## Supplementary Information

### 1. Concentrations of iron in different water types

Supplementary Table 1 documents published concentrations of iron measured across a range of different glacial water types. We draw upon these published concentrations to constrain the likely iron concentrations in Antarctic subglacial meltwaters (SGM-Fe, here defined as aqueous, nanoparticulate iron species and some colloids < 0.4 μm following (Raiswell and Canfield, 2012)). The reported range of Fe concentrations, which includes values for Greenland runoff and valley glaciers in the McMurdo Dry Valleys Antarctica and groundwaters present in glacial sediments, leads us to assume lower and upper values for concentrations (including colloids in some cases) of 3 and 30 μM respectively derived from the range of iron concentrations reported in runoff from valley glaciers in the McMurdo Dry Valleys/Greenland Ice Sheet runoff and groundwaters present in glacial sediments respectively. Fluxes of DFe in subglacial meltwater are calculated from the product of these concentration values and the total water flux (52.8 Gt $a^{-1}$: see main manuscript).

**Supplementary Table 1 Summary of iron concentrations measured in glacier ice, sea ice, glacial runoff and groundwaters worldwide (mean, range or single sample concentrations reported)**

| Sample/site description | Reference | Concentration (μM) | Filtration method |
|---|---|---|---|
| **Iceberg/glacier ice** | | | |
| Iceberg, Antarctica | (Raiswell et al., 2008) | 0.00069 | 0.2 μm filters |
| Glacier ice, Antarctica | (Raiswell et al., 2008) | 0.0015 | 0.2 μm filters |
| Glacier ice, Antarctica | (Loscher et al., 1997) | 0.0204 | 0.4 μm filters |
| **Sea ice/snow on sea ice** | | | |
| Snow (on sea ice), Antarctica | (Loscher et al., 1997) | 0.042 | 0.4 μm filters |
| Sea ice, Antarctica | (Loscher et al., 1997) | 0.019 | 0.4 μm filters |
| Sea ice, Antarctica | (Martin et al., 1990) | 0.026 | No filtration/acid digest – total dissolvable Fe |
| **Glacial runoff, Northern Hemisphere** | | | |
| Greenland Ice Sheet runoff | (Statham et al., 2008) | 0.053 | 0.4 μm filters |
| Greenland Ice Sheet runoff | (Bhatia et al., 2013) | 2-9 | 0.2 μm filters |
| **Glacial runoff, Antarctica** | | | |
| Runoff - Blood Falls, McMurdo Dry Valleys, Antarctica | (Mikucki et al., 2009) | 3450 | 0.2 μm filters |
| Runoff - Onyx River at Lower Wright glacier margin, McMurdo Dry Valleys, Antarctica | (Green et al., 2005) | 1.1 | 0.4 μm filters |
| Runoff - streams in McMurdo Dry Valleys, Antarctica (Onyx river and Vanda station) | (Sheppard et al., 1997) | 2.1 | 0.4 μm filters |
| **Glacial groundwaters** | | | |
| Groundwaters in glacial drift aquifers, Nebraska, USA | (Gosselin et al., 2001) | 35.5 | 0.45 μm filters |
| Groundwaters in glacial drift aquifers, S. Michigan, USA | (Kim et al., 2002) | 18.4 | 0.45 μm filters |
| Groundwaters in glacial drift aquifers, Michigan, USA | (Szramek et al., 2004) | 17100 | 0.45 μm filters |
| Groundwaters in glacial drift aquifers, Illinois, USA | (Warner, 2001) | 31.5 | 0.45 μm filters |

## 2. Antarctic meltwater export

### 2.1. Evidence for meltwater export

There is mounting evidence that meltwater generated at the bed of the Antarctic Ice Sheet is exported to the Southern Ocean (SO) from the ice sheet margin. Land-based and sub-marine geomorphological data display paleo-channels and other hydrological features indicative of the occurrence of outburst floods (Sugden et al., 2006;Lowe and Anderson, 2003) , which is also supported by direct observations of such flood events from the ice margin (Goodwin, 1988). Traces of channels incised into the base of a large number of ice shelves around the continent have also been recently observed in satellite images of the ice shelf surface and suggests extensive meltwater export at the ice sheet margins by large subglacial channels (Le Brocq et al., submitted). Continuous discharge of water from the ice sheet is also supported by sand and/clay deposits in ice-marginal core records which indicate that sediment-laden meltwater plumes originate beneath the ice sheet (Lowe and Anderson, 2002). Sub-marine groundwater discharge has also recently been measured from the East Antarctic coast, at rates that were two orders of magnitude higher than rates reported for mid latitude sites (Uemura et al., 2011). Hence, the notion that meltwater generated at the bed of the ice sheet is ultimately exported is now becoming well established.

## 3. Numerical modeling

### 3.1. Description of the MIT global ocean biogeochemical/ecological model

We employ the MIT global ocean biogeochemical/ecological model (Monteiro et al., 2010) which combines the 1ºx1º MITgcm ocean model with a self-assembling phytoplankton ecosystem(Follows et al., 2007). The ocean circulation is prescribed from the ECCO-GODDAE state estimate in which the model circulation has been constrained to closely match observations (Wunsch and Heimbach, 2007). The phytoplankton ecosystem is self-assembled from a random population of 78 phytoplankton including different types of diatoms, nitrogen fixers, *Prochlorococcus*, other small cyanobacteria and large eukaryotes(Follows et al., 2007;Monteiro et al., 2010). The model also includes two zooplankton types (large and small). In addition to the activity of phytoplankton and grazing, the model captures the dynamics of dissolved and particulate organic matter. Biogeochemical cycles of nitrogen, phosphorus, iron and silica are resolved within the MIT global ocean model.

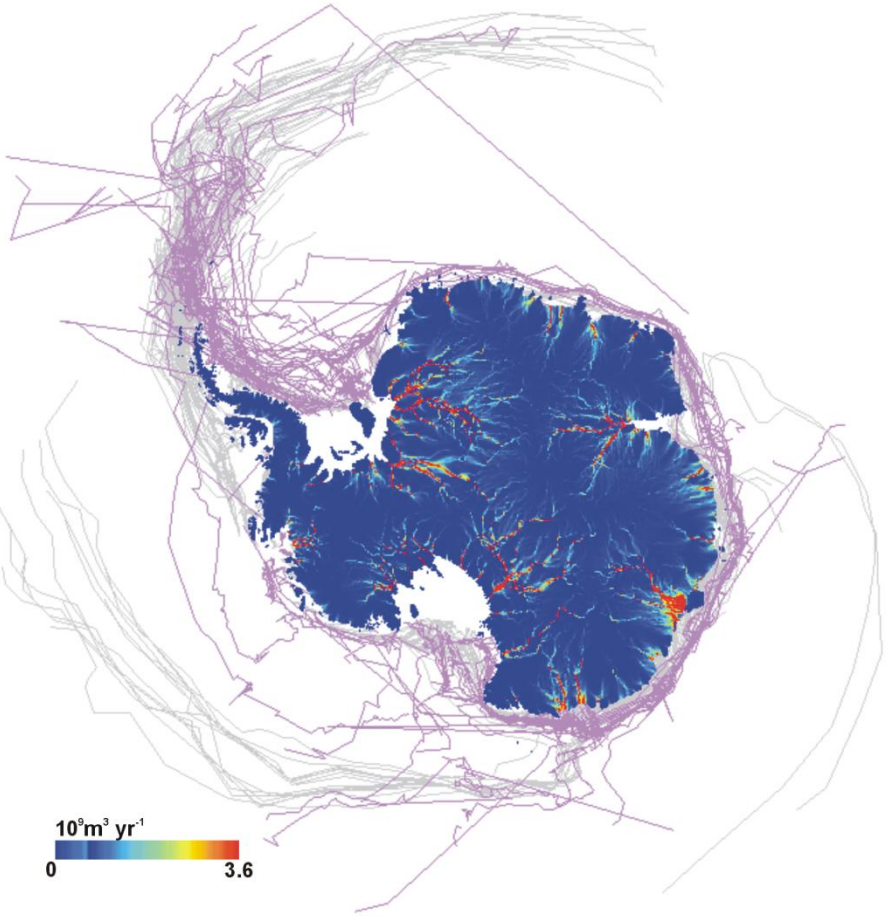
Within the model framework, geochemical and biological processes interact via the uptake of nutrients, phytoplankton growth and decay and remineralisation of organic matter at depth. The four main nutrient cycles of phosphorus, nitrogen, silica, and iron are all represented in the model. Of particular interest to this study is the manner in which the model deals with iron cycling and how the surface ocean phytoplankton community simulated by the model respond to changes in iron bioavailability. The

parameterisation of the iron cycle within the MIT model is prescribed (Parekh et al., 2004;Parekh et al., 2005), with iron existing in a 'free' state or complexed to an organic ligand with binding strength of $K_{FeL}$ ($2\times10^5$ $\mu M^{-1}$). The amount of iron that exists in an organic complex is determined by the total number of ligands available (where the maximum ligand concentration = 1 nM) and the stability of the ligand complex ($K_{FeL}$). Removal of iron occurs either via biological uptake or by scavenging of free iron to particles, with a scavenging rate of $1.1\times10^{-3}$ $d^{-1}$. The rate at which iron is removed from the surface ocean waters and transported to depth is controlled by the sinking rate of particulate organic matter (POM) (10 m $d^{-1}$). The rate at which dissolved iron is returned to the water column through remineralisation depends on whether it is in an organic or nanoparticulate form. The organic matter remineralisation rate is 0.01 $d^{-1}$, while the particulate matter rate is 0.02 $d^{-1}$. Therefore, the vertical profile of dissolved iron in the water column is determined by the balance between the rate of iron acquisition and mineralization versus the rate of iron losses via biological uptake and/or scavenging . Finally, iron sources from subglacial meltwaters and icebergs are prescribed as a forcing into the surface of the ocean.

### 3.2 Iron input fluxes to the model: comparison with observations

Five model scenarios are simulated, each prescribing a different set of iron inputs. These scenarios are A) Dust-only, B) Dust+iceberg fluxes C) Dust+subglacial meltwater (where [Fe] = 3μM) and D) Dust+subglacial meltwater (where [Fe]=30 μM) (S Table 1) and E) Dust+icebergs+subglacial meltwater fluxes (where [Fe]=3 μM]). The following sections detail how iron fluxes from a) dust, b) subglacial meltwater and c) icebergs are calculated and input to the model as forcing fields for primary productivity of the Southern Ocean. The four types of iron source inputs to the model are described in the following sections. Other glacially-sourced nutrient inputs (e.g Si) are not included in these scenarios.

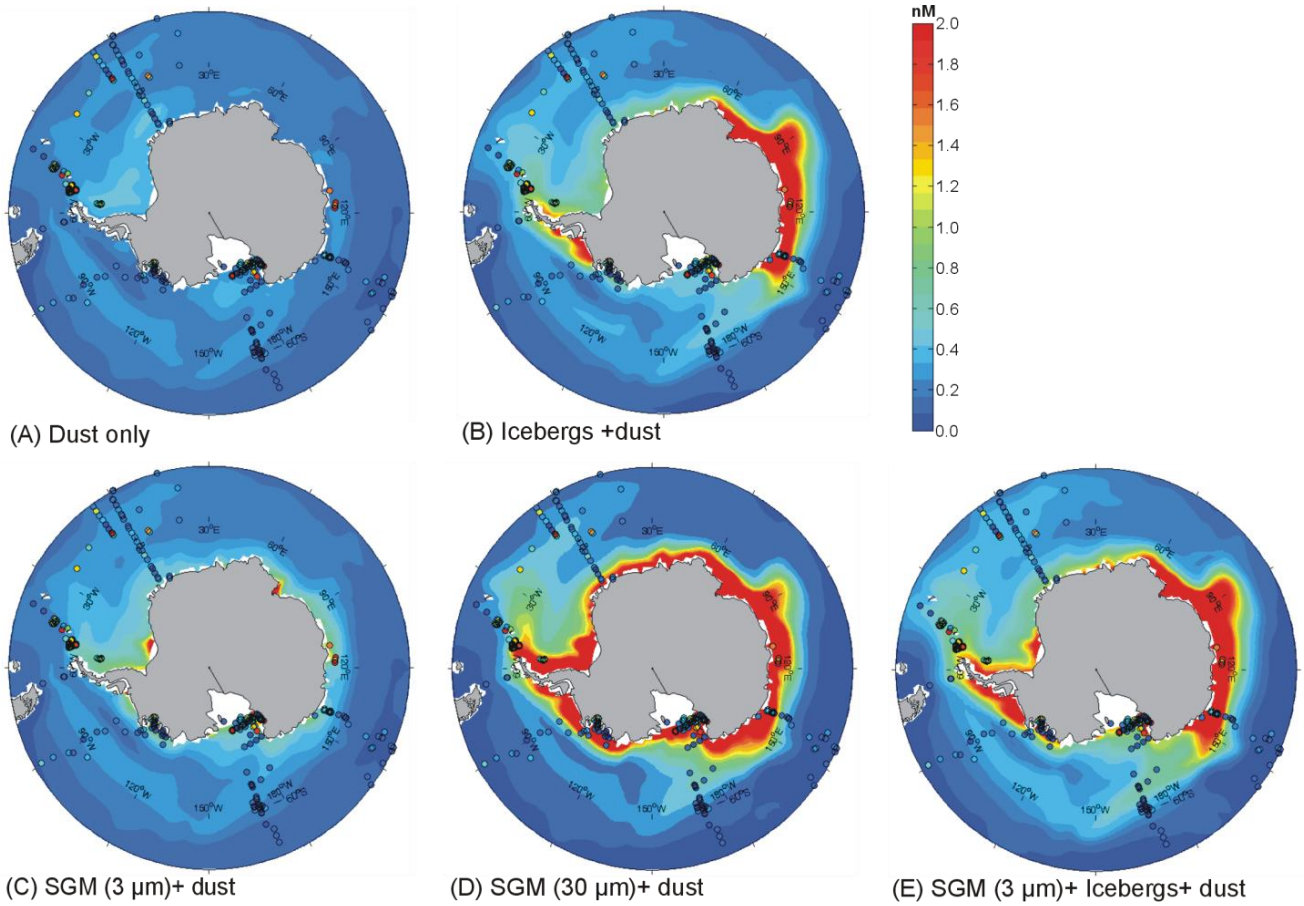
The modelled iceberg tracks are comparative to observations (Suppl. Fig. 1). The general trend is for decay in the concentration of iceberg tracks with distance from the ice sheet. The strong Antarctic Coastal Current flowing anti –clockwise around the continent pins the icebergs to the near coastal zone. In agreement with observational data there are three locations where icebergs are able to escape northwards; (1) tracking up the Antarctic Peninsula (~55 °W), (2) around the Kergulen Plateau (~85 °E) and (3) in the Ross Sea (~180 °E). In these regions the bathymetry of the ocean floor drives the ocean currents northwards so transporting the icebergs entrained within them away from the continent(Gladstone et al., 2001). Once the icebergs move northwards they are caught in the Antarctic Circumpolar Current, which carries them clockwise into the sub-polar waters of the Southern Ocean.




**Supplementary Figure 1. Observed iceberg tracks for icebergs greater than 10 nautical miles (pink) compared to the modelled iceberg tracks (grey). Meltwater generation beneath the ice sheet is also shown using a coloured scale (in $10^9$ $m^3$ $yr^{-1}$ – see legend).**

The iron input scenarios described in the main manuscript provide the MIT model with four different iron input fields, resulting in the surface ocean iron concentrations shown in Suppl. Fig. 2. These modelled surface (0-100 m vertically integrated) iron concentrations are compared with measurements of surface dissolved iron (0-103 m) in the Southern Ocean from a recent compilation of data (Moore and Braucher, 2008) (superimposed on the model results in Fig.2). Measured dissolved iron concentrations in open water areas from the Southern Ocean tend to be < 0.2 nM which agrees largely with the modelled values of all four scenarios. Enhanced coastal dissolved Fe concentrations (> 2nM) are evident in simulations B-E, consistent with marine observations from the Antarctic marginal ice zone, where observed Fe concentrations of up to and greater than 1 nM have been observed (Sedwick et al., 2000;Gerringa et al., 2012;Ardelan et al., 2010;Westerlund and Ohman, 1991) Elevated iron concentrations measured in

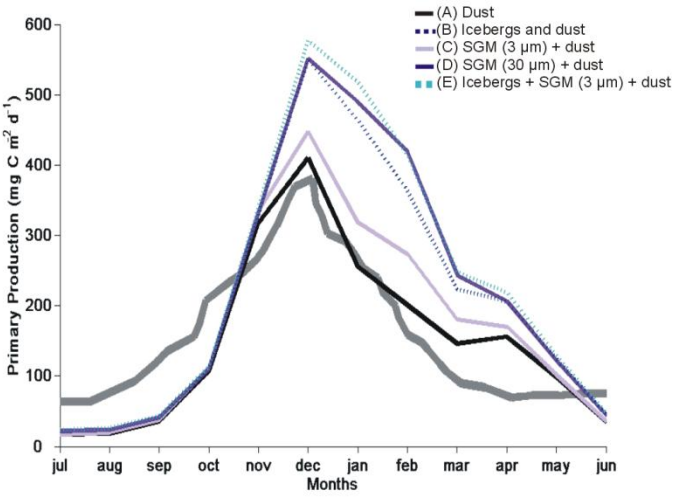
coastal polynyas around Pine Island Glacier have been shown to be capable of sustaining phytoplankton growth, up to 150 km away from the glacier front (Gerringa et al., 2012). In this study the authors assigned the iron input as due to the melt out of basal sediments beneath the Pine Island Glacier tongue,where this iron-rich meltwater is laterally advected within ocean currents to supply the phytoplankton blooms. Studies that sample waters surrounding icebergs have also found increased dissolved iron concentrations (> 2 nM) in waters up to several kilometers distance from melting bergs (Lin et al., 2011). Such elevated ocean surface iron concentrations are not apparent in the control dust-only model simulations (A) and point towards an additional source of Fe near the continent. Previously identified sources of this additional Fe are sea-ice, coastal upwelling, coastal sediments, and, more recently, icebergs (Lancelot et al., 2009). Hence our model results indicate that additional glacially-derived iron fluxes are likely to have a significant impact on the coastal concentrations of iron.




**Supplementary Figure 2 Model-data comparison of dissolved iron concentrations in the surface waters of the Southern Ocean.** Model results are in color and data are represented by the dots (based on the data compilation of (Tagliabue et al., 2012)). Modelled dissolved iron concentrations in the surface waters of the Southern Ocean under Scenarios A-E.

## 3.2 Modelling the annual cycle of Southern Ocean Primary Productivity

The temporal pattern of PP simulated in all model runs corresponds well with that derived from satellite data (Arrigo et al., 2008), with peak productivity in the austral summer (Supplementary Figure 3).




**Supplementary Figure 3 Monthly time series of modelled annual primary productivity for aeolian dust, icebergs and subglacial meltwater (SMW) and a comparison with the modelled primary productivity previously documented by ref (Arrigo et al., 2008) (thick grey line).**

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