IMPACT OF THE 2009/2010 EXTREME NEGATIVE NORTH ATLANTIC OSCILLATION ON THE SUBPOLAR PHYTOPLANKTON BLOOM

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1. An anomalous phytoplankton bloom

A basin-wide, highly anomalous phytoplankton bloom was observed in the Irminger Basin in summer 2010. Figure 1 shows an example satellite chlorophyll anomaly plot from 12th-19th July 2010. The positive chlorophyll anomalies, of up to 2 mg m^{-3}, extend throughout the basin. The time series of chlorophyll data shows that the typical North Atlantic seasonal cycle of a spring bloom, followed by a decrease in summer, and a further bloom in autumn, did not occur in 2010. Instead, the bloom starts in spring as usual, but continues to build in magnitude until reaching a peak in mid-July.

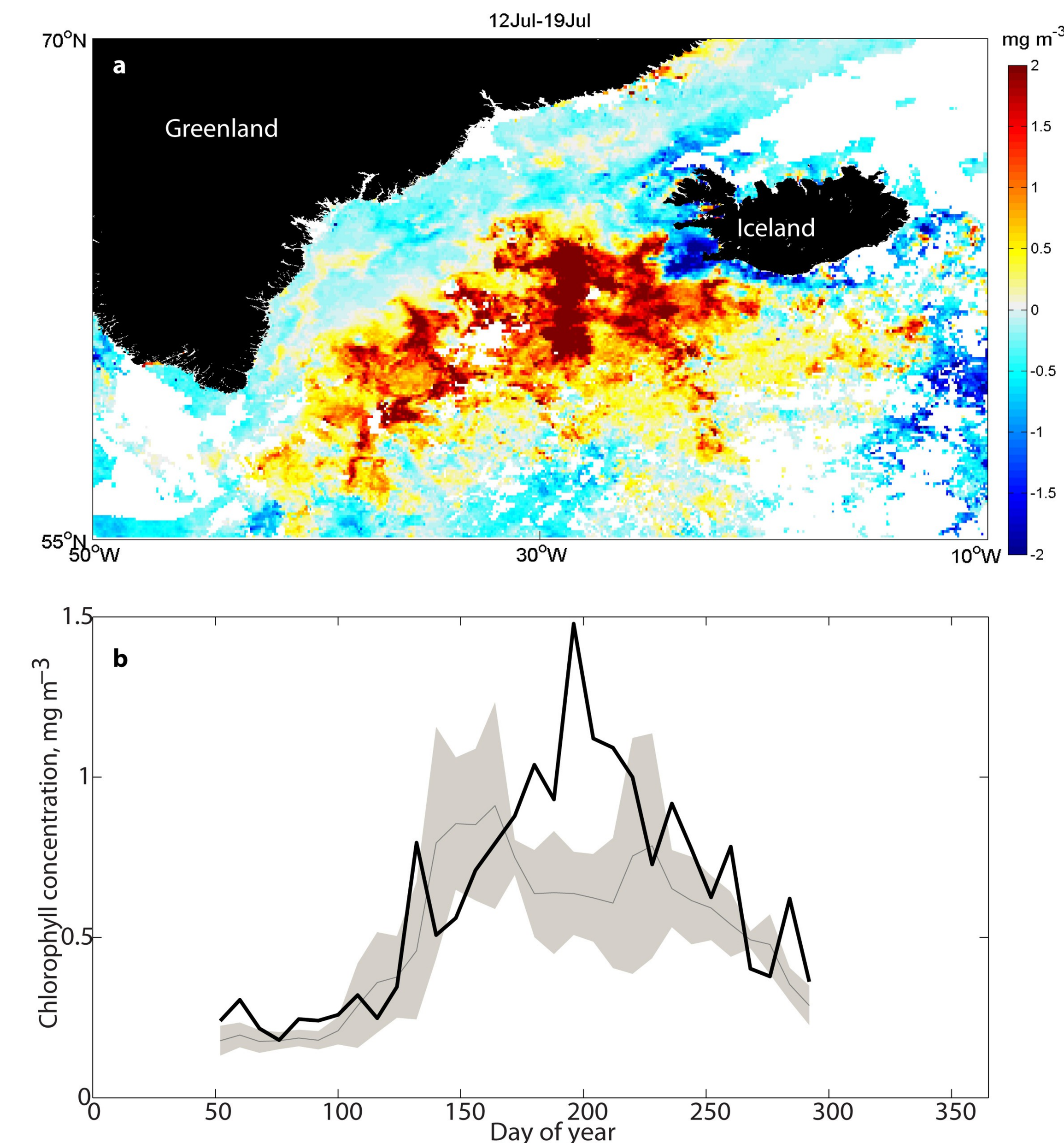

Figure 1: Anomalous chlorophyll conditions in the Irminger Basin in 2010. a) Chlorophyll anomaly for 12th-19th July 2010, relative to the mean of 2003-2009. b) Time series of chlorophyll concentration in the central Irminger Basin in 2010 (thick black line), the mean (thin grey line) and standard deviation (grey shading) of years 2003-2009.

2. Two possible explanations

Two unusual events occurred in 2010 that are contenders for explaining the highly anomalous bloom. One is the phase of the North Atlantic Oscillation (NAO), and the other is the eruption of the Icelandic Eyjafjallajökull volcano. In the winter 2009/2010, the NAO switched from the generally positive or neutral conditions typical of the last 20 years to an exceptionally negative state. The NAO phase from December 2009-March 2010 was the second strongest negative NAO on record. In April/May 2010, the Eyjafjallajökull volcano in Iceland erupted, depositing an estimated 10 million cubic metres of tephra into the surface waters of the North Atlantic. Volcanic ash is known to contain iron, a micro-nutrient required for phytoplankton growth. So which of these unusual events is most likely to have prompted the anomalous phytoplankton bloom?

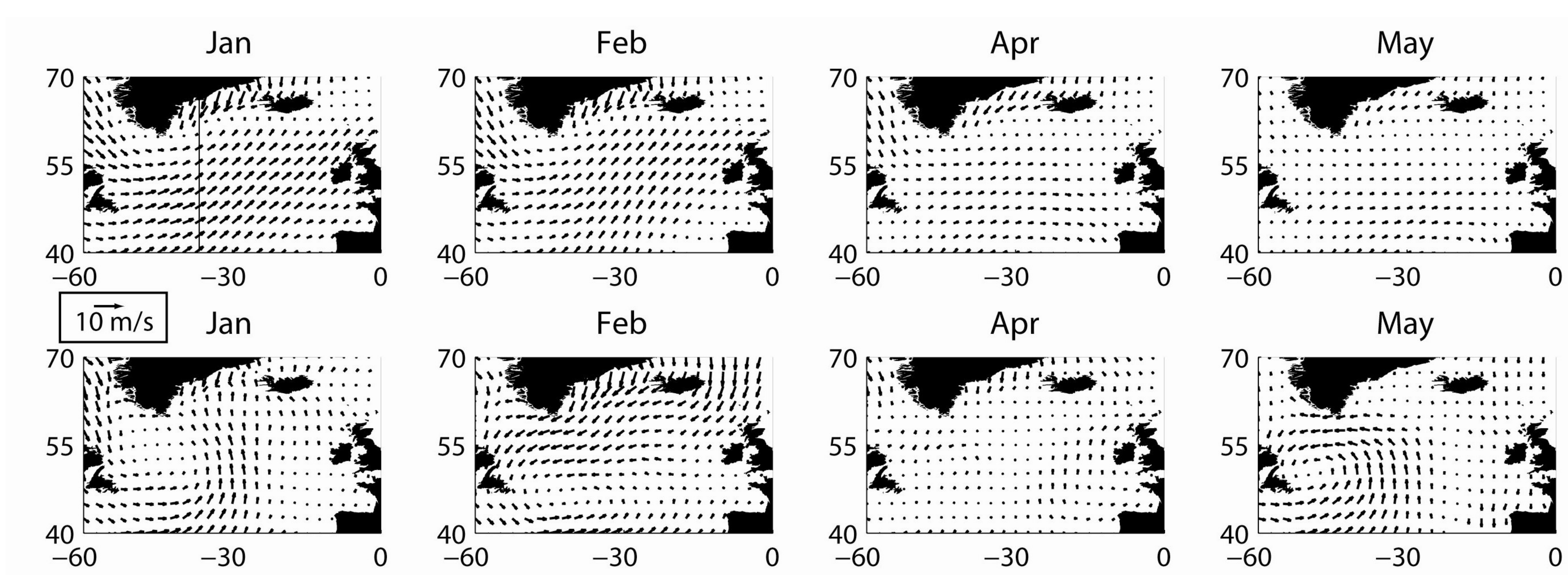

Figure 2: Top row: Mean (1998-2009) wind speed over the North Atlantic in selected months. Bottom row: Wind speed in selected months of 2010. Horizontal line in panel 1 shows the position of the transect presented in Figure 3.

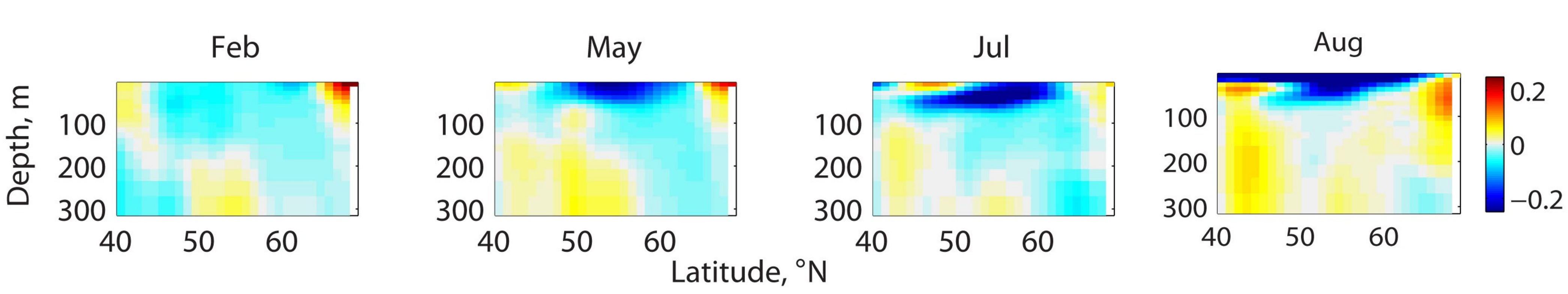

Figure 3: Density anomaly (kg m^{-3}), relative to 1998-2009, for selected months in 2010 along a transect at 33 W.

3. Impact of the NAO

During negative phases of the NAO, surface pressure increases in the Icelandic low and decreases in the Azores high, resulting in weaker westerly winds and a southward shift of the storm track. In the case of 2010, the wind stress during December 2009-June 2010 is either northerly (in January and March) or easterly (in February and May), i.e. in the opposite direction entirely, compared to mean conditions (Figure 2). The effect of the anomalous winds on hydrographic conditions in the Irminger Basin are seen in optimally interpolated temperature and salinity data. The northward movement of an anomalous water mass is clearly seen in transects of density anomaly along 33 W (Figure 3). The anomaly extends over only the top 50-80 m of the water column, i.e. it likely originates from anomalous surface, or near-surface, conditions.

4. Impact of the volcano

In addition to the unusual hydrographic conditions in 2010, the Eyjafjallajökull volcano in Iceland was also actively erupting between 15th April and 23rd May. The ash ejected from the volcano was approximately 10% iron oxide by weight and so could potentially have added substantial quantities of iron to the surface ocean. The potential iron deposition map of Achterberg et al. (in prep) shows that ~ 0.3 nmol l^{-1} of iron were likely deposited in the very northern part of the Irminger Basin over the course of the eruption (Figure 4), the majority of it in one day, 14th May. If any additional deposited iron is to have a fertilisation effect, phytoplankton growth must be iron limited. Two NOC-led cruises to the Iceland and Irminger Basins in April/May and July/August 2010 were able to sample conditions during and after the eruption. The on-board incubation experiments demonstrated that ash from the volcano had the potential to alleviate iron limitation and stimulate growth in the Iceland and, possibly, Irminger Basins.

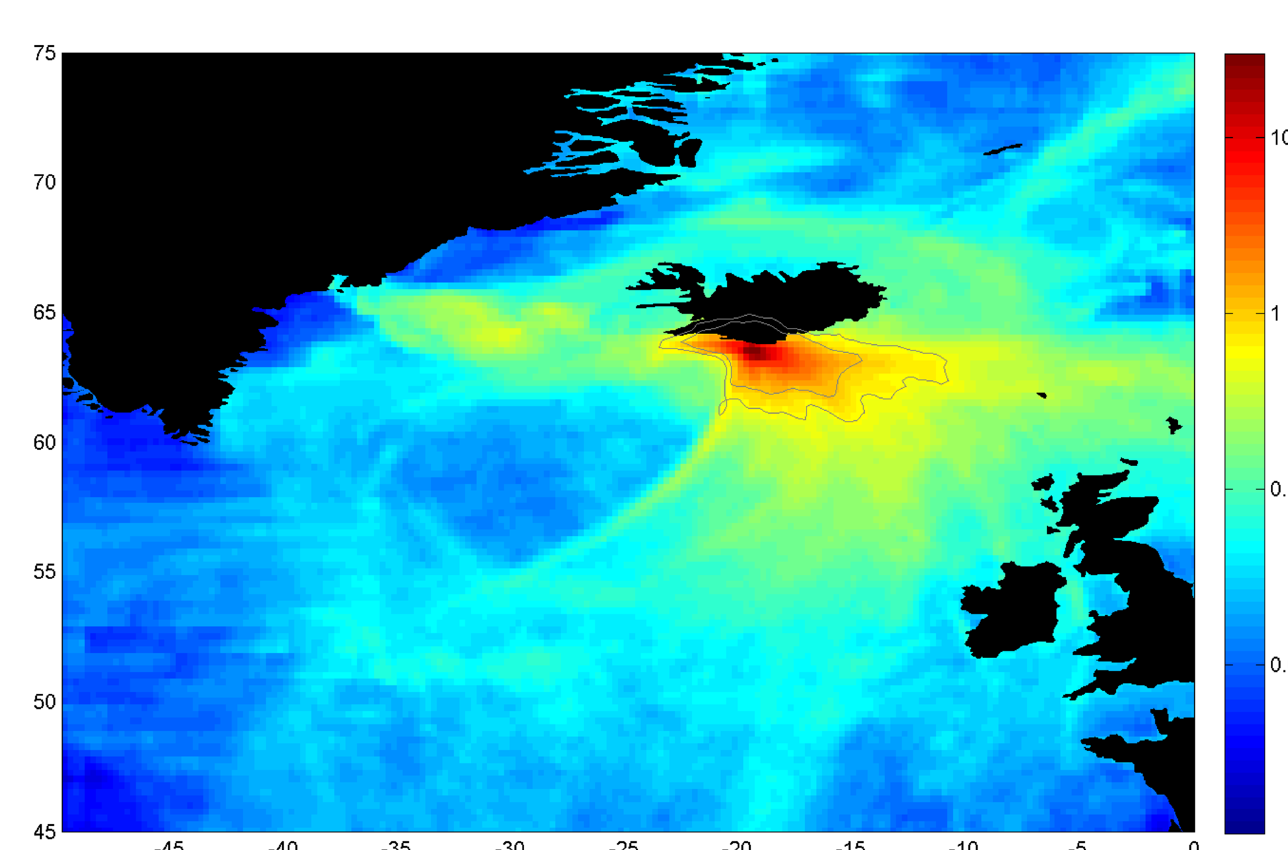

Figure 4: Total modelled dissolved iron deposition (nM) from volcanic ash ejected during the eruption of Eyjafjallajökull from 15th April - 23rd May 2010 (derived from Achterberg et al., in prep and Stohl et al., submitted).

5. Outstanding questions

So far in our investigations, there are no clear cut answers as to what promoted the anomalous bloom. The extreme negative NAO resulted in large-scale hydrographic changes in the region, but where did the anomalous water mass observed in 2010 originate? Why would an influx of freshwater result in an enhanced bloom? And could different nutrient concentrations, phytoplankton or grazer communities have been introduced to the Irminger Basin? Volcanic eruptions have been hypothesised to result in massive increases in primary production and drawdown of CO_2, but did the Eyjafjallajökull volcano deposit enough iron in the Irminger Basin to promote a bloom? Did the circulation in the basin distribute iron-rich water around the basin? Is a 55 day gap between ash deposition and peak chl values likely? We participated in two cruises to the Iceland and Irminger Basins during and after the eruption, and we hope that the ongoing analysis of data collected during the cruises will shed further light on the reasons for the anomalous bloom of 2010.