Impact of iron on DMS cycling in the Subarctic Pacific: a synthesis of SERIES and SEEDS-II

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FeAX's

(adapted from de Baar et al. 2005)
Impact of Fe on DMS during FeAX’s (the pre-SEEDS/SERIES era)

(de Baar et al. 2005)
Impact of FE on DMS
SERIES

DMS (μmol m$^{-2}$)

Days since fertilization

Levasseur et al. in press
Impact of Fe on DMS
SEEDS II

Seawater DMS (nM)

Day from Iron fertilization

IN
OUT

Courtesy of I. Nagao et al.
What we learned from SEEDS and SERIES?

The impact of iron on DMS production is more variable than suggested by the results from first FeAX’s

Large temporal variations in DMS outside the patch

Large day-to-day variations

Importance of the ‘control’ station
Marine DMS production

DMSP\(_p\) \(\rightarrow\) DMSP\(_d\) 

- **ALGAE** 
  - DMSP-lyase \(\text{algal}\) 
  - DMSP-lyase \(\text{BACTERIA}\) (C source)

- **ZOOPLOANKTON** 
  - Grazing
  - Cell lysis

- **BACTERIA** 
  - Bacterial demethylation (C & S source)
  - Bacterial consumption
  - Photo-oxydation
  - Oxygenation

DMS 

- **BACTERIA** 
  - Consumption
  - Ventilation
QUESTIONS

1. What makes a HNLC region DMS-rich?

   More algal DMSP?
   More dissolved DMSP?
   More grazing?
   More bacteria?
   More efficient conversion of DMSP into DMS?
THREE SYSTEMS WILL BE COMPARED
SABINA
Study of Air-sea Biogeochemical Interactions in the North Atlantic

![Map of North Atlantic with locations marked and a graph showing DMS (nM) vs Latitude °N for Spring, Summer, and Fall Cruises.](image-url)
SABINA

Study of Air-sea Biogeochemical Interactions in the North Atlantic
Relationships between three S pools

DMSP particulate
DMSP dissolved
DMS
DMS versus DMSPp

North West Atlantic July 2003

T6
Similar range in DMSPp concentrations
DMS increases with DMSPp at OSP
T6 is ‘Pacific’ style
SEEDS II

North West Atlantic July 2003 (L, T1 to T7) (T6)
North East Pacific July 2002 'OUT'

SEEDS II is ‘Atlantic style’
Dissolved DMSP versus particulate DMSP

North West Atlantic July 2003
North West Atlantic July 2003 (L, T1 to T7) (T6)
North East Pacific July 2002 'OUT'

More DMSPd at OSP
SEEDS II

North West Atlantic July 2003 (L, T1 to T7) (T6)
North East Pacific July 2002 'OUT'

SERIES and SEEDS II

Efficient transfer of particulate DMSP to the dissolved pool.

DMSPd-rich environment for bacteria.
QUESTIONS

1. What makes a HNLC region DMS-rich?

- More algal DMSP? **NO**
- More dissolved DMSP? **MAYBE**
- More grazing?
- More bacteria?
- More efficient conversion of DMSP into DMS?
Fe stimulated microzooplankton ingestion rates of nanoplankton

**Ingestion (µg C l⁻¹ d⁻¹)**

<table>
<thead>
<tr>
<th>Days Since Iron Addition</th>
<th>Phytoplankton</th>
<th>Bacteria</th>
<th>Phytoplankton + Bacteria</th>
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<tbody>
<tr>
<td>2</td>
<td></td>
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<td>18</td>
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<td></td>
</tr>
<tr>
<td>Out</td>
<td></td>
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</table>

*Courtesy of Rivkin’s lab*
Microzooplankton ingestion rates during SABINA

Ingestion of phytoplankton

Ingestion of bacteria

Low ingestion

Courtesy of R. Rivkin
QUESTIONS

1. What makes a HNLC region DMS-rich?

   High algal DMSP?  NO
   High dissolved DMSP? MAYBE
   High microzooplankton grazing? NO
   High bacterial abundance?
   More efficient conversion of DMSP into DMS?
Bacterial abundance

IN-OUT bacterial abundance

SEEDS II

SERIES

No clear effect of Fe in SEEDS II

Mean abundance in SERIES

Increase in bacterial abundance at the end in SERIES
DMS versus bacterial abundance

SERIES

Levasseur et al. in press
DMS versus bacterial abundance

SERIES and SEEDS-II

Bacterial abundance (cells L⁻¹)

DMS (nmol L⁻¹)
Low Bacteria High DMS regions (LBHD)

SERIES, SEEDS-II, and T6

![Graph showing bacterial abundance vs. DMS concentration]
QUESTIONS

1. What makes a HNLC region DMS-rich?

More algal DMSP? NO
More dissolved DMSP? MAYBE
More grazing? NO
More bacteria? NO (less is better actually!)

HOW LESS BACTERIA MAY PRODUCE MORE DMS?

- Increasing their DMSP consumption per cell
- Decreasing their DMS consumption
- Increasing their DMS yield
What is controlling this ‘bacterial switch’ in DMSP metabolism?
DMS bacterial yield as a function of DMSP concentrations and S demand

Kiene et al. 2000 hypothesis
Evolution of Kiene et al. hypothesis

1. DMS bacterial yield varies with the bacterial S demand and the availability of DMSP (Kiene et al. 2000)

2. DMS bacterial yield varies with the bacterial S demand and the production of dissolved DMSP (Simó 2001)

3. Bacterial DMS yield varies with the bacterial S demand and the relative contribution of dissolved DMSP to the total dissolved organic S pool/organic matter pool (Pinhassi et al. 2005)
Our results support Pinhassi et al. hypothesis

... and suggest that conditions leading to high DMS yields are mostly encountered when bacterial abundance is low.

Low bacterial S demand in a high DMSPd environment.
Bacterial consumption of DMSP

**SEEDS II**

Maximum rate in SEEDS II

**SERIES**

Very high utilisation rate in SERIES in spite of low bacterial abundance
Bacterial DMS yield in SEEDS II

Proportion of DMSP taken up and cleaved into DMS

Days since fertilization

Bacterial DMS yield (% of DMSPd cleaved)
Microbial DMS yield in SEEDS II

D) Bacterial DMS yield (%)

Few outpatch values

Maximum yield in SEEDS II

DMS (μmol m$^{-2}$)

Days since fertilization
Future Works

We need better sampling of the unfertilized region (control)
   Same sampling frequency, same rate measurements

We need better characterisation of the bacterial DMS(P) dynamics
   DOC and DOS measurements
   Bacterial DMS yield
   Bacterioplankton assemblage
Collaborators

Michael Scarratt
Sonia Michaud
CS Wong
Richard Rivkin
Michelle Hale
Ronald Kiene
Alain Vézina
Atsushi Tsuda
Yvonnick Le Clainche
Gitane Caron
Anissa Merzouk
Martine Lizotte
…and all SERIES and SEEDS II colleagues
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Simulation of the seasonal cycle of sea surface DMS concentration at OSP (subarctic N E Pacific) using the coupled ocean-biogeochemical model developed in collaboration between U.LAVAL (Y. Le Clainche, M. Levasseur) and CCCma (N. Steiner, K. Denman)
\[ \text{DMSP}_p \text{(Ph1)} \quad S_{\text{DMSP}}:N \; \gamma_1 = 0.5 \]

\[ \text{DMSP}_d \quad \gamma_1 \times \begin{cases} \text{Grazing} \\ \text{Excretion} \\ \text{Mortality} \end{cases} \]

\[ \text{DMSP}_d \quad \text{bacterial} \quad \text{consumption} \quad \delta_1 \times \text{DMSP}_d(z) \quad \delta_1 = 3 \; \text{d}^{-1} \]

\[ \text{DMS yield} \; \alpha = 0.4 \]

\[ \text{Surface ventilation} \quad \text{Wanninkhof (1992)} \]

\[ \text{Photo-oxydation} \quad \Phi. \; I(z) \times \text{DMS}(z) \quad \Phi = 0.006 \; \text{d}^{-1} \cdot (\text{W.m}^{-2})^{-1} \]

\[ \text{DMSP}_p \text{(Ph2)} \quad S_{\text{DMSP}}:N \; \gamma_2 = 0.1 \]

\[ \text{DMSP}_d \quad \gamma_2 \times \begin{cases} \text{Grazing} \\ \text{Excretion} \\ \text{Mortality} \end{cases} \]

\[ \text{Demethylation} \]

\[ \text{Bacterial} \quad \text{consumption} \quad \delta_2 \times \text{DMS}(z) \quad \delta_2 = 0.4 \; \text{d}^{-1} \]
Q-Panel UVA-340 lamps
(2 x 40 W)
ratio of UVB/UVA = 0.06 = to ratio in NE pacific at 1 m.
295 nm wavelength cut-off

Tedlar® gas-sampling bag

Sylvania cool white fluorescent lamps
(6 x 40W)
Testing the light hypothesis

Courtesy of Louise Darroch
## Initial concentrations in algal DMSP in FeAX’x

<table>
<thead>
<tr>
<th>Study area</th>
<th>DMSPp (nmol L(^{-1}))</th>
<th>DMS (nmol L(^{-1}))</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td>Equatorial Pacific (IronEx-1)</td>
<td>30</td>
<td>2.7</td>
<td>Turner et al. (2004)</td>
</tr>
<tr>
<td>Equatorial Pacific (IronEx-2)</td>
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<td>2.5</td>
<td>Turner et al. (2004)</td>
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<td>Southern Ocean (SOIREE)</td>
<td>27</td>
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<td>Southern Ocean (EisenEx)</td>
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<td>1.9</td>
<td>Turner et al. (2004)</td>
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<td>South-East Pacific</td>
<td>4-16</td>
<td>n.m.*</td>
<td>Riseman and DiTullio (2004)</td>
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<tr>
<td>North East Pacific (SERIES)</td>
<td>98-130</td>
<td>8.5-10.9</td>
<td>This study</td>
</tr>
<tr>
<td>North West Pacific (SEEDS II)</td>
<td>5-53</td>
<td>~3.8</td>
<td>I. Nagao (pers. Comm.)</td>
</tr>
</tbody>
</table>

**SERIES:** HIGHEST LEVELS OF DMSPp

**SEEDS II:** SIMILAR CONCENTRATIONS THAN EisenEx

Levasseur et al. (in press)