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

*Simon James Marsland[1,2,3,4], Stephen M. Griffies[5], Gokhan Danabasoglu[6]

1. CSIRO Oceans and Atmosphere, Aspendale, VIC, Australia, 2. Australian Research Council Centre of Excellence for Climate System Science (ARCCSS), 3. Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC), University of Tasmania, Australia, 4. Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Australia, 5. NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA, 6. National Centre for Atmospheric Research, Boulder, CO, USA

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

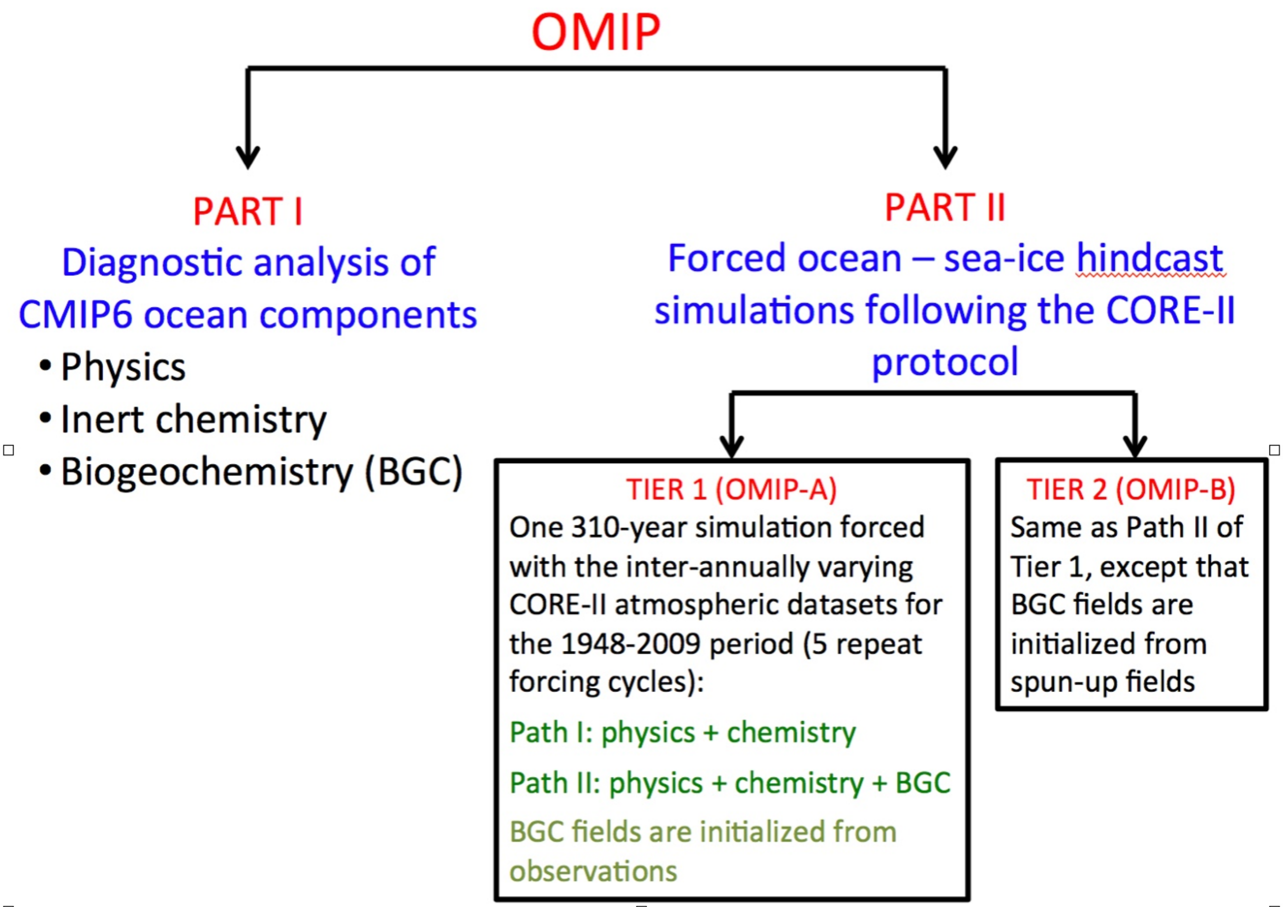


Figure 1. Schematic of OMIP overview. In the spirit of AMIP, OMIP can be considered as part of future DECK experiments. Note that OMIP is independent of any particular CMIPX.

JRA-55に基づく海洋ー海氷モデル駆動用データセット（JRA55-do）．Part I：海面大気場と大気ー海洋間フラックスデータセットの開発と検証

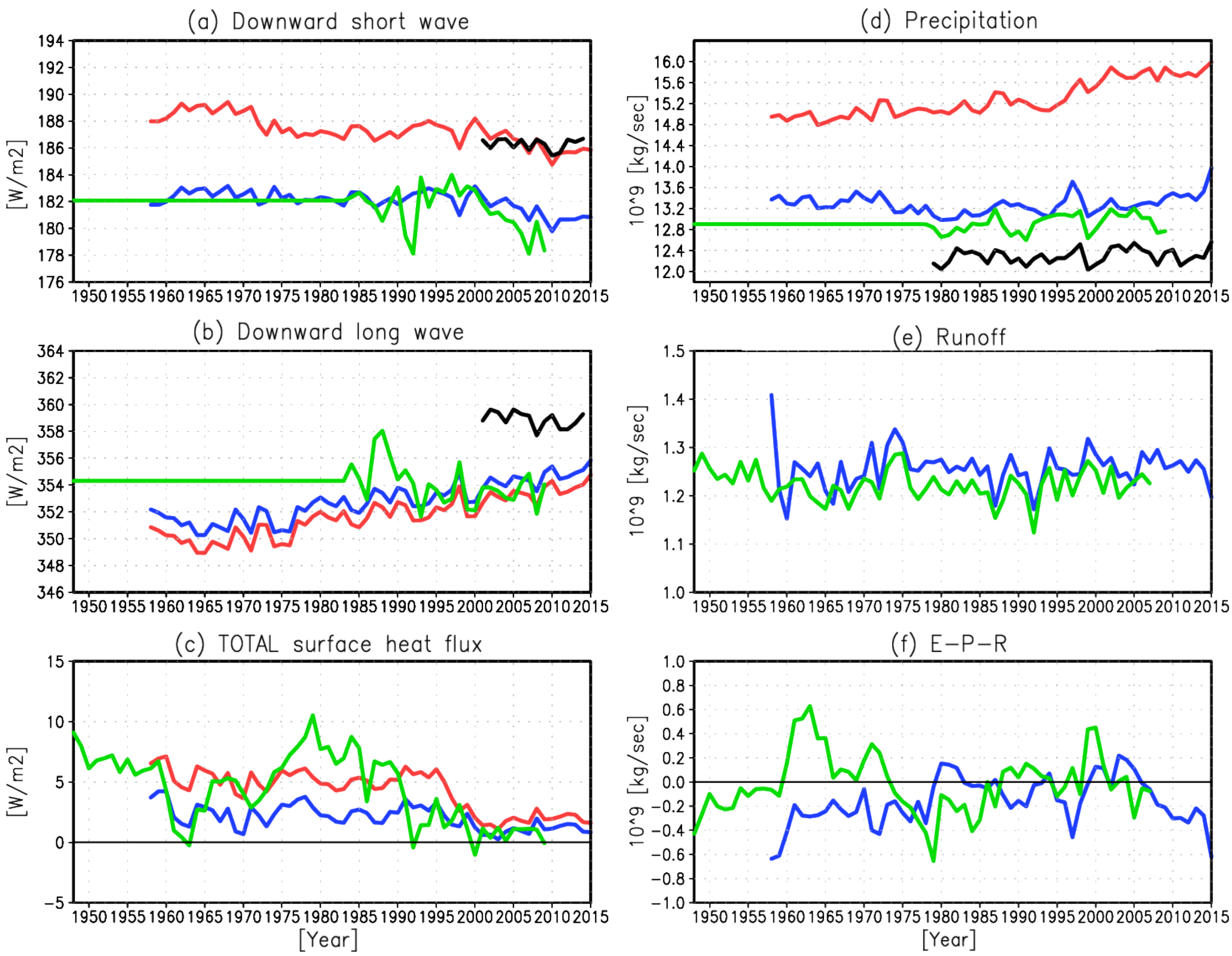
JRA-55 based surface data set for driving ocean-sea ice models (JRA55-do). Part I: Development and evaluation of surface atmospheric field and air-sea flux

*辻野 博之[1]、浦川 昇吾[1]、中野 英之[1]、Small Justin[2]、Yeager Stephen[2]、Kim Who[2]、Danabasoglu Gokhan[2]、Large William[2]、Josey Simon[3]、鈴木 立郎[4]、小室 芳樹[4]、山崎 大[4]、Griffies Stephen[5]、富田 裕之[6]、Valdivieso Maria[7]、Marsland Simon[8,10,11,9]、Dias Fabio[11,10,9,8]
*Hiroyuki Tsujino[1], Shogo L. Urakawa[1], Hideyuki Nakano[1], R. Justin Small[2], Stephen G. Yeager[2], Who M. Kim[2], Gokhan Danabasoglu[2], William G. Large[2], Simon A. Josey[3], Tatsuo Suzuki[4], Yoshiki Komuro[4], Dai Yamazaki[4], Stephen M. Griffies[5], Hiroyuki Tomita[6], Maria Valdivieso[7], Simon J. Marsland[8,10,11,9], Fabio Boeira Dias[11,10,9,8]

1. 気象庁気象研究所、2. NCAR, USA、3. NOC, UK、4. 国立研究開発法人海洋研究開発機構、5. GFDL, USA、6. 名古屋大学、7. Reading Univ., UK、8. CSIRO Oceans and Atmosphere, Austraria、9. Centre of Excellence for Climate System Science, Australia、10. Antarctic Climate and Ecosystems Cooperative Research Centre, University of Tasmania、11. Institute for Marine and Antarctic Studies, University of Tasmania
1. Japan Meteorological Agency / Meteorological Research Institute, 2. NCAR, USA, 3. NOC, UK, 4. JAMSTEC, 5. GFDL, USA, 6. Nagoya Univ., 7. Reading Univ., UK, 8. CSIRO Oceans and Atmosphere, Austraria, 9. Centre of Excellence for Climate System Science, Australia, 10. Antarctic Climate and Ecosystems Cooperative Research Centre, University of Tasmania, 11. Institute for Marine and Antarctic Studies, University of Tasmania

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.



気象研究所におけるCMIP6に向けた全球海洋モデル開発とその海洋大循環再現性能

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

*浦川 昇吾[1]、辻野 博之[1]、中野 英之[1]、坂本 圭[1]、山中 吾郎[1]
*Shogo Urakawa[1], Hiroyuki Tsujino[1], Hideyuki Nakano[1], Kei Sakamoto[1], Goro Yamanaka[1]

1. 気象庁気象研究所
1. Meteorological Research Institute, Japan Meteorological Agency

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

*小室 芳樹[1]、建部 洋晶[1]、鈴木 立郎[1]、黒木 聖夫[1]、渡辺 路生[1]
*Yoshiki Komuro[1], Hiroaki Tatebe[1], Tatsuo Suzuki[1], Masao Kurogi[1], Michio Watanabe[1]

1. 国立研究開発法人海洋研究開発機構
1. Japan Agency for Marine-Earth Science and Technology

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.

キーワード：CMIP6、OMIP、JRA-55、海氷-海洋結合モデル、全給気候モデリング、北極海
Keywords: CMIP6, OMIP, JRA-55, ice-ocean coupled model, global climate modeling, Arctic Ocean

確率分布関数を導入したモデルによる高解像度モデル開発への指針：北極海予測への応用

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

*池田 元美[1,2]
*Motoyoshi Ikeda[1,2]

1. 北海道大学、2. 海洋研究開発機構
1. Hokkaido University, 2. JAMSTEC

将来予測のためのモデル開発を目指し、簡略ボックスモデルに確率分布関数（PDF）を導入した。北極海表層をボックスで表し、高密度の亜表層と鉛直混合すると共に、高温高塩分の大西洋とは海水交換する。海水温（T）と塩分濃度（S）平面上のグリッドで定義されたPDFは、水平方向の不均一性を表す（下図参照）。T–S分布は異なる水塊の存在確率を示すが、ボックス内での位置は保持しない。PDFの時間変動を基礎方程式として数値的に解く。その不均一性は外部海水と大気などの駆動力による変動によって増幅し、ボックス内の水平混合によって低下する。亜表層との鉛直混合は、PDFをその（T, S）に引き込む。

本研究ではボックスモデルを用いたが、中程度の解像度を持つ数値モデルの各グリッドにPDFを導入して、サブグリッド現象を表すことも可能である。その結果は、PDFモデルでは不均一性とされたプロセスを陽に表す高解像度モデルに関して、その挙動を示すと考えられる。

このPDFボックスモデルを、地球温暖化によって海氷が減少している北極海に応用する。大西洋から流入する海水は、バレンツ海を経由する際に海氷生成が低下すると塩分追加が減り、北極海表層（0ー200m深）と亜表層（200ー500ｍ深）の密度差が小さくなる。表層ボックスは大気の影響と河川水流入を受け、南のグリーンランド海と海水交換し、亜表層と鉛直混合する。

簡略ボックスモデルは、グリーンランド海から流入する海水を低塩化して戻す塩分駆動解、および亜表層と完全に混合する対流解を持っている。PDFボックスモデルは、季節変動に相当する不均一性増幅を与えると、簡略ボックスモデルの塩分駆動解に近い解と、対流解に近い解の２つを持つ。他の条件は同じにして、不均一性を２倍にするか、あるいは亜表層塩分を0.1だけ下げると、対流解に近い解のみに収束する。すなわち、近い将来において、北極海表層が亜表層と混合し、その海氷が顕著に減少する状態が起こりうることが示された。

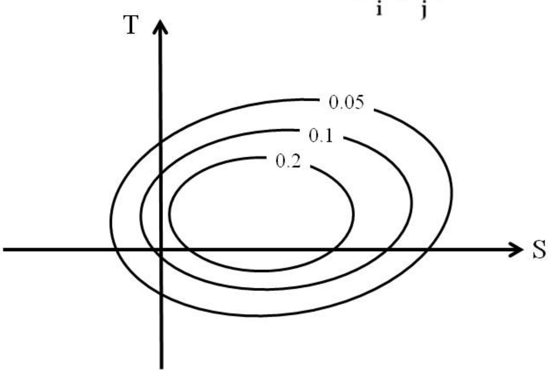
地球温暖化によって海氷分布に出る影響を明らかにすることは喫緊の課題である。表層が水平に一様であると亜表層と混合しにくいが、中規模変動、対流チムニー、海氷リードなどの不均一性があると、一部で表層が高密度になり鉛直混合が拡大する。将来予測への示唆として、海氷リード中の結氷と対流チムニーまで考慮したモデルが必要である。

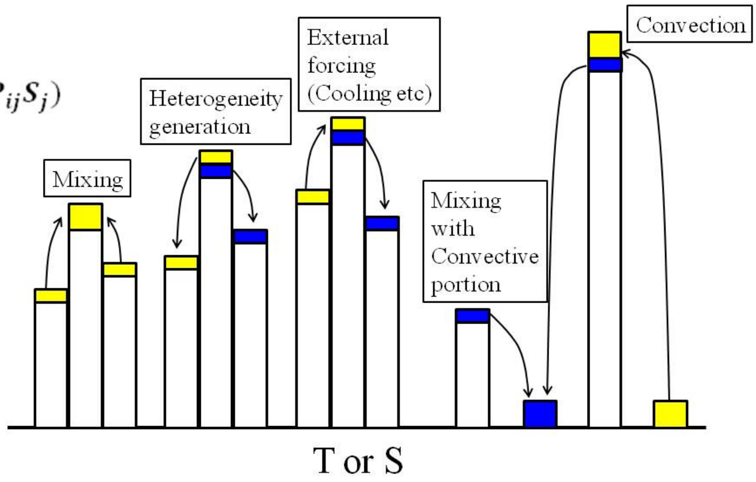
文献：Ikeda, M., 1997: *J. Phys. Oceanogr.*, **27**, 2576-2589.

キーワード：モデル開発指針、確率分布関数、対流
Keywords: modeling guideline, probability distribution function, convection

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

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





氷期の海洋炭素循環の理解に向けた海洋大循環モデルによる数値シミュレーション
Modeling of the glacial ocean carbon cycle with an ocean general circulation model

*小林 英貴[1]、岡 顕[1]
*Hidetaka Kobayashi[1], Akira Oka[1]

1. 東京大学大気海洋研究所
1. Atmosphere and Ocean Research Institute, The University of Tokyo

南極氷床コアの分析から、最近約 100 万年間の氷期–間氷期サイクルにおいて気温の変動に伴い大気中二酸化炭素濃度が変動し、氷期は間氷期に比べて大気中二酸化炭素濃度が約 100ppm 低下していたことが明らかになった。氷期は寒冷で乾燥した気候のため、陸域への炭素貯蔵は減少していたと考えられ、海洋炭素循環の変動が大気中二酸化炭素濃度の低下の主要因であると認識されている。しかしながら、氷期の低い大気中二酸化炭素濃度は、これまでに行われた海洋大循環モデルを用いた数値実験では十分に再現できず、変動メカニズムの詳細は未解明である。近年の古海洋プロキシデータから、最終氷期(LGM)の南大洋深層が高塩分で古い水塊で占められていたことが示唆され、塩分による密度成層の強化で深層の水塊年齢が増加し、炭素の蓄積が増加した可能性が考えられている。そこで本研究は、海洋大循環モデル(OGCM)を用いた数値実験を行い、塩分や水塊年齢についてのデータとモデル結果との直接の比較を行った上で、氷期の低い大気中二酸化炭素濃度に対する南大洋の過程の役割を定量的に評価した。

現代標準実験と LGM 標準実験の大気中二酸化炭素濃度の差は 44.1ppm で、海面水温・塩分に依る溶解度と、海洋循環、鉄肥沃化に依る海洋表層の生物生産の変化でもたらされた。先行研究と同様に、氷期の低い大気中二酸化炭素濃度の全てを説明することはできなかった。また、LGM 標準実験の南大洋深層において、プロキシデータが示唆するような高い塩分や水塊年齢の増加は見られなかった。そこで、LGM のデータが示唆する南大洋深層の塩分と水塊年齢の増加を再現するため、南大洋底層において高塩分への緩和と密度成層の強化を考慮した鉛直拡散係数の変化を与える感度実験を行った(LGM 成層化実験)。

LGM 成層化実験において、南大洋深層の高塩分は南極底層水の流量の増加をもたらし、深海で炭素の滞留時間が減少したため、大気中二酸化炭素濃度が増加した。一方、南大洋の鉛直混合の弱化は、溶解無機炭素の鉛直勾配を増加させ、大気中二酸化炭素濃度の減少に寄与した。しかしながら、気体交換や海洋循環ならびに生物生産の変化に加えて、上記の南大洋過程の貢献を含めたものの、氷床コアデータが示す氷期の低い大気中二酸化炭素濃度の全てを説明することはできず、現代標準実験と LGM 成層化実験の大気中二酸化炭素濃度の差は 50.5ppm であった [Kobayashi et al., 2015]。

海水中の溶存物質と炭酸塩堆積物との相互作用による炭酸塩補償過程は、氷期–間氷期の海洋炭素循環の変動を増幅すると報告されているが、この過程は上記の数値実験には含まれていない。そこで、新たに開発した単純な堆積物モデルを OGCM と組み合わせることにより、海洋内部の溶存物質の総量の変化をもたらす炭酸塩補償過程の役割を評価することを試みる。本発表ではこの数値実験の結果についても紹介する予定である。

キーワード：海洋炭素循環、氷期/間氷期サイクル、海洋子午面循環、炭酸塩補償過程
Keywords: ocean carbon cycle, glacial-interglacial cycle, global ocean meridional overturning circulation, carbonate compensation process

Continental river discharge for additional dataset of JRA55-do to drive a global ocean circulation model

*Tatsuo Suzuki[1], Dai Yamazaki[1], Hiroyuki Tsujino[2], Yoshiki Komuro[1], Hideyuki Nakano[2], Shogo Urakawa[2]

1. Japan Agency for Marine-Earth Science and Technology, 2. Meteorological Research Institute, Japan

A dataset of historical daily river discharge into oceans has been created using Global river routing model CaMa-Flood (Yamazaki et al., 2011) forced by runoff data from the land surface component of JRA-55 (Kobayashi et al. 2015). The major continental rivers are well resolved with 0.25-degree horizontal resolution. The total runoff on each drainage basin have some distinctive bias. Therefore, the input runoff data is modified by 5-year low pass filtered multiplicative factors to fit the long time mean and decadal variations of the major continental rivers and total river discharge into the individual basins to the reference dataset of Dai et al. (2009). The model is calculated from 1958 to 2016. The yearly and seasonal variations of major rivers are reasonably represented. This data production is planned to be update following the JRA-55.

Keywords: River discharge, Ocean modeling, JRA55

JRA-55 に基づく海洋ー海氷モデル駆動用データセット（JRA55-do）．Part II: 本データセットによって駆動した全球海洋ー海氷モデルの結果の検証

JRA-55 based surface data set for driving ocean-sea ice models (JRA55-do). Part II: Assessment on the results of global ocean-sea ice models forced by the data set

*辻野 博之[1]、浦川 昇吾[1]、中野 英之[1]、Small Justin[2]、Yeager Stephen[2]、Kim Who[2]、Danabasoglu Gokhan[2]、Large William[2]、Josey Simon[3]、鈴木 立郎[4]、小室 芳樹[4]、山崎 大[4]、Griffies Stephen[5]、富田 裕之[6]、Valdivieso Maria[7]、Marsland Simon[8,9,10,11]、Dias Fabio[11,10,9,8]
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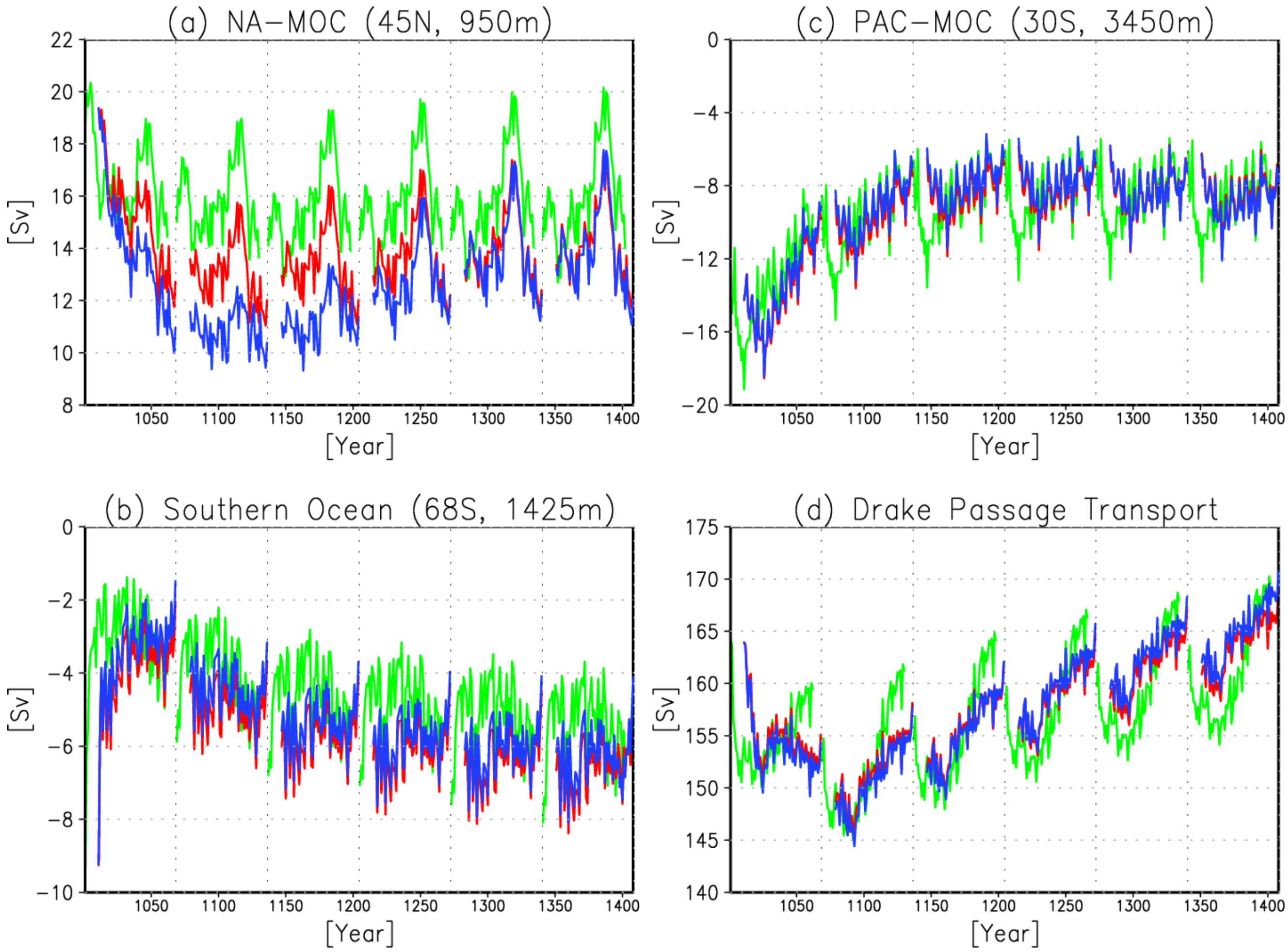
1. 気象庁気象研究所、2. NCAR, USA、3. NOC, UK、4. 国立研究開発法人海洋研究開発機構、5. GFDL, USA、6. 名古屋大学、7. Reading Univ., UK、8. CSIRO Oceans and Atmosphere, Australia、9. Centre of Excellence for Climate System Science, Australia、10. Antarctic Climate and Ecosystems Cooperative Research Centre, University of Tasmania、11. Institute for Marine and Antarctic Studies, University of Tasmania
1. Japan Meteorological Agency / Meteorological Research Institute, 2. NCAR, USA, 3. NOC, UK, 4. JAMSTEC, Japan, 5. GFDL, USA, 6. Nagoya Univ., Japan, 7. Reading Univ., UK, 8. CSIRO Oceans and Atmosphere, Australia, 9. Centre of Excellence for Climate System Science, Australia, 10. Antarctic Climate and Ecosystems Cooperative Research Centre, University of Tasmania, 11. Institute for Marine and Antarctic Studies, University of Tasmania

The surface data set for driving ocean-sea ice models based on JRA-55 (JRA55-do) presented in the companion paper (Part I) was used to force global ocean-ice models. The result was compared with the one forced by the CORE-II data set used in the current CORE / OMIP framework. The experiments followed the CORE / OMIP protocol: Integration starts from the state of rest with climatological temperature and salinity and lasts for about 300 years by repeatedly using the 58-year (1958-2015) forcing data set for five times. Sea surface salinity is weakly restored to climatology. Water volume and salt content in the ocean - sea ice system are kept fixed by adjusting surface fluxes every time step.
The two simulations by a JMA/MRI’s global ocean model, differing only in the surface forcing, largely showed similar features in the last (5th) forcing cycle in terms of mean state, biases, and interannual variability. However, there were two non-trivial differences in relation to the meridional overturning circulation (MOC). First, in the JRA55-do forced run, the Atlantic MOC (A-MOC) declined in the early stage, touching the minimum of about 11 Sverdrups (Sv) in the 2nd cycle. However, it gradually recovered to reach about 16 Sv in the last (5th) cycle. The mean A-MOC strength in the last cycle (16 Sv) was weaker than that of the CORE-II forced run by about 2 Sv, which would warrant a dedicated investigation in the future. The second noticeable difference was the formation of open water Polynyas in the Weddell Sea in the last cycle of the JRA55-do forced run. To understand these differences in the simulation results, we performed sensitivity experiments with the runoff from Greenland and Antarctica of JRA55-do being replaced by that of CORE-II. This is because the run-off from Greenland of JRA55-do has been increased by an order of magnitude relative to CORE-II and the run-off from Antarctica in JRA55-do has spatial distribution as opposed to the uniform distribution in CORE-II. In the sensitivity run, the initial decline of the A-MOC diminished (the minimum is about 14 Sv in the 2nd cycle), but the A-MOC in the last cycle was

almost identical with the original run. This may imply that, in the presence of weak surface salinity restoring, an anomalous fresh water forcing from Greenland will certainly have impacts on the strength of A-MOC in a short term, but that the A-MOC is resilient in a longer term. The formation of open water Polynyas in the Weddell Sea did not occur with the CORE-II run-off around Antarctica. The less (more) run-off east (west) of the Antarctic Peninsula than CORE-II may have caused this difference in the model behaviors. This would warrant some improvements in the representation of cryosphere-ocean interactions in models.

In the poster, results from other ocean modeling groups will be included to investigate whether the above results depend on a particular model or not.



Tuning a North Pacific OGCM with regard to the Kuroshio Current System.

*中野 英之[1]、辻野 博之[1]、坂本 圭[1]、浦川 昇吾[1]、山中 吾郎[1]
*Hideyuki Nakano[1], Hiroyuki Tsujino[1], Kei Sakamoto[1], Shogo Urakawa[1], Goro Yamanaka[1]

1. 気象研究所
1. Meteorological Research Institute

Meteorological Research Institute/Japan has been developing the next generation of monitoring and forecasting system of the north western Pacific Ocean. One of the main targets is the Kuroshio Current System, which is composed of the Kuroshio, Kuroshio Extension (KE) and its recirculation gyres. Due to the enormous effects of the Kuroshio Current System on the various aspects of the North Pacific, its better representation is essential for the overall performance of the system. Here, we consider the performance of a North Pacific model in that system. The North Pacific model with a resolution of about 1/10 degree is nested in a global ocean model with a resolution of 1 x 1/2. This model is also used for nesting a Japan Model, which simulates ocean near Japan with about 2 km resolution. In hindcast experiments under JRA55-do forcing, the North Pacific model can represent a realistic KE separation. Nevertheless, it had following shortcomings until tunings were conducted. (1) The eastward extension of the KE was limited near Japan and the eddy kinetic energy around the KE and the recirculation gyres is too weak compared to the AVISO. (2) The path of the Kuroshio south of Japan south was too unstable, sometimes causing an unrealistic high frequency of large meander of the Kuroshio. After trial and error, we have found that following parameters can be used to mitigate the above problems. (A) Dependency of the ocean surface current to calculate the surface wind stress. (B) Boundary viscosity south of Japan. The former parameter (A) appears in the following bulk formulation in calculating wind stress. Tau = rho C|U - u|(U −αu), where rho is the density of air sea level, C is the drag coefficient, U is the wind velocity and u is the ocean surface velocity. We introduce “α”, which describes the relative contribution of ocean surface velocity to the bulk formulation. Intuitively, this coefficient seems one, but in reality, it is not so simple because the momentum and energy transfer between the wind and ocean is caused not only by simple drag of the ocean current, but also through the excitation, spread, and break of ocean surface waves. We consider the parameter can take a value between 0 –1, and use this for a kind of turning parameter of the OGCM rather than going deeply into the detail mechanism. We have found that the KE is quite sensitive to the small change of this parameter. For the North Pacific model, the parameter is set to 0.05. Changing this value to 0.10 leads to significant reduction of eddy kinetic energy around the KE. We do not claim that this value is universal and physically correct. But we consider that this parameter can be a useful tuning parameter for the Kuroshio Extension. The latter parameter (B) is applied by using a large harmonic viscosity in the region near the southern coast of Japan. This works to stabilize the Kuroshio south of Japan, which tends to behave too vigorously. Too large value results in the failure of separation and reduction of eddy kinetic energy downstream along the KE. We set this as 2.5m^2/s. This parameter may represent unknown missing mechanism that stabilizes the Kuroshio path in reality. The former parameter, α, also can be used for this purpose. But to stabilize the path of the Kuroshio, the value of α should be increased and will not be suitable for the KE. The combined use of these two parameters enable us to tune the Kuroshio and KE separately.

キーワード：海洋モデル、黒潮、黒潮続流、チューニング
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