

The impacts of the atmospheric annular mode on the AMOC and its feedback in an idealized experiment

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ABSTRACT

The interdecadal variability of the atmospheric and oceanic meridional overturning circulation is studied, using a coupled model with two narrow meridional barriers representing the land and a flat bottomed Aquaplanet. Empirical orthogonal function (EOF) analysis is used in the atmospheric and oceanic meridional overturning cells, revealing the atmospheric interdecadal variability is dominated by an annular mode, in both hemispheres, which introduces in the ocean a set of patterns of variability. The most energetic EOFs in the ocean are the barotropic responses from the annular mode. The interaction between the heat anomalies, due to the barotropic response, and the thermohaline circulation of each basin leads to a resonance mechanism that feeds back to the atmospheric forcing, modulating the annular mode spectrum. Besides the barotropic response, the annular mode introduces anomalies of salinity and temperature in the subtropical Atlantic that affects its upper buoyancy. These anomalies are incorporated within the ocean circulation and advected until the areas of deep sinking in the northern Atlantic, impacting on its overturning circulation as well.

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1. Introduction

Idealized experiments are often used to investigate key aspects of climate while reducing its overall complexity. In a series of studies, the Massachusetts Institute of Technology General Circulation Model (MITgcm) was used with idealized topographies to investigate the role that geometrical constraints plays on climate. The Aquaplanet experiment, a planet covered by a constant-deep ocean, despite its simplicity, is shown to present a meridional heat transport partition between the atmosphere and ocean close to the present climate (Marshall et al., 2007). Its variability is dominated by an annular mode in the atmosphere, which produces heat anomalies in the ocean by anomalous Ekman pumping. These heat anomalies feed back to the atmosphere, affecting the spectrum of annular variability (Marshall et al., 2007). By adding one meridional barrier in Aquaplanet, ranging from the north pole until 35°S (the Drake experiment; Fig. 1b), a more realistic thermohaline circulation (THC) is reproduced, with deep sinking in the northern latitudes and upwelling in the southern ocean (Enderton and Marshall, 2009). The meridional ocean heat transport (OHT) in the Drake experiment leads to a climate even closer to the present climate, with interhemispheric asymmetries in both heat and salt content, and an intertropical convergence zone (ITCZ) positioned north of equator as in observations (Marshall et al., 2014). Continuing the set of experiments, the

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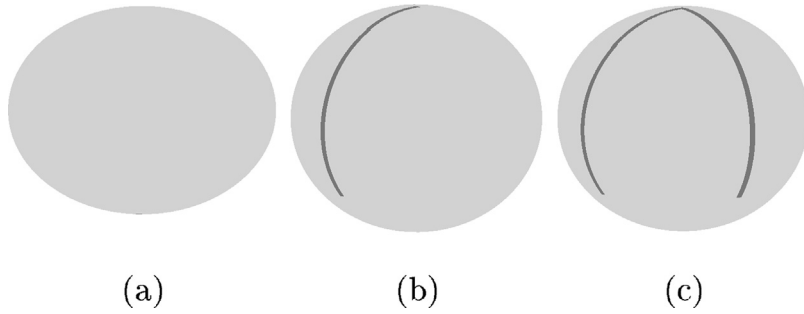


Fig. 1. Idealized topographies for the experiments Aquaplanet (a), Drake (b) and DDrake (c).

effects of two meridional barriers was explored, both barriers ranging from the North Pole until 35°S and separated by an arc of 90° of longitude (the DDrake experiment, which is used in the present study; Fig. 1c). The deep sinking in the DDrake is restricted to its small basin (hereafter referred to as Atlantic), while in the large basin (hereafter referred to as Pacific) the wind-driven shallow cells dominates the circulation, given to the DDrake a striking similarity to the present Atlantic and Pacific circulations (Ferreira et al., 2010). Variations of the DDrake geometry are investigated in Nilsson et al. (2013), where the zonal width of each ocean basin and the meridional extent of the land barriers are changed. It was suggested that, despite a variety of equilibria between the THC of each basin, the narrow Atlantic and the shorter African continent favors the deep sinking to be localized in the northern Atlantic basin.

Following the investigative path of idealized experiments, our goal here is not to reproduce in details the variability of the present climate. Rather, we intend to describe the coupling between the atmosphere and the THC found in an idealized experiment, having in mind that this idealized experiment captures, at least minimally, the overall ocean geometry similar to the Atlantic and Indo-Pacific basins. Thus, although the idealization, our investigation is able to focus on the Atlantic Meridional Overturning Circulation (AMOC).

The AMOC, in the real climate, is thought to be the major source of multi-decadal climate variations (Delworth and Mann, 2000; Knight et al., 2005; Zhang, 2008). It has been pointed to substantially contribute to changes on the northern Atlantic surface atmospheric temperature and in the sea ice coverage (Mahajan et al., 2011), as well as being linked to the Atlantic multidecadal oscillation (AMO; Zhang, 2008), which has been linked to many other aspects of the global and regional climate (Goldenberg et al., 2001; Folland et al., 1986; Sutton and Hodson, 2005; Folland et al., 2001).

Considering the importance of the AMOC to climate and the ability of the idealized experiments to reproduce the basic mechanisms of the coupled system, this study investigates the variability of the DDrake with the same topographical configuration used in Ferreira et al. (2010), with two meridional barriers from the North Pole until 35°S and separated by an arc of 90° of longitude.

The text is organized as follow: before entering in the DDrake variability, a brief description of the THC mean state is presented. In the sequence, the inter-decadal variability found in the atmospheric overturning circulation is described. Finally, the most significant patterns of inter-decadal variability of the AMOC are investigated, focusing on the northern Atlantic. The coupled model and the experiments are described in Section 2. Details of the DDrake mean state are in Section 3, while the inter-decadal variability of the atmospheric and oceanic overturning cells are shown in Sections 4 and 5, respectively. The final remarks and conclusions are in Section 6.

2. The coupled model and idealized topography

The numerical experiments are performed with an implementation of the ocean-atmosphere-sea ice coupled model of the Massachusetts Institute of Technology general circulation model (MITgcm), well documented in Marshall et al. (1997a,b). Only a brief description is presented here. The isomorphism between ocean and atmosphere fluids are explored to create a common dynamic core algorithm (Marshall et al., 2004), which allows the modeling of both fluids by changing a few parameters. The atmospheric and ocean models are integrated in a horizontal “cubed sphere” C32, composed of four faces with 32×32 cells each, yielding a nominal resolution of 2.8° (Adcroft et al., 2004).

The atmospheric model is based on a spectral primitive-equation dynamical core and a set of simplified physical parameterization schemes (abbreviated as Speedy), developed to work with few vertical levels (Molteni, 2003). The parameterization includes large-scale condensation, convection, clouds, short and long wave radiation, surface fluxes and vertical diffusion. The ocean model is a flat-bottomed 3 km deep divided into 15 vertical levels, with resolution that spans from 40 m at surface to 435 m at bottom. The mesoscale eddies are parameterized as an advective process and isopycnal diffusion (Gent and McWilliams, 1990; Redi, 1982), both with a transfer coefficient of $800 \text{ m}^2 \text{ s}^{-1}$. The diapycnal mixing is represented by a constant vertical diffusivity of $3 \times 10^{-5} \text{ m}^2 \text{ s}^{-1}$, while convective adjustment is represented by an enhanced vertical mixing of temperature and salinity. The vertical eddy viscosity is set to $10^{-3} \text{ m}^2 \text{ s}^{-1}$, while the horizontal eddy viscosity is set to $3 \times 10^5 \text{ m}^2 \text{ s}^{-1}$ to resolve the Munk layer. Sea ice is allowed to form and it is controlled by a thermodynamic two-and-a-half layer ice model based on Winton (2000). There is no sea-ice dynamic. The solar constant is fixed at $S_0 = 1368 \text{ W m}^{-2}$ and the

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