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Diatoms and biomarkers evidence for major changes in sea ice conditions prior the instrumental period in Antarctic Peninsula

Loïc Barbara [a,b,*], Xavier Crosta [a], Sabine Schmidt [a], Guillaume Massé [b,c]

[a] Université Bordeaux, EPOC, UMR 5805, F-33400 Talence, France
[b] UMR-CNRS 7159 LOCEAN, Université Pierre et Marie Curie, Paris VI, Jussieu, 75252 Paris Cedex 05, France
[c] UMI 3376 TAKUVIK, CNRS & Université Laval, 1045 Avenue de la Médecine, G1V 0A6 Québec, Canada

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ABSTRACT

The Antarctic Peninsula (AP) has been identified as one of the most rapidly warming region on Earth. Satellite monitoring currently allows for a detailed understanding of the relationship between sea ice extent and duration and atmospheric and oceanic circulations in this region. However, our knowledge on ocean–ice–atmosphere interactions is still relatively poor for the period extending beyond the last 30 years. Here, we describe environmental conditions in Northwestern and Northeastern Antarctic Peninsula areas over the last century using diatom census counts and diatom specific biomarkers (HBIs) in two marine sediment multicores (MTC-38C and -18A, respectively). Diatom census counts and HBIs show abrupt changes between 1935 and 1950, marked by ocean warming and sea ice retreat in both sides of the AP. Since 1950, inferred environmental conditions do not provide evidence for any trend related to the recent warming but demonstrate a pronounced variability on pluri-annual to decadal time scale. We propose that multi-decadal sea ice variations over the last century are forced by the recent warming, while the annual-to-decadal variability is mainly governed by synoptic and regional wind fields in relation with the position and intensity of the atmospheric low-pressure trough around the AP. However, the positive shift of the SAM since the last two decades cannot explain the regional trend observed in this study, probably due to the effect of local processes on the response of our biological proxies.

1. Introduction

The instrumental records, extending back over the last 60 years, reveal a rapid warming trend in Antarctic Peninsula (AP), with an average temperature rise of 0.56 °C per decade recorded in Vernadsky (previously Faraday) station (Fig. 1A) since 1951 (Vaughan et al., 2003; Turner et al., 2005). At the same time, satellites monitored a decrease in sea ice concentration (9.7% per decade) and duration in this region over the last two decades (Parkinson, 2002; Zwally et al., 2002; Stammerjohn et al., 2008a). These changes are attributed to modifications in the dominant modes of atmospheric circulation such as the Southern Annular Mode (SAM) (Marshall, 2003; Lefebvre et al., 2004; Liu et al., 2004) and the El Niño Southern Oscillation (ENSO) (Kwok and Comiso, 2002; Liu et al., 2004; Stammerjohn et al., 2008a). Increased incursions of warm Upper Circumpolar Deep Water (UCDW) onto the continental shelf (Klinck et al., 2004; Martinson et al., 2008) and/or warmer sea-surface temperatures over the last decade (Meredith and King, 2005), could also have contribute to sea ice decrease and ice shelf collapse in AP (Cook et al., 2005; Domack et al., 2005). This reduction in seasonal sea ice, increasing meltwater inputs, has a significant impact on seasonal sea surface conditions and therefore on the coastal water masses by modifying the upper water column stability, the nutrient availability and sea-surface temperatures (Martinson and Iannuzzi, 1998; Smith et al., 2007; Hendry and Rickaby, 2008). Additionally, reduction in sea ice cover enhances the heat flux between atmosphere and ocean and, subsequently, sea level pressures which, in turn, modulate seasonal sea ice duration (Yuan et al., 1999; Venegas and Drinkwater, 2001). Given these relationships and feedbacks, it is essential to learn more about environmental conditions history to better understand how sea ice has responded to the recent regional warming.

Antarctic ice cores extend back our knowledge of sea ice variability and temperature changes in AP beyond the instrumental period and demonstrate that the warming trend started at the very beginning of the 20th century (Thomas et al., 2009; Mulvaney et al.,

* Corresponding author. Present address: Instituto de Geofísica, Universidad Nacional Autonoma Mexico, Circuito de la investigación Científica s/n, Ciudad Universitaria, Delegación Coyoacán, C.P. 04510 México D.F., Mexico. Tel.: +52 56 22 58 39x3.
E-mail address: l.jb.barbara@gmail.com (L. Barbara).

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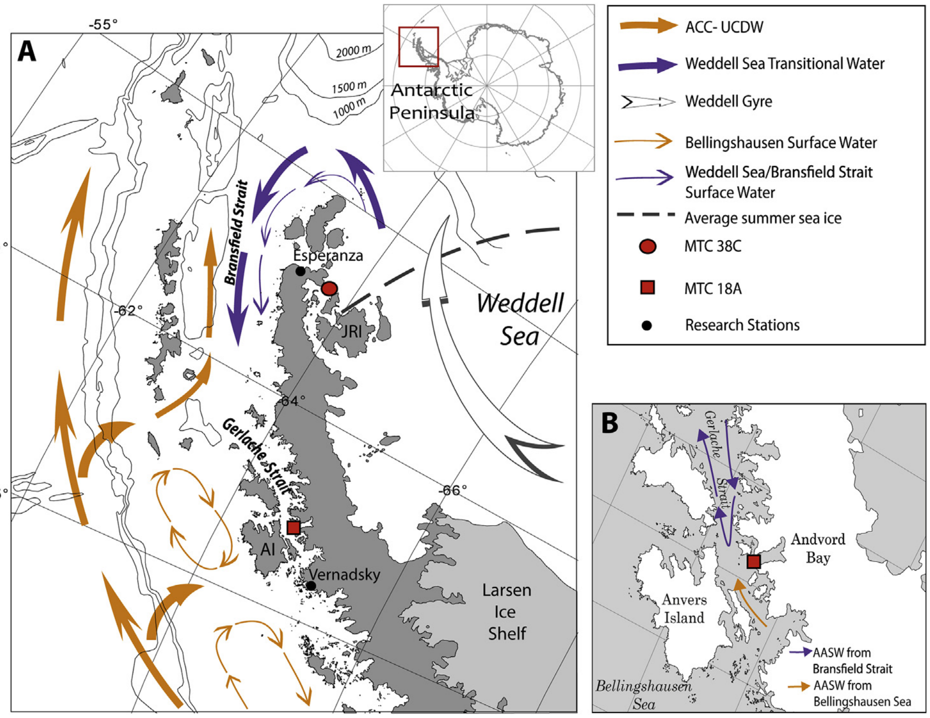

Fig. 1. Map of the Antarctic peninsula showing the location of the study region, and (A) map showing the location of MTC18A and MTC38C marine interface cores along with bathymetry (from GEBCO digital atlas, http://www.bodc.ac.uk/projects/international/gebco), location of Larsen Ice Shelf, location Vernadsky and Esperanza stations, detail of oceanographic currents and different water masses (modified from Hofmann et al., 1996; Zhou et al., 2002; Domack et al., 2003), position of the present day average summer sea ice limits (from Fetterer et al., 2002, updated 2007). Winter sea-ice covers the whole oceanic area encompassed by the map; (B) map detailing the Gerlache Strait showing, the location of MTC18A, and local oceanographic currents (Rodriguez et al., 2002). ACC: Antarctic Circumpolar Current; UCDW: Upper Circumpolar Deep Water; AASW: Antarctic Surface Water; AI: Anvers Island; JRI: James Ross Island.

2012). Marine studies also provide evidence for a recent regional warming and associated glacier retreat in AP (Appleby et al., 1995), but very few oceanic records covering the last century at a sub-decadal resolution are available in that region (Hendry and Rickaby, 2008). Additionally, despite its importance for feedback processes in the internal climate system, there is currently no sea ice data available for the last two centuries besides notification of the past location of the sea ice edge by early Antarctic explorers (Cook, Bellingshausen, Wilkes and Ross) in the late 18th and early 19th (Parkinson, 1990). Using whaler's logbooks, de la Mare (1997) reported a 25% decline in summer Antarctic sea ice between the 1950's and 1970's. However, there are still large uncertainties regarding the environmental changes that occurred beyond the instrumental period and the few studies focusing on this period with proxy records are scarce and/or are not sufficiently high resolution to document environmental responses to a warming trend in AP. It therefore appears important to better document the long-term atmosphere-ocean-sea ice interactions since the beginning of recent warming. This study presents the first high-resolution records of environmental conditions over the last 150 years, inferred from diatom census counts and diatom-specific biomarker analysis, in two marine multicores collected off the West and East North AP. In contrast to previously published paleo-data sets, this study highlighted contrasting trends between sea ice and the current warming between the Western and Eastern AP study site. It also allowed for describing the driving factors of the long-term environmental changes in west Antarctica.

2. Regional setting

The physiography of the AP induces a contrast in tropospheric and oceanographic circulation on both sides (King et al., 2003). Warmer and maritime conditions prevail on the western side of the Peninsula while the eastern side experiences a colder continental climate.

Water masses from the West Antarctic Peninsula (WAP) are influenced by the close proximity of the Antarctic Circumpolar Current (ACC) (Fig. 1) which is inflowing onto the continental shelf as the Upper Circumpolar Deep Water (UCDW) (Orsi et al., 1995; Smith et al., 1999). This water mass is separated from the Antarctic Surface Water (AASW) by a permanent pycnocline, whose the depth is mainly linked to sea ice conditions (Smith and Klinck, 2002) and acts as a source of nutrients for primary productivity (Hofmann et al., 1996; Smith et al., 1999).

Most of the clockwise circulation on the shelf is induced by the ACC which, under the influence of north-northeast wind, branches into an outer northeasterly flow and a more coastal southward flow (Hofmann et al., 1996). At a more regional scale, the water masses in the southwestern Gerlache Strait are characterized by cold (~ -0.5 °C) AASW reflecting the effect of ice melt in the neighboring Bellingshausen Sea whilst those from the northeastern Gerlache Strait and Bransfield Straits, are characterized by warmer (0.5 °C) AASW (Rodriguez et al., 2002). A persistent current in the middle part of the Gerlache Strait also transports surface water northeastward to the Bransfield Strait (Fig. 1B; Zhou et al., 2002). Atmospheric exchanges, sea ice formation and melting and, exchange across the permanent pycnocline affect the AASW. During summer, surface solar heating and freshwater inputs from sea ice melt induce a strong stratification of the surface layer ($\sim$30 m) (Klinck, 1998), although storms punctually lead to nutrient recharges (Annett et al., 2010). In autumn, increase in storm frequency and strong surface heat losses lead to the formation of a deep homogenous mixed layer ($\sim$100 m).

The East Antarctic Peninsula (EAP) oceanic system is governed by the Weddell Gyre (Orsi et al., 1993). This cyclonic circulation