

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

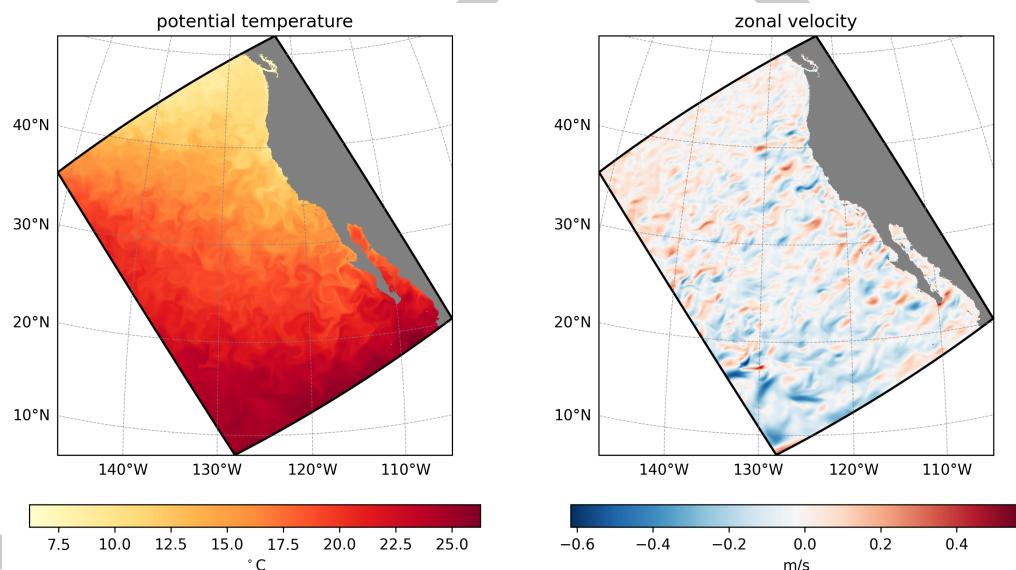
<sup>24</sup> A widely used regional ocean model is the **Regional Ocean Modeling System (ROMS)**  
<sup>25</sup> ([Shchepetkin & McWilliams, 2005](#)). To connect physical circulation with ecosystem dynamics  
<sup>26</sup> and the ocean carbon cycle, ROMS has been coupled to a BGC model called the Marine  
<sup>27</sup> Biogeochemistry Library (MARBL) ([Long et al., 2021](#); [Molemaker & contributors, 2025a](#)).  
<sup>28</sup> This coupled framework allows researchers to explore a variety of scientific and practical  
<sup>29</sup> questions. For example, it can be used to investigate the potential of ocean-based carbon  
<sup>30</sup> removal strategies, such as adding alkaline materials to the ocean to sequester atmospheric  
<sup>31</sup> carbon dioxide. It can also be used to study how physical processes drive ecosystem dynamics,  
<sup>32</sup> such as how nutrient-rich waters from upwelling fuel the phytoplankton blooms that form the  
<sup>33</sup> 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  
<sup>36</sup> like ROMS-MARBL remains a major technical challenge. Generating the required input files is  
<sup>37</sup> time-consuming, error-prone, and difficult to reproduce, creating a bottleneck for both new  
<sup>38</sup> and experienced model users. The Python package ROMS-Tools addresses this challenge by  
<sup>39</sup> providing a set of efficient, user-friendly, and extensible tools to design new regional grids for  
<sup>40</sup> ROMS-MARBL and to process and stage all required model input files. The package's user  
<sup>41</sup> interface and underlying data model are based on xarray ([Hoyer & Hamman, 2017](#)), allowing  
<sup>42</sup> 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 latitude-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. It 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. This process results in generating a wide range of complex input files, including the model grid, initial and boundary conditions, and forcing from the atmosphere, tides, and rivers. 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.<sup>1</sup>

ROMS-Tools was developed to meet this need. It draws on the legacy of the MATLAB

<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.

172 preprocessing scripts developed at UCLA ([Molemaker, 2024](#)), which encapsulate decades of  
173 expertise in configuring regional ocean model inputs. While many of the core algorithms and  
174 design principles are retained, ROMS-Tools provides an open-source Python implementation of  
175 these MATLAB tools using an object-oriented programming paradigm. This implementation  
176 enables a modernized workflow driven by high-level user API calls, enhancing reproducibility,  
177 reducing the potential for user errors, and supporting extensibility for additional features, forcing  
178 datasets, and use cases. In some cases, ROMS-Tools diverges from the MATLAB implementation  
179 to take advantage of new methods or better integration with the modern Python ecosystem.  
180 By streamlining input generation and analysis, ROMS-Tools reduces technical overhead, lowers  
181 the barrier to entry, and enables scientists to focus on research rather than data preparation.  
182 The primary users of the package include (i) ocean modelers developing new domains for any  
183 regional modeling application and (ii) researchers in the ocean-based CDR community who  
184 use ROMS-Tools to set up simulations that mimic climate intervention scenarios.

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