Coordinated Ocean-ice Reference Experiments (CORE-II): Ocean Model Intercomparison Project (OMIP)

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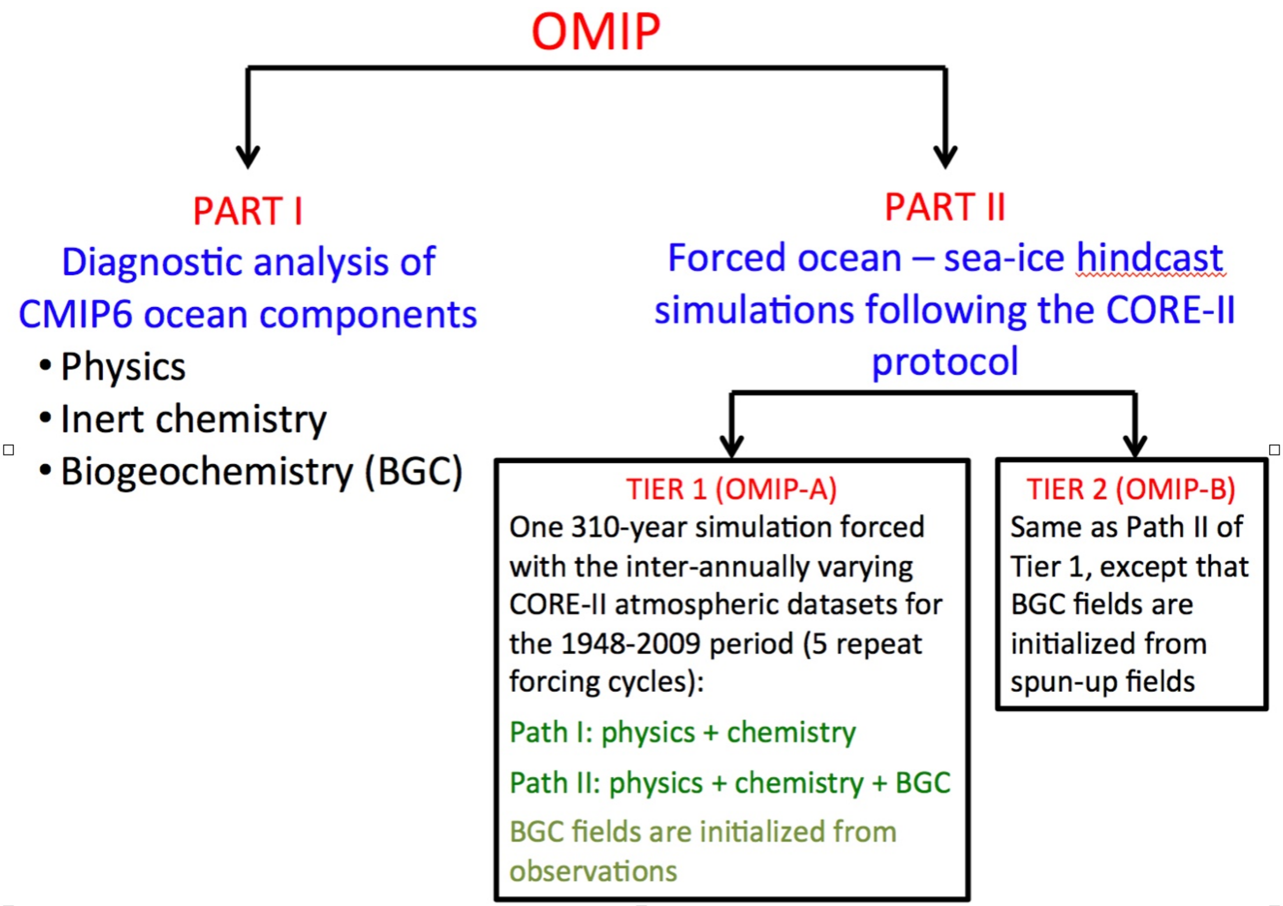
The Ocean Model Intercomparison Project (OMIP) aims to provide a framework for evaluating, understanding, and improving the ocean, sea-ice, tracer, and biogeochemical (BGC) components of global climate and earth system models contributing to CMIP6. Thus, OMIP includes the previously separate Ocean Carbon Model Intercomparison Project (OCMIP). OMIP addresses its aims in two complementary manners: (i) by providing a protocol for ocean diagnostics (including ocean physics, inert chemical tracers, and biogeochemistry) to be saved as part of CMIP6, and (ii) by providing an experimental protocol for global ocean –sea-ice models run with a prescribed atmospheric forcing. The OMIP diagnostic protocol is relevant for any ocean model component of CMIP6, including the DECK, historical simulation, idealized and realistic anthropogenic greenhouse gas increases, C4MIP, and FAFMIP. The physical portion of the OMIP experimental protocol follows that of the interannual Coordinated Ocean-ice Reference Experiments (CORE-II). Since 2009, CORE has become the standard method to evaluate global ocean –sea-ice simulations and to examine mechanisms for forced ocean climate variability. The inert chemical tracer portion of OMIP is based on the OCMIP2 protocol, while the BGC portion uses the OCMIP3 protocol, with each participating group using their own prognostic ocean BGC model.

Keywords: CORE-II, OMIP, CMIP6, OGCM



OMIP

PART I

Diagnostic analysis of CMIP6 ocean components

- Physics
- Inert chemistry
- Biogeochemistry (BGC)

PART II

Forced ocean – sea-ice hindcast simulations following the CORE-II protocol

TIER 1 (OMIP-A)

One 310-year simulation forced with the inter-annually varying CORE-II atmospheric datasets for the 1948-2009 period (5 repeat forcing cycles):

Path I: physics + chemistry

Path II: physics + chemistry + BGC

BGC fields are initialized from observations

TIER 2 (OMIP-B)

Same as Path II of Tier 1, except that BGC fields are initialized from spun-up fields

Figure 1. Schematic of OMIP overview. In the spirit of AMIP, OMIP can be considered as part of future DECK experiments. Note that OMIP is independent of any particular CMIPX.

JRA-55 based surface data set for driving ocean-sea ice models (JRA55-do). Part I: Development and evaluation of surface atmospheric field and air-sea flux

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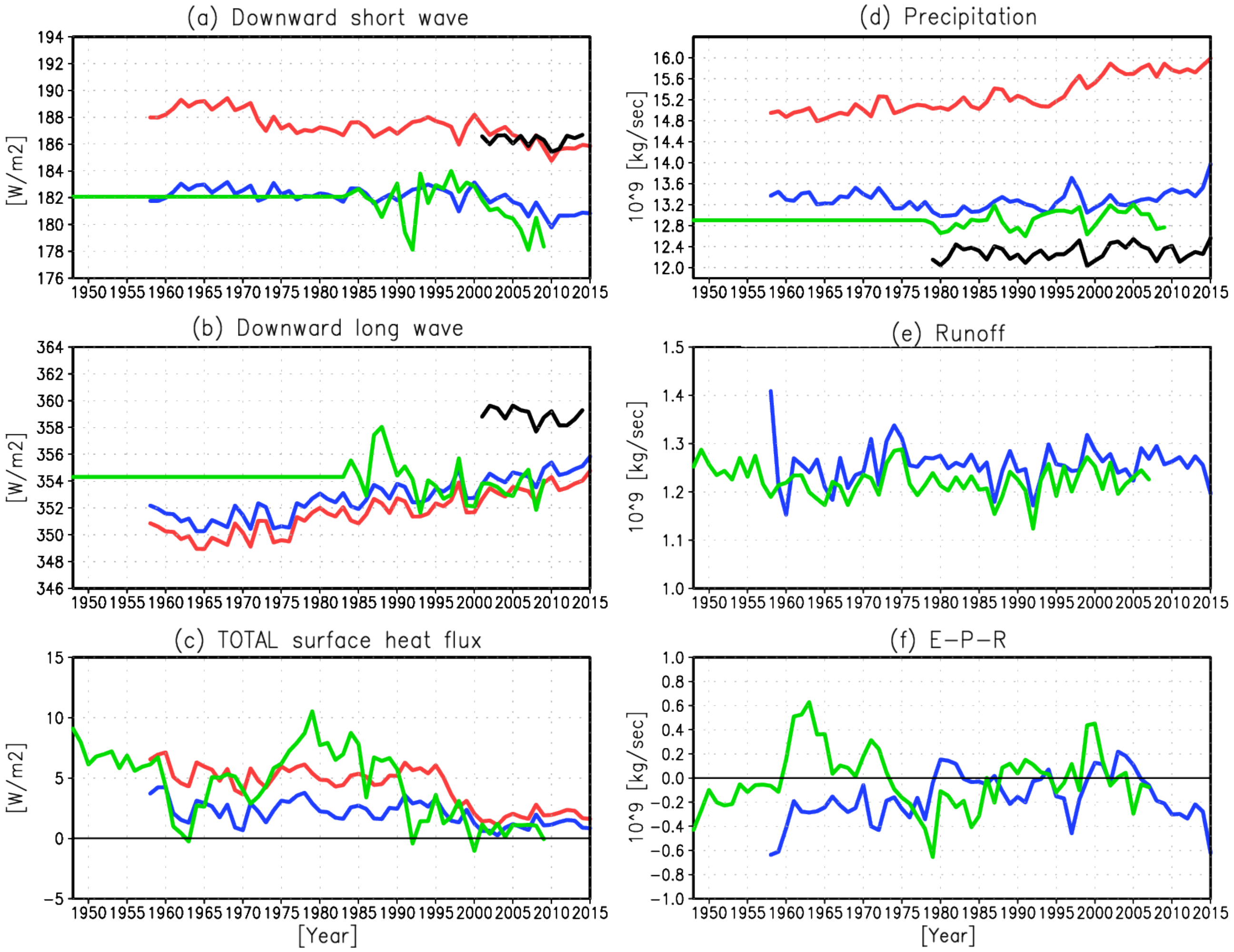
Framework of Coordinated Ocean-ice Reference Experiments (CORE) and the subsequent Ocean Model Intercomparison Project (OMIP) provides ocean and climate modelers with a common facility to perform hindcast simulations of the past ocean –sea-ice climate variability on interannual to decadal time scales. Given the success of this effort, requests to keep the forcing data set up to date would naturally emerge. This kind of framework should indeed provide opportunities to simulate recent climate extreme events, such as sea-ice reduction in the Arctic, global warming hiatus, and on-going El Nino / La Nina, and to understand them in the context of long-term variability. Unfortunately, it has been more than ten years since the current data set of this framework was first produced and it has not been kept up to date. New atmospheric reanalysis products with state-of-the-art technologies are now available. Some of the new satellite data products have now a duration long enough to be used as a reference data set for adjusting reanalysis products. There are also some concerns that the horizontal resolution (˜ 200 km) of the current forcing data set based on the NCEP/NCAR reanalysis may not be suitable for simulations that use high (eddy permitting / resolving) horizontal resolution. This development study is an international collaborative effort to produce a new atmospheric data set for driving ocean –sea-ice models based on JRA-55 (Japanese Meteorological Agency, the Japanese 55-year Reanalysis), aiming to replace the existing forcing data sets.

JRA-55 is one of the most recently conducted long-term reanalysis using high resolution (˜ 55 km) atmospheric model and updated assimilation techniques. The data set covers the period from 1958 to present and will be continued for forthcoming years. All atmospheric elements necessary for computing surface fluxes are based on the forecast mode of JRA-55. The temporal interval is 3 hours. Data are provided on the normal TL319 (˜ 55 km) grid. Elements are downward short and long wave fluxes, precipitation (separated into rain and snow), 10-m vector wind, 10-m air temperature, and specific humidity (shifted from their original height at 2 m), and sea level pressure. Our preliminary evaluation indicates that JRA-55 also needs the same kind of adjustments (bias corrections) as was done in CORE for the NCEP/NCAR reanalysis and in DRAKKAR for the ECMWF reanalysis. Necessary adjustments are applied on all elements except for sea level pressure. Time dependent adjustments are considered if spurious features due to a specific transition in the assimilation method are identified. However, to provide data on near-real time basis, adjustment factors for the most recent period will be climatological. The forcing data set also includes daily river discharge produced by operationally running a river model forced by an adjusted land surface data of JRA-55. Runoff from Greenland and Antarctica is the climatology derived from independent estimates.

The presentation will introduce the new forcing data set based on the JRA-55 reanalysis and show general

features, adjustments methods, and comprehensive assessments of the latest version.



Global ocean model development for CMIP6 in Meteorological Research Institute and its performance in reproducing ocean general circulation

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Meteorological Research Institute/Japan Meteorological Agency (MRI/JMA) has been developing an Earth System Model, MRI-ESM2.0, for CMIP6. Its ocean component called GONDOLA_100 is a global eddy-less model based on MRI Community Ocean Model (MRI.COM) version 4. This model employs the tripolar grid of Murray (1996) and its horizontal resolutions are primarily 1 degree in longitude and 0.5 degree in latitude with meridional refinement down to 0.3 degree within 10 degrees north and south of the equator. This model has 60 layers and 1 bottom boundary layer and its layer thickness ranges from 2 meters to 700 meters. We have made several improvements from our CMIP5 ocean model. For example, we adopt the second order moment scheme of Prather (1986) for tracer advection with a flux limiter of Morales Maqueda and Holloway (2006) method B. Thickness diffusion coefficients are calculated from buoyancy frequency with the use of Danabasoglu and Marshall’s (2007) scheme with modification of Danabasoglu et al. (2008). Isopycnal tracer diffusion turns into horizontal diffusion near the sea surface and in the steep slope region by using tapering method of Danabasoglu and Marshall (1995) and Large et al. (1997). This tapering method enables us to relax the upper limit of isopycnal slopes from 0.001 to 0.1. This model was integrated over 300 years by repeatedly imposing the corrected inter-annual forcing version 2 of Coordinated Ocean-ice Reference Experiments. The Atlantic meridional overturning circulation (MOC) at 26.5N reaches 16 Sv in the average from 2005 to 2007, which is still smaller than observational estimate (RAPID-MOC) but larger and more realistic than that in our old model. An unrealistic open-ocean polynya in the Weddell Sea is suppressed in GONDOLA_100, whereas our old model suffers from its frequent occurrence. Here, we discuss relationships between model developments and improvements in MOCs in our ocean model.

A preliminary hindcast experiment for CMIP6/OMIP using COCO4.9: comparison with a case forced by a new dataset JRA55-do

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A preliminary experiment for CMIP6/OMIP (Griffies et al., 2016) has been conducted by using an ice-ocean coupled general circulation model COCO4.9 (Hasumi, 2006), which is the ice-ocean component for the Model for Interdisciplinary Research on Climate version 6 (MIROC6; Tatebe et al., 2017, in preperation). Following the CMIP6/OMIP protocol, we have performed five cycles of 62-year-long experiment forced by 1948-2009 atmospheric forcing (Large and Yeager, 2009). The last cycle of the experiment shows realistic results. We have also conducted another experiment, in which the model has the same setting but is driven by a new surface dataset, JRA55-do version 1.1 (Tsujino et al., 2017, personal communication), based on the Japanese 55-year Reanalysis or JRA-55 (Kobayashi et al, 2015; Harada et al., 2016). Results of the two experiments are compared, with a focus on Arctic sea-ice. Over the last 30 years of the 20th century, climatological sea-ice extent and volume for summer and their interannual variability are similar between the two cases. On the other hand, decreasing trend in sea-ice extent and volume over the same period are significantly larger in the JRA55-do case.

Keywords: CMIP6, OMIP, JRA-55, ice-ocean coupled model, global climate modeling, Arctic Ocean

New modeling approach with probability distribution functions as a guideline for high resolution models: application for future states of the Arctic Ocean

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A new modeling approach for simulation of the future is proposed on the basis of a simple box model, with one active box for the surface layer, which interacts with the warmer and saltier box to the south and the lower box for the heavier subsurface layer. The new component to the simple model is a probability distribution function (PDF) defined at discrete grids on the temperature–salinity (*T–S*) plane, representing horizontal heterogeneity as shown in the attached figure. A *T–S* distribution retains only the probabilities of different water types, while their locations are discarded. Time progressions of the PDF are calculated as the basic equations. The mechanisms to increase and reduce heterogeneity are represented by divergence and convergence of the PDF, respectively. The heterogeneity is generated by the intrusion of exterior water and forcing variability, and reduced by horizontal diffusion within the box. Convection with the lower box tends to concentrate the PDF to the lower box (*T, S*).

This approach has provided the way to develop and use a medium resolution model, in each grid of which the PDF is implemented by representing sub-grid processes. The model results can provide guidelines about the basic behavior and performance of the high resolution models which resolve explicitly the heterogeneity represented by the PDF.

The box model with PDF has been applied for the Arctic Ocean, in which sea ice formation is decreasing under the global warming. The Atlantic Water, which flows into the Arctic Ocean partly modified under ice formation in the Barents Sea, will reduce the density of the subsurface layer (200 to 500-m depth) due to the warming. The active box of the surface layer (0 to 200-m depth) has sea ice and receives atmospheric forcing and freshwater flux, and interacts with the Greenland Sea.

The simple box model possesses a salinity-driven state, at which the saltier water enters the active box, is freshened, and becomes lighter, along with another solution, a convected state with the subsurface layer. Under the exterior condition that could produce both salinity-driven and convected states in the simple model, there are two partly convected solutions in the probability model near by the two states in the simple model, caused by the heterogeneity. As either the heterogeneity is doubled, or the subsurface layer is freshened by 0.1, the solution near the salinity-driven state has a convected portion increased, merging with the one near by the convected state. Thus, it is a possible consequence that the Arctic surface layer will be partly convected and have sea ice reduced significantly in the near future.

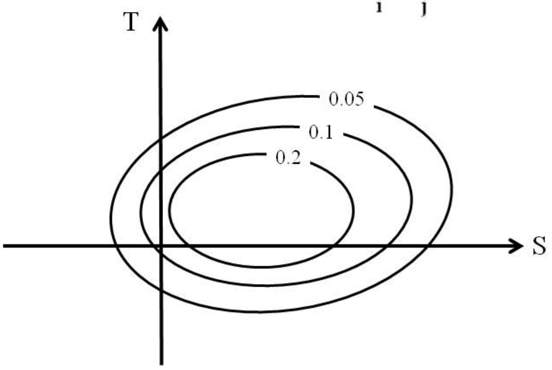
Our urgent issue is to clarify what consequences will occur due to the global warming. Under a horizontally uniform surface layer, convection hardly occurs with the subsurface layer, while heterogeneity associated with mesoscale variability, convective chimneys and sea ice leads tends to induce high density portions in the surface layer and expands convected areas. We certainly need a high resolution model with ice growth in open leads as well as convective chimneys in order to provide the future projection.

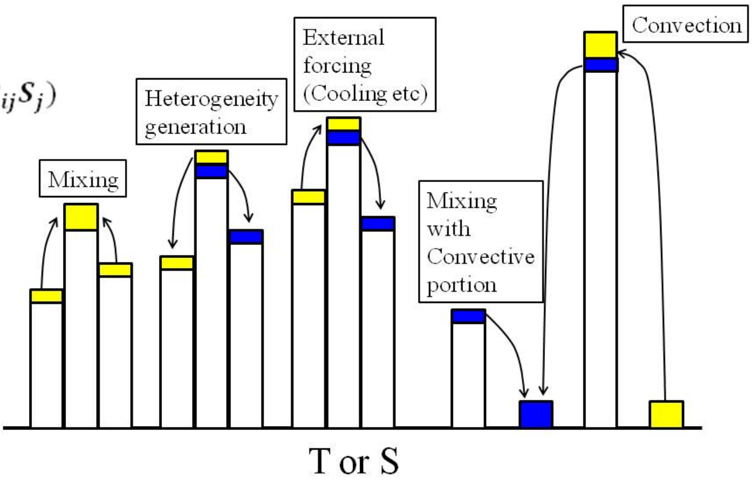
The reference is given as Ikeda (1997), *J. Phys. Oceanogr.*, **27**, 2576-2589.

Keywords: modeling guideline, probability distribution function, convection

$$(T_i, S_j) = (T_{ref}, S_{ref}) + (i\Delta T, j\Delta S)$$

$$([T],[S]) = (T_{ref}, S_{ref}) + \sum_{i}\sum_{j}(P_{ij}T_i, P_{ij}S_j)$$





Modeling of the glacial ocean carbon cycle with an ocean general circulation model

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Ice core data indicates that atmospheric carbon dioxide concentration ($pCO2^{atm}$) changed associated with glacial-interglacial cycle in last 100,000 years. In the glacial periods, $pCO2^{atm}$ was reduced by about 100 ppm compared to the interglacial periods. Variation in ocean carbon cycle is recognized as the main cause of the decline in $pCO2^{atm}$ because the storage of carbon in the land area was considered to be decreased in the cold and dry climate during the glacial period. Many previous studies using ocean general circulation models (OGCMs) tried to resolve the mechanisms of glacial $pCO2^{atm}$ but failed to reproduce the glacial CO2 reduction, quantitatively; therefore, the detailed mechanisms about glacial CO2 changes are not fully understood. In these days, paleo proxy data showed that the deep Southern Ocean in the Last Glacial Maximum (LGM) was occupied by high salinity and old water mass. This suggests that the enhanced stratification by salinity may have increased the residence time of carbon in the glacial Southern Ocean. For this reason, the Southern Ocean has been recognized as a key region for carbon uptake during glacial periods. We conducted numerical experiments using an OGCM to investigate the role of the Southern Ocean in the glacial variation of $pCO2^{atm}$; we evaluated the glacial response of ocean carbon cycles under the high salinity and long water mass age in the glacial Southern Ocean, which is suggested by previous findings from paleoclimate proxy data.

The difference in $pCO2^{atm}$ between the preindustrial control simulation and the LGM control simulation was 44.1 ppm. Changes in solubility depending on sea surface temperature and salinity, ocean circulation, and biological production in the ocean surface layers due to iron fertilization resulted in the reduction of $pCO2^{atm}$, but all of the variation of glacial $pCO2^{atm}$ could not be explained in our control experiment as in previous studies. LGM control simulation underestimated the salinity and water mass age suggested by proxy data in the Southern Ocean. We thus curried out a sensitivity experiment (LGM stratification experiment) to reproduce the salinity and water mass age in the glacial deep Southern Ocean suggested by LGM proxy data. In the LGM stratification experiment, sea bottom salinity around the Antarctica was restored to the high salinity to mimic the deep water formation process. In addition, we decreased vertical diffusivity considering the enhanced salinity stratification in the glacial Southern Ocean.

High salinity in the deep Southern Ocean resulted in increased $pCO2^{atm}$ because Antarctic Bottom Water flow increased and residence time of carbon decreased in the deep Pacific. On the other hand, weakening of vertical mixing contributed to the increase of the vertical gradient of dissolved inorganic carbon and decrease of $pCO2^{atm}$. However, it is unable to explain the full magnitude of recorded reduction of glacial $pCO2^{atm}$ in our simulations which include the above-mentioned contribution of the Southern Ocean process in addition to gas-exchange, ocean circulation, and iron fertilization changes [Kobayashi et al., 2015].

Carbonate compensation process has been reported to amplify the variation of glacial–interglacial ocean carbon cycle but it is not explicitly included in our above-mentioned simulations. We now try to evaluate the role of carbonate compensation process by coupling a newly developed simple sediment model with our OGCM.

Keywords: ocean carbon cycle, glacial-interglacial cycle, global ocean meridional overturning circulation, carbonate compensation process