Subarctic Ecosystem Response to Iron Enrichment Study (SERIES): Eastern Subarctic Pacific, July 2002

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W. Keith Johnson has worked in oceanography on the British Columbia coast since 1971. He is presently lab manager for the Biogeochemistry group. He has been studying iron as a micronutrient in the NE Pacific for the past 5 years in an effort to understand its role in relation to climate. His other research interests include carbonate chemistry and green house gases in the NE Pacific. He has also recently participated in a number of cruises in conjunction with the International Collaboration Project on CO_2 Ocean Sequestration.

In recent years, low iron values have been shown to be a major cause for limiting phytoplankton growth in large, macronutrients-rich areas of the world's oceans. Iron enrichment experiments conducted in the Equatorial Pacific (IRONEX I and II) and the Southern Ocean (SOIREE), regions of high nitrate, low chlorophyll (HNLC), have demonstrated increased productivity as a response to the added iron. However, the sub-arctic Pacific waters had not been investigated. In 2001, the first such experiment (**S**ubarctic Pacific Iron **E**xperiment for **E**cosystem **D**ynamics **S**tudy - SEEDS) was conducted in the Northwest Pacific with similar results. This was part of a collaborative project between Canada and Japan, to study iron limitation in the subarctic Pacific, which has strong zonal gradients in atmospheric iron deposition and plankton communities. The co-operative plan was conceived at the first meeting of the PICES Iron Fertilization Experiment Advisory Panel (IFEP), held in Tsukuba, Japan, in 1999, in conjunction with PICES IX. Here we describe the second subarctic experiment: SERIES (**S**ubarctic **E**cosystem *R*esponse to **I**ron **E**nrichment **S**tudy), near station P (50ºN, 145ºW) in the Northeast Pacific. SERIES was the first field experiment of Canadian SOLAS (Surface Ocean Lower Atmosphere Study) funded jointly by NSERC (Natural Science and Engineering Research Council), CFCAS (Canadian Foundation for Climate and Atmospheric Sciences) and DFO (Fisheries and Oceans Canada).

SERIES involved scientists from universities and government institutions across Canada as well as international collaborators. Three ships, the CSS *John P. Tully*, the M/V *El Puma* (leased from Mexico) and the M/V *Kaiyo Maru* from Japan, along with 45 researchers from over 20 institutions participated in the experiment. The objectives included:

- measuring the response of bacteria, phytoplankton and zooplankton to the addition of iron
- measuring CO_2 draw-down and carbon flux to depth
- quantifying climate gas production and controlling factors, including biological production of DMS (dimethylsulfide) and its influence on atmospheric sulphur budget, sulphate aerosols and cloud microphysics

Fig. 1 SERIES participants on the CSS J.P. Tully *with SF_6 tanks in background.*

SERIES would enable comparison of varying plankton responses along the longitudinal dust gradient in the North Pacific, which causes distinct differences in phytoplankton communities between the western and eastern subarctic gyres. This was also to be the first detailed atmospheric study associated with an iron enrichment experiment in the ocean, and one of the most detailed studies on DMS, foodweb and iron interactions. By using three ships and staggering their schedules, we extended the continuous occupation of a created iron patch to probably the longest observational period to date. With this extended time frame we hoped to observe the post-bloom particle export, not seen in other iron enrichment experiments with shorter periods.

Preliminary field-testing of the SF_6-iron injection system was conducted in February 2002, on the CSS *John P Tully*. A small 25 km^2 patch was created by injecting SF_6-saturated seawater using the "creeping line forward method", and was monitored over 4 days to track the patch drift, buoy drift, and test mapping capabilities and instrumentation.

The SERIES experiment began on June 29, 2002, when the CSS *John P Tully* departed from IOS with 21 scientists on board (Fig. 1). Enroute to the test area, the regular line P and station P time-series work was conducted to ensure the experimental site was within HNLC waters. A CTD survey was carried out to determine density gradients in the surface water. In order to minimize the possibility of an iron patch subduction, an area with uniform physical characteristics was chosen to the northeast of station P.

Prior to arrival in the test area, two steel tanks containing 2,700 to 2,800 litres of seawater were saturated with SF_6 over a 36-hour period and sealed for later injection. Another two tanks were each filled with just under 10,000 litres of seawater acidified to a pH of 1.6-1.7 by HCl. 1,068 kilograms of iron sulphate heptahydrate were then added to each tank. This amount of iron was expected to give a 4 nM iron increase to ambient levels for a 65 km^2 patch of 30 meters depth.

The injection was initiated at 00:50 local time of July 9, on site (50º 08.6'N, 144º 45.4'W) using an "expanding square method" made possible by the ship's Search and Rescue EcPIN package. The release track covered an area of 4.75 x 4.74 nautical miles and was completed in 18 hours travelling at a speed of ~ 4 knots. The SF_6 and iron solutions were mixed and pumped over the stern into the prop mixed waters at rates of 5 and 20 litres per minute, respectively, at a depth of ~7 meters.

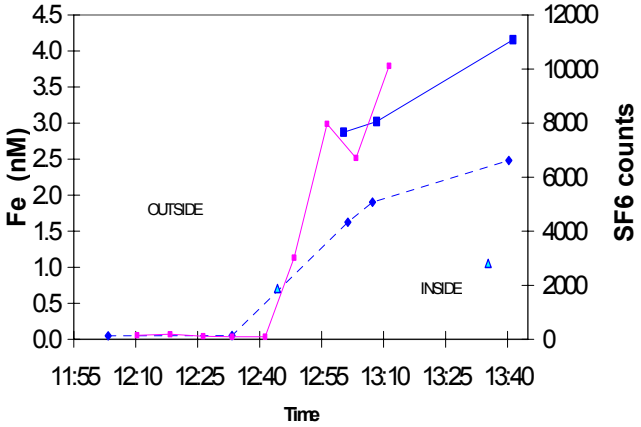

Fig. 2 Day 1 surface survey/transect into the patch for soluble (Δ), dissolved (♦) and labile (■) iron and SF_6 (□).

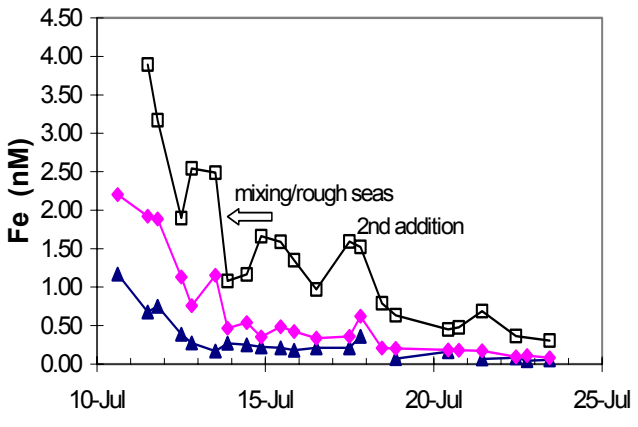

Fig. 3 Time series of soluble (▲), dissolved (♦) and labile (□) iron at 10-meter depth.

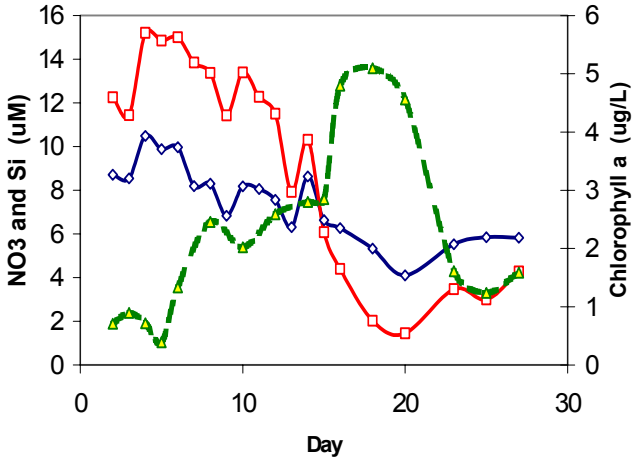

Fig. 4 Mixed layer NO_3 (◊), Si (□) and chlorophyll-a (Δ) levels throughout the SERIES experiment in July and August 2002. Data provided by F. Whitney, J. Barwell-Clarke, Y. Nojiri and H. Saito.

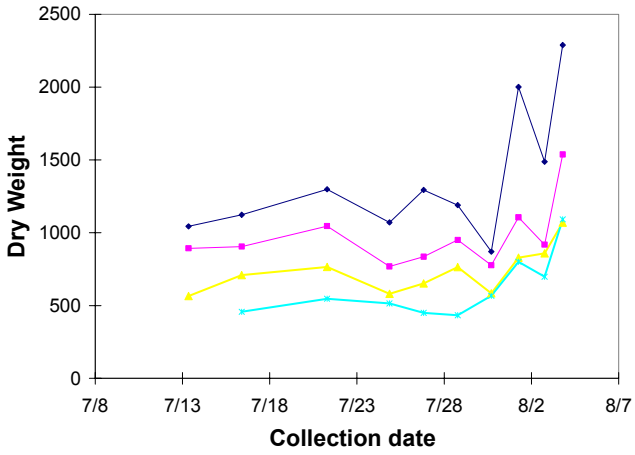

Fig. 5 Preliminary dry weight (mg/m^2/day) data at 50 m (♦), 75 m (■), 100 m (▲) and 125 m (*) depths from Knauer Free Drifting Sediment Traps, courtesy of Y. Nojiri.

The ship then remained outside the patch for a few hours to allow for vertical mixing. By that time, the M/V *El Puma* had also arrived in the test area so both ships were ready to start sampling on day 1. Typically the CSS *John P. Tully* located the patch center by using underway SF_6 measurements, sampled for a few hours, then moved out to allow the M/V *El Puma* in to sample. Meanwhile the CSS *John P. Tully* worked at a reference station outside the patch, and moved back in the afternoon to continue sampling inside the patch after the M/V *El Puma* had finished for the day. During the evening and night the CSS *John P. Tully* mapped the patch, so that by morning, a map with a projected center was available for that day's sampling of other chemical and biological properties. As the experiment progressed and the biological response was evident, underway surface pCO_2 and fluorescence augmented the SF_6 mapping.

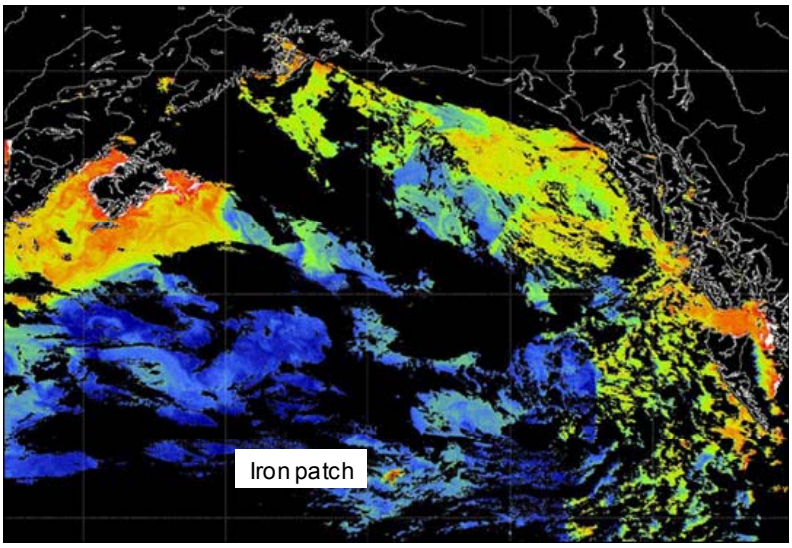

Fig. 6 Satellite image of chlorophyll in the North Pacific 20 days after iron injection, courtesy of Jim Gower (black is cloud coverage).

The following day a transect using a V-fin Fish was conducted to collect clean seawater as the ship travelled from outside the patch towards the expected center. Samples for analysis were collected and processed on board for labile (unfiltered seawater buffered to pH 3.2), dissolved (filtered through 0.22 micron cartridge filter) and soluble (filtered through 0.03 micron filter) iron. Figure 2 showed that both the SF_6 and iron were good indicators of the patch. The iron values were near the target of 4 nM, even though the 30-meter mixed layer was complicated by a weak 10-meter thermal layer caused by unusually calm weather.

Although the iron started to decrease immediately (Fig. 3), the biological response was much slower. After some stormy weather chlorophyll-*a* increased but only by 2-fold from initial values, and therefore a second smaller (25% of original iron) injection was carried out on July 16. By this time the chlorophyll-*a* levels were almost an order of magnitude higher, and these changes could be seen with the naked eye. But it was not until the CSS *John P. Tully* left and the M/V *Kaiyo Maru* arrived that the chlorophyll-*a* values peaked (July 24 to 26) at close to 5 ug/L (Fig 4). At the same time there was a large drawdown of silica and pCO_2.

After the CSS *John P. Tully* left, the M/V *Kaiyo Maru* continued to monitor the patch until August 4, giving 26 days of coverage which is the longest continuous monitoring of an iron-enriched patch to date. Sediment trap

deployments showed no increase during the observational period of the CSS *John P. Tully*. However, the M/V *Kaiyo Maru* was able to see a doubling of material settling at all depths (50 m, 75 m, 100 m and 125 m) indicating a flux of particulate matter out of the surface layer (Fig. 5).

A good SeaWiFS satellite image (Fig. 6) was obtained showing the drastic difference between the iron-enriched waters of the patch and the natural surrounding waters.

To facilitate discussions and publications on the experiment two workshops have been planned. The first is a Canadian SOLAS Workshop on *SERIES preliminary results and data*, to be held March 9-12, 2003, at the Institute of Ocean Sciences, Sidney, British Columbia, Canada. The objectives of this workshop are:

- to foster exchange of preliminary SERIES data and ideas;
- to establish inventory of data holdings and archiving at the Canadian SOLAS office; and
- to co-ordinate co-authorship of manuscripts for a second workshop.

The second workshop, under the auspices of the PICES IFEP, on *"*In-situ*" iron enrichment experiments in the eastern and western subarctic Pacific*, will be convened December 4-6, 2003, also at the Institute of Ocean Sciences. The objectives of this workshop are:

- to synthesize results from the two *in-situ* iron enrichment experiments performed in the eastern and western subarctic Pacific (SEEDS-2001 and SERIES-2002);
- to discuss responses in lower and higher trophic levels, carbon cycles, trace-gas production and ocean-atmosphere flux and models;
- to determine similarity and differences in biogeochemical and ecosystem responses to iron addition between eastern and western subarctic Pacific;
- to identify specific scientific questions for the long-term experiment in the western subarctic Pacific (SEEDS-2004).