Abstract

About this manual and MRI.COM

This technical report is a manual of the Meteorological Research Institute Community Ocean Model (MRI.COM). MRI.COM is an ocean general circulation model developed and maintained at the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA). It has been used for studying large scale oceanic phenomena and as the oceanic part of the coupled climate models developed at MRI. Recently, it is expanding its coverage to coastal small scale phenomena.

Development of MRI.COM began around 2000. MRI.COM version 1 was created by integrating the two ocean models that had been used by MRI until then. Version 2 (early 2000s) was intended for use in the operational forecasting system in JMA. A Japanese mannual for this version was published in 2005 (Ishikawa et al., 2005), and eventually became the prototype of this manual. Version 3 was intended for use as an oceanic component of the Earth System Model of MRI (MRI-ESM1; Yukimoto et al., 2011). MRI used MRI-ESM1 to participate in the international project "Coupled Model Intercomparison Project Phase 5 (CMIP5)", so a detailed description of its oceanic component was prepared in English (Tsujino et al., 2010). Version 4 (2015) was intended for use as the oceanic part of the next operational forecasting systems of JMA as well as a new Earth System Model of MRI (MRI-ESM2) prepared for the Coupled Model Intercomparison Project Phase 6 (CMIP6). This version also renewed the vertical coordinate system (adopting the so-called z^* coordinate system (Adcroft and Campin, 2004)). For a detailed history of model development, see "Abstract" in the MRI.COMv4 manual (Tsujino et al., 2017).

This report is a manual for MRI.COM version 5, which was released in 2021. This version contains various improvements made for the "Japanese Coastal Ocean Monitoring and Forecasting System", that has been in operation at JMA since 2020. The main improvements are as follows.

- Renewal of time integration scheme from Leapfrog Matsuno method to Leapfrog Adams Moulton method. As a result, model stability and time accuracy have been improved, and calculation costs have been reduced.
- Various devices for speeding up, such as introduction of OpenMP, use of MPI-IO, reduction of communication in nesting experiments, etc.
- Addition of options to improve model stability
- Improvement of coupling with atmospheric model and sea ice model, such as introduction of bulk formula consistent with the JMA's operational atmosphere general circulation model, refinement of sea ice processes, etc.
- Enhancement of analysis function for modeling research, such as isopycnal analysis, particle tracking, netCDF output, etc.
- Many other improvements, such as introduction of physical schemes, parameter adjustment to improve accuracy, and so on.

Note that the purpose of this manual is to present a detailed description of a particular model system. The mathematical expressions of processes, the parameterization methods, and the numerical algorithms presented here follow those adopted in the latest code. They are largely state-of-the-art, but this does not necessarily mean that they are the complete reflections of physical, mathematical, and numerical integrity. Every method is subject to possible sophistication. We welcome critical comments and suggestions from any reader or user, which are necessary for further improvement.

For a more general or detailed description of OGCMs, please refer to textbooks by Griffies (2004) and Kantha and Clayson (2000). The former thoroughly describes the fundamentals of OGCMs, and the latter concisely summarizes the modeling of various oceanic processes such as tide and sea ice.

Development management

MRI.COM has been developed over almost 20 years, and, as a result, the program code has become larger and more complicated. Since it is now used for many projects, various departments and people of MRI and JMA are involved. To develop the model efficiently and maintain stability through widespread usage, we adopted tools and methods used in modern software development and redesigned our development management system. For example, a version control system of the code, Git, has been introduced, which enables multiple developers to work on multiple tasks in parallel. A project management system, Redmine, is also used for all development members to share the development situation. Based on these tools, we can share information and perform mutual checks daily as a development team. This greatly contributes to improvement of code quality. See Sakamoto et al. (2018) for more information on our development management.

Organization

Chapter 1 introduces OGCMs and MRI.COM. It also presents the classification of OGCMs and the status of MRI.COM with respect to the state-of-the-art OGCMs.

Part I describes the model configuration. Governing equations are derived in Chapter 2, and the spatial grid arrangement and grid area and volume calculation methods are explained in Chapter 3. The method of time integration is explained in Chapter 4.

Part II describes the solution procedures of diagnostic equations. Chapter 5 presents definition of the equation of state of sea water. Chapter 6 presents definition of the continuity equations for unit grid cells.

Part III describes the solution procedures of momentum equation. The method of solving the barotropic and the baroclinic part of the momentum equation are presented in Chapters 7 and 8, respectively.

Part IV describes the method of solving the advection-diffusion equation for tracers. After summarizing the equation in Chapter 9, Chapter 10 presents tracer advection schemes. Subgrid-scale parameterizations for horizontal and vertical mixing are explained in Chapters 11 and 12, respectively. Chapter 13 explains usage of the tracer package.

Part V describes boundary processes. Surface fluxes are presented in Chapter 14. Turbulence closure models that expresses small-scale processes in the sea surface mixed layer are presented in Chapter 15. Bottom boundary layer parameterization is explained in Chapter 16.

Part VI outlines coupling with other models. Combination with the sea ice model is described in Chapter 17, and combination with the tidal model in Chapter 18. Biogeochemical models are presented in Chapter 19, and some passive tracer models such as chlorofluorocarbons are described in Chapter 20. The program code for these models is included in MRI.COM and is being developed along with the physical model. Chapter 21 describes how to set up MRI.COM for the atmosphere-ocean general circulation model (AOGCM) experiment. Finally, how to construct and run a "nested-grid model" that combines multiple MRI.COM models is presented in Chapter 22.

Part VII contains miscellaneous topics. Basics of the finite difference method are presented in Chapter 23, general orthogonal curvilinear coordinates and related calculus are introduced in Chapter 24, and finally user's guide to construct and run a model is presented in Chapter 25.

Each chapter is almost independent from other chapters. Thus the readers might be able to understand the contents of each chapter without referring to other chapters. However, reading Part I will give the readers the background to help understand the remainder of this manual.

In this manual, we tried to derive the formula that directly corresponds to the program code. On the other hand, the description about the code itself is kept to a minimum. See the Japanese website `https://mri-ocean.github.io/mricom/` for commentary of the code. The content of this document is basically in line with version 5.0 released in 2021, though some content was developed after version 5.1.

The following are some comments about the notations used throughout this manual. The characters and expressions in `Courier` fonts are adopted from program codes. The subscripts and indices used in discrete equations are intended to express staggered grid arrangements. They do not necessarily correspond to the array indices in program codes.