Some (other) possible climate and biogeochemical effects of iron fertilization

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Special thanks to: Sue Turner (UEA), Manfredi Manizza (MIT)
Possible effects

The marine biota have a range of effects on the global environment, most of which might be influenced by widespread iron fertilization, e.g:

- Production of non-$CO_2$ greenhouse gases: $CH_4$, $N_2O$
- Production of aerosol and CCN precursors: DMS and isoprene.
- Changes to oxidation potential of the atmosphere (carbon monoxide, isoprene)
- Organo-halogen source/sink: influences tropospheric and stratospheric ozone and oxidation potential.
- Changing light climate in the surface layer - can alter surface temperature, hydrography, ocean circulation, ice cover.
**Side effects: nitrous oxide production**

- Enhanced sinking flux leads to lower $O_2$ concentrations below thermocline, potentially $N_2O$ production.
- Law and Ling (2001) observed ~ 7% increase in $N_2O$ in pycnocline during Soiree. They calculate that possibly 6-12% of the radiative effect of $CO_2$ reduction might be offset by increased $N_2O$ release.
Greenhouse gases: $\text{N}_2\text{O}$

$\text{N}_2\text{O}$ at SOIREE “in” stations compared to $\text{N}_2\text{O}$ predicted from the concentrations at outside stations

- They observed $\sim 7\%$ increase in $\text{N}_2\text{O}$ in pycnocline. They calculate that possibly $6-12\%$ of the radiative effect of $\text{CO}_2$ reduction might be offset by increased $\text{N}_2\text{O}$ release.

Law CS, Ling RD
Nitrous oxide flux and response to increased iron availability in the Antarctic Circumpolar Current
DEEP-SEA RES. II 48 : 2509-2527 2001
Jin and Gruber modelling study...

## Greenhouse gases: CH$_4$

<table>
<thead>
<tr>
<th>Compound</th>
<th>In-patch</th>
<th></th>
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<th>Out-of-patch</th>
<th></th>
<th></th>
<th>Change, %‡</th>
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<tbody>
<tr>
<td></td>
<td>Average</td>
<td>SD</td>
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<td>Average</td>
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<tr>
<td>O$_2$, ppmv</td>
<td>6,920</td>
<td>10</td>
<td>2.4</td>
<td>6,690</td>
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<tr>
<td>Fluorescence, V</td>
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<td>2.4</td>
<td>0.2</td>
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<tr>
<td>CO$_2$, ppmv</td>
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<td>376.7</td>
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<td>-8.3</td>
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<tr>
<td>CH$_4$, ppmv§</td>
<td>1.739</td>
<td>0.004</td>
<td>2.4</td>
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<td>0.002</td>
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<tr>
<td>CO*, ppbv§</td>
<td>860</td>
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<td>1,790</td>
<td>80</td>
<td>4,200</td>
<td>-52</td>
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<tr>
<td>Isoprene, pptv</td>
<td>560</td>
<td>13</td>
<td>38,000</td>
<td>139</td>
<td>6</td>
<td>9,300</td>
<td>300</td>
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<tr>
<td>CH$_3$Br, pptv</td>
<td>6.5</td>
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<tr>
<td>DMS, pptv</td>
<td>7,600</td>
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<td>11,000</td>
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<td>90</td>
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*Wingenter et al., PNAS (2004) – results from SOFEX*
Greenhouse gases

- Minor production of \( \text{CH}_4 \) observed in SOFEX
- Moderate production of \( \text{N}_2\text{O} \) observed in SOIREE.
  - Might be expected: nitrification pathway (oxidation of hydroxylamine) is dependent on an iron-containing enzyme and produces \( \text{N}_2\text{O} \)
  - Law and Ling suggest about 6-12% offset of reduction in \( \text{CO}_2 \) greenhouse by \( \text{N}_2\text{O} \) based on their observations.
  - This is an underestimate if large-scale fertilization produces lowered oxygen concentrations in pycnocline.
  - Also an underestimate for the tropical oceans.
DMS

Percentage increase in surface DMS in three Fe enrichment experiments

Correlation between SF6 patch and DMS concentration in SOIREE and EISENEX (Turner et al., 2004)
DMS

- Substantial production of DMSP and DMS repeatedly observed in Fe Experiments.
  - Mostly produced by plankton groups other than diatoms.
  - Likely to be a dynamic response - might not be sustained in longer experiments.

- Iron sensitive regions (Southern Ocean and equatorial Pacific) are also thought to be most sensitive to cloud-albedo feedbacks because of lack of other sources of CCN.

- In large fertilizations, several-fold increase in flux to the atmosphere would be predicted to have a climate effect
Fig. 1. The 8-day averaged (A) SeaWiFS-observed chlorophyll $a$ and (B) MODIS-retrieved cloud (droplet) effective radius. Data for [Chl $a$] is gridded at a resolution of 9 by 9 km and zonally averaged between 49°S and 54°S; data for $R_{eff}$ is gridded at a resolution of 1° by 1° and averaged in the area of 49° to 54°S and 35° to 41°W. White areas in (A) indicate missing data.

Climatic effect of DMS release from Fe fertilization

• Effects locally ~1 degree C?
  - In the short -to- medium term, this cooling is considerably larger than any $CO_2$ sequestration effect.
Oxidation potential of the atmosphere (Wingenter et al., 2004, Moore and Wang, 2006)

- Substantial (50%) decrease in oceanic CO source observed during SOFEX
- Substantial increase in isoprene in SOFEX and SERIES (but it's a minor atmospheric constituent).
- CO is a sink for [OH]. Isoprene is also a sink.
- Wingenter et al. estimate a net increase in [OH] in the lower troposphere over the S.O. of 7% if the trends in the experiment were to extend to the entire S.O.
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Wingenter et al., PNAS (2005) - results from SOFEX
Halocarbons

- Gervais et al (2003, EISENEX) report a decrease in surface concentrations of \( \text{CH}_3\text{Br} \) and an increase in \( \text{CH}_3\text{I} \).
- Wingenter et al (2004, SOFEX) report the opposite trends -- increase in \( \text{CH}_3\text{Br} \) and decrease in \( \text{CH}_3\text{I} \).
Trace gas concentrations during Eisenex:

- **A. Chl a**
- **B. CO₂**
- **C. DMS**
- **D. CH₃I**
- **E. CH₃ONO₂**
- **F. CHBr₃**

*Gervais et al., 2003, Liss et al., (2006).*
Summary: “other” gases

- Enhanced DMS and isoprene production
- Enhanced N$_2$O production, possibly CH$_4$
- No overall pattern for CH$_3$I or CH$_3$Br: sometimes a decrease, sometimes an increase, sometimes no trend.
- Decreased source of CO.
Bio-optical feedback effects of plankton

- Light absorption by plankton has substantial effects on ocean physics
  - Increase in mixed layer temperature
  - Decrease in mixed layer depth
  - Increased baroclinicity leading to stronger “thermal wind” currents, upwelling in tropics
  - Decreased ice coverage.
Impact of chlorophyll on the Pacific cold tongue in a coupled OAGCM: Anderson, Gnanadesikan et al., GRL June 2007
Bio-optical feedback effects of Fe Fertilization

- No specific modelling studies (that I'm aware of).
- Scaling from Manizza et al, and assuming large scale fertilizations that double plankton abundances in Southern Ocean, equatorial Pacific, we might expect:
  - ~0.2°C warming in Southern Ocean
  - ~0.3°C cooling in parts of equatorial Pacific (and enhanced baroclinicity, leading to stronger geostrophic currents).
  - A few percent decrease in sea ice cover in Southern Ocean.
  - Overall, changes in SST and PP lead to changes in the physical uptake of CO₂ in the oceans (probably a decrease ~0.1 GtC per year; Manizza et al., submitted to JGR)
Conclusions

• Numerous biogeochemical and biophysical “side effects”. Some may help combat climate change, some exacerbate it.
• DMS emissions are potentially more efficient at combating global warming than CO$_2$ uptake.
• Greenhouse gas emissions will partially negate the positive effect of CO$_2$ uptake.
• Biophysical effects potentially quite substantial, and little investigated thus far. They might decrease overall uptake of CO$_2$ by reducing ocean overturning.
Greenhouse gases: N$_2$O

Law CS, Ling RD

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Legal questions?

- Will organizations undertaking Fe fertilization (whether commercial, scientific, governmental or intergovernmental) be legally responsible for the side effects they engender?
Atmospheric Consequences

- Enhanced atmospheric greenhouse (N\(_2\)O)
- Increased cloud albedo (DMS, Isoprene)
- Increased [OH] content (CO decrease)