Supporting Online Material

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Materials and Methods

The two regions for the experimental enrichments were chosen based on their hydrography, nutrients, the corresponding biogeochemical provinces they represent and the studies performed in these regions as part of the recent Joint Global Ocean Flux study conducted in these regions throughout the 1990's. In this way the findings could be extrapolated over much larger regions of the Southern Ocean during the seasonal period studied. Nutrient distributions for this region for this time period are depicted in Figure S1.

We enriched two distinct regions of the Southern Ocean, characterized by low (2 μM) and high (60 μM) ambient concentrations of Si. Successive additions of acidic (pH 3) iron sulfate were pumped into the ship's wake to achieve iron enrichments of the mixed layer calculated to be 1.2 nM, 1.2 nM and 1.5 nM at the North Patch site whereas 4 additions resulting in 0.7nM enrichments each at the South Patch site, formed the basis of the experimental patches (Table S1 and S2). These enriched regions (referred to as patches) were intensively studied over time with successive occupations by the research vessels Revelle, Melville and USCG RIB Polar Star resulting in a cumulative 40 and 28 days of observation at the North Patch and South Patch respectively.

Hydrography

The hydrographic conditions at the North and South Patch differed in several ways. First, high wind stress and frontal boundaries led to variations in the mixed-depth layer and distortion of the North Patch which evolved into a fast moving filament 7 km wide by at least 340 km long by day 38. This is characteristic of conditions near the Subantarctic Front Zone. In contrast, the South Patch, located in the region just south of the Southern Antarctic Circumpolar Front, was relatively coherent throughout the observational period expanding from an initial 225 km^2 to a patch 26 km by 84 km or an area of 2100 km^2 by day 20 (Fig. S1C). The average mixed-layer temperatures and depths at the North and South Patch sites were 5^oC, 40m; and -0.5^oC, 45m

Storm mixing provided variability in the depth of the mixed layer and periodic infusions of thermocline nutrients at both sites thus the absolute changes in mixed layer concentrations reflect a conservative estimate of nitrate uptake. Nonetheless, measurable depletions in nitrate, Si and pCO_2 at both sites were consistent increases in chlorophyll, production of particulate, and dissolved, organic carbon and the development of excess oxygen anomalies at both patches. Silicic acid concentrations at the northern site can vary between 1and 10 µM whereas concentrations at the southern site are consistently above 55 µM reaching 70 µM (3).

While phytoplankton biomass outside the patches remained constant throughout the observational period, Chl-a concentration in the euphotic zone increased ca. 14-fold inside both North and South patches (Figure S2 A, B). Although the filamentous nature of the North Patch prevented accurate assessment of its areal extent, the 3-D mapping of phytoplankton distribution in the South patch showed that the iron infusion (infusion of 2 tons of iron) produced 107 tons of Chl-a within the period of three weeks. Assuming C/Chl-a = 78, this corresponds to 8.3×10^3 tons iron-induced carbon the drawdown of which is depicted in Figures S2 E, F as measured shipboard during underway surveys of the enriched areas.

To elucidate the factors controlling the floristic shift in the phytoplankton community, we measured variable fluorescence and photosynthetic parameters in individual cells (2). Prior to iron release, large (>20 µm) cells exhibited lowered values of F_v/F_m, suggesting that these cells are more susceptible to iron deficiency than small cells. Following the iron fertilization, F_v/F_m

increased in all cell size groups (from ~1 μm to >100 μm), indicating a broad community response to iron enrichment stimulating photosynthesis in all groups of phytoplankton (Figures S2C, D). However, the relative increase in F_v/F_m was twice as high for large cells (a factor of 4 in cells >20 μm, compared to a factor of 2 for cells <5 μm), indicating stronger stimulation of photosynthetic activity by iron. The Fe contents of large cells doubled following fertilization while the Fe:C ratios stayed constant in picoplankton, further indicating that the larger cells had been more severely limited by Fe. Iron-enhanced growth rates were observed for small cells in the South Patch (~0.25 d^{-1} versus the ambient 0.15 d^{-1}), but their biomass did not increase substantially due to a simultaneous and comparable increase in the grazing pressure on them. Thus, larger cells increased disproportionately relative to smaller cells. The overall shift in the community structure in both patches was towards larger cells (> 5 μm). In the North Patch, enhanced growth was evident for flagellated phytoplankton groups (prymnesiophytes, pelagophytes, dinoflagellates) as well as the diatom *Pseudonitzschia spp*. By day 28, diatom biomass represented about half of the total biomass and showed the largest change relative to initial values (Fig. S3).

Figure S1). Surface water distributions of Si (A) and nitrate (B) in the Southern Ocean (1). About 70% of the Southern Ocean is characterized by Si concentrations less than 5 μM and 30% above 60 μM. Intermediate and deep waters of the oceans, carrying high partial pressures of CO_2 and large amounts of dissolved nitrate and phosphate, outcrop in the Antarctic Circumpolar Current (ACC) between the Antarctic Polar Front (APF) and the South ACC Front (SACCF). (C) Ships tracks and general location of the SOFeX enrichments. Cruise tracks of each vessel together with the locations of the North Patch and South Patch are presented graphically and are not to scale, but do represent the spatial evolution of the experimental sites.

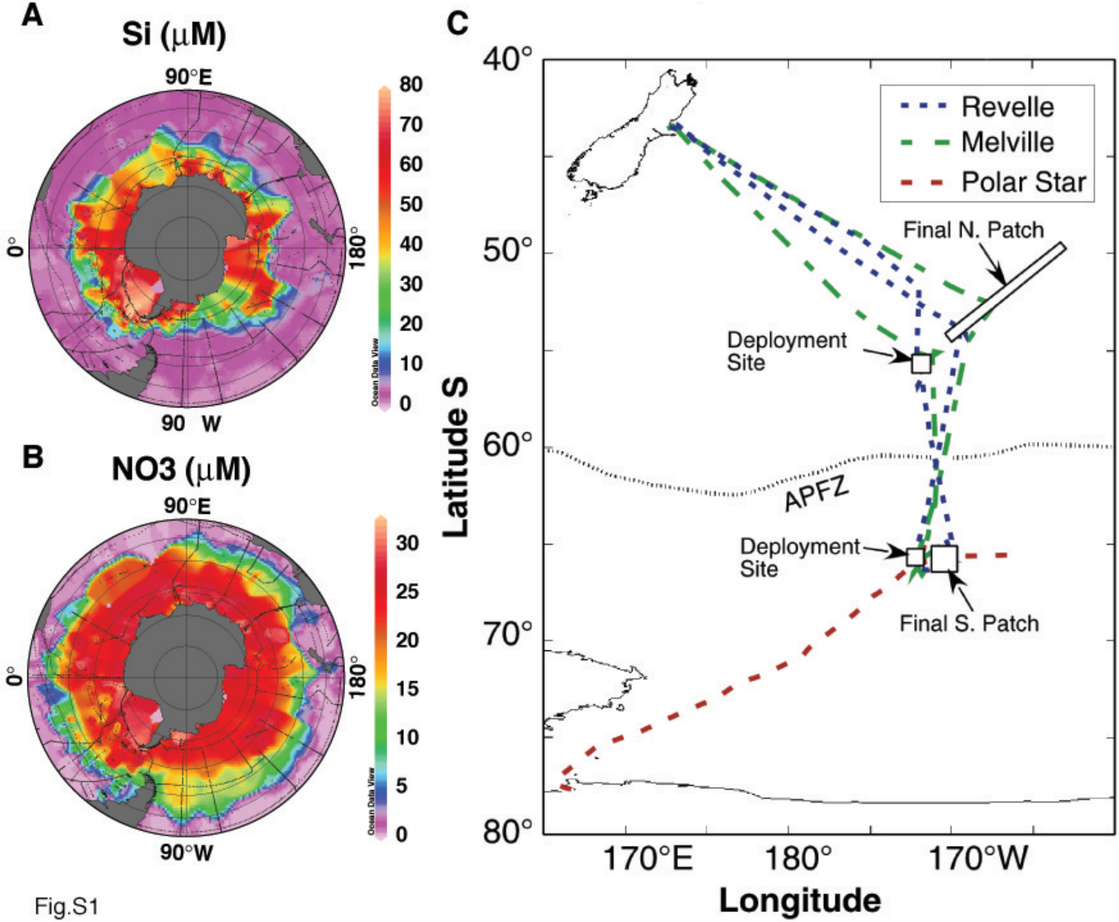
A
Si (μM)
90°E
0°
180°
90 W
80
70
60
50
40
30
20
10
0
Ocean Data View
B
NO3 (μM)
90°E
0°
180°
90°W
30
25
20
15
10
5
0
Ocean Data View
C
Revelle
Melville
Polar Star
Final N. Patch
Deployment Site
APFZ
Deployment Site
Final S. Patch
40°
50°
60°
70°
80°
Latitude S
170°E
180°
170°W
Longitude

Fig.S1

Figure S2. The concentration of particulate organic carbon (POC) in the North and South Patches. In each case the solid line represents an exponential fit to the *in situ* observations and the dashed line represents the [POC] expected in the absence of dilution due to patch dynamics. POC was modeled as:

$$POC_{in,t} = POC_{in,t-1} + \{POC_{in,t-1} \times (g-d) \times \Delta t\} + \{POC_{out} \times d \times \Delta t\}$$

Where:
$POC_{in,t}$ = POC inside patch at time t [μmol kg^{-1}]
$POC_{in,t-1}$ = POC inside patch at time t-1 [μmol kg^{-1}]
g = net growth rate per day – *ie* {growth – grazing – sinking} [day^{-1}]
d = dilution [day^{-1}]
Δt = the time step [days]
POC_{out} = POC outside the patch, assumed constant [μmol kg^{-1}]

This model inherently overestimates the effect of dilution because the growth rate, g, is constant. In the fertilized patch, g likely increases with time, so the effect of dilution is more pronounced towards the end of the experiment.

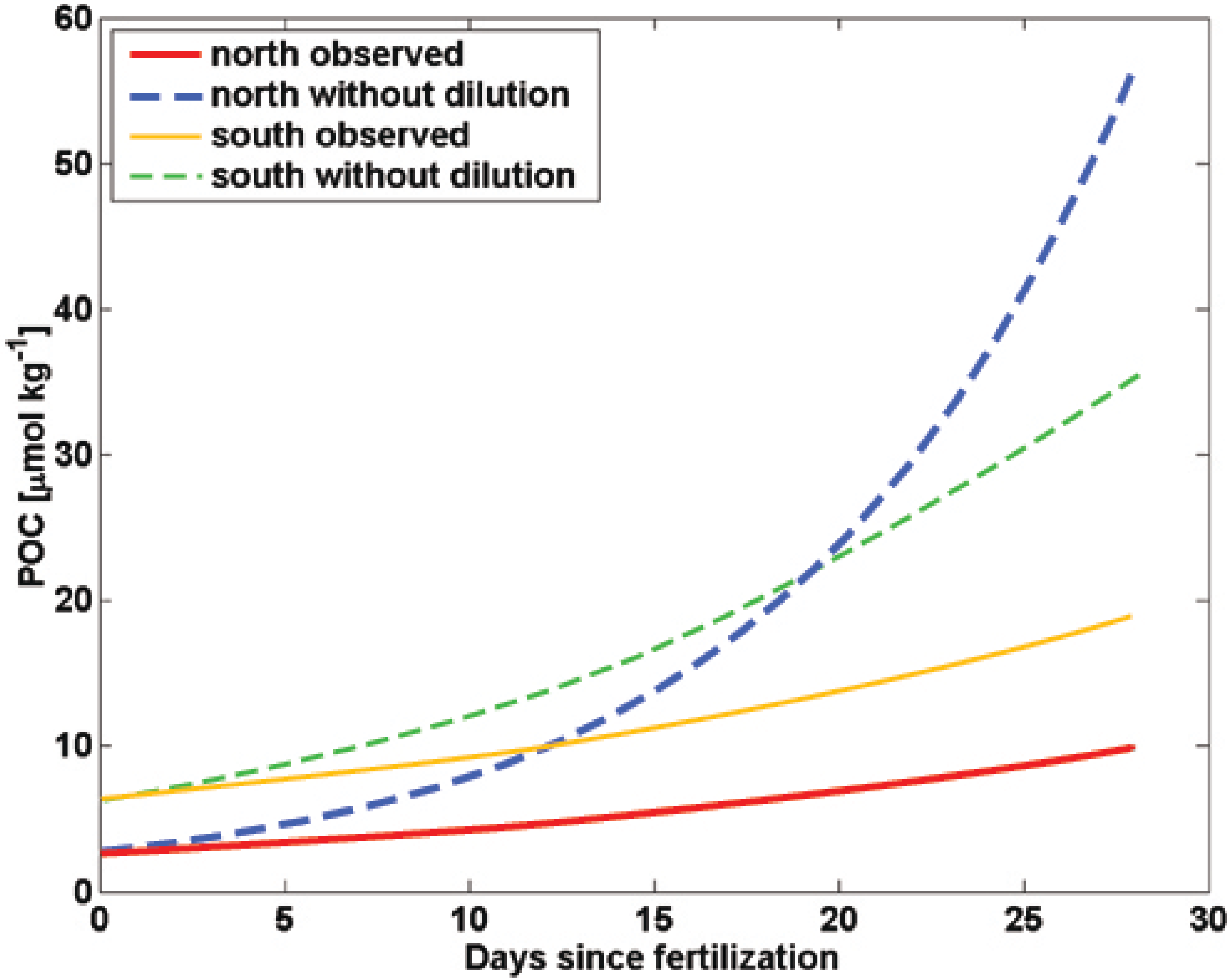
north observed
north without dilution
south observed
south without dilution
POC [μmol kg-1]
Days since fertilization
0
10
20
30
40
50
60
0
5
10
15
20
25
30

Fig. S2

Figure S3. North Patch parameters (upper panel), South Patch parameters (lower panel). A, B) Distribution of chlorophyll a as measured using flow-through fast repetition rate fluorometer (FRRF); C, D) photosynthetic efficiency (Fv/Fm); The spatial distributions of phytoplankton photosynthetic efficiency (F_v/F_m) and Chl-*a* have been reconstructed from underway measurements of Chl-a variable fluorescence. The ship track is shown as a black line. E, F) North Patch pCO_2 distribution. Observed pCO_2 decreased monotonically throughout the entire experiment. All South Patch data (B, D, F) are from experiment day 20. North Patch data are from experiment days 38 (A, C) and 37 (E).

Figure S4. Time series of fluorometric chlorophyll *a* from transits by three ships through the patch of iron enriched water at the South Patch (about 66°S latitude).

Figure S5. Taxonomic evolution of the iron enrichment experiments North (top) and South (bottom) of the APFZ. HP: heterotrophic picoplankton, RFP: red fluorescing picoplankton, Flags: prymnesiophytes, peligophytes and dinoflagellates, Diat: diatoms. Values are in micromoles carbon per liter. Biomass estimates were determined from measured cell volumes and published volume:carbon ratios. Percentages represent the total amount of phytoplankton biomass. Evident by these values is the dominance of diatoms in the South Patch whereas non-silicious phytoplankton comprised the majority of the biomass in the North Patch.

References

1. N. Mahowald et al., *J. Geophys. Res.* 104, 15895 (1999).

2. M. Y. Gorbunov, Z. S. Kolber, P. G. Falkowski, *Photosynthesis Res.* **62**, 141 (1999).

3. W. O. Smith et al., *Deep-Sea Res. II*, **47**, 3073 (2000).

Table S1

The time course of iron injections for the Northern Patch indicating target concentrations and mixed layer depths.

Patch	Start date/time	End date/time	Fe added [kg]	MLD [m]	Fe [nM]	TIME Z
North Survey 0[1]	10/Jan/02 13:00 Local	12/Jan/02 11:00 Local				
	10/Jan/02 00:00 UTC	11/Jan/02 22:00 UTC				
North Fertilization 1	13/Jan/02 03:00 Local	15/Jan/02 03:30 Local	631	45	1.2	Day0= 1/12 UTC
	12/Jan/02 14:00 UTC	14/Jan/02 14:30 UTC				
North Survey 1	15/Jan/02 03:30 Local	16/Jan/02 02:30 Local				
	14/Jan/02 14:30 UTC	15/Jan/02 13:30 UTC				
North Fertilization 2	16/Jan/02 16:30 Local	18/Jan/02 04:00 Local	631	45	1.2	
	16/Jan/02 03:30 UTC	17/Jan/02 15:00 UTC				
North Survey 2	18/Jan/02 06:00 Local	20/Jan/02 03:00 Local				
	17/Jan/02 17:00 UTC	19/Jan/02 14:00 UTC				
North Survey 3[1]	08/Feb/02 13:00 Local	09/Feb/02 14:30 Local				
	08/Feb/02 00:00 UTC	09/Feb/02 01:30 UTC				
North Fertilization 3[1]	10/Feb/02 00:00 Local	10/Feb/02 14:00 Local	450	55	1.5	
	09/Feb/02 11:00 UTC	10/Feb/02 01:00 UTC				
Notes:	[1]No 'relative to drifter' positions for these time periods - no drifter deployed					
	[2]All grids 15km x 15km, 500m line spacing except for					
	South 4 (750m spacing) and North 3 (20 x 5 and variable)					

Table S2

The time course of iron injections for the Southern Patch indicating target concentrations and mixed layer depths.

Patch	Start date/time	End date/time	Fe added [kg]	MLD [m]	~Fe [nM]	TIME Ze
South Survey 0[1]	22/Jan/02 17:50 Local 22/Jan/02 04:50 UTC	24/Jan/02 02:00 Local 23/Jan/02 13:00 UTC				
South Fertilization 1	24/Jan/02 20:30 Local 24/Jan/02 07:30 UTC	26/Jan/02 14:30 Local 26/Jan/02 01:30 UTC	315	35	0.71	Day0= 1/24 UTC
South Survey 1	26/Jan/02 14:30 Local 26/Jan/02 01:30 UTC	29/Jan/02 02:00 Local 28/Jan/02 13:00 UTC				
South Fertilization 2	29/Jan/02 03:30 Local 28/Jan/02 14:30 UTC	30/Jan/02 14:30 Local 30/Jan/02 01:30 UTC	315	35	0.7	
South Survey 2	30/Jan/02 19:30 Local 30/Jan/02 06:30 UTC	01/Feb/02 23:00 Local 01/Feb/02 10:00 UTC				
South Fertilization 3	01/Feb/02 23:00 Local 01/Feb/02 10:00 UTC	03/Feb/02 00:00 Local 02/Feb/02 11:00 UTC	315	35	0.7	
South Survey 3	03/Feb/02 00:30 Local 02/Feb/02 11:30 UTC	04/Feb/02 10:00 Local 03/Feb/02 21:00 UTC				
South Fertilization 4[2]	05/Feb/02 00:00 Local 04/Feb/02 11:00 UTC	05/Feb/02 16:00 Local 05/Feb/02 03:00 UTC	315	35	0.7	
South Survey 4[1]	05/Feb/02 16:00 Local 05/Feb/02 03:00 UTC	06/Feb/02 01:00 Local 05/Feb/02 12:00 UTC				
Notes:	[1]No 'relative to drifter' positions for these time periods - no drifter deployed					
	[2]All grids 15km x 15km, 500m line spacing except for					
	South 4 (750m spacing) and North 3 (20 x 5 and variable)					