A parsimonious mechanistic model for assessing multiple drivers of Gulf hypoxia

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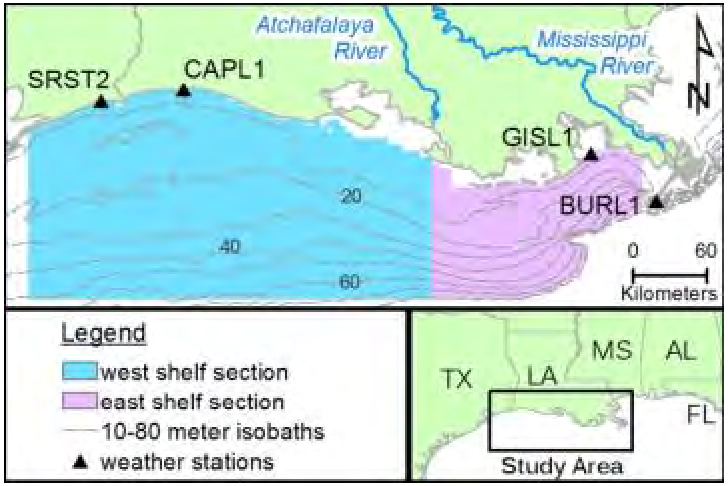
Management Questions

- Response: mean bottom water DO
  - for east and west shelf
  - mid-summer conditions
  - easily converted to hypoxic area
- Biophysical factors addressed:
  - Nutrient loading
  - River flow (stratification and dilution effects)
  - Winds (stratification and transport effects)
- Analyze nutrient loading reduction scenarios
  - potential to also study changes in hydrology and river operations



Key Assumptions

- System represented as 4 mixed reactors (east/west and surface/bottom)
- Parsimonious selection of biochemical processes to represent within model.
- Hydrodynamic transport based on simple flow partitioning equation (function of east-west wind velocity)
- Spring and summer river inputs generally correspond to “nutrient” and “stratification” effects, respectively.
- Steady-state model solution (moving window-approach)

Input/Output

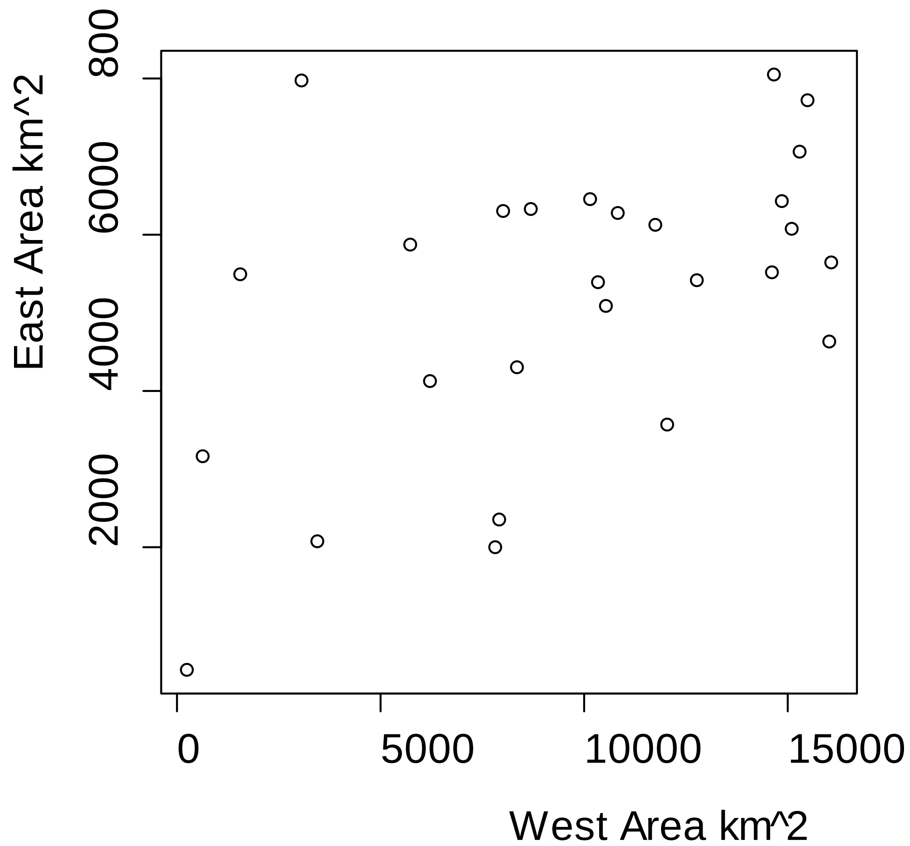
Input variables:

- River flow and load
  (Miss. and Atch.)
- Mean east-west wind velocity
- Wind stress
  (on east and west shelf)

Response variables:

- Mean bottom water dissolved oxygen
  (on east and west shelf)
- Hypoxic extent
  (on east and west shelf)

East vs. west shelf hypoxic area



Model formulation

$$DO = \frac{1}{(K_a + B/C_{O,B})}\left(K_a C_{O,S} - \frac{R_{O:N} L_N}{([Q_r + Q_c]/v_s + A)}\right)$$

Calibration Parameters

- v_s ~ effective settling rate (m/d)
- B ~ benthic oxygen demand (g/m²/d)
- Q_c ~ spring coastal flow, (Gm³/d)

"Known" Parameters

- $C_{O,B}$ ~ reference DO concentration for B (g/m³)
- $C_{O,S}$ ~ saturation DO concentration (g/m³)
- $R_{O:N}$ ~ ratio of net oxygen demand:nitrogen
- A ~ area (Gm²)

Sub-model

- K_a ~ reaeration rate (m/d), **f(Q, w²)**

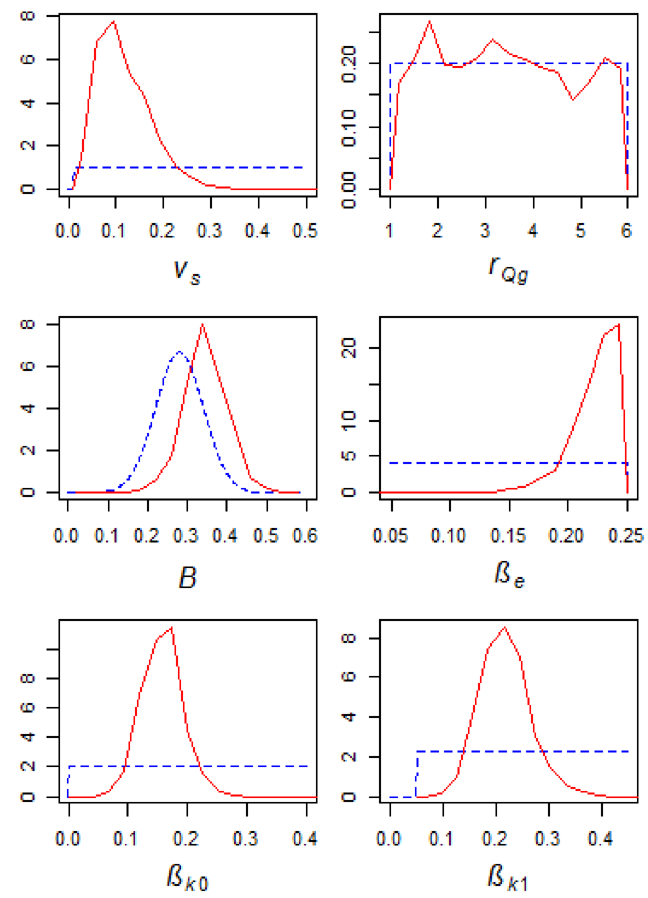
Input data

- L_N ~ spring nitrate loading, (Gg/d)
- Q_r ~ spring river discharge,(Gm³/d)

Flow partitioning equation, **f(w)**

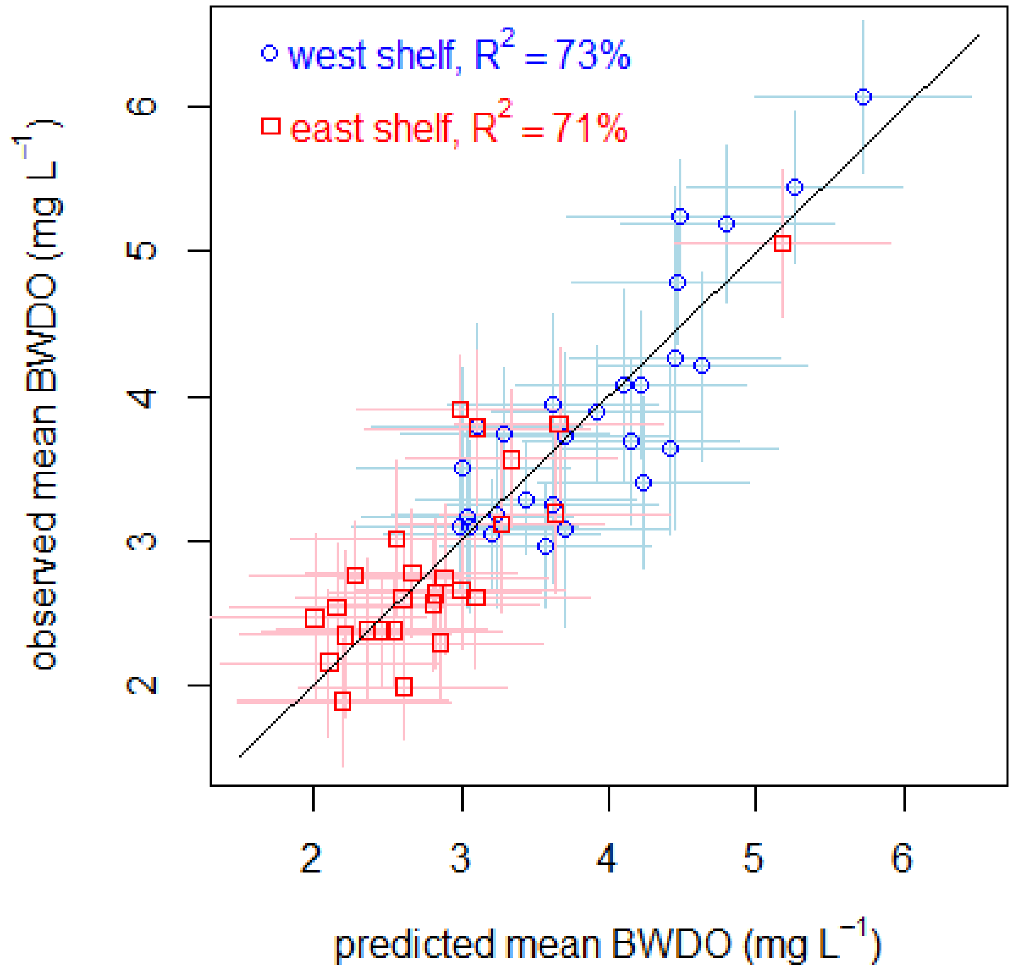
Scalability

- **Model calibration < 15 min on desktop computer**
  - Probabilistic (Bayesian) calibration of biophysical parameters
  - 27 years of shelfwide cruises (east & west shelf)
- **Application of model to various scenarios < 1 min**
- **Model cross validation = a few hours**



Prior (blue) and posterior (red) distributions for biophysical model parameters

Skill Assessment



← Full Model (no "outlier" years)

In cross validation mode:

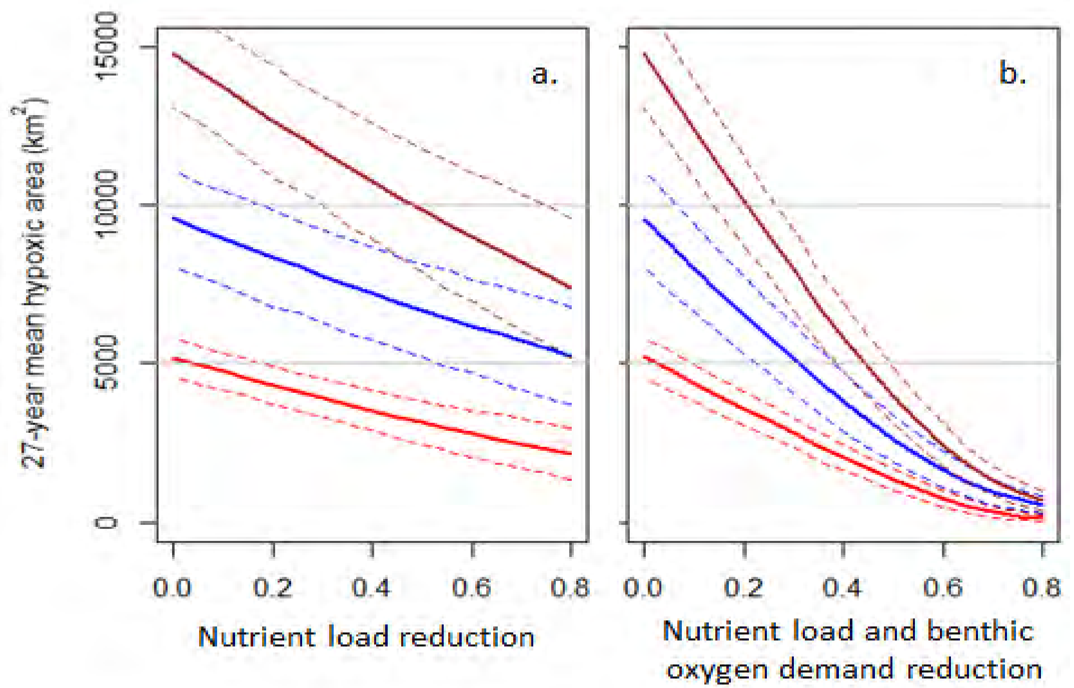
West shelf R^2 = 70%

East shelf R^2 = 65%

Management Applications

- **Nutrient loading scenarios:**

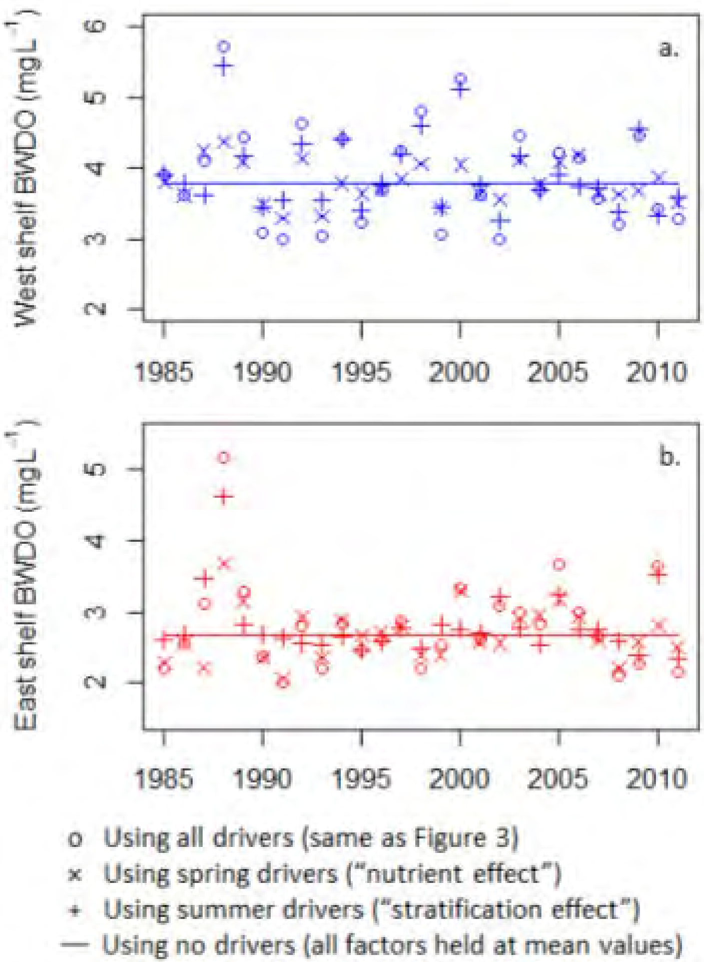
<u>Legend</u>
Total shelf –
West shelf –
East shelf –



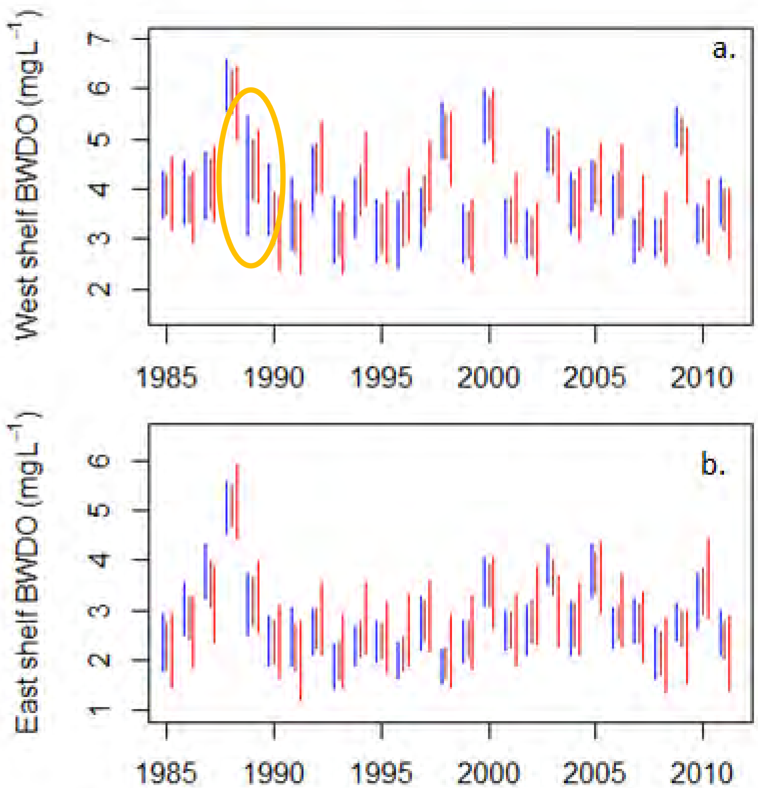
- **Future:**
  - **Forecasting/Hindcasting**
  - **Climate change scenarios**
  - **Modeling over entire summer**

Other Applications

- Analyze "nutrient" and "stratification" effects:



- Fusion (brown) of biophysical model results (red) and geostatistical estimates (blue):



(95% credible intervals)

Transitioning to Operation?

1. Cycle of operation is flexible
2. All input is available online
3. Parsimonious biophysical formulation → fairly transparent model
4. Knowledge of statistics helpful if probabilistic components of model are to be processed and presented to users.

Remaining needs

1. Extend model to predict volume (in addition to area)
2. Utilize information from other monitoring cruises
3. Perform modeling over entire summer and assess severity of hypoxia for entire summer
4. Update biophysical processes represented in model (perhaps based on recommendations of hypoxia research community)
5. Update prior information used in model based on current or future studies