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Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

ICES CM 2012/R:03

How the Subpolar gyre strength influences phytoplankton blooms dynamics in the North Atlantic

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Abstract

Changes in the North Atlantic Subpolar gyre (NASPG) have been linked to the interannual variability of primary production. However, little is known about the mechanisms behind both environmental processes, and how the NASPG strength may extend its potential impacts to higher trophic levels, including early life stages of commercial fish species. We assess NASPG strength effect on North Atlantic phytoplankton bloom dynamics. We analysed time series (from 1998 to 2010) of chlorophyll α as a proxy of phytoplankton abundance, and the NASPG as a proxy for environmental variability. 17 regions were strategically chosen to characterize positions relative to the NASPG and its dynamics. It is hypothesized that a strong NASPG index will be associated with a low abundance, late phytoplankton bloom, possibly induced by higher heat losses, and thus lower temperatures. In general, across the entire North Atlantic, later blooms were observed in higher latitudes and for stronger NAPSG index (negative values). This pattern though has regional variations. In the eastern sectors, latitudinal timing differences are much stronger for strong NAPSG index than for weak index. Indications of a strong influence of NASPG index are related to areas within the NAPSG, which may have an impact in the ecosystem functioning. The results also suggest that physical forcing other than the strength of the NASPG influences primary production, particularly at regional scales.

Keywords: Phytoplankton blooms, subpolar gyre, North Atlantic,

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Introduction

Phytoplankton require light and nutrients in order to grow. When the concentration of nutrients and light availability match phytoplankton demands, blooms occur. The entrainment of nutrients, as well as retention of phytoplankton, is strongly influenced by physical processes, such as mixing of water masses (Racault et al. 2012). Increased mixing has been linked to an increase in nutrient supply, but may also act as a light-limiting factor. As Huisman et al (1999) reported, there has to be a balance between water-column depth and diffusivity coefficient so the phytoplankton can flourish. Phytoplankton will then have a cascading effect on zooplankton production and, subsequently, on fish survival (Hátún et al. 2009b, Platt et al. 2009).

Ocean currents influence the outcome of primary production (Longhurst 1995, Mann 1993). Wind-influenced currents may form large systems of water masses with similar properties. The North Atlantic SubPolar Gyre (NASPG) is formed by four major currents (North Atlantic Current - NAC, Irminger Current - IC, East

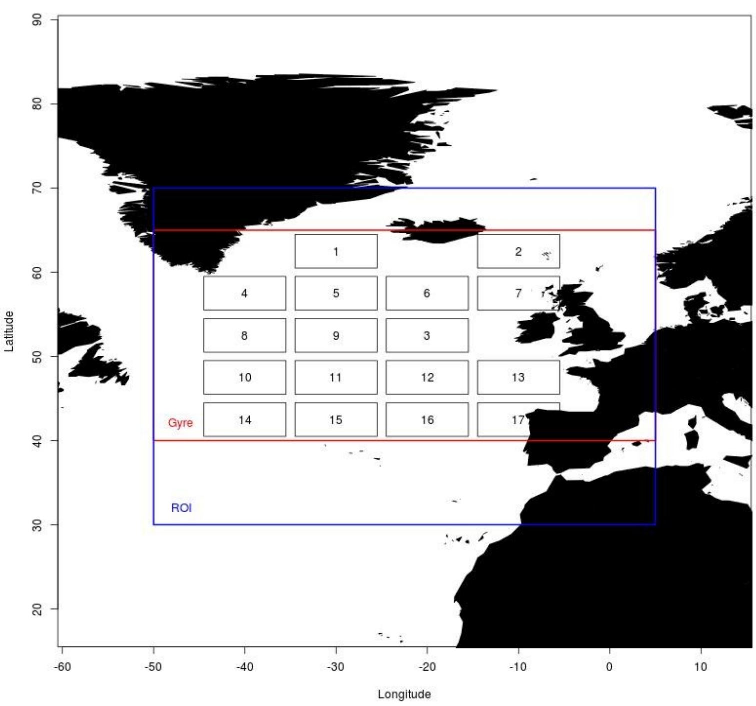
Greenland Current - EGC, and Labrador Current - LC) with a counterclockwise circulation (Schmitz and McCartney 1993). A strong gyre is, thus, defined by eastward drift of cold, fresh waters; while a weak gyre is defined by westward drift of warm, saline waters (Hátún et al. 2009a). Previous studies have looked at the influence of NASPG in phytoplankton abundance (Hátún et al. 2009b). Additionally, there have been some discussions regarding the onset of phytoplankton blooms (Chiswell 2011). Yet, no studies have focused on the influence of NASPG on the bloom dynamics: timing, duration, and magnitude. However, their relevance has been noticed, for they may extend their potential impacts to higher trophic levels, including early life stages of commercial fish species.

Even though several attempts to describe phytoplankton blooms according to physical properties (Behrenfeld 2010), a clear answer for "what is a bloom" is yet to be answered. This study aims at investigating bloom dynamics (magnitude, timing, duration, and inter-annual variability) response from physical forcing at a regional scale, by using satellites imagery. Climate and oceanographic forcing conditions may trigger different responses in regards to the whole NA and within smaller regions. Depending on the strength of NASPG, different properties are expected to occur at specific locations surrounding the NASPG region. For instance, Hátún et al (2009b) reported an increase in phytoplankton abundance after 1995, a period coupled to a decline of the gyre index. For strong gyre characteristics in relation to a weak gyre, later and low amplitude blooms are expected, especially within regions of strong influence by the NASPG.

Material and Methods

Here, focus is given on two different spatial scales: a) the whole NA, and b) smaller regions that are expected to differently respond to physical forcing (e.g. North Atlantic Subpolar gyre – NASPG). Therefore, 17 different regions were strategically chosen to describe physical forcing (Fig. 1). For instance, regions 1, 2, and 3, were chosen to describe the dynamics over the Irminger Current (IC); the North Atlantic Current (NAC) and its northwards drift; and the within NASPG dynamics, respectively.

Figure 1: Map of region of interest (ROI), region of the NASPG (Gyre), and the 17 regions selected.



Chlorophyll *α*

Weekly and daily chlorophyll *α* (chl *α*) data product was downloaded from the Globcolour Project (http://www.globcolour.info), from 1998 to 2010, on 1º by 1º resolution. Bloom initiation (bloom timing) was defined by five different definitions: 1) week with the fastest rate of increase of chl *α* concentrations (maximum growth); 2) week when chl *α* is above 5 % of median value (Henson et al. 2009, Siegel et al. 2002); 3) week when chl *α* reaches 20 % of cumulative distribution; 4) week when chl *α* reaches 5 % of maximum values averaged over 12 years; and 5) week when chl *α* presented the maximum sum of daily increase rate (maximum growth). In order to choose the best definition from this list, all definitions were ranked according to the week of initiation, *i.e.* the definition that returns the earliest bloom gets a ranking value of 1, and a ranking 5 is given to the one that returns the latest. This analysis showed that different definitions apply better to different regions. In addition, all bloom timings were significantly different across latitudes (p-value < 0.05). Definitions 2 and 4 were removed, for they could not be used at the lowest latitudinal ranges. There was a high variability in the rankings of definitions 1 and 3. Therefore, definition 5 was selected. Bloom end was set as the week when chl *α* concentrations went back to the value at bloom timing. Bloom duration was defined as the number of weeks between bloom timing and bloom ending.

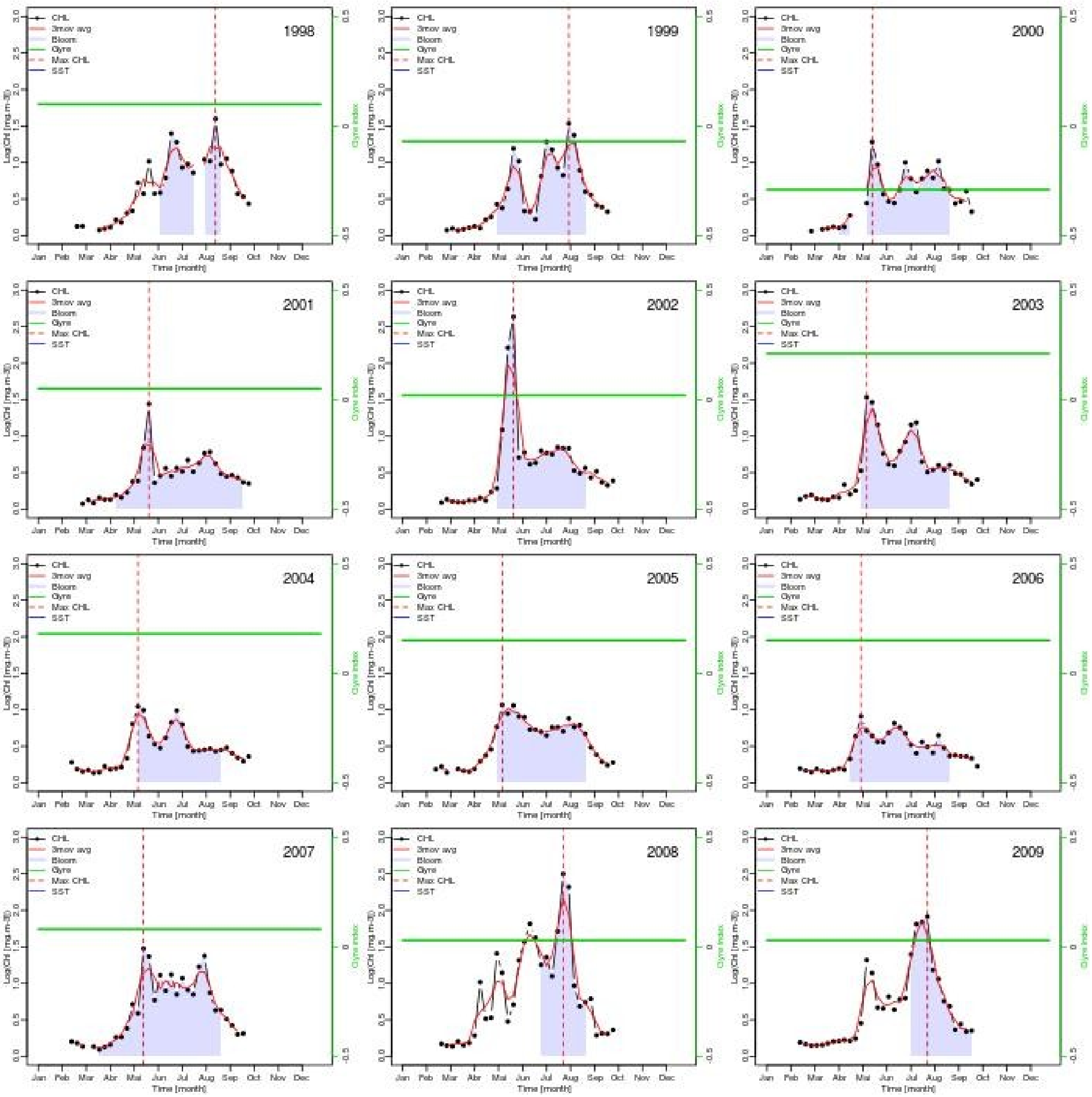


Figure 2: Chl *α* concentrations, averaged for each week, on logarithmic scale (block, dotted line), 3-week running mean of chl *α* (red line), timing of maximum chlorophyll (red, vertical line), bloom period from definition 5 - maximum growth rate on daily data (shaded area), and the inverted NASPG index (green, horizontal line) for region 1 (see Fig 1).

Gyre index

The NASPG used in this study has been published by Hátún and Gaard (2010) and Larsen et al (2012), and is based on an empirical orthogonal function (EOF) (Preisendorfer et al. 1988) created by Häkkinen & Rhines (2004) from gridded sea surface height (SSH) data. Here, we use a time series of the gyre index from 1997 to 2010, as in Larsen et al (2012).

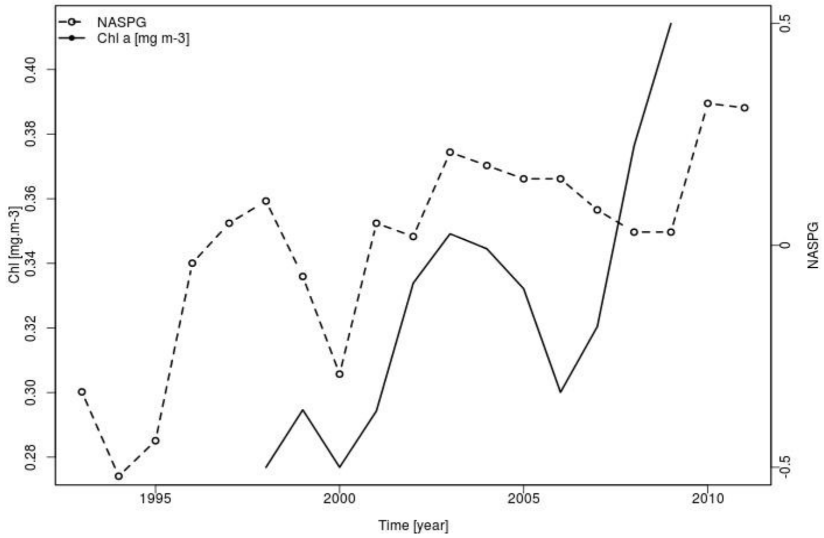


Figure 3: Chlorophyll concentrations and NAPSG.

Results and discussion

As expected, in years with a strong NASPG index (negative values), average chl *α* concentrations were lower (Fig 3 and 4). Bloom timing was significantly different for the entire range of latitudes within ROI and NASPG strength (p-value < 0.05), but not for NASPG alone.

Later blooms were observed in higher latitudes and lower longitudes (Fig 5 left). This is in accordance with previous findings that used different definitions for bloom timing (Racault et al 2012). Racault et al (2012) also noticed longer blooms at higher latitudes. Here, however, we found that bloom duration is higher in both the Northeastern and Southwestern sided of the NASPG. Similarities were found for bloom timing in the centre of the NASPG region (Fig 5 right). This may have implications in the recruitment of fish species that spawn within and outside the NASPG region, such as blue whiting (Hátún et al. 2009a, Hátún et al. 2009b), North Atlantic cod (ICES 2005), haddock (Platt et al. 2003), Atlantic salmon (Beaugrand and Reid 2003, Todd et al 2008), Northern shrimp (Koeller et al. 2009), and possibly Bluefin tuna (Lutcavage et al. 1999). The earlier the bloom initiates, and the longer it lasts, the higher the probability for the timing of copepod blooms to match of timing of fish spawning (Platt et al. 2003).

For years with a strong NASPG, bloom timing was highly variable across latitudes (Fig 6 left). This may indicate that a strong NASPG, ant thus an eastward shift of cold, freshwater, has a stronger impact on phytoplankton growth than a weak NASPG. This impact is even steeper when we focus on a single longitude (Fig 6 right). This finding emphasizes how important it is to cover the physical properties of the North Atlantic waters, for there may be key regional patterns triggering different phytoplankton responses.

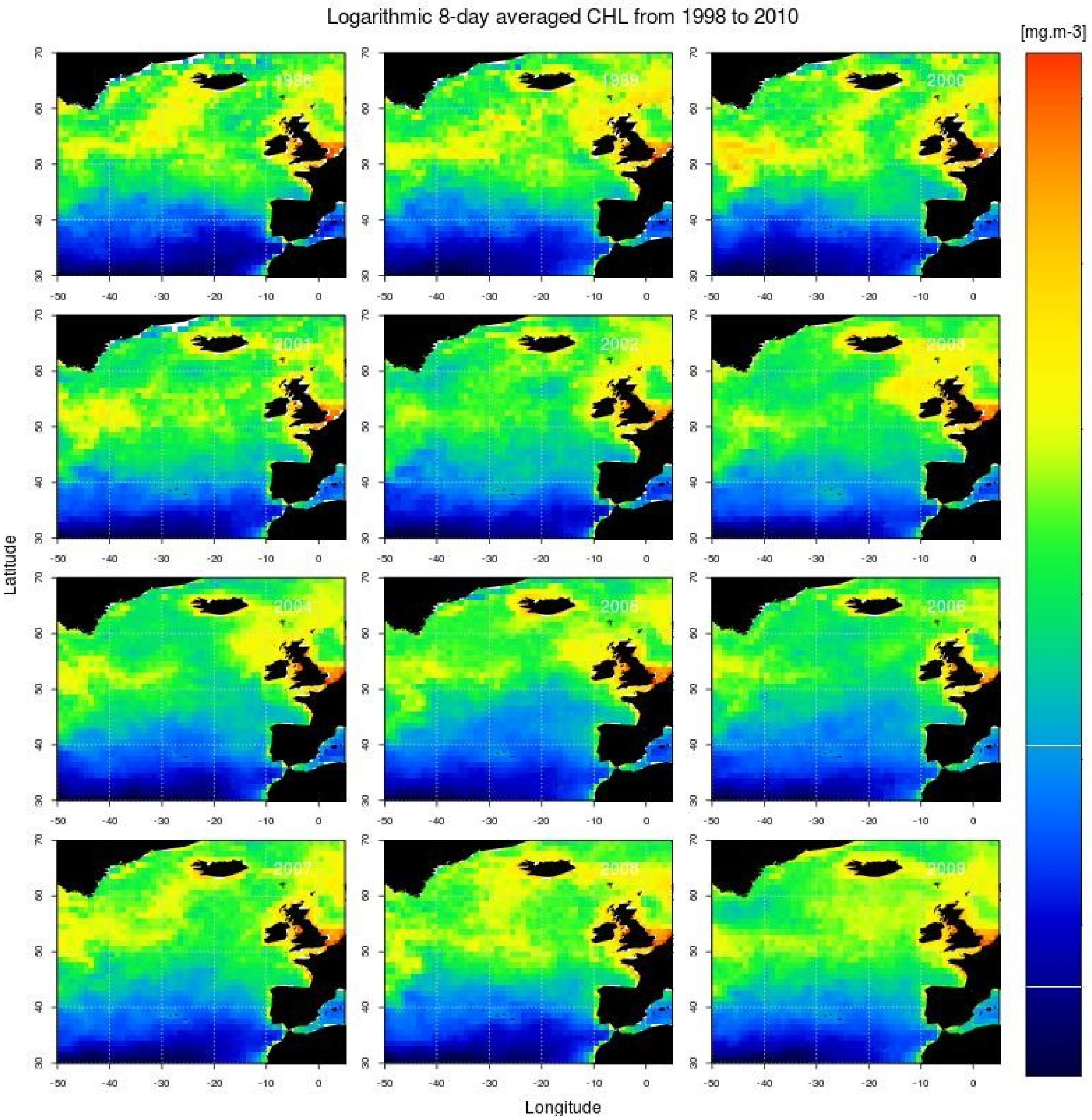


Figure 4: Chlorophyll concentrations on logarithmic scale averaged for each year for the ROI (see Fig 1).

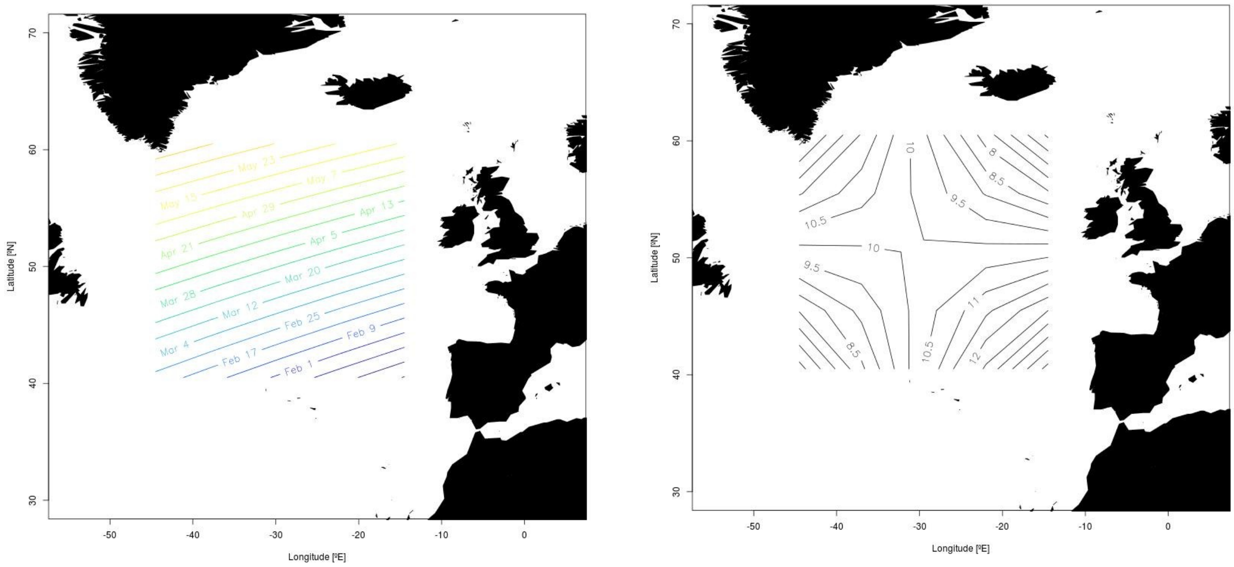


Figure 5: Maps of bloom timing (left) and duration (right) averaged for all years.

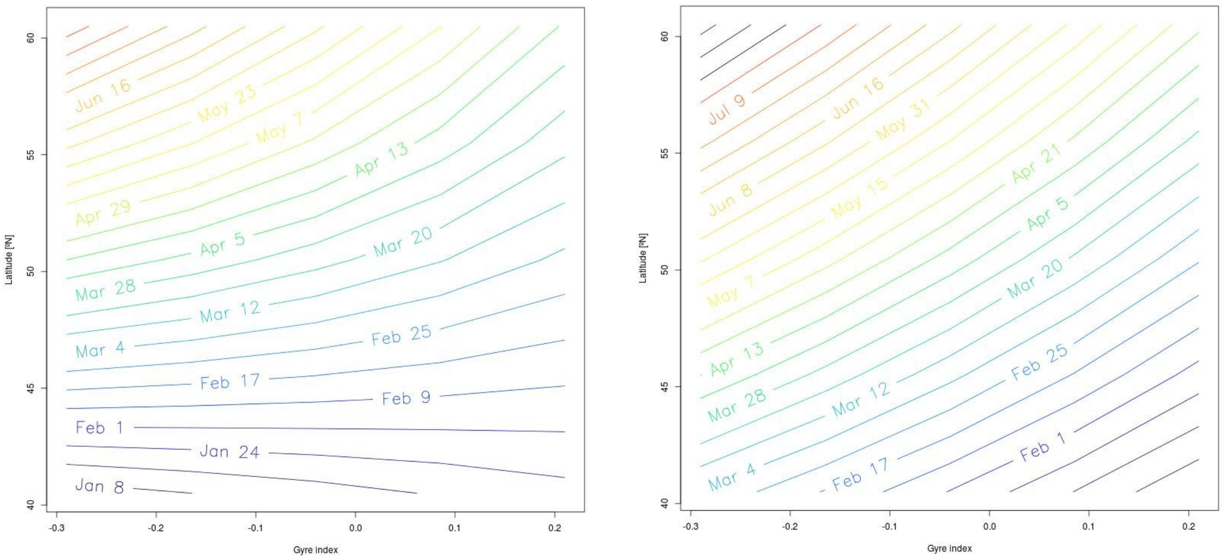


Figure 6: Scatter plots of bloom timing averaged for all years for all latitudes and NASPG strength for all longitudes (left) and when longitude was set to 15 ºW (right).

Conclusions

In order to understand how the bloom dynamics may impact fish recruitment, it is crucial to focus on the factors influencing the physical environment at more regional scales. Indications of a strong influence of NASPG index are related to areas within the gyre, which may have an impact in the ecosystem functioning. Moreover, it has been long known that bloom dynamics are described by different processes in different regions of the North Atlantic. This is specially true when one compares high-seasonality, light-limited regions, such as at high latitudes, with the more nutrient-limited, low latitudes regions. The results also suggest that physical forcing other than the strength of the NASPG may be influence the primary production of the more northerly regions east and west of Iceland. We hereby conclude that researched on physical forcing is central to characterise different scenarios on the phytoplankton phenology.

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