

# <sup>1</sup> ROMS-Tools: A Python Package for Preparing and Analyzing ROMS Simulations

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## <sup>9</sup> Summary

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

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

## <sup>34</sup> Input Data and Preprocessing

<sup>35</sup> Whether for research or industrial-focused applications, configuring a regional ocean model like ROMS-MARBL remains a major technical challenge. Generating the required input files is time-consuming, error-prone, and difficult to reproduce, creating a bottleneck for both new and experienced model users. The Python package ROMS-Tools addresses this challenge by providing an efficient, user-friendly, and reproducible workflow to generate all required model input files. Its user interface and underlying data model are based on xarray ([Hoyer & Hamman, 2017](#)), enabling seamless handling of multidimensional datasets with rich metadata and optional parallelization via a dask ([Dask Development Team, 2016](#)) backend.

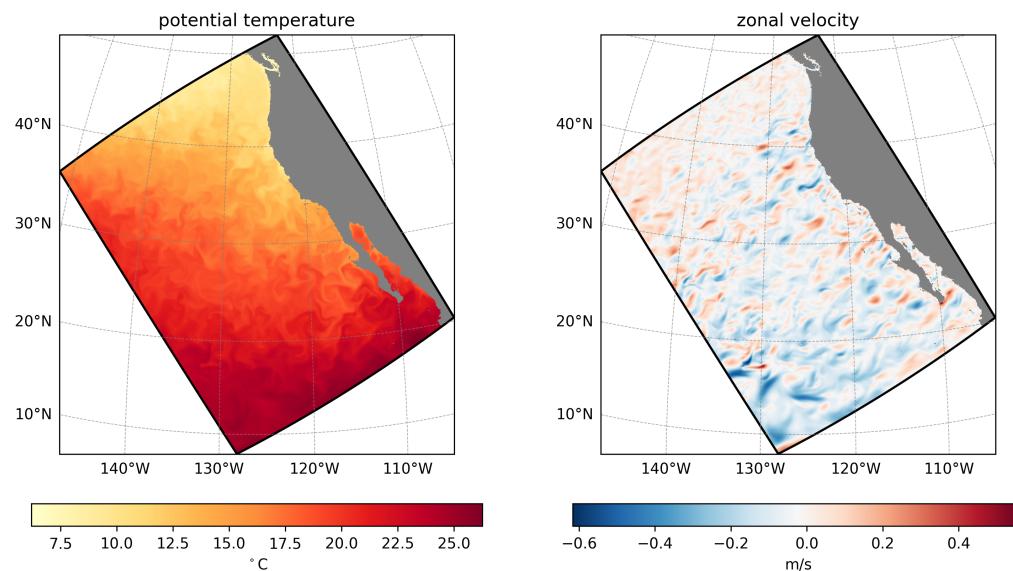
43 ROMS-Tools can automatically process commonly used datasets or incorporate custom user  
44 data and routines. Currently, it can generate the following inputs:

- 45    1. **Model Grid:** Customizable, curvilinear grid, rotatable to align with coastlines, with a  
46    terrain-following vertical coordinate.
- 47    2. **Bathymetry:** Derived from **SRTM15** ([Tozer et al., 2019](#)).
- 48    3. **Land Mask:** Inferred from **Natural Earth** coastlines.
- 49    4. **Physical Ocean Conditions:** Initial and open boundary conditions for sea surface height,  
50    temperature, salinity, and velocities derived from GLORYS ([Lellouche et al., 2021](#)).
- 51    5. **BGC Ocean Conditions:** Initial and open boundary conditions for dissolved inorganic  
52    carbon, alkalinity, and other biogeochemical tracers from CESM output ([Yeager et al.,  
53    2022](#)) or hybrid observational-model sources.
- 54    6. **Meteorological forcing:** Wind, radiation, precipitation, and air temperature/humidity  
55    processed from ERA5 ([Hersbach et al., 2020](#)) with optional corrections for radiation bias  
56    and coastal wind.
- 57    7. **BGC surface forcing:** Partial pressure of carbon dioxide, as well as iron, dust, and nitrogen  
58    deposition from CESM output ([Yeager et al., 2022](#)) or hybrid observational-model sources.
- 59    8. **Tidal Forcing:** Tidal potential, elevation, and velocities derived from **TPXO** ([Egbert &  
60    Erofeeva, 2002](#)) including self-attraction and loading (SAL) corrections.
- 61    9. **River Forcing:** Freshwater runoff derived from **Dai & Trenberth** ([Dai & Trenberth, 2002](#))  
62    or user-provided custom files.
- 63    10. **CDR Forcing:** User-defined interventions that inject BGC tracers at point sources or as  
64    larger-scale Gaussian perturbations, suitable for the simulation of field- or large-scale  
65    CDR experiments.

66 While the source datasets listed above (GLORYS, ERA5, SRTM15, TPXO, etc.) are the  
67 ones currently supported, the package's modular design makes it straightforward to add new  
68 data sources or custom routines in the future. To generate the model inputs listed above,  
69 ROMS-Tools automates several intermediate processing steps, including:

- 70    ▪ **Bathymetry processing:** The bathymetry is smoothed in two stages, first across the  
71    entire model domain and then along the shelf, to ensure local steepness ratios are not  
72    exceeded and to reduce pressure-gradient errors. A minimum depth is enforced to prevent  
73    water levels from becoming negative during large tidal excursions.
- 74    ▪ **Mask definition:** The land-sea mask is generated by comparing the ROMS grid's  
75    horizontal coordinates with a coastline dataset using `regionmask` ([Hauser et al., 2024](#)).  
76    Enclosed basins are subsequently filled with land.
- 77    ▪ **Land value handling:** Land values are filled via an algebraic multigrid method using  
78    `pyamg` ([Bell et al., 2023](#)) prior to horizontal regridding. This extends ocean values into  
79    land areas to resolve discrepancies between source data and ROMS land masks that  
80    could otherwise produce artificial values in ocean cells.
- 81    ▪ **Regridding:** Ocean and atmospheric fields are horizontally and vertically regridded from  
82    standard latitude-longitude-depth grids to the model's curvilinear grid with a terrain-  
83    following vertical coordinate using `xarray` ([Hoyer & Hamman, 2017](#)). Optional sea surface  
84    height corrections can be applied, and velocities are rotated to align with the curvilinear  
85    ROMS grid.
- 86    ▪ **Longitude conventions:** ROMS-Tools handles differences in longitude conventions, con-  
87    verting between  $[-180^\circ, 180^\circ]$  and  $[0^\circ, 360^\circ]$  as needed.
- 88    ▪ **River locations:** Rivers that fall within the model domain are automatically identified  
89    and relocated to the nearest coastal grid cell. Rivers that need to be shifted manually or  
90    span multiple cells can be configured by the user.
- 91    ▪ **Atmospheric data streaming:** ERA5 atmospheric data can be accessed directly from the  
92    cloud, removing the need for users to pre-download large datasets locally.

93 Users can quickly design and visualize regional grids and inspect all input fields with built-in  
94 plotting utilities. An example of surface initial conditions generated for a California Current  
95 System simulation at 5 km horizontal resolution 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.

96 ROMS-Tools also includes features that facilitate simulation management. It supports parti-  
 97 tioning input files to enable parallelized ROMS simulations across multiple nodes, and writes  
 98 NetCDF outputs with metadata fully compatible with ROMS-MARBL. Currently, UCLA-ROMS  
 99 ([Molemaker & contributors, 2025](#)) is fully supported, with the potential to add other ROMS  
 100 versions, such as Rutgers ROMS ([Arango & contributors, 2024](#)), in the future.

## 101 Postprocessing and Analysis

102 ROMS-Tools includes analysis tools for postprocessing ROMS-MARBL output. It first provides  
 103 a joining tool (the counterpart to the input file partitioning utility described earlier) that merges  
 104 ROMS output files produced as tiles from multi-node simulations. Beyond file management,  
 105 there are ROMS-Tools analysis utilities for general-purpose tasks, such as loading model output  
 106 directly into an Xarray dataset with additional useful metadata, enabling seamless use of  
 107 the Pangeo scientific Python ecosystem for further analysis and visualization. The analysis  
 108 layer also supports regridding from the native curvilinear ROMS grid with terrain-following  
 109 coordinate to a standard latitude-longitude-depth grid using xesmf ([Zhuang et al., 2023](#)), and  
 110 includes built-in plotting on both the native and latitude-longitude-depth grids. Beyond these  
 111 general-purpose features, the ROMS-Tools analysis layer offers a suite of targeted tools for  
 112 evaluating CDR interventions. These include utilities for generating standard plots, such as  
 113 CDR efficiency curves, and performing specialized tasks essential for CDR monitoring, reporting,  
 114 and verification.

## 115 Workflow, Reproducibility, and Performance

116 ROMS-Tools is designed to support modern, reproducible workflows. It is easily installable via  
 117 Conda or PyPI and can be run interactively from Jupyter Notebooks. To ensure reproducibility  
 118 and facilitate collaboration, each workflow is defined in a simple YAML configuration file.  
 119 These compact, text-based YAML files can be version-controlled and easily shared, eliminating  
 120 the need to transfer large NetCDF files between researchers, as source data like GLORYS and  
 121 ERA5 are accessible in the cloud. For performance, the package is integrated with dask ([Dask  
 122 Development Team, 2016](#)) to enable efficient, out-of-core computations on large datasets.  
 123 Finally, to ensure reliability, the software is rigorously tested with continuous integration (CI)  
 124 and supported by comprehensive documentation.

## 125 Statement of Need

126 Setting up a regional ocean model is a major undertaking. It requires generating a wide range  
127 of complex input files, including the model grid, initial and boundary conditions, and forcing  
128 from the atmosphere, tides, and rivers. Traditionally, this work has depended on a patchwork  
129 of custom scripts and lab-specific workflows, which can be time-consuming, error-prone, and  
130 difficult to reproduce. These challenges slow down science, create a steep barrier to entry for  
131 new researchers, and limit collaboration across groups.

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

147 ROMS-Tools was developed to meet this need. It draws on the legacy of the MATLAB  
148 preprocessing scripts developed at UCLA ([Molemaker, 2024](#)), which encapsulate decades of  
149 expertise in configuring regional ocean model inputs. While many of the core algorithms and  
150 design principles are retained, ROMS-Tools provides an open-source Python implementation of  
151 these MATLAB tools using an object-oriented programming paradigm. This implementation  
152 enables a modernized workflow driven by high-level user API calls, enhancing reproducibility,  
153 reducing the potential for user errors, and supporting extensibility for additional features, forcing  
154 datasets, and use cases. In some cases, ROMS-Tools diverges from the MATLAB implementation  
155 to take advantage of new methods or better integration with the modern Python ecosystem. By  
156 streamlining input generation and analysis, ROMS-Tools reduces technical overhead, lowers the  
157 barrier to entry, and enables scientists to focus on research rather than data preparation. The  
158 primary users of the package include ocean modelers developing new domains and researchers  
159 in the CDR community, who use ROMS-Tools to test climate intervention scenarios.

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

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