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Phytoplankton production in the Southern Ocean is controlled by complicated interactions of light, nutrients, and iron availability. In early 2002, the Southern Ocean Iron Experiment (SOFeX), was completed in the Southern Pacific (along ~ 170° W). Two iron enriched patches were created North and South of the Polar Front with initially distinct silicic acid concentrations, ~1 μM and ~60 μM, respectively. PAM was employed for measuring phytoplankton whole water (bulk) and single-celled photochemical efficiency of Photosystem II ( $F_v/F_m$ ). Bulk measurements of photochemical efficiency for PAM show increases as phytoplankton from iron-enriched patches are relieved from iron stress for both the North and South Patch. For single-celled analysis with PAM, a time course from the South Patch will be presented along with late North Patch data. For the Southern Patch, a distinct increase in  $F_v/F_m$  with time was detected for all diatom genera analyzed and  $F_v/F_m$  values continued to increase over the duration of analysis. For the late Northern Patch phytoplankton assemblage, bulk  $F_v/F_m$  estimates were still elevated, ~0.5. However, the dominant species, *Pseudonitzschia sp.*, exhibited lower photochemical efficiency (0.25-0.35), suggesting that it may have been experiencing iron or silica stress. In contrast,  $F_v/F_m$  measurements of another dominant species, *Phaeocystis antarctica*, exhibited higher (0.5-0.6) values, suggesting that the colonial haptophyte was not significantly stressed at the time of measurement.

## OS11A-0203 0830h POSTER

## Interactions of Iron and Ammonium on N-Uptake in the Southern Ocean South of Australia

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The ability to model new production is important for prognostic studies of the global carbon cycle, as new production represents the exportable fraction of carbon from the photic zone. Here we consider the effects of ammonium and iron availability on algal nitrogen uptake and the f-ratio (the relative fraction of new vs. regenerated production) in the Southern Ocean. To investigate the individual and combined effects of ammonium and iron availability on nitrogen uptake in natural plankton assemblages, we conducted shipboard experiments at three locations between Australia and Antarctica during austral spring (CLIVAR SR3 transect, November 2001): the Subantarctic Zone (SAZ), the Polar Front Zone (PFZ) and the Antarctic Zone-South (AZ-S). Here ambient surface-water dissolved iron levels were 0.26, 0.14 and 0.11 nM, respectively. Cleanly-collected seawater was divided into two incubation treatments: one with added iron (+1.8 nM) and one without (control). After incubation for ca. one week, we measured the uptake of nitrate, ammonium and urea, in both the control and iron-enriched treatments, both with and without added ammonium (0.2 to 0.9 M).

Iron enrichment enhanced nitrate (4-7x), ammonium (2x) and urea (2-3x) uptake rates, with a concomitant increase in the f-ratio of about 1.4x. Overall, ammonium additions resulted in enhanced ammonium uptake rates and lowered nitrate uptake rates, while there was no clear effect on the uptake of urea. Consequently, ammonium addition decreased the f-ratio in both Fe-enriched and non-Fe-enriched experiments. These results are in agreement with previous field observations from the SAZ, and suggest that there is a synergistic interaction between iron and ammonium in regulating community nitrogen uptake and the f-ratio. Iron availability increases the f-ratio and hence new production, implying enhanced particle flux from the surface ocean to the mesopelagic zone. In contrast, ammonium addition leads to decreases in nitrate use and the f-ratio, with the largest impact in situations where ambient iron levels are high and ammonium low. Thus there is not necessarily a simple relationship between Fe availability and enhancement of new production.

## OS11A-0204 0830h POSTER

## Enhanced Carbohydrate Production by Phytoplankton of the Southern Ocean in Response to Iron Fertilization

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Iron concentrations in the Southern Ocean are generally low. At these concentrations microalgal growth, in particular of large diatoms, is affected because iron plays a central role in photosynthesis and several metabolic processes. During the Polarstern 2000 iron release experiment, we studied the effect of in situ iron enrichment on the microalgal production and consumption of water-extractable carbohydrates. The experiment was performed in the Southern Polar Frontal Zone and lasted three weeks. During the course of the experiment, discrete samples were taken along vertical profiles (0-100m), both in the center of the iron enriched patch and outside the patch. In the patch, the carbohydrate concentration in the particulate fraction had doubled at the end of the experiment. An increasing part of the carbohydrates was produced by large diatom cells. Outside the patch, little changes were observed. On day 6, 10 and 19 after the release, seawater from inside and outside the patch was incubated on deck for 24h. In all three deck incubations, the diurnal production and nocturnal consumption of carbohydrates by phytoplankton were higher in iron-enriched bottles. Concluding, carbohydrate production showed to be a sensitive parameter that clearly indicated enhanced phytoplankton growth in response to iron fertilization. This study contributes to a better understanding of factors governing phytoplankton growth in High Nitrogen Low Chlorophyll areas.

## OS11A-0205 0830h POSTER

## Fe:C Ratios Within the Plankton Community During the Southern Ocean Iron Experiment (SOFeX)

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Two techniques were used to measure the (C-normalized) accumulation of Fe by various components of the plankton community during the Southern Ocean Iron Experiment (SOFeX). Long-term (6 d) deck incubations with <sup>55</sup>Fe and <sup>14</sup>C allowed us to measure bulk Fe:C ratios in bacteria (0.2-1 μm), as well as larger size classes (3-20 μm, >20 μm). Samples were collected simultaneously for measurements of Fe (as well as Si, Ca, Mn, Cu, and Zn) in individual phytoplankton and protozoa cells using a synchrotron x-ray fluorescence (XRF) microprobe. This technique allows us to map the distribution of bioactive trace elements within cells from this region, in addition to providing quantitative measurements of whole-cell metal concentrations. Radioisotope experiments conducted at the south patch pre-fertilization station (Sta. 19) provide internal cell quotas for bacteria (Ti/citrate-EDTA rinsed cells, 6.4 ± 0.2 μmol Fe:mol C) that are comparable to other Fe-limited regions, with the 3-20 μm and >20 μm size classes showing lower bulk Fe concentrations (3.8 ± 0.4 and 3.0 ± 0.2 μmol:mol, respectively). The overall Fe content of bacterial cells from this station was notably higher (seawater-rinsed cells, 23.4 ± 0.1), though larger cells had a smaller fraction of externally-bound Fe. XRF analyses of single cells from this station reveal higher Fe:C ratios in dinoflagellates (16 ± 9) than diatoms (7 ± 3), with heterotrophic species showing higher mean concentrations than autotrophic/mixotrophic cells (as determined by presence of Chl a autofluorescence). Iron appears to be associated with chloroplasts, while zinc tends to map onto the nucleus. Highly localized regions of Si within some dinoflagellates suggest that phagotrophic cells may have grazed on small diatoms in the south patch. Following iron fertilization, overall bacterial Fe content rose substantially (seawater-rinsed cells, 66.8-116.0), but increases in internal Fe quotas were less dramatic (9.2-12.7). XRF analyses of diatoms and heterotrophic

and autotrophic dinoflagellates and nanoflagellates collected following Fe-enrichment in the southern patch are currently being performed and will be presented. We plan to use these cellular Fe contents, along with grazing rates measured with simultaneous dilution experiments, to estimate Fe recycling rates as mediated by protozoan grazing.

## OS11A-0206 0830h POSTER

## Distribution and fate of iron during Southern Ocean iron release experiment

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An iron enrichment experiment was carried out in the Polar Frontal Zone of the Southern Ocean during the austral late spring on board of the german RV Polarstern (Nov. 2000). An eddy structure was selected to initiate the Fe-fertilized patch. In order to understand the Fe-dynamics, the complete physical and chemical speciation of iron was studied for first time in the upper-water column (0-100 m) of the fertilized-patch in the course of the bloom development over 23 days and compared to the ambient non-fertilized waters. The physical speciation of iron was investigated in several size-fractionated pools, as defined as: particulate >0.2 micron, dissolved <0.2 micron, 200 kDa < colloids < 0.2 micron and truly dissolved <200 kDa, using ultrafiltration technique and Fe(III)-detection by the FIA-Chemiluminescence method. The organic speciation of iron was studied in the dissolved and ultrafiltered truly dissolved (<200 kDa) samples using voltammetric technique. The redox-speciation of Fe (Fe(II)-Fe(III)) was measured in the dissolved pool (<0.2 micron) with detection by FIA-Chemiluminescence. Three Fe-releases were made to these waters. The processes which result in keeping high iron concentration in the surface layer after iron releases and the changes of the Fe-partitioning between soluble/colloidal, inorganic/organic fractions are discussed.

## OS11A-0207 0830h POSTER

## Measurement of Nutrient and Carbon System Parameters during the Southern Ocean Iron Experiment (SOFeX)

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During the 2002 austral summer two in situ, mesoscale iron fertilization experiments were conducted in the Southern Ocean (SOFeX) north and south of the 60° S Antarctic Polar Front Zone (APFZ) and referred to as the North and the South Patch. The limited iron availability in these two regimes of the Southern Ocean prevents complete biological utilization of the ambient nutrients and influences phytoplankton species composition. These two high-nutrient-low-chlorophyll (HNLC) regions, connotating high nitrate and high phosphate, were primarily chosen to examine the role of iron in the low silica region (<3 μM) of the North Patch versus high silica concentrations (>60 μM) of South Patch. The carbonate parameters total alkalinity (TA), total inorganic carbon (TCO<sub>2</sub>), and pH were determined for individual water samples collected at the surface and at depth. In addition, continuous flowing methods were employed in the determination of the fugacity of CO<sub>2</sub> (fCO<sub>2</sub>) and TCO<sub>2</sub> in the surface water. Shipboard analysis of Dickson Certified Reference Material (CRM) agreed with certified TCO<sub>2</sub> values to ± 3.7 μmol kg<sup>-1</sup>, certified TA values to ± 4.3 μmol kg<sup>-1</sup> and certified pH values to ± 0.010. A flowing nutrient system measured the concentrations of silicate (Si(OH)<sub>4</sub>), phosphate (PO<sub>4</sub>), nitrate (NO<sub>3</sub>), and nitrite (NO<sub>2</sub>) continuously in the surface waters and was also employed to measure batch samples collected at depth. Preliminary results for the carbonate parameters TA and TCO<sub>2</sub> have been normalized to salinity 35 (NTA, NTCO<sub>2</sub>), and fCO<sub>2</sub> is calculated at in situ temperature. The South Patch was initiated on 23-24 January 2002 and the R/V Melville sampled water in

and around the South Patch for 19 days upon arriving on 29 January. Interpolation of the fCO<sub>2</sub> in the surface water shows an enlarging and intensification of a fCO<sub>2</sub> gradient over this time period at the South Patch. The maximum change ( $\Delta$ ) of the carbonate parameters in the mixed layer of the South Patch are dNTCO<sub>2</sub> = -23 +/- 4  $\mu$ mol kg<sup>-1</sup>, dTA = 0 +/- 4  $\mu$ mol kg<sup>-1</sup>, dpH = -0.057 +/- 0.01, and dFCO<sub>2</sub> = 36 +/- 3 uatm. The nutrient parameters measured in the South Patch have a calculated maximum change of dPO<sub>4</sub> = -0.22 +/- 0.02  $\mu$ M, dSi(OH)<sub>4</sub> = -4.7 +/- 0.2  $\mu$ M, and dNO<sub>3</sub> = -4.7 +/- 0.1  $\mu$ M. Similarly the maximum change is calculated for the carbonate and nutrient parameters in the North Patch; the calculated values are dNTCO<sub>2</sub> = -14 +/- 4  $\mu$ mol kg<sup>-1</sup>, dNTA = 0 +/- 4  $\mu$ mol kg<sup>-1</sup>, dpH = -0.032 +/- 0.01, and dFCO<sub>2</sub> = 26 +/- 3 uatm, dPO<sub>4</sub> = -0.06 +/- 0.02  $\mu$ M, dSi(OH)<sub>4</sub> = -0.9 +/- 0.2  $\mu$ M, and dNO<sub>3</sub> = -2.0 +/- 0.1  $\mu$ M. The changes in the carbonate and nutrient systems of the South Patch were larger compared to the changes in the North Patch. Varying meteorological and hydrographic conditions and possibly differences in grazing pressure promoted a difference in the evolution of inorganic carbon and nutrient draw down upon iron enrichment between the two regimes. In comparison to IRONEX II, the changes measured for the chemical parameters of the carbonate system were slightly higher for IRONEX II; dNTCO<sub>2</sub> = -27  $\mu$ mol kg<sup>-1</sup> and dFCO<sub>2</sub> = 73 uatm.

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#### OS11A-0208 0830h POSTER

##### Distributions and Partitioning of Dissolved Organic C, N and P During the Southern Ocean Iron Experiment (SOFeX)

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Several open ocean experiments have now evaluated the production of particulate organic matter, and the fluxes of particulate and inorganic forms of C, N and P during iron fertilization. However, few, if any, of these studies have measured dissolved organic C, N and P (DOC, DON and DOP, respectively) during Fe fertilization, and incorporated these pools into biogeochemical models of organic matter and biogenic elemental cycling. We present new findings on DOC, DON and DOP distributions during the recent Southern Ocean Fe Experiment (SOFeX) conducted in Jan-Feb 2002. Concentrations of DOC were low, ranging from 30-45  $\mu$ M in the mixed layer and from 25-35  $\mu$ M at 50 m, and were at times lowest within the area of Fe fertilization (using SF6 as a proxy tracer). DON ranged from 2.5-5.5  $\mu$ M N, and while shallow and deep concentrations tracked each other, they showed little depth difference. Concentrations of DOP at all depths were 0.1-0.2  $\mu$ M P, and showed no relationship with DOC, DON or SF6 concentrations. Ratios of both DOC:DON and DON:DOP were slightly greater than Redfield, and were consistent with DOM elemental ratios measured previously in the Southern Ocean (Loh and Bauer, 2000, Deep-Sea Res. I, vol. 47:2287-2316). The apparent uncoupling between DOC, DON and DOP suggests that the dissolved organic forms of these elements may be produced and recycled to different extents by auto- and heterotrophic populations in these waters over short horizontal and vertical spatial scales. Alternatively, more C-rich (i.e., hydrophobic) components may be removed by mechanisms such as co-metabolism, or via sorption to particles produced during the Fe-stimulated phytoplankton bloom.

#### OS11A-0209 0830h POSTER

##### Size-Fractionated Maximum Quantum Yield Responses of Phytoplankton to two Open-Ocean Mesoscale Iron Enrichments - Results From the 2002 Southern Ocean Iron Experiment (SOFeX)

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We measured the size-fractionated (>0.7 and >20  $\mu$ m) maximum quantum yield of photosynthesis during two iron enrichment experiments in the Pacific Sector of the Southern Ocean. The south patch area (~66°S, 172°W), south of the Southern Boundary of the Antarctic Circumpolar Current (ACC), is characterized by high nitrate and high silicic acid, while the north patch area (~56°S, 172°W), within the Subantarctic Zone, is characterized by high nitrate and low silicic acid. Both regions responded to iron addition with an increase in maximum quantum yield, however the response within size fractions differed between the two sites. In the south patch, there was a large, rapid, and sustained size-independent increase in maximum quantum yield ( $\phi_m$ , mol C mol quanta<sup>-1</sup>). Outside the patch,  $\phi_m$  was 0.012 and 0.013 mol C mol quanta<sup>-1</sup> for the >0.7 and >20  $\mu$ m size fractions, respectively. Inside the patch,  $\phi_m$  was 0.029 and 0.030 mol C mol quanta<sup>-1</sup> for the two size fractions. In the north patch, there was no response in  $\phi_m$  to iron enrichment in the >0.7  $\mu$ m size fraction (0.023 mol C mol quanta<sup>-1</sup> both outside and inside the north patch). The  $\phi_m$  of the >20  $\mu$ m size fraction, however, was significantly higher inside the patch than outside the patch. These results are consistent with the hypothesis that smaller phytoplankton in the Subantarctic Zone are not iron limited, while the larger size fractions of phytoplankton in the Subantarctic Zone and all size fractions of open-ocean phytoplankton south of the Southern Boundary of the ACC are strongly iron limited. Furthermore, these results support the hypothesis that the initial physiological response of iron limited phytoplankton to iron enrichment is an increase in maximum quantum yield.

#### OS11A-0210 0830h POSTER

##### Changes in biomass and $\delta^{13}$ C of POC during mesoscale iron fertilization in the Southern Ocean

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Although  $\delta^{13}$ C of marine sediments has been used to infer past changes in [CO<sub>2</sub>]<sub>aq</sub>, the roles of physiological state (manifested through growth rate), cell size and species assemblage also have strong influences on  $\delta^{13}$ C of phytoplankton and sinking particulates. As part of the Southern Ocean Fe Experiment (SOFeX), we tracked  $\delta^{13}$ C of particulate matter during Fe-induced blooms in high-nitrate, low-silicate and low-chlorophyll waters north of the polar front (52°S, 167°W) and in high-nitrate, high-silicate and low-chlorophyll waters south of the polar front (66°S, 172°W). Interpretation of results from the north patch is confounded, not only by our limited sample set, but also because our sampling did not catch the full extent of the bloom that occurred there. At the southerly patch, there was a significant accumulation of POC (~10  $\mu$ M C over an 18 day period), while control stations showed little or no biomass accumulation. The biomass accumulation in the southern patch was accompanied by a drop in pCO<sub>2</sub>, but we did not detect a significant change in  $\delta^{13}$ C of the particulates, although changes in size fractionated samples have yet to be determined. Our results will be interpreted in light of changes in species composition, growth rate and [CO<sub>2</sub>]<sub>aq</sub>.

#### OS11A-0211 0830h POSTER

##### Changes in biomass and $\delta^{15}$ N of nitrate and PON during a mesoscale iron fertilization experiment in the Southern Ocean

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Deep-sea sedimentary  $\delta^{15}$ N has been used to estimate past changes in relative nutrient drawdown in Fe-limited, high-nitrate, low-chlorophyll regions. In many settings, corroboration between surface-water  $\delta^{15}$ N systematics and modern sedimentary  $\delta^{15}$ N exists. In the Southern Ocean, in particular, sedimentary  $\delta^{15}$ N has been used to infer greater nutrient drawdown and hence less CO<sub>2</sub> degassing to the atmosphere during glacial periods. While the relationship between nutrient drawdown and  $\delta^{15}$ N of sinking particles is robust with a fairly consistent fractionation factor for nitrate uptake, release from Fe-stress may produce modifications either through changes in species composition and/or phytoplankton physiological state.

The Southern Ocean Fe Experiment (SOFeX), provided an opportunity to study the influence of Fe-enhanced phytoplankton growth on nitrogen isotope biogeochemistry and its relationship with nutrient drawdown. Changes in  $\delta^{15}$ N of nitrate,  $\delta^{15}$ N of PON and POM concentration were tracked during a mesoscale Fe fertilization (66°S 172°W) south of the Antarctic Polar Front, where nitrate (>20  $\mu$ M) and silicic acid (>60  $\mu$ M) concentrations were high, but initial chlorophyll concentrations low (<0.2  $\mu$ g L<sup>-1</sup>). In and out of the fertilized patch, nitrate concentrations decreased by 2  $\mu$ M or more over an 18 day period. Accompanying this NO<sub>3</sub><sup>-</sup> drawdown was an increase in POM of about 2  $\mu$ M N and 10  $\mu$ M C in the fertilized region, but negligible POM changes out of the patch. Consistent with fractionation kinetics,  $\delta^{15}$ N of both NO<sub>3</sub><sup>-</sup> and PON increased by approximately 1‰, while out of the patch little or no changes in  $\delta^{15}$ N of NO<sub>3</sub><sup>-</sup> and PON were observed. The difference in biomass response during nutrient drawdown in and out of the patch was likely caused by the growth of large diatoms within the patch. The isotope data support interpretations that downcore changes in  $\delta^{15}$ N in the Southern Ocean result from variations in nitrate drawdown. The observed influence of iron addition to fractionation kinetics will be discussed.

#### OS11A-0212 0830h POSTER

##### Inorganic and Organic Nitrogen Utilization During the Southern Ocean Iron Enrichment Experiments (SOFeX)

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The nitrogen uptake dynamics by natural phytoplankton assemblages were measured during two progressive iron enrichment experiments conducted in High Nitrate, Low Chlorophyll (HNLC) regions of the Southern Ocean during austral summer 2002. The experiments were designed to determine if iron enrichment enhances new production in the low silicate waters north (ca. 55°S) and high silicate waters south (ca. 65°S) of the Antarctic Polar Front Zone, along the 170°W meridian of longitude. Absolute uptake rates of nitrate (determined using the N-15 tracer technique) increased ca. ten-fold in the northern patch and ca. 25-fold in the southern patch, but remained relatively constant in the un-enriched (control) waters. Biomass (particulate nitrogen) specific uptake rates of nitrate increased ca. four-fold and up to tenfold in the northern and southern patches respectively, whereas specific uptake rates of ammonium and urea did not increase as a result of Fe enrichment. Based on progressive sampling of the 47% and 16% light depths, and the results of surface transects conducted across the southern Fe-infused region at the beginning, middle, and end of the southern patch monitoring period (>3 weeks), a clear change in the relative utilization of new and regenerated nitrogen due to Fe enrichment was evident; the daily f-ratio (f-ratio = nitrate uptake/total nitrogen uptake) increased from ca. 0.2-0.3 to 0.5-0.6 (ratio uncorrected for isotopic dilution and DON effects). However, unlike previous mesoscale enrichment experiments conducted here (SQUIRE) and in the subarctic (SEEDS & SERIES) and equatorial Pacific (IronEx II), the size-structure of the phytoplankton community did not change in the southern patch following Fe enrichment; it only changed in the northern patch, where larger cells (> 5  $\mu$ m) dominated the assemblage following Fe enrichment. Ambient concentrations of ammonium in the surface waters of the northern SOFeX patch declined by 0.1-0.2  $\mu$ M as a consequence of Fe enrichment, but ammonium concentrations increased both inside and outside of the southern patch as a function of

time; the potential inhibitory effects of ammonium on nitrate uptake will be discussed in the context of alleviation of Fe limitation in HNLC regions of the Southern Ocean.

#### OS11A-0213 0830h POSTER

##### The Physical Context of the Southern Ocean Iron Experiment as Observed by Shipboard Acoustic Doppler Current Profilers

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The Southern Ocean Iron Experiment in January-February 2002 involved three ships making numerous measurements to help quantify and study two iron-infused patches of water. The main purpose of the study was to investigate the biological and chemical effects of iron fertilization on phytoplankton productivity. Physical processes in the Southern Ocean play a large role in the formation, evolution, and eventual dispersion of natural phytoplankton patches. The Northern (56 S) and Southern (66.5 S) patches were infused with iron sulfate three and four times, respectively, and tracked over a seven week period. Two of the ships, the R/V *Revelle* and the R/V *Melville*, were outfitted with 150 kHz narrowband acoustic Doppler current profilers. Good quality velocity data between 20 and 300 m depths are available continuously along the shiptracks.

The available transects running south in the vicinity of 170 W, from 52-66.5 S, reveal the zonally banded velocity structure characteristic of the Antarctic Circumpolar Current. To the north of the 59-61 S Polar Frontal zone, mesoscale bands of eastward currents up to 0.4 m/s alternate with generally smaller westward bands. Farther south, the alternating structure continues but with smaller eastward velocities of about 0.2 m/s. The Northern iron patch was successfully created in a relatively low-velocity region amidst strong velocities immediately north and south. The overall mean velocity during the initial Northern patch occupation by the R/V *Revelle* (12-19 January) was small and northward at 0.1 m/s. By the second *Revelle* occupation of the Northern patch (8-10 February), however, the mean patch velocity was 0.2 m/s to the east-northeast. Significantly, the patch at this time extended across the flank of a strong eastward jet, associated with a sharp surface temperature change from 8-11 C. Whereas the northern end of the North patch experienced a strong 0.5 m/s northeast velocity, the southern end remained in a low-velocity region, resulting in a stretching of the patch.

#### OS11A-0214 0830h POSTER

##### The Heterotrophic Bacterial Response During the Meso-scale Southern Ocean Iron Experiment (SOFEX)

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Previous meso-scale iron enrichments have demonstrated the stimulatory effect of iron on primary productivity and the accelerated flow of carbon into the surface ocean foodweb. In stratified waters, heterotrophic activity can work against carbon export by remineralizing POC and/or DOC back to CO<sub>2</sub>, effectively slowing the biological pump. To assess the response of heterotrophic activity to iron enrichment, we measured heterotrophic bacterial production and abundance during the Southern Ocean Iron Experiment (SOFEX). Heterotrophic bacterial processes primarily affect the latter of the two carbon export mechanisms, removal of DOC to the deep ocean. Heterotrophic bacterial production (BP), measured via tritiated thymidine (<sup>3</sup>H-TdR) and leucine (<sup>3</sup>H-Leu) incorporation, increased ~40% over the 18-d observation period in iron fertilized waters south of the Polar Front (South Patch). Also, South Patch BP was 61% higher than in the surrounding unfertilized waters. Abundance, measured by flow cytometry (FCM) and acridine orange direct counts (AODC), also increased in the South Patch

from 3 to 5 x 10<sup>8</sup> cells liter<sup>-1</sup>, a 70% increase. Bacterial biomass increased from ~3.6 to 6.3 μg C liter<sup>-1</sup>, a clear indication that production rates exceeded removal rates (bactiolytic, viral lysis) over the course of 18 days. Biomass within the fertilized patch was 11% higher than in surrounding unfertilized waters reflecting a similar trend. This pattern is in contrast to SOIREE where no accumulation of biomass was observed. High DNA-containing (HDNA) cells detected by FCM also increased over time in iron fertilized waters from 20% to 46% relative to the total population suggesting an active subpopulation of cells that were growing faster than the removal rates. In iron fertilized waters north of the Polar Front (North Patch), BP and abundance were ~90% and 80% higher, respectively, than in unfertilized waters. Our results suggest an active bacterial population that responded to iron fertilization by utilizing newly produced DOC and/or iron and which grew at rates that exceeded removal rates. Differences in the microbial response between SOFEX and SOIREE are subtle, and may be related to differences in foodweb structure prior to and during the response to iron enrichment.

#### OS11A-0215 0830h POSTER

##### Long-Term Autonomous Measurements of Biomass Variability in the Vicinity of the Ice Edge in the Southern Ocean

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Carbon Explorers (autonomous profiling floats equipped with physical and bio-optical sensors) were deployed from the R/V *Revelle* during the Southern Ocean Iron Experiment (SOFEX) in Jan-Feb 2002. An Explorer was launched on 4 February at the center of the southernmost fertilization site (66° S, 172° W) following the completion of the iron addition. Comparing the Explorer's GPS position data with SeaWiFS satellite images and shipboard SF6 measurements demonstrated that the float remained in or near the fertilized patch of water through 21 February, when the final survey of the site was completed by the USCGS *Polar Star*. Based on transmissometry data, a ~30% increase in biomass was observed in surface (< 50 m) waters during the 2 weeks following deployment of the float, suggesting a response by the phytoplankton community to the iron fertilization. A steady decrease in biomass was subsequently observed, with surface biomass concentrations dropping to roughly 5% of their peak values by the end of June. This was likely due to a combination of heterotrophic consumption, sinking particles, and lateral advection. The Explorer continued to operate through the Austral winter in areas that were sometimes completely covered by sea ice. At the time of this submission, the Explorer was still recording and transmitting data on a regular basis. Recent (i.e., mid-late August) observations of increasing biomass in surface waters are consistent with the onset of phytoplankton growth near the ice edge at the beginning of Austral spring.

#### OS11A-0216 0830h POSTER

##### Plankton Community Response to Iron-Fertilization in the Northern Patch at 56° S

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Taxon-specific pigment and microscopical analyses were coupled with seawater dilution experiments to investigate plankton community dynamics during the 2002 Southern Ocean iron-fertilization experiment in the low-silicate waters north of the Antarctic Polar Front Zone (56° S). Preliminary results show an overall response by the phytoplankton community of a nearly 4-fold increase in biomass over a 28-day period. Phytoplankton biomass reached 60 μg C L<sup>-1</sup> approximately

12 days after the initial fertilization and was comprised almost entirely of flagellates, mainly in the 5-20 μm size fraction. Equally high biomass was still apparent two weeks later, but both pigment analyses and microscopy revealed a dramatic shift in phytoplankton community composition from the previous dominance of flagellate cells to pennate diatoms. By this time, cells >20 μm comprised half of the phytoplankton biomass, many of which were diatoms in chains of >100 μm in length. Similarly, the biomass of micrograzers (2-200 μm) increased 3-fold by day 12, largely attributed to an increase in grazers >20 μm in length. By the time of diatom dominance, grazer biomass appeared to be in decline. The accumulation of accessory pigments over time, specific for different phytoplankton groups, also demonstrated a shift in the composition of the phytoplankton community. Fucoxanthin, a proxy for diatom biomass, continued to increase throughout the sampling period, while pigments representative of flagellate populations (peridinin, 19-butanoyloxyfucoxanthin, and 19-hexanoyloxyfucoxanthin) peaked earlier and exhibited a plateau or decrease in concentration by day 28. Both phytoplankton biomass and pigment concentrations were constant over time at stations outside of the iron-fertilized patch. Preliminary rate estimates from dilution experiments point to higher growth rates for the total phytoplankton community inside the patch (mean = 0.45 d<sup>-1</sup>) versus outside the patch (mean = 0.29 d<sup>-1</sup>) with the largest excess of growth over grazing occurring early in the time series. The highest rate of mortality due to grazing (0.42 d<sup>-1</sup>) occurred midway through the sampling period, corresponding to the peak in grazer biomass. Group-specific rate estimates derived from accessory pigments infer differential growth and grazing responses to the iron-fertilization. These group-specific differences in rates will be discussed in relation to standing stocks.

#### OS11A-0217 0830h POSTER

##### Photosynthetic response of phytoplankton during the Southern Ocean iron experiment (SOFEX)

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The Southern Ocean Iron Experiment (SOFEX) was conducted in the Pacific sector of the Southern Ocean in the austral summer of 2002 with the goal to test Martin's iron hypothesis. Two mesoscale patches were fertilized by iron in a low and high silica regions (56° S and 66° S along the 172° W meridian, respectively). The temporal evolution (in 3D) of the iron-fertilized patches was monitored by using Fast Repetition Rate (FRR) fluorometry. Here we report the dynamics of bio-optical and photosynthetic characteristics and the abundance of phytoplankton during the SOFEX. In both patches, iron enrichment resulted in a rapid (~2-3 days) increase in the photochemical efficiency (Fv/Fm) and the rate of electron transport in Photosystem II, with a parallel decrease in chlorophyll-a fluorescence yield. All together, these are the established biophysical signatures of iron limitation. In near-surface phytoplankton Fv/Fm increased from 0.2 to 0.5 in the Northern patch, and from 0.25 to 0.65 in the Southern patch. Chl-a concentration in the euphotic zone increased over the period of three weeks from 0.15 to 2.2 mg/L and 0.3 to 4 mg/L, respectively. The 3-D mapping of phytoplankton distribution in the Southern patch showed that the iron infusion produced 107 tons of Chl-a. The initial decrease in the functional absorption cross section of Photosystem II (PSII) was identical (by 20%) in the two patches, but the long-term (2-3 weeks) trends were strikingly different. In the Southern patch, PSII continued to decrease throughout the experiment. In contrast, the cross section increased in the Northern patch. The analysis revealed that the slow changes in PSII were due to specific floristic shifts in the phytoplankton community structure. The single-celled FRR measurements revealed that big cells were characterized by lowered values of Fv/Fm, suggesting that big cells were more susceptible to iron deficiency than small ones. Following the iron fertilization, Fv/Fm increased in all cell size groups (from 1 μm to >100 μm), indicating that iron enrichment stimulated photosynthetic activity in all groups of phytoplankton. However, the relative increase in Fv/Fm was higher in big cells (mainly diatoms), suggesting stronger stimulation of photosynthetic activity by iron. The results provide direct evidence that iron availability is the central factor, that limits primary productivity in both high and low silica regions of the Southern Ocean.

## OS11A-0218 0830h POSTER

## Large Volume In-Situ Filtration During Sofex: an Overview of Preliminary Results

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We deployed the Multiple Unit Large Volume in-situ Filtration System (MULVFS) during the Southern Ocean Iron Experiment (SOFeX) in Jan/Feb 2002 from the R/V Revelle. The MULVFS collected samples over 4 hours of pumping at depths between the surface and 1000m from 3 flow channels: size-fractionated particles (>51 $\mu$ m, 1-51 $\mu$ m, and nominally <1 $\mu$ m) using a 51 $\mu$ m polyester mesh and a pair of microquartz fiber filters (1 $\mu$ m) in sequence from up to 12,000L of seawater; Th samples through absorber cartridges from up to 3500L; and >0.4 $\mu$ m and >0.7 $\mu$ m particles from up to 25L. Samples were shared with several groups in SOFeX. Profiles from the North Patch (55S 172W; hereafter 55S) were collected on Julian Day 12 before the first Fe infusion, and "in the patch" on JD 19 and 40. Five profiles were collected in the South Patch (66S, 172W; hereafter 66S); two "out of the patch" profiles on JD 24 and 34, and three "in the patch" profiles on JD 28, 31, and 35.

We observed the following in the (>51 $\mu$ m) size fraction: 55S was initially characterized by a predominance of small particles in the mixed layer, with very little captured on the >51 $\mu$ m filters. Four weeks after the first Fe addition, the >51 $\mu$ m samples from 35m were heavily loaded. There was a clear increase in large sized organic matter in the mixed layer, but there was no visible evidence of enhanced deep particle export at this point in the experiment. Samples collected over a shorter (12 day) period at 66S showed a concurrent natural bloom outside of the patch, obscuring detection of biomass differences inside the patch.

We have calculated POC in our samples using gravimetric techniques in the >51 $\mu$ m fraction (polyester filter) and measured directly in the 1-51 $\mu$ m and "<1 $\mu$ m" fractions (quartz fiber filters). We will also present preliminary results of bulk chemical analyses for CaCO<sub>3</sub>, Si, and acid leachable bioactive trace metals, with an emphasis on iron.

## OS11A-0219 0830h POSTER

## Soluble and Colloidal Iron in Southern Ocean Waters During Spring

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Historical measurements of "dissolved" iron in open-ocean seawater have been operationally defined as the fraction of iron which passes through a 0.4 $\mu$ m (or 0.2 $\mu$ m) pore membrane filter. As such, these measurements are likely to include iron(III) and iron(II), both free and complexed by a variety of organic and inorganic ligands, as well as colloidal organic and inorganic iron-containing species. While this "dissolved" fraction may be a useful indicator for the biological availability of iron in the field, recent work suggests that perhaps only soluble iron in the <0.03 $\mu$ m size range is directly available to phytoplankton.

The spatial and temporal changes in the vertical distribution of soluble iron (<0.03 $\mu$ m), colloidal iron in two size-fractions (0.03-0.2 $\mu$ m and 0.2-0.4 $\mu$ m) and acid-soluble particulate iron (total dissolvable minus "dissolved") were studied in the open Southern Ocean and seasonal sea-ice zone during austral spring along a transect from Hobart (Australia) to the Antarctic continent, with analysis by flow injection chemiluminescence. Our results show that the majority (59% on average) of the "dissolved" pool was in the smallest size-fraction (i.e. soluble species). However, colloidal iron accounted for a significant fraction (up to 67% of the "dissolved" pool in the upper water column at stations near the sea-ice zone and in ice-free waters over

the Antarctic shelf. Clear differences in iron distributions were observed between the <0.2 $\mu$ m and <0.4 $\mu$ m size-fractions at all stations, which has important implications for the choice of filter size used by different investigators to define the "dissolved" pool. Total dissolvable iron concentrations were ~41% greater than "dissolved" (<0.4 $\mu$ m) iron values, implying the presence of a significant proportion of acid-soluble particulate iron. These observations will be compared to other ocean regions and discussed in terms of the bioavailability of different iron fractions to the Antarctic biomass.

## OS11A-0220 0830h POSTER

## Dissolved Iron in the Australian Sector of the Southern Ocean During Spring: Implications for the Seasonal Cycle of Iron in Antarctic Surface Waters

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Colorimetric flow injection analysis was used to measure dissolved iron (<0.4 $\mu$ m, dFe) in upper-ocean (<400 m depth) water samples collected from the CLIVAR SR3 section (~142°E) between Tasmania and Antarctica in November-December 2001. These are the first such data for this region during austral spring, and include results from two stations occupied in melting pack ice, as well as one station near the 61°S SOIREE site, occupied twice. Combining these new results with data from a March 1998 cruise and the February 1999 SOIREE campaign allows us to infer seasonal (spring-fall) changes in dFe concentrations in surface waters of our study region, assuming interannual variability is small. The data suggest a seasonal drawdown of ~0.1-0.2 nM dFe in the Subantarctic Zone waters (~47°S); a seasonal accumulation of ~0.1 nM dFe in near-surface (~25 m) waters and a drawdown of ~0.05 nM dFe in deeper (~50-300 m) waters of the Subantarctic Front (~51°S); and little or no seasonal dFe drawdown (~0.05 nM or less) in surface waters south of the Subantarctic Front, where dFe concentrations were uniformly low (~0.1 nM). Thus, if winter mixing provides a significant vertical resupply of dFe to Antarctic surface waters, our results suggest that most of this winter reserve of dissolved iron is removed from the upper water column very early in the growing season. In addition, our new data provide no evidence of significant iron inputs to surface waters from melting sea ice, which may explain the lack of ice-edge algal blooms in this sector of the Southern Ocean, as inferred from ocean-color satellite images.

## OS11A-0221 0830h POSTER

## Inorganic Carbon Changes During a Southern Ocean Iron Release Experiment: Effects of Iron, Hydrography and Meteorology

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In the Polarstern 2000 iron release experiment (ANT 18-2), iron was added to the centre of an eddy at 47S 21E on 7-8 November. During this experiment, Dissolved Inorganic Carbon (DIC) concentrations, carbon dioxide fugacity (fCO<sub>2</sub>) and pH measurement were investigated. Samples were collected for stations inside and outside the patch as well as in an underway mode from the ships continuous seawater supply. DIC has been determined by the coulometric method of Johnson et al. (1993) and underway pH was measured spectrophotometrically. On Day 0, the values found for the Carbon dioxide system were 2130  $\mu$ mol/kg for DIC and 364  $\mu$ atm for the fCO<sub>2</sub> in the center of the eddy. Four days after the first addition, enhanced algal growth promoted a deltaDIC (DIC<sub>outside</sub> the patch-DIC<sub>inside</sub> the patch) of 5  $\mu$ mol/kg compare to day 0 in the surface water. On day 7 the deltaDIC was back to 0  $\mu$ mol/kg due to horizontal (mixed layer down to 80 meters) and

vertical mixing during the first big storm which occurred between days 6 and 7. This succession of calm, sunny weather and storms characterized the 22 days of the ANT 18-2 experiment. Indeed, on day 12 and 16, deltaDIC was back to 5  $\mu$ mol/kg in a mixed layer of 20 meters and 80 meters respectively. Although the passage of depressions and mixing events left their imprint on the evolution of algal carbon uptake, after 20 days, the maximum deltaDIC was 12-13  $\mu$ mol/kg with concomitants decrease in pCO<sub>2</sub> of 20  $\mu$ atm and increase in seawater pH of 0.025 units. The iron release experiment demonstrates beyond doubt that iron supply influences phytoplankton growth and the structure of the marine foodweb in the Southern Ocean. Contrasting meteorological and hydrographic conditions and possibly differences in grazing pressure promoted different patterns of algal growth and inorganic carbon drawdown upon iron enrichment.

## OS11B MCC: Hall D Monday 0830h

## Impacts of Air/Sea Exchange on Biogeochemical Processes in the Ocean II Posters (joint with A, B, GC)

Presiding: W M Landing, Florida State University; C Measures, University of Hawaii; G A Cutter, Old Dominion University

## OS11B-0222 0830h POSTER

## Heat fluxes, overturning, and the uptake of anthropogenic carbon in the North Atlantic

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The influence of the overturning circulation on the anthropogenic carbon sink in the North Atlantic is investigated with a simple box model. The net air-sea flux of anthropogenic carbon is the result of two opposing fluxes: one is uptake caused by the disequilibrium between the rapidly rising atmospheric pCO<sub>2</sub> and the dissolved carbon content in the ocean, depending mainly on the water exchange rate between mixed layer and interior North Atlantic ocean. Superimposed is a second flux, related to the northward transport of heat within the Atlantic basin, that is directed out of the ocean, contrary to conventional wisdom. It is related to cooling and freshening of surface water on its way north, causing a latitudinal gradient in the ratio of seawater alkalinity to total dissolved inorganic carbon. This flux depends strongly on the vertical structure of the upper branch of the overturning circulation and on the distribution of under- and super-saturation of CO<sub>2</sub> in Atlantic surface waters. A data-based estimate of anthropogenic carbon inventory in the North Atlantic is consistent with a dominance of the disequilibrium flux over the heat-flux-related outgassing at the present time, but, in our model, does not place a strong constraint on the net anthropogenic air-sea flux. Stabilization of the atmospheric pCO<sub>2</sub> on a higher level will change the relative role of the two opposing fluxes, making the North Atlantic a source of anthropogenic carbon to the atmosphere.

## OS11B-0223 0830h POSTER

## Dry Deposition of Trace Elements to the Western North Atlantic

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