Quantifying the relative importance of different nitrogen sources on hypoxia development in the northern Gulf of Mexico: A biogeochemical model analysis

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Introduction: In the northern Gulf of Mexico, a large region (15,000 km^2 on average) is affected by hypoxia, i.e., dissolved oxygen (O_2) concentrations below 2.0 mg/L, every summer (www.gulfhypoxia.net). The hypoxic conditions result from a combination of seasonal stratification and decay of organic matter, predominantly derived from nutrient inputs from the Mississippi/Atchafalaya River System. We combine the Regional Ocean Modeling System (ROMS; Haidvogel et al., 2008; Hetland and DiMarco, 2008, 2012; Fennel et al., 2006, 2011; Laurent et al., 2012) with an element tracing method (Ménesguen et al., 2006) to track nitrogen (N) from three sources: the Mississippi River, the Atchafalaya River, and the open Gulf. This allows us to quantify their relative contributions to total N (TN), dissolved inorganic N (DIN), net primary production (NPP), and sediment oxygen consumption (SOC) in the northern Gulf of Mexico.

Nitrogen tracking in ROMS

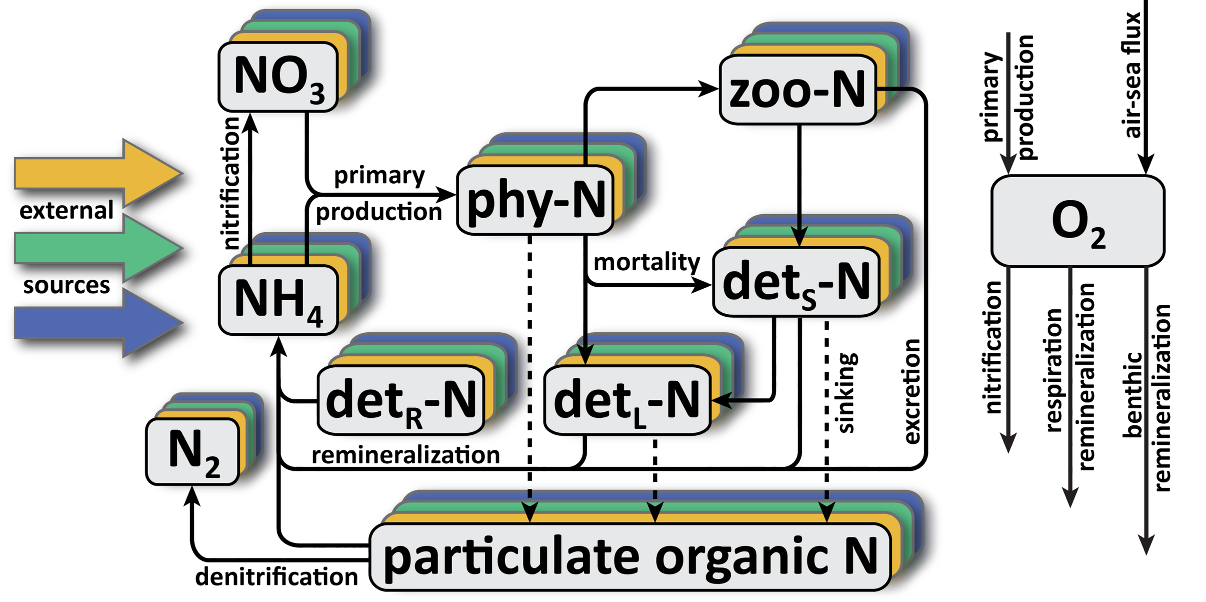

Fig. 1: Schematic of ROMS nitrogen cycle, and O_2-affecting processes. Colored arrows and boxes represent different N sources and additional sets of model tracers (incl. corresponding processes) for each source.

- ROMS simulation: 2000–2011, daily output
- nitrogen tracing: 2000 spin-up, 2001–2011 analysis
  - sources: Mississippi, Atchafalaya, Open Boundary
  - initialization: Mississippi = 100%, others = 0%

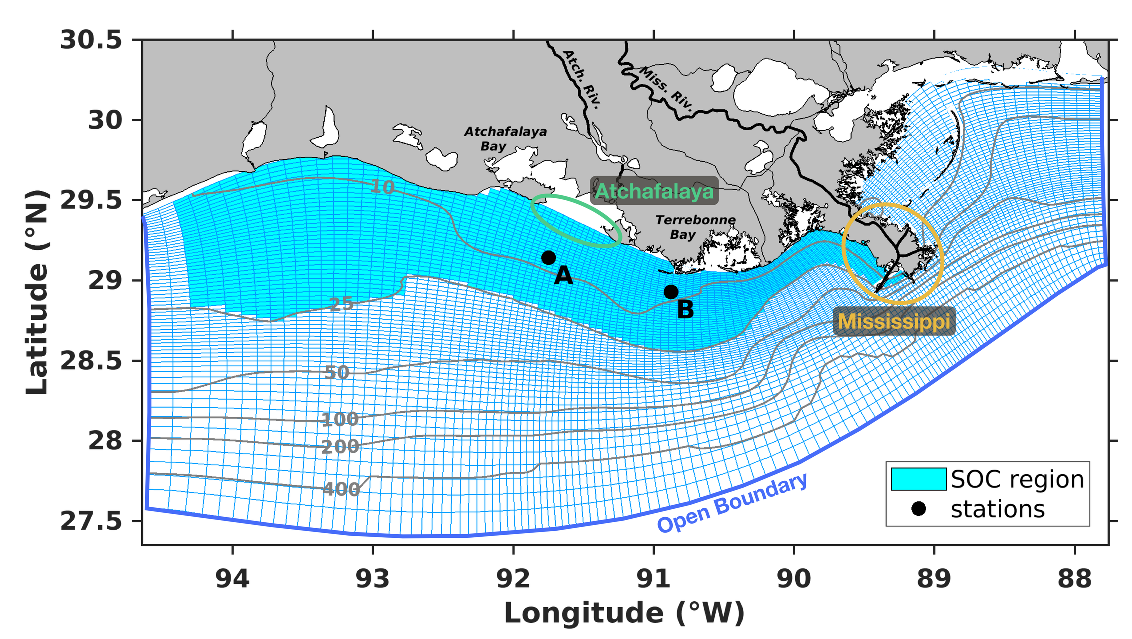

Fig. 2.: Model domain with locations of N sources, stations for daily time series (see Fig. 4), and region for analysis of summer SOC (see Fig. 6).

Average spatial distributions of summer TN, NPP and SOC, and relative contributions by Mississippi and Atchafalaya

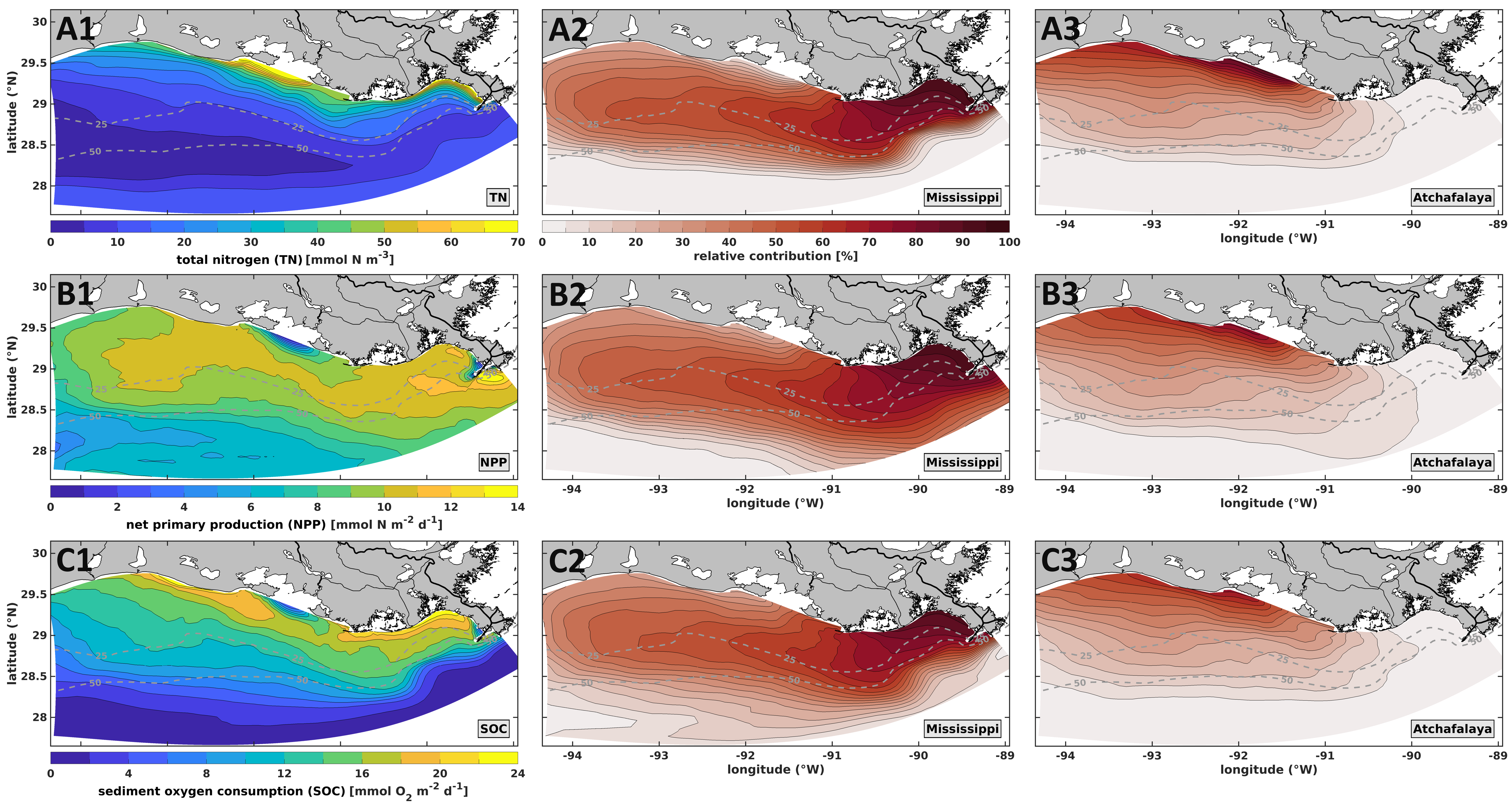

Fig. 3: 11-year-averaged, near-surface (0-25m) TN (row A), NPP (row B), and SOC (row C) during June–August. Column 1: total quantities. Columns 2 and 3: relative contributions by Mississippi and Atchafalaya, respectively. Color scale of panel A2 applies to all panels of columns 2 and 3.

- very different spatial patterns in quantities ⇔ very similar patterns in relative contributions on the shelf
- eastern & central shelf: Mississippi dominant; western shelf: Atchafalaya (on-shore) & Mississippi (off-shore)
- patterns in relative contributions similar to patterns in freshwater thickness (Zhang et al., 2012)
  ➔ freshwater thickness good proxy for "area of biogeochemical influence"

Temporal variability of source-specific DIN and NPP

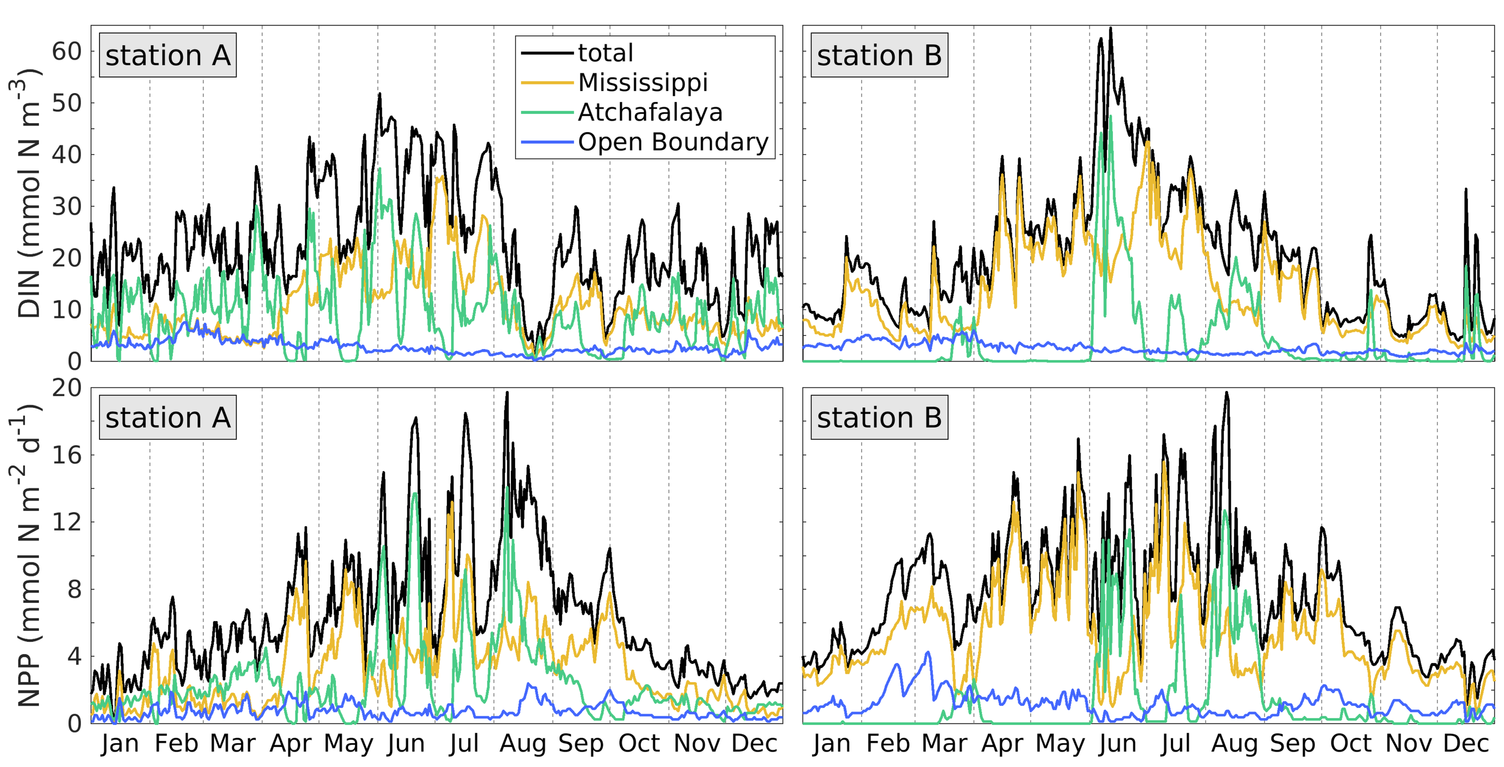

Fig. 4: Daily time series of total and source-specific water column averaged DIN (top) and water column integrated NPP (bottom) at stations A (left) and B (right; see Fig. 2) in 2010.

- stations A+B: high temporal variability in total DIN and NPP driven by variability in riverine contributions
- station A: comparable average contributions by Mississippi and Atchafalaya; high Atchafalaya contribution to summer NPP
- station B: dominated by Mississippi; summer events of high Atchafalaya influence ➔ changes in wind field and circulation

Biochemical "efficiency" of riverine N

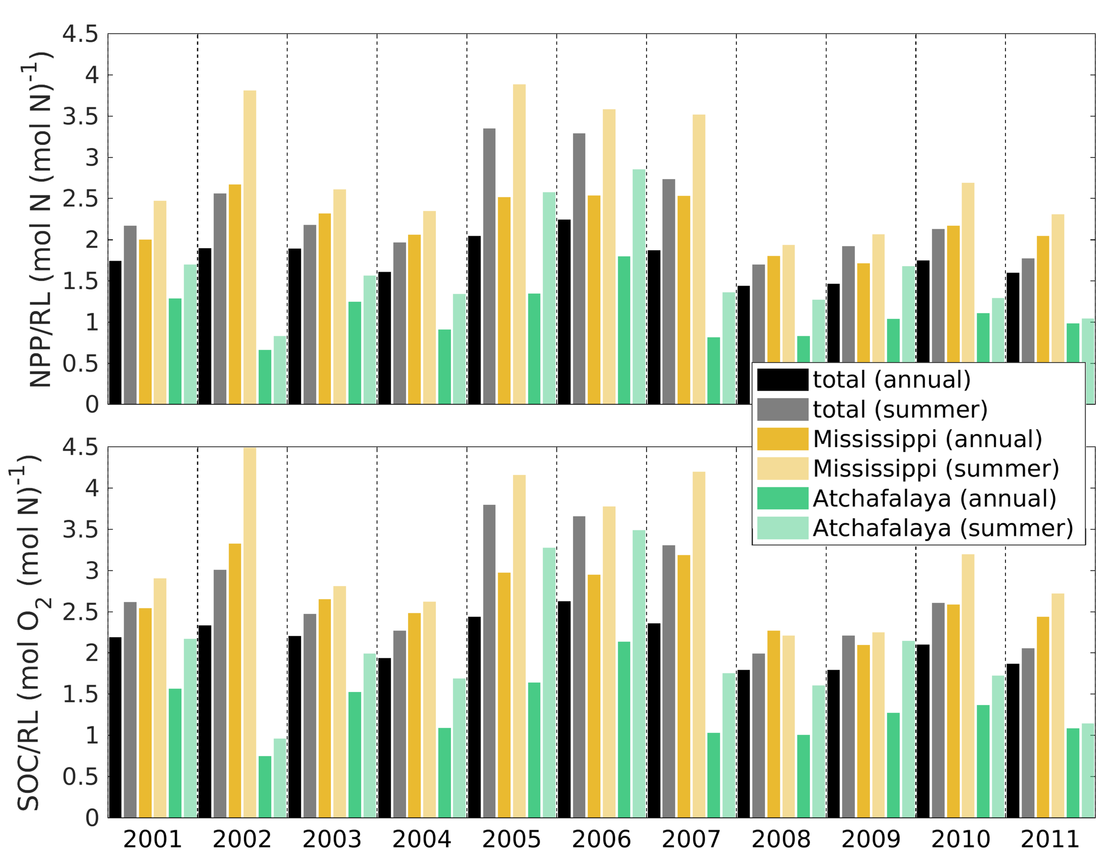

Fig. 5: Time series of NPP (top) and SOC (bottom) per river load (RL) within model domain west of Mississippi delta. 'Summer': May–August.

- annually: Mississippi N consistently contributes more to NPP and SOC per unit N load: ≈40% (2006) to ≈4.5-fold (2002) higher
- summer efficiency higher than annual efficiency ➔ longer residence time on shelf

Summer source-specific SOC

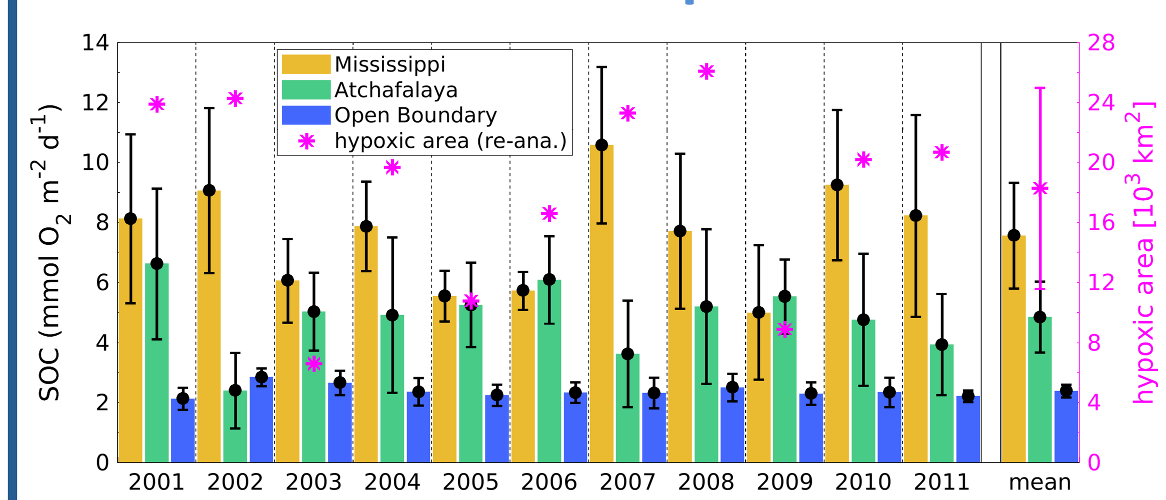

Fig. 6: Time series of source-specific SOC in region shallower than 25m (see Fig. 2) during June–August, and hypoxic area from Obenour et al. (2013). Error bars indicate standard deviations.

- average: Mississippi ≈51%, Atchafalaya ≈33%
- high variability (±8-9%) in both contributions
- high Mississippi contribution often coincides with large hypoxic area

Conclusions

Our study reveals that Mississippi N dominates NPP and SOC in most shelf regions and during most years. On average, about 84% of summer SOC can be attributed to riverine N inputs. This suggests a high potential of riverine N reductions for mitigating hypoxia on the shelf. However, sensitivity studies on the actual effect of N reductions and the corresponding changes in the relative contributions are required.

References

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