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# Observed glacial changes on the King George Island ice cap, Antarctica, in the last decade

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ABSTRACT

The Antarctic Peninsula has been identified as a region of rapid on-going climate change with impacts on the cryosphere. The knowledge of glacial changes and freshwater budgets resulting from intensified glacier melt is an important boundary condition for many biological and integrated earth system science approaches. We provide a case study on glacier and mass balance changes for the ice cap of King George Island. The area loss between 2000 and 2008 amounted to about 20 $km^2$ (about 1.6% of the island area) and compares to glacier retreat rates observed in previous years. Measured net accumulation rates for two years (2007 and 2008) show a strong interannual variability with maximum net accumulation rates of 4950 mm w.e. $a^{-1}$ and 3184 mm w.e. $a^{-1}$, respectively. These net accumulation rates are at least 4 times higher than reported mean values (1926–95) from an ice core. An elevation dependent precipitation rate of 343 mm w.e. $a^{-1}$ (2007) and 432 mm w.e. $a^{-1}$ (2008) per 100 m elevation increase was observed. Despite these rather high net accumulation rates on the main ice cap, consistent surface lowering was observed at elevations below 270 m above ellipsoid over an 11-year period. These DGPS records reveal a linear dependence of surface lowering with altitude with a maximum annual surface lowering rate of 1.44 $ma^{-1}$ at 40 m and $-0.20$ $ma^{-1}$ at 270 m above ellipsoid. These results fit well to observations by other authors and surface lowering rates derived from the ICESat laser altimeter. Assuming that climate conditions of the past 11 years continue, the small ice cap of Bellingshausen Dome will disappear in about 285 years.



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## 1. Introduction

The Antarctic Peninsula is one of the most rapidly warming locations on Earth with 0.56 K decade$^{-1}$ measured at the Faraday/Vernadsky station over the last 50 years (Turner et al., 2005a; Steig et al., 2009). Turner et al. (1997, 2005b) and Thomas et al. (2008) have also shown an increase in precipitation in this area. Additionally, observations and model results show a warming of the ocean in the upper 50 m and a reduced extent of sea ice in the Bellingshausen sector (Meredith and King, 2005). These climatic changes are frequently directly linked to observed changes in the cryosphere as e.g. the retreat and break-up of ice shelves (Scambos et al., 2000) or the widespread retreat of glaciers along the west coast of the peninsula with intensification during the last decade (Rau et al., 2004; Cook et al., 2005).

Mountain glaciers and ice caps around Antarctica make a large sea level rise contribution. Hock et al. (2009) give an estimate of 0.22 mm a$^{-1}$, which accounts for 28% of the global surface mass loss of mountain glaciers and ice caps. Pritchard and Vaughan (2007) reported a 12% speed-up of glaciers along the west coast of the Antarctic Peninsula based on velocity measurements, derived from feature tracking, from repeat ERS-1/2 SAR images from 1992 to 2005. This alone resulted in an annual contribution to sea level rise of 0.047 ± 0.011 mm a$^{-1}$ (1993–2003). They explain this acceleration of the glacier tongues by dynamic thinning of the glacier fronts and the observed retreat. In a subsequent study (Pritchard et al. (2009) quantified surface elevation changes between 2003 and 2007 from ICESat (Ice, Cloud and land Elevation Satellite) altimeter data. They showed that the elevation changes at the northern Antarctic Peninsula and South Shetland Islands (SSI) add up to 1.5 m a$^{-1}$. This is consistent with the estimates of melt rates given by (Vaughan, 2006) using a simple degree-day approach, but lacking direct quantitative validation. Vaughan (2006) proposed an almost doubling of melt rates from 1950 to 2000. Assuming similar warming rates for the future Vaughan (2006) estimates a sea level rise contribution of 0.008 to 0.055 mm a$^{-1}$. These values also reflect the high degree of uncertainty in such predictions and the urgent need for better in-situ observation to validate models. Although the Antarctic Peninsula is a heavily glaciated region with about 80% of its area classified as melt and percolation zone (Rau and Braun, 2002) it has only recently been included in volume change estimates. Radić and Hock (2010) have demonstrated the lack of knowledge and respective databases for glaciers of Antarctica and the Arctic, both regions with the highest potential and uncertainties in regard to estimates and predictions of glacier volume changes. Hence, more measurements of glacier mass balance on the Antarctic Peninsula and surrounding sub-Antarctic islands are required. Only a few studies exist for the Antarctic Peninsula (e.g., Smith et al., 1998; Skvarca et al., 2003; Molina et al., 2007).

Freshwater budgets from glaciers under changing climate conditions are not only important from a glaciological or sea level perspective but also form boundary conditions for marine ecosystems. Meltwater leads to lower salinity, changes in temperature, and a stabilization of the water column in adjacent bays and fjords. Recent sedimentological studies suggest that increased suspended particulate matter transport from land and glaciers impacts the marine ecosystems e.g. by changes in light climate and requirements for adaptation to increasing sedimentation rates (Schloss et al., 1999; Pakhamov et al., 2003). These higher sedimentation rates might be linked to increased glacier ablation (Hass et al., 2009). On King George Island (KGI) in the SSI environment interdisciplinary research programs are investigating the impact of glacier retreat on marine ecosystems. They require detailed information on glacier mass balance, melt water budgets and newly ice-free areas.

Various glaciological studies have been carried out on KGI. Modeling scenarios revealed considerable sensitivity of the KGI ice masses toward warming due to its maritime climate. Knap et al. (1996) predicted a 36% reduction in ice volume over the next 100 years under +1 K conditions and a total disappearance of the entire KGI ice cap under a worst case +5 K scenario. Barboza et al. (2004) predicted that a reduction of the net accumulation (annual mass gain at the surface minus loss by melt and sublimation) rate of 50% over the Lange Glacier would lead to a surface lowering of 26 m in the next 100 years. For Ecology Glacier (Admiralty Bay) a 15% rise in ablation is forecasted by Bintanja (1995) in case of a 1 K temperature increase based on surface energy balance computations for a 4-week summer period. This coincides with extrapolations given by Braun et al. (2001a, 2004) based on melt modeling for three summer periods on Bellingshausen Dome (BD). Their extrapolations for the end of the 1990's would double the measured ablation rates of 750 mm water equivalent (w.e.) by Orheim and Govorukha (1982) for the late 1960's. Also noticeable is the reported rise of the equilibrium line altitude (ELA) since 1967 from 140 m to >200 m in 1999 (Orheim and Govorukha, 1982; Wen et al., 1994; Braun et al., 2000). On the other hand, Wen et al. (1994) concluded by means of mass balance measurements and modeling that BD was stable from 1971 to 1992.

This paper aims at the following three objectives: (1) We investigate the area change and current surface lowering on King George Island. For this purpose we use satellite time series to show changes in glacier extent since 1956 to present for the entire island and Differential Global Positioning System (DGPS) measurements to determine ice surface elevation changes on BD. We extrapolate these findings to the entire island in order to provide melt water budgets for individual catchments. (2) We use the measured surface lowering rates (1997/98 to 2010) and the ice geometry to extrapolate the disappearance of BD. (3) We present net accumulation measurements from two consecutive years that reveal strong interannual variability. This reflects the challenges to be met by surface mass balance modelling and future projections.

## 2. Study site

KGI is located at the northern tip of the Antarctic Peninsula in the archipelago of the SSI. Eight permanent research stations and various seasonal huts and research camps are located on the island. About 90% of the island's surface (1250 km$^2$) is glaciated (Fig. 1). The island's ice cover consists of several connected ice caps with pronounced outlet glaciers. The highest elevation reaches slightly more than 720 m at a dominating central dome.[5] While the northern coast exhibits gentle slopes, the southern coastline has steeper slopes and fjordlike inlets. Two small icefields (Warzawa and Krakow Icefield) with elevations up to 400 m fringe the main ice cap.

The observed mean annual air temperature at Bellingshausen station is −2.3 °C at sea level and the annual decadal air temperature trend (1969–2010) is +0.259 K decade$^{-1}$ ± 0.172 K decade$^{-1}$ (http://www.antarctica.ac.uk/met/gjma/, accessed May 2011). Air temperatures during summer rise well above the freezing point and

[5] All elevations are given in reference to WGS84 ellipsoid if not stated otherwise.