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# Dissolved iron concentration in the recent snow of the Lambert Glacial Basin, Antarctica

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ABSTRACT

Iron (Fe) is a limiting nutrient in the Southern Ocean (SO), and the input of atmospheric iron may fertilize the SO. Therefore, it is important to estimate the deposition and solubility of atmospheric iron in the Antarctica. For this purpose, we measured iron in a 3 m snow pit from the Lambert Glacial Basin (LGB), covering the period 2012–2017. We estimated an average annual dissolved iron (DFe) flux of $1.29 \times 10^{-3}$ mg m$^{-2}$ a$^{-1}$ and an average total dissolvable iron (TDFe) flux of 0.14 mg m$^{-2}$ a$^{-1}$ for this site. The atmospheric fractional iron solubility (FFS) ranges from 0.01% to 21.47% (mean value 1.20%) and shows an inverse hyperbolic relationship with the TDFe concentration. This relationship suggests that atmospheric iron in the LGB comes from a mixture of mineral dust with low FFS and aerosol with high FFS (e.g. combustion aerosols and volcanic ash). Based on the mean value of the atmospheric iron deposit fluxes from both this and previous studies, we estimated that ~0.013 Gg of dissolved atmospheric iron could be deposited in the seasonal sea ice zone (SSIZ) every year, potentially supporting an annual algal production of ~$2.52 \times 10^{12}$ g C in the Antarctic coastal water. This is less than 1% of the annual primary production in the SSIZ of the SO estimated from satellite data. The result shows that, compared with other sources of iron such as iceberg and glacier meltwater, the dissolved atmospheric iron has very small effect on the annual primary production in the SSIZ.

## 1. Introduction

The primary productivity of the Southern Ocean (SO) is largely limited by iron (Fe), a critical component in the global carbon cycle and other important biogeochemical cycles. It has an important impact on the climate, because ocean productivity provides a major mechanism for the drawdown of atmospheric $CO_2$ (Coale et al., 2004). Taking up 10% of total ocean surface area, the SO accounts for 5–10% of the primary production and 25% of the atmospheric $CO_2$ uptake by the global ocean (Arrigo et al., 2008; Moore and Abbott, 2000; Takahashi et al., 2011). However, the SO has low input of bioavailable iron, leading to high-nutrient, low-chlorophyll (HNLC) conditions, as phytoplankton growth is limited by iron (Martin, 1990). It is therefore important to understand how iron modulates the SO productivity and carbon sequestration in order to project the SO responses to future environmental changes. Sources of iron to the SO include continental shelf sediments, upwelling of recycled iron (Tagliabue et al., 2009), atmospheric dust deposition (Jickells et al., 2005), and sea ice (Edwards and Sedwick, 2001). Estimating the amount of iron in the ice sheet is an important way to quantify the contribution of atmospheric Fe in the polar oceans (Smith et al., 2007). This can be achieved by careful measurements of dissolved iron (DFe) from ice and snow, but this kind of work is largely lacking. Many studies suggest that iceberg and subglacial meltwater are important iron transport pathways (Bhatia et al., 2013; Raiswell et al., 2008; Statham et al., 2008), and their contribution is vital for primary productivity and iron cycling of SO (Death et al., 2014). However, recent satellite observations suggest that substantial subglacial meltwater is transported from the Antarctic ice sheet into the SO via channels beneath the ground and ice shelves (Le Brocq et al., 2013). As a result, there may be fundamental differences between iron concentration in subglacial meltwater and glacial ice sheet because of elevated physical erosion rates, prolonged meltwater residence times and greater anoxia under ice sheet (Raiswell et al., 2016). Therefore, iron in subglacial meltwater and iceberg is not representative of iron in the Antarctic ice sheet. In addition, for both glacial meltwater and icebergs, there are almost no data to separate the proportions of iron

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from basal sediment and ice sheet (Hawkings et al., 2014). Consequently, there is a great need for direct measurements of atmospheric iron concentration of the ice sheet. Currently, the atmospheric DFe concentration of the Antarctic ice sheet is poorly constrained and there are few data on fluxes from large ice sheets (Winton et al., 2016b). The isolated Lambert Glacial Basin (LGB) provided a perfect location for researching DFe from atmospheric dust from the continent of Southern Hemisphere (Delmonte et al., 2002). This study examines the iron fluxes in the recent Antarctic snow at the LGB and evaluates the contribution of dissolved atmospheric iron to the primary production in the seasonal sea ice zone (SSIZ).

## 2. Materials and methods

### 2.1. Sampling site and materials

All samples were collected at the LGB in January 2017 during the 33rd Chinese Antarctic Research Expedition (CHINARE) project. Easterly wind, also the direction of the katabatic wind, dominates the LGB throughout the year (Parish and Bromwich, 2007). Annual mean temperature is −26.5 °C, and annual mean wind velocity is 9.0 m/s. Stake measurements from January 1999 reveal a relatively high accumulation rate at the LGB (162–286 kg $m^2$ $a^{-1}$) (Ding et al., 2015; Xiao et al., 2005). High snow accumulation at the sampling site provides an ideal setting to examine the seasonal variability of atmospheric Fe deposition. A total of 85 samples were collected in a 3 m snow pit located 190 km away from the coast of East Antarctica (77.2684°E, 71.0167°S, 1985 m above sea level, Fig. 1). A series of precautions were taken as follows to prevent the possibility of contamination. Low-density polyethylene (LDPE) sample bottles were precleaned in a clean room following the procedure below: they are (1) submerged in 25% (v/v) analytical grade nitric acid (Fisher Scientific®, Canada) for 7 days and rinsed with ultrapure water (Milli-Q, 18.2 MΩ); (2) submerged in 25% (v/v) trace metal grade nitric acid for 7 days and rinsed with ultrapure water; (3) submerged in 1% (v/v) optima grade nitric acid for 7 days and rinsed with ultrapure water; (4) submerged in 1% (v/v) optima grade nitric acid until use. All sampling items were carefully cleaned following the procedure described in Liu et al. (2011, 2009). The snow pit was located 2 km upwind of the camping point and dug by researchers wearing LDPE gloves and clean room suit. About 10 cm of surface snow from the upwind wall were then shaved away by stainless steel shovel. Then an additional 5 cm of surface snow were shaved away by acid-cleaned ultraclean polytetrafluoroethylene (PTFE) scrapers until the profile was smooth. The snow samples were collected at a ~3.5 cm interval (diameter of bottle) using 250 mL acid-clean LDPE bottles. Field blanks were collected with every ten samples by simply opening the bottles without sampling the snow. These field blanks were collected to measure the ambient iron contribution during the sampling process. All samples were sealed in precleaned zipper bags and kept frozen in expanded polypropylene box until analysis.

### 2.2. Sample analyses

All sample preparation was conducted in a class 100 clean bench. The samples were first thawed and then aliquoted into polypropylene centrifuge tubes (As One®, Japan), which had been cleaned before use following the same rigorous acid rinsing procedure described in section 2.1. Dissolved iron (DFe) samples and Total Dissolvable iron (TDFe)

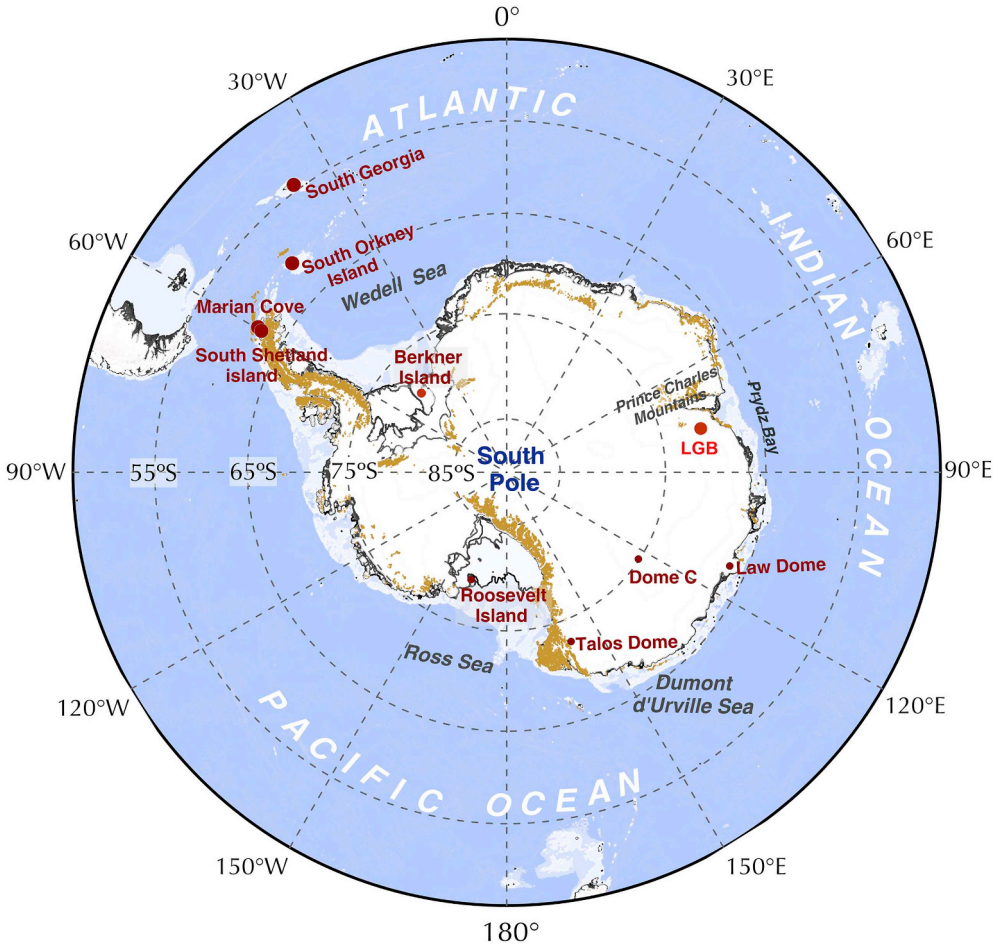


**Fig. 1.** The locations of the snow pit at the Lambert Glacier Basin (LGB), East Antarctica and other research sites mentioned in this paper.