAPID

Future Work

- Expansion beyond the Texas Regional Domain



Thank You

- **Zong-Liang Yang** (PI)
- David Maidment (co-I), Paul Montagna (co-PI), James McClelland (co-I), Hongjie Xie (co-PI), Wei Min Hao (Co-PI)
- Guo-Yue Niu, Xiaoyan Jiang, Seungbum Hong, Cédric David, Hae-Cheol Kim, Sandra Arismendez, Rae Mooney, Patty Garlough, Rachel Mills, Beibei Yu, Ling Lu, Almoutaz El Hassan, Zhongfeng Xu, Xitian Cai, Ahmad Tavakoly
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DON: concentration-runoff relationships