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North Atlantic simulations in Coordinated Ocean-ice Reference Experiments phase II (CORE-II). Part II: Inter-annual to decadal variability

Gokhan Danabasoglu[a,*], Steve G. Yeager[a], Who M. Kim[b], Erik Behrens[c], Mats Bentsen[d], Daohua Bi[e], Arne Biastoch[c], Rainer Bleck[f,g], Claus Böning[c], Alexandra Bozec[h], Vittorio M. Canuto[g], Christophe Cassou[i], Eric Chassignet[h], Andrew C. Coward[j], Sergey Danilov[k], Nikolay Diansky[l], Helge Drange[m], Riccardo Farneti[n], Elodie Fernandez[i,o], Pier Giuseppe Fogli[p], Gael Forget[q], Yosuke Fujii[r], Stephen M. Griffies[s], Anatoly Gusev[l], Patrick Heimbach[q], Armando Howard[g,t], Mehmet Ilicak[d], Thomas Jung[k], Alicia R. Karspeck[a], Maxwell Kelley[g], William G. Large[a], Anthony Leboissetier[g], Jianhua Lu[h], Gurvan Madec[u], Simon J. Marsland[e], Simona Masina[p,v], Antonio Navarra[p,v], A.J. George Nurser[j], Anna Pirani[w], Anastasia Romanou[g,x], David Salas y Mélia[y], Bonita L. Samuels[s], Markus Scheinert[c], Dmitry Sidorenko[k], Shan Sun[f], Anne-Marie Treguier[z], Hiroyuki Tsujino[r], Petteri Uotila[e,aa], Sophie Valcke[i], Aurore Voldoire[y], Qiang Wang[k], Igor Yashayaev[ab]

[a] National Center for Atmospheric Research (NCAR), Boulder,CO, USA
[b] Texas A & M University, College Station, TX, USA
[c] Helmholtz Center for Ocean Research, GEOMAR, Kiel, Germany
[d] Uni Research Climate, Bjerknes Centre for Climate Research, Bergen, Norway
[e] Centre for Australian Weather and Climate Research, a partnership between CSIRO and the Bureau of Meteorology, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Melbourne, Australia
[f] NOAA Earth System Research Laboratory, Boulder, CO, USA
[g] NASA Goddard Institute for Space Studies (GISS), New York, NY, USA
[h] Center for Ocean-Atmospheric Prediction Studies (COAPS), Florida State University, Tallahassee, FL, USA
[i] Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CERFACS), Toulouse, France
[j] National Oceanography Centre Southampton (NOCS), Southampton, UK
[k] Alfred Wegener Institute for Polar and Marine Research (AWI), Bremerhaven, Germany
[l] Institute of Numerical Mathematics, Russian Academy of Sciences, Moscow, Russia
[m] Geophysical Institute, University of Bergen and Bjerknes Centre for Climate Research, Bergen, Norway
[n] International Centre for Theoretical Physics (ICTP), Trieste, Italy
[o] Mercator-Ocean, Toulouse, France
[p] Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), Bologna, Italy
[q] Massachusetts Institute of Technology, Cambridge, MA, USA
[r] Meteorological Research Institute (MRI), Japan Meteorological Agency, Tsukuba, Japan
[s] NOAA Geophysical Fluid Dynamics Laboratory (GFDL), Princeton, NJ, USA
[t] Medgar Evers College of the City University of New York, Brooklyn, NY, USA
[u] IPSL/LOCEAN, CNRS-IRD-UPMC, Paris, France
[v] Istituto Nazionale di Geofisica e Vulcanologia (INGV), Bologna, Italy
[w] International CLIVAR Project Office, ICTP, Trieste, Italy
[x] Columbia University, New York, NY, USA
[y] Centre National de Recherches Météorologiques (CNRM-GAME), Toulouse, France
[z] Laboratoire de Physique des Océans, UMR 6523, CNRS-Ifremer-IRD-UBO, IUEM, Plouzane, France
[aa] Finnish Meteorological Institute, Helsinki, Finland
[ab] Bedford Institute of Oceanography, Fisheries and Oceans Canada, Dartmouth, Canada

* Corresponding author. Tel.: +1 303 497 1604; fax: +1 303 497 1700.
E-mail address: gokhan@ucar.edu (G. Danabasoglu).

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ABSTRACT

Simulated inter-annual to decadal variability and trends in the North Atlantic for the 1958–2007 period from twenty global ocean – sea-ice coupled models are presented. These simulations are performed as contributions to the second phase of the Coordinated Ocean-ice Reference Experiments (CORE-II). The study is Part II of our companion paper (Danabasoglu et al., 2014) which documented the mean states in the North Atlantic from the same models. A major focus of the present study is the representation of Atlantic meridional overturning circulation (AMOC) variability in the participating models. Relationships between AMOC variability and those of some other related variables, such as subpolar mixed layer depths, the North Atlantic Oscillation (NAO), and the Labrador Sea upper-ocean hydrographic properties, are also investigated. In general, AMOC variability shows three distinct stages. During the first stage that lasts until the mid- to late-1970s, AMOC is relatively steady, remaining lower than its long-term (1958–2007) mean. Thereafter, AMOC intensifies with maximum transports achieved in the mid- to late-1990s. This enhancement is then followed by a weakening trend until the end of our integration period. This sequence of low frequency AMOC variability is consistent with previous studies. Regarding strengthening of AMOC between about the mid-1970s and the mid-1990s, our results support a previously identified variability mechanism where AMOC intensification is connected to increased deep water formation in the subpolar North Atlantic, driven by NAO-related surface fluxes. The simulations tend to show general agreement in their temporal representations of, for example, AMOC, sea surface temperature (SST), and subpolar mixed layer depth variabilities. In particular, the observed variability of the North Atlantic SSTs is captured well by all models. These findings indicate that simulated variability and trends are primarily dictated by the atmospheric datasets which include the influence of ocean dynamics from nature superimposed onto anthropogenic effects. Despite these general agreements, there are many differences among the model solutions, particularly in the spatial structures of variability patterns. For example, the location of the maximum AMOC variability differs among the models between Northern and Southern Hemispheres.

1. Introduction

This study presents an analysis of the simulated inter-annual to decadal variability and trends in the North Atlantic Ocean for the 1958–2007 period from a set of simulations participating in the second phase of the Coordinated Ocean-ice Reference Experiments (CORE-II). It is Part II of our companion paper, Danabasoglu et al. (2014) (hereafter DY14), where the mean states in the Atlantic basin from these simulations are documented to provide a baseline for the present variability analysis.

Our primary focus is again on the Atlantic meridional overturning circulation (AMOC), but here we investigate representation of its inter-annual to decadal variability and trends in the participating models. As stated in DY14, AMOC is presumed to play a major role in decadal and longer time scale climate variability and in prediction of the earth's future climate on these time scales through its heat and salt transports and its impacts on sea surface temperatures (SSTs) and sea level. Due to lack of long and continuous AMOC observations, the main support for such an important role for AMOC in influencing the earth's climate comes from coupled general circulation model (CGCM) simulations. In long control simulations with CGCMs, usually for pre-industrial conditions run without either changes in radiative forcings or inclusion of anthropogenic forcings, AMOC intrinsic variability is rather rich with a variety of time scales, e.g., inter-annual, decadal, centennial. Furthermore, such low frequency AMOC anomalies tend to precede the basin scale SST anomalies in the Atlantic Ocean, thus suggesting a driving role for AMOC in models (e.g., Delworth et al., 1993; Danabasoglu, 2008; Kwon and Frankignoul, 2012; Delworth and Zeng, 2012; Danabasoglu et al., 2012). Hence, the basin scale, low frequency variability (40–70 year period) of the observed SSTs in the Atlantic Ocean is assumed to be linked to AMOC fluctuations. This basin scale SST variability is usually referred to as the Atlantic Multidecadal Variability (AMV) or Atlantic Multidecadal Oscillation. AMV represents an index of detrended, observed (North) Atlantic SST variability estimated from instrumental records and proxy data (e.g., Schlesinger and Ramankutty, 1994; Kushnir, 1994; Delworth and Mann, 2000). We also note that some studies suggest that variability of AMOC and upper-ocean temperatures may be potentially predictable on decadal time scales (e.g., Griffies and Bryan, 1997; Pohlmann et al., 2004; Msadek et al., 2010; Branstator and Teng, 2010), thus making appropriate initialization of the AMOC state for decadal prediction experiments an important endeavor.

For studies of AMOC variability and its mechanisms and prediction, CGCMs are an essential tool. However, their fidelity remains a serious concern, and a fundamental understanding of the mechanisms of simulated AMOC variability remains elusive (see Liu, 2012 and Srokosz et al., 2012 for recent reviews). For example, the magnitude and dominant time scales of AMOC variability and its mechanisms can differ substantially from one model to another (see above references), from one version of a model to another (Danabasoglu, 2008; Danabasoglu et al., 2012), and, in some cases, even from one time segment of a model simulation to another (Kwon and Frankignoul, 2012; 2014). Some oceanic subgrid scale parameterizations are shown to affect the variability of AMOC as well, e.g., magnitude of vertical diffusivity coefficients (Farneti and Vallis, 2011); representation of the Nordic Sea overflows (Yeager and Danabasoglu, 2012) and of meso- and submesoscale eddies (Danabasoglu et al., 2012). In addition, various aspects of AMOC variability are sensitive to both the atmosphere and ocean model resolutions (Bryan et al., 2006). Given these significant model sensitivities and many unanswered questions, there is a critical need for improving our understanding of the mechanisms and assessing the fidelity and robustness of simulated AMOC variability against limited available observations.

The CORE-II hindcast experiments provide a common framework to address some of these issues. Specifically, they can be used to investigate AMOC variability and its mechanisms on seasonal, inter-annual, and decadal time scales and to understand and separate forced variability from natural variability – the latter in combination with (coupled) control experiments that exclude external and anthropogenic effects. Additionally, robustness of variability mechanisms across models can be evaluated. Continuous, observationally-based estimates of AMOC are available only starting in early 2004 through the Rapid Climate Change transbasin observing array installed along 26.5°N (RAPID; Cunningham et al., 2007). The CORE-II hindcasts – along with the reanalysis products – can provide complementary information on AMOC for the pre-RAPID era.