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Physical behavior of the SEEDS iron-fertilized patch by sulphur hexafluoride tracer release

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Abstract

The first iron (Fe) – fertilization experiment in the western North Pacific was carried out using SF_6 to trace the Fe-fertilized water mass. A solution in 10,800 liters of seawater of 350 kg of Fe and 0.48 M of SF_6 tracer was released into the mixed layer over a 8×10 km area. On the first underway transects through the patch after the Fe release, we observed a significant increase of dissolved Fe (ave. 2.89 nM). The fertilized patch was traced for 14 days by on-board SF_6 analysis. A Lagrangian frame of reference was maintained by the use of a drogued GPS buoy released at the center of the patch. The patch moved westward at a rate of 6.8 km d^{-1}. Mixed layer depth increased from 8.5 to 15 m during the experiment. Horizontal diffusivity was determined by the change of SF_6 concentration in the patch. The horizontal diffusivity increased during the experiment. We evaluate here the fate of Fe in a Fe-fertilized patch using the dilution rate determined from sulphur hexafluoride (SF_6) concentration. Dissolved Fe concentrations subsequently decreased rapidly to ~0.15 nM on Day 13. However, the dissolved Fe half-life of ~43 h was relatively longer than in previous Fe-enrichment studies, and we observed a larger increase of the centric diatom standing stock and corresponding draw-down of macro-nutrients and carbon dioxide than in the previous studies. The most important reason for the larger response was the phytoplankton species in the western North Pacific. In addition, the smaller diffusivity and shallower mixed layer were effective to sustain the higher dissolved Fe concentration compared to previous experiments. This might be one reason for the larger response of diatoms in SEEDS.

Keywords: SF_6 tracer; Dilution rate; Experimental methods; Patch; Fe behavior

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1. Introduction

Several in situ iron (Fe) fertilization experiments have been performed with the general goal of evaluating whether Fe availability controls phytoplankton production in high nitrate low chlorophyll (HNLC) waters in the equatorial Pacific and Southern Ocean (Boyd et al., 2000; Coale et al., 1996; Martin et al., 1994). The Fe-limitation hypothesis has also been investigated in the western subarctic North Pacific by a mesoscale, single Fe infusion called the Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study (SEEDS) (Tsuda et al., 2003).

In all of these in situ Fe-enrichment experiments, sulphur hexafluoride (SF_6) concentrations were used as proxies for the enriched Fe concentration without any effects of biochemical processes (Law, Watson, Liddicoat, & Stanton, 1998). SF_6 concentration decreases by physical dilution and also air-sea gas exchange. Physical dilution rate can be determined from the SF_6 concentration when considered together with the loss by air-sea gas exchange (Liss & Merlivat, 1986; Wanninkhof, 1992).

SEEDS showed the largest biological and chemical responses to Fe supply (Tsuda et al., 2003) among all such experiments to date in HNLC areas: in the equatorial Pacific, IronEx I and II (Martin et al., 1994; Coale et al., 1996) and in the Southern Ocean, SOIREE (Boyd et al., 2000) and EisenEx (Gervais, Riebesell, & Gorbunov, 2002). The most likely reason for the greater level of induced bloom was the stronger response of diatom species in the western North Pacific (Tsuda et al., 2003). In addition, SEEDS might have had some advantages in physical conditions in comparison with the previous experiments.

Except for IronEx I (Martin et al., 1994), multiple Fe infusions were conducted in the previous Fe enrichment studies: IronEx II (Coale et al., 1996), SOIREE (Boyd et al., 2000) and EisenEX (Gervais et al., 2002). However, Bowie et al. (2001) suggested that multiple infusions brought some difficulties in understanding the quantitative changes in chemical Fe species in the Fe-enriched patch in SOIREE, and it is more difficult to compare experimental results with natural events. Therefore, the single infusion of Fe in the SEEDS study has advantages for understanding the Fe dynamics during the experiment. Progress in our understanding of the biogeochemical cycle of Fe in seawater is one goal of these in situ Fe-fertilization experiments. In this paper, we summarize the methodology and behavior of the SEEDS Fe-enriched patch, and also changes in the concentrations of Fe in the patch during the induced phytoplankton bloom.

2. Methods

The first Fe-enrichment experiment in the western North Pacific was carried out by R.V. Kaiyo Maru from June 28 to August 6, 2001. The first leg was from June 28 to 9 July, 2001 as a pre-survey to select the experimental site and the second leg was from July 14 to August 6 in 2001 for the Fe-enrichment experiment. The pre-survey around the experimental site was conducted with XBT observations, an underway survey and vertical bottle sampling to determine the biological, chemical and physical heterogeneity of the experimental area. Fe was supplied on July 18–19 over 23 h, and the Fe-enriched water mass (hereafter patch) was traced for 14 days. Tracing of the Fe-enriched patch was conducted with a combination of SF_6 and the drogued GPS buoy, similar to those of previous experiments (Law et al., 1998).

2.1. Iron and SF_6 tracer release

The method of SF_6 tracer release in SEEDS was similar to the previous Fe-fertilization experiments (Law et al., 1998). The saturated SF_6 solution was prepared in the port of Kushiro after the first leg. Two 2000 L steel tanks were filled with seawater from the experimental area defined during the pre-survey. Therefore, it was not necessary to adjust the salinity of the solutions. SF_6 solubility is very low for seawater; therefore, we employed the same method as in a previous experiment to make the SF_6 solution effectively