The European Commission
Community Research
Energy, Environment and Sustainable Development

Coordination by
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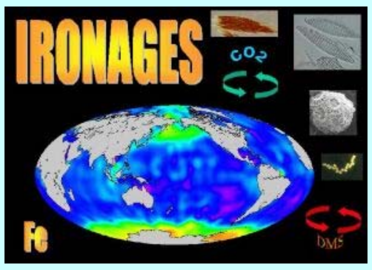
IRONAGES

Iron Resources and Oceanic Nutrients
Advancement of Global Environment Simulations



Objectives

Iron limits productivity in 40% of the oceans, and is a co-limitation in the remaining 60% of surface waters. Moreover the paradigm of a single factor limiting plankton blooms, is presently giving way to co-limitation by light, and the nutrients N, P, Si and Fe (de Baar, 1994; de Baar and Boyd, 2000). Primary production, export into the deep sea, and CO2 uptake together form the atmosphere together form the 'biological pump' in Ocean Biogeochemical Climate Models (OBCM's). Thus far OBCM's assume just one limiting nutrient (P) and one universal phytoplankton species, for deriving C budgets and CO_2 exchange. New realistic OBCM's are developed for budgeting and exchanges of both CO2 and DMS, implementing (i) co-limitation by 4 nutrients of 5 major taxonomic classes of phytoplankton, (ii) DMS(P) pathways, (iii) global iron cycling, (iv) chemical forms of iron and (v) iron supply into surface waters. The new OBCM's will predict realistic climate scenario's, notably climatic feedbacks on oceanic biogeochemistry.

Ironages is a consortium of 12 European institutes. There are eight (8) teams working on 8 TASK themes all contributing to the overall aim. The Inputs of Fe from below (TASK 1) and above (TASK 2) into the oceans were assessed during two cruises IRONAGES-2 (March 2002) and IRONAGES-3 (October 2002) aboard RV Pelagia (Royal NIOZ) in the eastern Atlantic Ocean. The TASK 3 is focusing on the chemical speciation as well as accuracy of Fe in seawater for which an international Fe certification study was done. In TASK 4 the focus is on 2 major DMS-producing algal groups, colony-forming *Phaeocystis* sp. and the calcifying algae where *Emiliania huxleyi* is taken as the model-organism. For each group the life cycle, Fe limitation, limitations by light and major nutrients (N, P) and export production, CO2 uptake and DMS emissions have been synthesized from existing literature and extra laboratory experiments. Moreover in TASK 5 know-how has been synthesized for three other major bloom-forming classes, the diatoms, and N2-fixing diazotrophs where Trichodesmium is taken as the model organism. Within TASK 6 this know-how has been fed into ecosystem modeling, as well as into DMS(P) pathway modeling. The plankton ecosystem model is being developed to predicts the limitation by 4 nutrients (N, P, Si, Fe) of all five algal groups including export and air/sea exchange of both CO2 and DMS. Moreover in TASK 7 attention is given to modeling of the chemical speciation of Fe. Both the plankton ecosystem model and its simplified versions (Task 6) and the iron-modeling (Task 7) are feeding into two OBCM's (TASK 8) being run in France and Germany respectively. The two different OBCM's are verified versus pre-industrial and present conditions.

TASK 1. Iron from below

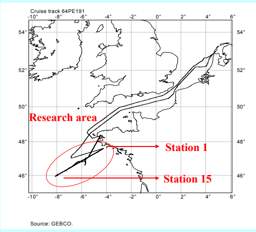


Fig 1-1. Track of IRONAGES-2 cruise (March 2002) with major 2-D section of stations across the shelf break into the deep ocean, situated southwest off Brittany. See below for dissolved Mn at stations 1 and 15.

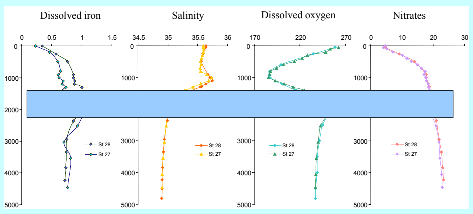


Fig 1-2. Vertical profiles at deep stations 27 and 28 of dissolved Fe, S, O_2 and nitrate. The dissolved Fe has a nutrient type (i.e. nitrate) profile, except from the maximum at 1500-2000 metres being consistent with a Labrador Sea water component. Data by Agathe Laes, Stephane Blain, Patrick Laan, Eric Achterberg, Hein de Baar.

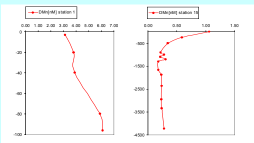


Fig 1-4. High (> 1 nM) dissolved Mn at inshore station 1 is evidence for diagenetic input from reducing sediments. Deep station 15 has typical oceanic scavenging profile for Mn, maxima at 1200-1400m depth consistent with Fe coming off continental margins in righthand Fig 1-3. Data by Patrick Laan and colleagues.

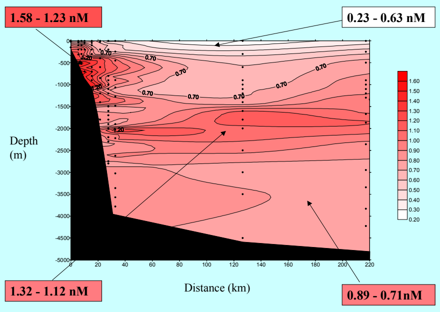
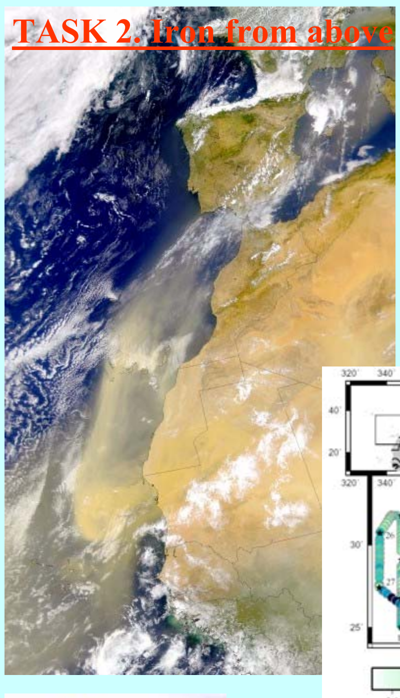


Fig 1-3. Dissolved Fe at 10 stations at the oceanic part of the section with Fe coming off the shelf break, and elevated Fe in core of Labrador Sea signature. Data by Agathe Laes, Stephane Blain, Patrick Laan, Eric Achterberg, Hein de Baar.

TASK 2. Iron from above



The IRONAGES-3 cruise (October 1992) off West Africa was in the region where extensive dust plumes are blown off the Sahara region (left photo). Their imprint on dissolved Fe in surface waters (below Fig 2-1) was sampled while in transit by using the towed torpedo (above photo) with ultraclean tubing feeding into the FI-CL analyzer system. Data by Geraldine Sarthou and colleagues.

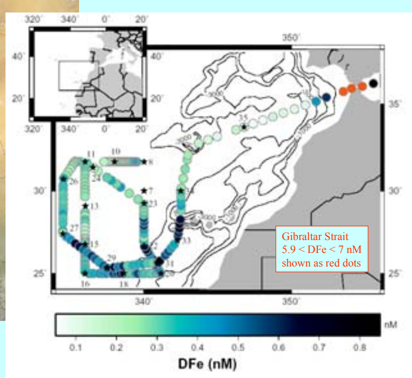
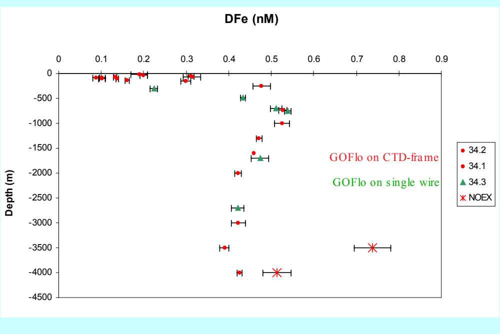


Fig 2-1. Surface water concentrations of dissolved Fe collected underway with above torpedo/pumping assembly. Data by Geraldine Sarthou and colleagues. Range 0.07 to 0.76 nM

Deep-sea winch holding 10,000 metres kevlar wire of 16 mm diameter with internal signal cables. This allows clean sampling for trace metals.



The ultraclean CTD Rosette frame as used with the above clean wire winch. Teflon-coated GoFlo samplers are tripped by air-pressure line controlled via signal cables (see above winch) from the surface ship. Light-gray samplers are NOEX type for routine oceanography.

Fig 2-2. Deep water profile of dissolved Fe collected at stations 34.1. and 34.2 with the kevlar wire deep sea winch and CTD Rosette frame as shown in adjacent photographs. Notice excellent agreement with 6 samples (34.3. green triangles) collected by conventional single GoFlo samplers mounted on nutrient type (nitrate) vertical distribution. This agreement demonstrates feasibility of ultraclean sampling for metals with multibottle frame towards GEOSECS II initiative for mapping metals in the deep oceans. (N.B. The two samples of regular but pre-cleaned NOEX bottles yield too high values, albeit still subnanomolar).

TASK 3. Fe availability and certification

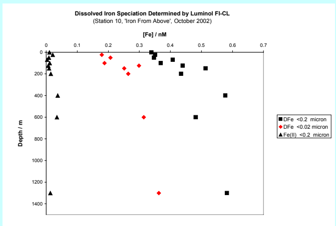


Fig 3-1. Availability of Fe is related to its physical and chemical speciation in seawater. Seawater collected at station 10 of IRONAGES-3 cruise (see also TASK 2) was filtered using 0.2 and 0.02 micron poresize membranes. The total 0.2 micron filtered pool (filled squares) has a nutrient type profile, of which only a small portion (filled triangles) is in the reduced Fe(II) state. About half of the 'dissolved Fe is in fact in the very fine 'colloidal' range between 0.02 and 0.2 micron, the other half (red diamonds) is smaller than 0.01 micron. Analysis by FI-Cl by Ussher, Achterberg, Worsfold and colleagues.

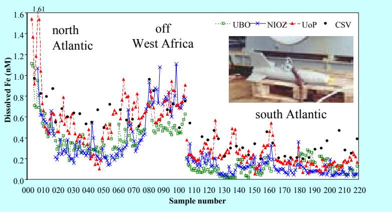
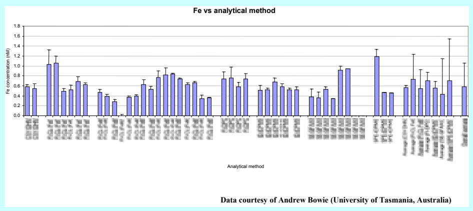


Fig 3-2. An international excercise for development of a certified standard of Fe in seawater started with sample collection during cruise IRONAGES-1 aboard RV Polarstern. While in transit from Europe around West Africa to Capetown (South Africa) the torpedo/pumpline was towed adjacent to the ship. The filtered seawater was analyzed by four different analists using three different methods leading to overall good agreement.

Data by Stephane Blain, Geraldine Sarthou, Eric Achterberg, Andy Bowie, Peter Croot, Patrick Laan

Fig 3-3. Within the south Atlantic the ambient dissolved Fe (<0.3 nM) was deemed low enough to fill a one cubic metre vessel via the torpedo pumpline and a cartridge filter. Upon acidication the water was distributed over 200 bottles of 1 ltr each. The dissolved Fe was anlyzed by 26 laboratories submitting their values to independent chair Jim Moffett (WHOI).



This first international Fe certification excercise was co-sponsored by IRONAGES (EU), the US National Science Foundation and SCOR.

TASK 4. Producers of DMS(P)

Species group	DMSP:C (mol:mol)
Nitrogen-fixers	0
Picoplankton	0 - 0.02
Diatoms	0.0018
Emiliania huxleyi	0.015
Phaeocystis sp.	0.02

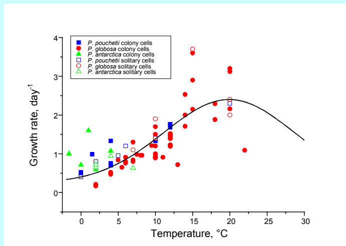
The two groups *Phaeocystis* sp. and *Emiliania huxleyi* are the major producers of DMSP, hence under suitable conditions of the ecosystem leading to DMS emissions. Adjacent table is extracted from a synthesis manuscript by Jacqueline Stefels and co-workers

One of the IRONAGES tasks is to include the production of the climate active gas dimethyl sulphide (DMS) in Global Ocean Models. DMS is the enzymatic cleavage product of a compound produced by algae: DMSP. The ultimate concentration of DMS in the water that drives the flux to the atmosphere, is the result of a multitude of biological processes. This means that the ecosystem structure is of vital importance. One of the factors that affect the DMS-production most is the species related production of the precursor DMSP. In order to include in models the specific production of DMSP of the five functional groups defined within IRONAGES, we recalculated literature data to arrive at ratios of DMSP:Carbon (Table xx)

4.1. Phaeocystis sp.

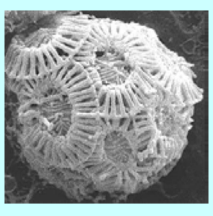
Fig 4-1. The synthesis of published data on *Phaeocystis* spp suggests that it is possible to derive unique relations for describing bottom-up controls of *Phaeocystis* growth without consideration of species and location. One example is given by the temperature-dependence of the maximum growth rates described by the equation below :

$$\mu = \mu_{max} * [0.1 + 0.9 * EXP [(-T - T_{opt})^2 / dT^2]$$



After *Phaeocystis* synthesis article by Veronique Schoemann, Christiane Lancelot and colleagues.

4.2. Emiliania huxleyi



Emiliania huxleyi with coccolith platelets excreted after internal calcification.

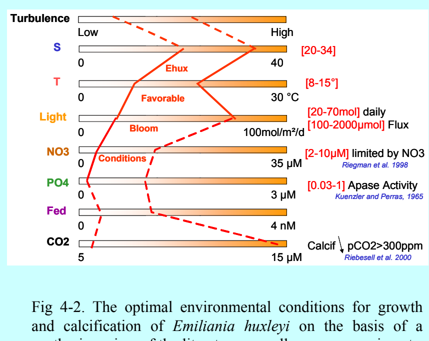
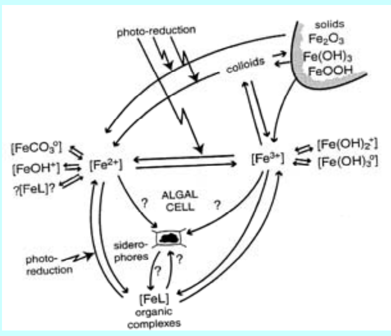


Fig 4-2. The optimal environmental conditions for growth and calcification of *Emiliania huxleyi* on the basis of a synthesis review of the literature as well as own experiments. Manuscript by Briac LeVu and Diana Ruiz-Pino.

7. Iron modeling

Fig 7-1.
Scheme of the different chemical forms of Fe in seawater and their conversions. These are being modeled both with regards to equilibria and kinetics, notably with respect to the rate of uptake of a given chemical species into the plankton cell.



TASK 5. Diatoms, N2-fixers, Picoplankton

5.1. Diatoms

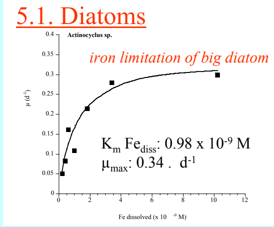
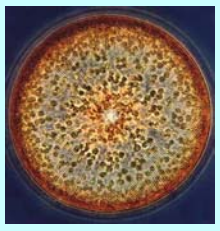


Fig 5-1 Growth curve after Monod for the very large diatom Actinocyclus sp. (see below) grown in pristine natural seawater (without EDTA) by Klaas Timmermans.



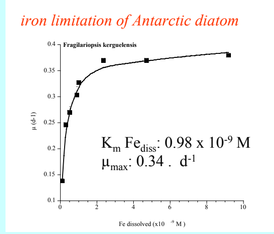
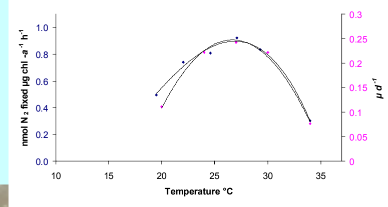


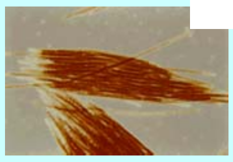
Fig 5-2 Iron limitation growth curve after Monod for the very robust Antarctic diatom *Fragilariopsis kerguelensis* by Klaas Timmermans. Photo shows single cells of this pennate diatom, which in Polar Front blooms can be found in long chains consisting of up to 50-60 cells.

Existing knowledge of limitations and growth of all diatoms has been synthesized in a manuscript 'Importance of diatoms in the biological pump of CO_2 in the ocean' by Geraldine Sarthou, Klaas Timmermans, Stephane Blain and Paul Treguer.

5.2. Nitrogen fixing species

Fig 5-3. The rate of nitrogen fixation and the specific growth rate of an axenic culture Trichodesmium IMS-101, which were assessed as function of temperature.



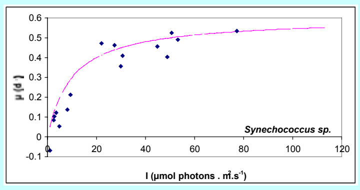


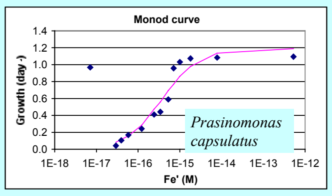
Trichodesmium is one of the most important nitrogen fixers in the oceans. Field observations suggest Trichodesmium is limited to temperatures above 20 degree C. This first experimental study of the temperature trends for Trichodesmium was done by Eike Breitbarth and Julie La Roche.

Synthesis manuscript on *Trichodesmium* limitations and ecology by the same authors

5.3. Picoplankton

Fig 5-4. Growth versus irradiance curve for light limitation of below Synechococcus sp. by Marcel Veldhuis and Klaas Timmermans and





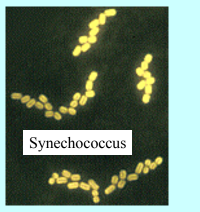


Fig 5-5. Growth limitation curves of two picoplankton species versus availability of Fe' in seawater. In the pristine (EDTA-free) seawater limitation was achieved by addition of minute quantities of the siderophore DFB. Data by Klaas Timmermans and Marcel Veldhuis.

6. Plankton Ecosystem Modeling

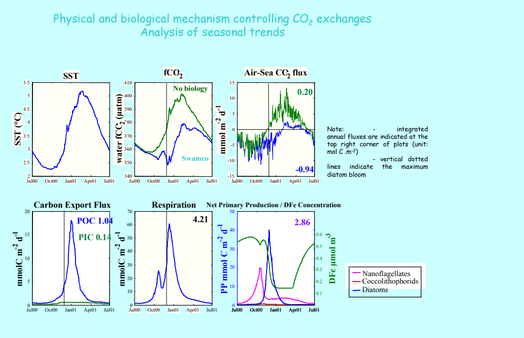


Fig 6-1. The SWAMCO model includes all trophic levels in the plankton ecosystem and has already been applied successfully for two phytoplankton groups (diatoms and pico-nano-plankton in the Southern Ocean (Lancelot et al., 2000; Hannon etal., 2001). Here shown are runs with the model extended with *E. huxleyi* for the KERFIX site at Kerguelen region. Further extensions with Phaeocystis sp. and Nitrogen fixers are being developed on basis of know-how within above TASKS 4. and 5. Christiane Lancelot, Benedict Pasquer, Veronique Schoemann.

8. Ocean Biogeochemical Climate Modeling

Fig 8-1. Section plot of the western Atlantic basin following the classical GEOSECS transect. Shown are the dissolved Fe concentrations throughout the water column as derived from the Hamburg ocean model of Ernst Maier-Reimer, Katherina Six and colleagues.