

¹ ROMS-Tools: A Python Package for Preparing and Analyzing ROMS Simulations

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⁹ Summary

¹⁰ The ocean shapes Earth's climate and sustains marine ecosystems by circulating and storing
¹¹ vast amounts of heat, oxygen, carbon, and nutrients, while exchanging heat and gases with
¹² the atmosphere. To understand these complex dynamics, scientists rely on ocean models,
¹³ powerful computer simulations of physical circulation and biogeochemical (BGC) processes.
¹⁴ These models represent the ocean on a grid of cells, where finer grid spacing (more, smaller
¹⁵ cells) provides higher fidelity and greater detail at the cost of more computing power. While
¹⁶ global ocean models simulate the entire ocean, **regional ocean models** focus computational
¹⁷ resources on a specific area to achieve much finer grid spacing than is computationally feasible
¹⁸ over the global domain. This finer grid spacing enables regional ocean models to explicitly
¹⁹ resolve fine-scale phenomena, like mesoscale (10-100 km) and submesoscale (0.1-10 km)
²⁰ features, tidal dynamics, coastal currents, upwelling, and detailed BGC processes. Capturing
²¹ these dynamics and processes at high fidelity is essential for applications in environmental
²² management, fisheries, for assessing regional impacts of climate change, and for evaluating
²³ ocean-based carbon dioxide removal (CDR) strategies.

²⁴ A widely used regional ocean model is the **Regional Ocean Modeling System (ROMS)**
²⁵ ([Shchepetkin & McWilliams, 2005](#)). To connect physical circulation with ecosystem dynamics
²⁶ and the ocean carbon cycle, ROMS has been coupled to a BGC model called the Marine
²⁷ Biogeochemistry Library (MARBL) ([Long et al., 2021](#); [Molemaker & contributors, 2025a](#)).
²⁸ This coupled framework allows researchers to explore a variety of scientific and practical
²⁹ questions. For example, it can be used to investigate the potential of ocean-based carbon
³⁰ removal strategies, such as adding alkaline materials to the ocean to sequester atmospheric
³¹ carbon dioxide. It can also be used to study how physical processes drive ecosystem dynamics,
³² such as how nutrient-rich waters from upwelling fuel the phytoplankton blooms that form the
³³ base of the marine food web ([Gruber et al., 2006](#)).

³⁴ Input Data and Preprocessing

³⁵ Whether for research or industrial-focused applications, configuring a regional ocean model
³⁶ like ROMS-MARBL remains a major technical challenge. Generating the required input files is
³⁷ time-consuming, error-prone, and difficult to reproduce, creating a bottleneck for both new
³⁸ and experienced model users. The Python package ROMS-Tools addresses this challenge by
³⁹ providing a set of efficient, user-friendly, and extensible tools to design new regional grids for
⁴⁰ ROMS-MARBL and to process and stage all required model input files. The package's user
⁴¹ interface and underlying data model are based on xarray ([Hoyer & Hamman, 2017](#)), allowing
⁴² seamless handling of multidimensional datasets with rich metadata and optional parallelization

- 43 via a dask ([Dask Development Team, 2016](#)) backend.
- 44 ROMS-Tools can automatically process commonly used datasets or incorporate custom user
45 data and routines. Currently, it can generate the following inputs:
- 46 1. **Model Grid:** Customizable, curvilinear, and orthogonal grid designed to maintain a nearly
47 uniform horizontal resolution across the domain. The grid is rotatable to align with
48 coastlines and features a terrain-following vertical coordinate.
 - 49 2. **Bathymetry:** Derived from **SRTM15** ([Tozer et al., 2019](#)).
 - 50 3. **Land Mask:** Inferred from coastlines provided by **Natural Earth** or the Global Self-
51 consistent, Hierarchical, High-resolution Geography (**GSHHG**) Database ([Wessel &
52 Smith, 1996](#)).
 - 53 4. **Physical Ocean Conditions:** Initial and open boundary conditions for sea surface height,
54 temperature, salinity, and velocities derived from the 1/12° Global Ocean Physics
55 Reanalysis (**GLORYS**) ([Lellouche et al., 2021](#)).
 - 56 5. **BGC Ocean Conditions:** Initial and open boundary conditions for dissolved inorganic
57 carbon, alkalinity, and other biogeochemical tracers from Community Earth System
58 Model (**CESM**) output ([Yeager et al., 2022](#)) or hybrid observational-model sources
59 ([Garcia et al., 2019](#); [Huang et al., 2022](#); [Lauvset et al., 2016](#); [Yang et al., 2020](#); [Yeager
60 et al., 2022](#)).
 - 61 6. **Meteorological forcing:** Wind, radiation, precipitation, and air temperature/humidity
62 processed from the global 1/4° ECMWF Reanalysis v5 (**ERA5**) ([Hersbach et al., 2020](#))
63 with optional corrections for radiation bias and coastal wind.
 - 64 7. **BGC surface forcing:** Partial pressure of carbon dioxide, as well as iron, dust, and
65 nitrogen deposition from **CESM** output ([Yeager et al., 2022](#)) or hybrid observational-
66 model sources ([Hamilton et al., 2022](#); [Kok et al., 2021](#); [Landschützer et al., 2016](#); [Yeager
67 et al., 2022](#)).
 - 68 8. **Tidal Forcing:** Tidal potential, elevation, and velocities derived from **TPXO** ([Egbert &
69 Erofeeva, 2002](#)) including self-attraction and loading (SAL) corrections.
 - 70 9. **River Forcing:** Freshwater runoff derived from **Dai & Trenberth** ([Dai & Trenberth, 2002](#))
71 or user-provided custom files.
 - 72 10. **CDR Forcing:** User-defined interventions that inject BGC tracers at point sources or
73 as larger-scale Gaussian perturbations, designed to simulate CDR interventions. The
74 CDR forcing provides an external forcing term prescribed as volume and tracer fluxes
75 (e.g., alkalinity for ocean alkalinity enhancement, iron for iron fertilization, or other BGC
76 constituents). Users can specify the magnitude, spatial footprint, and time dependence
77 of the forcing, enabling flexible representation of CDR interventions.
- 78 Some source datasets are accessed automatically by the package, including Natural Earth, Dai
79 & Trenberth runoff, and ERA5 meteorology, while users must manually download SRTM15,
80 GSHHG, GLORYS, the BGC datasets, and TPXO tidal files. While the source datasets listed
81 above are the ones currently supported, the package's modular design makes it straightforward
82 to add new data sources or custom routines in the future. To generate the model inputs listed
83 above, ROMS-Tools automates several intermediate processing steps, including:
- 84 ▪ **Bathymetry processing:** The bathymetry is smoothed in two stages, first across the
85 entire model domain and then locally in areas with steep slopes, to ensure local steepness
86 ratios do not exceed a prescribed threshold in order to reduce pressure-gradient errors.
87 A minimum depth is enforced to prevent water levels from becoming negative during
88 large tidal excursions.
 - 89 ▪ **Mask definition:** The land-sea mask is generated by comparing the ROMS grid's
90 horizontal coordinates with a coastline dataset using the `regionmask` package ([Hauser
91 et al., 2024](#)). Enclosed basins are subsequently filled with land.
 - 92 ▪ **Land value handling:** Land values are filled via an algebraic multigrid method using `pyamg`
93 ([Bell et al., 2023](#)) prior to horizontal regridding. This extends ocean values into land
94 areas to resolve discrepancies between source data and ROMS land masks, preventing
95 land-originating values from appearing in ocean cells.

- 96 ▪ **Regridding:** Ocean and atmospheric fields are horizontally and vertically regridded from
 - 97 standard latitude-longitude-depth grids to the model's curvilinear grid with a terrain-
 - 98 following vertical coordinate using `xarray` (Hoyer & Hamman, 2017). Optional sea
 - 99 surface height corrections can be applied, and velocities are rotated to align with the
 - 100 curvilinear ROMS grid.
 - 101 ▪ **Longitude conventions:** ROMS-Tools handles differences in longitude conventions, con-
 - 102 verting between $[-180^\circ, 180^\circ]$ and $[0^\circ, 360^\circ]$ as needed.
 - 103 ▪ **River locations:** Rivers that fall within the model domain are automatically identified
 - 104 and relocated to the nearest coastal grid cell. Rivers that need to be shifted manually or
 - 105 span multiple cells can be configured by the user.
 - 106 ▪ **Data streaming:** ERA5 atmospheric data can be accessed directly from the cloud,
 - 107 removing the need for users to pre-download large datasets locally. Similar streaming
 - 108 capabilities may be implemented for other datasets in the future.
- 109 Users can quickly design and visualize regional grids and inspect all input fields with built-in
- 110 plotting utilities. An example of surface initial conditions generated for a California Current
- 111 System simulation at 5 km horizontal grid spacing is shown in [Figure 1](#).

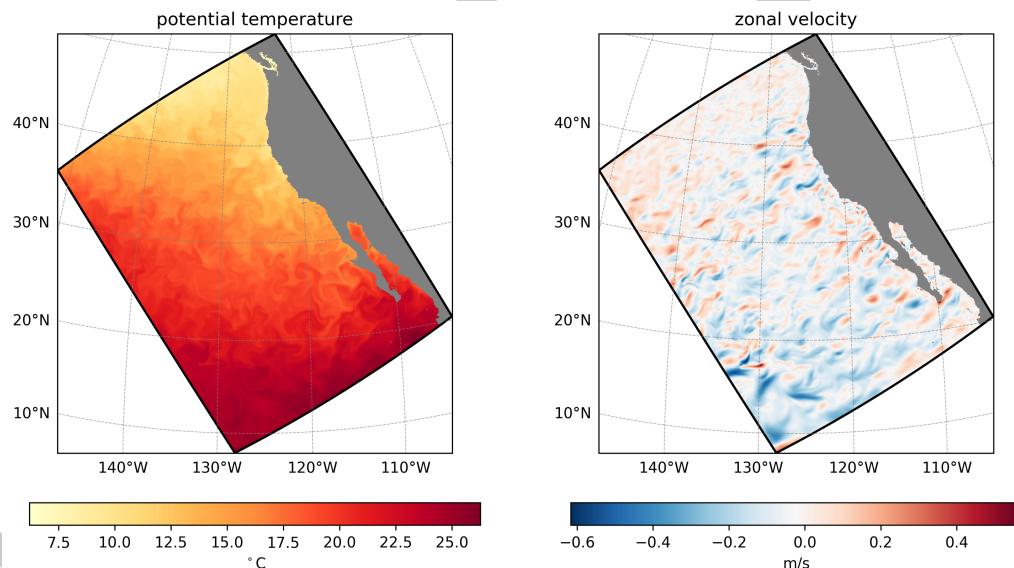


Figure 1: Surface initial conditions for the California Current System created with ROMS-Tools from GLORYS. Left: potential temperature. Right: zonal velocity. Shown for January 1, 2000.

112 ROMS-Tools also includes features that facilitate simulation management. It supports parti-

113 tioning input files to enable parallelized ROMS simulations across multiple nodes, and writes

114 NetCDF outputs with metadata fully compatible with ROMS-MARBL. Currently, all capabilities

115 in ROMS-Tools are fully compatible with UCLA-ROMS (Molemaker & contributors, 2025a,

116 2025b), with the potential to add other ROMS versions, such as Rutgers ROMS (Arango &

117 contributors, 2024), in the future.

118 Postprocessing and Analysis

119 ROMS-Tools also includes analysis tools for postprocessing ROMS-MARBL output. It first

120 provides a joining tool (the counterpart to the input file partitioning utility described earlier)

121 that merges ROMS output files produced as tiles from multi-node simulations. Beyond file

122 management, there are ROMS-Tools analysis utilities for general-purpose tasks, such as loading

123 model output directly into an `xarray` dataset with additional useful metadata, enabling seamless

124 use of the Pangeo scientific Python ecosystem for further analysis and visualization. The

analysis layer also supports regridding from the native curvilinear ROMS grid with terrain-following coordinate to a standard latitude-longitude-depth grid using xesmf (Zhuang et al., 2023), and includes built-in plotting on both the native and latitud-longitude-depth grids. Beyond these general-purpose features, the ROMS-Tools analysis layer offers a suite of targeted tools for evaluating CDR interventions. These include utilities for generating standard plots, such as CDR efficiency curves, and performing specialized tasks essential for CDR monitoring, reporting, and verification.

Workflow, Reproducibility, and Performance

ROMS-Tools enables reproducible and easy-to-interpret workflows for faster and more robust ROMS-MARBL setups. The package is easily installable via Conda or PyPI and can be run interactively from Jupyter Notebooks. To ensure reproducibility and facilitate collaboration, each workflow is defined in a simple YAML configuration file. These compact, text-based YAML files can be version-controlled and easily shared, eliminating the need to transfer large NetCDF files between researchers, as source data like GLORYS and ERA5 are accessible in the cloud. For performance, the package is integrated with dask (Dask Development Team, 2016) to enable efficient, out-of-core computations on large datasets. Finally, to ensure reliability, the software is rigorously tested with continuous integration (CI) and supported by comprehensive documentation with examples and tutorials.

Statement of Need

Setting up a regional ocean model is a major undertaking. The model must be initialized and forced over time with relevant oceanic and atmospheric data, which often come from multiple external data providers in a variety of formats and can reach several petabytes for global, multi-purpose datasets. These data must be subsetted, processed, and mapped onto the specific model geometry of the target domain, resulting in input datasets that can still be on the order of 10-100 terabytes for larger regional models. Traditionally, such work has depended on a patchwork of custom scripts and lab-specific workflows, which can be time-consuming, error-prone, and difficult to reproduce. These challenges slow down science, create a steep barrier to entry for new researchers, and limit collaboration across groups.

Within the ROMS community, the preprocessing landscape has been shaped by tools like pyroms (Hedstrom & contributors, 2023). While pyroms has long provided valuable low-level utilities, it also presents challenges for new users. Installation can be cumbersome due to its Python and Fortran dependencies, and its inconsistent Application Programming Interface (API) and limited documentation make it hard to learn. The package was not designed with reproducible workflows in mind, and it lacks tests, CI, and support for modern Python tools such as xarray and dask. Since development of pyroms has largely ceased, its suitability for new projects, such as CDR simulations, is increasingly limited. Furthermore, tools from other modeling communities cannot simply be adopted, since each ocean model has distinct structural requirements. For example, the new regional-mom6 package (Barnes et al., 2024), developed for the Modular Ocean Model v6 (MOM6) (Adcroft et al., 2019), cannot be used to generate ROMS inputs, because ROMS employs a terrain-following vertical coordinate system that requires a specialized vertical regridding approach, whereas MOM6 accepts inputs on arbitrary depth levels and does not require vertical regridding at all. Several other differences further prevent cross-compatibility. Together, these limitations underscored the need for a modern, maintainable, and reproducible tool designed specifically for ROMS.¹

ROMS-Tools was developed to meet this need. It draws on the legacy of the MATLAB preprocessing scripts developed at UCLA (Molemaker, 2024), which encapsulate decades of expertise in configuring regional ocean model inputs. While many of the core algorithms and

¹In the future, packages like ROMS-Tools and regional-mom6 could share a common backbone, with model-specific adaptations layered on top.

design principles are retained, ROMS-Tools provides an open-source Python implementation of these MATLAB tools using an object-oriented programming paradigm. This implementation enables a modernized workflow driven by high-level user API calls, enhancing reproducibility, reducing the potential for user errors, and supporting extensibility for additional features, forcing datasets, and use cases. In some cases, ROMS-Tools diverges from the MATLAB implementation to take advantage of new methods or better integration with the modern Python ecosystem. By streamlining input generation and analysis, ROMS-Tools reduces technical overhead, lowers the barrier to entry, and enables scientists to focus on research rather than data preparation. The primary users of the package include (i) ocean modelers developing new domains for any regional modeling application and (ii) researchers in the ocean-based CDR community who use ROMS-Tools to set up simulations that mimic climate intervention scenarios.

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