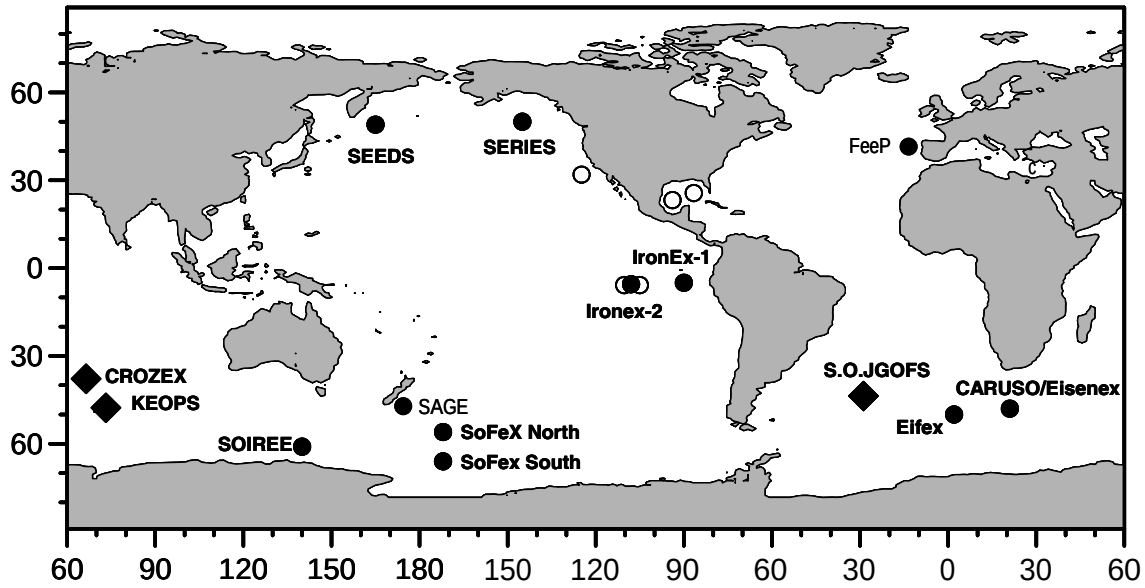
Proposal for a SCOR Working Group

# The Legacy of *in situ* Iron Enrichments: Data Compilation and Modeling

## Introduction

From 1993 onwards there have been 10 *in situ* iron fertilization experiments, from Ironex-1 (1993) to SEEDS-2 (2004), as well as 3 natural fertilization studies (1992 Southern Ocean JGOFS, 2004-2005 Crozex, 2005 KEOPS). Primary results of individual experiments have been reported in *Nature* and *Science* as well as in oceanography journals, sometimes in special issues of journals like *Deep-Sea Research II* and *Progress in Oceanography*. For the most recent experiments (e.g. Eifex 2004, SEEDS-2, CROZEX, KEOPS) several articles have either been published or are accepted for publication.

Synthesis of the combined experiments has only just now started with one first semi-quantitative effort by multiple authors (*de Baar et al., 2005*) focusing on only the most basic variables (i.e., primary production, major nutrients, $CO_2$ system variables) of the then-available 8 experiments. This is seen as the modest first step towards more rigorous quantitative assessment by ecosystem simulation modeling of these unique time-series experiments. Nevertheless, several remarkable trends are becoming apparent from the combination of experiments. For example, light limitation due to depth of the wind-mixed layer was highly significant, and the major floristic response was always by larger size class diatoms, with almost universal flourishing of *Pseudonitzschia* sp. Unfortunately, during this first synthesis effort it was found that integrated datasets of even the earlier single experiments of the 1993-2000 period hardly existed, with one laudable exception (SOIREE, data CD in 2001 *DSR-II* special issue). At most, the individual scientists had their own data files which were kindly and generously made available. Sometimes fundamental data (e.g., hydrography, incoming sunlight or PAR) could hardly be traced; some other data of interest could not be located in time vis-à-vis the publication time frame of the synthesis article.




The *in situ* fertilization experiments (filled dots) and natural fertilization studies (filled diamonds) thus far: S.O.JGOFS (1992), IronEx-1 (1993), IronEx-2 (1995), SOIREE (1999), CARUSO/EisenEx (2000), SEEDS-1 (2001), SOFeX-North (2002), SOFeX-South (2002), SERIES (2002), EIFEX (2004), SAGE (2004), FEEP (2004), SEEDS-2 (2004), CROZEX (2004/2005), KEOPS (2005). Cyclops (C in East Mediterranean) P fertilization, FeCycle (not shown) and various pilot experiments (open circles) are beyond scope of this WG proposal (map after *deBaar etal., 2005*)

In addition to this synthesis of basic variables of the first 8 experiments, there have been some recent articles combining 2-3 experiments for specific topics, that is, $CO_2$ budgeting (*Bakker et al. 2005*) and DMS(P) processes (*Turner et al., 2004*).

A special synthesis workshop (FeAX) was held in Wellington (New Zealand) in November 2005 under the aegis of SOLAS. The insights gained during that workshop have been reported in a recent multi-authored article in *Nature* (*Boyd et al., 2007*). At this meeting it was unanimously agreed by all participants that a special effort should be developed towards establishing a common open-access database of the *in situ* iron enrichment experiments. From this unanimous agreement follows this proposal for a SCOR WG. Success of this group could provide a model for data synthesis within SOLAS, IMBER, and other projects.

Rationale

The iron enrichment experiments have been done at great expenditure of scientists' time, research vessel time, and other costs. Thus overall, taxpayers of various nations worldwide have invested heavily in these experiments. Yet apart from the typical first round of articles on any single experiment, this investment has not led to an international resource or heritage. The already collected but thus far widely scattered data, once brought together, would be extremely valuable for various reasons:

- the ocean science community needs to fully exploit the results of preceding *in situ* experiments before proposing and implementing the next generation of experiments. In other words, there is no credibility to continue asking taxpayers to subsidize one experiment after another in the future, unless the ocean science community first fully exploits the investments of the past decade. Full use of existing data may yield insights to help design future experiments.
- properly compiled datasets of both natural and *in situ* iron fertilizations will allow the application of 'generic' simulation modeling, thus yielding insights and model robustness far beyond what is feasible by simulating just one experiment.
- the value of the experiments is far beyond the 'iron issue'. For example, the experiences and findings of labeling ($SF_6$ and sometimes $^3H$ as well) and following a patch of water are most valuable for designing future 'lagrangian' experiments for a wide variety of purposes. If nothing else, the dispersion of the added tracer(s) is a powerful tool for quantifying lateral and vertical mixing in the surface oceans. Moreover, the practical ability to follow a surface water mass or 'patch' over periods of weeks to months allows a wide range of topical biogeochemistry studies.

Objectives

The objectives of the proposed working group are twofold:

1. Data compilation. Assembling a common open-access database of the *in situ* iron experiments, beginning with the first period (1993-2002; Ironex-1, Ironex-2, SOIREE, EisenEx, SEEDS-1; SOFeX, SERIES) where primary articles have already been published, to be followed by the 2004 experiments where primary articles are now in progress (EIFEX, SEEDS-2; SAGE, FeeP). Similarly for the natural fertilizations S.O. JGOFS (1992), CROZEX (2004/2005) and KEOPS (2005).

2. Modeling and data synthesis of specific aspects of two or more such experiments for various topics, such as physical mixing, phytoplankton productivity, overall ecosystem functioning, iron chemistry, $CO_2$ budgeting, nutrient uptake ratios, DMS(P) processes, and combinations of these variables and processes.

*1. Data compilation*

An international Working Group under the aegis of SCOR and with full endorsements by SCAR, SOLAS, IMBER is deemed essential for success in compiling all the appropriate databases. At the planning stages of each experiment, mutual access of data is commonly agreed and most funding agencies require the data to enter the public domain within 24-36 months after completion of the granted project. Nevertheless, in practice, compilations beyond individual investigators rarely occur, for a variety of reasons:

- Projects tend to be under-funded, often subject to budget cuts before granting, and the originally intended data management often is quietly sacrificed.
- At the level of the individual scientist only the most essential data are rapidly picked out for publication of articles, and an individual dataset often is not even compiled. Scientists are under considerable time pressure for publishing scientific articles and applying for future research funding. As a result the data management and submission to a central database too often is neglected.
- Some types of data can be produced relatively rapidly, and are sometimes already available at the end of the cruise, while other types of data require much painstaking labor afterwards in the home laboratory. Physical oceanography data tend to become available for the community at large within 2-3 months, but marine chemists and biologists seem to be far slower in data dissemination.

In summary, our marine science community at the onset of each new project has been intending data management and eventual open access, yet for various reasons in the end this has rarely been accomplished. This proposal aims to remedy this situation for the *in situ* iron enrichment experiments and natural fertilization studies, which may also serve to improve data practice of other, future ocean experiments.

An international Working Group will be able to set the example (i) for readily making available data, first to colleagues of the given experiment and next to the open access database, (ii) for proper recognition of the original scientist, (iii) for spreading the good practice of fast data dissimination in one discipline to other disciplines with a slower culture for data dissemination, and (iv) for re-assuring hesitant scientists about protection of their interests as the original data producer.

*2. Modeling and data synthesis*

Simulation models pivoting around phytoplankton ecology have thus far been performed independently for SOIREE (Hannon et al., 2001), IronEx (Chai et al., 2002), SEEDS-1 (Yoshie et al., 2005), SERIES (Takeda et al., 2005; Denman et al., in press), and comparison of Ironex-SOIREE-SEEDS (Fujii et al., 2005; Fujii and Chai, submitted). Moreover, there exists a refined simulation model on DMS(P) of SERIES (LeClainche et al., 2006). For physical mixing versus dispersion of $SF_6$ tracer, efforts are being made by Goldson, Law and others. Implications for Ocean Biogeochemical Climate Models (OBCMs) including full ocean circulation and cycling of trace element iron are being pursued by Follows, Sarmiento and others. In general within each class of models, that is, plankton models, mixing models, OBCMs, the individual models vary widely in design and objectives, and much can be learned by comparison between such models.

The Working Group will in a suite of 2-3 workshops bring together these modelers and key experimentalists to encourage data synthesis, compare models, define common standard scenarios for validation and, in general, make available the compiled datasets (objective 1) to the wider scientific community.

Terms of Reference

Within the proposed 4-year period of existence, the WG plans to achieve the below objectives. Work on the first objective is already underway for several of the experiments, yet on the other hand this first objective is also essential before the next objectives 2, 3, and 4. can be realized. Therefore, we propose approval and implementation of the WG in two steps. In the first step, the WG would be formed and would be funded to work on only the first Term of Reference. Once this is realized and approved by SCOR, the remaining second part of the usual WG funding would be approved by SCOR and allocated towards realization of the remaining objectives 2. and 3. and 4. Thus, the corresponding four Terms of Reference would be as follows:

1. Compilation of a database for open access (via the Internet) of the following experiments:
   1.1. the 1999-2001 era (IronEx-1, IronEx-2, SOIREE, EisenEx, SEEDS-1), plus 1992 S.O. JGOFS
   1.2. the 2002 experiments (SOFeX-North, SOFeX-South, SERIES)
   1.3. the 2004 experiments (Eifex, SEEDS-2, SAGE, FeeP), plus natural fertilizations CROZEX, KEOPS

This effort will include a commonly agreed data policy for users to best acknowledge the original data producers (e.g., by offering co-authorship and perhaps assignment of digital object identifiers for individual data sets). Obviously, a practical description of methods used, calibration etc. (so-called metadata) will also be included. In essence, the WG members are committed to send their data files to the common data centre, and encourage their colleagues in any given experiment to do the same. Finally, an official data publication or publication(s) will be placed in a suitable venue, for example, in the special issue on the SCOR WG (see item 4. below) and in *Eos* (Transactions Am. Geophys. Union). In 2006-2007 efforts are already underway for compilation and rescue of the EisenEx dataset, also there is very good progress for SEEDS-2, SERIES, CROZEX and KEOPS. However, the statement in the original proposal that no meeting would be necessary to achieve the first term of reference was overly optimistic. It appears that a face-to-face meeting sponsored by SCOR or some other internationally recognized organization is necessary to work out the details of bringing together the data sets in a way that will make it possible to achieve the other terms of reference.

2. Organization of 2-3 workshops where simulation modelers and key scientists of the experiments will meet. These workshops will be publicized in advance (SCOR website, other websites and newsletters) to allow colleagues beyond the actual WG membership to express interest in participation. Colleagues from developing nations will actively be encouraged to attend.

3. Organization of 2-3 special sessions at international marine science conferences will encourage a broad participation from scientists not yet involved in the activity.

4. Publication of new synthesis papers based on data comparison, a suite of simulation modeling articles, as well as the common database (i.e., its brief description) in a special issue of an oceanographic journal, as well as a multi-authored paper with recommendations for the next generation of *in situ* experiments and other types of process studies. The latter will include guidelines and advice on standardization of measurement protocols, as well as best procedures to ascertain timely submission of experimental data to a common database.

Optional. Beyond the above 4 terms of reference to be accomplished, the WG may organize or contribute to a training and education activity, for example, a summer school.

Data Management

The EUR-OCEANS Network of Excellence comprises a Data Integration and Networked Database task force with major objectives: (1) to rescue relevant historical datasets, (2) to organise long-term archiving of scientific information, (3) to develop an electronic portal for online access and dissemination. Dr. Nicolas Dittert, as head of this task force, will also be Full Member of the proposed SCOR WG, and relies on the permanent data centres World Data Centre-MARE (Bremen) and PANGAEA (AWI, Bremerhaven) for implementation of the above Terms of Reference number 1. The WDC-MARE is within the WDC Network linked with the relevant data centres in North America (e.g., CDIAC at Oak Ridge), Asia and other regions. The World Data Centres will also ensure long-term data storage.

Working Group Membership

Full and associate membership aims for a good mix of junior and senior scientists in both categories, where senior colleagues are urged to pursue own funds for workshop participation, thus allowing optimal allocation of the WG budget to participation of junior scientists.

Membership includes a mixture of pivotal leaders of the experiments, as well as scientists from the range of disciplines, as well as various modelers. In accordance with SCOR requirements, the Working Group consists of 10 Full Members. An extensive group of Associate Members will be sought in order to ensure the necessary additional expertise, as well as representation from the various *in situ* experiments, natural experiments, and simulation modeling. Both for Full Members and Associate Members, appropriate representation of both gender and developing country scientists is achieved. Several more excellent scientists are envisioned to contribute datasets and/or modeling expertise via liaison with the Full and Associate Members, and workshops will be open to draw in a broad involvement. Below is a suite of names of Liaison Scientists, to which more names will be added in due course.

| **Name** | **Major Relevant Expertise** | **Experiment(s)** | **Nation** |
|---|---|---|---|
| ***Co-chairs:*** | | | |
| Bakker, Dorothee | $CO_2$ system | S.O.JGOFS, SOIREE, EisenEx, CROZEX | UK |
| Boyd, Philip | plankton ecology | SOIREE, SERIES | New Zealand |
| ***Other Full Members:*** | | | |
| Bathmann, Uli | polar mesozooplankton | S.O. JGOFS, EisenEx, Eifex | Germany |
| Coale, Kenneth | iron-biota experiments | Ironex-1&2, SOFeX | USA |
| De Baar, Hein | iron and $CO_2$, Geotraces | S.O.JGOFS, EisenEx | Netherlands |
| Dittert, Nicolas | data management | EUR-OCEANS and WDC-MARE | European Union |
| Minhan Dai | ocean cycling of carbon and metals | GEOTRACES | China |
| Levasseur, Maurice | DMS(P) and plankton | SEEDS-2, SERIES | Canada |
| Takeda, Shigenobu | iron chemistry & biology | SEEDS-1&2, SERIES | Japan |
| Pollard, Raymond | physical oceanography | CROZEX | UK |
| ***Associate Members:*** | | | |
| Assmy, Philip | diatom responses | EisenEx, Eifex | Germany |
| Blain, Stephane | iron biogeochemistry | KEOPS | France |
| Buesseler, Ken | export production | IronEx, SOFeX | USA |
| Croot, Peter | iron chemistry | Eisenex, SOFeX, Eifex | Germany |
| Denman, Ken | modeling | SERIES | Canada |

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|---|---|---|---|
| Goldson, Laura | tracer dispersion & mixing | EisenEx, SOFeX | UK |
| Follows, Mick | various modeling including OBCMs | | USA |
| Fujii, Masahiko | simulation modeling | SEEDS-1&2, SERIES | Japan |
| Hong, Huasheng | ocean biogeochemistry | | China |
| Kozyr, Alex | ocean $CO_2$ data management | CDIAC, Oak Ridge | USA |
| Law, Cliff | tracer dispersion & mixing | SOIREE, SERIES | New Zealand |
| Marchetti, Adrian | diatom responses | SERIES | Canada |
| Nishioka, Jun | iron physical chemistry | EisenEx, SEEDS-1&2, SERIES | Japan |
| Rijkenberg, Micha | iron photoredox chemistry | SOIREE, EisenEx | UK |
| RutgersVanDerLoeff, Michiel | export production | GEOTRACES, S.O. JGOFS, EisenEx | Germany |
| Schoemann, Veronique | iron-phytoplankton, *Phaeocystis* | | Belgium |
| Strass, Volker | polar physical oceanography | EisenEx, Eifex | Germany |
| Tsuda, Atsushi | zooplankton ecology | SEEDS-1&2, SERIES | Japan |
| Tung, Yuan-Ho | marine chemistry and ecology | | Taiwan |
| Turner, Sue | DMS(P) cycles | IronEx, SOIREE, EisenEx | UK |
| Timmermans, Klaas | iron-diatom interactions | EisenEx, KEOPS | The Netherlands |
| Twining, Benjamin | intracellular iron | SOFeX | USA |
| Watson, Andy | $CO_2$ system, tracer dispersion | IroneEx I, SOIREE, EisenEx | UK |
| Wingenter, O. | rarely studied trace gases | SOFeX | USA |
| Wang, Wen-Xiong | trace elements uptake and transfer in phyto-zooplankton | | China |
| Zhong, Shaojun | GEOTRACES Standards and Intercalibration task team | | China |

***Liaison Scientist:***

(*Liaison Scientists will be informed about and invited to all activities, they will submit datasets and/or are involved as simulation modeling experts. The below names merely are the beginning of a growing list of enthusiastic colleagues, each with excellent scientific credentials)*

| | | | |
|---|---|---|---|
| Gnanadesikan, Anand | ocean modeling including OBCM's, iron cycle | | USA |
| Le Clainche, Yvonnick | ecosystem DMS(P) modeling | SERIES | Canada |
| Nightingale, Philip | tracer dispersion, air/sea | IronEx, EisenEx | UK |
| Rivkin, Richard | bacterial responses | SERIES | Canada |
| Sanders, Richard | carbon export | CROZEX | UK |
| Sarmiento, Jorge | ocean modeling including OBCM's, iron cycle | | USA |
| Savoye, Nicolas | export production | Eifex | France |
| Vezina, Alain | ecosystem inverse modeling, DMS(P) | | Canada |

Endorsements and Financial Support and Budget

This SCOR Working Group proposal has been endorsed by SCAR in its July 2006 meeting at Hobart, and by the Scientific Steering Committees of SCOR-IGBP-SOLAS, SCOR-IGBP-IMBER, and SCOR-GEOTRACES. These endorsements are of primary importance for fostering the constructive, collaborative spirit essential to meet the terms of reference. Copies of endorsement letters/documents are

available on request. Nevertheless, SCOR is envisioned to take primary responsibility and accountability for the proposed working group.

The standard budget for a SCOR WG would allow organization of 3 workshops for 10-12 Full Members at a cost of US $ 15000 per workshop, i.e. in the order of US $ 45000 in total. The first installment of the subsidy would be allocated for the first workshop aiming primarily at the first Term of Reference.

Other participants would finance their travel costs from their own sources. Nevertheless additional finances may well be realized towards supporting Associate members, as well as financing other costs such as data management expenses or publication costs. We envision considering video-conferencing as another approach in order to save travel time and expenses as well as to avoid $CO_2$ emissions. Once this initiative is approved and established as a SCOR Working Group, we hope that national agencies (and the European Union) will be more convinced that their contributions are justified. These may range from a travel grant of one scientist of such nation, to hosting one of the workshops. For example Dr. Minhan Dai (China) and Prof. De Baar (The Netherlands) are confident in being able to raise national support for hosting one workshop in their country.

References of overview articles each containing many more references

Boyd,P., T.Jickells, C.Law, S.Blain, E.Boyle, K.Buesseler, K.Coale, J.Cullen, H.deBaar, M.Follows, M.Harvey, C.Lancelot, M.Levasseur, R.Pollard, R.Rivkin, J.Sarmiento, V.Schoemann, V.Smetacek, S.Takeda, A.Tsuda, S.Turner, A.Watson (2007) Mesoscale iron-enrichment experiments 1993-2005: synthesis and future directions. Science,315,612-617.

De Baar, H.J.W., P.W. Boyd, Kenneth H. Coale, Michael R. Landry, Atsuhsi Tsuda, Philip Assmy, D.C.E. Bakker, Y. Bozec, R.T. Barber, M.A. Brzezinski, K.O. Buesseler, M. Boyé, P. L. Croot, F. Gervais, M.Y. Gorbunov, P. J. Harrison, W.T. Hiscock, P. Laan, C. Lancelot, C. Law, M. Levasseur, A. Marchetti, F. J. Millero, J. Nishioka, Y. Nojiri, T. van Oijen, U. Riebesell, M.J.A. Rijkenberg, H. Saito, S. Takeda, K.R. Timmermans, M. J.W. Veldhuis, A. Waite and C.S. Wong (2005) Synthesis of Iron Fertilization Experiments: From the Iron Age in the Age of Enlightenment. In: Orr, J. C., S. Pantoja, and H.-O. Pörtner (eds.) The Oceans in High $CO_2$ World, Special Issue of *J. Geophys. Res. (Oceans)*, *110*, C09S16, doi:10.1029/2004JC002601, pp 1-24.

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Recent relevant article on the natural Fe fertilization study KEOPS:

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