The Journal of Open Source Software

regional-mom6: Automatic generation of regional configurations for the Modular Ocean Model 6 in Python

Ashley J. Barnes [1,2], **Navid C. Constantinou** [1,2], **Angus H. Gibson** [1], **Chris Chapman** [3], **Dhruv Bhagtani** [1,2], **John Reily**[4], and **Andrew E. Kiss** [1,2]

1 Australian National University, Australia **2** ARC Centre of Excellence in Climate Extremes, Australia **3** CSIRO Environment, Hobart, Tasmania, Australia **4** University of Tasmania, Australia

DOI: 10.xxxxxx/draft

Software

- Review
- Repository
- Archive

Editor: Open Journals

Reviewers:

- @openjournals

Submitted: 01 January 1970
Published: unpublished

Summary

The Modular Ocean Model version 6 (MOM6) is a widely-used open-source general circulation ocean–sea ice model, developed mainly at the NOAA Geophysical Fluid Dynamics Laboratory (Adcroft et al., 2019). MOM6 contains several improvements over its predecessor MOM5 (Griffies, 2014), including the implementation of the Arbitrary-Lagrangian-Eulerian vertical coordinates (Griffies et al., 2020), more efficient tracer advection schemes, and state-of-the art parameterizations of sub-grid scale physics.

The nature of turbulent flows is such that smaller scales of motion emerge emerge spontaneously. Oceanic flows are no exception to this rule. What might seem counter-intuitive, is that in the ocean small-scale motions (motions from ~100m to ~100km) turn out to be very important since they shape the large-scale ocean circulation and climate (motions of ~10,000km) (de Lavergne et al., 2022; Gula et al., 2022; Melet et al., 2022). Thus, despite the increase in computational power and use of graphical processing units that bring about breakthrough performance and speedup (Silvestri et al., 2023), there will always be smaller-scale processes that remain unresolved. To resolve more scales of motion given restrictions in computational power we can resolve to regional ocean modeling. Regional ocean modeling is an ocean simulation that only simulates a subset of the global ocean. To do that, we need to apply open boundary conditions at the region's boundaries, that is, we need to impose conditions that mimic the oceanic flow that we are not simulating. Figure 1 that shows the surface currents from a regional ocean simulation of the Tasman sea that was configured using the `regional-mom6` package. The boundaries of the domain depicted in Figure 1b are forced with the ocean flow from a reanalysis product that is shown in Figure 1a.

MOM6 provides support for open boundary conditions and thus is becoming popular for regional ocean modeling studies (see, e.g., Ross et al. (2023), Ross et al. (2024)) in addition to global configurations. However, setting up a regional configuration for MOM6 can be challenging, time consuming, and often involves using several programming languages, a few different tools, and also manually editing/tweaking some input files. The `regional-mom6` Python package overcomes these difficulties, automatically generating a regional MOM6 configuration with relatively simple domain geometry.

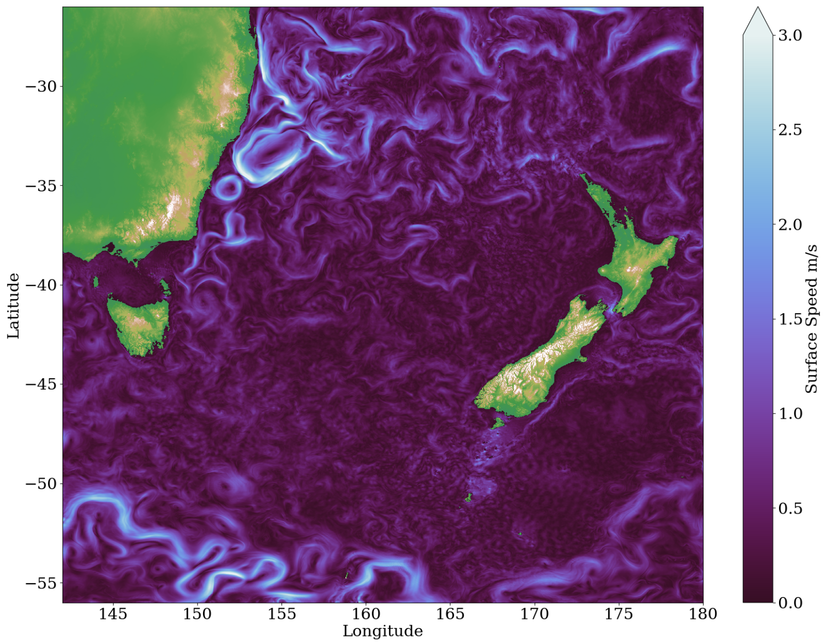

Figure 1: A snapshot of the ocean surface currents from a MOM6 regional simulation of the Tasman sea. The simulation is forced by GLORYS and ERA5 reanalysis datasets and configured with a horizontal resolution of 1/80th degree and 100 vertical levels (see Barnes (2024) for the source code).

The `regional-mom6` package takes as input various datasets that containing the ocean initial condition, the boundary forcing (ocean and atmosphere) for the regional domain, and the bathymetry. The input datasets can be on the Arakawa A, B, or C grids (Arakawa & Lamb, 1977); the package performs the appropriate interpolation using `xESMF` (Zhuang et al., 2023) under the hood, to put the everything on the C grid required by MOM6. This base grid for the regional configuration can either be constructed based on the user's desired resolution preference and choice of pre-configured options, or from a user-provided horizontal and/or vertical pre-existing MOM6 grids. The user can use MOM6's Arbitrary-Lagrangian-Eulerian vertical coordinates, regardless of the native vertical coordinates of the boundary forcing input. The package automates the re-gridding of all the required forcing input, takes care of all the metadata encoding, generates the regional grid, and ensures that the final input files are in the format expected by MOM6. Additionally, the tricky case of a regional configuration that includes the 'seam' in the longitude of the raw input data is handled automatically, removing the need for any preprocessing of the input data. (For example, such a 'seam'-related issue arises for a 10°-wide regional configuration centered at Fiji (178°E) when forced by input with native longitude coordinate in the range between 180°W and 180°E.) The above-mentioned automation allows users to setup a regional MOM6 configuration using only Python and from the convenience of a single Jupyter notebook. Rules-of-thumb to guide the user in setting grid parameters such as the regional domains resolution, can be found in the paper by Herzfeld et al. (2011).

`regional-mom6` is installable via `conda`, it is continuously tested, and comes with an extensive documentation that also includes documented tutorials and examples for setting up regional MOM6 configurations using publicly-available forcing and bathymetry datasets (namely, the GLORYS dataset for ocean boundary forcing (Copernicus Marine Services, 2024), the ERA5 reanalysis for atmospheric forcing (Copernicus Climate Change Service, 2024), and the GEBCO dataset for bathymetry (GEBCO Bathymetric Compilation Group 2023, 2023)).

With the entire process for setting up a regional configuration streamlined to run within a Jupyter notebook, the package dramatically reduces the barrier-to-entry for first-time users, or those without a strong background in Fortran, experience in compiling and running scripts in terminals, and manipulating netCDF files. Besides making regional modelling with MOM6 more accessible, our package can automate the generation of multiple experiments (e.g., a series of perturbation experiments), saving time and effort, and improving reproducibility.

We designed `regional-mom6` with automation of regional configurations in mind. However, the package's code design and modularity makes more complex configurations possible since users can use their own custom-made grids with more complex boundaries and construct the boundary forcing terms one by one.

Statement of need

The learning curve for setting up a regional ocean model can be quite steep, and it is not obvious for a new user what inputs are required, nor the appropriate format. In the case of MOM6, there are several tools scattered in Github repositories, for example those collected in Earth System Modeling Group grid tools (Simkins et al., 2021). Also, there exist several regional configuration examples (e.g., [cite here 1-2 repos?]) but they are hardcoded for particular domains, specific input files, and work only on specific high-performance computing machines.

Until now there has been no one-stop-shop for users to learn how to get a regional MOM6 configuration up and running. Users are required to use several tools in several programming languages and then modify –sometimes by hand– some of the input metadata to bring everything into the format that MOM6 expects. Many parts of this process are not documented, requiring users to dig into the MOM6 Fortran source code. Other ocean models have packages to aid in regional configuration setup, for example `Pyroms` (Hedstrom & contributors, 2023) for the Regional Oceanic Modelling System (ROMS; Shchepetkin & McWilliams (2005)) and `MITgcm_python` (Naughten & Jones, 2023) for the Massachusetts Institute of Technology General Circulation Model (MITgcm; Marshall et al. (1997)). With MOM6's growing user base for regional applications, there is a need for a platform that walks users through regional domain configuration from start to finish and, ideally, automates the process on the way. `regional-mom6` fills precisely this need.

By having a shared set of tools that the community can work with and contribute to, this package also facilitates collaboration and knowledge-sharing between different research groups. Using a shared framework for setting up regional models, it is easier to compare and contrast examples of different experiments and allows for users to gain intuition for generating their chosen domain.

`regional-mom6` package can also be used for educational purposes, for example as part of course curricula. With the technically-challenging aspects of setting up a regional configuration now being automated by the `regional-mom6` package, students can set up and run simple MOM6 regional configurations and also change parameters like the model's resolution or the forcing, run again, and see how these parameters affect the ocean flow.

Acknowledgements

We thank the Consortium for Ocean–Sea Ice Modeling in Australia (cosima.org.au) for useful discussions during the development of this package. We acknowledge support from the Australian Research Council under DECRA Fellowship DE210100749 (N.C.C.) and grant LP200100406 (A.E.K.). We would also like to acknowledge the code and notes by James Simkins, Andrew Ross, and Rob Cermak, which helped us to troubleshoot and improve the algorithms in our package.

References

Adcroft, A., Anderson, W., Balaji, V., Blanton, C., Bushuk, M., Dufour, C. O., Dunne, J. P., Griffies, S. M., Hallberg, R., Harrison, M. J., Held, I. M., Jansen, M. F., John, J. G., Krasting, J. P., Langenhorst, A. R., Legg, S., Liang, Z., McHugh, C., Radhakrishnan, A., … Zhang, R. (2019). The GFDL global ocean and sea ice model OM4.0: Model description and simulation features. *Journal of Advances in Modeling Earth Systems*, *11*(10), 3167–3211. https://doi.org/10.1029/2019MS001726

Arakawa, A., & Lamb, V. R. (1977). Computational design of the basic dynamical processes of the UCLA general circulation model. *Methods in Computational Physics: Advances in Research and Applications*, *17*(Supplement C), 173–265. https://doi.org/10.1016/B978-0-12-460817-7.50009-4

Barnes, A. J. (2024). Tasman-tides. In *GitHub repository*. GitHub. https://github.com/ashjbarnes/tasman-tides

Copernicus Climate Change Service. (2024). *ECMWF Reanalysis v5*. European Centre for Medium-Range Weather Forecasts. https://doi.org/10.48670/moi-00021

Copernicus Marine Services. (2024). *Global ocean physics reanalysis*. Mercator Ocean International. https://doi.org/10.48670/moi-00021

de Lavergne, C., Groeskamp, S., Zika, J., & Johnson, H. L. (2022). Chapter 3 – the role of mixing in the large-scale ocean circulation. In M. Meredith & A. Naveira Garabato (Eds.), *Ocean mixing* (pp. 35–63). Elsevier. https://doi.org/10.1016/B978-0-12-821512-8.00010-4

GEBCO Bathymetric Compilation Group 2023. (2023). *The GEBCO_2023 Grid - a continuous terrain model of the global oceans and land*. NERC EDS British Oceanographic Data Centre NOC. https://doi.org/10.5285/f98b053b-0cbc-6c23-e053-6c86abc0af7b

Griffies, S. M. (2014). Elements of the modular ocean model (MOM). *GFDL Ocean Group Tech. Rep.*, *7*, 47. https://mom-ocean.github.io/assets/pdfs/MOM5_manual.pdf

Griffies, S. M., Adcroft, A., & Hallberg, R. W. (2020). A primer on the vertical Lagrangian-remap method in ocean models based on finite volume generalized vertical coordinates. *Journal of Advances in Modeling Earth Systems*, *12*(10), e2019MS001954. https://doi.org/10.1029/2019MS001954

Gula, J., Taylor, J., Shcherbina, A., & Mahadevan, A. (2022). Chapter 8 – submesoscale processes and mixing. In M. Meredith & A. Naveira Garabato (Eds.), *Ocean mixing* (pp. 181–214). Elsevier. https://doi.org/10.1016/B978-0-12-821512-8.00015-3

Hedstrom, K., & contributors. (2023). Pyroms. In *GitHub repository*. GitHub. https://github.com/ESMG/pyroms

Herzfeld, M., Schmidt, M., Griffies, S. M., & Liang, Z. (2011). Realistic test cases for limited area ocean modelling. *Ocean Modelling*, *37*(1), 1–34. https://doi.org/10.1016/j.ocemod.2010.12.008

Marshall, J., Adcroft, A., Hill, C., Perelman, L., & Heisey, C. (1997). A finite-volume, incompressible Navier Stokes model for studies of the ocean on parallel computers. *Journal of Geophysical Research: Oceans*, *102*(C3), 5753–5766. https://doi.org/10.1029/96JC02775

Melet, A. V., Hallberg, R., & Marshall, D. P. (2022). Chapter 2 – the role of ocean mixing in the climate system. In M. Meredith & A. Naveira Garabato (Eds.), *Ocean mixing* (pp. 5–34). Elsevier. https://doi.org/10.1016/B978-0-12-821512-8.00009-8

Naughten, K., & Jones, D. (2023). MITgcm_python. In *GitHub repository*. GitHub. https://github.com/knaughten/mitgcm_python

Ross, A. C., Stock, C. A., Adcroft, A., Curchitser, E., Hallberg, R., Harrison, M. J., Hedstrom, K., Zadeh, N., Alexander, M., Chen, W., Drenkard, E. J., Pontavice, H. du, Dussin, R., Gomez, F., John, J. G., Kang, D., Lavoie, D., Resplandy, L., Roobaert, A., … Simkins, J. (2023). A high-resolution physical–biogeochemical model for marine resource applications in the northwest Atlantic (MOM6-COBALT-NWA12 v1.0). *Geoscientific Model Development*, *16*(23), 6943–6985. https://doi.org/10.5194/gmd-16-6943-2023

Ross, A. C., Stock, C. A., Koul, V., Delworth, T. L., Lu, F., Wittenberg, A., & Alexander, M. A. (2024). Dynamically downscaled seasonal ocean forecasts for North American East Coast ecosystems. *EGUsphere*, *2024*, 1–40. https://doi.org/10.5194/egusphere-2024-394

Shchepetkin, A. F., & McWilliams, J. C. (2005). The regional oceanic modeling system (ROMS): A split-explicit, free-surface, topography-following-coordinate oceanic model. *Ocean Modelling*, *9*(4), 347–404. https://doi.org/10.1016/j.ocemod.2004.08.002

Silvestri, S., Wagner, G. L., Hill, C., Ardakani, M. R., Blaschke, J., Campin, J.-M., Churavy, V., Constantinou, N. C., Edelman, A., Marshall, J., Ramadhan, A., Souza, A., & Ferrari, R. (2023). *Oceananigans.jl: A model that achieves breakthrough resolution, memory and energy efficiency in global ocean simulations*. https://arxiv.org/abs/2309.06662

Simkins, J., Cermak, R., Hedstrom, K., & Gibson, A. (2021). Earth System Modeling Group (ESMG) gridtools. In *GitHub repository*. GitHub. https://github.com/ESMG/gridtools

Zhuang, J., Dussin, R., Huard, D., Bourgault, P., Banihirwe, A., Raynaud, S., Malevich, B., Schupfner, M., Filipe, Levang, S., Gauthier, C., Jüling, A., Almansi, M., Scott, R., RondeauG, Rasp, S., Smith, T. J., Stachelek, J., Plough, M., & Li, X. (2023). xESMF: Universal regridder for geospatial data. In *GitHub repository*. Zenodo. https://github.com/pangeo-data/xESMF