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:

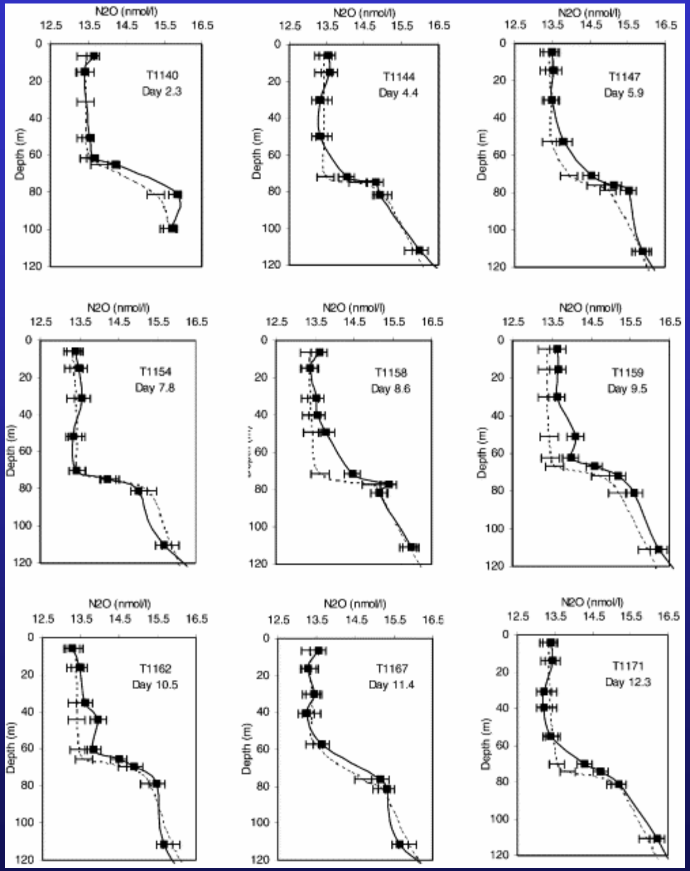
- Production of non-CO_2 greenhouse gases: CH_4, N_2O
- Production of aerosol and CCN precursors: DMS and isoprene.
- Changes to oxidation potential of the atmosphere (carbon monoxide, isoprene)
- Organo-halogen source/sink: influences tropospheric and stratospheric ozone and oxidation potential.
- Changing 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 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: N_2O

N_2O at SOIREE "in" stations compared to N2O predicted from the concentrations at outside stations



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

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Jin and Gruber modelling study…

Southern Ocean

Tropical oceans

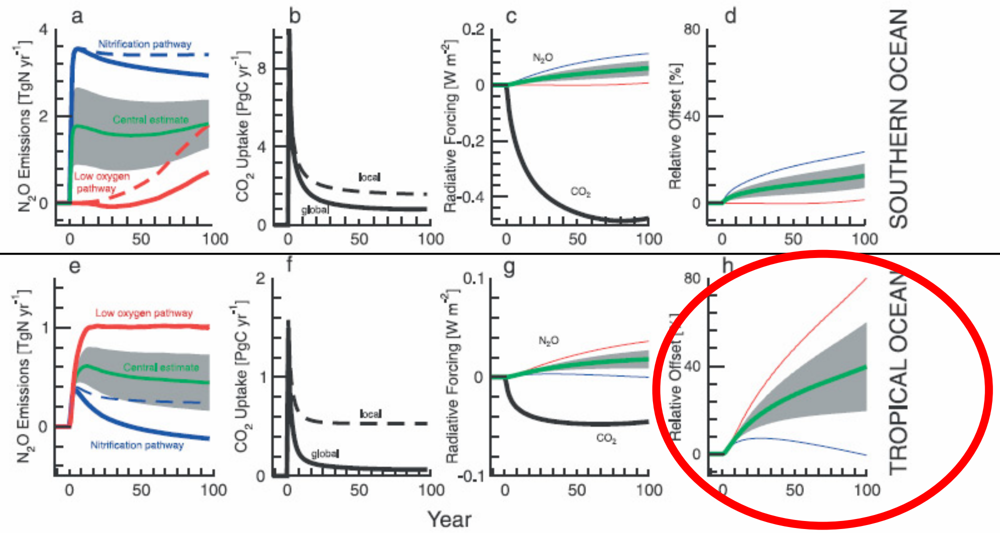


Figure 1. Time series of the response of oceanic and atmospheric N_2O and CO_2 to long-term (100yr) and large-scale fertilizations. Shown are the changes in response to fertilization (a–d) in the Southern Ocean (south of 31°S) and (e–h) in the Tropics (18°S–18°N) relative to control simulations. (a) and (e): Fertilization induced N_2O emissions from the ocean surface. (b) and (f): Fertilization induced CO_2 uptake by the ocean surface. (c) and (g): Fertilization induced changes in atmospheric radiative forcing. (d) and (h): Magnitudes of the N_2O offsetting effect. The blue and red lines indicate the emissions induced by the nitrification and low oxygen pathways, respectively. The green line represents our central estimate, with the uncertainties indicated as a gray band. All solid lines show global changes, while the dashed lines represent the fluxes integrated over the fertilized areas only. The results are from the HiSo-Lo model.

Jin, X., a nd N. Gruber, Offsetting the radiative benefit of ocean iron fertilization by enhancing N_2O emissions, *Geophysical Research Letters*, **30**(24), 2249, doi:10.1029/2003GL018458, 2003

Greenhouse gases: CH_4

	In-patch			Out-of-patch			
Compound	Average	SD	SA, %†	Average	SD	SA, %	Change, %‡
O_2, ppmv	6,920	10		6,690	17		3.4
Fluorescence, V	12.3	0.7		2.4	0.2		400
CO_2, ppmv	346	1		376.7	0.8		-8.3
CH_4, ppmv§	1.739	0.004	2.4	1.722	0.002	1.4	0.99
CO*, ppbv§	860	60	1,900	1,790	80	4,200	-52
Isoprene, pptv	560	13	38,000	139	6	9,300	300
CH_3Br, pptv	6.5	0.1	-1.5	5.7	0.1	-14	14
CH_3I, pptv	4.94	0.07	1100	6.4	0.2	1500	-23
DMS, pptv	7,600	480	11,000	1,560	90	2,200	390

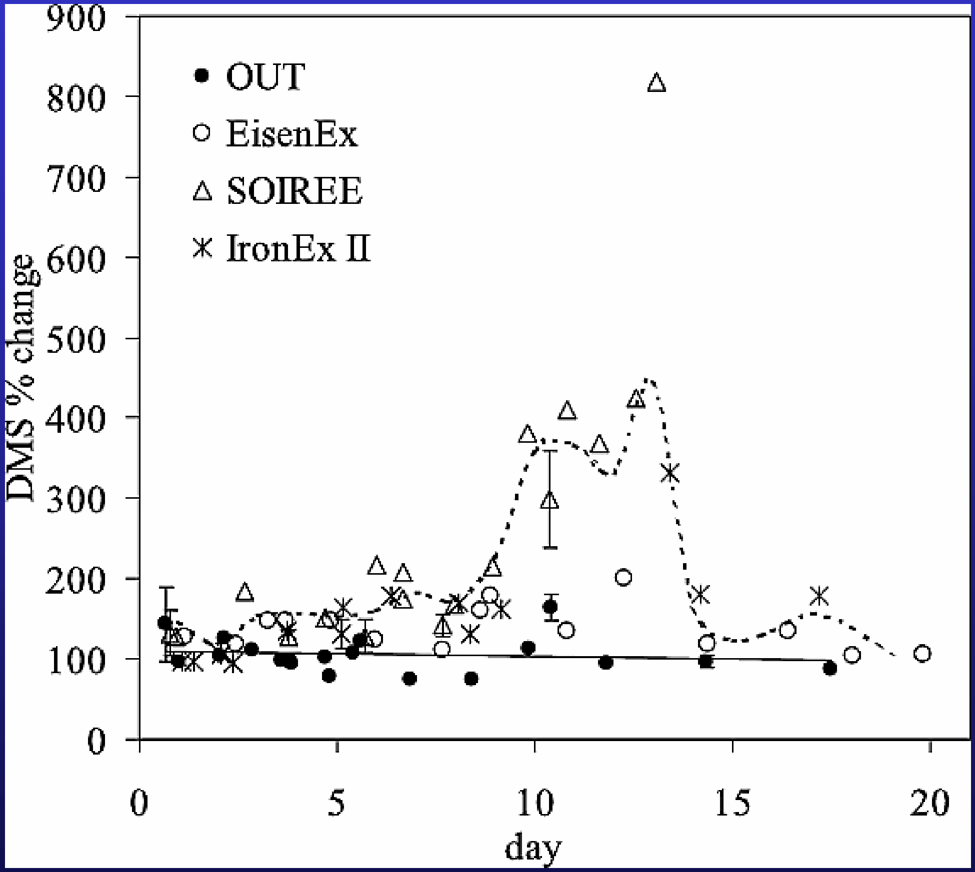
Wingenter et al., PNAS (2004) – results from SOFEX

Greenhouse gases

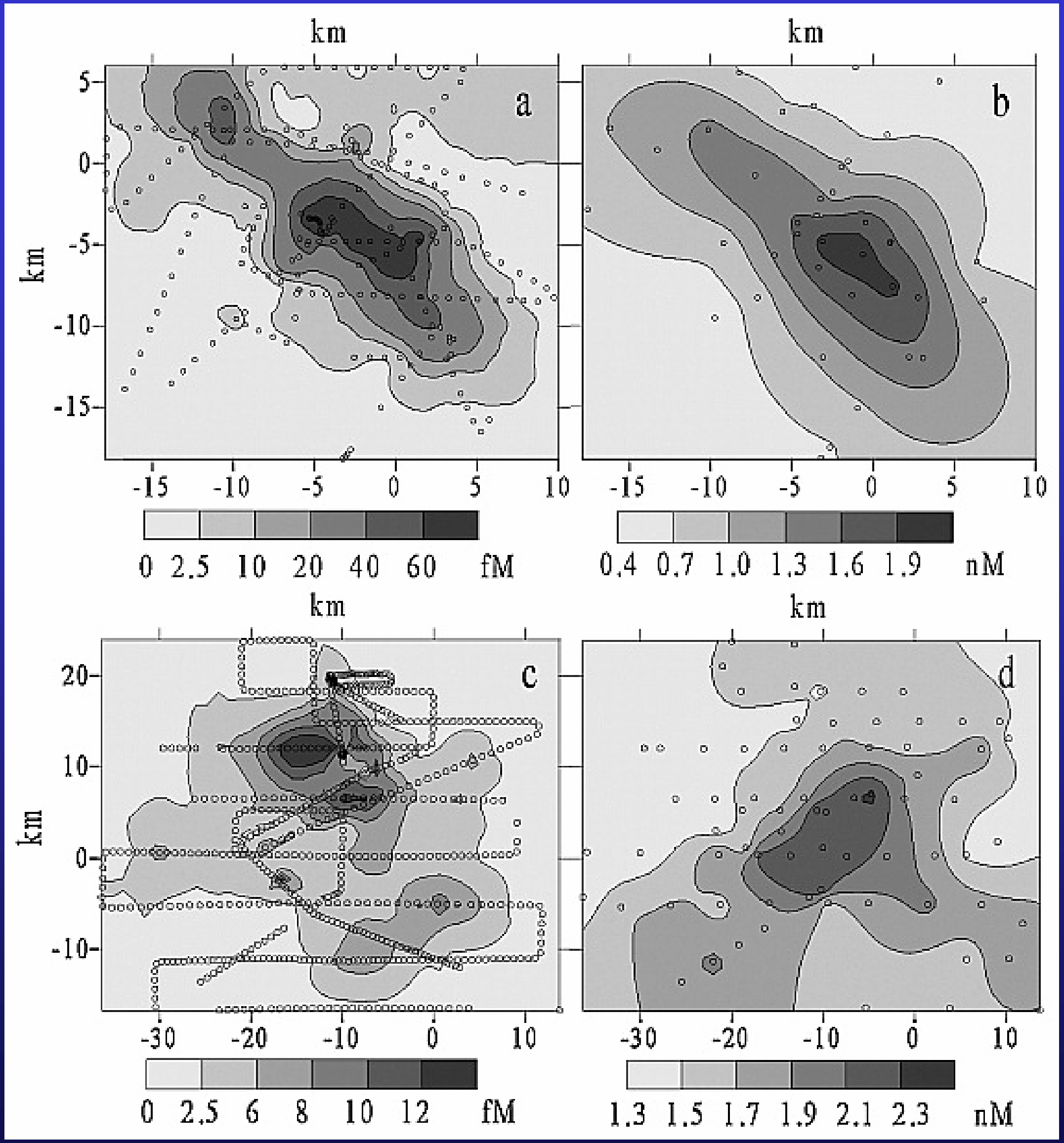
- Minor production of CH_4 observed in SOFEX
- Moderate production of N_2O observed in SOIREE.
  - Might be expected: nitrification pathway (oxidation of hydroxylamine) is dependent on an iron-containing enzyme and produces N_2O
  - Law and Ling suggest about 6-12% offset of reduction in CO_2 greenhouse by N_2O 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



Turner, S. M., M. J. Harvey, C. S. Law, P. D. Nightingale, and P. S. Liss (2004), Iron-induced changes in oceanic sulfur biogeochemistry, Geophys. Res. Lett., 31, L14307, doi:10.1029/2004GL020296.



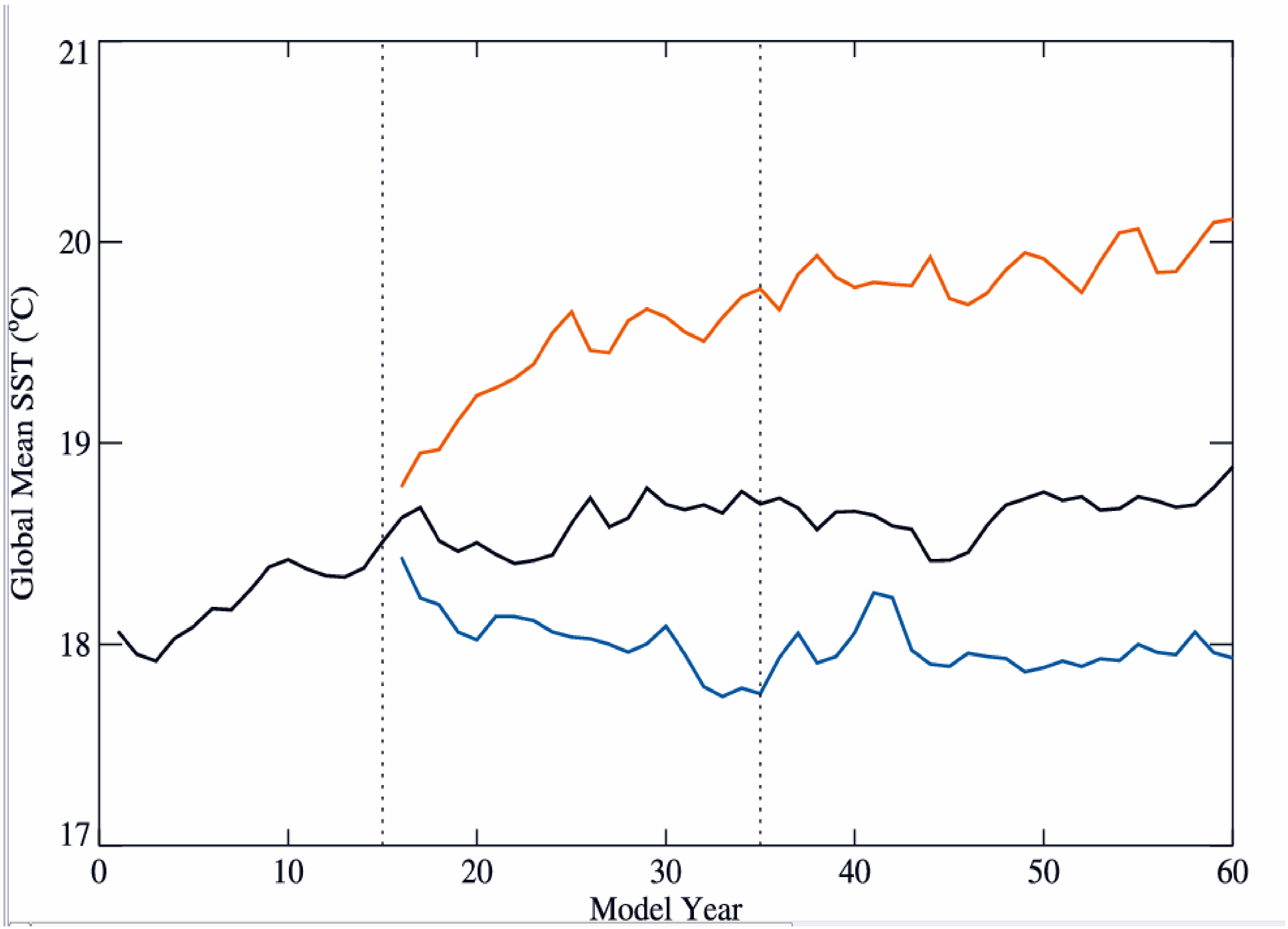
Correlation between SF6 patch and DMS concentration in SOIREE and EISENEX (Turner et al., 2004)

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



Effect in HADCM3 of approximately doubling and halving global DMS flux (Gunson et al, GRL (2006) 33, L07701, doi:10.1029/2005GL024982.

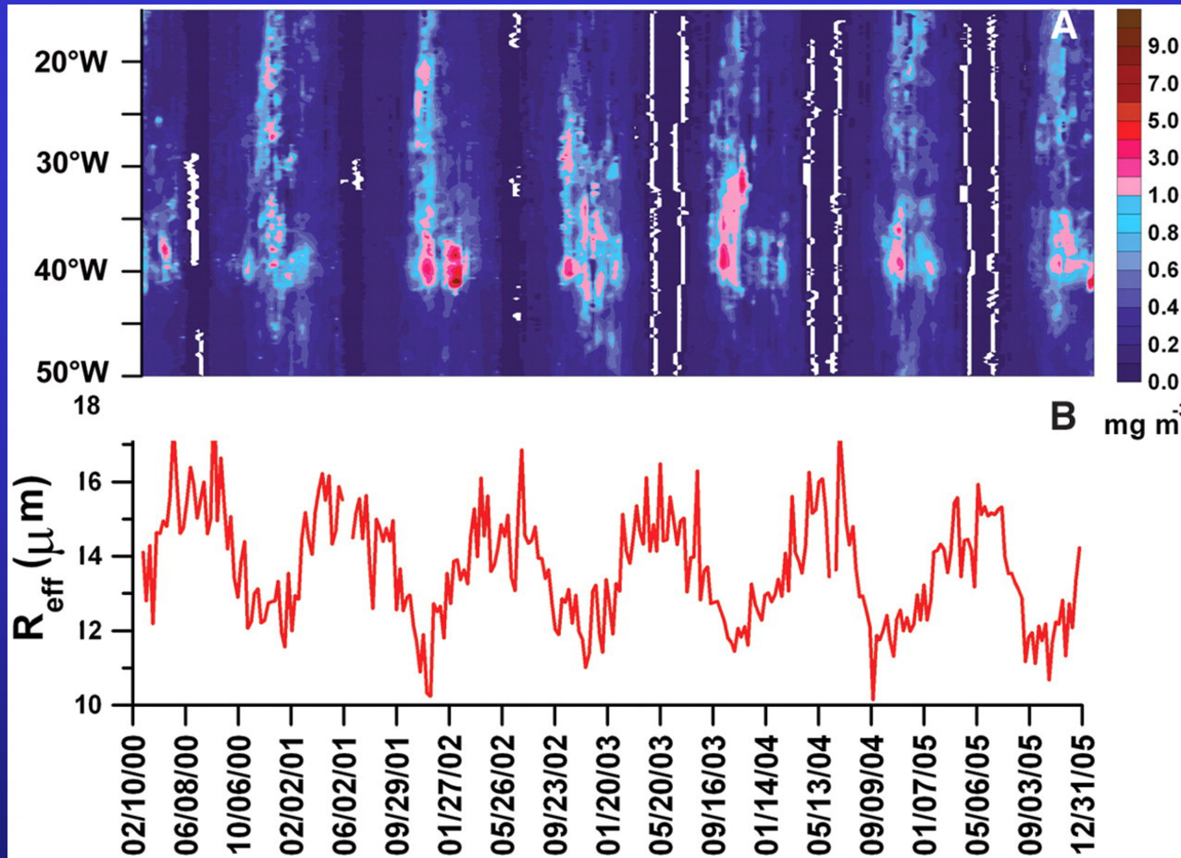


Fig. 1. The 8-day averaged (**A**) SeaWiFS-observed chlorophyll *a* and (**B**) MODIS-retrieved cloud (droplet) effective radius. Data for [Chl a] is gridded at a resolution of 9 by 9 km and zonally averaged between 49°S and 54°S; data for *Reff* is gridded at a resolution of 1° by 1° and averaged in the area of 49° to 54°S and 35° to 41°W. White areas in (A) indicate missing data.

Meskhidze N, Nenes A, Phytoplankton and cloudiness in the **Southern Ocean**
SCIENCE 314 1419-1423 2006

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.

	Equilibrator samples						
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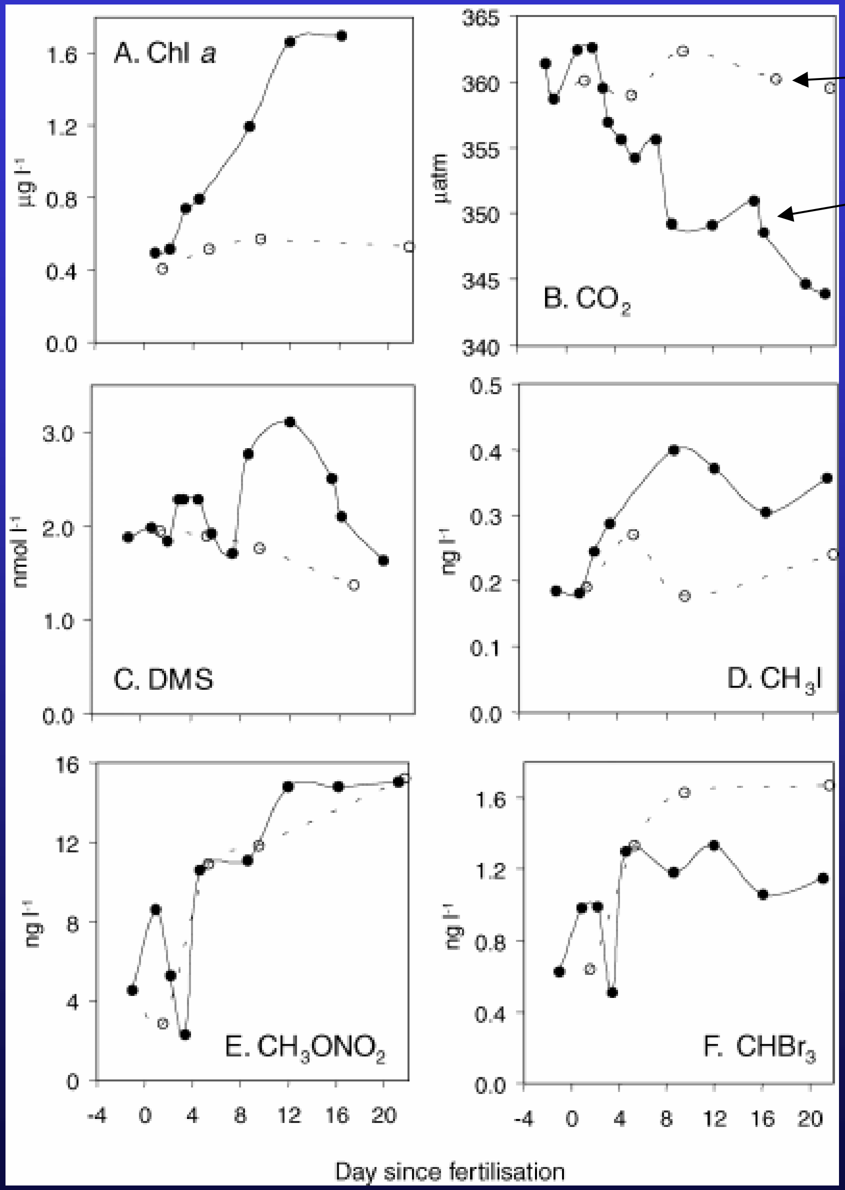
Wingenter et al., PNAS (2005) – results from SOFEX

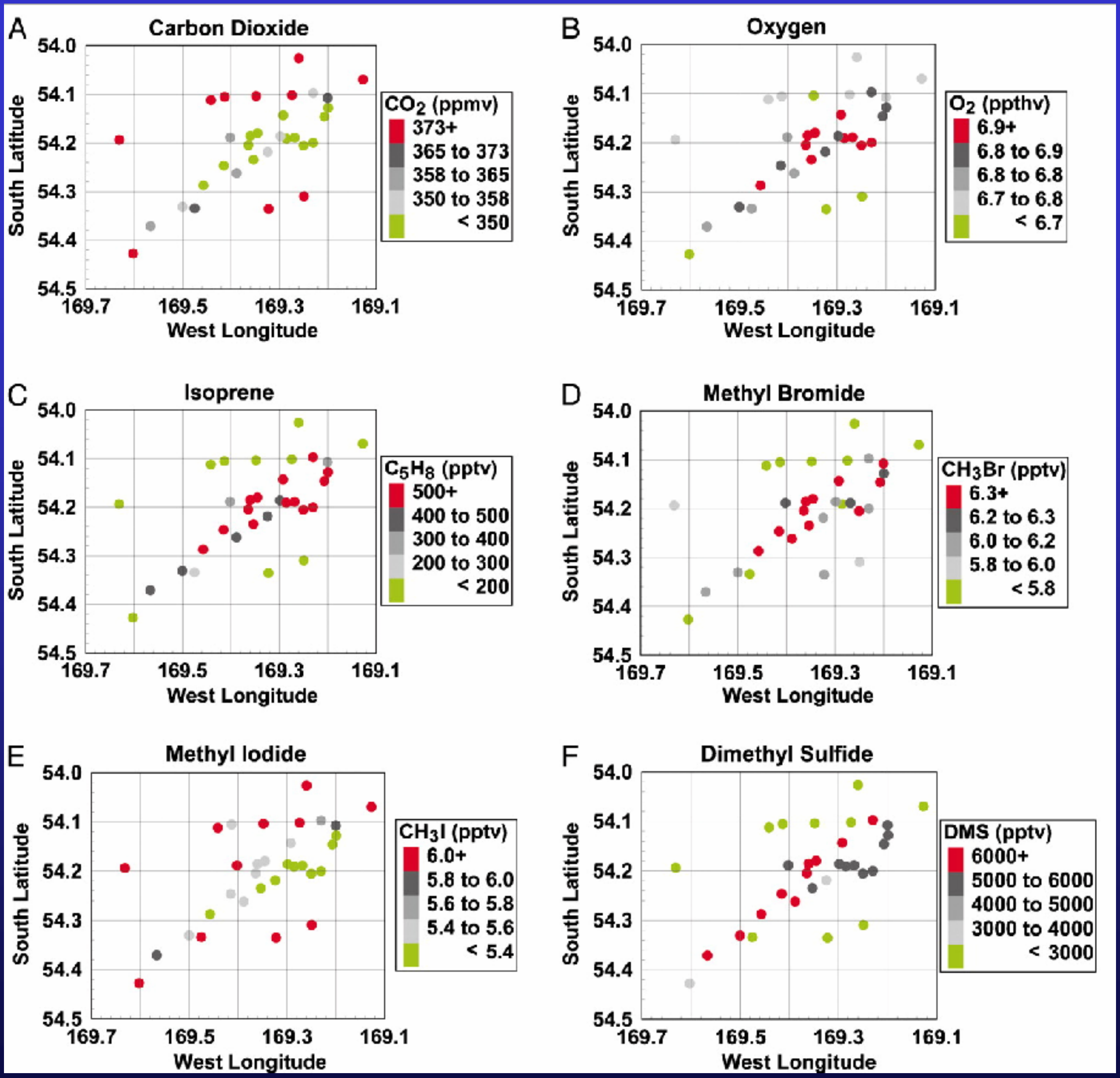
Halocarbons

- Gervais et al (2003, EISENEX) report a decrease in surface concentrations of CH_3Br and an increase in CH_3I.
- Wingenter et al (2004, SOFEX) report the opposite trends -- increase in CH_3Br and decrease in CH_3I.
- Moore and Wang (2006, SERIES) report no trend in either compound.

Trace gas concentrations during Eisenex:



Gervais et al., 2003, Liss et al., (2006).



Wingenter et al., PNAS 2004: SOFEX data

Summary: "other" gases

- Enhanced DMS and isoprene production
- Enhanced N_2O production, possibly CH_4
- No overall pattern for CH_3I or CH_3Br: sometimes a decrease, sometimes an increase, sometimes no trend.
- Decreased source of CO.

Bio-optical feedback effects of plankton

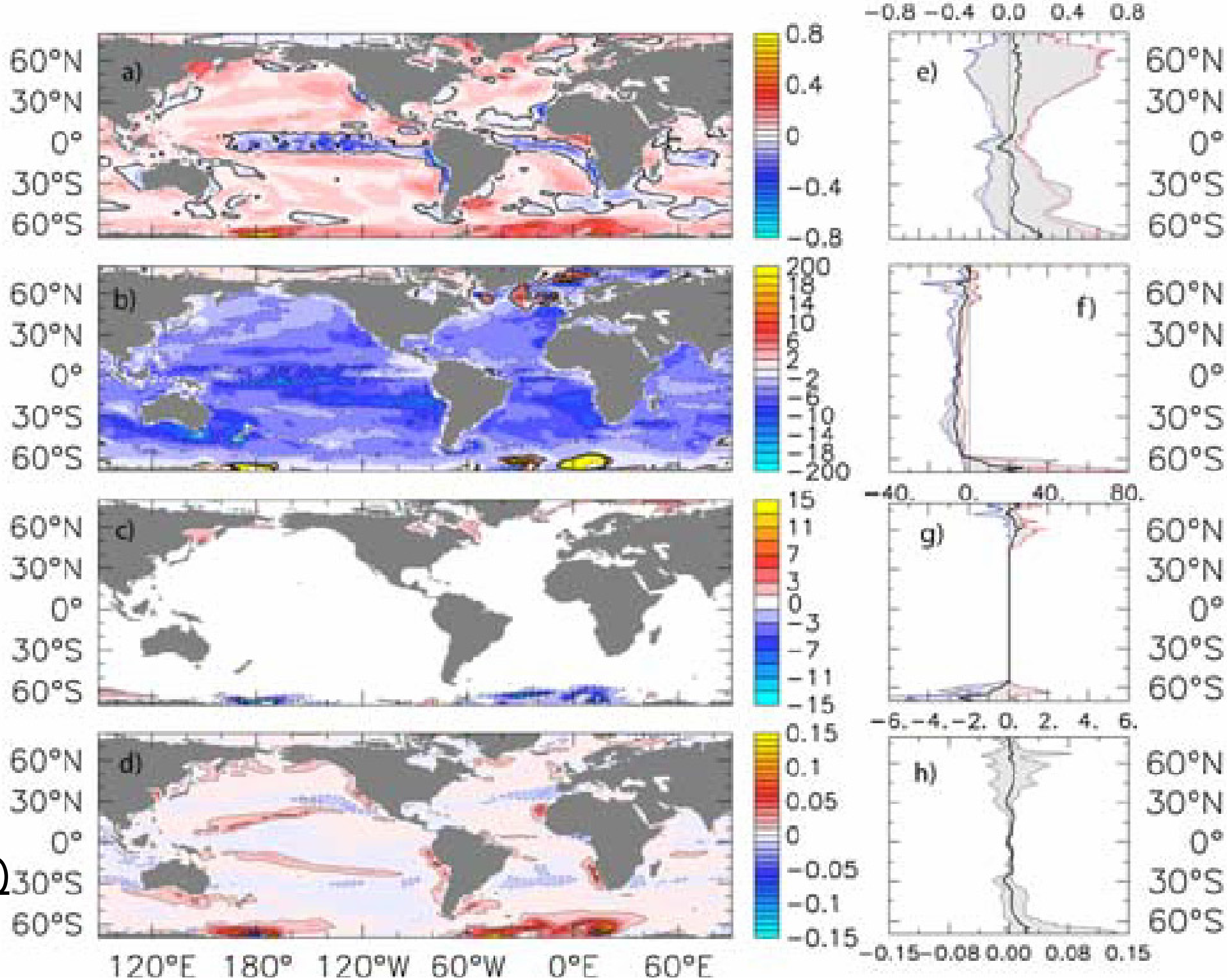
- Light absorption by plankton has substantial effects on ocean physics
  - Increase in mixed layer temperature
  - Decrease in mixed layer depth
  - Increased baroclinicity leading to stronger "thermal wind" currents, upwelling in tropics
  - Decreased ice coverage.

Temperature change

MLD change (m)

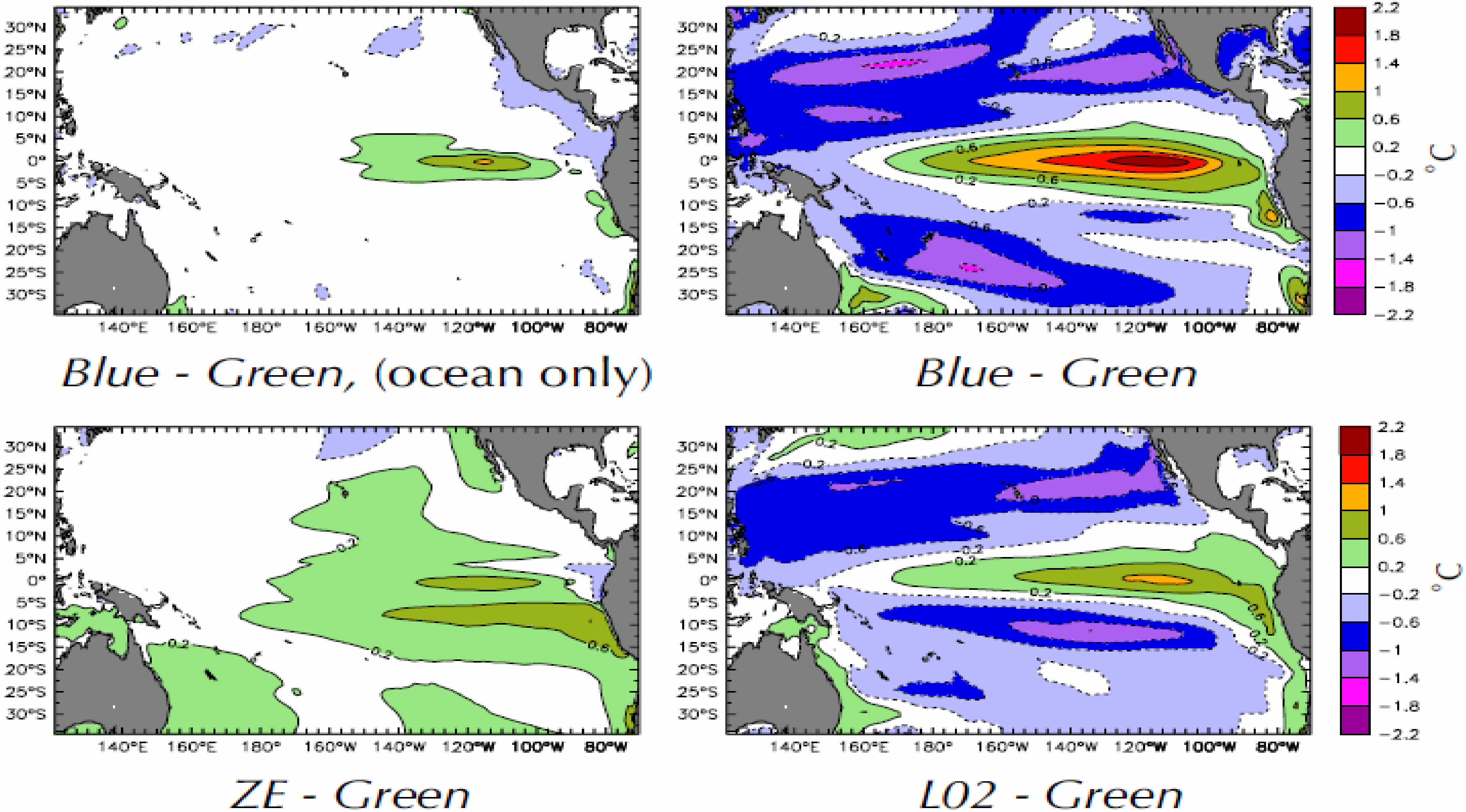
Sea ice cover (%)

Chlorophyll (mg m^{-3})



Manizza et al., (2005). Bio-optical feedbacks among phytoplankton, upper ocean physics and sea-ice in a global model, Geophysical Research Letters, 32, L05603, doi:10.1029/2004GL020778.)

Sea Surface Temperature



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 Fertlization

- 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 CO_2 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_2O

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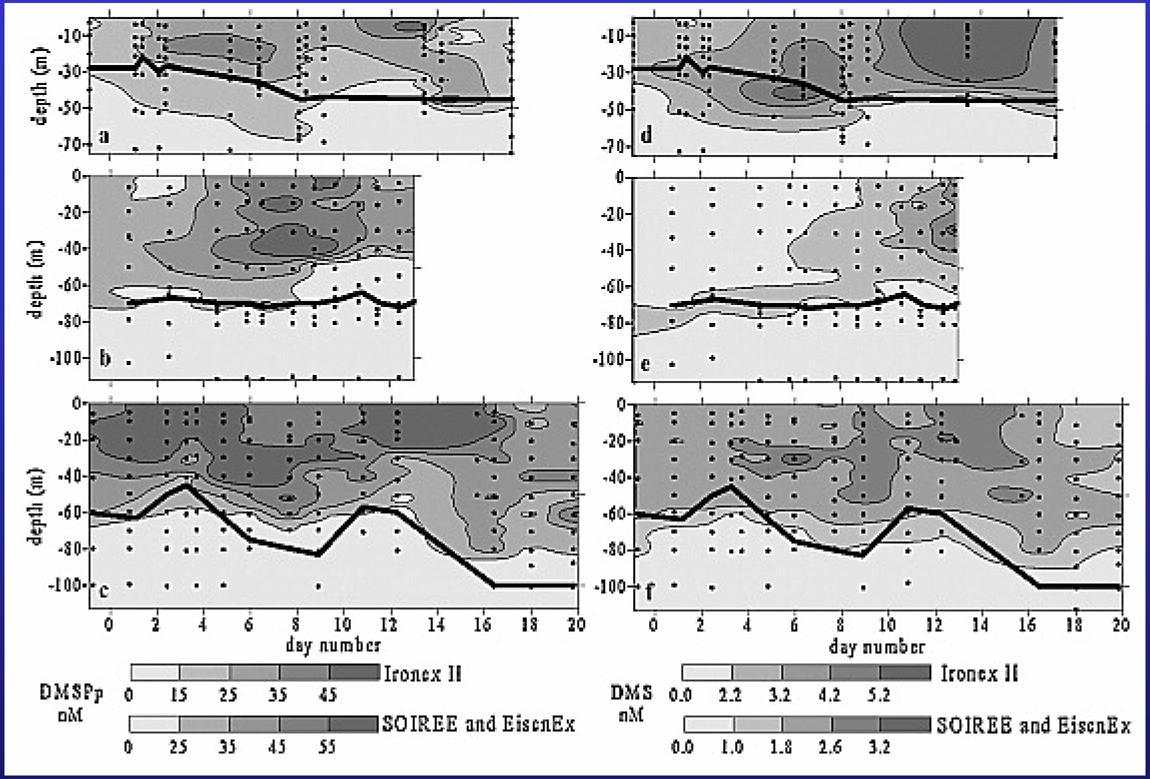
Legal questions?

- 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_2O)
- Increased cloud albedo (DMS, Isoprene)
- Increased [OH] content (CO decrease)

DMS



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