

## SHORT CONTRIBUTION

# Ocean fertilization with iron: effects on climate and air quality

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### ABSTRACT

It is well known that iron fertilization can increase primary production and hence CO<sub>2</sub> drawdown over a significant fraction of the oceans. What is less well established is the extent to which this leads to long-term sequestration of carbon to the deep oceans, and to feedbacks to the atmosphere arising from increased biological activity. In this note results for changes in trace gas concentrations during an iron addition experiment in the Southern Ocean are presented. They demonstrate that a complex situation exists; some gases (DMS, CH<sub>3</sub>I, CHBr<sub>2</sub>Cl) show increases in concentration following fertilization with iron while others show no change (CH<sub>3</sub>ONO<sub>2</sub>, CH<sub>2</sub>ClI) or even a decrease (CHBr<sub>3</sub>). The concomitant effects on air–sea fluxes of these gases are potentially important for climate and atmospheric composition.

## 1. Introduction

With rising levels of atmospheric CO<sub>2</sub> and a growing consensus that this is leading to changes in climate at local, regional and global levels (Houghton et al., 2001), people are increasingly thinking of ways to deal with the planet's growing greenhouse effect. Buesseler and Boyd (2003) have tried to answer the question of whether purposefully fertilizing the oceans with iron could significantly increase the amount of CO<sub>2</sub> absorbed from the atmosphere. These authors conclude that "ocean iron fertilization may not be a cheap and attractive option if impacts on carbon export and sequestration (to the ocean depths) are as low as observed to date". A less studied question, but one raised in a recent letter (Lawrence, 2002), is whether other atmospheric trace gases, be they greenhouse or affecting air quality, would be changed by the increased marine biological activity arising from purposeful iron addition. Changes in the air–sea fluxes of such gases would alter atmospheric composition, which could augment or negate the intended climate cooling through CO<sub>2</sub> manipulation, and also lead to other perturbations. Dimethyl sulfide (DMS), nitrous oxide and methane, as well as CO<sub>2</sub>, are radiatively active gases which are biologically produced and/or consumed in the oceans. Similarly organo-halogen, alkyl nitrate and non-methane hydrocarbon gases, which affect the oxidation

(cleansing) capacity of the atmosphere through the destruction of tropospheric and stratospheric ozone and reaction with other redox active gases/radicals, are also formed either directly by biological activity in sea water or by (photo)chemical reactions involving organic precursor molecules. In addition, atmospheric oxidation of organo-iodine gases together with DMS and carbonyl sulfide produces particles which affect atmospheric and cloud albedos. All of these marine-derived gases (and CO<sub>2</sub>) are potentially subject to change in concentration and hence air–sea flux following iron fertilization of surface ocean waters. Much of the technical background to the above processes and reactions is to be found in the science plan for the international SOLAS Project (Liss et al., 2004).

## 2. Results

To illustrate this issue we present in Fig. 1 results from an iron fertilization study (EisenEx) conducted in the Southern Ocean, which is the most extensive oceanic area where iron appears to be the limiting nutrient for biological productivity. The experiment was carried out in the region of the Antarctic Polar Front, due south of Africa (48°S, 21°E) in November 2000. The panels in Fig. 1 show how the concentrations of trace gases, CO<sub>2</sub> and chlorophyll a (Gervais et al., 2002) behaved with time since fertilization with iron, as compared with unfertilized water outside the iron-enriched patch.

Panel A clearly shows the increase in biomass, as measured by chlorophyll a, in the fertilized patch arising from the iron

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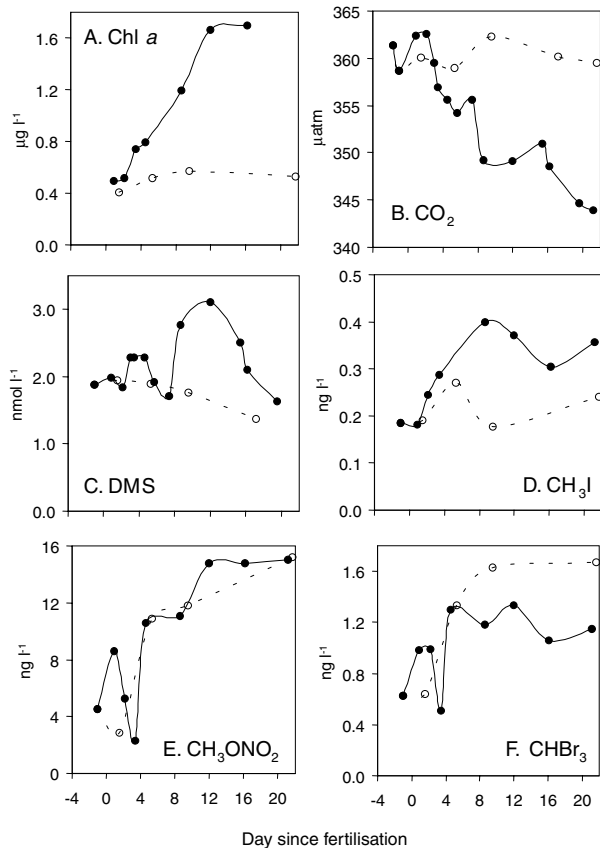


Fig. 1. Trace gas, CO<sub>2</sub> and chlorophyll *a* concentrations in surface water (5 to 11 m depth). Inside and outside patch samples are shown as filled and open circles, respectively.

addition. The corresponding drawdown of CO<sub>2</sub> is also plain (B) and DMS and iodomethane (CH<sub>3</sub>I) both show substantial increases (C and D), as does dibromochloromethane (not shown). The situation for methyl nitrate (CH<sub>3</sub>ONO<sub>2</sub>) is less clear-cut (E), with no definite change over time with iron addition (a similar situation was found with chloriodomethane, not shown). Finally, bromoform concentrations were found to decrease in the iron-enriched patch (F), probably due to enhanced bacterial consumption of this compound arising from the increased level of biological activity.

### 3. Discussion

From the results in Fig. 1, we conclude that even if drawdown of CO<sub>2</sub> leads to long-term removal of carbon from the atmosphere–surface ocean system to the deep oceans and underlying sediments, which is far from certain (Buesseler and Boyd, 2003), the effect of fertilization on the production of other trace gases cannot be ignored. The increase in DMS is a common finding in all the iron fertilization studies published to date, where three-fold increases are typical and can be up to eight-fold (Turner et al., 2004). According to a modelling study (Gunson et al.,

2005), a two-fold increase in DMS emission, if occurring globally, would produce an atmospheric temperature decrease of the order of 1–2 °C. From the standpoint of climate amelioration, the effect is in the right direction, but there are many uncertainties in the model due to our lack of understanding of the cycle of DMS in the ocean–atmosphere system, and the magnitude of change is uncertain. On the other hand, for a powerful greenhouse gas like nitrous oxide, increased emissions resulting from iron fertilization, for which there is some evidence from an earlier study (Law and Ling, 2001), would tend to offset any cooling due to enhanced carbon sequestration or DMS release, a conclusion supported by a recent modelling study (Jin and Gruber, 2003).

For the gases shown in Fig. 1 which affect air quality, the outcome is not coherent, since there are increases (CH<sub>3</sub>I, CHBr<sub>2</sub>Cl), decreases (CHBr<sub>3</sub>) and no significant changes (CH<sub>3</sub>ONO<sub>2</sub>, CH<sub>2</sub>ClI) in concentrations following iron fertilization. Trace gas results from other investigators during a more recent iron enrichment study in the Southern Ocean (SOFeX at 56.2°S, 172.0°W; Wingenter et al., 2004) show a substantial within-patch increase in DMS (×4) and isoprene (×3). In contrast to our finding, a small decrease was observed for iodomethane. In this situation prediction of the net effect on air chemistry of iron fertilization is clearly impossible; a situation which can only be improved by substantial further field experiments and modelling studies.

Our conclusion is that any serious proposal to use iron fertilization to ameliorate climate change would not only have to show that it could remove carbon effectively, but would also have to account for additive, countervailing or detrimental effects on climate and air quality arising from changes in ocean–atmosphere trace gas exchanges. We do not discuss here the substantial ethical and legal issues which are also involved, nor the potential for significant alterations to the biology of the oceans.

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