Quantifying the Impact of River Nutrient Loadings on Coastal Chlorophyll and Oxygen at Global Scale

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Abstract We investigate the role of riverine dissolved nutrient loadings in driving coastal biogeochemical processes at global scale through application of a state-of-the-art, high-resolution (1/4°) global ocean-ice-ecosystem model with time varying river point sources estimated from an offline land model, both developed at NOAA GFDL. Focused on chlorophyll and oxygen, our model experiments depict a global view of "river impacted zones" with boundaries extended up to 1,000 km from the discharge points. We show that intensity and distribution of coastal extremes (i.e., blooms and hypoxia) in some coastal systems are strongly influenced by temporal variability of river nutrients, while these events are driven more by climate and oceanic dynamics in other coastal systems. Our results emphasize that future prediction of coastal ecosystem tipping points requires resolution of both oceanic and terrestrial (e.g. riverine) drivers of coastal change.

Background and Motivation

Coastal ocean is increasingly threatened in a high CO2, urbanized world. Coastal stressors, e.g. harmful algal blooms and oxygen deprivation, are forecast to intensify over the next century owing to the combined effects of global warming and enhanced nutrient inputs. As a major terrestrial source of nutrients to the ocean, rivers play a critical but poorly quantified role in driving both coastal biogeochemical processes and global carbon cycling. Studies have shown that river nutrient loadings are subject to substantial seasonal and interannual variability linked to vegatation dynamics, land-use changes, and hydrological cycles. However, such variability and their adjacent shelf-scale dynamics are often poorly resolved, if at all, in global biogeochemical models.

Temporal variability of riverine dissolved nitrogen concentration

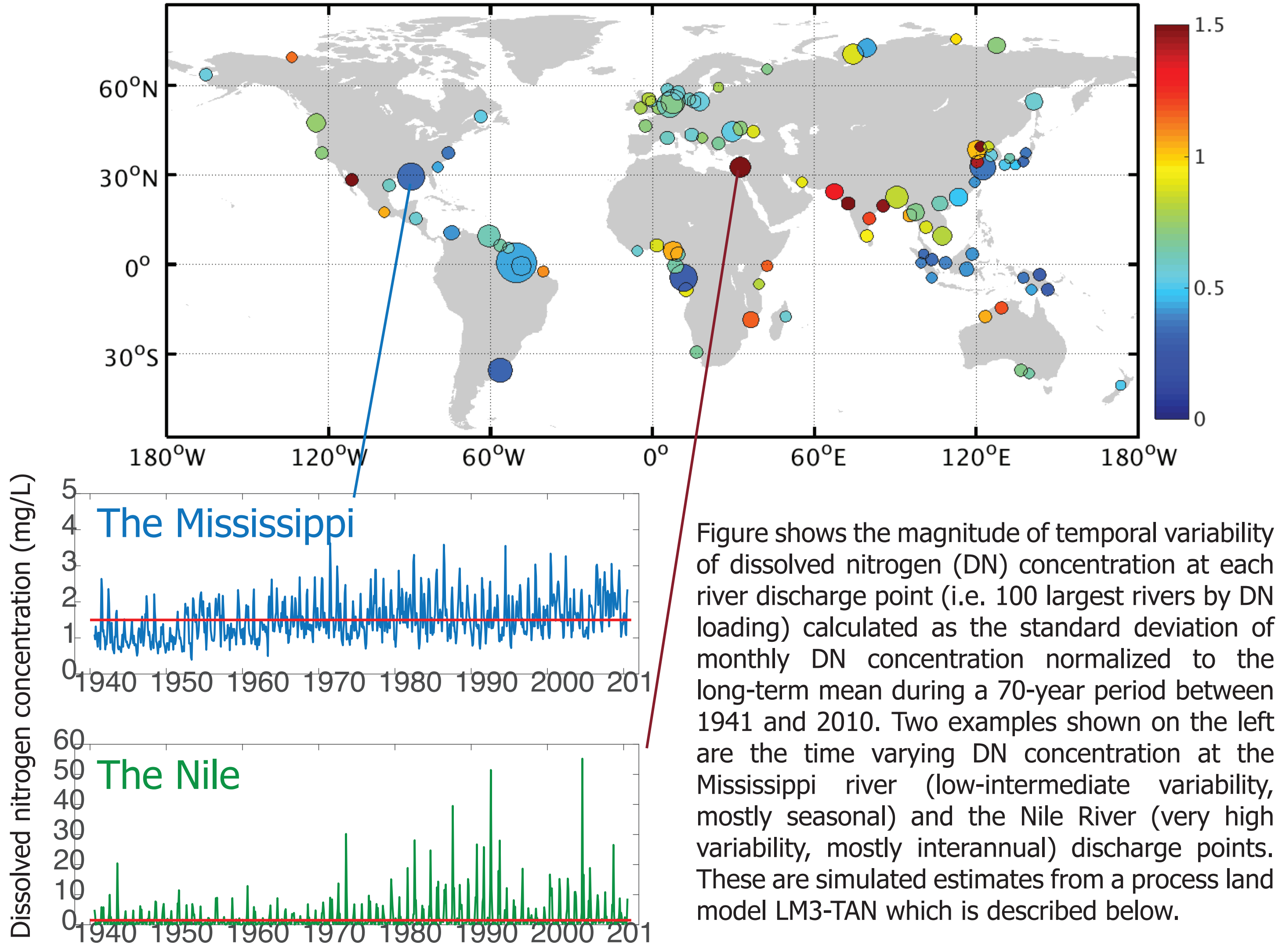

Figure shows the magnitude of temporal variability of dissolved nitrogen (DN) concentration at each river discharge point (i.e. 100 largest rivers by DN loading) calculated as the standard deviation of monthly DN concentration normalized to the long-term mean during a 70-year period between 1941 and 2010. Two examples shown on the left are the time varying DN concentration at the Mississippi river (low-intermediate variability, mostly seasonal) and the Nile River (very high variability, mostly interannual) discharge points. These are simulated estimates from a process land model LM3-TAN which is described below.

Models and Experiments

- LM3-TAN — a process land model at 1° horizontal resolution that describes key controls of the transport and fate of nitrogen in the vegatation-soil-river system and thus captures both seasonal and interannual variations of river DN loadings.
- MOM6-SIS2-COBALTv2 — a global ocean-ice-biogeochemical model at 1/4° horizontal resolution that reasonably resolves shelf-scale dynamics and coast-to-ocean exchanges.
- The baseline simulation is run for 26 years (1985-2010) following a 52-year spinup forced with JRA-55, with prescribed time varying inputs of river freshwater and DN fluxes estimated from LM3-TAN simulations. Dissolved phosphorus (DP) is estimated based on observed DN:DP ratio for each river obtained from the Global-NEWS datasets. Here river nutrients are referred as DN and DP.
- Sensitivity experiments are performed with removed (0x), reduced (0.5x), elevated (2x), and "static" river nutrients, where "static" means that the prescribed inputs of river DN and DP concentrations are the long-term means and do not change with time.

Significance Changes in coastal extreme events such as hypoxia represent a potential risk to human health. Effective mitigation strategies requires a quantitative understanding of how impacted coastal regions are influenced by human activities. Our models show the capacity of capturing temporal variations of river nutrient loadings, spatially resolving shelf-scale dynamics, and together linking riverine eutrophication, coast-to-ocean exchanges, and coastal blooms and hypoxia on a global scale. This would allow regions that are susceptble to changes in river nutrient inputs or shifts in oceanic dynamics to be identified, and thus, help guide future monitoring efforts.

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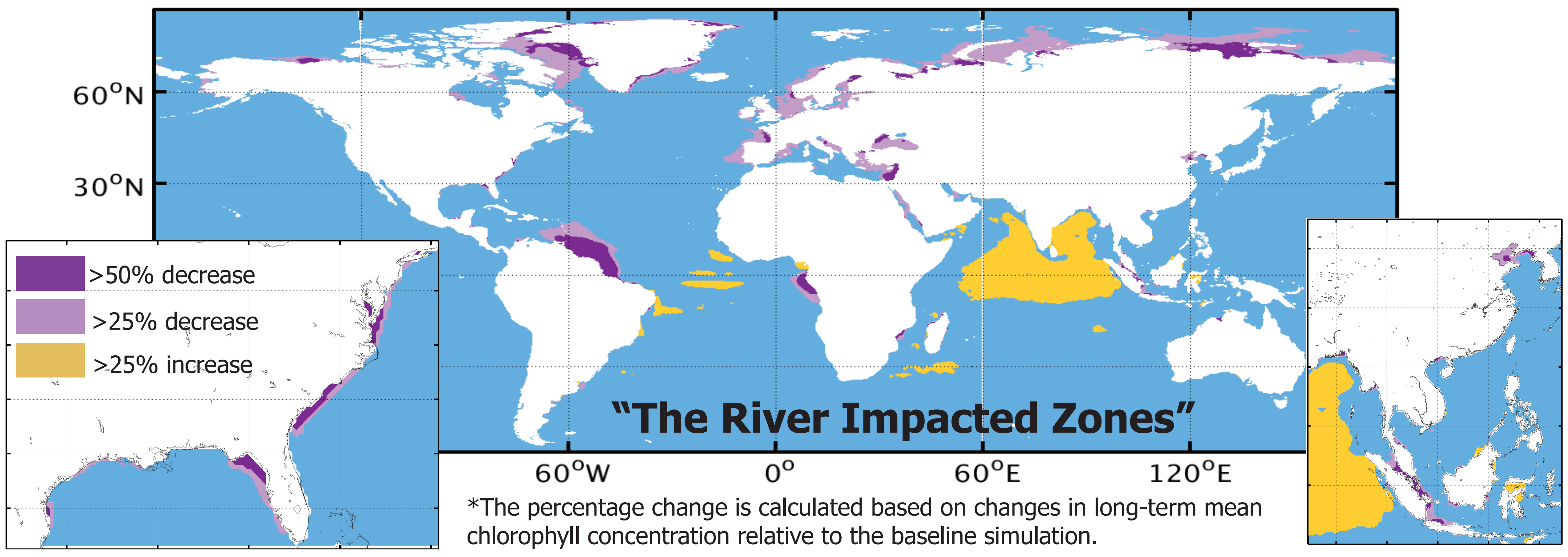
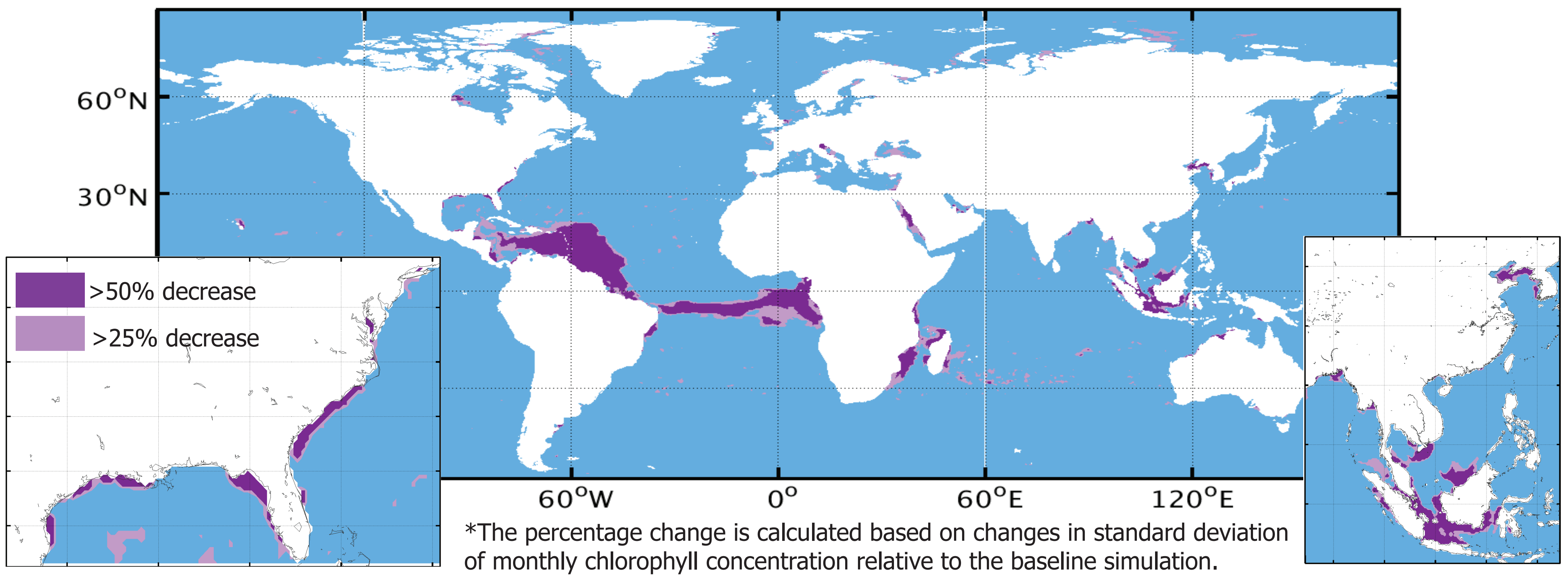
Impact of River Nutrients on Coastal Chlorophyll

1. How does oceanic chlorophyll change if all nutrients are removed from the rivers?



*The percentage change is calculated based on changes in long-term mean chlorophyll concentration relative to the baseline simulation.

2. How does it impact chlorophyll temporal variability if river nutrient concentrations are "static"?

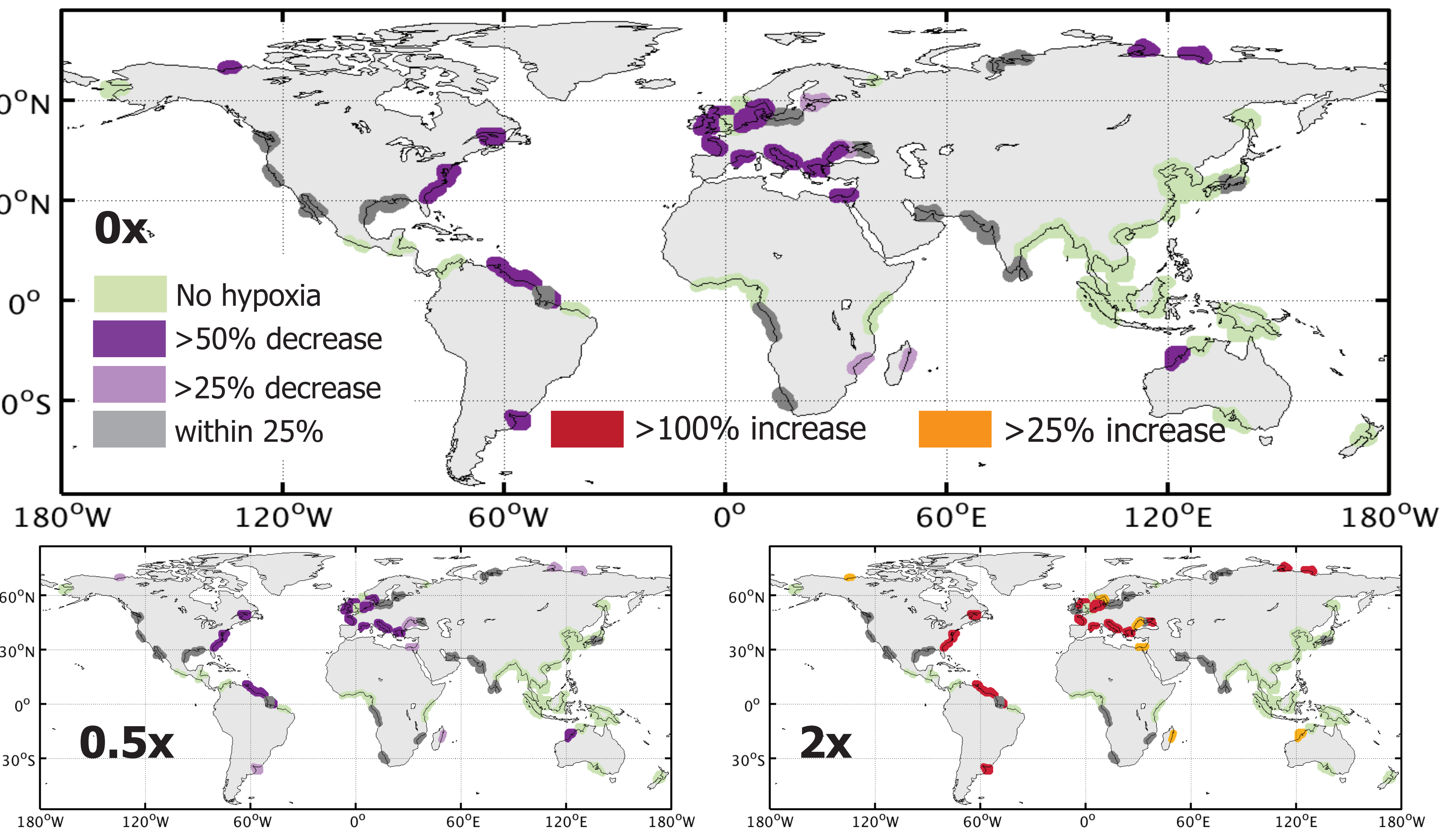


*The percentage change is calculated based on changes in standard deviation of monthly chlorophyll concentration relative to the baseline simulation.

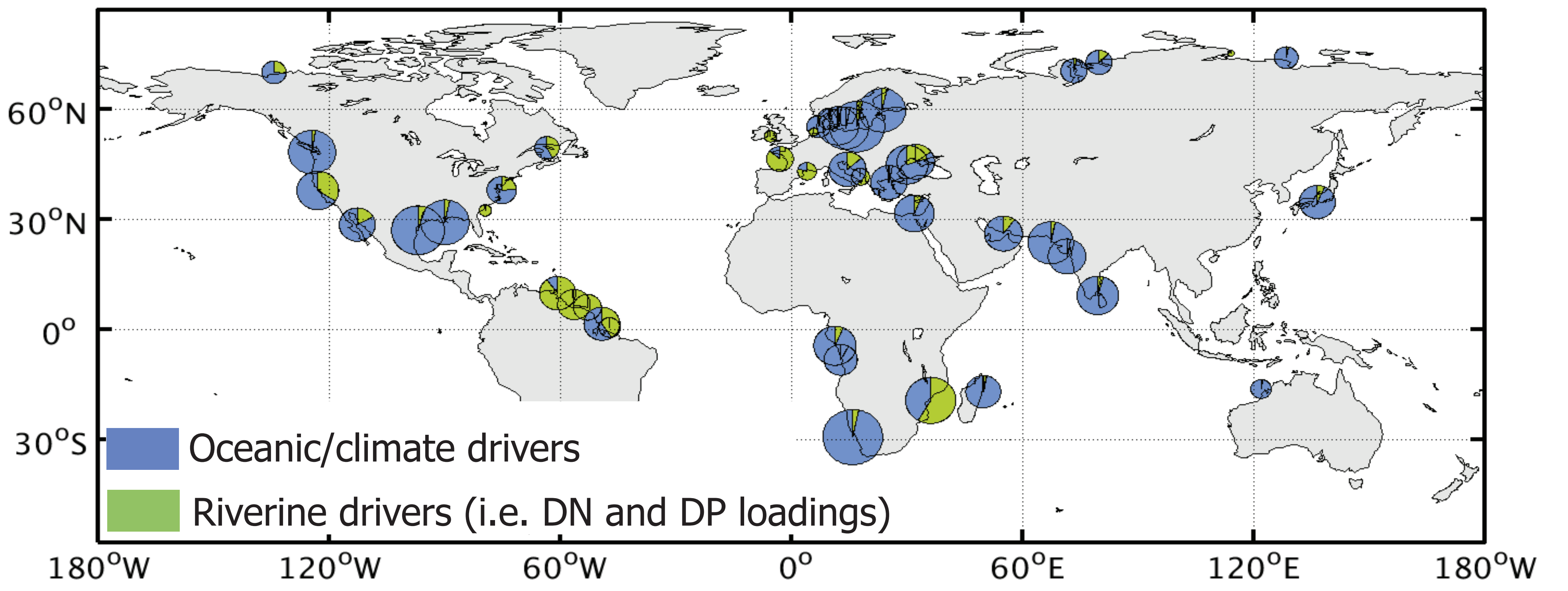
Impact of River Nutrients on Coastal Hypoxia

*Modeled oxygen was evaluated and calibrated prior to calculation of total volume of hypoxic waters (<2 mg/L) near each river discharge point, defined as a 5x5° domain centered at the discharge point. Oxygen meansurements from stations and CTD were compiled from the World Ocean Database, and median-binned on the model grid for each season during the 26-year period. A correction term was then applied to modeled oxygen within each domain.

1. How does coastal hypoxic volume change if river nutrients are removed, reduced or elevated?



2. Temporal variability in coastal hypoxic volume: oceanic/climate or riverine drivers?



*The oceanic/climate percentage is calculated as the standard deviation of monthly hypoxic volume from the "static" river nutrient experiment relative to that of the baseline simulation. The riverine percentage is then estimated as (1-oceanic/climate percentage).