Working Group 22

Iron supply and its impact on biogeochemistry and ecosystems in the North Pacific Ocean

Approved at PICES XVI (Oct. 2007), 3-year Term

Parent Committee: **BIO**

Co-Chairman: Fei Chai and Shigenobu Takeda

WG-22 Members

Canada	William R. Crawford Paul J. Harrison Maurice Levasseur Charles Trick C.S. Wong
China	Zhongyong Gao (Xiuren Ning)
Korea	Kyung-Ryul Kim Kitack Lee
Japan	Jun Nishioka Hiroaki Saito Shigenobu Takeda Mitsuo Uematsu Yasuhiro Yamanaka
Russia	Vladimir M. Shulkin
U.S.A.	Fei Chai William P. Cochlan Natalie Mahowald Suzanne Strom Mark L. Wells

Terms of reference

1.Compile and synthesize available iron biogeochemistry data in the North Pacific.

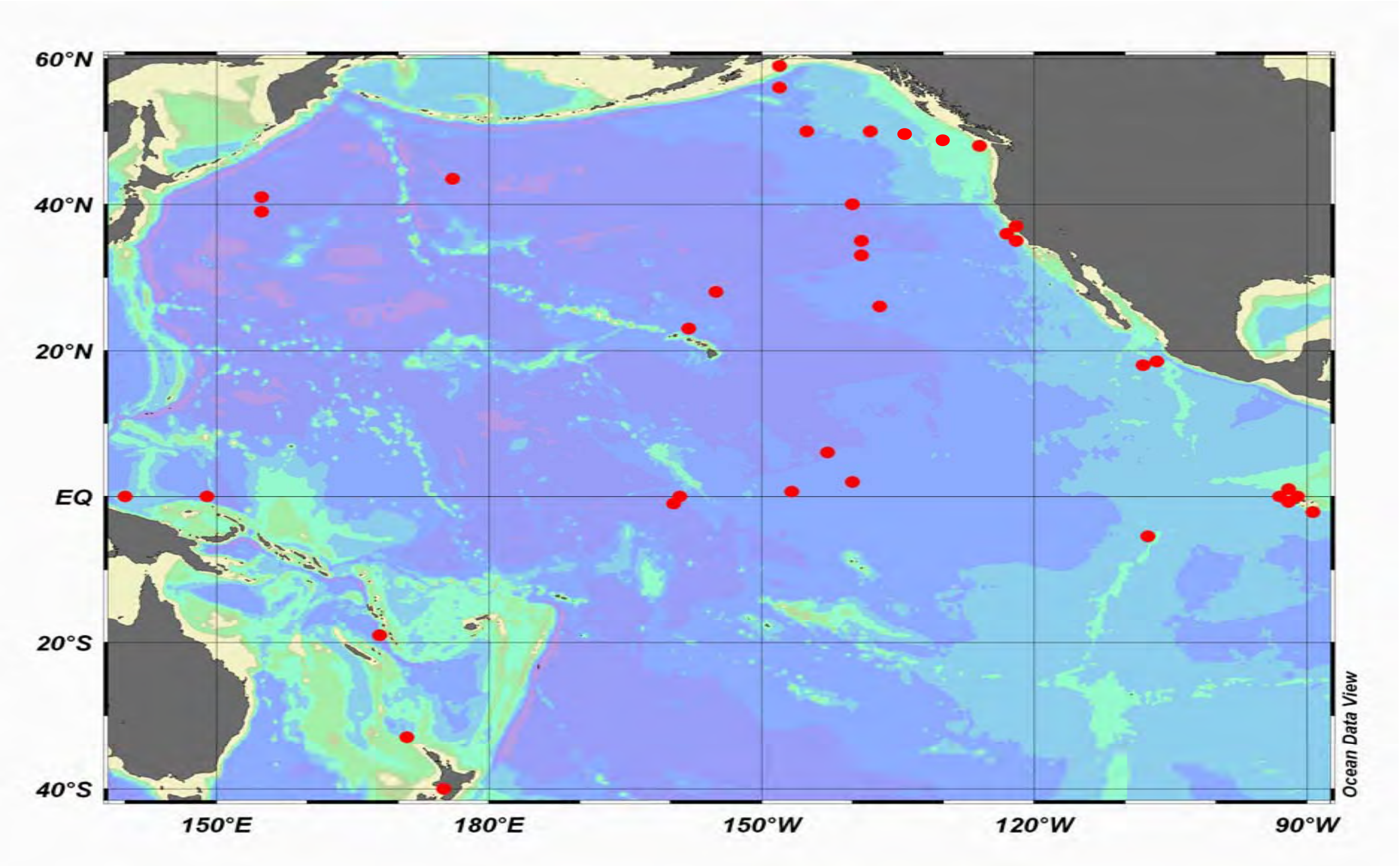
2.Review the past and ongoing laboratory, field and modeling studies on iron biogeochemistry and its impact on biological productivity and marine ecosystems in the North Pacific Ocean.

3.Determine the natural supplies of iron to the North Pacific, which includes atmospheric dust transport and movement of iron-enriched waters, and examine linkages between iron supply and ecosystem responses.

4.Identify gaps and issues related to experimental and modeling activities, encourage and plan national and international scientific programs on iron biogeochemistry and its impact on marine ecosystems in the North Pacific.

5.Elucidate the role of iron as a potential regulator of harmful algal bloom (HAB) in coastal ecosystems of the North Pacific.

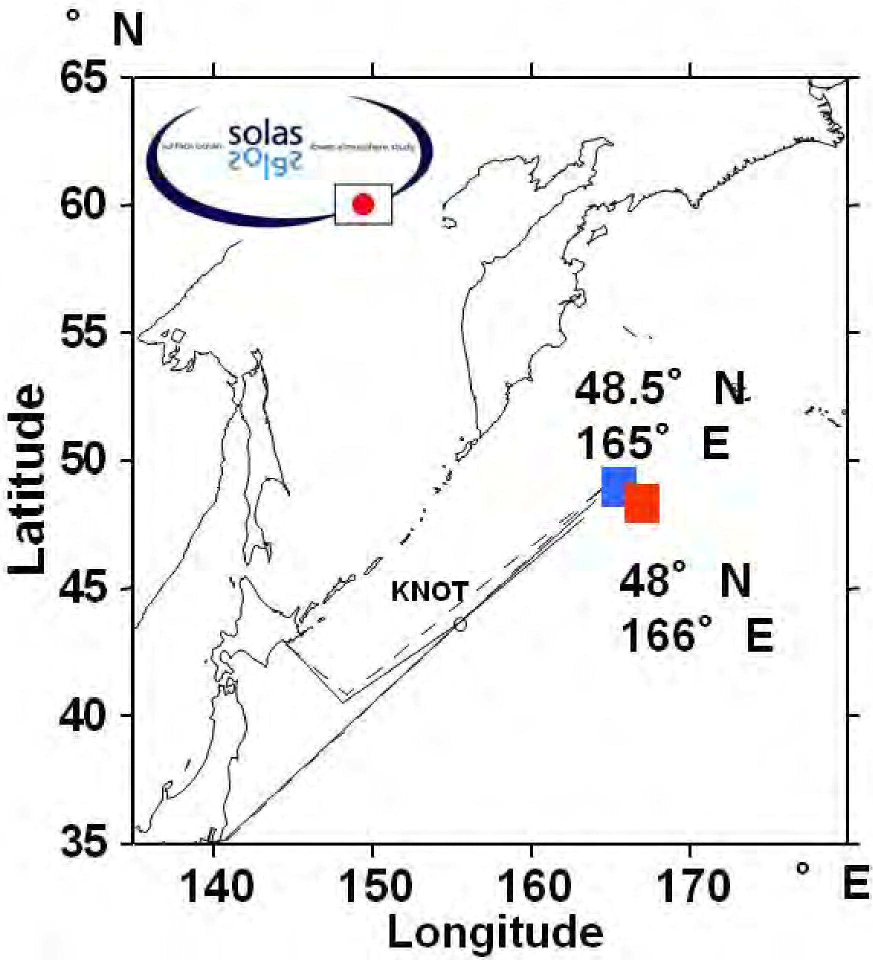
1. Compile and synthesize available iron biogeochemistry data in the North Pacific



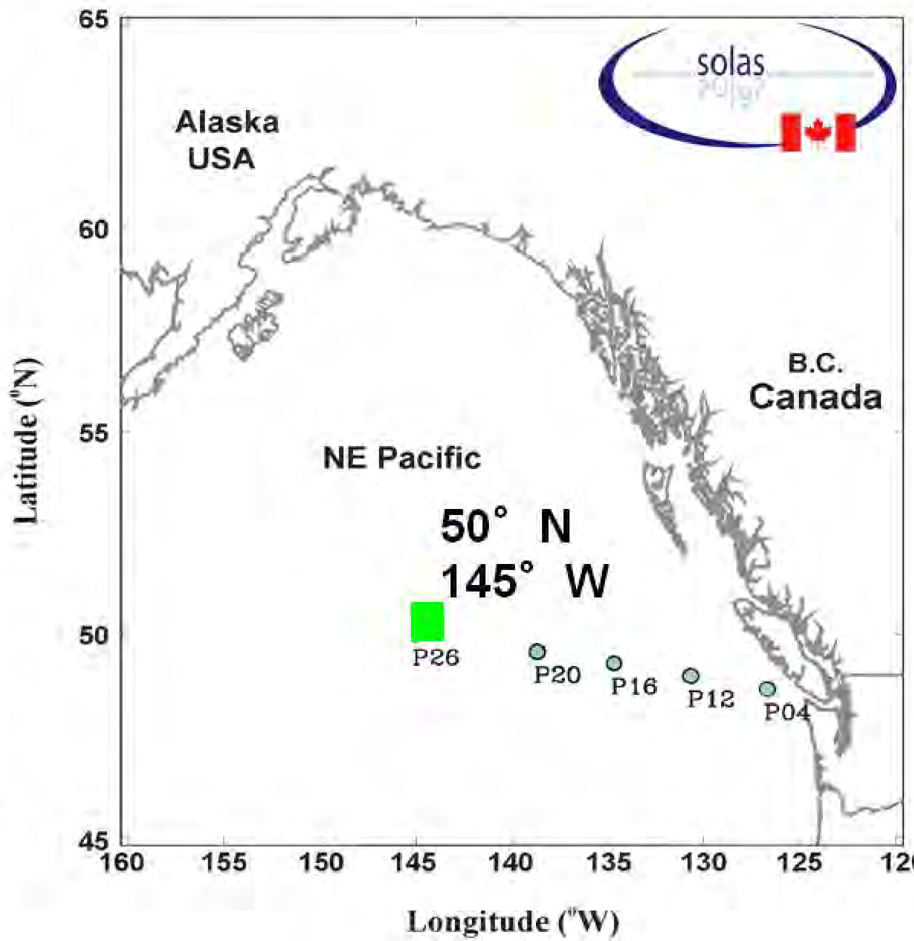
Dissolved Fe data in the Pacific Ocean before 2001

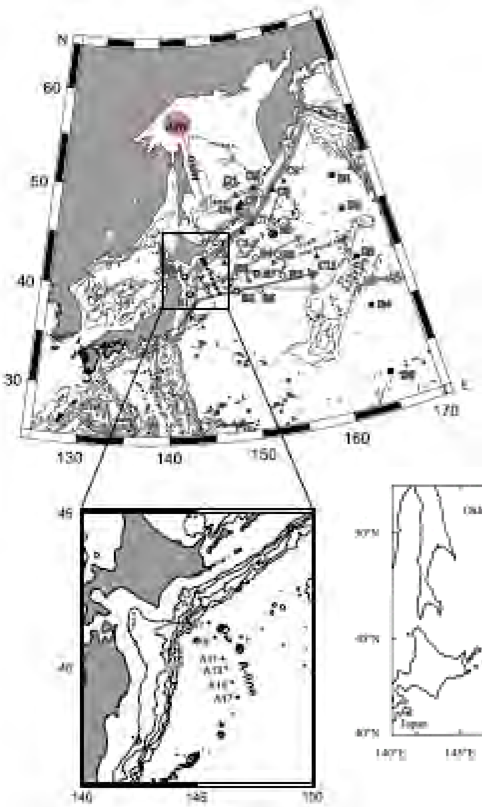
SEEDS-I
(18 Jul 2001)

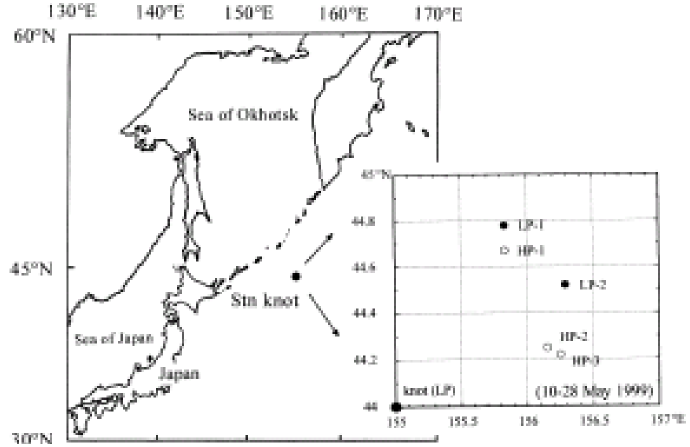
SEEDS-II
(20 Jul 2004)

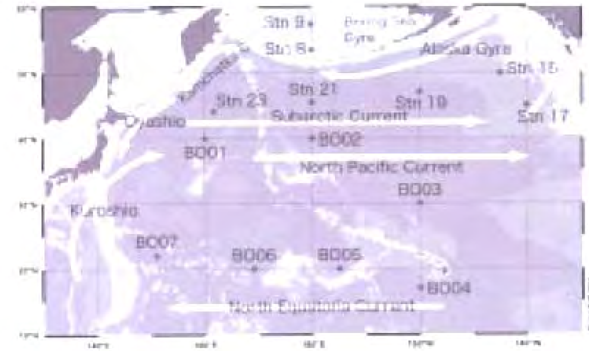


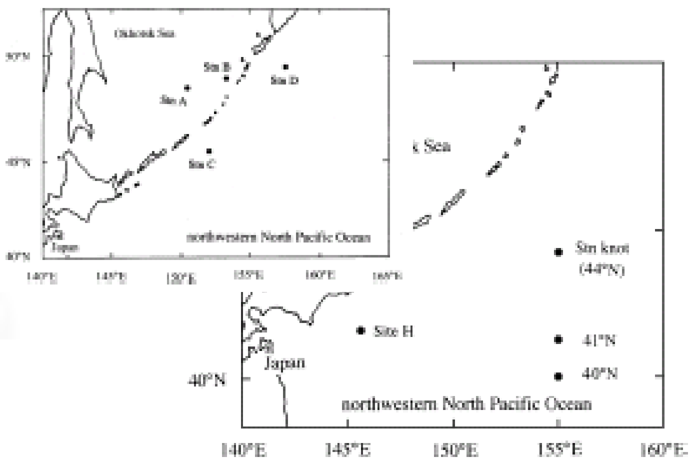
SERIES
(9 Jul 2002)

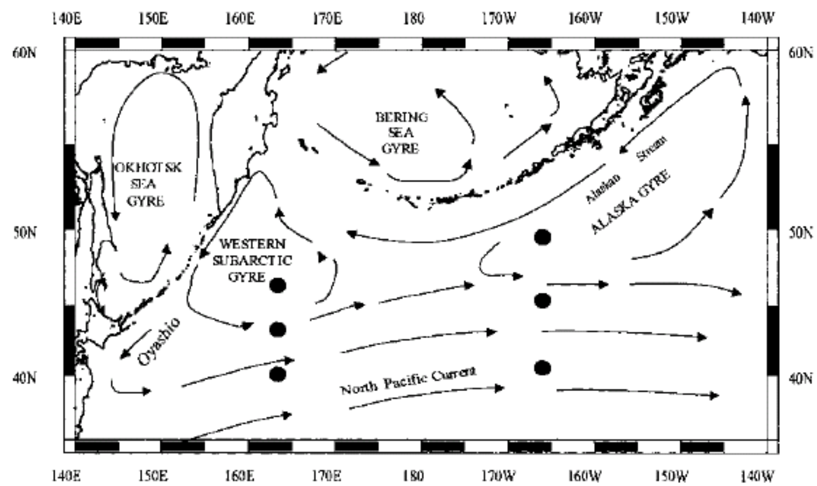


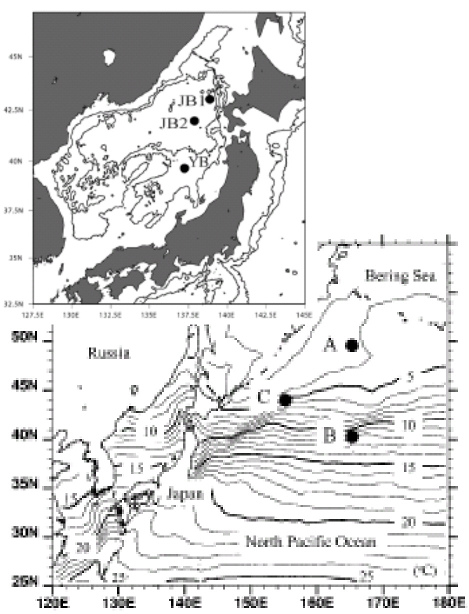

N
60
50
40
30
130
140
150
160
170
E
40
46
140
146
150

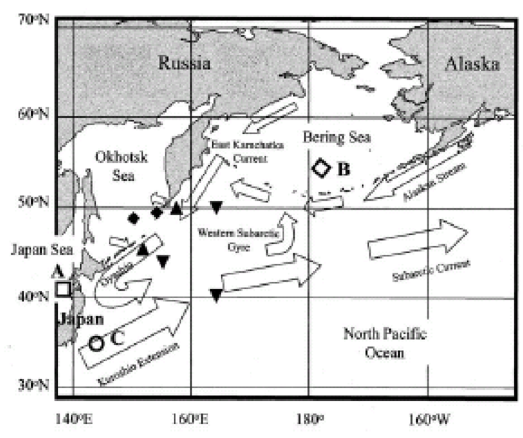

130°E
140°E
150°E
160°E
170°E
60°N
45°N
30°N
Sea of Okhotsk
Stn knot
Sea of Japan
Japan
LP-1
HP-1
LP-2
HP-2
HP-3
knot (LP)
(10-28 May 1999)
44.8
44.6
44.4
44.2
44
155
155.5
156
156.5
157°E

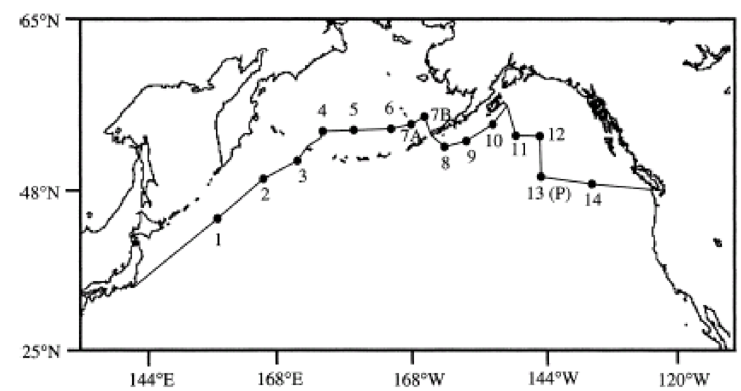

Stn 9
Stn 8
Alaska Gyre
Stn 15
Stn 21
Stn 23
Stn 19
Stn 17
Oyashio
Subarctic Current
BO01
BO02
North Pacific Current
BO03
Kuroshio
BO07
BO06
BO05
BO04
North Equatoria Current


Okhotsk Sea
Stn B
Stn D
Stn A
Stn C
northwestern North Pacific Ocean
Japan
140°E
145°E
150°E
155°E
160°E
165°E
Stn knot
(44°N)
Site H
41°N
40°N
Japan
40°N
northwestern North Pacific Ocean
140°E
145°E
150°E
155°E
160°E

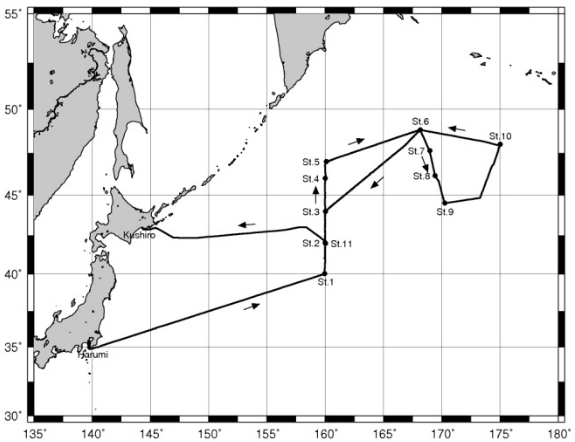

140E
150E
160E
170E
180
170W
160W
150W
140W
60N
50N
40N
BERING SEA GYRE
OKHOTSK SEA GYRE
WESTERN SUBARCTIC GYRE
Alaskan Stream
ALASKA GYRE
Oyashio
North Pacific Current


JB1
JB2
YB
Bering Sea
Russia
A
C
B
Japan
North Pacific Ocean
(°C)
50N
45N
40N
35N
30N
25N
120E
130E
140E
150E
160E
170E
180E

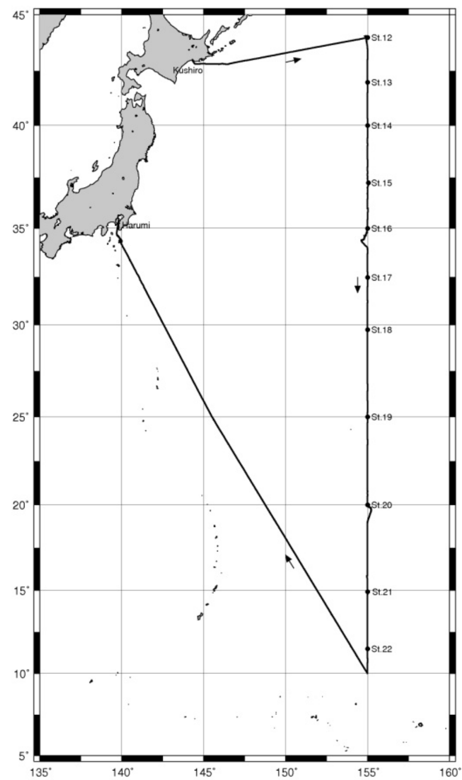

70°N
60°N
50°N
40°N
30°N
Russia
Alaska
Okhotsk Sea
Bering Sea
East Kamchatka Current
B
Alaskan Stream
Japan Sea
A
Western Subarctic Gyre
Subarctic Current
Oyashio
Japan
C
Kuroshio Extension
North Pacific Ocean
140°E
160°E
180°
160°W


65°N
48°N
25°N
1
2
3
4
5
6
7
7B
8
9
10
11
12
13 (P)
14
144°E
168°E
168°W
144°W
120°W

KH-08-2 Leg1 (Harumi-Kushiro)

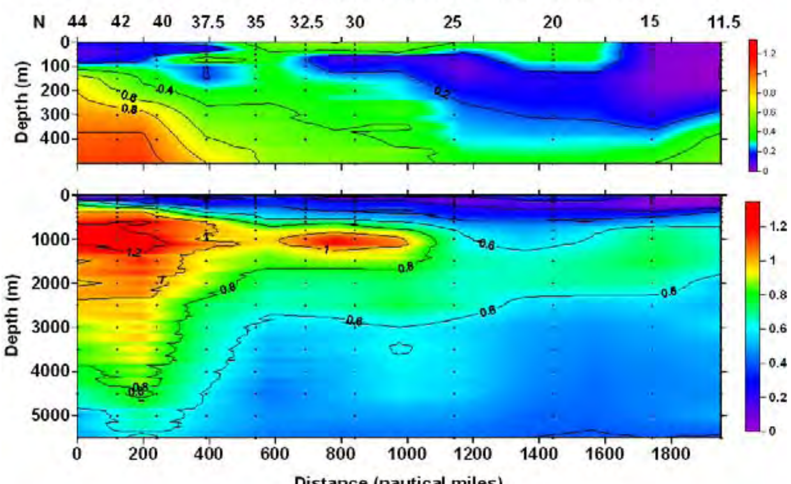


KH-08-2 Leg2 (Kushiro-Harumi)



R/V Hakuho-maru
July-September 2008

Vertical section profile of dissolved iron on line 155 E



from Jun Nishioka

Nishioka, J., S. Takeda, C. S. Wong and W. K. Johnson (2001) Size-fractionated iron concentrations in the northeast Pacific Ocean: distribution of soluble and small colloidal iron, Marine Chemistry, 74, 157-179.

Nishioka, J., S. Takeda, I. Kudo, D. Tsumune, T. Yoshimura, K. Kuma and A. Tsuda (2003) Size-fractionated iron and iron-limitation processes in the subarctic NW Pacific, Geophysical Research Letters, Vol 30, No. 14, 1730, doi:10.1029/2002GL016853.

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Takata, H., K. Kuma, Y. Saitoh, M. Chigira, S. Saitoh, Y. Isoda, S. Takagi, and K. Sakaoka. Comparing the vertical distribution of iron in the eastern and western subarctic North Pacific Ocean. Geophys. Res. Lett., 33: L02613, doi:1029/2005GL024538 (2006).

Kitayama, S., K. Kuma, E. Manabe, K. Sugie, H. Takata, Y. Isoda, K. Toya, S. Saitoh, S. Takagi, Y. Kamei, and K. Sakaoka. Controls on iron distributions in the deep water column of the North Pacific Ocean: Iron(III) hydroxide solubility and humic-type fluorescent dissolved organic matter. J. Geophys. Res., 114: C08019, doi:10.1029/2008JC004754 (2009).

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2. Review the past and ongoing laboratory, field and modeling studies on iron biogeochemistry and its impact on biological productivity and marine ecosystems in the North Pacific Ocean

PICES 2009 Annual Meeting BIO Workshop (W1)

Natural supplies of iron to the North Pacific and linkages between iron supply and ecosystem responses

PICES 2010 Annual Meeting Session 2 (S2)

Understanding the role of iron in regulating biogeochemical cycles and ecosystem structures in the North Pacific Ocean

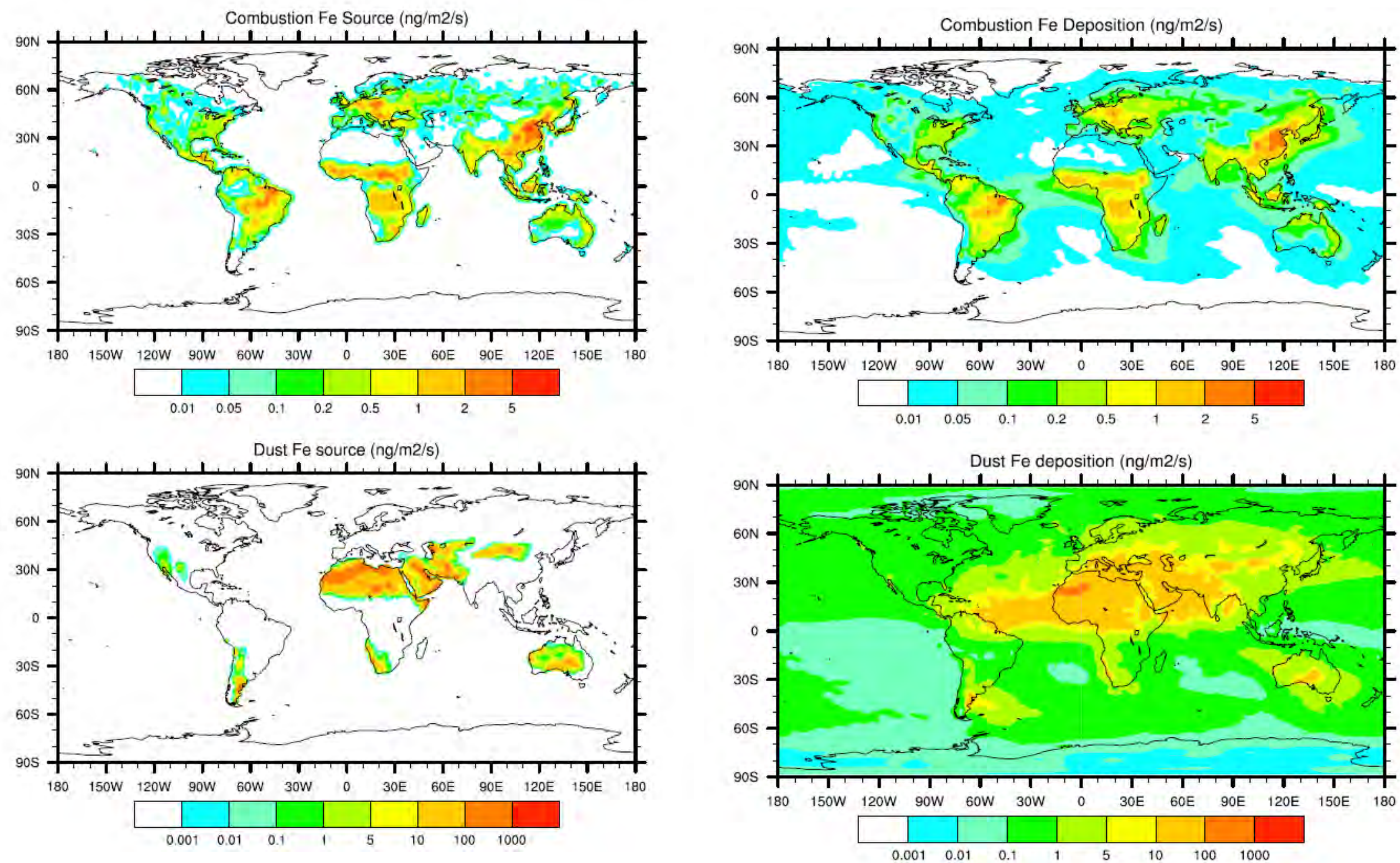
PICES 2009 Annual Meeting   BIO Workshop (W1)

1. ***Reactive iron in the subarctic North Pacific; natural iron enrichments (Kenneth W. Bruland)***
2. ***Comparison of iron distribution between the western and the eastern subarctic Pacific (Jun Nishioka)***
3. ***The role of Haida eddies in iron transport to the eastern subarctic Pacific Ocean (Mark Wells)***
4. ***Factors controlling the spatial variability of spring bloom dynamics in the Oyashio Region(Hiroaki Saito)***
5. ***Natural volcanic iron fertilization of the Subarctic North Pacific (William Crawford)***
6. ***Fe nutrition in micro-sized diatoms in the Oyashio region of the NW subarctic Pacific during spring 2007 (Ai Hattori-Saito)***
7. ***A simulation of chlorofluorocarbons in the Sea of Okhotsk (Keisuke Uchimoto)***
8. ***New NEMURO-based model incorporating the iron cycle (Yasuhiro Yamanaka)***
9. ***Interplay between ecosystem structures and iron availability in a global marine ecosystem model (Stephanie Dutkiewicz)***
10. ***Effect of Asian dust on the picophytoplankton growth rate and cell cycle (Youngju Lee)***

PICES 2010 Annual Meeting Session 2 (S2)

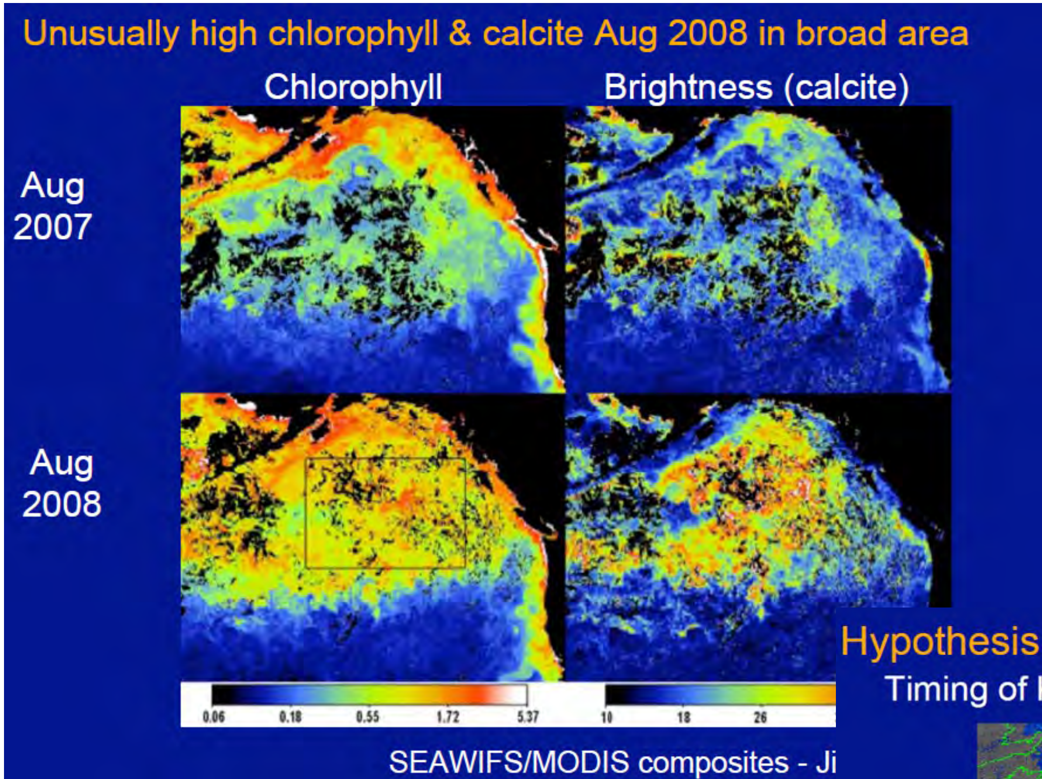
1. *Iron speciation and bioavailability: Insight gained from analytical chemistry and microbial physiology (Jay T. Cullen)*
2. *Response of marine ecosystem to Asian dust fertilization from coastal sea to open ocean (Huiwang Gao)*
3. *A review of the influence of ocean fertilization on marine biodiversity (Hong Chen)*
4. *Advection of deep-sea and coastal water into the HNLC region of the northeast Pacific Ocean (William Crawford)*
5. *Evidence for regulation of Fe(II) Oxidation Rates by Organic Complexing Ligands in the Eastern Subarctic Pacific (Mark L. Wells)*
6. *Impact of Asian dust on plankton and DMS production in the Northeast Subarctic Pacific (Maurice Levasseur)*
7. *Mechanisms controlling dissolved iron distribution in the North Pacific: A model study (Kazuhiro Misumi)*
8. *Modeling impacts of mesoscale eddies on iron cycle and biogeochemical processes in the Gulf of Alaska (Fei Chai)*
9. *Oceanic iron supply mechanisms supporting the spring diatom bloom in the Oyashio region, western subarctic Pacific (Jun Nishioka)*
10. *The international Surface Ocean- Lower Atmosphere Study (SOLAS) project and its mid-term strategy (Emilie Brévière)*
11. *The role of zooplankton in buffering geographical heterogeneity of primary productivity (Hiroaki Saito)*

3. Determine the natural supplies of iron to the North Pacific, which includes atmospheric dust transport and movement of iron-enriched waters, and examine linkages between iron supply and ecosystem responses.

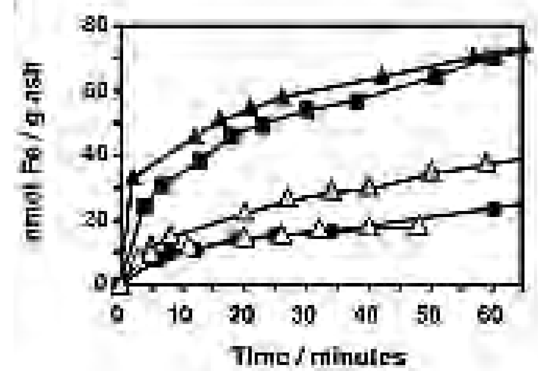


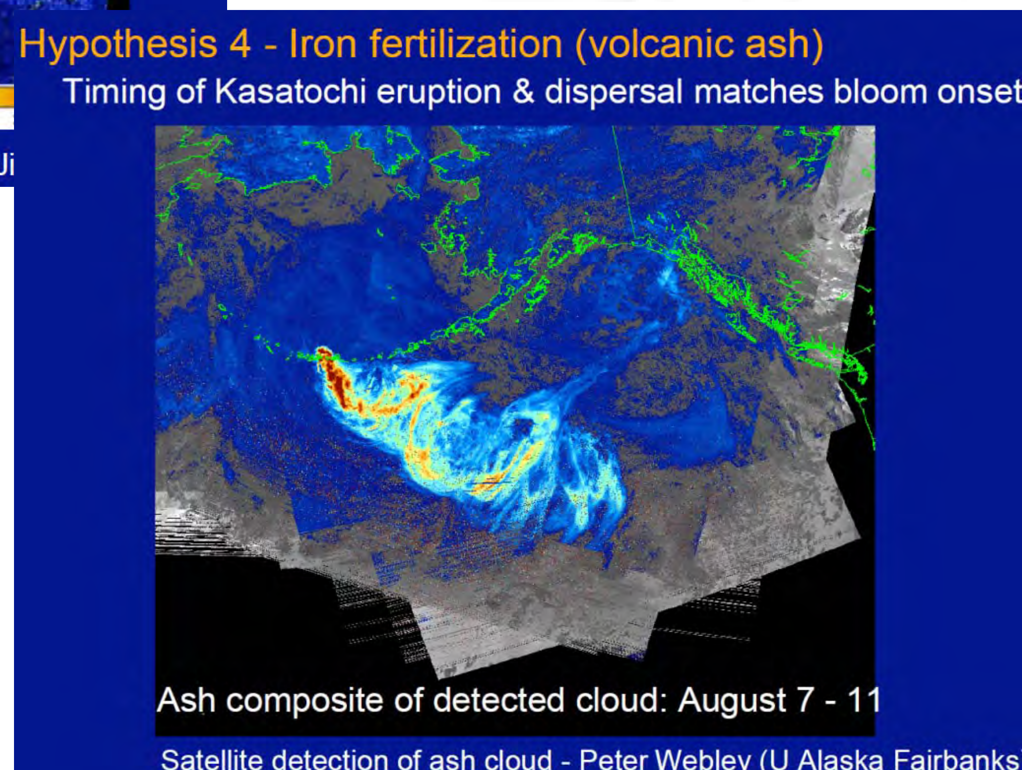
(Luo et al., 2008, GBC)

Atmospheric dust input and Fe solubility vary in association with different types of dusts, including industrial combustion sources, biomass burning and volcanic ash.



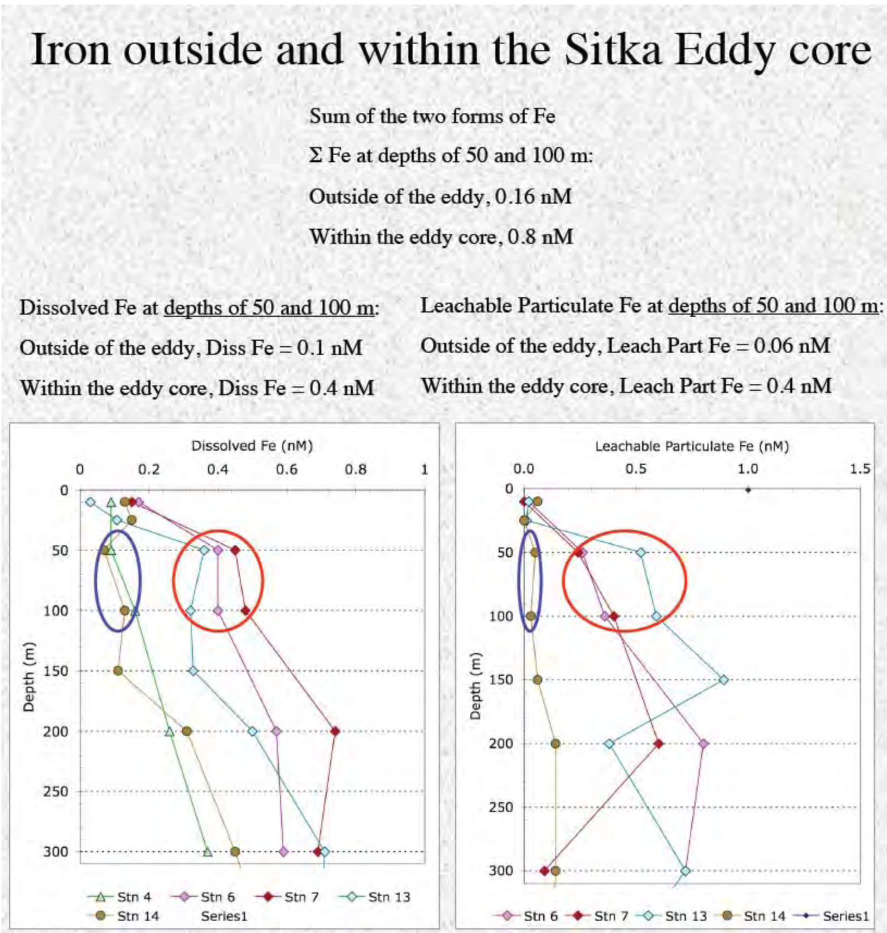
Laboratory experiments have shown iron
Release from volcanic ash in seawater
(Duggen et al., 2007, 2010)

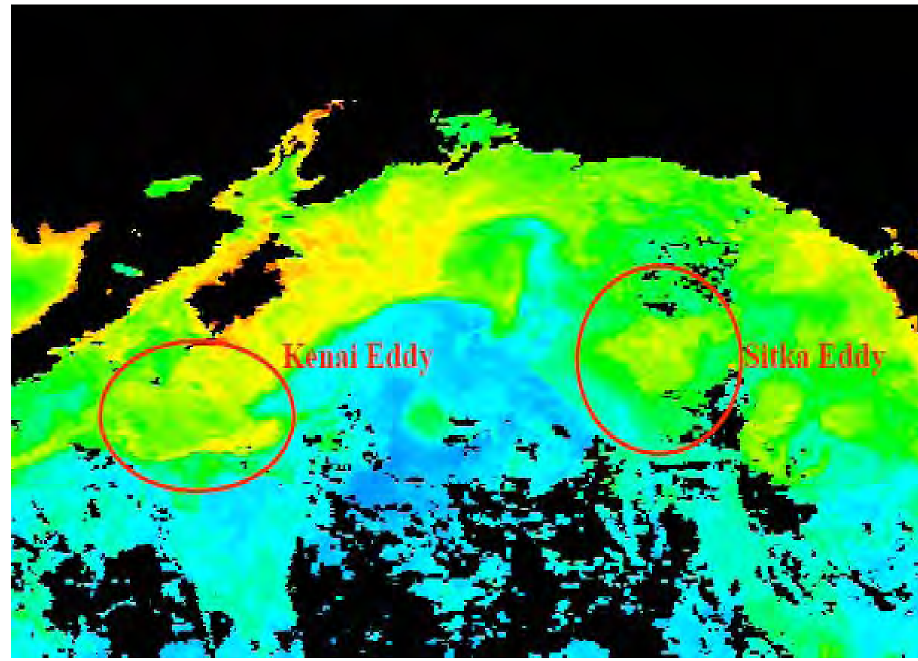




(Roberta Hamme et al., PICES 2009 meeting)

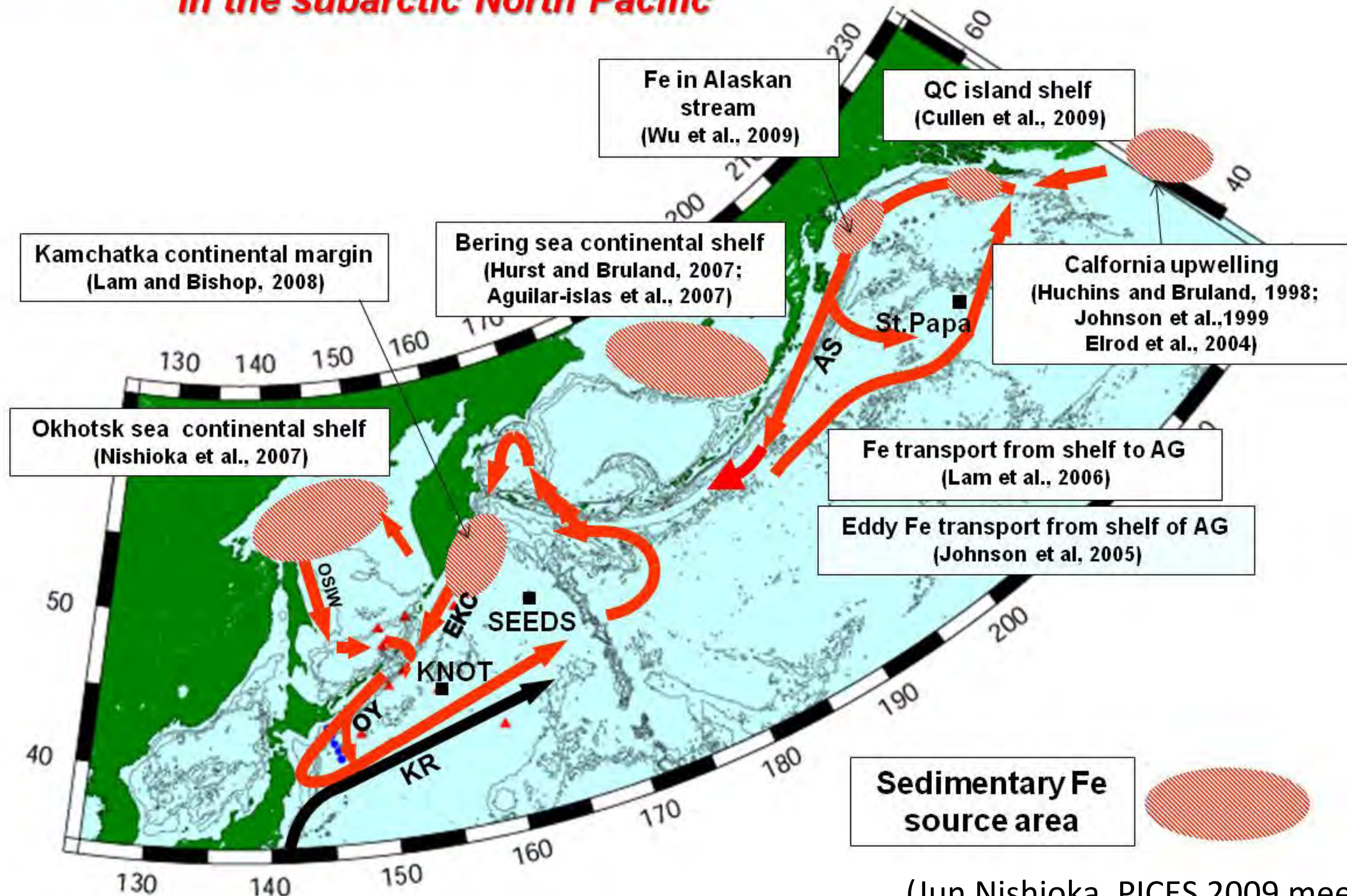
Eddies and coastal currents are playing an important role in transporting dissolved and particulate Fe, especially the continental source from rivers and resuspended sediments.





(Ken Bruland, PICES 2009 meeting)

Sedimentary Fe source area and current direction in the subarctic North Pacific

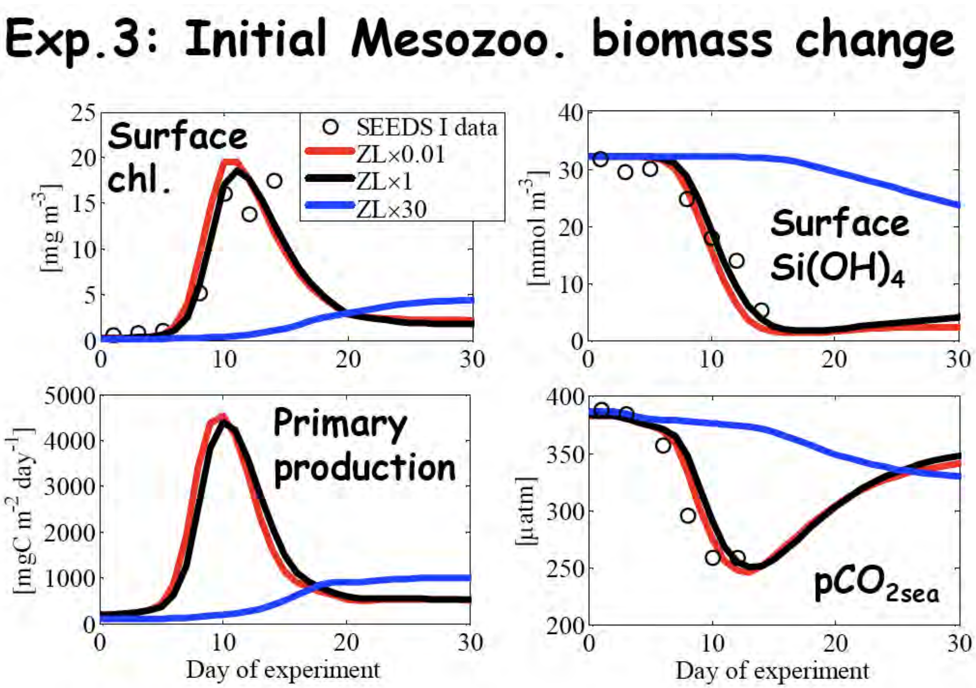


(Jun Nishioka, PICES 2009 meeting)

Both dissolved Fe and leachable particulate Fe are important for better understandings of Fe biogeochemistry in the North Pacific.

Information on the residence time of particulate Fe during the lateral transport is missing.

4. Identify gaps and issues related to experimental and modeling activities, encourage and plan national and international scientific programs on iron biogeochemistry and its impact on marine ecosystems in the North Pacific.

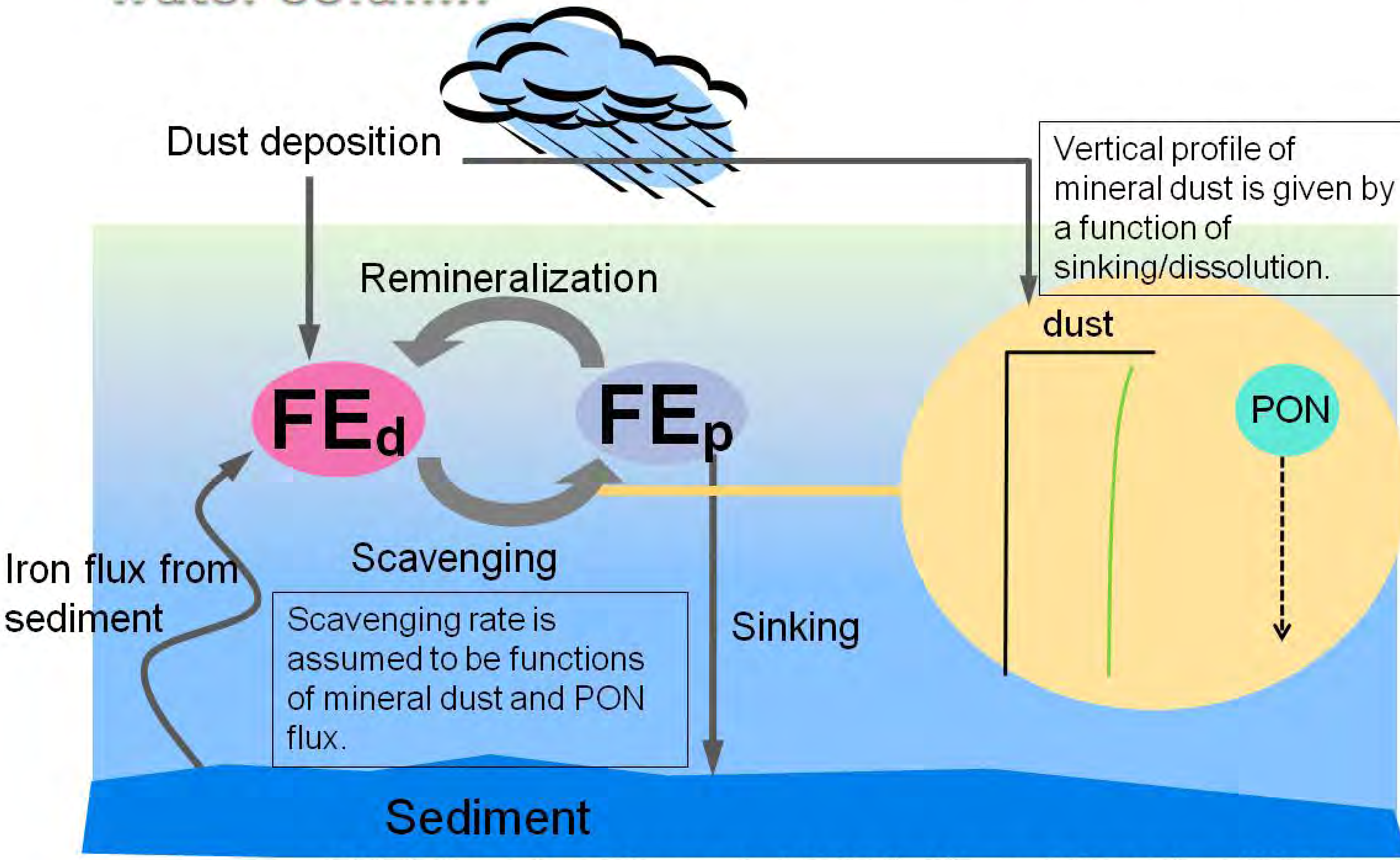


Testing the initial conditions (mixed layer depth, phytoplankton and zooplankton biomass) on the outcome of iron fertilization experiments (SEEDS I and II).

Fujii and Chai, 2009.

- **Model parameterizations should be improved with iron supplies from various sources**
- **Fe removal and recycling are not well described in models**
- **More experimental data are needed regarding physiological response of phytoplankton groups to Fe and community structure changes to Fe supplies.**
- **Complied Fe data and OIF results will benefit model development and improvement.**

Dissolved and particulate iron cycles in the water column



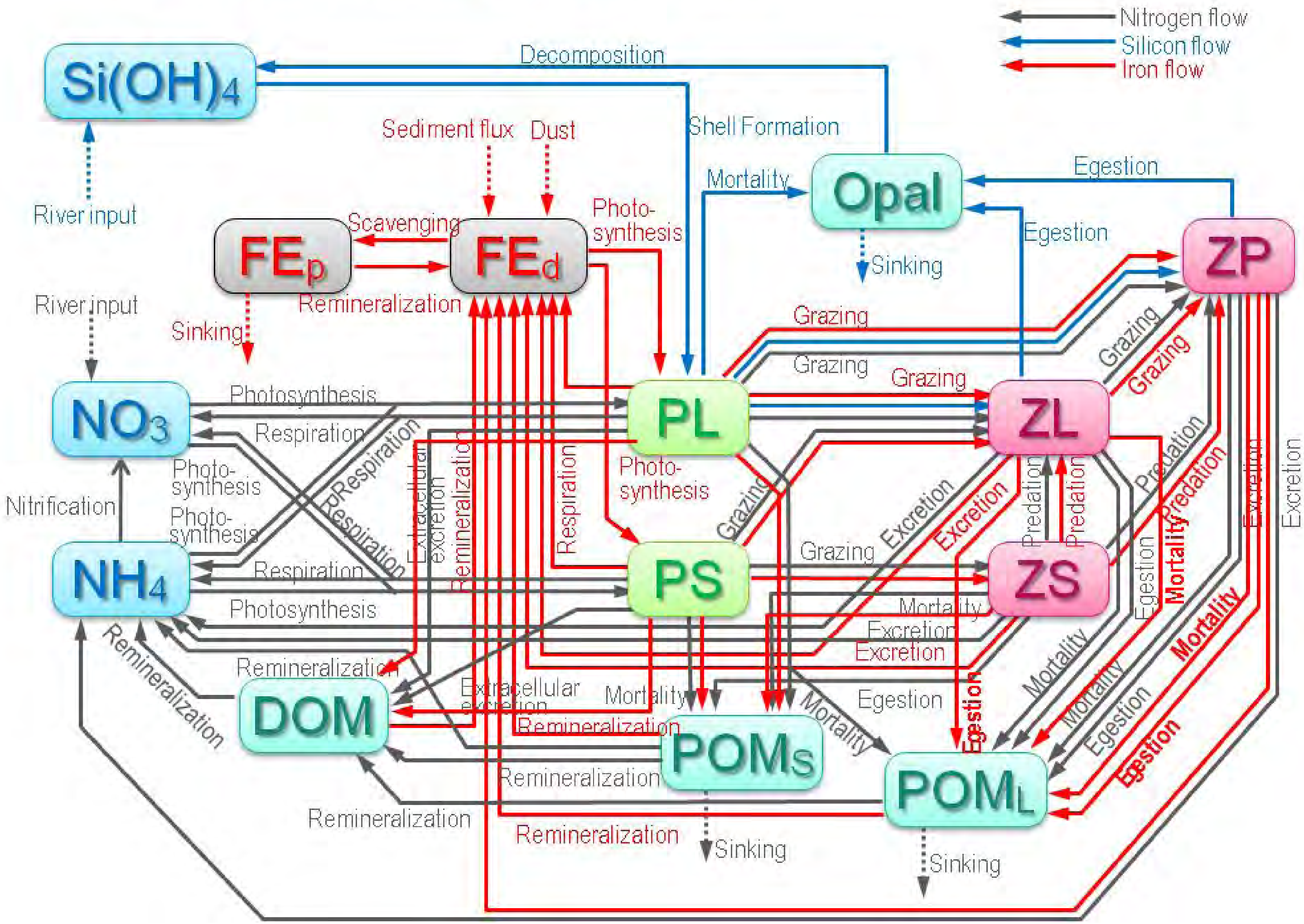
Mainly based on Moore et al.(2004), Moore & Braucher (2008)

(Yasuhiro Yamanaka, PICES 2009 meeting)

Flow chart of New Model

The original NEMURO has no iron cycle.

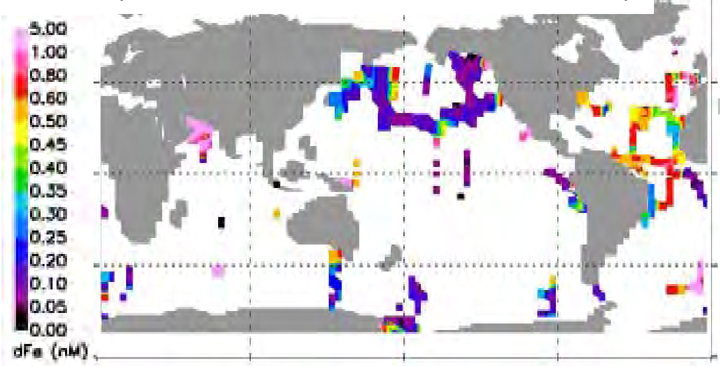
(Yasuhiro Yamanaka, PICES 2009 meeting)



The new model greatly improved its model performance compared with the original NEMURO.

Interplay between iron and ecosystem

Observations of Iron (nM)
(from Moore+Braucher, BG, 2008)



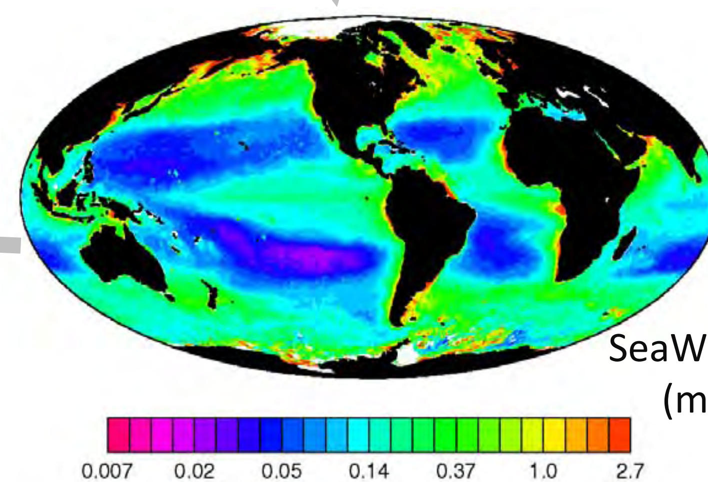
iron sets ecosystem structure
and concentrations

change in source of iron leads to:

- increased biomass in iron limited regions
- increased regions of nitrogen fixation and increased biomass in those regions
- increased biomass leads to decreased lateral nitrogen supply, and reduced biomass in some regions

community affect iron concentrations:

- change in phytoplankton physiology leads to change in iron concentration (but only where iron is limiting that phytoplankton)
- diazotroph physiology control where nitrogen fixation can occur



SeaWiFS Chl a (mg/m^3)

WG22 final report

- Data sets of iron and related parameters in the North Pacific

- Descriptions on
  the natural supplies of iron to the North Pacific, and
  linkages between iron supply and ecosystem responses

- Basic questions and hypothesis for future Fe-related activities in the North Pacific

- Proposal of national and international scientific programs for testing the hypothesis

- Extended abstracts from the WG22 workshop/session

Linkages between WG22 activities and FUTURE program/COVE

- **Data sets of iron and related parameters in the North Pacific would contribute to improvement of marine ecosystem models that will be used for understanding** *how do ecosystems respond to natural and anthropogenic forcing***.**

- **Basic questions and hypothesis that will be summarized in the final report of WG22 would give useful suggestions to narrow the target of COVE activities concerning the role of iron in regulating ecosystem responses to natural and anthropogenic forcing.**

Potential linkages to FUTURE

◆ A new research proposal by Maurice Levasseur (U. Laval, Canada)

Sensitivity of HNLC regions to Fe-dust deposition in a low pH ocean: a case for a multiple-stressor approach

◆ **WG-22 TOR-5** "*Elucidate the role of iron as a potential regulator of harmful algal bloom (HAB) in coastal ecosystems of the North Pacific*" **has not been fully taken up for discussion in WG-22. This topic could be incorporated in the activity plans of FUTURE.**

Sensitivity of HNLC regions to Fe-dust deposition in a low pH ocean: a case for a multiple-stressor approach

Maurice Levasseur

With the intellectual contributions of Martine Lizotte (U. Laval, Canada), Shigenobu Takeda (U. of Tokyo, Japan), Philippe Tortell (UBC, Canada), Gui-Peng Yang (Ocean University of China, China), Guangyu Shi (Institute of Atmospheric Physics, China), Hui-Wang Gao (Ocean Institute of China, China), Nadja Steiner (Institute of Ocean Sciences, Canada), Lisa Miller (Institute of Ocean Sciences, Canada), Michael Scarratt (Maurice Lamontagne Institute, Canada)

Objectives

1. To determine how the predicted decrease in ocean pH will impact the response of the HNLC ecosystems to dust (Fe) deposition in the Subarctic Pacific.

2. To develop standardized protocols to test the co-effect of Fe and pH (onboard or *in situ* mesocosms) to be applied in the different HNLC regions as part of a SOLAS coordinated effort.

Rational

- Twelve large scale iron ocean fertilizations (IOFs) have been conducted so far in order to assess the impact of Fe deposition on primary production, carbon sequestration, climate-relevant trace gas emissions, and global climate.
- These experiments have shown that Fe-dust can increase, albeit modestly, carbon sequestration, and significantly affect the production and flux of DMS and other trace gases to the atmosphere (see review MEPS 2008).
- In several of these experiments, the dynamics of DMS were tightly coupled to the growth and decline of prymnesiophytes such as *Emiliania huxleyi* and *Phaeocystis* spp. which tended to respond quickly to iron addition.
- These early blooms of prymnesiophytes also contributed to carbon production and sequestration by diverting a portion of the nutrients from the diatom blooms.
- Several prymnesiophytes are calicifying organisms, which are highly sensitive to variations in pH.
- Thus, the current and predicted decrease in oceanic pH levels could affect their response to iron availability.

This could significantly alter, to an unknown degree, the impact of Fe-dust reported during the past IOFs.

General Approaches

- This important question should ideally be addressed through large scale *in situ* experiments (addition of Dust, Fe, Fe+CO_2, CO_2, control).
- But this represents a technical, financial, and logistical challenge probably out of reach.
- For this reason, we propose to start with the development of onboard and *in situ* mesocosms protocols.
- Such protocols should allow maintaining a constant pH level for the duration of the experiment (several days).
- These experiments should be conducted in the different HNLC regions.

The target area for the PICES FUTURE/COVEcould be the North Pacific HNLC waters.

Specific approaches for PICES/FUTURE

- In Canada, part of this project could be associated with the ongoing Line P cruise program lead by the Institute of Ocean Sciences of the Department of Fisheries and Oceans Canada. Additional days devoted to the project could be added to the two Line P summer cruises if we can find extra money (NSERC) to cover these extra days at sea.

- Chinese colleagues could explore the possibility of obtaining a special research permit to use Chinese dust during PICES experiments.

- Mesocosms have been developed for ocean pH studies by Ulf Riebesell. Levasseur contacted Riebesell for potential use of the mesocosms at OSP (2011?).