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Recent regional climate cooling on the Antarctic Peninsula and associated impacts on the cryosphere

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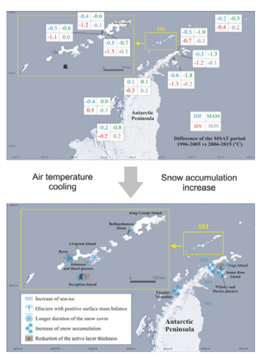
HIGHLIGHTS

- We examine climate variability since the 1950s in the Antarctic Peninsula region.
- This region is often cited among those with the fastest warming rates on Earth.
- A re-assessment of climate data shows a cooling trend initiated around 1998/1999.
- This recent cooling has already impacted the cryosphere in the northern AP.
- Observed changes on glacial mass balances, snow cover and permafrost state

GRAPHICAL ABSTRACT



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ABSTRACT

The Antarctic Peninsula (AP) is often described as a region with one of the largest warming trends on Earth since the 1950s, based on the temperature trend of 0.54 °C/decade during 1951–2011 recorded at Faraday/Vernadsky station. Accordingly, most works describing the evolution of the natural systems in the AP region cite this extreme trend as the underlying cause of their observed changes. However, a recent analysis (Turner et al., 2016) has shown that the regionally stacked temperature record for the last three decades has shifted from a warming trend of 0.32 °C/decade during 1979–1997 to a cooling trend of −0.47 °C/decade during 1999–2014. While that study focuses on the period 1979–2014, averaging the data over the entire AP region, we here update and reassess the spatially-distributed temperature trends and inter-decadal variability from 1950 to 2015, using data from ten stations distributed across the AP region. We show that Faraday/Vernadsky warming trend is an extreme case, circa twice those of the long-term records from other parts of the northern AP. Our results also indicate that the cooling initiated in 1998/1999 has been most significant in the N and NE of the AP and the South Shetland Islands (>0.5 °C between the two last decades), modest in the Orkney Islands, and absent in the SW of the AP. This recent cooling has already impacted the cryosphere in the northern AP, including slow-down of

Abbreviations: AP, Antarctic Peninsula; DJF, December-January-February; ENSO, El Niño–Southern Oscillation; JJA, June-July-August; MAAT, Mean Annual Air Temperature; MAM, March-April-May; MSAT, Mean Seasonal Air Temperature; PDO, Pacific Decadal Oscillation; SAM, Southern Annular Mode; SMB, Surface Mass Balance; SON, September-October-November; SSI, South Shetland Islands.

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glacier recession, a shift to surface mass gains of the peripheral glacier and a thinning of the active layer of permafrost in northern AP islands.

1. Introduction

During recent years several studies have analysed the evolution of Antarctic climate during the second half of the 20th century and the beginning of the 21st century. While there is no agreement on the magnitude and rate of warming for the whole continent (Vaughan et al., 2001; Steig et al., 2009; Schneider et al., 2012; Bromwich et al., 2013, 2014), all studies consistently show evidence of the pronounced warming that occurred on and around the Antarctic Peninsula (AP) prior to the 2000s (King, 1994; Marshall et al., 2002; Vaughan et al., 2003; Turner et al., 2005a; Stastna, 2010; Kejna et al., 2013). In fact, the AP has recorded one of the strongest warming rates on Earth, with an increase of ~0.5 °C/decade since 1950 (Turner et al., 2014). Accordingly, the vast majority of recent studies published examining marine and terrestrial ecosystem dynamics, and the evolution of the cryosphere in the AP region have referred to the review papers (e.g. Turner et al., 2014) and international reports (e.g. Vaughan et al., 2013) that underline this regional thermal increase. Higher temperatures have been accompanied by increased precipitation, as suggested both by observations (Turner et al., 2005b; Miles et al., 2008) and modelling (van den Broeke et al., 2006), which has led to higher snow accumulation, particularly in the western AP (Thomas et al., 2008). Marshall et al. (2006) attributed these trends to increased westerlies across the northern AP region associated to variations in the Southern Annular Mode (SAM) and El Niño–Southern Oscillation (ENSO) atmospheric teleconnections (Ding et al., 2011; Clem and Fogt, 2013) as well as to ozone depletion (Thompson & Solomon, 2002).

Observed processes occurring in the natural systems of the AP region have been related to this "recent" regional atmospheric warming trend, and concurrent oceanic changes, including (1) reductions of the seasonal sea-ice extent (Stammerjohn et al., 2008; Goosse & Zunz, 2014; Li et al., 2014), (2) increased ocean temperatures both in the Weddell (Robertson et al., 2002) and Bellingshausen seas (Meredith & King, 2005), (3) retreating ice fronts of both marine- and land-terminating glaciers in the region (Rau et al., 2004; Cook et al., 2005, 2014, 2016), (4) ice-shelf disintegration or retreat and subsequent acceleration of the inland glaciers feeding the ice-shelves (Rignot et al., 2004; Scambos et al., 2004; van den Broeke, 2005; Cook & Vaughan, 2010), (5) enhanced glacier dynamic thinning, acceleration and retreat driven by basal melting of ice shelves (Pritchard et al., 2012; Rignot et al., 2013; Wouters et al., 2015; Fürst et al., 2016), (6) changes on terrestrial biology (Convey, 2003; Convey & Smith, 2006; Convey et al., 2009), and (7) variations of geomorphic processes, permafrost degradation and active layer thickness in ice-free environments (Bockheim et al., 2013; Oliva & Ruiz-Fernández, 2015).

However, most of these studies, typically using periods spanning between the late 1950s and the early 2000s, often do not include climatic data referred to the last decade. Moreover, the trends are usually inferred for the whole period of the instrumental series, but generally do not analyse the interdecadal or short-term variability. Certain reports recently presented preliminary indications that the warming over the AP region has slowed down markedly since the beginning of the century (Blunden & Arndt, 2012; Turner et al., 2015). Carrasco (2013) detected a decrease in the warming rate in stations from the western side of the AP between 2001 and 2010 with even a slight cooling trend in King George Island (South Shetland Islands, SSI). More recently, Turner et al. (2016) have presented a thorough analysis of the regional stacked temperature record of the AP for the period 1979–2014, with the choice of 1979 as start of the time series because it marks the start of the availability of reliable atmospheric reanalyses datasets that incorporate satellite data, as well as fields of sea-ice concentration. Their analysis has shown a diverging trend from warming (by 0.32 ± 0.20 °C/decade) during 1979–1997 to cooling (by -0.47 ± 0.25 °C/decade) during 1999–2014, with the cooling trend being largest in summer.

However, the analysis by Turner et al. (2016) has considered a stacked temperature record describing the regional average temperature evolution, and does not use the complete temperature time series available. We here complete and extend their study by presenting an updated assessment of the spatially-distributed temperature trends and inter-decadal variability of mean annual air temperature (MAAT) and mean seasonal air temperature (MSAT) from 1950 to 2015, using data from ten stations distributed across the AP region. Some recent studies have presented indications of certain environmental impacts on the cryosphere of this recent cooling, though a regional analysis is still lacking. To fill this gap, in this paper we pay special attention to the evaluation of the spatial distribution of the regional cooling between the two most recent decades, and analyse its cryospheric impacts, including slow-down of glacier recession, a shift to surface mass gains of the glaciers peripheral to the AP, and thinning of the active layer of permafrost in the northern AP islands. As the paper by Turner et al. (2016) provides a detailed study of the main atmospheric drivers of the recent cooling trend, here we specifically focus on the role of sea ice – a component of the cryosphere – as a controlling factor of the observed changes in the cryosphere.

2. Study area

The AP is a mountainous landmass stretching northwards >1000 km between 63° and 73°S. This ridge-shaped peninsula encompasses an emerged terrestrial surface exceeding 520,000 km^2 (Summerhayes et al., 2009), which corresponds to the northernmost part of the Antarctic continent (Fig. 1). The average altitude of the AP summit plateaux is ~1500 m a.s.l. (Summerhayes et al., 2009), with an average width of ~70 km between 63° S and 69° S and of ~200 km between 69° and 73°S. Along this N-S mountain chain, several islands and archipelagos surround the AP.

About 98% of the AP is ice-covered (Bockheim, 2015), with a large ice sheet extending over the terrestrial surface and some ice shelves along the western and eastern margins of the peninsula. Moreover, most of the peripheral islands are heavily glaciated and covered by ice caps and valley glaciers (Bliss et al., 2013). The AP Ice Sheet has experienced significant mass losses in recent decades, especially in its northern part, mostly resulting from the acceleration and thinning of outlet glaciers following ice-shelf break-up (Vaughan et al., 2013). These losses currently (2005–2010) contribute 0.10 ± 0.03 mm a^{-1} to global sea level rise (Shepherd et al., 2012). The contribution to sea level rise from the peripheral glaciers is currently believed to be negligible, at 0.017 ± 0.028 mm a^{-1} for the period 2003–2009 (Gardner et al., 2013), contrary to some previous estimates suggesting a rather large contribution of 0.22 ± 0.16 mm a^{-1} for the period 1961–2004 (Hock et al., 2009).

The low-pressure systems moving eastward-southeastwards across the AP bring prevailing westerly winds along the AP during the whole year, more intense in the northern tip of the peninsula. The AP ridge constitutes an orographic barrier to the wet westerly winds, which causes a föhn effect in the eastern side (Grosvenor et al., 2014; Elvidge et al., 2015) inducing a warming effect over this region, associated with the adiabatic heating from the air subsidence. It also implicates distinct moisture content values in the two sides of the AP, with the eastern side becoming comparatively drier than the western side. However, the eastern side of the AP is also strongly affected by the cold air masses

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