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Formation, transport and decay of an intense phytoplankton bloom within the High-Nutrient Low-Chlorophyll belt of the Southern Ocean

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Abstract

The blooms associated with South Georgia coincide with the largest predicted carbon sink in the Southern Ocean. A major injection of iron and silica is required to sustain them over a long growth season that exceeds 4 months. The mechanisms for this are still poorly known but a cruise in January 2005 provided an opportunity to sample waters both upstream and downstream of the North Scotia Ridge to examine the processes involved. SeaWiFS imagery gave a misleading impression of bloom progression due to pronounced but highly regionalised subsurface chlorophyll-*a* (chl-*a*) maxima. Our combined measurements of oceanography, macronutrients, chl-*a* and floral composition showed that a single bloom that had seeded over the western shelf of South Georgia two months before the cruise developed into two distinct entities. Water retention and turbulent mixing south of the island led to severe nutrient depletion, low chl-*a* concentrations in surface waters (and in SeaWiFS images) yet pronounced subsurface maxima. By contrast the bloom over the northern shelf persisted in a shallow mixed layer, was florally different and appeared to be advected downstream into oceanic waters to the north. We found evidence for upwelling of nutrients on the upstream shelf edge of the island where the flow diverges to pass around each side of its shelf. This would provide one mechanism for the injection of iron and silica to sustain these massive South Georgia blooms and seed waters downstream for an extended growing season.
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1. Introduction

Against the backdrop of the High-Nutrient Low-Chlorophyll (HNLC) belt of the circumpolar Antarctic Zone (AAZ), South Georgia's blooms regularly comprise chlorophyll *a* (chl-*a*) concentrations > 10 mg m^{-3} and may be sustained for four months or more (Korb et al., 2004). They seed the ocean for hundreds of kilometres downstream and are associated with the strongest predicted carbon sink in the Southern Ocean (Schlitzer, 2002). Furthermore, the enhanced primary production (Gilpin et al., 2002; Korb and Whitehouse, 2004) supports a rich food web that is also a valuable commercial resource (Atkinson et al., 2001).

The major factor behind these blooms is likely to be iron input (Holeton et al., 2005), brought about by the impact of the Antarctic Circumpolar Current (ACC) on South Georgia and the North Scotia Ridge (NSR) (de Baar et al., 1995; Korb and Whitehouse, 2004). However, in

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northern AAZ waters, silicic acid as well as iron can limit phytoplankton growth (Boyd, 2002). There is a marked north–south silicic acid gradient across the Southern Ocean, with concentrations increasing southwards. Silicic acid depletion can be substantial in the northernmost parts of the Scotia Sea, with concentrations near South Georgia reduced from winter values of >30 mmol m^{-3} to <1 mmol m^{-3} by January (Whitehouse et al., 1996, 2000).

To sustain such substantial diatom blooms, silicic acid and iron are likely to be re-supplied to the euphotic layer throughout the growing season. However, despite intense research, the mechanisms for this, including the locations of nutrient supply, are still debated (Hardy and Gunther, 1935; Korb et al., 2004; Korb and Whitehouse, 2004). During January 2005 we conducted an intensive survey to address this issue. Unlike all recent surveys we were able to study mesoscale processes to the south and upstream of the island, as well as downstream to the north. This allowed the formation, transport and decay of the bloom to be interpreted in relation to the complex physics and chemistry of this area.

2. Methods

2.1. Study site and sampling

Data were collected at stations along ten transects in the vicinity of South Georgia from the RRS *James Clark Ross* during cruise JR116 between 26 December 2004 and 14 January 2005 (Fig. 1A, B). The station symbols in Fig. 1B indicate the regions referred to in the text (north, transects 1, 2 and 10; west, transects 3 and 4; south, transects 5 to 9) and the partition between stations over shelf (500 m deep) and ocean. Stations are identified in the text by their unique transect/station designation, e.g. 4.1 for transect four's station one. At each station, vertical profiles of temperature and salinity were measured with a SeaBird 911+ CTD. A 12-position carousel water sampler with 10 l Niskin bottles attached to the CTD allowed the collection of discrete water samples from the CTD's upcast. Typical sampling depths were 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 120, 140, 160, 180, 200, 500, 1000, 2000, 3000 m and within 10 m of the seabed. A similar sampling frequency to within 10 m of the seabed was used in shallower shelf waters.

2.2. CTD measurements

The CTD conductivity sensor was calibrated against water samples analysed for salinity (Guildline 8400B salinometer) that in turn were calibrated with standard seawater (*Ocean Scientific International Ltd.*). The CTD upcast data were averaged onto 2 dbar pressure levels for analysis.

The depth of the euphotic zone (*Ze*) was defined as that of the 1% incident light level (measured by PAR sensor). It was calculated by estimating the scalar attenuation coefficient (*Kd*) of the water column from the linear regression of the log-transformed irradiance (PAR) vs. depth profile of the shallow CTD (Kirk, 1994). At night-time stations, euphotic depth was

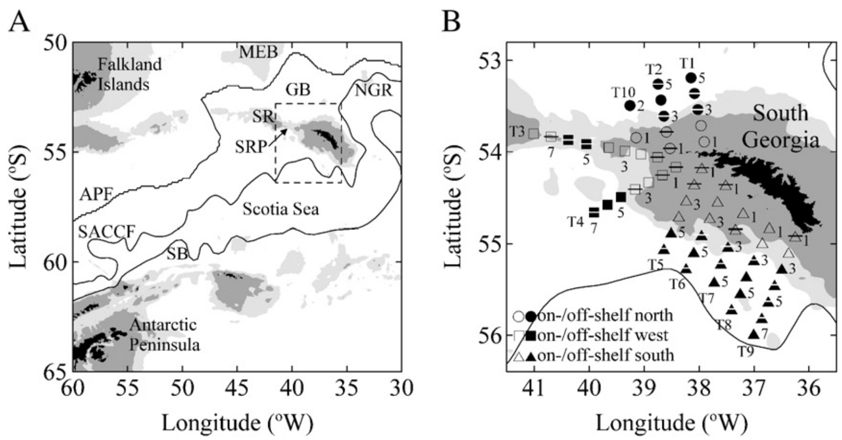

Fig. 1. A. The Scotia Sea region showing the mean positions of the Antarctic Polar Front (APF; Moore et al., 1999), the Southern Antarctic Circumpolar Current Front (SACCF; Thorpe et al., 2002) and the Southern Boundary of the Antarctic Circumpolar Current (SB; Orsi et al., 1995) and the locations of the Maurice Ewing Bank (MEB), Shag Rocks (SR), Shag Rocks Passage (SRP), the Georgia Basin (GB) the Northeast Georgia Rise (NGR) and the study site (dotted boundary). B. Transect locations (T1 to T10) and the regional grouping of on- and off-shelf stations. Stations are numbered from South Georgia outwards, with alternate stations labelled. Note that only 2 stations were occupied along transect 10, both of which are labelled. The 29 locations where primary production was measured are indicated by a bar through the station symbol. The SACCF is marked as a solid black line. The pale and dark grey shading in both maps are delineated by the 2000 m and 500 m isobaths.

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