CANADIAN SOLAS PROGRAM
Subarctic Ecosystem Response to Iron Enhancement Study (SERIES)
CRUISE REPORT
(August 9, 2002)

SHIP: EL PUMA

DATES : July 3 to August 3, 2002

CRUISE TITLE: SERIES (Subarctic Ecosystem Response to Iron Enhancement Study)

AGENCY OR GROUP: First cruise of the Canadian SOLAS program, a program funded by NSERC (Network), the Canadian Foundation for Climate and Atmospheric Science (CFCAS), DFO and DOE.

PROJECT : Canadian SOLAS

SCIENTIFIC STAFF LIST

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STUDY AREA: North-East Pacific, Station P area

CRUISE OBJECTIVES:
The productivity of large parts of the North Pacific Ocean is limited by iron. In this system, iron is naturally supplied by atmospheric deposition. Such natural iron fertilization is presumed to enhance plankton productivity. Given the episodic nature of these natural iron delivery events, it is impossible to plan in advance a cruise to study their impact on the ocean productivity. The goal of this project is to artificially reproduce and study the impact of such an event by releasing a small amount of iron in a ca. 64 km^2 area of the subarctic Northeastern Pacific. An inert gas (SF6) will be added with the iron and serve as a tracer of the patch. Previous iron enrichment experiments conducted in other parts of the global ocean resulted in important increases in phytoplankton biomass. The iron-induced increase in plankton productivity may also change the capacity of the ocean to absorb or produce climatically relevant gases such as CO_2 and dimethylsulfide (DMS). Therefore, an important part of our project is to quantify the influence of iron on the dynamics of these gases, and on their concentrations in the atmosphere. In contrast with previous iron enrichment studies, oceanographic measurements will be complemented by a series of atmospheric measurements during SERIES.

TYPE OF DATA COLLECTED

1. Oceanographic data

CTD profiles

Light and fluorescence profiles

Rosette equipped with Niskin (or GO-FLOWs) at 6 optical depths (100, 33, 10, 3.3, 1, 0.15%)

Biological variables:	Heterotrophic protists enumeration
	Chlorophyll *a* (total and size fractionated – 20, 5 and 0.2 μm)
	Bacterial abundance
	Photosynthetic picoplankton
	Bacterial diversity (Fluorescence *in situ* hybridization)
Chemical variables:	Macronutrients (nitrate, nitrite, silicate, phosphate)
	SF6
	Particulate carbon and nitrogen
	Dissolved carbon
	Thorium - 234
	Particulate DMSP (total and size fractionated – 20, 5 and 0.2 μm)
	Dissolved DMSP and DMS
Rates determinations:	Primary productivity (C14; size fractionated – 20, 5 and 0.2 μm)
	Nutrient (nitrate) uptake rates (15N)
	Bacterial productivity
	Respiration
	DMS production and consumption (size fractionated – total, < 1μm, < 0.2 μm)
	DMSP bacterial consumption (^{35}S; size fractionated – total, < 1μm, < 0.2 μm)
	Microzooplankton grazing
Net tows:	Macrozooplankton abundance and growth rates (enzymatic method)

2. Atmospheric data

A suite of atmospheric measurements were taken everyday, usually in the afternoon after the sampling of the patch, and during the evening and night (see summary of activities below).

Variables measured:	DMS concentrations in the air
	SO_2
	Ozone
Aerosols size spectrum and chemical composition	
	Cloud condensation nuclei
	Aerosol sulfur isotopic determination
UV radiation	

ITINERARY

The entire cruise took place north of station P (50°N; 145°W) where iron was released from the JP Tully over a ca. 3 by 6 miles area. The iron-enriched patch was sampled every day from July 11 to July 28 (18

days). In addition to these «in-patch» stations, a reference station located outside the patch (generally north-east of the patch) was sampled on 5 occasions. Atmospheric sampling took place everyday in the afternoon, the evening and night. On two occasions (July 25 and 27), atmospheric and oceanographic sampling (salinity, temperature, nitrate, fluorescence and surface and atmospheric DMS) were determined along a west-east transect across the patch.

LOCATION OF THE SAMPLING STATIONS

Date	IN PATCH		OUT PATCH	
	Longitude	Latitude	Longitude	Latitude
10			50°20.2	144°46.3
11	50°12.7	144°45.7		
12	50°16.5	144°47.4		
13	50°20.4	144°48.6		
14	50°22.8	144°45.6		
15	50°25.1	144°45.1	50°31.7	144°58.2
16	50°27.8	144°46.6		
17	50°30.0	144°45.3		
18	50°34.8	144°49.2		
19	50°36.0	144°48.0		
20	50°41.4	144°43.2	50°43.2	144°40.8
21	50°50.4	144°41.1		
22	50°52.8	144°36.9		
23	50°58.5	144°23.6		
24	50°57.7	144°25.7		
25	50°54.4	144°27.2	51°03.0	144°13.4
26	50°57.6	144°20.6		
27	50°57.7	144°10.0		
28	50°03.0	144°16.0	51°03.0	144°00.0

ACTIVITIES SUMMARY

Date	**Major Activities (PDT -Pacific daylight time)**
July 2	Arrive at IOS
July 3	Loading, preparation of laboratories, electrical work in most labs
July 4	Preparation of laboratories, electrical work in most labs
July 5	Loading and preparation of laboratories, electrical work in most labs
July 6	8h30 Leave IOS and test of the rosette and CTD in Patricia Bay
July 7	Steaming to station P
July 8	Steaming to station P
July 9	Steaming to station P. El Puma reached a standby station at ca. 13h00
July 10	12h30 First out patch sampling for El Puma. Filling of 6 microcosms Visit of P. Boyd to El Puma
July 11	9h15 First in patch sampling. Rosette one for RR. Rosette 2 failed. Return to in patch station at 12h40 for rosette 2. Filling of 2 additional microcosms 10h00 to 6h00 (12^{th}) Atmospheric sampling downwind of the patch
July 12	7h15 Initial sampling of the microcosms 9h15 Sampling In patch station

	13h40 Sampling In patch station 9h00 to 6h00 (13th) Atmospheric sampling downwind of the patch
July 13	9h40 First IN station (Thorium and Rosette PP) 13h00 Second IN station (light, bongos) 15h30 Standby station north of the patch (10 miles) for atmospheric sampling
July 14	7h00 Microcosms sampling (second sampling) 8h30 In patch station (rosette, go-flow) 13:00 to 16:00 Atmospheric sampling (Tully out of the patch) 17:00 Exchange of samples between Tully and El Puma (DMS, others)
July 15	8h30 Out patch station (new position north-west of the patch) 13h00 In patch station ca. 15h00 to 19h00 Atmospheric sampling (downwind of the patch, east) 19h00 Rendez-vous with Tully in the patch (exchange of samples)
July 16	6h30 Out patch station (deep cast for Thorium) 7h00 Microcosms sampling (third sampling) 9h20 In patch station (last visit to the patch today) 10h45 Out patch station (east) for atmospheric sampling Tully re-injects iron from noon to evening (low iron concentrations left in the patch) and will map the patch for the rest of the night
July 17	9h30 In patch station (Primary Production rosette and GO-FLOW) 13h00 In patch station (Bacterial production rosette, Thorium rosette, 2 bongos, light profile) Standby station for atmospheric sampling Rendez-vous with Tully at 19h00 (exchange of samples)
July 18	00h15 Bongos 7h00 Microcosms sampling (fourth sampling) 8h30 In patch station (Rosette, GO-FLOW) 12h00 In patch 14h00 Atmospheric sampling east from the patch (ca. 12 nautical miles – very good conditions, low wind and full sunlight for a part of the afternoon) 17h30 Rendez-vous with Tully postponed to allow El Puma to steam east as soon as possible to pursue atmospheric sampling
July 19	9h45 In patch station (all measurements, 2 rosettes, GO-FLOWs, plankton net, light cast, Thorium) End of cast 12h10 13h00 Standby at 6 nautical miles out the patch (downwind) to fix the exhaust pipes of the El Puma. Done at 17h30. 17h30 Steaming toward the south of the patch for atmospheric sampling during the night. 18h30 Mid cruise special diner
July 20	6h45 Microcosms sampling (fifth sampling) 8h30 Out patch station 13h00 In patch station
July 21	00h15 Bongos 8h30 In patch station 13:00 Visit of M. Levasseur, Hugh Maclean and Nelson Sherry to the Tully to prepare Tully departure 13h30 In patch station 20h30-24h30 First attempt of El Puma to map the patch with fluorescence.
July 22	6h45 Microcosms sampling (sixth sampling) 10h00 Turn on the two Argos buoys to test reception 10h50 In patch station 14hh30 In patch station
July 23	8h40 In patch station 13h15 Last rendez-vous with Tully (exchange of equipments) 13h45 Fire in the engine room! Tuned out to be an electrical problem. The hydraulics is not working.

	14h40 In patch station (Thorium) El Puma deployed the Argos 300099 at the centre of the patch after Tully recovery of the present Argos. 17h00 Tully departs for IOS 19h00 to 24h00 El Puma first mapping of the patch (fluorescence) 22h00 Arrival of Kaiyo-Maru (station Papa) 22h30 First radio contact with Dr. Tsuda
July 24	6h45 Microcosms sampling (seventh and final sampling) 7:00 Determination of the patch centre from night fluorescence mapping 8h30 In patch station (delayed due to rosette failure; start sampling at 9h45) 11h00 First in patch sampling of Kaiyo-Maru 16h00 In patch station 17h00 to 6h00 (25^{th}) Atmospheric sampling 20h30 Kaiyo-Maru starts to map the patch (PCO_2 and fluorescence)
July 25	8h45 Out patch station 10h45 Steaming 20 nautical miles North-East to begin atmospheric sampling (clear sky, wind ca. 12 knots) 12h45 Start of the atmospheric transect (with surface DMS concentrations) 21h00 End of the atmospheric transect
July 26	9h00 In patch station (all sampling done during this visit) 12h00 to 12h30 Exchange of water (inter-calibration for DMS, primary production and bacterial production) and equipment (Argos buoy, bottles) with Kaiyo-Maru . West to east transect across the front and the patch between 16h00 and 20h00 (13 fluo-temp-sal profiles, one each 2 miles). Atmospheric sampling at fixed station for the rest of the night
July 27	9h00 In patch station (all measurements) 13h20 to 17h30 Atmospheric transect with water DMS measurements 19h00 to 07h00 (28^{th}) Mapping of the patch
July 28	8h30 In patch station 13h45 Out patch station 16h00 Short encounter between El Puma and Kaiyo-Maru for final send-off and best wishes 16h45 Depart for Patricia Bay
July 29	Transit to Patricia Bay
July 30	Transit to Patricia Bay
July 31	Transit to Patricia Bay
August 1	Unloading
August 2	Unloading
August 3	Unloading

GOALS ACHIEVED

This cruise may be considered as a total success, which is somewhat surprising since it was a challenging one in many aspects. First, we were successful in loading and making operational all of our equipment in spite of the electrical limitations of the ship. Thanks to the hard work of the crew (and some extra funds from SOLAS…) the electrical capacity of each laboratory was increased to the required amperage. It should also be noted that the brand new Aerosol Mass Spec decided finally to work only a few hours prior departure…We all shared the happiness and relief of the atmospheric team We could finally depart with all our systems working on the morning of the 6^{th} . Second, the iron enrichment carried out by the John P Tully went well. A coherent and relatively homogenous iron-enriched patch was created, the patch remained at the surface (no subduction below lighter waters) and drifted in a predictable manner during the whole experiment. Third, the weather was relatively good allowing sampling of the iron patch for 18 consecutive days in spite of the modest size of the El Puma (150 feet).

We arrived in the patch area on July 9th and conducted our first out patch sampling on the 10th. We first sampled the patch on the 11th. The presence of two ships in the area required careful planning for obvious safety reasons. The day usually started with the JP Tully providing us with the position of a standby station close to the patch at 7h00, followed by the position of the centre of the patch. We usually sampled the in patch station twice a day – around 8h30 and at around 13h00.

General response to the iron enrichment* - These visits to the patch allowed us to follow the progressive utilisation of nitrate by the iron-stimulated phytoplankton assemblage. Small flagellates seem to have benefited first from the added iron during the initial 9 days. This period was characterised by a significant increase in fluorescence. The expected diatom bloom seems to have started later, around day 10-11, and proceeded until our departure from the patch on day 18. This phytoplankton succession was accompanied by important changes in water properties. Although most samples will need to be processed in our respective laboratories, some very interesting and new results are emerging. The following is a suite a comments obtained from participants during the last days of the cruise on our way back to Patricia Bay.

* these interpretations are based only on partial measurements and should be considered as pre-preliminary results.

Irradiance data (Ziolkowski)

Using a free falling irradiance sensor, which measured irradiance on 13 discreet wavebands, the downwelling irradiance was measured over 30 times in the waters inside and outside the patch. Outside the patch, and in the early stages of the fertilization, the water was fairly transparent with a Kpar of close to 0.06 and there was still light in the 489 nm channel at 55 meters depth. As the experiment went on, the Kpar increased (upto 0.21) and at some stations, all of the light was attenuated by 25 meters. These light casts were fundamental in calculating the PAR light depths for biological sampling. The fluorescence, conductivity and temperature were recorded on all of the casts. These fluorescence profiles are the only ones that were collected on the El Puma. Upwelling radiance data (which can be correlated with SeaWiFs data) was collected at many stations during the cruise and will be processed once Lori is back in Halifax. There was also a shipmounted irradiance sensor (with 5 wavebands) that was continuously measuring the downwelling irradiance during the cruise. I also looked at the spectral absorbance of the colour dissolved organic matter in the water during the SERIES experiment. During the first week of the cruise, I worked in the lab trying to measure the apparent quantum yield for dissolved inorganic carbon photoproduction, however due to time constrains and instrument difficulties, these experiments did not continue throughout the cruise.

Primary Productivity (Marchetti, Sherry)

In assessing the fulfilment of our research objectives it goes without question that our group was very pleased with the outcome of the cruise. Having been to Ocean Station Papa (OSP) on six previous occasions, I am fully aware of the rarity of not missing a sampling day due to poor weather conditions. The fact that we were able to sample 20 days in a row without missing any sampling needs is somewhat of a miracle.

Beyond collecting baseline productivity measurements throughout the succession of the Fe induced bloom, we had several other objectives that were also met. The first was to observe whether phytoplankton composition in on-deck incubations closely reflected that of in situ composition during an Fe-induced bloom. By following the succession of the bloom it was clear that bottles closely reflect the floral changes which occur naturally. This gives validity to the countless experiments performed previously at OSP using bottle incubations and allows us the interpret many of the effects of Fe fertilisation without having to perform large-scale Fe fertilisation experiments. Another objective, assessing the change in nitrogen isotope ratio (Del 15N), required the draw down of nitrate to low levels. We were aware that this is possible in bottles as this is a closed system, not allowing an influx of nitrate, however we were uncertain how low the nitrate levels would get within the fertilised patch. Surface nitrate concentrations were decreased from 11 μM to less that 2 μM by day 20 and should provide a good nitrogen isotope fractionation signal over the course of this Fe-induced bloom. The use of Pulse Amplitude Modulated (PAM) fluorometry to assess phytoplankton physiology is a growing area of research. Previously, the limitations to field observations were due to the high biomass required to achieve an accurate signal. On this cruise we tested a model that

is believed to be sensitive enough to acquire data from ambient phytoplankton communities. Even though ambient phytoplankton concentrations at OSP seemed too low to acquire the full suite of useful information, during the latter part of the bloom we were able to assess phytoplankton community photosynthetic conditioning using the PAM. With this data we are planning to compare primary productivity measured with 14C uptake to that estimated from PAM induction curve kinetics. The use of PAM fluorescence techniques to assess primary productivity may someday replace traditional methods of 14C incubations.

Finally I would like to close by saying that it was a privilege to take part in this cruise and a great learning experience. The co-operation and collaboration between scientists and crew of the El Puma, J.P. Tully and Kaiyo-Maru made this project a great success and speaks volumes in terms of taking a step in the right direction for the field of oceanography.

Bacterial productivity (Rivkin, Matthews, Agawin)

The Canadian Surface Ocean-Lower Atmosphere (SOLAS) Fe-fertilization experiment in the HNLC region of the Northeast Subarctic Pacific in the vicinity of Ocean Station Papa was a three-ship international expedition. The mission aboard the B/O El Puma, lead by Chief Scientist Dr. Maurice Levasseur, carried out a 20-day time series process study of the planktonic community and the inter-relationship of this community with the production and cycling of climate reactive gasses. The subproject lead by Rivkin studied the dynamics of the heterotrophic components of the microbial food web and their role in the cycling of both carbon (i.e consumption of biogenic carbon and production of CO2) and sulfur (in collaboration with Levasseur's group). Time series measurements of stocks (i.e. autotrophic and heterotrophic bacteria, bacterial diversity) and rates (i.e. production, respiration, and microzooplankton grazing) were within the patch and during all out-patch station visits. Vertical profiles to the 0.1% irradiance depth and and at times to 200m were routinely determimed. Despite the diverse nature of the scientific party, the wide range of objectives, the lack of prior experience working together and with the research vessel, the mission was a resounding success. This was in large part due to the careful and thorough pre-cruise planning and the proactive and consultative leadership by the Chief Scientist. Although it will be many months before the samples that my 3-person field team collected will be analyzed, from an operational perspective, we fully achieved our pre-cruise goals.

Macrozooplankton (Sastri, Dower)

My objective for this cruise was to investigate potential changes in the species composition/abundance and growth rates of the macrozooplankton community in response to pulsed primary production in the iron fertilized patch. Net samples were taken on a regular basis throughout the evolution of the patch and outside of the patch. Bongo nets (237 μm) were used to sample the water column from 170 m and depths corresponding to the mixed layer. Growth rates were measured via the rate of decay and hence turnover of the chitinolytic enzyme chitobiase. This enzyme is released into the water column by moulting crustaceans, and its activity was measured both in and out of the patch for the duration of the experiment.

DMS and DMSP measurements (Levasseur, Scarratt, Michaud, Merzouk)

The entire study area was rich in DMS when we started our sampling. We nevertheless observed a massive increase in DMS concentration in the patch during the first ten days, reaching concentration as high as 40 nM in what appears to be a *Phaeocystis* bloom. During that period, high DMS concentrations were also measured outside the patch at some reference stations. It is thus too early to state with certitude if the increase in DMS in the patch was totally due to the iron. Particulate DMSP concentrations were however clearly higher in the patch than in the surrounding area. The massive increase in DMS concentrations was followed (in the patch only) by a rapid decrease apparently associated with the growth of diatoms. During the final days of sampling, DMS levels were lower in the patch than outside, which is a totally new observation with very important consequences regarding the potential impact of these enrichments (natural of man made) on climate. DMS production and consumption rates were also measured during the 18-day sampling period. Important variations in the rates were measured which remain to be explained. DMS measurements were also made in the microcosm experiments, and showed a response to iron enrichment similar to that observed in the water column. The temporal pattern observed in the water in term of DMS concentrations was also observed in the atmosphere (see below).

Marine DMS Photochemistry (Bouillon)

Seven polychromatic irradiation experiments were carried out, using in-patch (x 5) and out-patch (x 2) water samples, to determine the AQY (Apparent Quantum Yield) of DMS photo-degradation in water. In addition, two full spectrum experiments were performed, using in-patch and out-patch water samples (collected July 25 and 26), to determine the pseudo first-order rate constant of DMS photo-degradation. I observed that both pseudo first-order rate constants were similar. These results suggest that the chemistry of molecules initiating the photo-degradation of DMS did not significantly evolve during SERIES.

Atmospheric Sampling (Leaitch, Lohmann, Marshall, Phinney, Shantz, Sharma)

Measurements were made on board the El Puma from July 6 until July 30 for the following quantities:

Trace Gases

1. Sulphur Dioxide
2. Ozone

Aerosol Particles

1. Size Distribution
    - 5-300 nm diameter
    - 0. 14-3 μm diameter
    - 2-40 μm diameter
2. Number Concentration
    - >3 nm diameter
    - >5 nm diameter
3. Size Segregated Chemistry
    - Sulphate, ammonium, organics, nitrate every 15 min.
    - Inorganic ions from filters integrated over several hours
4. Bulk Filter Chemistry
    - Total particulate carbon integrated over several hours
    - Major ions integrated over several hours
5. Cloud Condensation Nucleus Concentrations active at several water supersaturations
6. Light Extinction
    - Volume light scattering coefficient at 3 visible wavelengths
    - Back scattering coefficient at 3 visible wavelengths
    - Visible aerosol absorption coefficient

Other

1. UV Irradiance

Hi-volume aerosol and atmospheric DMS (Wadleigh, Norman, Burridge and Sharma)

Atmospheric aerosols were collected on board El Puma onto quartz filters using four hi-volume samplers. Two were equipped with SO2 filters for the collection of bulk aerosols. The other two were equipped with 5-stage cascade impactors for the collection of size-segregated aerosols. The cascade impactors separated aerosols into the following size fractions: aerodynamic diameters >7.2, 3.0-7.2, 1.5-3.0, 0.95-1.5, 0.49-0.95 and <0.49 μm. Two of each type (bulk and size-segregated) were employed outside and upwind of the fertilized patch, while the other two were used inside and downwind of the patch. Over the course of the fertilization experiment a total of 60 aerosol samples were collected ranging in duration from 4 to 31 hours.

DMS measurements air:

Atmospheric DMS measurements were also made during SERIES. Samples were collected every hour, 24 hours a day, and were analysed on board. Twice during the experiment (July 25 and 27) atmospheric DMS measurements were made at more frequent intervals to accompany transects across the patch described above. Approximately 420 samples were collected and analysed.

Preliminary Results:
Chemical and stable isotope analysis of the aerosols will be performed after the cruise in laboratories at Memorial University of Newfoundland and University of Calgary. DMS measurements were made on board and will be compiled by Wadleigh, Burridge and Sharma.

Personnel:
An MSc student, Carolyn Burridge, commenced study with Wadleigh in January 2002. She accompanied Wadleigh on the SERIES cruise. Wadleigh and Burridge collected aerosol samples for theirs and A. L. Norman's components of the project. Atmospheric DMS measurements described above were performed using equipment provided by S. Sharma (MSC).