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

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

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

Current and future: interannual to hourly

Atmospheric Model or Dataset

Land Surface Model

Vector River Network - High-Performance Computing River Network Model
Framework for calculation

Modeling across spatial and temporal scales:
Global → Regional
The New Dynamic Downscaling (NDD) method

- Central Idea
  - Correct climatological mean bias in GCM outputs

Diagram:

1. Run GCM
2. Correct GCM bias
3. Run RCM
Methodology of GCM bias correction

\[
CAM = \overline{CAM} + CAM'
\]
\[
NNRP = \overline{NNRP} + NNRP'
\]

- **Bias correction 1:**
  \[
  CAM_{bc1} = NNRP + CAM'
  \]

- **Bias correction 2:**
  \[
  CAM_{bc2} = NNRP + CAM' \cdot \frac{D_{NNRP}}{D_{CAM}}
  \]
  \(D:\) standard deviation
Annual mean RMSEs in GCM and RCM

RMSE in GCM
Before downscaling

RMSE in RCM
After downscaling
Framework for calculation

Modeling across spatial and temporal scales: Global → Regional → Watershed
Noah land surface model with multi-physics options

Noah LSM in NCEP Eta, MM5 and WRF Models
(Pan and Mahrt, 1987; Chen et al., 1996; Chen and Dudhia, 2001; Ek et al., 2003)
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:
     
     \[ \text{Gap} = F(\text{3D structure}; \text{solar zenith angle}; ... \leq 1-\text{GVF} \]
     
     Two-stream applied to the entire grid cell: \( \text{Gap} = 0 \)
     
     Two-stream applied to fractional vegetated area: \( \text{Gap} = 1-\text{GVF} \)

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:
    
    \[
    \text{Gap} = F(3D \text{ structure}; \text{ solar zenith angle}; ...) \leq 1-\text{GVF}
    \]
    
    Two-stream applied to the entire grid cell: \( \text{Gap} = 0 \)
    
    Two-stream applied to fractional vegetated area: \( \text{Gap} = 1-\text{GVF} \)
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

\[2 \times 2 \times 3 \times 2 \times 2 \times 2 \times 2 \times 3 \times 2 \times 4 = 4608 \text{ combinations}\]

Process understanding, probabilistic forecasting, quantifying uncertainties
Framework for calculation

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

Current and future: interannual to hourly

Vector River Network - High-Performance Computing River Network Model
River network modeling

RAPID
- Uses mapped rivers
- Uses high-performance parallel computing
- Computes everywhere including ungauged locations
River Network Model: RAPID

Routing Application for Parallel computation of Discharge

\[(I - C_1 \cdot N) \cdot Q(t+\Delta t) = C_1 \cdot Q^e(t) + C_2 \cdot [N \cdot Q(t) + Q^e(t)] + C_3 \cdot Q(t)\]

\[V(t+\Delta t) = V(t) + [N \cdot Q(t) + Q^e(t)] \cdot \Delta t - Q(t) \cdot \Delta t\]

Based on Muskingum Method

David et al. (2011)
RAPID and Noah-MP Performance Results

Guadalupe River nr Victoria

- Observations
- Lumped Noah runoff
- RAPID simulation

Flow (m$^3$/s)

Time

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
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

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

(David et al., 2011, HP, JHM)
Framework; what is missing?
San Antonio, Guadalupe, Mission, and Aransas Rivers

Legend
Guadalupe
San Antonio
Mission
Aransas
Land Use/Land Cover
Open Water
Developed
Rock/Sand/Clay
Forest/Shrub
Grassland/Pasture
Cultivated Crops
Wetland

Urban/developed
Less Urban
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
- $\Delta=1$ hr & RK $4^{\text{th}}$ 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)

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)
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

- Funded by NASA Interdisciplinary Research in Earth Sciences (IDS)
DON: concentration-runoff relationships

[Graph showing the relationship between DON concentration (μM) and runoff (mm/day) for Guadalupe, San Antonio, Mission, and Aransas.]