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A note on the intraseasonal variability in an Antarctic polynia: Prior to and after the Mertz Glacier calving

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ABSTRACT

During winter, thin sea ice is formed in coastal polynias, areas of open-water within a sea ice pack and important sites of dense shelf water formation. In the Mertz Glacier polynia (138°E–147°E, East Antarctica), we examined the effects of an extreme calving event, the last Mertz glacier calving, on the regional sea ice distribution. The high-frequency variability of sea ice concentration was studied for years 1992 to 2011 from passive microwave satellite data with fine spatial (6.25 km and 12.5 km) and temporal (1 day) resolutions. Our results showed that the last calving of the Mertz glacier tongue in February 2010 greatly modified the size and shape of the polynia with a significant westward shift in the regional ice regimes. We also identified a post-calving transition state characterised by a 70%-decrease in polynia area from the pre-calving mean. In the eastern part of the study area, our findings are in agreement with other studies predicting an important decrease in polynia activity. In the western part, where the main polynia activity has shifted after the calving, the new sea ice distribution is expected to have a major impact on local sea ice production, dense shelf water sinking, and potentially the regional thermohaline circulation. With extreme climatic events predicted to occur more frequently, long-term monitoring of the regional icescape could be used to evaluate the vulnerability of Antarctic physical processes and related ecosystems.

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1. Introduction

In winter, polynias are recurrent openings within the sea ice pack and are sites of intense air–sea-ice interactions and sea ice production (Barber and Massom, 2007). Cold and strong katabatic or synoptic winds drive the newly formed sea ice away, exposing more surface water that quickly freezes (Bromwich and Kurtz, 1984; Markus et al., 1998). Around Antarctica, coastal polynias often get formed in the lee of fixed boundaries, such as continental coastline or glacier tongues, that restrict regional ice movements (Massom et al., 1998). As ice production factories, coastal polynias release large amounts of brine leading to the formation and export of high-salinity and high-density shelf waters, often precursor to Antarctic Bottom Water (AABW, Wu et al., 2003). Antarctic Bottom Water is the densest water mass in the world ocean and the most important source of the abyssal circulation (Orsi et al., 1999). The sinking of dense shelf water drives the global thermohaline circulation, leading to heat and material exchange between the atmosphere and the deep ocean (Manabe and Stouffer, 1999). Latent-heat polynias near the Mertz Glacier and neighbouring embayments (hereinafter referred to as the Mertz Glacier Polynia, MGP) are one of the largest sources of dense water formation and sea ice production in East Antarctica (Orsi et al., 1999; Tamura et al., 2008; Wu et al., 2003). With satellite data, the large and persistent MGP has been estimated to be over 20,000 km^2 in averaged areal extent (Massom et al., 1998), to present several areas with strong interannual variability (Smith et al., 2011) and to have high sea ice production rates (Lytle et al., 2001; Tamura et al., 2008). Between 142° and 146°E, the Mertz Glacier Tongue (MGT) concurs to blocking the near-coastal westward advection of sea ice (Fig. 1). In addition, fast/stationary-ice forms each winter between grounded icebergs to the north of the MGT and significantly increases the length of this barrier to near the shelf break (Lytle et al., 2001). By projecting seaward over 160 km from the coast, the MGT and its associated icebergs cause fast-ice to build up on its Eastern and Northern flanks (see Fig. 1 and details in Fraser et al., 2012) and helps in the formation of the MGP on its Western flank (Massom et al., 2001).

In February 2010, an extreme event radically affected the MGP area: the ungrounding of vast iceberg B-9B and the subsequent calving of the MGT (Legrésy et al., 2010; Young et al., 2010). The calved glacier tongue (berg C-28) rapidly drifted out of the area system (Fig. 1). After the calving, the shorter Mertz tongue and a decrease in fast-ice build-up to the north and east of the MGT drastically reduced the barrier effect for the polynia. Another major change to the regional icescape has been the migration of iceberg B-9B across the Adélie Depression and its grounding in Commonwealth Bay with a NNE-ward orientation during fall 2011 (Fig. 1). Since then, parts of iceberg B-9B have ungrounded again and drifted towards the East outside the study area. In the short-term, these abrupt and dramatic changes were shown to impact dense shelf water formation (Kusahara et al., 2011a,b; Shadwick et al.,

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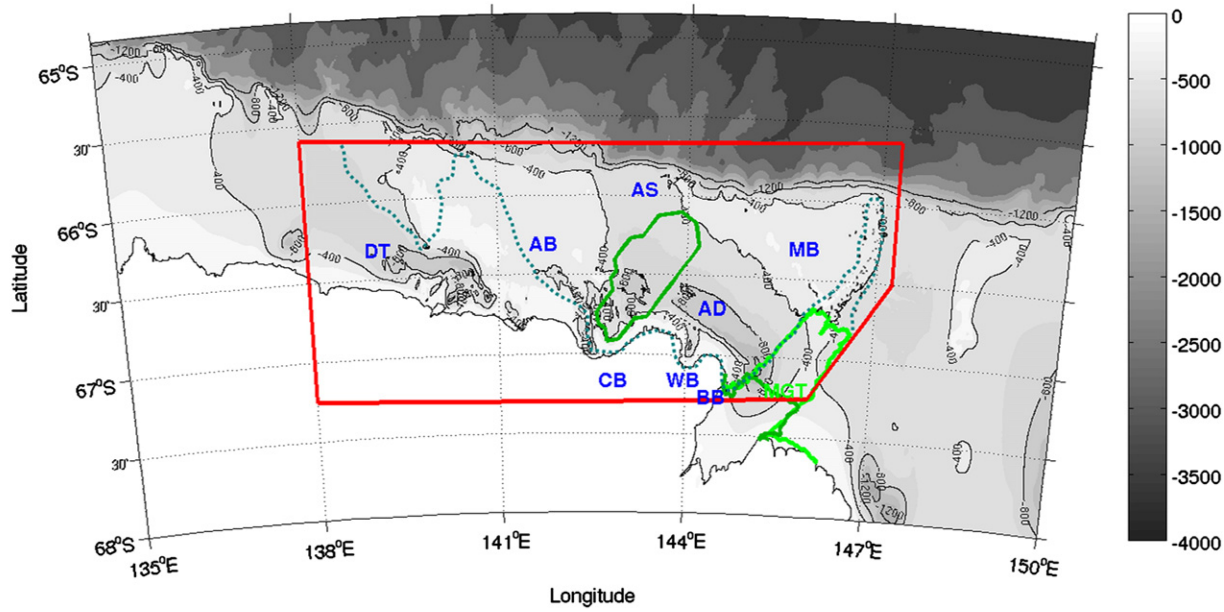

Fig. 1. Domain of study (red bold solid line) and regional bathymetry (after Beaman et al., 2011). Contour interval is 100 m with thin black contour indicating the 0 m, 400 m, 800 m and 1200 m isobaths. Major features of the topography are: D'Urville Trough (DT), Adélie Bank (AB), Adélie Sill (AS), Adélie Depression (AD), Mertz Bank (MB), Commonwealth Bay (CB), Watt Bay (WB) and Buchanan Bay (BB). Grounded icebergs to the north of the MGT are represented by black dots. The maximum fast-ice extent (average extent before the Mertz calving, dotted green line) is from Fraser et al., 2012. The light green bold solid line is the contour of the Mertz Glacier Tongue (MGT) prior to the Mertz calving and the dark green bold solid line is the one after (2010 and 2011). Also indicated in dark green is the contour of iceberg B-9B after its grounding in Commonwealth Bay.

2013) and sea ice production (Tamura et al., 2012). Kusahara et al. (2011a) used an ice-ocean model to show changes in regional circulation and to estimate a decrease by up to 23% in the regional export of dense shelf water. Using mid-resolution (12.5 km grid) remote sensing data, Tamura et al. (2012) estimated a decrease of sea ice production by 14% (20%) in winter 2010 (2011) compared to the 2000–2009 mean. In previous studies, sea ice variability in Antarctica has been largely analysed through monthly sea ice extent anomalies (Cavalieri and Parkinson, 2008) and 20-day composites of fast-ice extent (Fraser et al., 2012). Considerable work has been carried out on the regional changes and variability in sea ice seasonality (e.g. Stammerjohn et al., 2008). However, those studies need to be completed by focusing on higher frequency variability of the MGP, since sea ice conditions can dynamically change within a week, due to short-term variability in winds and storms (Mathiot et al., 2012). Here, we use long-term mid-resolution (12.5 km grid) and high-resolution (6.25 km grid) remote sensing data from before and after the calving event to examine its fine-scale consequences in a key Antarctic region. Our study adds an additional layer in combining the time series of satellite-derived Sea ice Concentration (SIC) to an innovative use of time series methodology in order to investigate the impact of an abrupt calving on intraseasonal polynia variability. The specific objectives of our work are: 1) to present the spatial distribution of intraseasonal sea ice regimes and 2) to examine these regimes' variability prior to and after the extreme event of the regional Mertz icescape.

2. Data and methods

2.1. Study area

Our work focuses on the western part of the MGP region in the Adélie–George V Land sector. The study area extends from 138°E to147°E and from 65.5°S to 67.5°S. This area has rarely been included in previous studies although it presents SIC characteristics similar to those of the main Mertz polynia. Furthermore, the westward coastal flow is expected to intensify the variations in sea ice distribution created by the disappearance of the Mertz tongue morphological barrier. Finally, Fraser et al. (2012) focused on the east of the MGT and studied in detail the local fast-ice distribution and its variability prior to the Mertz calving. In the western part of the MGP region, the ocean bottom topography of the Antarctic shelf is composed of two deep regions and two plateaus (see Fig. 1, Beaman et al., 2011). To the west, the D'Urville Trough (DT) extends from the coast at approximately 141°E toward the northwest. Grounded icebergs over shallow bathymetry lead to the development of polynias in their western lee at 141–142°E to the north of DT and at 146–147°E to the north of the Mertz Bank (Massom, 2003). To the east, the floating ice tongue of the Mertz glacier was grounded on the Mertz bank until February 2010 (Legrésy et al., 2010; Young et al., 2010). The coastline of the Adélie–George V Land sector is dominated by three large bays to the west of the Mertz Glacier: Commonwealth Bay (CB), Watt Bay (WB) and Buchanan Bay (BB). Persistent katabatic winds, with an average speed greater than 12 m s^{-1} and a temperature typically less than −16 °C in austral winter (Roberts et al., 2001), are channelled over land by topographic depressions and blow out across these three bays (Ball, 1957; Wendler et al., 1997). Of these three coastal bays, CB and WB are characterised by bathymetric depressions deeper than 870 m and 940 m, respectively. BB, located at the southern extremity of the MGT, is a shallow (ca. 400 m) bay which connects directly to the Adélie Depression. The westward advection blocking effect produces other open areas in the sea ice cover on the eastern flanks of each of the three bays (Massom, 2003).

2.2. Sea ice data from 1992 to 2012

Given the paucity of in situ data, satellite products provide us with one of the few means to investigate coherent variability over small, medium and large spatio-temporal scales. In order to establish robust short-term and high-resolution variability patterns in sea ice concentration with sufficient reliability, a combination of two daily remote sensing datasets was used in our analyses which cover a 21-year time period (1992–2012). Daily brightness temperature maps for the period April 2003–September 2011 were obtained from the Bremen University

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