Ecosystem modeling

VII. Introduction to Regional Ocean Modeling System and coupled ecosystem models

Jang-Geun Choi

Center for Ocean Engineering
University of New Hampshire

July, 2025

Regional Ocean Modeling System (ROMS)

ROMS is free-surface, sigma-coordinate, Boussinesq, hydrostatic, primitive equation ocean model.

Useful websites

- myROMS: https://www.myroms.org
  - Github repository: https://github.com/myroms/roms
  - User community: https://www.myroms.org/forum
  - Blog: https://www.myroms.org/wiki
- Path notes
  - https://github.com/myroms/roms/pulls
  - https://www.myroms.org/projects/src/report/4[1]
- Preprocessing toolbox
  - ROMS matlab: https://github.com/myroms/roms_matlab
  - CROCO tools: https://www.croco-ocean.org
  - GridBuilder: https://austides.com/downloads

[1] Starting Jan 1, 2025, ROMS is no more distributed via Subversion (SVN) and exclusively provided by Github.

ROMS installation

Prerequisite programs[2]: Make, GCC (C and Fortran), NetCDF (including NetCDF-Fortran library)[3], Openmpi.

Installation guide

- Window[4] and Ubuntu:
  https://www.youtube.com/watch?v=tVYuHdVmoJ0
- MacOS:
  https://www.youtube.com/watch?v=DCg0u015qek&t=32s

Default test problem: Upwelling

- Problem configuration:
  https://www.myroms.org/wiki/UPWELLING_CASE
- Output visualization:
  https://www.youtube.com/watch?v=KP8U5tQ8EH0

[2] Other Fortran compliers and Message Passing Interfaces (MPI) are allowed.

[3] There are also prerequisites for NetCDF version 4: Zlib and HDF5.

[4] Use Windows Subsystem for Linux (WSL).

Ecosystem models in ROMS

Nutrient-Phytoplankton-Zooplankton-Detritus (NPZD) model

- Ecosystem model describing simple nitrogen cycles.
- Two different original NPZD models: Powell et al. (2006) and Franks, Wroblewski, and Flierl (1986)[5].
- Many variations:
  - Fiechter et al. (2009):NPZD with iron limitation, available in ROMS.
  - Choi, Lippmann, and Harvey (2023): NPZD with additional P group having different prey avoidance.
  - Choi and Lippmann (2024): NPZD with phosphate cycle, denitrification, and nitrogen fixers.

[5] Quite legacy. Cannot consider changes in the light intensity.

Ecosystem models in ROMS

North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO) model

- Complex model describing both nitrogen and silicon cycles (Kishi et al., 2007).
- Three nutrients (silicate, nitrate, and ammonium), two phytoplankton (small and large phytoplankton[6]), three zooplankton (small zooplankton, large zooplankton, zooplankton predator), and three detritus (opal, dissolved orgnaic nitrogen, and particulate organic nitrogen).
- Designed for the North Pacific but applicable for many other ocean (e.g., Shropshire et al., 2020)

[6] Each represents silicate-independent non-diatom and silicate-dependent diatom, respectively.

Ecosystem models in ROMS

Fennel's ecosystem model

- Originally, designed for complex nitrogen cycle model including two nutrient (nitrate and ammonium), one phytoplankton, one zooplankton, and two (small and large) detritus.
- Aggregation, nonlinear dynamics between phytoplankton biomass and chlorophyll[7], and sediment remineralization-denitrification coupled processes[8] are considered (Fennel et al., 2006).
- Can be extended to resolve[9]:
  - Carbonate system (Fennel et al., 2008)
  - Phosphorus cycle (Laurent et al., 2012)
  - Oxygen dynamics (Yu et al., 2015).

[7] This explicitly simulates chlorophyll concentration, provided as the model output.

[8] Simplified without explicit resolving sediment redox dynamics.

[9] Both oxygen and carbon dynamics include air-sea gas exchanges (Wanninkhof, 2014)

Ecosystem models in ROMS

There are also "diagnostic models" where several variables are replaced with observations:

Hypoxia Simple Respiration Model

- Simulates oxygen with considering air-sea gas exchanges and prescribed respiration rate term (Scully, 2010; Scully, 2013; Irby et al., 2016).

Red-tide model

- Simulates only a harmful algae group[10] with considering germination from cysts and vertical swimming ability (Stock et al., 2005; He et al., 2008; Li et al., 2020).
- Nutrient in water and cysts in sediments are prescribed by observations.

[10] Representing *Alexandrium fundyense*.

References I

- Choi, Jang-Geun and Thomas C Lippmann (2024). "Biogeochemical dynamics underlying equilibrium between nitrogen fixation and denitrification and its impact on a coastal marine ecosystem model". In: *Ecological Modelling* 494, p. 110767.
- Choi, Jang-Geun, Thomas C Lippmann, and Elizabeth L Harvey (2023). "Analytical population dynamics underlying harmful algal blooms triggered by prey avoidance". In: *Ecological Modelling* 481, p. 110366.
- Fennel, Katja et al. (2006). "Nitrogen cycling in the Middle Atlantic Bight: Results from a three-dimensional model and implications for the North Atlantic nitrogen budget". In: *Global Biogeochemical Cycles* 20.3.
- Fennel, Katja et al. (2008). "Denitrification effects on air-sea CO2 flux in the coastal ocean: Simulations for the northwest North Atlantic". In: *Geophysical Research Letters* 35.24.

References II

- Fiechter, Jerome et al. (2009). "Modeling iron limitation of primary production in the coastal Gulf of Alaska". In: *Deep Sea Research Part II: Topical Studies in Oceanography* 56.24, pp. 2503–2519.
- Franks, PJS, JS Wroblewski, and GR Flierl (1986). "Behavior of a simple plankton model with food-level acclimation by herbivores". In: *Marine Biology* 91.1, pp. 121–129.
- He, Ruoying et al. (2008). "Historic 2005 toxic bloom of Alexandrium fundyense in the western Gulf of Maine: 2. Coupled biophysical numerical modeling". In: *Journal of Geophysical Research: Oceans* 113.C7.
- Irby, Isaac D et al. (2016). "Challenges associated with modeling low-oxygen waters in Chesapeake Bay: a multiple model comparison". In: *Biogeosciences* 13.7, pp. 2011–2028.

References III

- Kishi, Michio J et al. (2007). "NEMURO—a lower trophic level model for the North Pacific marine ecosystem". In: *Ecological Modelling* 202.1-2, pp. 12–25.
- Laurent, A et al. (2012). "Simulating the effects of phosphorus limitation in the Mississippi and Atchafalaya River plumes". In: *Biogeosciences* 9.11, pp. 4707–4723.
- Li, Yizhen et al. (2020). "Dynamics of an intense Alexandrium catenella red tide in the Gulf of Maine: satellite observations and numerical modeling". In: *Harmful Algae* 99, p. 101927.
- Powell, T. M. et al. (2006). "Results from a three-dimensional, nested biological-physical model of the California Current System and comparisons with statistics from satellite imagery". In: *Journal of Geophysical Research: Oceans* 111.C7.
- Scully, Malcolm E (2010). "Wind modulation of dissolved oxygen in Chesapeake Bay". In: *Estuaries and coasts* 33.5, pp. 1164–1175.

References IV

- Scully, Malcolm E (2013). "Physical controls on hypoxia in Chesapeake Bay: A numerical modeling study". In: *Journal of Geophysical Research: Oceans* 118.3, pp. 1239–1256.
- Shropshire, Taylor A et al. (2020). "Quantifying spatiotemporal variability in zooplankton dynamics in the Gulf of Mexico with a physical–biogeochemical model". In: *Biogeosciences* 17.13, pp. 3385–3407.
- Stock, Charles A et al. (2005). "Evaluating hypotheses for the initiation and development of Alexandrium fundyense blooms in the western Gulf of Maine using a coupled physical–biological model". In: *Deep Sea Research Part II: Topical Studies in Oceanography* 52.19-21, pp. 2715–2744.
- Wanninkhof, Rik (2014). "Relationship between wind speed and gas exchange over the ocean revisited". In: *Limnology and Oceanography: Methods* 12.6, pp. 351–362.

References V

Yu, Liuqian et al. (2015). "Numerical analysis of the primary processes controlling oxygen dynamics on the Louisiana shelf". In: *Biogeosciences* 12.7, pp. 2063–2076.