Eddy-permitting Ocean Circulation Hindcasts Of Past Decades

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1. Introduction

Research conducted by the DRAKKAR consortium is motivated by open questions related to the variability of the ocean circulation and water mass properties during past decades, and their effects on climate through the transport of heat. Of primary concern is the circulation and the daily-to-decadal variability in the North Atlantic Ocean, as driven by the atmospheric forcing, by interactions between processes of different scales, by exchanges between basins and regional circulation features of the North Atlantic (including the Nordic Seas), and by the influence of the world ocean circulation (including the Arctic). DRAKKAR carries out these investigations using a hierarchy of high resolution model configurations based on the NEMO system (Madec, 2007). Simulation outputs are carefully evaluated by comparison with collocated existing observations (Penduff et al., this issue).

The DRAKKAR consortium was created to take up the challenges of developing realistic global eddy-resolving/permitting ocean/sea-ice models, and of building an ensemble of high resolution model hindcasts representing the ocean circulation from the 1960s to present. The Consortium favours an integration of the complementary expertise from every member of the group; the coordination of a simulation program that builds a consistent ensemble of 50 year long hindcasts; and an increase of available manpower and computer resources.

2. DRAKKAR hierarchy of models

A hierarchy of embedded model configurations of different grid resolution (from coarse to eddy-resolving) has been constructed to make possible realistic, long term (several decades) simulations of the ocean/sea-ice circulation and variability at regional and global scale, and to perform sensitivity studies investigating key dynamical processes (requiring especially high resolution) and their impact at larger scales. The DRAKKAR model configurations are used by the participating research teams to address their scientific objectives. All configurations are based on the NEMO Ocean/Sea-Ice GCM numerical code and use the quasi-isotropic global ORCA grid (Madec, 2007).

2.1. Global ORCAii configurations

Global DRAKKAR configurations span resolutions of 2° (ORCA2), 1° (ORCA1), 1/2° (ORCA05) and 1/4° (ORCA025, Fig. 1 page 14).

The targeted configuration for the ensemble of hindcasts is the eddy permitting ORCA025, extensively described in Barnier et al. (2006). Such eddy-permitting models are still worth exploring and enhancing, since they will be the target resolution of the next generation of climate models. The ORCA grid becomes finer with increasing latitude, so the effective 1/4° resolution is 27.75 km at the equator and 13.8 km at 60°S or 60°N. It is ~7 km in the center of the Weddell and Ross Seas and ~10 km in the Arctic. In the vertical, there are 46 levels with partial steps in the lowest level. Coarser resolution configurations ORCA05, ORCA1, and ORCA2 are as similar as possible to ORCA025. The AGRIF refinement package (Debreu et al., 2007) allows local grid refinements as shown in the Agulhas Retroflection region (Fig. 1, Biastoch et al., 2007).

2.2. Regional NATLii configurations

Two North Atlantic/Nordic Seas configurations have been implemented: the 1/4° eddy-permitting NATL4 configuration (extracted from ORCA025), and the 1/12° eddy-resolving NATL12 configuration (Fig. 2). Both include prognostic sea-ice, and use open boundary conditions where information provided by the global hindcast experiments can be applied. The NATL12 resolution reaches 4.6 km at 60°N.

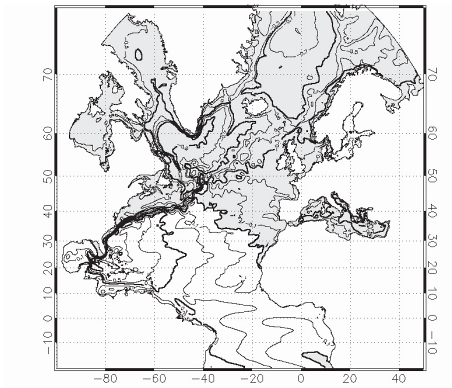

Fig. 2. The NATL12 domain (1615×1585×50 grid points with partial step) and the 2004-2006 mean SSH (in meter, contour interval of 0.1) from a hindcast started in 1998 (MERCATOR-Océan)

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3. 1958-2004 global 1/4° hindcasts carried out in 2006

A key objective of DRAKKAR is to perform long term simulations of the atmospherically driven ocean circulation and variability over the last 50 years with the ORCA025 configuration. A coordinated series of simulations were conducted in 2006 at LEGI (G70), IFM-GEOMAR (KAB0012, KAB002) and KNMI (KNM01) (Table 1), which compare the ability of the Coordinated Ocean adn sea-ice Reference Experiment (CORE) (Large & Yeager, 2004, LY04) and ERA40 atmospheric forcing data sets, and of different T,S restoring scenarios to control the strength of the Atlantic meridional overturning cell (AMOC) and global T,S drifts.

ORCA025 2006 sensitivity experiments				
Run	G70	KAB001	KAB002	KNM01
Integration period	1958-2004	1958-2004	1985-2004	1958-2004
Radiation fluxes	CORE	CORE	CORE	CORE
Turbulent fluxes	ERA40	CORE	CORE	ERA40
Precipitation	CORE*	CORE	CORE	CORE*
SSS restoring	60 days	300 days	60 days	60 days
SSS restoring under sea-ice	15 days	300 days	60 days	None
3D T,S restoring in polar areas	None	180 days	None	None
Transient Tracers	CFC_{11},C_{14b}	CFC_{11}, SF_6	CFC_{11}, SF_6	CFC_{11},C_{14b}

Table 1: Forcing parametersof the different experiments. The KNM01 experiment has not been analysed yet. KAB002 is started from KAB001 on January 1st 1985.

All experiments use the downward shortwave and longwave radiation forcing from CORE (derived from satellite ISCCP products), these variables being significantly biased in ERA40 (Brodeau et al., 2006). Turbulent fluxes are calculated using LY04 bulk formulas, input variables being wind components, air temperature and air humidity. Restoring of varying strengths to climatological sea surface salinity (SSS) is also used. In addition, for the rather uncertain precipation, two different versions were used: the original CORE fields and a modified version, CORE*, in which original CORE precipation is reduced northward of 30°N by 15-20%.

3.1. Global drifts

Fig. 3 shows the global drift in temperature and sea surface height (SSH). G70 exhibits the smallest SSH drift in 47 years, partly a consequence of the restoring to SSS but also due to an excess of freshwater (and therefore volume) in the CORE data. The comparison of KAB001 and KAB002 demonstrates that this drift is more than doubled by the 3D T,S restoring applied in polar oceans in KAB001. Drifts are very comparable in G70 and KAB002 for temperature (0.001°C/y corresponding to a surface heat flux imbalance of -0.18 Wm-2), suggesting that CORE and ERA40 turbulent fluxes have similar effects on the model drift

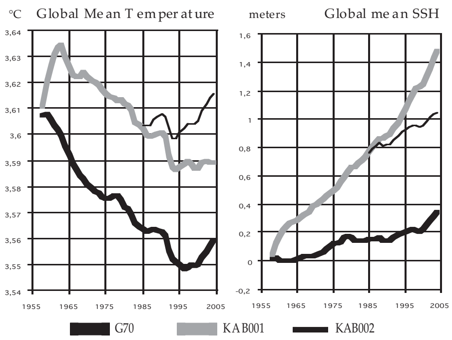

Fig. 3: Evolution of global ocean average temperature and sea level in G70, KAB001 and KAB002

3.2. Atlantic Meridional Overturning Circulation (AMOC) and deep overflows

The strongest AMOC is obtained with the ERA40 forcing and reduced northern hemisphere precipitation (G70), with a maximum of 17 Sv at 35N (Fig. 4). With the CORE forcing, an AMOC of similar structure and reasonable strength (above 14 Sv at 35N) is obtained only with the 3D restoring at polar latitudes (KAB001, not shown). Without this restoring, it collapses to under 12 Sv (KAB002, not shown). Other series of experiments with ORCA2, ORCA1 and ORCA05 confirmed that the AMOC obtained using original CORE turbulent fluxes and precipitation is significantly weaker than that obtained from ERA40 and reduced CORE precipitation in the northern hemisphere. Results from ORCA1 also highlight the importance of strong under-ice SSS relaxation in maintaining a strong AMOC.

Fig. 5 page 14 demonstrates that the weak 3D T,S restoring in polar seas (KAB001) maintains realistic dense overflows at the Nordic sills over the 47 years, whereas these waters rapidly disappear when this condition is removed in KAB002 (with a subsequent decrease of the AMOC). Meanwhile, the use of ERA40 turbulent fluxes instead of NCEP in the CORE data set, in combination with a modification (reduction) of the CORE precipation over the Arctic Ocean, allows a reasonable dense water transport at the sills to be maintained without a relaxation of this kind.

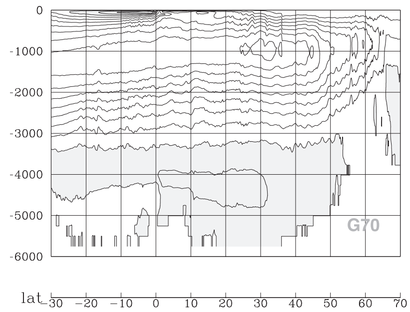

Figure 4: Mean (1990-2004) AMOC in the North Atlantic for hindcast G70. Negative vaues are shaded grey and contour interval is 2 Sv. Fig. 6:

Also the freshwater balance and its effect on the deep water formation in the Labrador Sea seem to be critical in this respect. Further sensitivity experiments are underway to identify the critical model factors governing this behaviour.

3.3. Sea-ice

ORCA025 hindcasts show a decrease of the Arctic sea-ice area since the early 1980's, as seen in satellite data. Arctic sea-ice area and concentration generally compare well with observations, in spatial patterns as well as integral values (Fig. 6, page 14). Sea-ice volume (not shown) is larger (and more realistic) in experiments using CORE turbulent fluxes (ice is too thin with ERA40). The simulation of Antarctic sea-ice is less satisfactory, with too little ice remaining in summer, and an overly large winter ice extent.

3.4. Long term variability

Hindcasts from the various integrations tend to simulate very comparable long term variabilities, i.e. an increase of the AMOC maximum (Fig. 7) in the 1980's and early 1990's and a significant decrease from the mid 1990's. However, important year-to-year differences are observed which need to be explained.

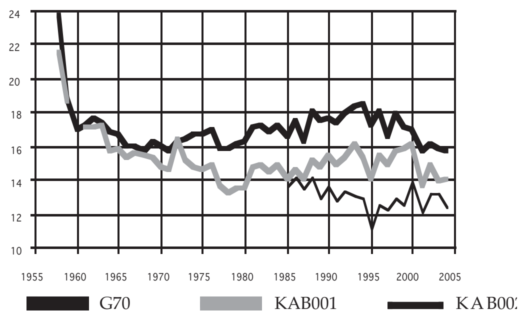

Fig. 7: Variation of the AMOC maximum in the North Atlantic in hindcasts G70, KAB001 and KAB002.

All hindcasts do a remarkable job in simulating the observed El Nino related variability (Fig. 8). However, the SST is biased warm (by a few tenths of a degree, but sometimes up to 1°C) when ERA40 the turbulent fluxes are used instead of CORE

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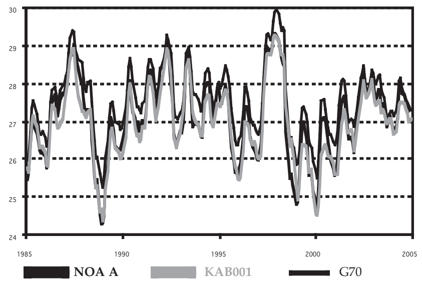

Fig. 8: Time evolution of the monthly mean ocean surface temperature (°C) in the Nino Box 3-4 in hindcasts G70, KAB001 and NOAA observations. Curve for the KAB002 run (not shown) is almost identical to KAB001.

Finally, it is obvious that applying a 3D restoring on T,S might have an impact on the simulated variability. This is illustrated in the Antarctic Circumpolar Current (ACC) transport (Fig. 9). Hindcasts without 3D restoring (G70 and KAB002) show that more than 20 years of spin-up are necessary before the ACC transport stabilises. Note that ACC transport will likely remain stronger (above 120 Sv) in KAB002 than in G70 (above 110 Sv) because of stronger winds in CORE. This spin-up phase does not exist when 3D T,S relaxation is applied at polar latitudes (beyond 50S) in KAB001. This strongly suggests that the spin-up is due to the adjustment of the mass field at high southern latitudes. The long term variability is quite different in G70 and KAB001, e.g. the latter experiment does not show the decadal oscillations typical of G70. Although weak, this relaxation tends to seriously limit the low-frequency variability.

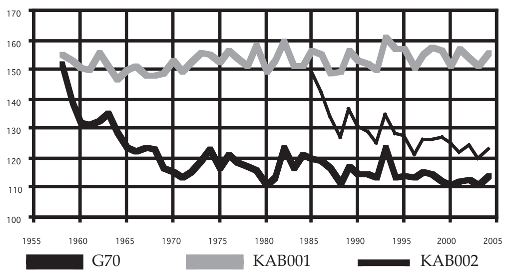

Fig. 9: Mean transport (in Sv) at Drake Passage in hindcasts G70, KAB001, and KAB002.

4. Conclusion

Series of ~50-year hindcasts (of which a small part is described here) have been carried out with the DRAKKAR hierarchy of model configurations, which has allowed improvements in model numerics, parameterizations and surface forcing. The hybrid forcing using CORE radiation fluxes and precipitation fields with ERA40 turbulent variables (wind, air temperature and air humidity), referred to as the DRAKKAR Forcing Set #3 (DFS3) is currently our best choice to obtain an AMOC of realistic strength with the ORCAii configurations. Comparison of CORE and DFS3 driven hindcasts is presently under investigation and already indicates new directions for improvements for the next forcing set (DFS4) now under construction. DRAKKAR hindcasts planned for 2007 will concern the model sensitivity to sea-ice parameters and freshwater fluxes, the objective being to completely remove any restoring to SSS. Hindcasts with the eddy-resolving configuration NATL12 will also begin. The DRAKKAR hindcast database is available upon request to research scientists outside the consortium. Additional information about DRAKKAR can be found on the project web site (www.ifremer.fr/lpo/drakkar).

Acknowledgments

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Guoxiong Wu

Congratulations to Professor Guoxiong Wu on his election as the new President of the International Association of Meteorology and Atmospheric Sciences (IAMAS). Guoxiong is a past CLIVAR SSG member and is now a member of the Joint Scientific Committee for WCRP.

Howard Cattle

From Barnier et al, page 8: Eddy-permitting Ocean Circulation Hindcasts of Past Decades

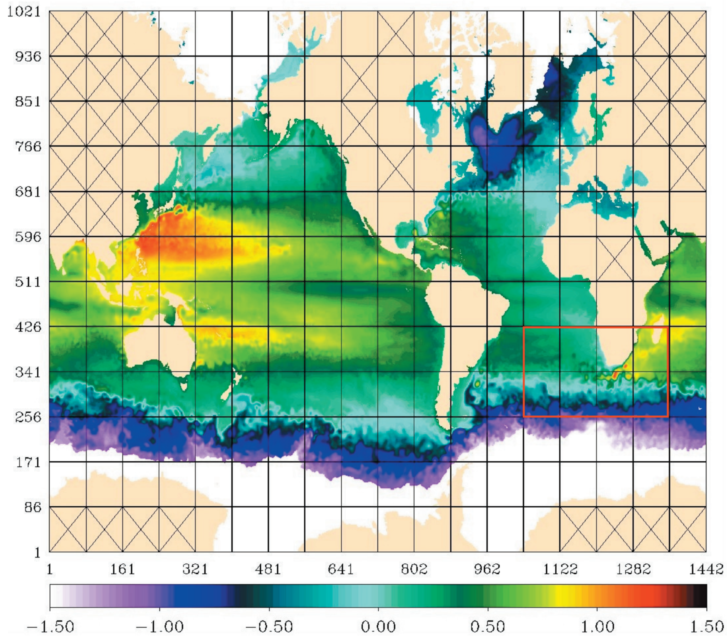
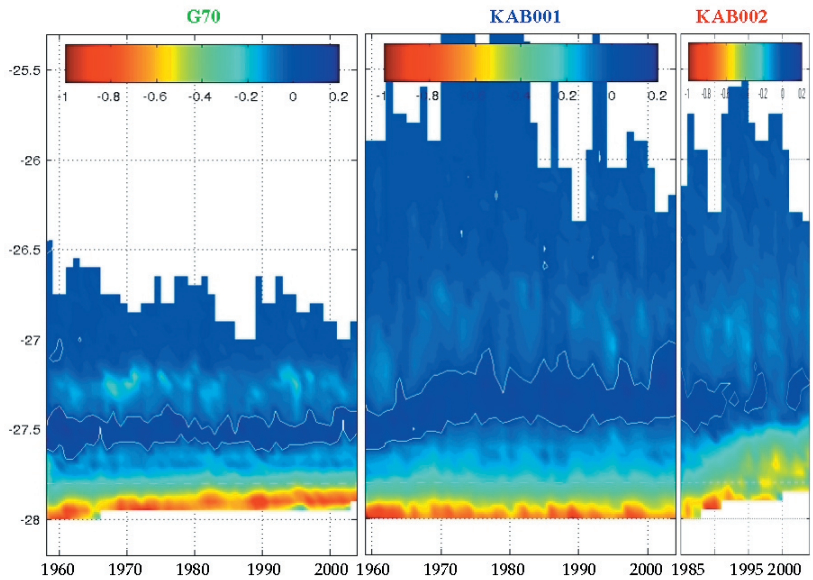


Fig. 1: ORCAii global configurations. The model domain and land-sea mask are shown for the 1⁄4° ORCA025 configuration (axes correspond to grid points). Colours show a SSH snapshot (in meter) on June 24, 1998 from one of the hindcast runs (G70), sea-ice cover being in white. Boxes show the domain decomposition on a large number of processors, ocean processors (not marked by a cross, 186 of those) being the only ones retained in the calculation. On vector computers a more moderate parallelization (typically up to 32 processors) is used. The red box is the region where a 2-way grid refinement at 1/10-1/12°is being implemented.

Figure 5: Evolution of the annual mean transport (in Sv) by density classes across the Denmark Strait. Negative values indicate a flow from the Nordic Seas into the Atlantic. The zero contour line is shown in white.



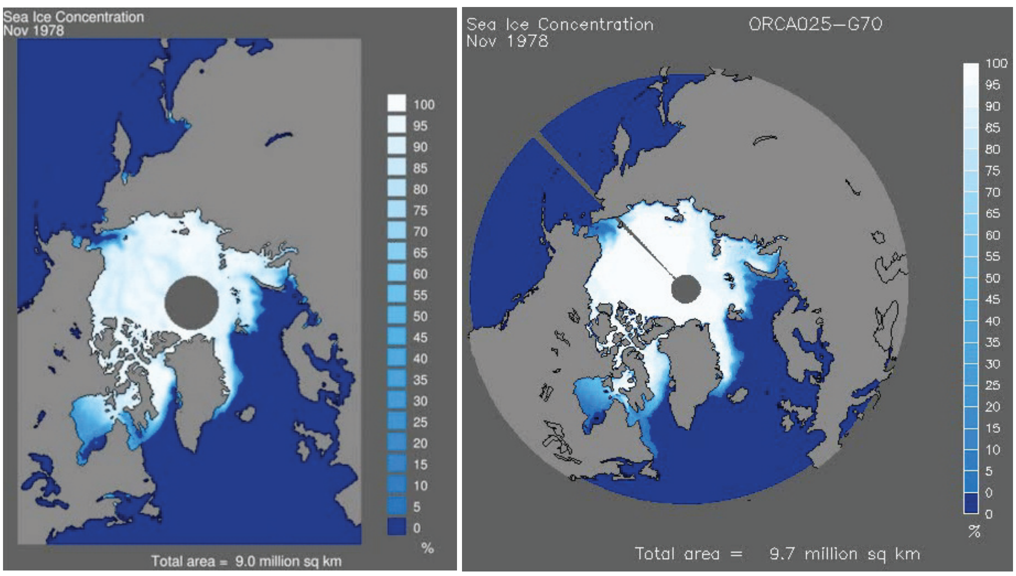


Fig. 6: Monthly mean sea-ice concentration and total area in November 1978 (left) from satellite observations (Sea Ice index, Fetterer and Knowles, 2002) and(right) from the G70 hindcast.