Controls on primary production in a new, mid-complexity, biophysical model of Hood Canal

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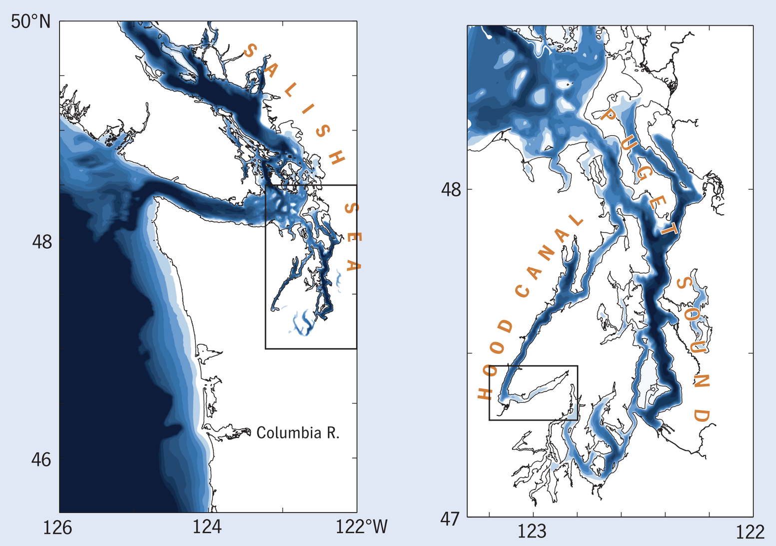
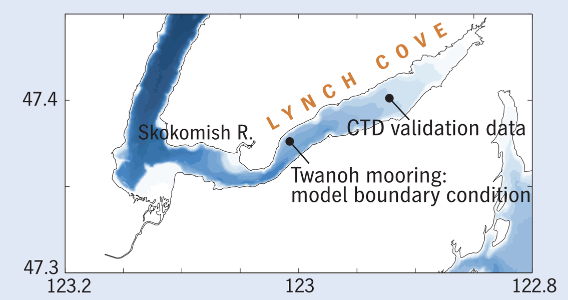
A new mid-complexity oceanographic model, designed to connect watershed and oceanic inputs with seasonal patterns of primary production and hypoxia, is described and demonstrated for Lynch Cove, at the tip of Hood Canal, Washington. Hood Canal is a deep fjord in Puget Sound in which hypoxia concerns have been growing in the last decade. The new model is highly resolved in the vertical but idealized into km-scale boxes in the horizontal. Velocities are determined by a scheme based on the tidally-averaged estuary model described by MacCready (2007).

A five-compartment planktonic ecosystem model (dissolved nutrients, phytoplankton, zooplankton, detritus, and oxygen) is run within the resulting circulation. This model design is intended to reproduce crucial vertical processes (like the dependence of primary production on stratification) while keeping the model simple and fast enough that decadal-scale simulations are possible, as is realtime scenario testing in a web browser. Comparisons with observations of light attenuation, nitrate, chlorophyll, and oxygen are shown.

Study area



Hood Canal is a deep, slowly flushed fjord in Puget Sound, Washington, where oxygen levels are historically low and have trended downward over the last decade (Bassin et al., in prep). Variability in oceanic oxygen inputs, variability in streamflow, and anthropogenic nutrient loading all contribute to the intermittent occurrence of anoxic water and fish kills.



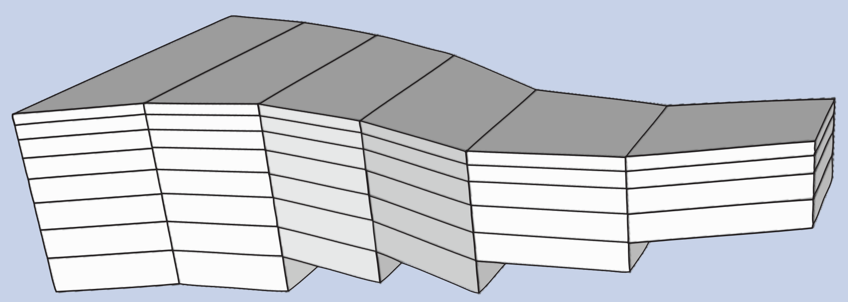
This poster presents a model of Lynch Cove, at the tip of Hood Canal, where summer oxygen concentrations are generally lowest.

The long-term goal of this work is to link climate change and other long-term change to hypoxia and other ecosystem processes in Puget Sound and the rest of the Salish Sea.

The model

The Lynch Cove model is a first application of Tonicella, a model system for implementing small, segmented* models of circulation and biogeochemistry in estuaries and fjords.

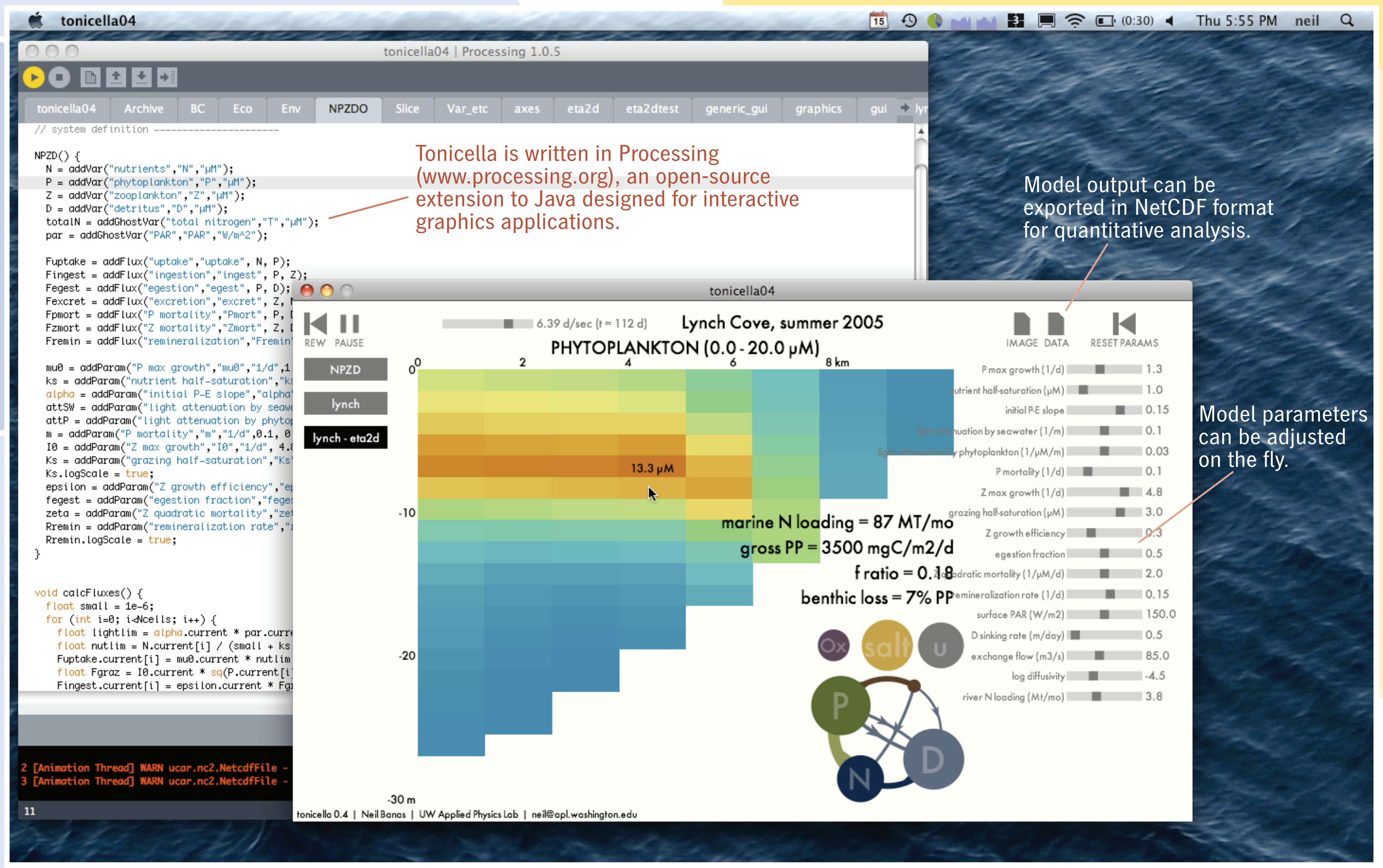
It occupies a middle ground between **box models**, like the two-layer model that Babson et al. (2006) used to investigate interannual variation in Puget Sound circulation, and **high-resolution, three-dimensional hydrodynamic models**, like the biophysical model of the Salish Sea under development by Parker MacCready, Dave Sutherland, and Neil Banas at UW (http://faculty.washington.edu/dsuth/MoSSea/index.html)



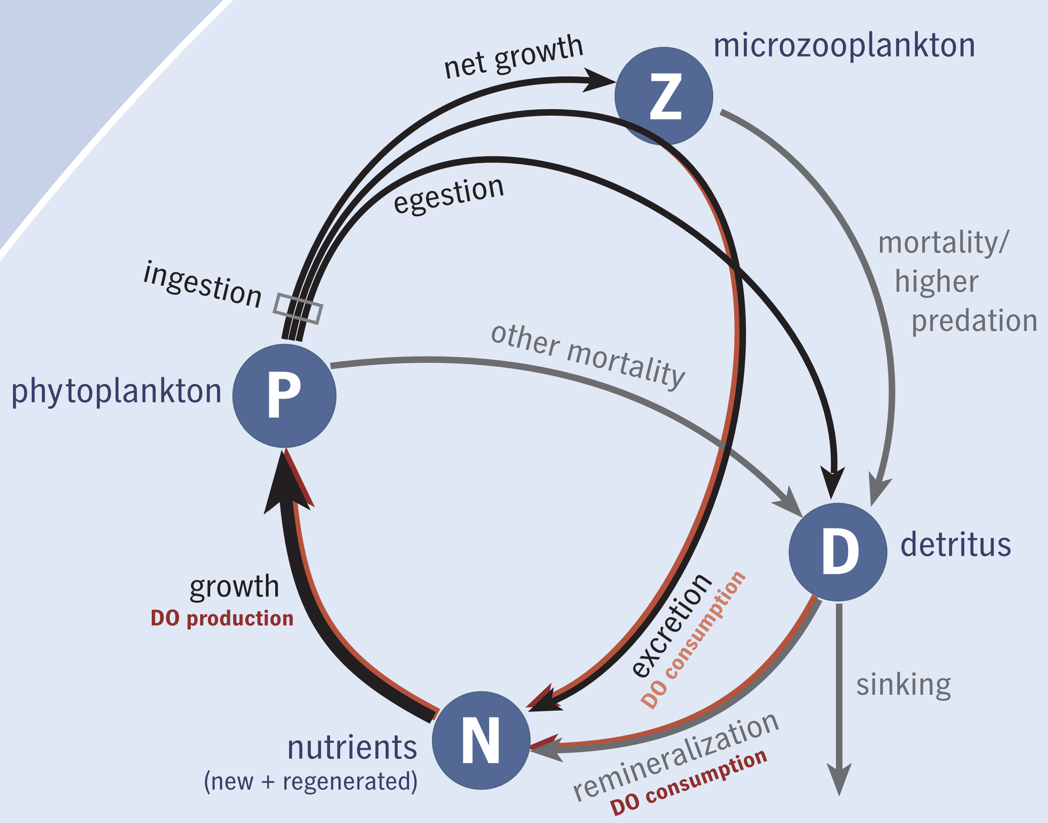
Tonicella is a finite-volume model with a fixed cartesian grid in the along-channel (x) and vertical (z) directions. Width is allowed to vary in the x direction. At each timestep, velocity and vertical diffusivity are calculated, tracers are advected and mixed, and biogeochemical transformations are calculated.

The scheme for choosing velocity and diffusivity profiles is adapted from the semi-analytical, tidally averaged estuary model described by MacCready (2007). In this scheme, the along-channel density gradient is used to determine the magnitude of the exchange flow at every x location and timestep—a quasi-steady extension of the classic Hansen and Rattray (1965) solution.

In the Lynch Cove model, the exchange flow at the mouth is specified (volume flux 85 m^3/s, equivalent to a residence time of 50 d). The MacCready (2007) solution is then used to determine the extent to which this exchange flow penetrates into Lynch Cove. (Modeling the exchange flow prognostically requires an accurate along-channel salinity field, which here would require the inclusion of rivers outside the model domain.)



Model biology

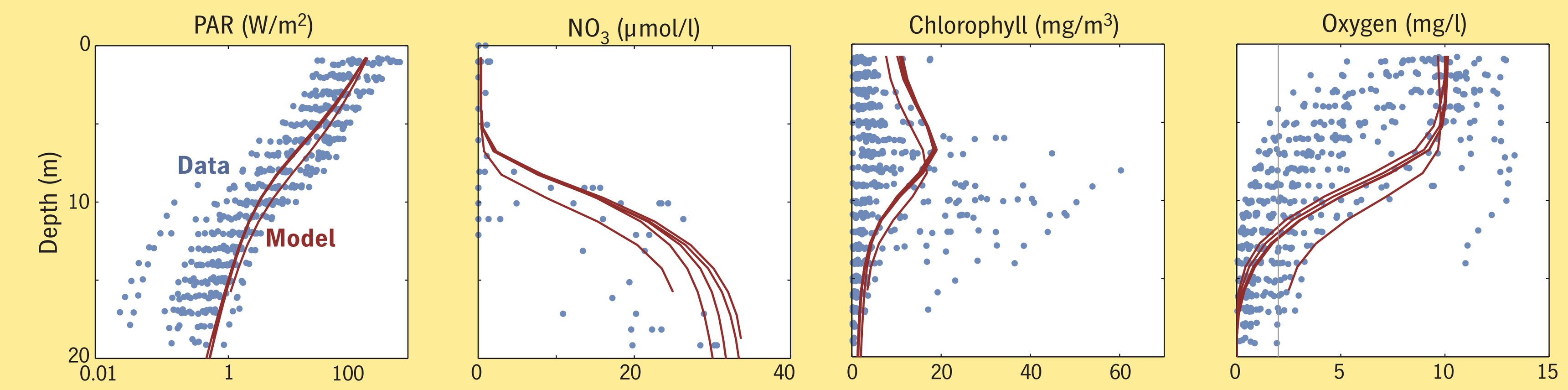


The biogeochemical model consists of a four-compartment nitrogen budget plus dissolved oxygen. It has been kept very simple to minimize the number of components that cannot be compared with observations.

Banas et al. (2009) present a detailed validation of a similar nitrogen-budget model (without oxygen) for the Washington-Oregon coast: most parameters have been taken from that study without adjustment. The sinking rate for detritus was tuned (by hand) to match the Lynch Cove observations shown under "Validation."

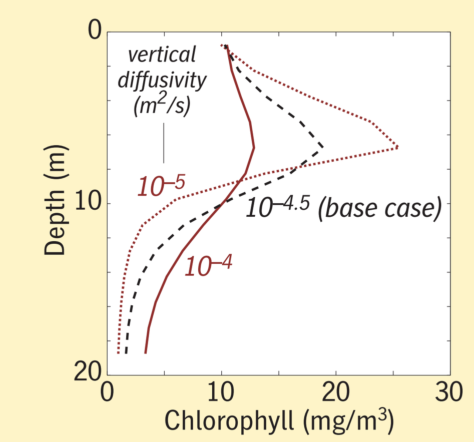
Validation

The model was run for 100 d under steady forcing taken from an Jul-Sep average, 2005-08, and the results compared with summer observations. The seaward boundary condition is from a moored profiler at Twanoh (see map, left). Validation data is from a mid-channel Lynch Cove station. Some additional integral measures of model behavior (such as mean vertically integrated primary production) are shown in the screenshot below.

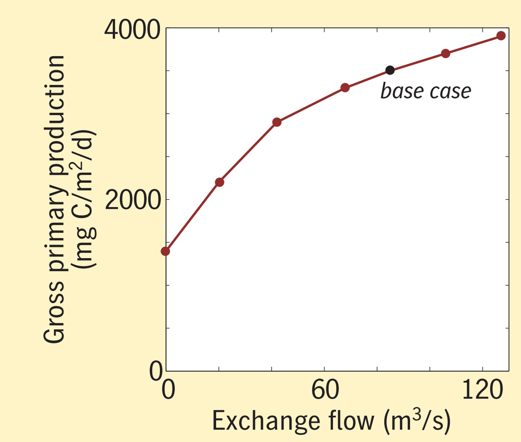


Model nutrients fall within the range of nitrate observations with the nutricline at the correct depth; model phytoplankton biomass has a similar profile to the mean of summer observations (albeit shifted higher in the water column), and the vertical integral of modeled dissolved oxygen matches observations within 20%.

First results: physical controls on primary production

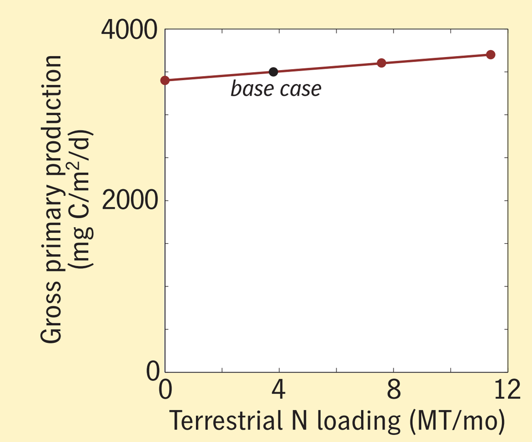


Varying vertical mixing in the model has *no* measurable effect on gross production after 100 d of run time, but does affect the vertical distribution of biomass and productivity (as well as nutrients and oxygen).



Primary production *does* depend significantly on the strength of the exchange circulation, which brings marine N into the system. Marine N is 80-95% or more of the total N load (Devol et al., this meeting).

The exchange flow is driven by freshwater input, but the two are not proportional, since the largest river in the area (the Skokomish) is outside Lynch Cove. Thus the relationship between riverflow and primary production is likely to be complex and nonlinear—and may be inseparable from the wind-driven flow that pushes the Skokomish plume either into or away from Lynch Cove.



Direct addition of terrestrial N into the surface layer (along the entire length of the domain) has a smaller effect on gross production—again because marine N dominates.

The future

We plan to extend Toncella to the rest of Hood Canal and Puget Sound, and then to the Salish Sea (the inland waters of the Pacific Northwest) as a whole.

Eventually, a running version of the model and source code wil be posted online. In the meantime, earlier versions of the interactive ecosystem model are available online at

http://faculty.washington.edu/banasn/NPZvisualizer/

References

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