Validation of a Four-Component Nutrient, Phytoplankton, Zooplankton, and Detritus (NPZD) Model for the Mesohaline Chesapeake Bay

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Abstract

Field data on water column parameters, nutrient concentrations, and plankton counts were collected on four different days from the deep channel of the mesohaline Chesapeake Bay to initialize and validate a MATLAB coupled one-dimensional (1D) Mixed-layer and four-component Nutrient, Phytoplankton, Zooplankton, and Detritus (NPZD) model designed for ocean studies. Results will be used to assess the applicability of the model in its current state and to make recommendations for improvements for future applications to investigate plankton bloom dynamics and nutrient cycling in the Chesapeake Bay estuary. The results of this study will allow for further research into the development and application of coupled physical and biogeochemical models to investigate the cycling of organic matter and nutrients in a complex estuarine system like the Chesapeake Bay.

Study Area and Methods

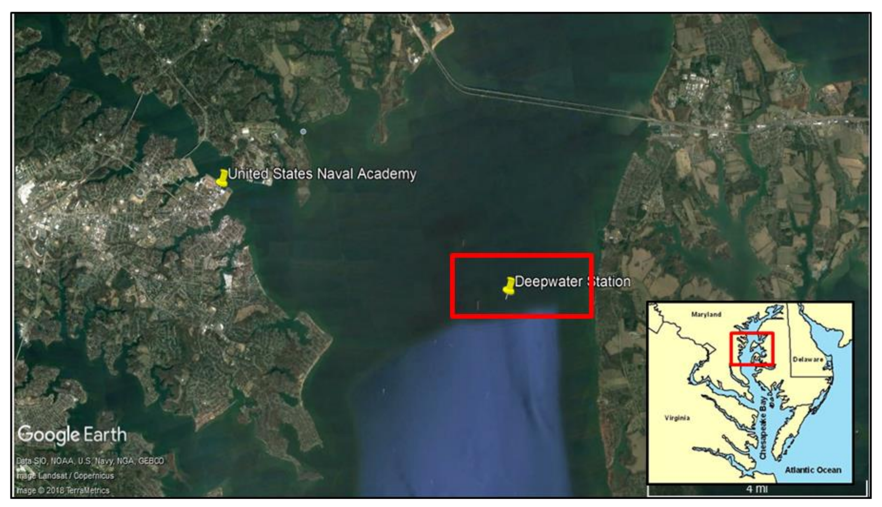
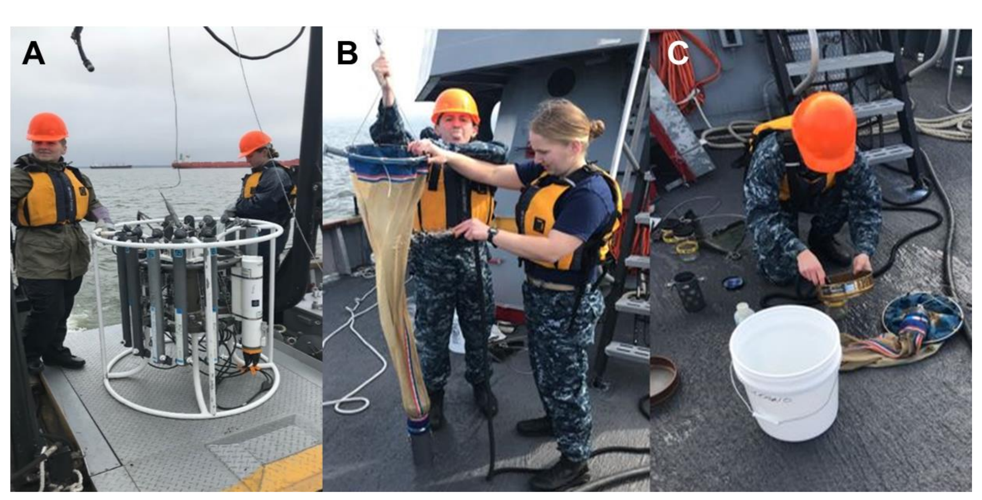


Figure 1. Map of the Chesapeake Bay showing location of the USNA Deepwater Station (38.944 °N 76.391 °W) where water column data, nutrient samples, and plankton were collected.

Water column data, nutrient samples, and plankton were collected from *YP-686*, a USNA Yard Patrol Craft specially outfitted for Oceanography, on 22 FEB, 27 FEB, 01 MAR and 08 MAR 2018 at the USNA Oceanography Department Deepwater Station (**Fig. 1**). During each sampling event a Sea-Bird Scientific Conductivity, Temperature, and Depth (CTD) Rosette with 12, 2-L Niskin Bottles was deployed to 25 m. Water quality data was collected every meter and water was collected from 1, 5, 10, 15, and 25 m depths (**Fig. 2A**). About 60 ml of water from each depth was syringe-filtered into a LDPE bottle through a 0.7 µm GFF filter, frozen, then sent to the Chesapeake Biological Laboratory at the University of Maryland Center for Environmental Science for nutrient analysis (NO_3^-, NH_4^+, and PO_4^{3-}). Two 5 minute plankton net tows (60 µm mesh) were conducted in the upper 1-5 m of the water column. Collected plankton were sorted into large (>250 µm) and small (< 250 µm, >125 µm) zooplankton and (< 125 µm, >63 µm) phytoplankton size classes then counted (**Fig. 2B** & **C**).

Adapted from *Kearney et al. (2012)*, simulations for a MATLAB Mixed-layer/NPZD water column model were run from 22 FEB – 08 MAR 2018 at the Deepwater Station. The model was run with a vertical spacing of 5 m and a time step of 1800 seconds using initial conditions from the CTD temperature and salinity profile collected on 22 FEB 2018. Forcings from surface winds, shortwave radiation, and temperature from the National Weather Service GFS model were downloaded via EDMAPS. Horizontal advection is neglected in the model, although vertical processes remain. The coupled physical-biological Carbon, Ocean Biogeochemistry and Lower Trophics (COBALT; *Stock et al., 2014*) model simulates primary and secondary production/food web dynamics and was initialized with measured initial N-normalized plankton counts and nutrient concentrations.

Figure 2. (**A**) The CTD Rosette being deployed off *YP-686*; (**B**) MIDN 1/C Timmons and Jones rinsing plankton nets, and; (**C**) MIDN 1/C Timmons sieving and sorting plankton samples.



Results

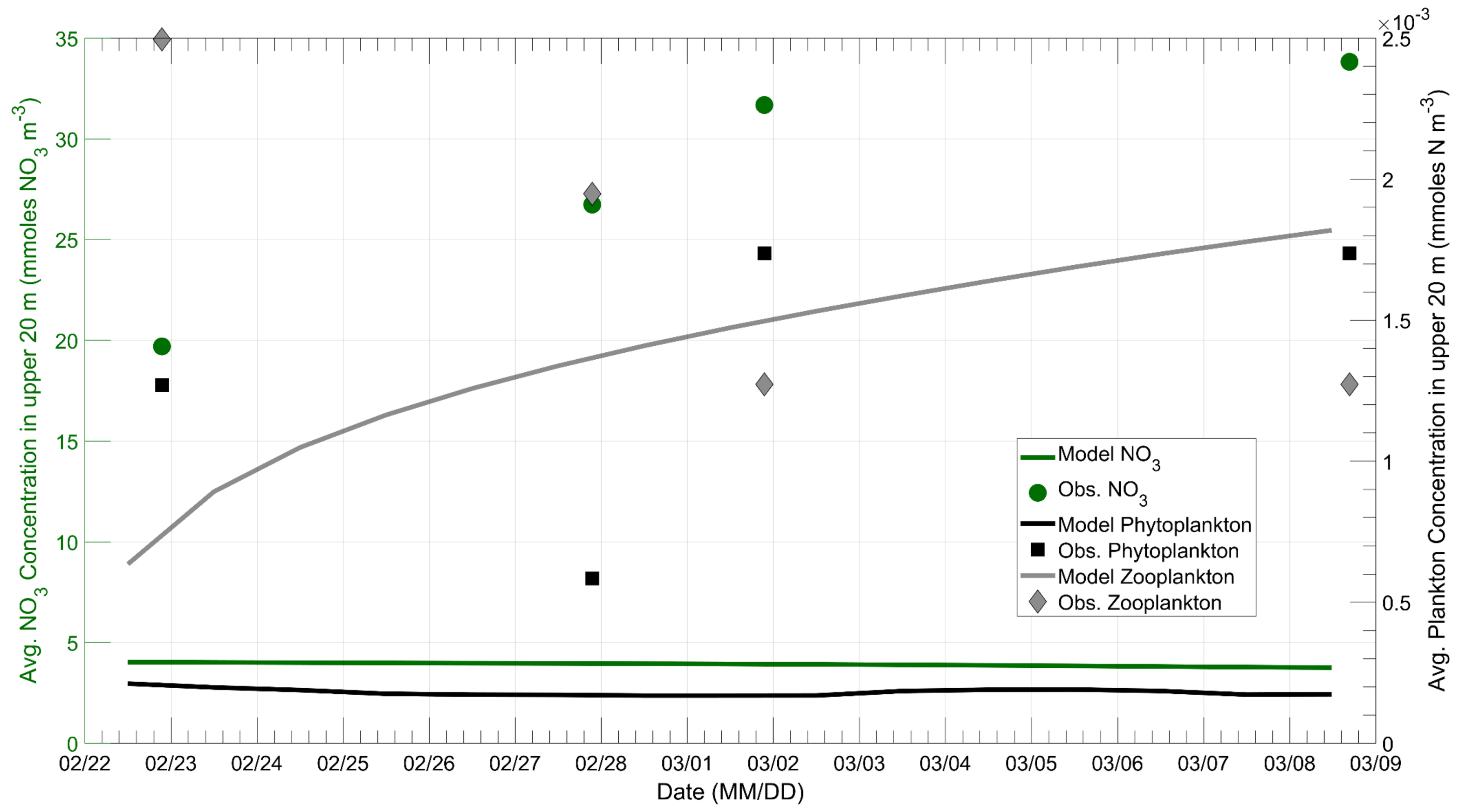


Figure 3. Simulated averaged phytoplankton, zooplankton (mmol-N equivalent/m³) and NO_3^- (mmol-NO_3^-/m³) from the Mixed-layer/NPZD model (lines) and observed phytoplankton, zooplankton, and NO_3^- (symbols) in the upper 20 m at the Deepwater Station, 22 FEB – 08 MAR 2018.

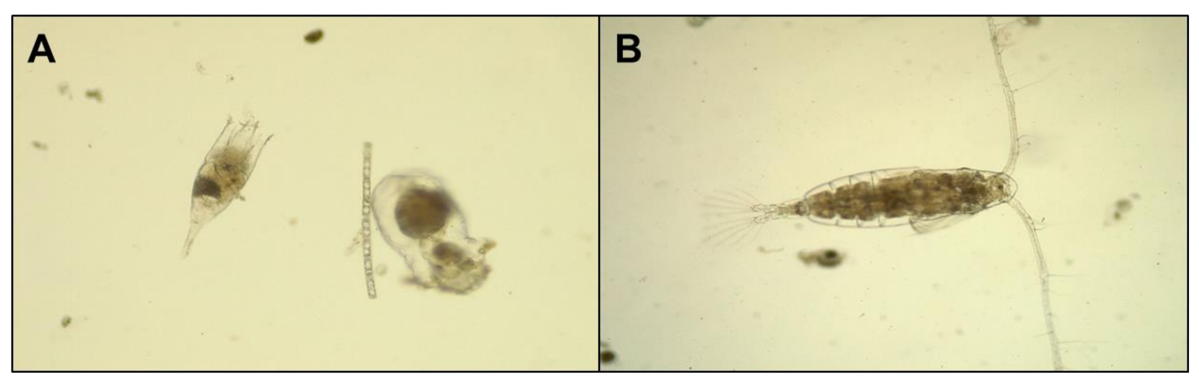


Figure 4. Microscope photos of: (**A**) two small zooplankton and a diatom, sieved at 125 µm and (**B**) a large zooplankton sieved at 250 µm.

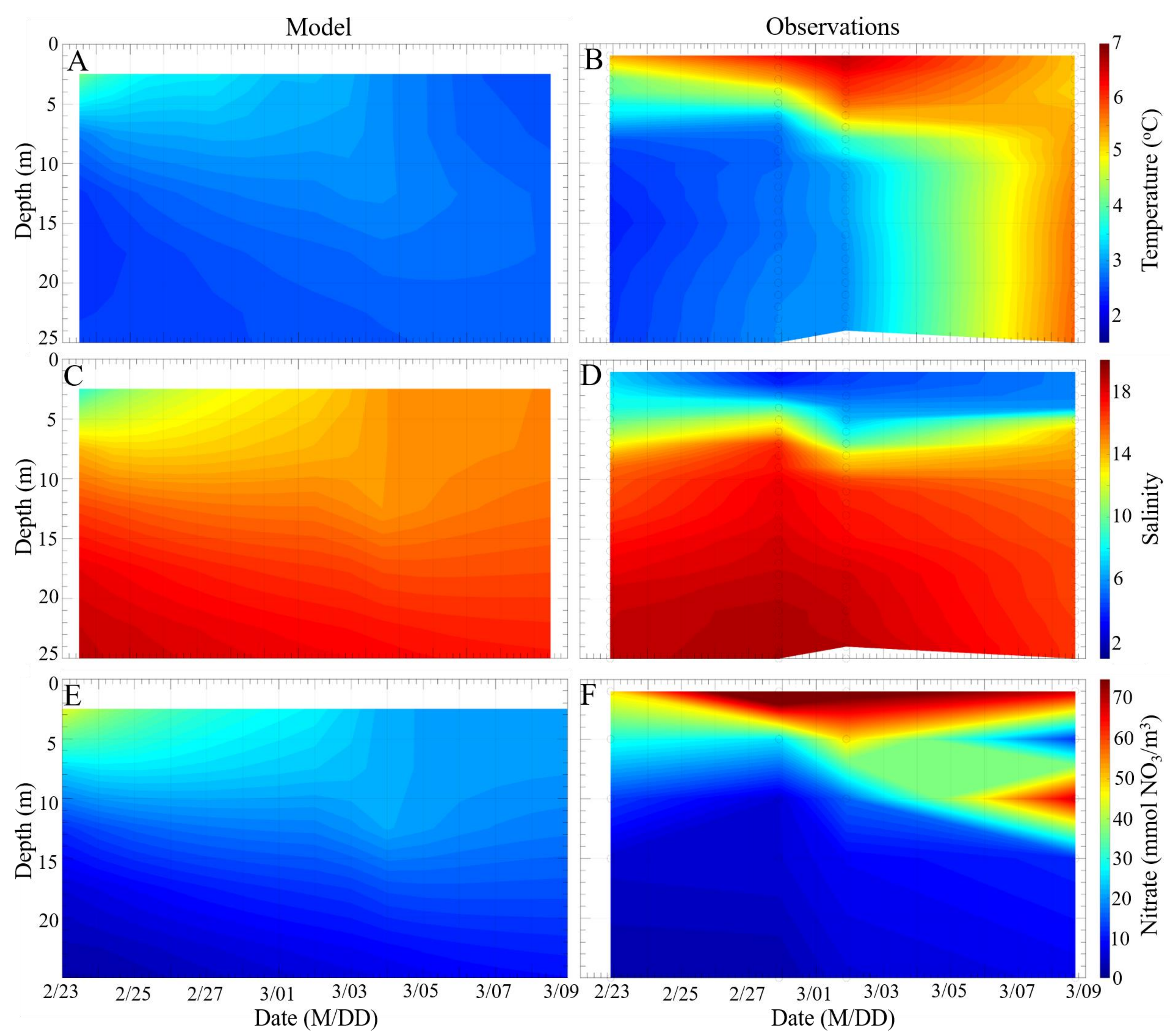


Figure 5. Mixed-Layer/NPZD model simulation of: (**A**) temperature (°C); (**C**) salinity, and; (**E**) NO_3^- concentration (mmol-N/m³) in the upper 20 m at the Deepwater Station from 22(23) FEB – 09 MAR 2018. Observed values (1 m interpolated bin) of: (**B**) temperature (°C); (**D**) salinity, and; (**F**) NO_3^- concentration (mmol-N/m³) in the upper 20 m at the Deepwater Station on (22)23 FEB, 27 FEB, 01 MAR and 08 MAR. Sampling dates and locations shown by circles on the plots.

Discussion

Figure 3 shows that the Mixed-layer/NPZD model used in this study did an adequate job of simulating zooplankton levels at the Deepwater Station in Chesapeake Bay over the 15-day period of the study but underestimated phytoplankton. The simulation also underestimated NO_3^- concentrations by an order of magnitude. Some of the differences in simulated vs. observed results are due to the model assumptions and initial inputs. Plankton counts, bacterial counts, particulate and dissolved nitrogen, and detritus were expressed as mmol-N/m³ using assumptions from research by others. For example, the model is very sensitive to distinctions of nitrogen concentrations in small and large plankton (**Fig. 4**). The light values used also affected productivity rates and thus the cycling of nitrogen.

More importantly, the Mixed-layer model used in this study is for open ocean and does not account for horizontal advection or two-layer estuarine circulation. A comparison of simulated to observed results shows that the Mixed-layer model fails to simulate thermal stratification and structure in the estuary and thereby failed to represent actual observed water column temperatures following a major mixing event from a Nor-Easter that passed through the region (**Fig. 5A** & **B**). More importantly measured salinity values clearly show the influence of freshwater inputs into the Chesapeake Bay during the course of the study not captured by the model (**Fig. 5C** & **D**). Discharge from the Susquehanna River through the Conowingo Dam, the largest freshwater source to the Bay, was exceptionally high during the course of the study. This likely led to horizontal advection and density stratification at the Deepwater Station, increased nutrient supply from land, and decreased light penetration due to higher water column turbidity (**Fig. 6**). This could explain differences between simulated and observed phytoplankton counts and NO_3^- concentrations (**Fig. 5E** & **F**).

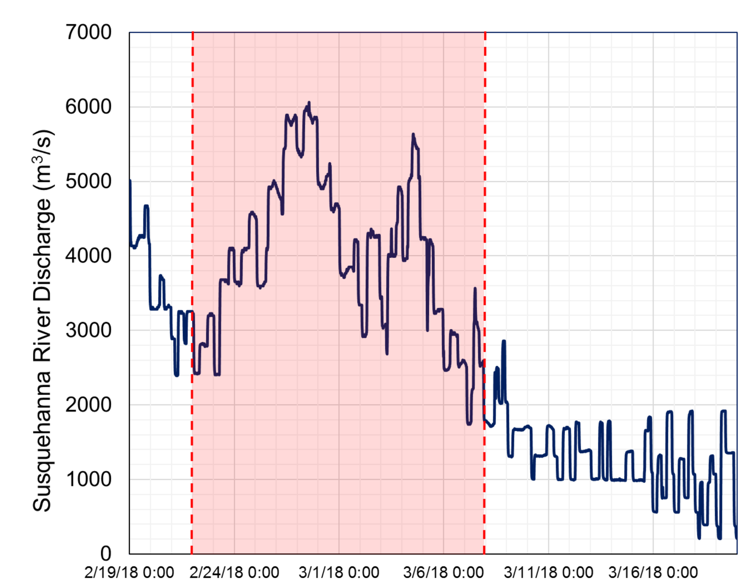
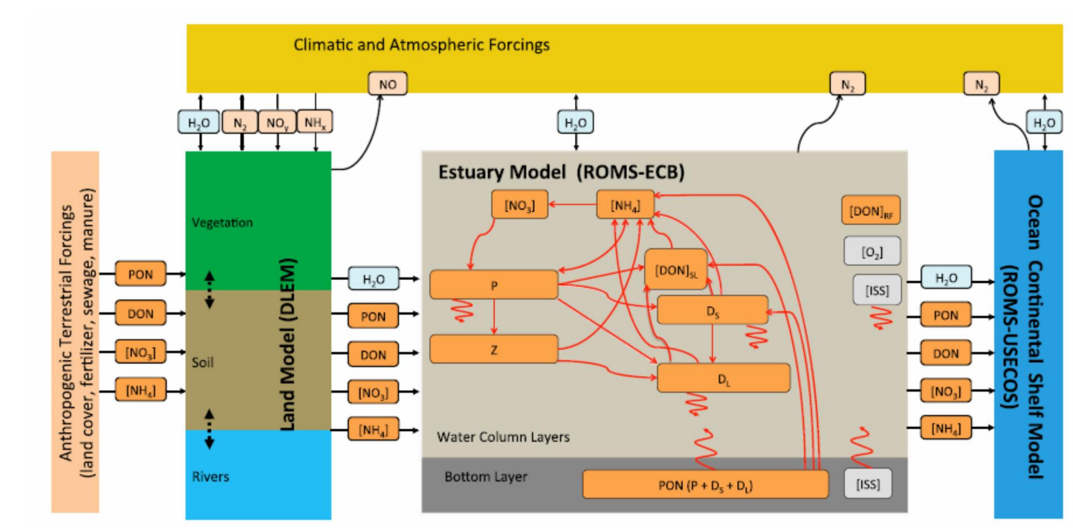


Figure 6. Susquehanna River Discharge at Conowingo Dam from 19 FEB - 19 MAR 2018 (USGS Station 01578310: Red shaded area indicates time period of study. https://waterdata.usgs.gov/md/nwis/uv?01578310).

Figure 7. Example of a land-estuarine ocean bio-geochemical modeling system (from Fig. 2*; Feng et al., 2015*).



Conclusions

- ***The Mixed-layer/NPZD model evaluated in this study does not adequately simulate the physical forcing factors and biogeochemical cycles in a dynamic estuarine system like Chesapeake Bay.***
- ***Further research should be conducted to develop, apply, and evaluate more complex, estuarine-specific, coupled physical and biogeochemical models (Fig. 7) in the Chesapeake Bay and other estuarine systems.***

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