Workshop on SEEDS-II

By Atsushi Tsuda, Shigenobu Takeda, Mitsuo Uematsu, Mark L. Wells and Maurice Levasseur

A workshop on SEEDS-II (**S**ubarctic Pacific Iron **E**xperiment for **E**cosystem **D**ynamics **S**tudy II) was held from October 17-18, 2005, at the Ocean Research Institute, University of Tokyo. In attendance were scientists from Canada, Japan, New Zealand and the United States of America (see photo below). There were 7 keynote talks and 13 posters presented, followed by working group discussions aimed at synthesizing these findings. The SEEDS-II expedition was conducted in the western subarctic Pacific in the summer of 2004, following the successful SEEDS-I expedition done in these same waters in the summer of 2001. The earlier experiment generated a massive centric diatom bloom that caused a larger drawdown of macro-nutrients and pCO_2 than any iron-enrichment experiment done in the world's oceans to date (Tsuda *et al*., 2003; de Baar *et al*., 2005). However, the fate of the carbon assimilated into phytoplankton during SEEDS-I could not be determined because of the short observation period (13 days). SEEDS-II employed two research vessels, the R/V *Hakuho-Maru* and R/V *Kilo Moana*, and was designed to measure how the fertilized patch would evolve over a longer time scale (1 month) and with a greater range of parameters than used during SEEDS-I.

The major goals of SEEDS II were: 1) to observe the initiation, development and decline of the iron-induced diatom bloom and elucidate the fate of fixed carbon; 2) to measure additional parameters to determine the overall biogeochemical responses to iron enrichment; 3) to determine the influence of iron on trace gas production and aerosol formation; and 4) to measure gas fluxes from ocean surface to atmosphere.

The number of participants in the second experiment was much higher than in SEEDS-I. We added the same amount of iron into the same locality at the same season, and expected a big diatom bloom. The preliminary results from SEEDS-II showed both the iron-induced increase and subsequent decline in phytoplankton biomass. However, the iron-initiated bloom was much less intense than observed in SEEDS-I. Chlorophyll-*a* concentration increased only 2 to 3 times over the initial values, and the drawdown of nutrients and pCO_2 were small. The aim of the SEEDS-II Workshop was to provide a forum for exchanging scientific information and expertise to better understand the underlying cause for the dramatically different chemical and biological responses observed in the experiment. The workshop main themes were:

- To synthesize the key biological findings of SEEDS-II;
- To elucidate the changes in iron biogeochemistry;
- To determine the effect of iron addition on the production of trace gases; and
- To compare the biogeochemical changes associated with SEEDS-I and SEEDS-II.

In the keynote talks, preliminary results were summarized for patch dynamics (D. Tsumune), iron chemistry (J. Nishioka), biological responses (H. Saito), carbon and nitrogen budgets (I. Kudo), onboard incubation experiments (W. Cochlan), DMS (dimethylsulfide) dynamics (M. Levasseur and I. Nagao), and atmospheric chemistry (M. Uematsu). In addition, a summary talk was presented on SAGE (**S**OLAS **A**ir-Sea **G**as **E**xperiment), an iron-enrichment experiment in the sub-Antarctic Ocean whose results had similarities with the SEEDS-II findings. After the poster presentations that followed, 3 discussion

SEEDS-II workshop participants.

groups were formed: (1) *Iron and trace metal chemistry* (chaired by S. Takeda), (2) *Biological responses and budgets* (chaired by H. Saito) and (3) *DMS and atmospheric chemistry* (chaired by M. Uematsu).

The *Iron and trace metal chemistry* group focused on determining the fate and behaviour of iron during SEEDS-II. The observed changes in total and dissolved iron concentrations as well as its chemical speciation, indicate that diatoms would have had more difficulty acquiring iron during SEEDS-II than was the case in SEEDS-I. During SEEDS-I, the shallower mixed layer, higher added iron concentrations, more photoreduction, and less dilution of the patch with seawater containing free Fe(III) complexing ligands, all would have combined to increase the biological availability of iron and stimulate diatom growth. In contrast, lower added iron concentrations and greater dilution of the patch by vertical and horizontal mixing during SEEDS-II worked against increasing the iron supply to diatoms. However, the heterogeneous horizontal distribution of iron will make it very hard to construct a quantitative iron budget for SEEDS-II. The workshop participants chose the following key questions (Q) for elucidating the changes in iron biogeochemistry during SEEDS-II:

Q1: What is the reason that the actual concentrations of iron in surface waters after the first infusion was less than target concentration?

Q2: What is the dilution rate of iron in the patch during SEEDS-II? How does it compare with the dilution rate of patch during SEEDS-I?

Q3: Do ADCP data support movement of the surface mixed layer relative to the deeper water?

Q4: Did the expected loss in chemical reactivity of colloidal and particulate Fe(III) oxyhydroxides affect the analytical measurement of iron?

Q5: What are the differences in the light conditions at the time of infusion between SEEDS-I and SEEDS-II (photochemical effects on iron speciation)?

Q6: How did the concentrations of other trace metals change during the patch evolution?

Q7: Is there a difference in the conditional stability constant for iron between <200 kDa and 200 kDa – 0.2 µm size fractions?

The *Biological responses and budgets* group tabulated the system response chronically, including the changes in iron concentration, chlorophyll, phytoplankton physiology, zooplankton and bacteria, before turning their attention to the causes of the weak biological response to iron addition in SEEDS-II. In SAGE, 5 factors have been suggested (micronutrients, silicate, grazing, seed population, light limitation, dilution of the patch). The similarities and dissimilarities in the initial *in-situ* conditions for SEEDS-I and SEEDS-II were compared and contrasted. The differences included mixed layer depth, seed population of diatom, zooplankton biomass and dilution of the patch. The discussion finished after considering the budget calculation for the patch.

Workshop in session.

Young Japanese SEEDS-II workshop participants.

The *DMS and atmospheric chemistry* group discussed data exchange and comparison among the collaborating groups. Preliminary data (DMS, DMSPp, NMHCs, N_2O, CH_4, CO, CH_3Cl, CH_3Br, CH_3I, CH_2Cl_2, CH_2ClI, Isoprene and DMDS) from analysis of seawater samples (Nagoya University, University of Shizuoka, Hokkaido University, and Laval University) were listed, and differences in surface water concentrations and vertical profiles between IN and OUT patches over time were discussed. These data revealed pronounced changes in some parameters with time in the IN patch samples. However, careful determinations are still required before any final conclusions can be made. Atmospheric sampling (Nagoya University and Tokyo Metropolitan University) provided no evidence of increased emission of DMS from the iron patch. Its average atmospheric concentration (0.9 ppb) was one order of magnitude lower than that measured during SERIES (**S**ubarctic **E**cosystem **R**esponse to **I**ron **E**nrichment **S**tudy) in the eastern subarctic Pacific. There were no pronounced differences in biogases (organic halogens, isoprene *etc.*) between IN and OUT patch samples. However, regional sources and transport of DMS will strongly affect the ability of shipboard measurements to acquire this signal.

The aerosol measurements (University of Tokyo and Science University of Tokyo) showed that sulfate was dominant in the submicron aerosol (0.3-0.5μm) and that aerosol growth and changing particle spectra were observed in the marine boundary layer over the investigated region.

After presentations by the Chair of each working group, there were two presentations from modelers that suggested that the high biomass of copepods and low iron availability generated the low accumulation of phytoplankton during SEEDS-II. However, there were some discrepancies between the modeled results and the observations, especially in zooplankton biomass changes. These differences will be important considerations to be addressed during a workshop on “Modeling iron biogeochemistry and ocean ecosystems” and a topic session on “Synthesis of in situ iron enrichment experiments in the eastern and western subarctic Pacific” at the next PICES Annual Meeting in Yokohama, Japan.





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