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The possible role of Brazilian promontory in Little Ice Age

Youjia Zou[a,*], Xiangying Xi[b]

[a] Department of Meteorology and Oceanography, Shanghai Maritime University, PR China
[b] Management Faculty, Wuhan University of Technology, PR China

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ABSTRACT

The Gulf Stream, one of the strongest currents in the world, transports approximately 31 Sv of water (Kelly and Gille, 1990; Baringer and Larsen, 2001; Leaman et al., 1995) and 1.3×10^{15} W (Larsen, 1992) of heat into the Atlantic Ocean, and warms the vast European continent. Thus any change of the Gulf Stream could lead to the climate change in the European continent, and even worldwide (Bryden et al., 2005). Past studies have revealed a diminished Gulf Stream and oceanic heat transport that was possibly associated with a southward migration of intertropical convergence zone (ITCZ) and may have contributed to Little Ice Age (AD ~1200 to 1850) in the North Atlantic (Lund et al., 2006). However, the causations of the Gulf Stream weakening due to the southward migration of the ITCZ remain uncertain. Here we use satellite observation data and employ a model (oceanic general circulation model – OGCM) to demonstrate that the Brazilian promontory in the east coast of South America may have played a crucial role in allocating the equatorial currents, while the mean position of the equatorial currents migrates between northern and southern hemisphere in the Atlantic Ocean. Northward migrations of the equatorial currents in the Atlantic Ocean have little influence on the Gulf Stream. Nevertheless, southward migrations, especially abrupt large southward migrations of the equatorial currents, can lead to the increase of the Brazil Current and the significant decrease of the North Brazil Current, in turn the weakening of the Gulf Stream. The results from the

* Corresponding author at: Haigang Avenue 1550, Pudong District, Shanghai, 201306, PR China. Merchant Marine College, Shanghai Maritime University. Tel.: +86 2138329200.

E-mail addresses: marscar@126.com, yjzou@shmtu.edu.cn (Y. Zou).

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model simulations suggest the mean position of the equatorial currents in the Atlantic Ocean shifted at least 180–260 km southwards of its present-day position during the Little Ice Age based on the calculations of simple linear equations and the OGCM simulations.

1. Introduction

The Gulf Stream is one of the world's most intensely studied current systems (Meinen et al., 2009). This extensive western boundary current plays an important role in the poleward transfer of heat and salt and serves to warm the European subcontinent (Bryden et al., 2005). Previous studies already found that the Gulf Stream has a marked seasonal variability, with peak-to-peak amplitude in sea surface height of 10–15 cm, and significant fluctuations in volume transport and velocity. The fluctuations are mostly confined to the upper 200–300 m of the water column and are a result of seasonal heating and expansion of the surface waters (Hogg and Johns, 1995).

However, the non-seasonal variations of the Gulf Stream, which may play a significant role in the climate change, are likely to be overlooked. Its variability on decadal to longer timescales remains a topic of debate (Taylor and Stephens, 1998; Rossby and Benway, 2000; Frankignoul et al., 2001). The possibility of abrupt changes in the Gulf Stream heat transport in response to the abrupt changes of the Gulf Stream volume transport is considered to be one of the key uncertainties in predictions of climate change for the coming centuries (Lund et al., 2006). Thus, the mechanisms responsible for the variability in the Gulf Stream deserve major consideration by researchers.

2. Recent study on Gulf Stream transport and ITCZ

Recent studies, however, indicate that the change of the Gulf Stream in transport is connected with the migrations of the intertropical convergence zone (ITCZ) (Lund et al., 2006; Haug et al., 2001; Broccoli et al., 2006). The seasonal variations of the ITCZ can result in the seasonal changes of the Gulf Stream (Lund et al., 2006), but are not likely to have significant impact on the climate. The newly-developed models also reveal that the ITCZ tends to shift northward from its mean position lying at 10° N in summer and nearly over equator in winter (Peng and Miller, 2008; Haug et al., 2001), in correspondence with the mean position of the equatorial currents in the Atlantic Ocean. However, anomalous southward shifts, especially large southward shifts, are rare (Haug et al., 2001).

Nevertheless, the southward migration, which is speculated to be southward displacement (may be a regular behavior in terms of long timescales), was indeed observed during the Little Ice Age (LIA) by the investigations into the titanium and iron contents in Cariaco Basin sediments (on the northern shelf of Venezuela, a highly sensitive recorder of past climates in the tropical ocean). The new sediment records from Lake Titicaca also indicate that precipitation steadily increased in that region during the LIA (Haug et al., 2001). Pollen records from the southern margin of Amazonia also suggest a southward expansion of humid evergreen forest during the late Holocene (Peng and Miller, 2008; Haug et al., 2001). These changes are anti-correlated with decreases in precipitation indicated in the Cariaco records. Together, they generally confirm that these climate events were associated with southward movements of the ITCZ (Haug et al., 2001).

The Cariaco record, when combined with other records from South America (Baker et al., 2001; Mayle et al., 2000; Maslin and Burns, 2000), unambiguously shows that climate changes in Central and South America over the course of the Holocene are due, at least in part, to a general southward shift of the ITCZ (Haug et al., 2001).

The fact that a large and long period southward migration of the ITCZ in tropical Atlantic can create climate change in the North Atlantic invites questions as to why the significant global climate events, such as Younger Dryas events (Stansell et al., 2010) and the LIA, originate always from the Atlantic Ocean rather than Pacific Ocean where the similar southward migration of the ITCZ was also observed