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A numerical study of the South Atlantic circulation at the Last Glacial Maximum

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Abstract

In this study, we examine the simulation results from the paleoclimate version of the National Center of Atmospheric Research coupled Climate System Model (CSM 1.4) for the Last Glacial Maximum (LGM) in order to understand changes in the South Atlantic (SA) circulation relative to the Present Day (PD). The LGM simulation is validated with the available proxy data in the region. The results show good agreement, except in the eastern equatorial and eastern SA region, where the model is not able to reproduce the correct cloud cover and the associated air–sea interactions. Ocean transport in the PD simulation is in good agreement with observational estimates. Results show that at subsurface levels there are two distinct patterns: (i) strengthening of the transport for the LGM in the southern SA (35°S to 25°S); and (ii) weakening of the mass transport in the northern SA (25°S to the Equator). In intermediate layers, there is an intensification of the subtropical gyre and a northward shift of the South Equatorial Current (SEC) bifurcation for the LGM. This leads to the intensification of the southward transport by the Brazil Current (BC) and the associated BC recirculation cell in the southern basin for the LGM. This shift in the position of the SEC bifurcation leads to a weakening in the northward transport and the western recirculation of the central SEC in the northern basin. This northward shift of the SEC (upper limit of the subtropical gyre) is consistent with the northward shift observed in the subtropical convergence zone and suggests a displacement of the sub-tropical gyre 3°–5° towards the Equator. In deeper layers, a shallower and weaker North Atlantic Deep Water (NADW) circulation in the LGM contributes to the reduction of the southward transport in the northern part of the basin and is associated with a greater northward intrusion of Antarctic Bottom Water. This intrusion plus the increase of the Indian Water inflow is responsible for the northward transport intensification in the southern basin.

Keywords: Coupled climate model; Last Glacial Maximum; Ocean circulation; South Atlantic; Paleoceanography; Paleoclimatology

1. Introduction/Background

The study of past climates plays an essential role in understanding the natural variability of the climate system and modeling of past climates tests model sensitivity for extreme climates. The redistribution of mass and heat by the atmosphere and ocean is one of the most important aspects of the climate system, given that variations in oceanic heat and mass transport have been suggested as causes of abrupt climatic change. The pathways and mechanisms of oceanic transport in the past are critical issues in understanding the present climate state and the

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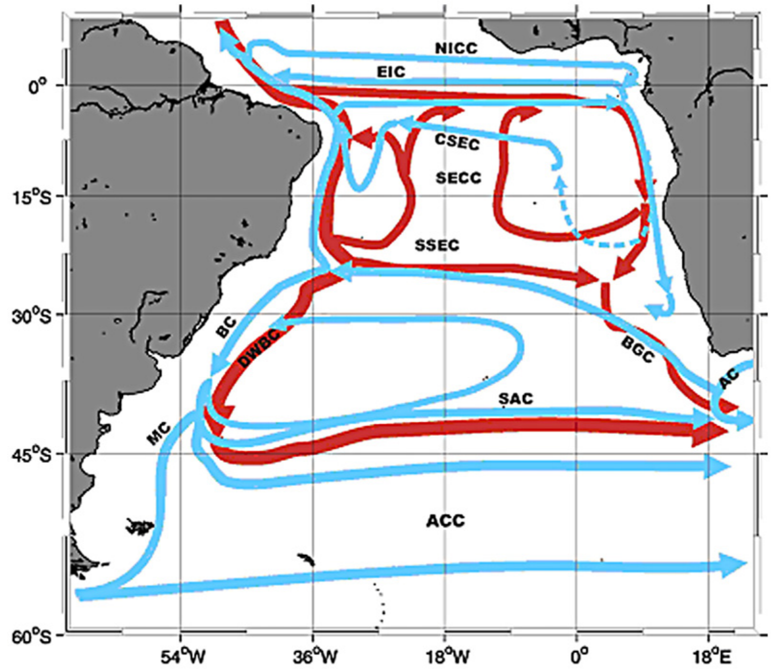

Fig. 1. Schematic representation of the large-scale South Atlantic circulation. In blue, the intermediate geostrophic currents (about 500 to 1200 m). In red, the deep flow (near 2000 m depth). Shown are the Malvinas Current (MC); the Brazil Current (BC); the South Atlantic Current (SAC); the Benguela Current (BGC); the Antarctic Circumpolar Current (ACC); the South Equatorial Current (SEC); with the southern (SSEC) and central (CSEC) branches; the South Equatorial Countercurrent (SECC); Equatorial Intermediate Current (EIC); Northern Intermediate Countercurrent (NICC) (adapted from Stramma and England, 1999). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

possibilities of future changes. In this context, the South Atlantic is a unifying link for exchanging waters of the world's major ocean basins and is the only ocean basin in the Southern Hemisphere that transports heat equatorward (Gordon, 1986).

The dominant horizontal circulation in the South Atlantic is the anticyclonic Subtropical Gyre. Four major currents delimit the Subtropical Gyre (see Fig. 1): to the east the Benguela Current (BGC), to the north the South Equatorial Current (SEC), the Brazil Current (BC) delimits the western boundary, and at the southern edge the South Atlantic Current (SAC). Three other currents are also important for the circulation associated with the Subtropical Gyre: the Malvinas Current (MC), the Agulhas Current (AC), and the Antarctic Circumpolar Current (ACC).

The BGC begins as a northward flow off the Cape of Good Hope, and flows along the African coast before it splits into two branches near 30°S (Peterson and Stramma, 1991). The first branch continues to flow northward parallel to the coast; the second branch flows northwest into the SEC. The water of the BGC is replenished from two routes. The warm route (Gordon, 1986) originates in the AC and supplies the BGC with large eddies shed from the Agulhas Retroflection, which transports warm water from the Indian Ocean. The second one, called the cold route (Rintoul, 1991), comes from the SAC and contains the relatively cold water from the South Atlantic Central Water and Antarctic Intermediate Water (Pickard and Emery, 1982). This branch of the subtropical gyre is responsible for the northward transport of surface and thermocline waters. Estimates of the magnitude of the associated flows are important to understanding of the South Atlantic.

Several studies estimate the transports of the BGC and AC. These observational estimates provide an excellent opportunity to evaluate how well the numerical model used here simulates the ocean dynamics in the present. For the BGC transport, Sverdrup et al. (1942) was the first to estimate the value of 18.7 Sv at 30°S relative to 1200 m; Fu (1981) calculated the geostrophic transport at 500 m across 32°S to be 20 Sv and Stramma and Peterson (1989) found it to be 21 Sv at 32°S and 18 Sv at 30°S, away from the coast. These results indicate that the average Benguela transport across 30°S is about 20–25 Sv.

The AC is a western boundary current in the South Indian Ocean. It flows down the east coast of Africa