

Science highlight from KEOPS (Kerguelen Ocean and Plateau compared Study)

The extreme sensitivity of the carbon export to iron addition in the Southern Ocean revealed by a multidisciplinary study of the Kerguelen bloom.

Stéphane Blain, Laboratoire d'Océanographie et de Biogéochimie, Marseille, France

During January and February 2005, 47 marine scientists embarked on the RV *Marion Dufresne*, to carry out multidisciplinary investigations in one of the largest biological oases of the Southern Ocean: the Kerguelen bloom (Fig. 6). This bloom can easily be observed from satellite. It extends southeast of the archipelago and is clearly delineated by the isobath around 1000m and is present each year from the beginning of November until March.

What are the causes of this massive bloom in an ocean typically characterised by High Nutrient Low Chlorophyll conditions? In the Southern Ocean, similar levels of chlorophyll *a* (1-3 $\mu\text{g L}^{-1}$ Chl *a*) in the surface water have been observed after the deliberate addition of iron during mesoscale iron enrichment experiments (Boyd et al. 2007). Therefore, it is tempting to postulate that the natural addition of iron might be an important factor explaining the occurrence of the bloom around the Kerguelen plateau. The first objective of KEOPS was to address this possibility.

The comparison of the concentrations of dissolved iron in the surface waters within and outside the bloom revealed two important features. In the surface water the concentrations of dissolved Fe were low in both environments. However, below 150 m, a carbon export in the fertilised region was twice that in the HNLC waters. Based on these measurements it was possible to estimate the efficiency of the iron fertilisation, defined as the excess of carbon divided by the excess of dissolved Fe supply. This yielded an efficiency of $70,000 \pm 46,000$ (mol.mol^{-1}). Other independent approaches to determine the carbon export and careful examination of the possible biases lead to the conclusion that the natural iron fertilisation is at least ten times more efficient in sequestering carbon than artificial iron additions (Blain et al. 2007). This discrepancy results both from an underestimate of the carbon export and a

large reservoir of dissolved Fe was only found above the plateau. This resource is made available to the phytoplankton following diapycnal vertical mixing and winter mixing. Another Fe source to satisfy the iron demand by phytoplankton was very likely provided by biologically mediated dissolution of particulate lithogenic iron. Besides the dissolved Fe fluxes, the continuous input of major nutrients sustained the bloom for an exceptionally long period. The second objective of KEOPS was to investigate the impact of natural iron fertilisation on the ecosystem and biogeochemical cycles.

During the cruise, pCO_2 in the surface water was continuously measured by the OISO (Indian Ocean Observation Service) team. The bloom was a large sink for atmospheric CO_2 with most of the carbon fixed by chain-forming diatoms. *Eucampia antarctica* (Fig. 7) was among the key organisms. But how much of the particulate organic carbon was transferred below 200 m?

The impact of iron fertilisation on carbon export is one issue that has not been fully resolved by artificial iron fertilisation experiments. One of the major objectives of KEOPS was to bring new insights to this issue and compare two contrasting regions. The carbon export was derived from $^{234}\text{Thorium}$ deficit measurements that showed

massive loss of the added iron during the meso-scale perturbation experiments. The findings of KEOPS are relevant to paleo-scenarios in which more iron would have been supplied by the Antarctic upwelling during the glacial period. However, the mode of addition of iron above the Kerguelen plateau and the concomitant supply of major nutrients does not correctly represent iron fertilisation by episodic dust deposition. For the same reasons the high efficiency observed during KEOPS cannot be used as an argument to assess that the geo-engineering proposals of large-scale Fe fertilisation for CO_2 mitigation will obtain a high efficiency.

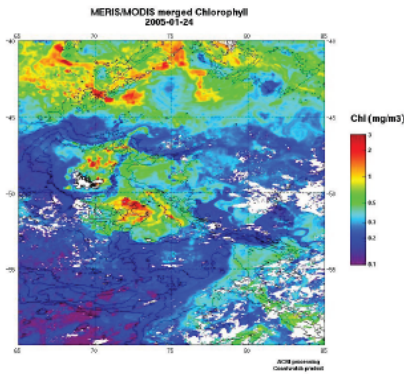


Figure 6. The Kerguelen bloom: a typical satellite image received during the cruise.

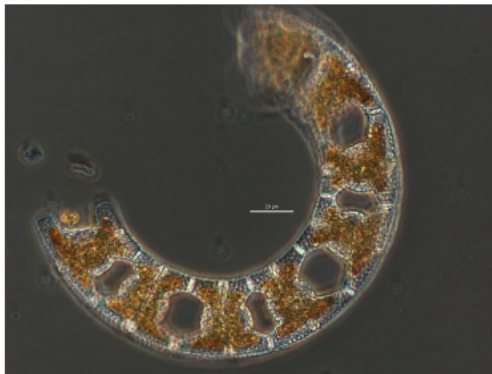


Figure 7. The chain forming *Eucampia antarctica* was one of the dominant species observed within the bloom. (Photo Leanne Armand).

Besides the carbon export issue, KEOPS has revealed other important features of the natural bloom that will be detailed in a special issue of *Deep Sea Research II*.

For example, (i) within the bloom there was a strong decoupling between nitrate and silicic acid cycling; (ii) the diatoms had a high affinity for silicic acid, enabling them to grow when this resource became rare; (iii) in contrast to artificial mesoscale iron fertilisation experiments, the production of DMS was modest during KEOPS. Modelling studies of DMS cycling in the Southern Ocean enable us to reconcile both observations. Besides the classical diatom-copepods food web, a very active population of heterotrophic bacteria was observed and molecular tools have shown that the bloom contained a bacterial diversity distinct from that in HNLC waters.

An impressive amount of new knowledge has been gained. However, KEOPS only provides an exciting snapshot of a complex and fascinating system. The potential of this natural laboratory for new and exciting research is high

References : Blain et al. (2007) *Nature* 446, 1070-1075, Boyd et al. (2007) *Sciences* 315, 612-617.

KEOPS is supported by the Institut National des Sciences de L'Univers (INSU) and the Centre National de la Recherche Scientifique (CNRS), l'Institut Paul Emile Victor (IPEV), French-Australian Science and Technology (FAST), the Australian Commonwealth Cooperative Research Centre program through the Antarctic Climate and Ecosystem CRC and Belgian Science Policy (BELSPO).