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Note

Ecological and Biogeochemical Response of Antarctic Ecosystems to Iron Fertilization and Implications on Global Carbon Cycle

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Abstract : The European Iron Fertilization Experiment EIFEX studied the growth and decline of a phytoplankton bloom stimulated by fertilising 10 km^2 in the core of a mesoscale (80 × 120 km) cyclonic eddy south of the Antarctic Polar Front with about 2 times 7 tonnes of iron sulphate. The phytoplankton accumulation induced by iron fertilization did not exceed 3 μg chl a l^{-1} despite a draw down of 5 μM of nitrate that should have resulted in at least double to triple the amount of phytoplankton biomass assuming regular Redfield-ratios for draw down after phytoplankton growth in the Southern Ocean. During EIFEX the fertilized core of the mesoscale eddy evolved to a hotspot for a variety of small and medium sized mesozooplankton copepods. In contrast to copepods, the biomass of salps (*Salpa thompsoni*) that dominated zooplankton biomass before the onset of our experiment decreased to nearly extinction. Most of the species of the mesozooplankton community showed extremely high feeding rates compared to literature values from Southern Ocean summer communities. At the end of the experiment, massive phytoplankton sedimentation reached the sea floor at about 3800 m water depth.

Key words : Antarctic ecosystem, iron fertilization, carbon cycle, mesozooplankton

1. Introduction

The European Iron Fertilization Experiment (EIFEX, Fig. 1) studied the growth and decline of a phytoplankton bloom stimulated by fertilising 10 km^2 in the core of a mesoscale (80 × 120 km) cyclonic eddy (Strass *et al.* 2005) south of the Antarctic Polar Front (Fig. 2) with about 2 times 7 tonnes of iron sulphate. Iron was shown to be the limiting factor of phytoplankton growth by seven previous experiments (Boyd *et al.* 2000; Landry *et al.* 2000; Coale *et al.* 2003; Martin and Fitzwater 1988; Abraham *et al.* 2000; Buesseler *et al.* 2005; Coale *et al.* 1996; Coale *et al.* 2004; Smetacek 2001) in so called high nutrient – low chlorophyll (HNLC) regions of the world oceans. All of those experiments - 2 in the Equatorial Pacific (Ironex I and II), 3 in the Southern Ocean (SOIREE, EISENEX, SOFEX), and 2 in the Subarctic Pacific – lasted only a few weeks leaving insufficient time to determine the fate of the iron induced, newly formed phytoplankton biomass.

The overarching goal of EIFEX was to further our understanding how open ocean ecosystem function in the

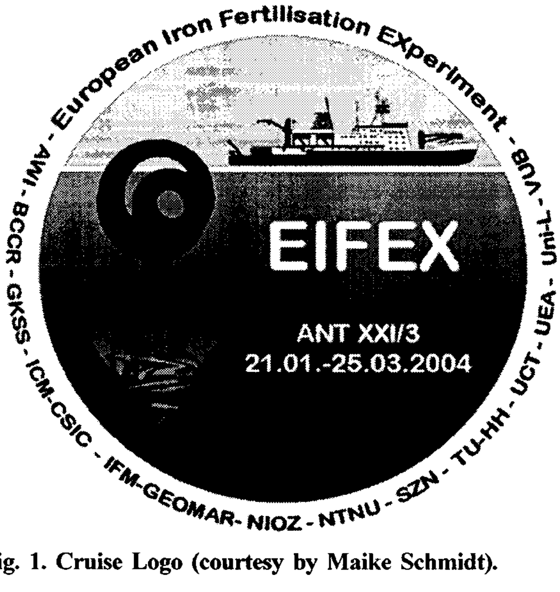

Fig. 1. Cruise Logo (courtesy by Maike Schmidt).

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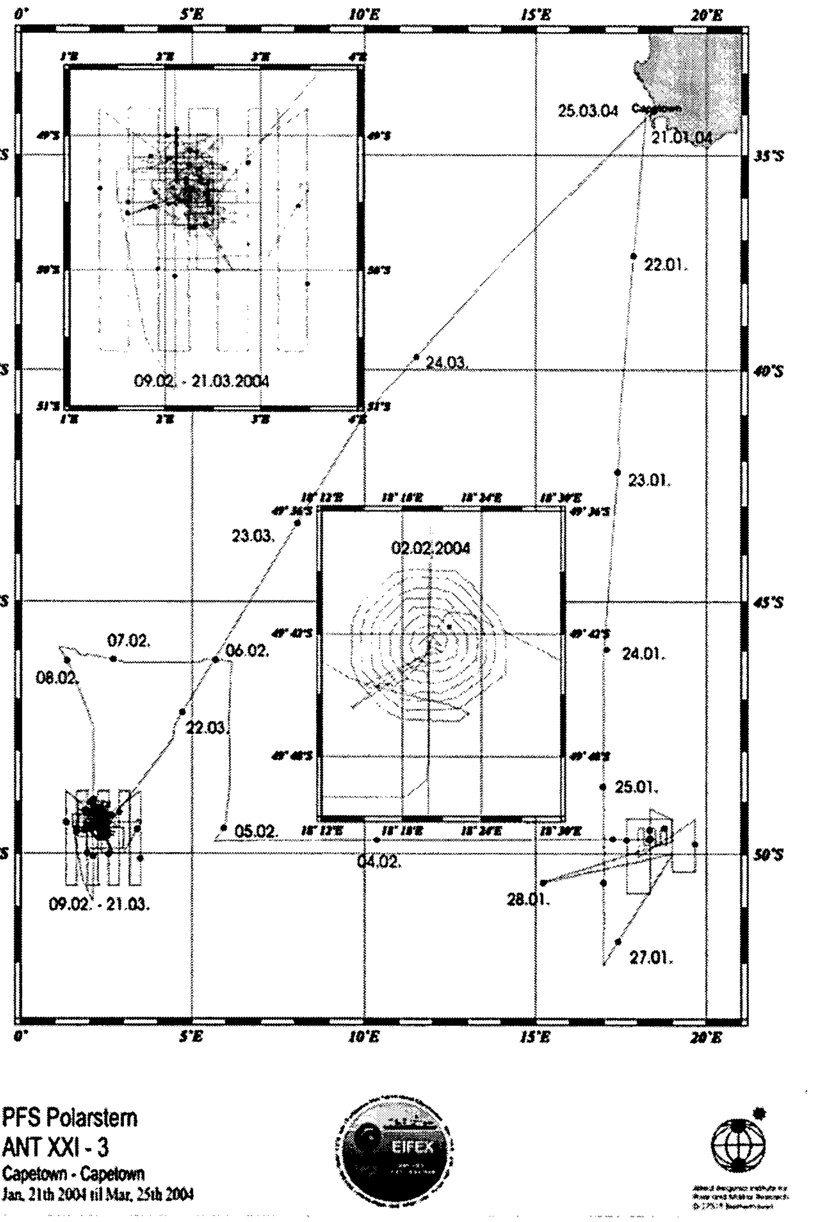

Fig. 2. Cruise track with inserts (courtesy by FIELAX).

course of glacial-interglacial cycles, and how the species of the plankton communities interact with one another and with the environment, and how these species drive biogeochemical cycles. During glacial periods the atmosphere was loaded with dust particles containing iron from land soils to a much higher degree compared to interglacial cycles (Mahowald *et al.* 1999). As indicated by sediment cores (Bramati *et al.* 1997) and ice core (Delmonte *et al.* 2002), this iron dust was transported into remote areas of the glacial ocean that are known today as HNLC areas and that see very little input of iron from the atmosphere today. Another source of biological available iron in ocean surface waters originates from melting ice bergs (Strass *et al.* 2002), e.g. that are transported from high latitude waters to the Polar Front. This process is best known in so-called ice berg years in the Antarctic Circumpolar Current (ACC) at the location of the Antarctic Polar Front (APF). Thus, the artificial iron fertilization carried out during EIFEX simulates natural processes that introduce iron to iron-limited, land-remote ocean waters.

The structure and succession of a pelagic food web after artificial iron fertilization depends on growth rates by the various phytoplankton species and the subsequent accumulation of plankton biomass. The latter is the net product of production and loss due to grazing by pelagic heterotrophs (bacteria, protozoo- and metazooplankton) and otherwise induced mortality (e.g. viruses). All of these biological processes in turn are influenced by a range of physical (e.g. vertical mixing, light penetration depth) and chemical (e.g. concentration of iron and other trace elements, ratio of silicate to nitrate) factors that together determine the environment for living and growth. Most likely those effects are species specific and moreover might be different in different pelagic food webs as will be discussed below.

2. The experiment

EIFEX lasted for continuous 9 weeks with adequately interdisciplinary sampling of physical, chemical, biochemical, and biological parameters by the 55 scientists aboard RV POLARSTERN. (Smetacek *et al.* 2005). During a consecutive cruise the study site was sampled again 11 weeks after the start of the experiment.

3. Results and discussion

A main focus of EIFEX was to study the relationship between growth of phytoplankton and the concomitant effect of grazing on phytoplankton species composition and biomass, and to determine the breakdown of the inventories of biogenic elements in the surface layers of the ACC. The phytoplankton accumulation induced by iron fertilization did not exceed 3 μg chl a l^{-1} (Klaas *et al.* in preparation) despite a draw down of 5 μM of nitrate that should have resulted in at least double to triple the amount of phytoplankton biomass assuming regular Redfield-ratios for draw down after phytoplankton growth in the Southern Ocean (C:N = 9 to 11; Riebesell *et al.* in preparation; C: chl a = 30 to 80). We assume that sinking (sedimentation) of phytoplankton cells and grazing by proto- and mesozooplankton accounted for the additional loss. In the following both processes will be explained in more detail.

Small (cyclopoid) copepods became known to be efficient grazer in the Southern Ocean (Dubischar *et al.* 2002). During EIFEX the fertilized core of the mesoscale eddy evolved to a hotspot for a variety of small and medium sized mesozooplankton copepods (Krägefsky *et al.* in preparation). In contrast to copepods, the biomass of salps (*Salpa thompsoni*) that dominated zooplankton biomass before the onset of our experiment decreased to nearly extinction (von Harbou *et al.* in preparation). Most of the species of the mesozooplankton community showed extremely high feeding rates compared to literature values from Southern Ocean summer communities (Bathmann *et al.* in preparation). We explain these shifts in species composition as zooplankton response to increased phytoplankton biomass production and the concurrent change in species composition, in the non-silicified, flagellate dominated phytoplankton assemblage of the microbial food web as well as within the slower growing diatom fraction (Assmy *et al.* in preparation). Protozooplankter remained rather constant on biomass levels but also showed high growth rates (turnover rates) (Henjes *et al.* in preparation) indicating that protozooplankter did efficiently top-down control the microbial food web but also were kept under control by mesozooplankton (copepod) grazing (Smetacek *et al.* 2004). At the end of the experiment, massive phytoplankton sedimentation reached the sea floor at about 3800 m water depth. This was recorded in CTD profiles down to the sea floor (Strass *et al.* in prep), by microscopically derived records of phytoplankton cells sinking (Assmy *et al.* in prep.), by pigment analysis of organic fluff accumulating on the deep-sea floor (Peeken *et al.* in prep) and by *in situ* oxygen profiles that were taken 11 weeks after the start of the experiment in the first few centimetres of the sediments underlying the study site (Sachs *et al.* in prep). Such a direct impact of fresh plankton material was the first ever recorded in deep-sea Antarctic waters.

4. Conclusion

From the experiment we conclude that iron fertilisation in the Southern Ocean may stimulate new carbon production but only in areas where hydrographical conditions stabilise the upper water layers for at least two to three weeks. Depending on phytoplankton species composition at the onset of the experiment, the physico-chemical conditions of the upper mixed water layer and the grazing pressure, the fate of the newly fixed carbon might be quite different. We postulate that similar conditions of iron fertilization compared to EIFEX but at larger scale may occur naturally today (e.g. during melting of ice bergs being transported into the Antarctic Polar frontal Zone) or may have occurred during the last glacial maximum when stronger winds may have transported more dust (with iron) from arid areas on land to high ocean areas (Mahowald *et al.* 1999). Thus, the physical-chemical-biological mechanisms and processes detected during EIFEX will enhance our understanding how the global carbon cycle is regulated.

Acknowledgements

This note is a contribution from the ship-board party as a team, and details are found in our expedition report (Smetacek *et al.*, 2005).

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