2. Outline of MRI-ESM1

The configuration of MRI-ESM1 is illustrated in Fig. 1. The atmosphere–ocean coupled model forming its core component is MRI-CGCM3, which itself consists of MRI's latest AGCM and OGCM versions. The AGCM includes terrestrial biosphere carbon cycle processes, and the OGCM includes ocean biogeochemical processes. Transports and exchanges of atmospheric CO_2 at the land and ocean surfaces integrate the terrestrial and ocean carbon cycles, allowing representation of the global carbon cycle. The AGCM is coupled with an aerosol model and an atmospheric chemistry–climate model (CCM) (focused on ozone chemistry), which allows representation of the interaction between climate and variations in several aerosols, ozone, and trace gases. Not only is the CCM coupled with the AGCM, the aerosol model and the CCM are coupled with each other, which enables simulation of interactions such as heterogeneous chemical reactions on aerosol surfaces.

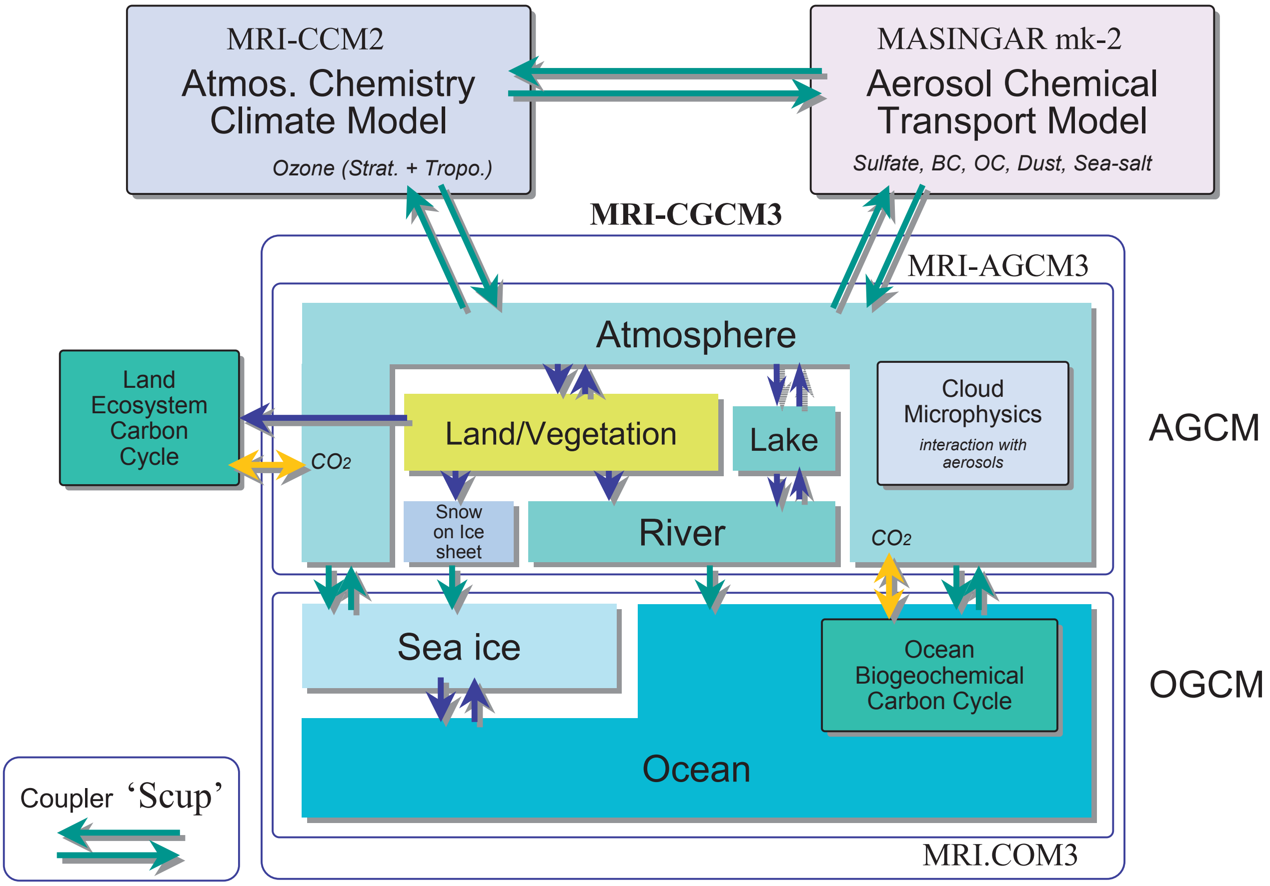

Figure 1 Configuration of the component models in MRI-ESM1. Green arrows denote data exchange with using Scup between the component models.

The AGCM, called MRI-AGCM3, was developed at MRI (Mizuta et al., 2006) and is based on JMA's operational weather prediction model. Its dynamics framework uses a semi-Lagrangian method (Yoshimura, in preparation; see Section 3.1) that has the important advantages of computational efficiency and good conservational properties for mass, static energy, and any tracers. In addition to the parameterizations of the operational model, many new or improved parameterizations of various physical processes have been developed. In particular, new parameterization schemes for important processes, cumulus convection, radiation, clouds, the planetary boundary layer (PBL), and terrestrial hydrology have been introduced. These newly introduced schemes are incorporated as optional alternatives to the conventional schemes.

For cumulus convection, either a new scheme developed by Yoshimura et al. (in preparation; see Section 3.2.2) or a Kain-Fritsch scheme (e.g., Kain and Fritsch, 1990; Section 3.2.3) can be selected, or a prognostic Arakawa-Schubert-type scheme, which was modified from the original scheme (e.g., Arakawa and Schubert, 1974; Randall and Pan, 1993a, 1993b) for the operational model. For radiation processes, the parameterization scheme used in the operational model (see Section 3.3) has been introduced as an alternative to the scheme used in MRI-CGCM2.3 (Shibata and Aoki, 1989; Shibata and Uchiyama, 1992). A cloud microphysics scheme has also been incorporated into MRI-AGCM3 so that the indirect effects of aerosols on radiative forcing can be represented. This cloud microphysics scheme is a two-moment bulk formulation (Section 3.4) that explicitly represents two concentrations, i.e., mass (mixing ratio) and number concentrations, separately for cloud droplets and ice crystals. To model the PBL, in addition to the conventional Mellor-Yamada (Mellor and Yamada, 1974) level 2 scheme, a modification of that scheme developed by Nakanishi (2001) and Nakanishi and Niino (2004, 2006, 2009) (Section 3.5) can now be selected. A new land-surface model called HAL (Hosaka, in preparation; Section 3.6) has been developed that can handle arbitrary numbers of snow and soil layers and mosaic vegetation types, and it allows individual property parameters to be set for special land-surface types such as rice fields and urban areas. This land-surface model is much more flexible than that in MRI-CGCM2.3, which is a simple biosphere model (SiB: Sellers et al., 1986; Sato et al., 1989) modified to handle more soil layers (Hirai et al., 2007). River channels and lakes are also modeled (Section 3.8) as part of a closed global water cycle.

The ocean component of MRI-CGCM3 is a global version of MRI.COM3 (Tsujino et al., 2010; Section 4) developed at MRI that supports general orthogonal curvilinear coordinates. We employ a tripolar coordinate system that does not have the North Pole as a singular point, because MRI-ESM1 covers the world's oceans, including the Arctic Ocean; south of latitude 64°N, the coordinate axes parallel latitude and longitude. A sophisticated sea-ice model was introduced in MRI.COM3, following the Los Alamos sea-ice model (CICE; Hunke and Lipscomb, 2006), which formulates dynamics processes such as categorized thickness distribution, ridging, and rheology, in addition to the thermodynamics processes in the sea ice model of MRI-CGCM2.3, which was based on a free-drift model developed by Mellor and Kantha (1989).

The aerosol model, called MASINGAR mk-2 (Section 5), is an advanced version of MASINGAR (Tanaka et al., 2003). The model handles five types of aerosols: sulfate, black carbon, organic carbon, mineral dust, and sea salt. For mineral dust and sea salt, the aerosols are calculated for several particle size bins. Processes related to aerosols treated in the model include natural and anthropogenic sources, chemical reactions in the air, transport, diffusion and mixing by atmospheric circulation and convection, and dry and wet deposition.

The atmospheric chemistry climate model MRI-CCM1 (Shibata et al., 2005), which was developed at MRI, primarily targets ozone in the stratosphere. The version incorporated into MRI-ESM1, MRI-CCM2 (Deushi and Shibata, 2010; Section 6), is based on MRI-CCM1, but the number of chemical species and (photo) chemical reactions that the model can handle is expanded, allowing MRI-CCM2 to simulate both tropospheric and stratospheric ozone. MRI-CCM2 can be coupled with the MASINGAR mk-2 aerosol model, which enables the ESM to simulate chemical–aerosol interactions, such as heterogeneous chemical reactions at the aerosol surface. For example, the effects of a stratospheric aerosol derived from a volcanic eruption on stratospheric ozone behavior can be taken into account.

One of the most important targets of ESMs is the global carbon cycle, which comprises mainly (at least on timescales of centuries up to a millennium) terrestrial biosphere carbon cycle processes, ocean biogeochemical processes, surface exchange and transport by atmospheric circulation, and anthropogenic emissions. The chemical creation of CO_2 in the atmosphere (calculated by MRI-CCM2), though it is a very small amount, is also included. Two optional schemes are available for parameterization of terrestrial biosphere carbon cycle processes. One is a simple scheme that uses empirical formulae based on air and soil temperatures and precipitation (Obata, 2007). The other is a more sophisticated scheme that takes into account photosynthesis related to vegetation represented by the land-surface model (Obata, in preparation; Section 8.1). For ocean biogeochemical processes, there are also two options: a simple model developed by Obata and Kitamura (2003), and a more complex scheme that explicitly calculates nitrate (i.e., nutrients), phytoplankton, zooplankton, and detritus (Section 8.2). The integrated land and ocean carbon cycle scheme into MRI-ESM1 realistically simulates the exchange of carbon at the land or ocean surface with the atmosphere (CO_2 flux) and the three-dimensional redistribution of the altered atmospheric CO_2 concentration by processes such as advection, vertical mixing due to diffusion, and cumulus convection.

An ESM generally consists of a number of complex components, each of which is independently developed by a specialized modeling group, and the component models must work together. For efficient development, it must be possible to integrate the component models into the ESM without any troublesome modification being required. One of the most important strong points of MRI-ESM1 is that the component models can be flexibly coupled with the Scup coupler (Yoshimura and Yukimoto, 2008; Section 9). Scup allows the flexible exchange of data between component models with different resolutions or grid coordinates and different time intervals. The data exchange, moreover, is done with good conservation of both three-dimensional data and horizontal two-dimentional data, which is essential for climate models and ESMs. This functionality means that MRI-ESM1 can perform the many kinds of experiments planned for CMIP5 by flexible configuration of the component models and parameterization schemes.