

**LOHAFEX (ANT-XXV/3)**

**7 January 2009 - 17 March 2009**

**Cape Town - Punta Arenas  
Stable Eddy North of South Georgia**

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# 1. ÜBERBLICK UND FAHRTVERLAUF

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## 7. January 2009 - 17. März 2009, Kapstadt, Südafrika nach Punta Arenas, Chile

Die Fahrt wird gemeinsam durchgeführt vom National Institute of Oceanography (NIO) Goa des Council of Scientific and Industrial Research, Indien, und dem Alfred-Wegener-Institut für Polar- und Meeresforschung, Forschungszentrum der Helmholtz-Gemeinschaft.

In den letzten 10 Jahren haben sich *in-situ* Eisendüngungsexperimente als verlässliche Methode herausgestellt biogeochemische und ökologische Hypothesen zu testen, die durch andere Mittel nicht zugänglich sind. Das interdisziplinäre Experiment LOHAFEX (Loha ist das Hindi Wort für Eisen, Fertilization EXperiment) wird eine Reihe von unabhängigen, aber miteinander verbundenen Hypothesen testen, von denen einige im Folgenden erwähnt sind:

- a) John Martins Eisen-Hypothese mit ihren Geo-Engineering Folgen.
- b) Die Planktonartenzusammensetzung in einer experimentell induzierten Blüte im produktiven Südwesten des Atlantischen Sektors wird sich von Planktonblüten vorheriger Experimente in Niedrigproduktionsgebieten unterscheiden.
- c) Die Krebstiere des Zooplanktons, insbesondere Krill, sind nahrungslimitiert, was den gegenwärtigen Rückgang der Krillbestände erklären könnte.
- d) Eisengedüngte Blüten führen zur Produktion schädlicher Gase mit nachteiligen Folgen für die Atmosphäre.

Diese und andere Hypothesen, die in den Unterkapiteln dieses Fahrtheftes behandelt werden, sprechen fundamentale Fragen der Erdsystemforschung an, die relevant für unser Verständnis von der Rolle der marinen Biosphäre für das Klima der Vergangenheit und der Gegenwart ist.

### Theoretischer Hintergrund

Alle bisherigen Experimente im Südpolarmeer (SOIREE, EisenEx, SOFEX I und II sowie EIFEX) wurden im landfernen Zirkumpolarstrom durchgeführt mit dem Ziel, die Eisenhypothese von John Martin (1990) zu testen: Höherer Staubeintrag während Eiszeiten stellte ausreichend Eisen zur Verfügung, um die Produktivität und den Kohlenstoffeintrag im Zirkumpolarstrom soweit zu erhöhen, dass diese Region eine global bedeutende CO<sub>2</sub>-Senke darstellte. Diese Hypothese wird zurzeit kontrovers diskutiert (Anderson et al. 2002). Verschiedene geochemische Paleo-Proxies aus Meeressedimenten zeigen niedrigere Produktivität während der Eiszeiten südlich der Polarfront, obwohl ökologische Proxies reiche Ablagerungen von Sporen küstennah lebender Diatomeen in dieser Region belegen, die das Gegenteil andeuten. Neue und verlässlichere biologische Proxies und eine verbesserte Validierung bereits bestehender Proxies sind notwendig, um die Kluft zwischen ökologischen und geochemischen Befunden zu überbrücken.

Die erste Bedingung von Martins Hypothese (der Aufbau einer Phytoplankton Blüte) wurde von allen fünf vorherigen Experimenten erfüllt. Die meisten blütenbildenden Arten waren typisch für den Zirkumpolarstrom und durch dicke Schalen (niedrige C:Si Verhältnisse) und ozeanische Lebenszyklen gekennzeichnet. Diese Artgemeinschaften unterscheiden sich stark von denen typisch für küstennahe, produktive Regionen des Südpolarmeeres, die durch kleinere, schwach verkieselte Arten gekennzeichnet sind und unter ungünstigen

Wachstumsbedingungen Dauersporen ausbilden und massenhaft aussinken. Der vertikale Partikelfluss solcher Gemeinschaften ist durch ein hohes C:Si Verhältnis geprägt. Diese Artengemeinschaft muss untersucht werden, wenn man Martins Hypothese angemessen testen will (Smetacek et al. 2004).

Die produktiven Regionen des Zirkumpolarstromes sind auf Bereiche in Nähe der Landmassen beschränkt, mit der größten Hochproduktivitätsregion entlang der Antarktischen Halbinsel, deren Fahne weit in den Südwesten des Atlantischen Sektors hinausreicht. Feldbeobachtungen aus den 30er Jahren (Hart 1942) zeigten hohe Phytoplankton-Biomasse im Frühjahr, die über den Sommer abschwächte trotz vorteilhafter Wachstumsbedingungen. Basierend auf den nachfolgenden Erwägungen nehmen wir an, dass der Rückgang durch Eisenzehrung, analog der Nitratzehrung anderer Kontinentalrandmeere, hervorgerufen wird. Erstens haben alle Experimente eindeutig gezeigt, dass Eisen, wie die anderen Makronährstoffe, sowohl Wachstumsraten als auch Biomasseaufbau von Phytoplankton limitiert. Zweitens basiert die Frühjahrsblüte der Antarktischen Halbinselfahne auf im Winter akkumuliertem Eisen aus Kontakt mit den Sedimenten und der Küste, welches nur ausreicht, einen Teil der Makronährstoffe zu zehren. Eisen aus Süßwassereintrag vom Land gipfelt im Sommer und kann zu massiven Blüten führen, die jedoch auf kleinere Buchten beschränkt sind. Drittens, wenn Eisendüngung im Sommer im offenen Ozean Blüten induziert, dann kann man das Gleiche im Südwest-Atlantik erwarten. Aufgrund der höheren Saatspopulationen als Relikt der Frühjahrsblüte erwarten wir, dass die Sommerblüte höhere Biomasse schneller erreicht als ozeanische Blüten und dass die Artenzusammensetzung charakteristisch für eine kohlenstoff-versenkende Gemeinschaft sensu Smetacek et al. (2004) sein wird.

Das folgende hypothetische Szenario einer Blüte wird während des Experiments getestet: Die Blüte wird schnell heranwachsen und durch schwach verkieselte, schnell wachsende Arten mittlerer Größe, wie *Chaetoceros* und *Thalassiosira* und möglicherweise auch *Phaeocystis*, dominiert sein. Diese Arten werden Biomassen von  $>5$  mg Chlorophyll  $m^{-3}$  (ungefähr doppelt so hoch wie in vorherigen Experimenten) aufbauen. Bakterien und das mikrobielle Nahrungsnetz werden Veränderungen durchlaufen und die planktonischen Krebstierchen werden mit erhöhter Eiablage reagieren. Teile der Blüte werden nach 4 - 6 Wochen zusammenbrechen und schnell absinkende Aggregate bilden. Die Größenordnung des Partikelniederschlags wird vom Fraßdruck der Räuber abhängen. Die Aggregate werden mehr Kohlenstoff pro Silikat versenken als während vorheriger Blüten, trotz des geringeren Ballasts, und werden den Meeresboden innerhalb von 10 Tagen nach dem Sinkereignis erreichen. Die Reaktion der Benthosgemeinschaft wird mit *in-situ* Sauerstoffprofilen und Oberflächensedimentbeprobung verfolgt. Die Stabilität des Wirbels über den Verlauf des Experiments ist eine entscheidende Voraussetzung für ein erfolgreiches Gelingen des Unternehmens. Andererseits, sollte sich der Blütenverlauf anders als oben geschildert entwickeln, liefert das Experiment trotzdem neuartige Erkenntnisse. In jedem Fall wird die Blüte Einblicke in die Biogeochemie pelagischer Ökosysteme im Allgemeinen und des Südwest Atlantiks im Speziellen erbringen. Weiterhin wird das Experiment die quantitativen Rahmenbedingungen erbringen, die zur Validierung bestehender und Identifizierung neuer Proxies notwendig sind.

Die mehrschichtige Fraßdruck-Hypothese, die von Smetacek et al. (2004) entworfen wurde, beinhaltet die Rolle des Zooplanktonfraßes bei der Gestaltung von Phytoplanktongemeinschaften auf Skalen, die sich von evolutionären bis hin zur unmittelbaren erstrecken. Eisendüngungsexperimente ermöglichen die Überprüfung dieser Hypothesen unter natürlichen Bedingungen, weil sie die Untersuchung von Interaktionen innerhalb des Ökosystems bei Anwesenheit der gesamten Bandbreite des Zooplanktons von Protozoen bis hin zum Krill

und zu Salpen erlauben. Der Einfluss der Eisendüngung auf höheren trophischen Ebenen hängt von der Region und Dauer des Experiments ab. Die Ergebnisse von EisenEx zeigten eine signifikante Zunahme der Biomasse kleinerer Copepoden und der Anzahl von Kotballen, die auf eine Nahrungsbegrenzung des ozeanischen Zooplanktons hindeuten (Henjes et al. 2007). Eine künstlich erzeugte Phytoplanktonblüte im Südwesten des Atlantiks wird wahrscheinlich Krill anlocken. Die Dezimierung einer natürlichen Blüte durch einen Krillschwarm wurde während einer früheren Polarsternfahrt beobachtet, die zu einer Veränderung der Phytoplanktongemeinschaft führte (Treguer und Jacques 1992). Wir erwarten eine ähnliche Wirkung auf einen Teil der LOHAFEX-Blüte falls Krillschwärme im Wirbel vorhanden sind. Allerdings, da unser Untersuchungsgebiet am nördlichen Rand des Hauptverbreitungsgebiets des Krills liegt, und angesichts des alarmierenden Rückgangs der Krillbestände in den letzten Jahrzehnten, ist es möglich, dass wir keinen größeren Schwärmen begegnen werden.

Die Durchführbarkeit von großräumiger Eisendüngung des Südlichen Ozeans als Maßnahme zur Sequestrierung von Kohlendioxid wird seit der Veröffentlichung von John Martins „Eisenhypothese“ und deren experimentellen Überprüfung heiß diskutiert. Einige Firmen hatten seinerzeit ihr Interesse an dieses Verfahren im Rahmen des Kyoto-Protokolls bekundet. Die wissenschaftliche Gemeinde betrachtet die Eisendüngung mit Skepsis, teilweise wegen der negativen Folgen einer Kommerzialisierung. Falls die Düngung funktioniert und ein beträchtlicher Teil der Algen aussinken würde, könnten maximal eine Milliarde Tonnen Kohlenstoff (eine Gigatonne, Gt) jährlich von der Atmosphäre entfernt werden, vorausgesetzt, dass der gesamte Südliche Ozean mit mehreren Millionen Tonnen Eisensulfat gedüngt wird (Smetacek und Naqvi 2008). Diese Menge ist nicht viel im Vergleich zur jährlichen Zunahme von ca. 3.5 Gt, aber zu viel, um ignoriert zu werden, vor allem angesichts der erheblich höheren Kosten anderer Techniken zur Entfernung vom atmosphärischen CO<sub>2</sub>. Vor kurzem haben mehrere wissenschaftliche und internationale Organisationen kritische Stellungnahmen zur Eisendüngung veröffentlicht und dazu aufgerufen, ein besseres Verständnis zu verschaffen, bevor großräumige Maßnahmen in Erwägung gezogen werden. LOHAFEX ist der Anfang von künftiger engen Kooperation zwischen Deutschland und Indien auf diesem Sektor der Meeresforschung.

#### Auswahl des Untersuchungsgebietes

Das LOHAFEX Untersuchungsgebiet wurde anhand zweier Kriterien ausgewählt: Erstens ist es im Krillverbreitungsgebiet angesiedelt und hat eine etwas andere Planktonzusammensetzung zum Rest des Südpolarmeeres, wo vorherige Experimente durchgeführt wurden. Die Auswirkungen der Düngung werden sich daher wahrscheinlich unterscheiden. Zweitens ist die Region durch stabile Wirbel gekennzeichnet, die für Monate ortstreu bleiben. Wirbel sind langsam rotierende, kreisförmige Wassermassen von 50 – 100 km Durchmesser, die bis zum Meeresboden in 4 km Tiefe reichen und von einer schnell fließenden Schleife des Frontenstroms umschlossen sind. Das Wirbelzentrum stellt daher den idealen „Behälter“ für das Düngungsexperiment dar, weil es ermöglicht die sinkenden Partikel in der tiefen Wassersäule zu verfolgen. Wirbel können über ihre gesamte Lebensspanne durch Satellitenaltimeterbilder identifiziert und verfolgt werden, wo sie als stationäre, annähernd kreisförmige Erhebungen oder Senken erscheinen. LOHAFEX wird im best-geeigneten Wirbel entlang der Polarfront platziert werden, etwa 300 km nördlich der Insel Südgeorgien.

#### Durchführung des Experiments

Nach der Ankunft im ausgesuchten Wirbel werden Oberflächen- sowie Tiefenbojen ausgesetzt, um das Zentrum des Wirbels festzustellen. Bei den Tiefenbojen handelt es sich um zu

Sinkstofffallen umgewandelte Argosbojen, die in verschiedenen Wassertiefen treiben werden, bevor sie wieder auftauchen. Während der 5 Tage, die hierfür gebraucht werden, wird der Wirbelkern mit dem undulierenden Instrumentenpaket Scanfish sowie mit Zooplanktonakustik vermessen. Danach wird eine lange Station (s. unten) im Zentrum durchgeführt, um die Situation vor der Düngung zu erfassen. Anschließend wird vom in konzentrischen Kreisen fahrenden Schiff eine Lösung von angesäuerten Eisensulfat (20 Tonnen) über eine Fläche von 300 km<sup>2</sup> ausgebracht. Der Eisenlösung wird, wie in früheren Experimenten, eine geringe Menge Schwefelhexafluorid (SF<sub>6</sub>) beigesetzt, das in sehr niedriger Konzentration noch nachweisbar ist, um den gedüngten Fleck zu markieren. Der Fleck wird sich durch horizontale Vermischung ausbreiten. Gegebenenfalls wird eine zweite Düngung nach ca. 2 Wochen im Zentrum des Flecks vorgenommen. 3 - 4 Wochen nach der ersten Düngung wird eine Fläche von 150 km<sup>2</sup> erneut mit SF<sub>6</sub> (diesmal ohne Eisen) markiert, um Verluste durch Ausgasung (SF<sub>6</sub> ist ein Gas) zu kompensieren. Weil LOHAFEX 10 Tage länger dauern wird als EIFEX wird etwa die doppelte Fläche gedüngt, um die Verdünnung durch Vermischung auszugleichen. Wir erwarten, dass gegen Ende des Experiments die Blüte von der Oberfläche verschwunden sein wird.

Lange Stationen werden regelmäßig im Zentrum des Flecks und im ungedüngten Wasser außerhalb durchgeführt. Zwischendurch wird der Fleck mit Scanfish und Krillakustik mehrmals während des Experiments vermessen. Die 5 frei treibenden Sinkstofffallen werden ständig überlappend im Einsatz sein. Die *in-situ* Sauerstoffzehrung an der Sedimentoberfläche wird in regelmäßigen Intervallen gemessen sowie Proben der Grenzschicht entnommen. Die Messungen werden durch Deckinkubationen zur Ermittlung von Wachstums- und Remineralisierungsraten verschiedener Planktongruppen ergänzt.

Drei Stationstypen werden durchgeführt:

Lange Stationen: 3 bis 4 CTD-Durchläufe (wenn Wasser für Experimente benötigt wird) mit Go-Flo-Flaschen (an einem Kevlardraht befestigt) und ein Multinetz sowie Bongo- und RMT-Netze vorzugsweise bei Nacht. Oberflächensedimente werden mit einem Multicorer beprobt.

Mittlere Stationen: 2 bis 3 CTD-Durchläufe mit Go-Flo und Multinetz.

Kurze Stationen: Ein kurzer CTD-Durchlauf.

Der Fahrtabschnitt ist ein Beitrag zu POGO, der Partnership for Observation of the Global Oceans, <http://www.ocean-partners.org/aboutPOGO.html>.

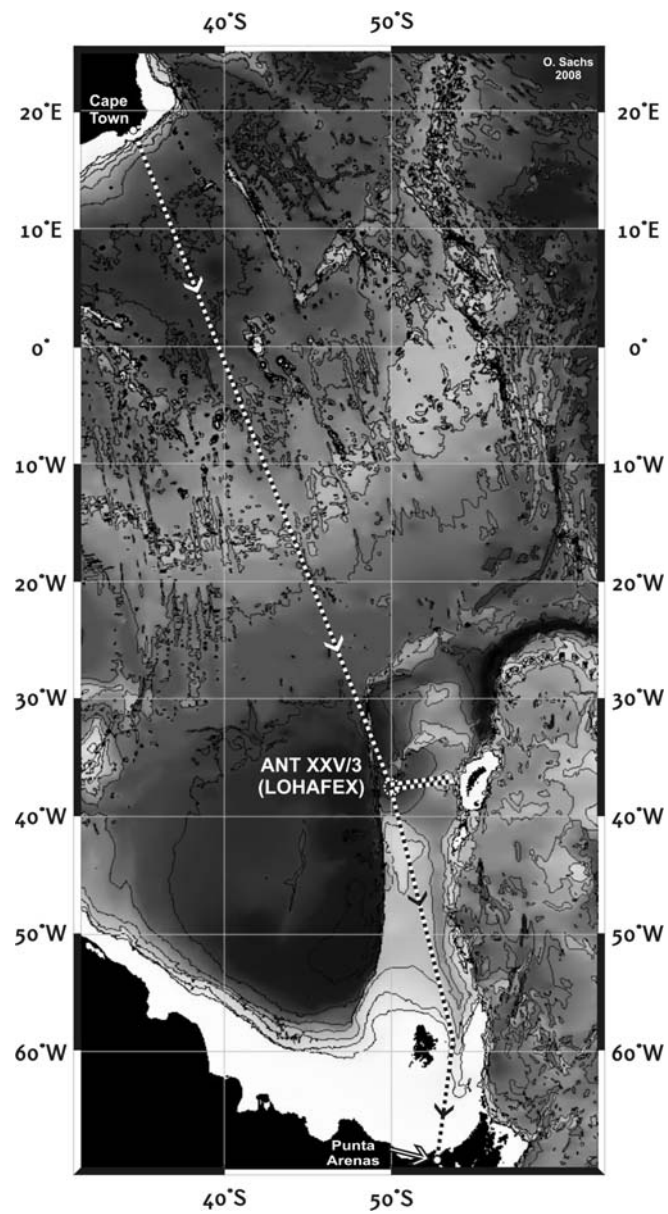


Abb. 1: Fahrtroute während ANT-XXV/3  
Fig. 1: Cruise track during ANT-XXV/3

## ITINERARY AND SUMMARY

### 7 January 2009 - 17 March 2009, Cape Town, S. Africa to Punta Arenas, Chile

The cruise will be jointly carried out by the National Institute of Oceanography (NIO) Goa of the Council of Scientific and Industrial Research, India, and the Alfred Wegener Institute for Polar and Marine Research, member of the Helmholtz Association of German Research Centres.

*In-situ* iron fertilization experiments have emerged in the last 10 years as a reliable method for testing biogeochemical and ecological hypotheses not accessible by other means. The interdisciplinary experiment LOHAFEX (Loha is Hindi for iron, Fertilization EXperiment) will test a range of independent yet interconnected hypotheses of which some are mentioned here: a) The iron hypothesis of John Martin with its geo-engineering corollary. b) Plankton species composition in an experimental bloom induced in the more productive southwest Atlantic Sector will differ from the plankton in blooms stimulated by previous experiments carried out in low productivity waters. This will have a strong effect on sinking of the bloom and on the ratio of carbon: silica of the sinking flux. c) Crustacean zooplankton, including krill, is food limited, with its perspectives for explaining the current decline in krill stocks. d) Iron-fertilized blooms lead to production of noxious gases with harmful effects on the atmosphere. These, and other hypotheses dealt with in the subchapters of this booklet, address fundamental questions of integrated earth system science that are relevant to our understanding of the role of the marine biosphere in past and ongoing climate change.

All Southern Ocean experiments (SOIREE, EisenEx, SOFEX 1 and 2, EIFEX) were carried out in the land-remote ACC with the aim of testing the iron hypothesis of Martin (1990): Higher levels of dust during glacials provided enough iron to enhance productivity and carbon drawdown in the ACC rendering this region a major glacial CO<sub>2</sub> sink. This hypothesis is currently under intense debate (Anderson et al. 2002). Several sedimentary geochemical palaeoproxies indicate lower levels of glacial productivity south of the Polar Front although ecological proxies – abundant spores of coastal diatoms in the land-remote glacial ACC - indicate the opposite. New and more reliable biological proxies and improved validation of the current ones are necessary to break the impasse between ecologists and geochemists and the experiment we propose will provide such information.

The first condition (build-up of a phytoplankton bloom) was met in all five experiments. Most of the species dominating these blooms were typical ACC species characterised by thick frustules (low C:Si ratios) and open ocean life cycles. This species assemblage is very different to those typical of the land-near, productive regions of the Southern Ocean which tend to have smaller, weakly silicified cells that form resting spores under unfavourable conditions and sink out en masse. Vertical flux from this assemblage will have high C:Si ratios. Smetacek et al. (2004) argue that it is this assemblage that needs to be studied if Martin's hypothesis is to be adequately tested.

The productive regions of the ACC are restricted to the vicinity of landmasses, with the largest high productive region located along the Peninsula and extending as a plume along the south-western Atlantic Sector. Field observations dating back to Hart (1942) indicate high phytoplankton biomass in the spring which tends to fade out in the course of the summer despite apparent favourable conditions for growth. We hypothesize, based on the following considerations, that the decline is caused by iron exhaustion analogous to nitrate exhaustion in other continental margins. Firstly, the experiments have all demonstrated unequivocally

that iron, like the other macronutrients, limits both growth rate and biomass build-up of phytoplankton. Secondly, the spring bloom in the Antarctic Peninsula Plume (APP) is based on winter-accumulated iron emanating from contact with the sediments and coasts which will suffice to enable uptake of only a fraction of the macronutrients. Iron from land run-off peaks in the summer can result in intense blooms which, however, are restricted to the coastal embayments although their extent due to seaward advection needs investigation. Thirdly, if fertilization in the summer induces blooms in HNLC waters then there is good reason to expect the same in the SW Atlantic. Because of the larger seeding stock left behind by the spring bloom, we expect that this summer bloom will attain higher biomass more rapidly than the open ocean blooms and that the species composition will be characteristic of the carbon-sinking community sensu Smetacek et al. (2004).

The following hypothetical scenario of the bloom will be tested in this experiment: The bloom will grow rapidly and be dominated by weakly silicified, fast-growing species of medium-sized, spore-forming diatoms such as *Chaetoceros* and *Thalassiosira*, and probably also *Phaeocystis*. They will build-up biomass to levels  $> 5 \text{ mg chlorophyll m}^{-3}$  (about double the values in previous experiments). Bacteria and the microbial food web will undergo changes and crustacean zooplankton will respond by laying eggs. Parts of the bloom will crash forming aggregates which will sink out rapidly after 4 - 6 weeks of growth. The magnitude of fall-out will depend on the grazing pressure (see below). The aggregates will sink more carbon per silicon than previous blooms, despite the lower ballast, and will reach the deep-sea floor within 10 days of initiation of mass sinking. Sinking aggregates will be monitored in the deep water column with an *in-situ* profiling camera system, a fluorometer and a transmissometer. They will be collected with neutrally buoyant sediment traps in addition to filtration of large volumes of water. The response of the benthos will be monitored by *in-situ* oxygen profiles and surface sediment sampling. Stability of the eddy over the time course of the experiment is a crucial prerequisite for successful monitoring of these processes. On the other hand, if the course of events in the bloom runs differently, the experiment will yield novel information. In either case the bloom will provide insights into the biogeochemistry of pelagic ecosystems in general and the SW Atlantic in particular and provide the quantitative framework necessary to validate current proxies of deep-ocean carbon sequestration and identify new ones.

The multi-level grazing hypothesis, reviewed in detail by Smetacek *et al.* (2004) comprises the role of grazing in shaping the structure of phytoplankton assemblages at scales ranging from evolutionary (ultimate levels) to that of specific water mass and season (proximate levels). *In-situ* iron fertilization experiments represent a powerful new methodology to test this series of hypotheses because they enable the study of interactions within ecosystems with their full complement of grazers and pathogens. The effect of iron fertilization on higher trophic levels will depend on the locality and duration of the experiment. The results of EisenEx indicated a significant increase within 3 weeks in biomass of small copepods and the numbers of faecal pellets relative to outside waters indicating that the open ocean zooplankton were food limited (Henjes et al. 2007). An artificially induced phytoplankton bloom in the SW Atlantic is likely to attract krill. Decimation of a natural phytoplankton bloom by a roving krill swarm was observed during the European Polarstern Study (EPOS) in the Weddell-Scotia Confluence in 1988/89 which resulted in a shift in the species composition of the phytoplankton (Treguer and Jacques 1992). We anticipate similar responses of krill swarms in the area on the induced bloom. However, since the experimental site is located at the northern end of the region of high krill biomass, it is possible that none are encountered.

The feasibility of large-scale ocean iron fertilization as a means to sequester atmospheric CO<sub>2</sub> has been hotly debated ever since the “Iron Hypothesis”, and ocean fertilization experiments to test it, was proposed by John Martin in 1990. Several companies announced their interest in ocean fertilization in the framework of the carbon credit market specified in the Kyoto Protocol. The scientific community has tended to view fertilization with scepticism, partly because of the negative side effects of uncontrolled commercialization. If fertilization works and a significant proportion of the phytoplankton bloom sinks out, then a maximum of 1 billion tonnes (1 Gigatonne or Gt) of carbon could be annually sequestered from the atmosphere by fertilizing the entire Southern Ocean with a few million tonnes of iron sulphate powder (Smetacek and Naqvi 2008). This is not much compared with the annual increase of CO<sub>2</sub> of around 3.5 Gt but it is again too much to ignore, particularly in view of the enormous costs associated with other techniques of CO<sub>2</sub> removal. Recently, various scientific and international organisations have issued critical statements on ocean iron fertilization and called for better understanding before embarking on large-scale operations. LOHAFEX is the beginning of close cooperation between India and Germany in the field of ocean research.

### **Site selection**

The LOHAFEX experimental site has been selected on the basis of two considerations. It is located within the krill habitat, albeit at its northern boundary, and has a somewhat different plankton composition to the rest of the Southern Ocean where earlier experiments were conducted. The effects of fertilization are likely to differ accordingly. Second, it is a region where stable eddies form and are maintained for several months. Eddies are slowly rotating, circular water masses of 50 – 100 km diameter that extend to the sea floor at 4 km depth and are enclosed by a loop of swiftly flowing, frontal-jet currents. The closed eddy core hence provides an ideal container to carry out fertilization experiments because it is possible to track sinking particles through the underlying deep water column. Eddies can be identified and followed through their life time in satellite images of sea-surface height where they appear as stationary, roughly circular bulges or depressions. LOHAFEX will be placed in the most suitable eddy along the Antarctic Polar Front, about 300 km north of the island of South Georgia.

### **Procedure of the experiment**

On arrival in the eddy selected from daily satellite altimeter images, the location of its closed core will be verified from ship-based measurements of current speeds and direction as well as from the tracks of surface and deep buoys deployed for the purpose. The surface buoys are fairly small but the deep buoys are autonomous, neutrally buoyant sediment traps that sink to a pre-programmed depth and surface after a few days. Confirming the location of the eddy centre will take about 5 days. After locating the centre and carrying out a long station (see below) to obtain baseline measurements of the region to be fertilized, the ship will steam around a drifting buoy in concentric circles 2 km apart while releasing a solution of iron sulphate in the ship’s propeller wash. The iron solution will be mixed with the inert tracer sulphur hexafluoride (SF<sub>6</sub>), which can be accurately measured in trace quantities, in order to mark the fertilized water. A circular patch of 20 km diameter (300 km<sup>2</sup>) will be fertilized with 20 tonnes of iron sulphate powder dissolved in weakly acidified sea water. The patch will spread to well over 1,000 square kilometres during the experiment.

LOHAFEX will fertilize an area about double that of EIFEX. This will reduce the dilution effect due to admixture of water from outside the patch. Iron fertilization of the patch centre will possibly be carried out once again during the first half of the cruise depending on patch spread and bloom development. After about 3 weeks the centre of the patch (150 km<sup>2</sup>) will

again be marked with SF<sub>6</sub> (but not iron) to compensate for loss to the atmosphere (SF<sub>6</sub> is a gas).

On several occasions during the cruise, the patch and the unfertilized water surrounding it will be surveyed with the towed undulating instrument package Scanfish and with zooplankton acoustics to estimate the spatial patterns of phytoplankton and zooplankton stocks respectively. The spatial mapping will be followed by grids of Medium and Short Stations (see below) to calibrate the Scanfish measurements and assess small-scale heterogeneity in nutrients, suspended particulates and species composition of plankton.

Research accent will be focussed on Long Stations, which will be carried out in the zone of highest biomass in the centre of the patch, marked with a drifting buoy, to minimise the dilution effect. These central stations with regular casts to the bottom will take about 12 hrs to conduct. Reproducibility of the various casts will be ensured by keeping the ship close to the drifting buoy. Long stations will also be carried out outside the patch. Neutrally buoyant sediment traps (that have to be retrieved when they surface) will be deployed routinely throughout the experiment at intervals of about 5 days. A bottom-lander will also be deployed and retrieved regularly to measure oxygen profiles in surface sediments and infer the organic carbon flux to the sea floor. *In-situ* observations will be furthermore supplemented by deck-board incubation experiments to study grazing, faecal pellet production and nutrient cycling by different zooplankton species and viability of copepod eggs.

Three types of stations will be carried out:

Long station: 3 – 4 CTD casts (when experimental water is needed) with Go-Flo bottles (mounted on Kevlar wire) and Multinet as well as Bongo and RMT nets, the latter preferably at night. Surface sediments will be sampled with a multicorer.

Medium station: 2 – 3 CTD casts with Go-Flo + Multinet.

Short station: 1 CTD dip.

The various approaches and measurements conducted during LOHAFEX are detailed in the following subchapters.

The experiment will depend on behaviour of the patch. We should expect rough weather about every 5 days with relatively calm spells in-between, although longer periods of favourable weather are also possible. There will be little sunshine but not much rain and outside temperatures will be ~ 4°C.

This leg is a contribution to POGO, der Partnership for Observation of the Global Oceans, <http://www.ocean-partners.org/aboutPOGO.html>.

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## 2. PHYSICAL OCEANOGRAPHY/HYDROGRAPHY

V.S.N. Murthy, P.V. Narvekar, A. Almeida, A. Methar, A. Kankonkar (NIO), M. Ribera (SZN) and D. Wolf-Gladrow (AWI)

### Objectives

The main task of the physical oceanography group will be to collect data necessary for defining the physical environment of the experimental site. It will also play the central role in experimental site selection and in tracking the spreading and movement of the fertilized patch as well as the flux of particles emanating from it through the deep water column.

### Work at sea

The various planned activities of the group are summarized below:

#### 2.1 IDENTIFICATION OF A SUITABLE EXPERIMENTAL SITE

Selection of an appropriate experimental site will, of course, be paramount for success of the LOHAFEX experiment. Initial selection is being done on the basis of satellite altimeter (sea surface height) data. As in the case of EISENEX and EIFEX, LOHAFEX will also fertilize a stationary, cold-core eddy. An important criterion for selection of such an eddy will be its stability. Examination of altimeter images for the past several years has enabled us to identify the best candidate for the experiment. This feature, occurring in the Polar Front region north of South Georgia, recurs every year and is fairly stable and stationary unlike eddies in the region to the south of the island which move very fast with the Antarctic Circumpolar Current. Such a priori information needs to be verified by *in-situ* measurements, which will be made during the first part of the cruise. For this purpose, we plan to (a) deploy drifting buoys with GPS senders tethered to subsurface drogues and monitor their movement, (b) deploy neutrally buoyant sediment traps attached to ARGOS floats primed for a range of depths that will monitor vertical coherence of the water column (c) undertake towed undulating scan fish surveys across the eddy, and (d) use the vessel-mounted acoustic Doppler current profiler (ADCP) to get a good idea of the current field. We hope that with these different approaches we will be able to identify the centre of the eddy with reasonable accuracy.

#### 2.2 TRACKING THE FERTILIZED PATCH

Constant tracking of the fertilized patch is essential for fertilization experiments. During LOHAFEX, besides satellite data, we plan to achieve it by monitoring changes in chemical and biological parameters – SF<sub>6</sub>, pCO<sub>2</sub>, chlorophyll, phytoplankton photosynthetic efficiency (Fv/Fm) measured by the FRRF (Fast Repetition Rate Fluorometer) – and also through the deployment of surface buoys drogued at mid depth of the mixed layer and tracked by radio

and satellite telemetry transmitting its GPS position. One of these buoys will be at the centre of the eddy to begin with and will be used for the relative navigation of the ship during iron release along a spiral path around the buoy. In order to monitor the dynamics of the patch and to determine the eddy's velocity and density field Scanfish surveys will be carried out at regular intervals and these data will be used along with the ADCP data. Such surveys along with chemical measurements will also allow us to determine the degree of mixing with surrounding waters and ascertain the integrity of the patch (if, for example, a part of the stimulated bloom is detrained from the eddy's interior through lateral shear or is subducted).

### 2.3 MEASUREMENTS DURING THE EXPERIMENT

The three-dimensional velocity field will be continuously studied with the vessel-mounted ADCP and the drift trajectories of surface buoys and neutrally buoyant sediment traps "parked" in subsurface and mesopelagic depths. Repeated runs by the towed Scanfish equipped with suitable sensors will provide sections of physical variables (temperature, salinity, density, transmittance, fluorescence, etc.). In addition, standard CTD casts will be carried out 1-2 times a day to a depth of at least 1,000 m and at least once every 2 - 3 days down to the maximum depth. Most of these stations will be located close to the centre of the eddy/fertilized patch, but less frequently we will also take samples from outside the fertilized patch for reference purposes. Measurements of salinity will be carried out on a few water samples collected from each cast for calibration. Profiles of the state variables will inter alia be used for calculating vertical stratification. The ship's CTD will also support auxiliary instruments such as a fluorometer for measuring the chlorophyll concentration and a transmissometer for measuring light transmission. The ship's CTD will be integrated with a rosette frame holding 24 12-litre bottles, for various biological and chemical measurements.

## 3. TRACING THE FERTILIZED PATCH WITH SF<sub>6</sub>

V. Desai and S.W.A. Naqvi (NIO)

### Objectives and work at sea

Like most previous Ocean Iron Fertilization (OIF) experiments LOHAFEX will also make use of SF<sub>6</sub> as a conservative tracer for marking the fertilized patch and to get a measure of the degree of dilution of the originally fertilized patch of water. The SF<sub>6</sub> saturated seawater from a saturation system kindly provided by Dr. Phil Nightingale (PML, Plymouth, UK) will be mixed with the FeSO<sub>4</sub> solution prior to release. The SF<sub>6</sub> concentration in the surface water will be regularly monitored using a GC-ECD system on board ship. Given the longer duration of LOHAFEX compared to all previous OIF experiments, marking the patch with SF<sub>6</sub> may have to be repeated during the course of the experiment.

## 4. MACRO- NUTRIENTS

A.K. Pratihary, Maya Muthirethy, and H. Naik (NIO)

### Objectives

Cycling of major nutrients (nitrogen, phosphorus and silicon) will be studied in detail during the LOHAFEX expedition. Iron fertilization is expected to promote rapid utilization of these nutrients in the surface water as phytoplankton biomass builds-up, and so their

concentrations and forms will be monitored throughout the cruise both within and outside the fertilized patch. All water samples collected during the expedition will be run for inorganic nutrients, whereas organic nutrients will be measured on a more selective basis. These data will help understand production and recycling of organic matter in the water column as a result of iron fertilization.

#### **Work at sea**

Samples for nutrient analyses will be taken from the ship's flow-through system, from all CTD casts and from experiments carried out on board. We will be carrying two auto-analyzers with us for measuring inorganic nutrients (nitrate, nitrite, ammonium, phosphate and silicate) as well as organic fractions (urea and dissolved organic carbon, nitrogen and phosphorus through measurements of total nitrogen and total phosphorus) on board ship following standard procedures. Samples for total nitrogen and total phosphorus will also be collected and preserved for later analysis in the home laboratory (NIO, Goa).

## **5. CO<sub>2</sub>-SYSTEM**

G. Narvenkar, Maya Muthirenty, and S.W.A. Naqvi (NIO)

#### **Objectives**

Previous iron fertilization experiments have revealed that the addition of iron to surface waters of the HNLC regions, including the Southern Ocean, results in drawdown of the surface pCO<sub>2</sub> levels thereby leading to uptake of CO<sub>2</sub> from the atmosphere. However, uncertainty remains as to what is the ultimate fate of the carbon fixed in the surface layer (i.e. whether it is largely recycled in the surface layer or a significant fraction of it is vertically exported out of the surface layer). Most of the OIF experiments have, however, been carried out for much shorter duration than the planned period of LOHAFEX, and so monitoring of various components of the CO<sub>2</sub> system during LOHAFEX is expected to improve our understanding of the fate of carbon produced due to iron enrichment.

#### **Work at sea**

The work plan includes continuous underway pCO<sub>2</sub> measurements as well as discrete analysis of samples collected with the CTD rosette sampler. CO<sub>2</sub> related parameters to be analyzed for the latter component are dissolved inorganic carbon (DIC) by coulometry, alkalinity by acid titration, and pH by the photometric method.

## **6. DISSOLVED GASES OTHER THAN CO<sub>2</sub>**

H. Naik, R. Roy, B. Thorat, K.B. Sujith, G. Narvenkar, H.S. Dalvi and S.W.A. Naqvi (NIO)

#### **Objectives**

Of the biogenic gases of interest, dissolved oxygen will be routinely analyzed in all discrete samples collected with the CTD using an automated titration system. Nitrous oxide (N<sub>2</sub>O) analysis will also be carried out at most stations using a GC-ECD system. Distribution of this gas is of particular interest because of widespread concerns that degradation of organic matter produced as a result of large-scale OIF could result in a substantial decrease in subsurface oxygen levels, thereby promoting the production of this powerful greenhouse gas

and offsetting in part the gains due to CO<sub>2</sub> sequestration. Of the OIFs conducted in the Southern Ocean N<sub>2</sub>O was measured during SOIREE and EIFEX. An increase in N<sub>2</sub>O was recorded in the thermocline during SOIREE, but not during EIFEX in spite of its longer duration. Additional measurements are therefore needed to reconcile these differences. Another biogenic gas of climatic significance is dimethyl sulphide (DMS). Previous OIF experiments have been found to typically increase concentrations of DMS and its precursor DMSP (dimethylsulphoniopropionate) by a factor of 3. Increases of this magnitude, if occurring globally, could lead to atmospheric cooling by 1 - 2° C, and so its production has potentially beneficial effects for the environment.

#### **Work at sea**

Measurements of DMS, DMSP and DMSO (dimethylsulphoxide) will be made on a regular basis on LOHAFEX using a GC-FPD (explain abbreviation) system. The concentration of methane (CH<sub>4</sub>) will also be measured using GC-FID. This will be particularly important at the later stage of the experiment when degradation of the organic matter is expected to occur. Finally, volatile halogenated organic compounds (VHOCs) such as chloroform, carbon tetrachloride and 1-iodopropanol will also be measured during the cruise to investigate the effect of OIF on their production by phytoplankton.

## **7. NATURAL ISOTOPE ABUNDANCE**

A. Sarkar and Maya Muthirenthi (NIO)

#### **Objectives**

The Southern Ocean has a large pool of non-utilized nitrate because of iron limitation of primary productivity. Nitrate uptake following iron enrichment is expected to cause a change in the isotopic composition of nitrate (enrichment of <sup>15</sup>N) that should be easily detectable during the course of the experiment. This effect has not been looked for in previous OIF studies.

#### **Work at sea**

During LOHAFEX we intend to monitor not only the isotopic composition of nitrate in surface waters, but also the composition of suspended and sinking particulate material to study the changes arising from iron enrichment which will provide insights into carbon cycling. Surface samples will be collected and stored in acidified condition for analysis of the natural isotope abundance of nitrate.

## 8. IRON CYCLING

L. Laglera, R. Martinez (CSIC-IMEDEA), H. Naik (NIO) and A. Bansiwai (NEERI)

### 8.1 TRACE METALS AND FE CONCENTRATION, PARTITION AND SPECIATION. THE ROLE OF KRILL IN METAL CYCLING

Luis M. Laglera and Regino Martinez (CSIC-IMEDEA)  
Collaborators not on board: Antonio Tovar-Sánchez and Carlos M. Duarte (CSIC-IMEDEA), Susana Agustí (IMEDEA)

#### Objectives

The contribution of the IMEDEA group will be the determination of changes in the concentration of trace metals and the partition and speciation of iron. The analyses will be performed in seawater samples from the fertilized patch and in samples obtained from the equilibration of grazers (krill, salps and copepods) with seawater under controlled experimental conditions.

#### Work at sea

For this purpose a voltameter supplied by Hema Naik from NIO will be used for onboard analysis of iron in seawater by CCSV (catalytic cathodic stripping voltammetry). Samples will be partitioned by filters of progressively smaller pore size (0.22 and 0.05  $\mu\text{m}$ ) for the analysis of dissolved, colloidal and truly dissolved iron concentrations. The organic speciation of iron will be determined by iron titrations of samples and detection of the labile part by CCSV. This will be carried out partially on board and partially after the cruise on frozen samples. Ag, Cd, Co, Cu, Fe, Ni, Mn, Mo, Pb and Zn will be acidified ( $\text{pH} < 1.5$ ) on board and determined after cruise in the laboratories of the IMEDEA by ICP-MS (Inductively Coupled Plasma mass spectrometer).

### 8.2 SOLUBILITY AND SPECIATION OF IRON IN AN HNLC AREA (STUDY AREA NOT TRULY HNLC CHARACTER) AFTER FERTILIZATION

#### Objectives

Iron is extremely insoluble at natural seawater conditions and it is necessary to check the effectiveness of the iron fertilization in increasing the concentration of non-particulate iron in the experimental area. Samples from the water column will be collected by means of a trace metal clean sampling system (NIO and IMEDEA) to follow the dispersion and solubility of the excess iron added during the fertilization.

#### Work at sea

The organic speciation will be analyzed to monitor changes in solubility caused by the possible release of ligands by the local biota. Ligand concentrations and the stability of their complexes will be obtained from iron titrations. The determination of Fe(II) will be attempted by the voltammetric method although this technique could be not sensitive enough if iron concentrations remain at subnanomolar levels.

### 8.3 QUANTIFICATION OF TRACE METALS AND KINETICS AND SPECIATION OF THE IRON PRESENT IN THE EXCRETION PRODUCTS OF KRILL, SALPS AND COPEPODS

#### Objectives

Antarctic krill (*Euphausia superba*) has been widely studied because of its important role in the dynamics of the Antarctic food web. Most of those studies have focussed on the life cycle and ecology of this pelagic organism. They are long-lived organisms (> 9 years) which migrate seasonally, and are widely distributed within the entire water column. Krill also ingest a broad range of materials (from nano- and micro-phytoplankton to detritus), and because of their high excretion rates, they provide a major source of regenerated nitrogen and iron (Tovar-Sanchez et al., 2007). Furthermore, because of their schooling behaviour (mega swarms reaching several kilometres in length) krill can also modify the chemical composition of the surrounding environment. These characteristics suggest that krill may play an important role in the biogeochemical cycling of various chemical constituents in the Southern Ocean, such as trace metals.

#### Work at sea

Three or four randomly selected individuals will be transferred using a plastic spoon, into each of 6 acid-washed 2-l opaque polycarbonate experimental bottles. Each experimental bottle will be filled with filtered (< 0.22 µm) surface seawater. Experimental bottles, including control bottles without krill, will be incubated in the dark at surface water ambient temperature ± 4 °C. In a class-100 HEPA hood, unfiltered and filtered water samples from each experimental bottle will be collected at 2-h intervals, from 1 h up to 6 h from the onset of each experiment. Seawater from each experiment will be acidified with sub-boiled, quartz-distilled HCl (Q-HCl) to a pH less than 1.5 and stored for at least 1 month prior to analysis. We will monitor changes in the partition, redox speciation (the voltameter method should be suitable for the expected concentration range) and organic speciation of Fe. The study will be repeated with other local zooplankton (i.e. Salps and copepods).

### 8.4 INCUBATION EXPERIMENTS TO ESTIMATE THE IMPACT OF KRILL EXCRETION PRODUCTS ON PRIMARY PRODUCTION

The effect of krill excretion products on the metabolic balance and net production of planktonic communities has been examined in the ICEPOS project (Duarte, Agustí, Arístegui and co-workers), but the evidence gathered at that cruise needs to be strengthened with additional experiments. We propose to run a series of experiments on LOHAFEX, which will represent a joint venture with parallel experiments run on board RV *Hesperides* under the ATOS cruise (Duarte, Agustí, Tovar-Sánchez, Arrieta, and co-workers), to examine the impact of krill excretion products on planktonic communities.

#### Work at sea

We will carry out experimental additions of krill metabolites to test the effects of krill excretion products on phytoplankton abundance and production. These experiments will follow a unified design, after the experience of experiments run at the ICEPOS 2005 cruise.

Susana Agustí provides a detailed protocol, so we can conduct coordinated parallel experiments. At least two such experiments will be conducted at each of LOHAFEX and ATOS, delivering a total of four experiments in addition to the two experiments already available from the ICEPOS 2005 cruise.

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## 9. NATURAL RADIONUCLIDES

### 9.1 <sup>234</sup>TH AS TRACER OF EXPORT PRODUCTION OF POC

R. Rengarajan (PRL), Melena Soares (NIO) and Michiel Rutgers van der Loeff (AWI)

#### Objectives

An essential parameter of the progress of the induced plankton bloom is the rate at which particulate matter, and especially POC is exported from the surface mixed layer to greater depths. Apart from the measurements by carbon budgets and sediment traps, we wish to quantify this flux by the measurement of the depletion of <sup>234</sup>Th in the surface waters. Repeated measurement of the integrated <sup>234</sup>Th depletion will allow the calculation of the downward flux of particulate <sup>234</sup>Th out of the surface water. In order to convert this flux to a carbon flux we will determine the POC/<sup>234</sup>Th ratio of large suspended and of sinking particles.

#### Work at sea

<sup>234</sup>Th and POC samples will be collected and processed during this cruise. Ideally about one depth profile of <sup>234</sup>Th will be sampled per day, thus producing a time series inside and outside the fertilized patch. An aliquot of 4-L of seawater will be collected at 0, 25, 50, 75, 100, 150 and 200 m depth. At selected stations, large suspended particles will be collected at several depths down to the sea floor by deployment of in-situ pumps using size-fractionated filtration. Nitex screens of various mesh size (10 and 50µ) with particulate matter are ultrasonicated and the suspension is filtered through a 25 mm precombusted QMA filter. Subsamples from the NB Sediment Traps will also be filtered over 25 mm precombusted QMA filters for <sup>234</sup>Th and POC analysis. The particulate and the total <sup>234</sup>Th samples will be counted onboard using RISO beta counters mounted in the geochemistry container.

In parallel, <sup>234</sup>Th will be measured with an automated system. This will allow the measurement in surface water at a temporal resolution of up to once every 2 hours.

### 9.2 RADIUM ISOTOPES

R. Rengarajan (PRL) and Michiel Rutgers van der Loeff (AWI)

#### Objectives

Four radium isotopes are supplied to the ocean by contact with the continent or (deep-sea)-sediments: <sup>223</sup>Ra, (half-life 11.4 d); <sup>224</sup>Ra (3.7 d), <sup>226</sup>Ra (1620 y) and <sup>228</sup>Ra (5.8 y). The distribution of these isotopes in seawater has been shown to be most helpful to evaluate shelf-basin exchange and water residence times. They can therefore help us to determine whether the water masses have been influenced by natural iron enrichments by contact with shelf sediments in preceding months (<sup>228</sup>Ra), weeks (<sup>223</sup>Ra) or days (<sup>224</sup>Ra). This study will be concentrated on our visit to the shelf of South Georgia.

### Work at sea

Large volume surface water samples will be collected for radium isotopes using the *Polarstern's* seawater intake, filtered through a 1  $\mu\text{m}$  cartridge filter. For  $^{228}\text{Ra}/^{226}\text{Ra}$ , 1-2  $\text{m}^3$  of filtrate is passed over  $\text{MnO}_2$ -coated polypropylene cartridges. The isotope ratio is quantified in the home laboratory by Soxhlet leaching and subsequent gamma spectroscopy;  $^{226}\text{Ra}$  is quantified by occasional co-precipitation of Radium on  $\text{BaSO}_4$  from 20-l samples.  $^{223}\text{Ra}$  in other samples will be interpolated from a relationship we expect to derive between  $^{226}\text{Ra}$  and dissolved silicate.

For short-lived radium isotopes, the filtrate is transferred to 250 l tanks. Each sample is pumped at ca 1 L/min using a peristaltic pump through  $\text{MnO}_2$ -impregnated acrylic fibre to scavenge radium isotopes. Fibres are partly dried using compressed air, and short-lived  $^{223}\text{Ra}$  and  $^{224}\text{Ra}$  measured at-sea using RaDeCC detectors. Longer-lived  $^{228}\text{Ra}$  will be measured on the fibres by gamma counting  $^{228}\text{Ra}/^{226}\text{Ra}$  ratio in the shore-based lab and/or by recounting the  $^{224}\text{Ra}$  activity after ingrowth of  $^{228}\text{Th}$ . For occasional deeper (i.e. below surface) sampling, large-volume samples require multiple (2-3) CTD casts and filling barrels or, if time allows, the deployment of in-situ pumps.

## 10. PRIMARY PRODUCTION, NEW AND REGENERATED PRODUCTION, SIZE-FRACTIONATED PRODUCTION

Mangesh Gauns (NIO), Christine Klaas (AWI), Gauri Mahadik, Sunita Mochemadkar, Shrikant Patil and Amit Sarkar (NIO)

### Objectives

The rate of carbon fixation by autotrophs will be measured by inoculating radioactive  $\text{NaHCO}_3$  into 250 ml seawater in polycarbonate bottles for tracing the uptake of radioactive  $^{14}\text{C}$  from the dissolved inorganic to the particulate form. The method involves incubation of samples at different depths from the euphotic zone, which include a set of five bottles (3 light +2 dark) at each depth from a vertical profile of 8 - 10 depths for each station. Deck board incubators (acrylic) will also be used using neutral density screens to mimic *in-situ* light conditions (100 %, 50 %, 10 % and 1 %). Incubator temperature will be maintained by a continuous flow of surface seawater. Size fractionated primary productivity of various size classes [pico / nano / micro) will also be measured simultaneously along with the total primary productivity (>0.7micron; GF/F filters will be used). Samples will be later analyzed using a scintillation counter at NIO/AWI.

### Work at sea

The study of nitrogen cycling in the surface oceans provides information to better understand primary production and its export flux. During the LOHAFEX expedition in addition to carbon fixation (primary production), nitrate uptake (new production), urea and ammonia uptake (regenerated production) will also be studied in detail using  $^{15}\text{N}$ -labelled tracers. Samples will be collected from selected stations inside and outside the fertilized patch within the photic zone before sunrise. Addition of labelled tracers ( $^{15}\text{N-NO}_3^-$ ,  $^{15}\text{N-NH}_4^+$  and  $^{15}\text{N-Urea}$ ) will be done in order to obtain 10 - 20 % enrichment of the ambient concentration based on real-time measurements. The nutrient amended samples will be incubated just after the tracer addition before dawn in deck incubators. Neutral density light filters of different dimensions will be used to cover the bottle in order to control the light penetration and the incubation

temperature will be maintained using continuous sea water flow through the incubators. After 24 hr (dawn to dawn) incubation final concentration of  $\text{NO}_3^-$ ,  $\text{NH}_4^+$  and urea will be measured and the rest of the samples will be filtered using pre-combusted selective filter papers at low vacuum pressure. The filter paper will be dried in the oven and stored dry. Isotopic measurements will be done in the shore laboratory (NIO, Goa).

## 11. PHYTOPLAKTON PIGMENTS, DILUTION EXPERIMENTS

R. Roy and M. Gauns (NIO)

### Objectives

To overcome some of the inadequacies of microscopy, high performance liquid chromatography (HPLC) pigment method has been used in recent years to obtain accurate chlorophyll *a* data as well as detailed information (for sure not as detailed as microscopy) about the composition of phytoplankton communities. This method is based on the premise that different algal classes have specific signature, or marker pigments. For example, fucoxanthin, zeaxanthin, and chlorophyll *b* have been selected as taxonomical pigments for bacillariophyta (diatoms), cyanobacteria (blue-green algae), and chlorophyta (green algae), respectively. HPLC phytoplankton pigment measurements will be carried out on board ship.

### Work at sea

Dilution experiments will be carried out for studying phytoplankton growth and grazing by microzooplankton. These experiments will be undertaken twice a week. Acrylic incubators with continuous flow of surface seawater will be used for onboard incubations.

## 12. POC, PON, $^{13}\text{C}$ , $^{15}\text{N}$ , TOC, TON

Mangesh Gauns (NIO), Christine Klaas (AWI), Amit Sarkar, Divyashree Barniya, Kanta Reshma and Maya Muthirethy (NIO)

### Objectives

Pools of particulate and total organic carbon and nitrogen will increase following fertilization and then decrease during the demise phase of the bloom due to sinking out of particles. Comparing these values with the measured losses in DIC and dissolved nitrogenous nutrients will enable us to derive budgets of these elements for the surface patch in order to obtain ratios for iron added and organic matter produced in and sunk from the surface layer. Analyses of the stable isotopes of  $^{13}\text{C}$  and  $^{15}\text{N}$  in surface pools will help to interpret ratios ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) measured in the sediments where they are used as palaeoproductivity proxies.

### Work at sea

Samples for measurements of POC, PON and for natural isotope abundance ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) will be collected on a routine basis from the CTD casts. These parameters are not only important for characterizing primary production, but will also serve as control for nutrient uptake (tracer addition) work described in section 11. Appropriate volumes of sea water (~1-2 l) will be filtered through pre-combusted GF/F filters (25 mm diameter) and filters will be stored deep frozen for analysis at NIO. Similarly an *in-situ* filtration pump capable of filtering

several tens of litres of water at selected depths will also be used for larger volume sampling. Part of these samples will be analyzed for stable isotopic analysis ( $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ) at NIO. Samples for TOC and TON will be stored after acidification with phosphoric acid for analysis in the shore laboratory following high temperature catalytic oxidation. The remaining part of the samples will be utilized for measurement of characteristic biomarkers at NIO.

## 13. PHYTOPLANKTON PHOTOPHYSIOLOGY AND BIO-OPTICS

Maurizio Ribera D'Alcalà (SZN)

### Objectives

Measurements based on chlorophyll fluorescence are a sensitive tool to determine alga biomass and photophysiological characteristics of phytoplankton. The quantum efficiency of photochemistry ( $F_v/F_m$ ) measured by variable chlorophyll fluorescence can be used to prove iron-limitation of plankton algae. During former iron fertilisation experiments a response of the phytoplankton was observable by variable chlorophyll fluorescence in between the first 2 days after the iron addition. Therefore it should be possible to detect a patch of iron-replete water by measurements of variable chlorophyll fluorescence only.

### Work at sea

During this cruise different methods for the determination of variable chlorophyll fluorescence (FRRF, PAM, Pump & Probe) will be used to determine basic photophysiological parameters of the phytoplankton and its photosynthetic performance. *In-situ* measurements of the fluorescence yield and photosynthetic parameter will be conducted continuously in a flow-through cuvette and during CTD casts using Fast Repetition Rate Fluorometry (FRRF). Total water column primary production will be calculated from the data of each depth-profile. This will be compared with modelled primary production using photosynthesis-light curves and the *in-situ* irradiance. Therefore photosynthesis-light curves will be determined for single water samples in the lab using PAM- and Pump & Probe-fluorescence and the radiocarbon method ( $^{14}\text{C}$ ). In addition this calculation needs the determination of the ambient light climate and the light absorbed by the phytoplankton itself. *In-situ* irradiance will be measured with a light profiler and water samples will be taken to determine the particular absorption. The data will be combined to determine the changes in phytoplankton photophysiology and photosynthesis of the induced algae bloom until its expected breakdown.

## 14. MICROBIOLOGY

### 14.1 BACTERIAL PRODUCTION

N. Ramaiah and Sanjay Singh (NIO)

Measurements of bacterioplankton production and abundance will provide a realistic estimate of bacterial growth yield. Previous results have shown that iron fertilization brings about major changes in the expression of bacterioplankton beta-glucosidase and aminopeptidase activity. In addition, increased bacterioplankton abundance and production were also observed without altering the richness of the bacterioplankton community. Whether the uptake of dissolved organic matter (DOM) by bacterioplankton following the Fe-release

was stimulated by iron alone making already existing but not utilized DOM available, or by a combination of iron and stimulated dissolved organic matter release by phytoplankton remained unclear.

### **Work at sea**

In addition to the parameters already measured during EISENEX, in order to investigate preferential uptake during LOHAFEX we will focus on measuring leucine and thymidine incorporation rates. In addition, for ascertaining if the metabolically active fractions of heterotrophic bacteria undergo variations during the experiment, samples from within the patch and outside it will be analyzed for enumerating direct viable counts. Through these measurements, we hope to recognize the inter-relationship between the proliferation and metabolic performance during the time series observations. Moreover, we plan to extract microbial DNA for DGGE analysis in order to profile the changes in assemblage composition as a consequence of iron fertilization as well as altered primary (and secondary) production.

## **14.2 BACTERIAL BIODIVERSITY**

V.R. Sundareswaran, G.S.N Reddy (CCMB)  
Collaborator not on board: S. Shivaji (CCMB)

### **Objectives**

The fact that OIF leads to a phytoplankton bloom has been well documented. But, comparatively little is known as to what ocean iron fertilization does to the bacterial communities after fertilization and after the phytoplankton bloom sinks out of the mixed layer. To investigate these changes, various methods will be adopted to monitor both the viable cultures and also the total bacterial biodiversity using the culture dependent rRNA approach.

### **Work at sea**

Water samples will be collected from all the casts / various depths and after some crude screening through pre-filter pads, the collected water will be passed through a 0.22  $\mu\text{m}$  filter to trap all the microbial matter. DNA will be extracted from this bacterial mass and the same will be preserved as pellets in suitable medium (alcohol), till further analysis in the home laboratory. On shore, 16S rRNA typing will be carried out on these DNA samples and communities / individual bacteria present in the region of OIF as also those affected by the OIF would be determined through various molecular approaches.

Also, duplicate filters will be placed on various growth media (such as Antarctic Bacterial Medium, etc.) and the same incubated at ambient / various temperatures for several days. The colonies that show up will be re-patched to get pure cultures. On shore, later, these bacteria will be classified using the polyphasic approach. A small quantity of water samples from each cast, both before and after OIF, would also be brought ashore to document both the culturable as well as non-culturable bacterial communities present through a polyphasic taxonomic approach.

### 14.3 BACTERIOPLANKTON COMPOSITION

Bernhard Fuchs and Jörg Wulf (MPI Bremen)

#### Objectives

The marine bacterioplankton community is strongly dependent on the primary production of the phytoplankton. Phytoplankton in turn is dependent on sufficient nutrients in the water column. During spring time blooms of mostly large eukaryotic algae develop in higher latitudes which in turn promote growth of specific groups of bacterioplankton. *Coccolithophore* blooms for example often induce an increase in *Roseobacter*-related bacteria in the North Sea. *Roseobacter* is able to incorporate and degrade the osmolyte dimethylsulfoniopropionate (DMSP) released by coccolithophores (Zubkov et al. 2001). Another algal group, *Phaeocystis*, has been found to bloom in Antarctic waters. Fluorescence *in-situ* hybridisation (FISH) have revealed a tight association of *Phaeocystis* colonies with *Bacteroidetes*, which are known to resemble polymer-degrading specialists (Simon et al. 1999). Iron-fertilization experiments are well suited to follow induced shifts in community composition and to establish links between the different plankton groups. Recently it has been shown, that the bacterioplankton community inside a naturally fertilized area at the Kerguelen upwelling plateau was qualitatively and quantitatively different from the outside community (West et al. 2008). We hypothesize that in artificially fertilized patches similar community shift in bacterioplankton will be observed.

#### Work at sea

During LOHAFEX we want to closely follow the bacterioplankton community composition by FISH and try to find key players in the degradation of the freshly produced organic matter. Fluorescently labelled oligonucleotide probes specific for different groups of bacterioplankton will be used to follow the community composition during the course of the fertilized patch. Bacterioplankton samples will be counted on board and correlated to nutrients and to phyto- and zooplankton counts. We would like to monitor the fertilized patch, the bloom and decay of the bloom through the water column down to the sediment. To assess the metabolic potential of specific groups of bacterioplankton we will incubate the bacterioplankton samples with isotopically labelled substrates and trace them in different groups of bacterioplankton. For example  $^{15}\text{N}$  labelled amino acids will be used as well as  $^{13}\text{C}$  labelled short organic compounds. Simultaneous detection of identity and uptake of substrates will be possible through a technique called Nano-SIMS – a next generation mass spectrometer with submicron spatial resolution. The later samples will be analysed back home at the institute. Additionally at chosen time points during the course of the experiment large volumes of water (>100 l) will be sampled for later on analysis of the metagenomes. A screening for key genes will help to reveal the metabolic potential of the bacterioplankton community present at a certain point during the phytoplankton bloom induced.

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dimethylsulphoniopropionate in an algal bloom in the North Sea. Environmental Microbiology 3, 304-311.

## **15. MICROPHYTO- AND PROTOZOOPLANKTON**

P. Assmy, F. Ebersbach, N. Fuchs, C. Klaas (AWI), M. Montresor (SZN) and V. Smetacek (AWI)

### **Objectives**

The phytoplankton group will study the response of the phytoplankton assemblage to iron addition over a period of roughly 45 days during the Indo-German large-scale iron fertilization experiment LOHAFEX scheduled for austral summer 2009 (January – March) in the SW Atlantic north of South Georgia. In order to interpret the wax and wane of individual species populations over the course of the iron induced bloom it will be critical to understand the mechanisms that trigger growth and mortality phases of the dominant species since the former will determine species dominance and the latter the transfer to higher trophic levels and/or the subsequent fate along the deep water column. Different methods will be applied in order to address the above objectives and are detailed in the following sections.

### **Work at sea**

#### **15.1 ROUTINE COUNTING OF THE MICROPHYTO- AND PROTOZOOPLANKTON ASSEMBLAGE**

For the quantitative assessment of the plankton assemblage water samples will be taken at 7 discrete depths between 10 and 150 m at in- and out-patch CTD stations using Niskin bottles. Both Formalin and Lugol fixed water samples of 200 ml will be sampled for diatoms, coccolithophores, choanoflagellates and thecate dinoflagellates in case of the former and for Phaeocystis, ciliates, naked dinoflagellates, silicoflagellates and other flagellates in case of the latter. One 2 l sample representative of the mixed layer (20 m depth) will be concentrated over 10 µm gauze and counted directly on board to keep track of the bloom. For large protozoa (mainly sarcodines) and small metazoa (mainly copepod nauplii and copepodites) larger volumes (at least 24 l) will be concentrated to a volume of about 50 ml by pouring the water gently through 20 µm gauze which will require one extra CTD cast. Large volume samples will also be sampled from the deep water column (150 m – sea floor) and concentrated over 10 µm gauze throughout the experiment to follow the sinking of individual species population.

#### **15.2 VITAL STAINING OF THE PLANKTON ASSEMBLAGE DIRECTLY ON BOARD**

Routine counting will be supplemented with the application of different staining techniques to follow the physiological status of individual phytoplankton species. Incubation experiments with the PDMPO stain that stains newly polymerised silica will be performed to estimate *in-situ* growth rates. Application of the viability stain FDA will provide information on the number of live cells within a population whereas the use of SYTOX Green will only label those cells that have lost their membrane integrity (dead cells). Thus the combination of both stains will provide an estimate of the number of dead and live cells within a population. Furthermore a fluorescent dye specifically binding to apoptotic cells will be applied to infer whether

programmed cell death is involved in the demise of individual species populations. Specific lipid stains will be used to infer the physiological status of phytoplankton species and DNA and RNA stains (SYBR Green I and II) in order to visualize particular cell compartments (nucleus, ribosomes). Furthermore compound specific dyes for polysaccharides and proteins (Alcian Blue and Coomassie Brilliant Blue respectively) will be applied to visualize the mucous matrix of sinking aggregates and infer their chemical composition.

### 15.3 ISOLATION AND CULTURING OF DOMINANT DIATOM SPECIES

Another major aim is to establish cultures of dominant diatom species during the experiment isolation and total preparations of diatom material for both light and electron microscopy. The unialgal cultures will be used for later morphological, phylogenetic, life history and experimental studies in the home laboratory.

### 15.4 SAMPLING FOR MOLECULAR STUDIES

Both DNA and RNA samples of the natural plankton assemblage will be taken on board for biodiversity/metagenomic and gene expression/metatranscriptomic analysis respectively. Large volume samples for DNA will be filtered and then stored away at  $-80^{\circ}\text{C}$  for later analysis. Samples for RNA will be immediately processed on board, including filtration, extraction and isolation. We are particularly interested in the expression of genes related to cell cycle regulation (e.g. PCNA, Cyclins) to determine *in-situ* growth rates and genes involved in the programmed cell death pathway (e.g. metacaspases). Quantitative real time RT-PCR analysis will later allow precisely determining the mRNA expression levels of the genes of interest and linking their expression with the pattern observed by microscopy.

### 15.5 LINKS TO OTHER GROUPS

- Zooplankton grazing experiments will be conducted in cooperation with Humberto Gonzalez and Maria Grazia Mazzochi.
- Dilution experiments to determine microzooplankton grazing will be conducted together with the group of Mangesh Gauns.
- Subsamples of the phytodetritus fluff layer on surface sediments provided by Oliver Sachs and Michael Schlüter will be sampled for species composition.
- Sampling of neutrally buoyant sediment traps will be performed in close cooperation with Patrick Martin and Kevin Saw.
- Klaus Valentin, Uwe John (AWI), Chris Bowler (ENS, Paris) will be involved in molecular studies.

## 16. MESO- AND MACROZOOPLANKTON

Grazia Mazzocchi Maurizio Ribera D'Alcalà (SZN), Humberto E. González (UACH-COPAS), K. Karuppasamy (NIO) and Pieter Vandrommes (UPMC-CNRS)

Collaborators not on board: Sigrid Schiel (AWI), Ann Bucklin (UCONN) and Lars Stemmann (UPMC-CNRS)

### Objectives

The general objective is to evaluate the structural and functional responses of primary consumers to the spatial and temporal variations of food quantity and quality, and the impact of zooplankton activity on the carbon flux during the evolution of the phytoplankton bloom induced by iron fertilization.

In particular, three aspects will be investigated onboard with sampling and experimental activities, by following a species-level approach: 1) species distribution and abundance in space and time, 2) feeding performances (grazing rates and selectivity) of dominant species, 3) copepod egg production and viability in dominant species. These investigations will be closely linked to the *in-situ* video recording of particle distribution by the Underwater Video Profiler 5 (UVP5). Moreover, target zooplankton species will be selected for DNA barcoding in association with Census of Marine Zooplankton (CmarZ).

### Work at sea

#### 16.1 DISTRIBUTION

Species composition, abundances, biomass, and vertical distribution patterns of dominant zooplankton species and their developmental stages will be analysed from Multinet, Rectangular Midwater Trawl, Bongo and WP2 samples. Day and night catches will be performed outside and within the fertilized patch, from onset till demise of the bloom. The taxonomic identification and specimen counts will be done at species level as far as possible. Supplementary tows will be performed on occasions to collect healthy organisms for experiments and for later analyses of the specific carbon and nitrogen content.

#### 16.2 GRAZING

The functional responses of dominant copepod species, euphausiids (*Euphausia superba*) and salps (*Salpa thompsoni*) will be investigated in terms of feeding behaviour and performances in relation to food quantity and quality. Copepods will be gently collected with WP2 net (200 µm) and krill with Bongo-net (300 µm) and target species will be sorted for conducting incubation experiments (24 hours) in natural particle assemblages. The feeding rates (clearance and ingestion) and selectivity of zooplankton species on phytoplankton species, the faecal pellet production and the grazing impact on phytoplankton concentration and composition will be estimated outside and inside the patch and during the bloom evolution.

The grazing experiments will be linked to the observations conducted by the (UVP5) for the *in-situ* distribution of particles (>60µm) and qualitative zooplankton-particle interactions.

### **16.3 COPEPOD EGG PRODUCTION AND VIABILITY**

The functional responses of the same dominant copepod species utilized for the grazing experiments will be investigated in terms of reproductive performances and recruitment. The egg production and viability will be estimated outside and inside the patch and during critical phases of the bloom evolution. Moreover, the hatched nauplii NI will be frozen to be later stained with TUNEL kit and observed under the epifluorescent microscope to record the presence of apoptotic cells. This procedure will allow us to obtain information on the health conditions of nauplii and their further development for population recruitment both inside and outside the patch.

### **16.4 POM EXPORT (BIOLOGICAL PUMP EFFICIENCY) DUE TO FAECAL MATERIAL FLUX AND MACROZOOPLANKTON STANDING STOCK**

Classification and enumeration of the faecal material from the neutrally buoyant, free-floating sediment trap samples should give a background to estimate the impact of the zooplankton on both the carbon flux and the possible fate of the phytoplankton bloom.

Collection of faecal pellets from the water column will be conducted using a Multi-net (55  $\mu\text{m}$  mesh size) at five water column strata: 0-50; 50-150; 150-300; 300-500 and 500-1,000 m depth.

The UVP5 will be used to monitor the spatial and temporal distribution of large particles and macrozooplankton (to a maximum depth of 3,000 m depth) during the cruise. The data on particle size spectra will be used to assess the success of aggregation following the bloom and to monitor the subsequent export of particles to the deep ocean. The data on macrozooplankton will be used to estimate their effect on particle transformation while those from sediment traps and nets will allow us to assess the contribution of aggregates of phytoplankton origin and zooplankton faeces to the total stock of large particles.

## 17. SINKING CARBON FLUX (PELAGRA: A NEUTRALLY-BUOYANT SEDIMENT TRAP)

Patrick Martin and Kevin Saw (NOCS)

### Objectives

Although it has been a key aim of iron fertilization experiments to date to measure whether the fertilization leads to removal of additional carbon from the upper ocean, as well as to its sequestration below the winter mixed layer, this measurement has so far proved elusive. This is due in part to insufficient cruise-duration, as well as to methodological problems with the use of sediment traps.

On LOHAFEX, we intend to use neutrally-buoyant sediment traps of the PELAGRA design to measure particle flux throughout the experiment. These traps very significantly reduce the problem of zooplankton 'swimmers' entering the sample cups, as well as virtually eliminating hydrodynamic biases due to their Lagrangian mode of operation. Hence we hope to provide accurate quantitative and qualitative information on the particle flux within the traps' depth range (200 - 900 m). The traps have been deployed successfully on previous cruises, but we are hoping to eliminate gaps in the flux record by staggering the deployments in such a fashion as to achieve continuous sampling of particle flux at two different depths. Given the duration of the cruise, we will thus be able to provide a convincing estimate of the particle flux resulting from the fertilized bloom, as well as to calculate its attenuation with depth. Moreover, aliquots of PELAGRA samples will be given to other scientists on board to conduct a suite of analyses on the composition of the sinking material that can be related to concomitant measurements in the upper ocean.

### Work at sea

Trap dimensions are 2 m height and approximately 1 m diameter, with a weight of 122 kg when fully equipped. They have a 1 m-tall titanium lifting-frame mounted on top, to which a strobe-light and a signal flag are attached to facilitate recovery. The traps are deployed by hooking the lifting-frame to a crane, lifting them over the side of the deck and as far clear of the ship as possible, and lowering them into the water. Similarly, the traps are retrieved by hooking the lifting-frame and then lifting the traps on board with a crane. Once they have dropped their ballast, they are buoyant enough for the lifting frame to protrude completely above the water. Upon surfacing at the end of a deployment, the traps transmit their position via the ARGOS satellite network, and notification e-mails with updated positions are sent to us regularly. Moreover, a Gonio receiver indicates the relative bearing of the traps' radio signal once they are within about 4 km of the ship. Due to the signal flag and the strobe light, the traps can be spotted both by day and by night. Each trap will be deployed for 3- 5 days.

## 18. SEDIMENT GEOCHEMISTRY

Oliver Sachs and Michael Schlüter (AWI)

### Objectives

The AWI geochemistry group will study and compare organic carbon ( $C_{org}$ ) fluxes at the seafloor below and adjacent to the LOHAFEX experimental site. Our contribution is to be seen as the link between the water column investigations and the sea floor: The sea floor as

the final recipient of deep carbon export stands between pelagic production and particle sedimentation on the one hand and the utilization of carbon resources by the benthic fauna on the other side. Therefore we expect to get new insights about the build up, fate and the process of sedimentation in the deep sea of an artificially induced diatom bloom. From the out patch stations we expect the first insights of the seasonal variation and episodic variabilities of benthic  $C_{org}$  fluxes in the SW Atlantic Ocean. From the geochemical point of view we will expand the still small data base of high quality benthic flux measurements in the Southern Ocean. This enables us to improve budget considerations in respect to organic carbon influx to the seafloor as well as the chance to improve transfer functions to correct existing laboratory measurements.

Early diagenetic processes in surface sediments are closely linked to the sedimentation of particulate organic matter. This allows the quantification of organic carbon influx into the sediment surface. For this purpose a free-fall Lander system equipped with an *in-situ* microprofiler will be deployed. Furthermore, the measurement of geochemical microgradients provides a tool to quantify the amount of  $C_{org}$  which was artificially produced and transferred to the seafloor.

Most of the organic carbon arriving at meso- and oligotrophic sediments is remineralized right below the sediment-water interface, consuming dissolved oxygen as a primary electron acceptor. In addition, oxygen functions as a final electron acceptor for anaerobic pathways. Thus, the measurement of the pore-water oxygen distribution provides a suitable tool for the determination of  $C_{org}$  fluxes. Besides the quantification of oxic respiration rates by *in-situ* chambers or laboratory core incubation,  $O_2$  microelectrodes have proven to be an appropriate tool to determine diffusive oxygen fluxes via the measurement of the porewater  $O_2$  depth distribution in very high resolution. In order to avoid sampling and pressure artefacts during core retrieval it is highly desirable to measure  $O_2$  microprofiles *in-situ*, i.e. at the sea floor (e. g. Glud et al., 1994; Sauter et al., 2001).

Only a limited data set, mostly measured *ex-situ*, exists for high latitudes beyond 60° N or S. During ANT-XXI/4 we had the opportunity to measure *in-situ* fluxes two weeks after the end of the European Iron Fertilization Experiment (EIFEX) and at the Polar Front (Sachs, 2008). Up to now, only little is known about the total amount of organic carbon remineralized and fixed within surface sediments of the Southern Ocean.

During LOHAFEX the main focus will therefore be on the *in-situ* measurement of  $O_2$ , pH,  $H_2S$  and porosity microprofiles and a complementing sediment sampling programme from the beginning till the end of the experiment. In addition pore water analysis will provide information about the turnover of biogenic silica and the release of nutrients.

### **Work at sea**

In this study *in-situ* microprofile measurements will be performed by means of an autonomously working microprofiler able to drive microsensors for  $O_2$ , pH, and  $H_2S$  as well as a resistivity probe into the sediment with a minimal vertical resolution of up to 0.1 mm. The profiler can either be mounted into a free falling lander system co-equipped e.g. with a deep-sea still or video camera, an acoustic Doppler velocimeter and / or a water sampler.

*In-situ* measurements will be complemented by *ex-situ* measurements of microprofiles sediment, pore water and bottom water sampling for the determination of other geochemical parameters like TOC, C/N ratio and nutrient profiles. Sediment sampling will be performed by a conventional multicorer.

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## 19. FAHRTTEILNEHMER / PARTICIPANTS

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| Rengarajan            | R.                     | PRL                    | Geochemist                  |
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| Saw                   | Kevin                  | NOCS                   | Engineer                    |

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| Wulf          | Joerg                          | MPI, Bremen                    | Microbiologist               |

## 20. BETEILIGTE INSTITUTE / PARTICIPATING INSTITUTES

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|            |   |
|------------|---|
| NEERI      | National Engineering Research Institute<br>Nehru Marg, Nagpur 440020<br>India   |
| NIO        | National Institute of Oceanography<br>Dona Paula - 403 004, Goa<br>India  |
| NOCS       | National Oceanography Centre, Southampton<br>(NOCS)<br>University of Southampton Waterfront<br>Campus, European Way,<br>Southampton SO14 3ZH<br>UK                        |
| PRL        | Physical Research Laboratory<br>Navrangpura<br>380 009, Ahmedabad<br>India  |
| SZN        | Stazione Zoologica 'A. Dohrn'<br>Villa Comunale<br>80121 - Napoli<br>Italy  |
| UACH-COPAS | Universidad Austral de Chile<br>Independencia 641<br>Valdivia<br>Chile  |
| UPMC-CNRS  | Laboratoire d'Océanologie de Villefranche<br>Université Pierre et Marie Curie, Paris<br>Station Zoologique,<br>Chemin du Lazaret,<br>06234 Villefranche sur mer<br>France |

## 21. SCHIFFSBESATZUNG / SHIP'S CREW

| No. | Name                        | Rank       |
|-----|-----------------------------|------------|
| 1.  | Schwarze, Stefan            | Master     |
| 2.  | Grundmann, Uwe              | 1.Offc.    |
| 3.  | Farysch, Bernd              | Ch. Eng.   |
| 4.  | Peine Lutz                  | 2. Offc.   |
| 5.  | Fallei, Holger              | 2. Offc.   |
| 6.  | Ettlin, Margrith            | 2.Offc.    |
| 7.  | Rudde-Teufel, Claus         | Doctor     |
| 8.  | Hecht, Andreas              | R.Offc.    |
| 9.  | Minzlaff, Hans-Ulrich       | 2.Eng.     |
| 10. | Sümnicht, Stefan            | 2.Eng.     |
| 11. | Schaefer, Marc              | 3.Eng.     |
| 12. | Scholz, Manfred             | Elec.Tech. |
| 13. | Nasis, Ilias                | Electron.  |
| 14. | Verhoeven, Roger            | Electron.  |
| 15. | Muhle, Helmut               | Electron.  |
| 16. | Himmel, Frank               | Electron   |
| 17. | Loidl, Reiner               | Boatsw.    |
| 18. | Reise, Lutz                 | Carpenter  |
| 19. | Guse, Hartmut               | A.B.       |
| 20. | Kreis, Reinhard             | A.B.       |
| 21. | Winkler, Michael            | A.B.       |
| 22. | Vehlow, Ringo               | A.B.       |
| 23. | Hagemann, Manfred           | A.B.       |
| 24. | Schmidt, Uwe                | A.B.       |
| 25. | Bäcker, Andreas             | A.B.       |
| 26. | Wende, Uwe                  | A.B.       |
| 27. | Preußner, Jörg              | Storek.    |
| 28. | NN                          | Mot-man    |
| 29. | Voy, Bernd                  | Mot-man    |
| 30. | Elsner, Klaus               | Mot-man    |
| 31. | Hartmann, Ernst-Uwe         | Mot-man    |
| 32. | Pinske, Lutz                | Mot-man    |
| 33. | Müller-Homburg, Ralf-Dieter | Cook       |
| 34. | Silinski, Frank             | Cooksmate  |
| 35. | Martens, Michael            | Cooksmate  |
| 36. | Jürgens, Monika             | 1.Stwdess  |
| 37. | Wöckener, Martina           | Stwdss/KS  |
| 38. | Czyborra, Bärbel            | 2.Stwdess  |
| 39. | Silinski, Carmen            | 2.Stwdess  |
| 40. | Gaude, Hans-Jürgen          | 2.Steward  |
| 41. | Möller, Wolfgang            | 2.Steward  |
| 42. | Huang, Wu-Mei               | 2.Steward  |
| 43. | Yu, Kwok Yuen               | Laundrym.  |
| 44. | NN                          | Appr.      |
| 45. | NN                          | Appr.      |