Remote sensing of diatom bloom succession

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Introduction

Marine diatoms are major biogeochemical and ecological *"influencers"* that contribute to a large fraction of the carbon export and supplying fisheries (Falkowski 2015).

The fluxes of carbon transfer to the food web or to the deep ocean vary according to the stage of a diatom bloom (Du Toit 2018). Stages can be determined using inherent optical properties that reflect their physiological state, such as the chlorophyll fluorescence to particulate backscattering ratio (ChlF/b_{bp}, Cetinic et al. 2015). Identifying the bloom stage can potentially improve biogeochemical models of carbon export and fishery management. However it is not yet possible to adequately determine the stage of phytoplankton blooms using satellites.

Satellite-derived remote sensing reflectance $R_{rs}(\lambda)$ allow for remote identification of diatom blooms in the open ocean (Sathyendranath et al. 2004), and there are techniques to estimate the fluorescence quantum yield (φ) that, when high, can indicate the nutrient limitation that often takes place when blooms start to senesce (Behrenfeld et al. 2009).

The goal of this study is to use the ratio between the normalized fluorescence line height from $R_{rs}(\lambda)$ (nFLH) and the particulate backscattering ($b_{bp}(443)$) provided by satellites to identify exponentially growing and senescent diatom blooms from space.

Methods

During the North Atlantic Bloom experiment in May 2008 (NAB08) (**Fig. 1**), the **succession** of a diatom bloom was described based on the **ChlF/b_{bp}** ratio (**Fig. 2**) from fluorescence and backscattering data aquired by a lagrangian float that followed the diatom bloom (Cetinic et al. 2015).

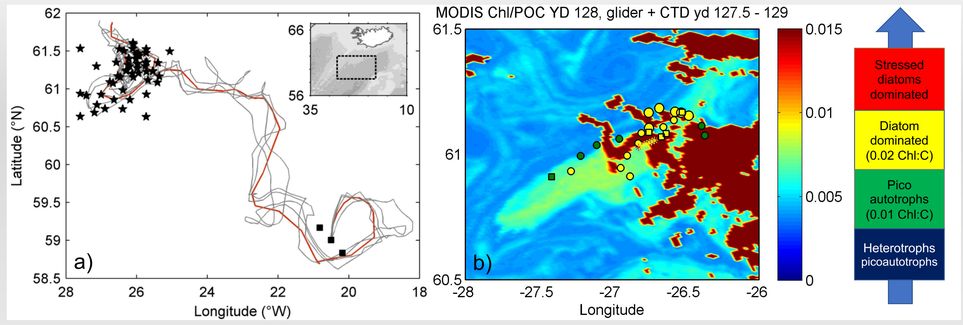


Figure 1. **a)** Track of the lagrangian float deployed during the NAB08, in the North Atlantic Ocean, where stars indicate CTD sampling stations, and **b)** Image of the chlorophyll to particulate organic carbon (POC) ratio from Aqua-MODIS products (May 8th, 2008), of the bloom surveyed by the NAB08. Figure (a) from Cetinic et al. (2015).

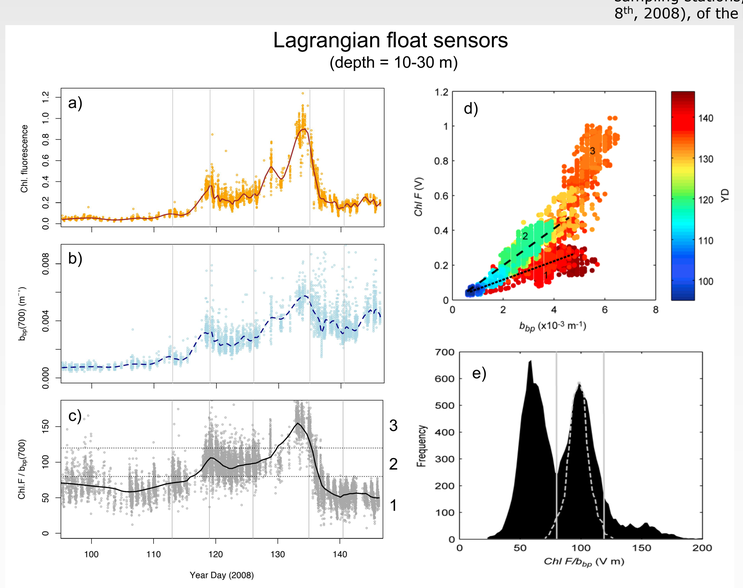


Figure 2. Inherent optical properties from lagrangian float sensors during the NAB08: **a)** chlorophyll fluorescence (ChlF) from active fluorescence sensor, **b)** particulate backscatter (b_{bp}) at 700 nm and **c)** ChlF/b_{bp} ratio, **d)** ChlF vs. b_{bp} and **e)** frequency distribution of Chl/b_{bp}. Horizontal dashed lines in (c and d) define the bloom stages of:

1) *ChlF/b_{bp} < 80*: Microbial population dominated by **small cells** (pico and nanoplankton and heterotrophic bacteria) – red in plot (d);
2) *ChlF/b_{bp} > 80 and < 120*: **Diatoms** on **exponential growth** stage – green in plot (d) – and;
3) *ChlF/b_{bp} > 120*: **Nutrient-stressed diatoms** going to senescence stage – orange in plot (d).

Lagrangian float **vs.** **Satellite product**

Fluorescence measured with active **fluorometer** → Chlorophyll concentration

Fluorescence under **natural light** (nFLH) → Chlorophyll concentration **photochemical quenching**

Compare **nFLH/b_{bp}** from Aqua-MODIS (**Fig. 3**) with **Fig. 2e**.

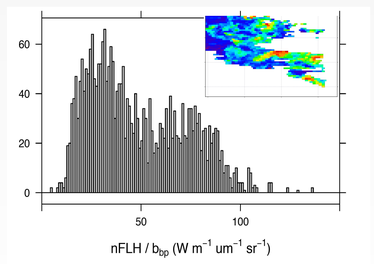


Figure 3. Frequency distribution of the fluorescence line height to backscattering (nFLH/b_{bp}) in the NAB08 diatom bloom image (Aqua-MODIS 4km daily image, May 8th 2008). Image on the top-right panel shows the nFLH/b_{bp}(700) ratio.

Compare **active fluorescence** (**Fig. 1a**) with **nFLH** from the float's $R_{rs}(\lambda)$ (**Fig. 4**).

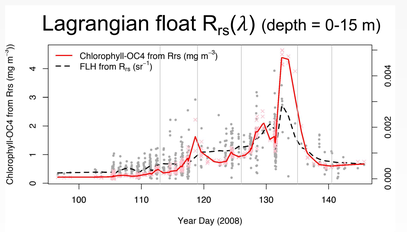
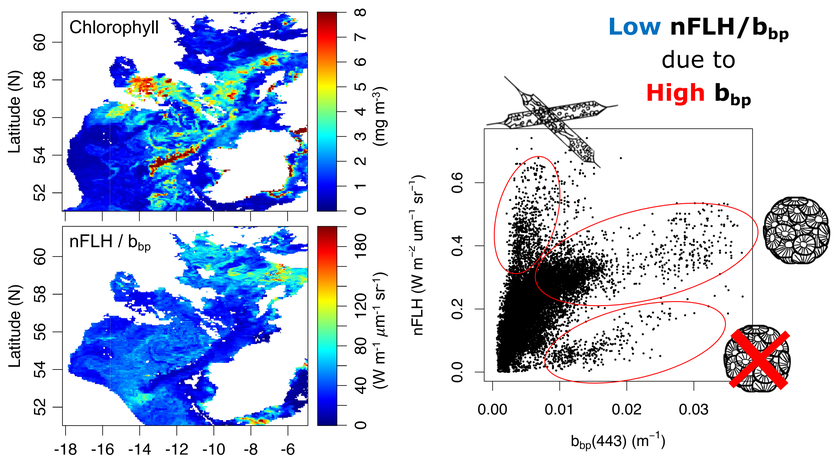


Figure 4. Chlorophyll concentration (mg m^{-3}) and fluorescence line height (nFLH, sr^{-1}) calculated from $R_{rs}(\lambda)$ (sr^{-1}) measured at the lagrangian float (Trios ARC radiometer).

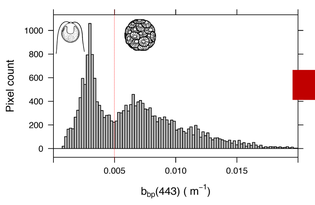
Application in the North Atlantic

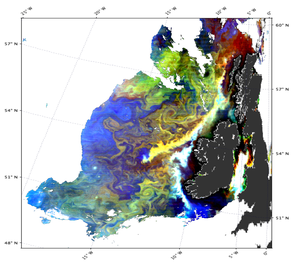
Coccolithophorid blooms

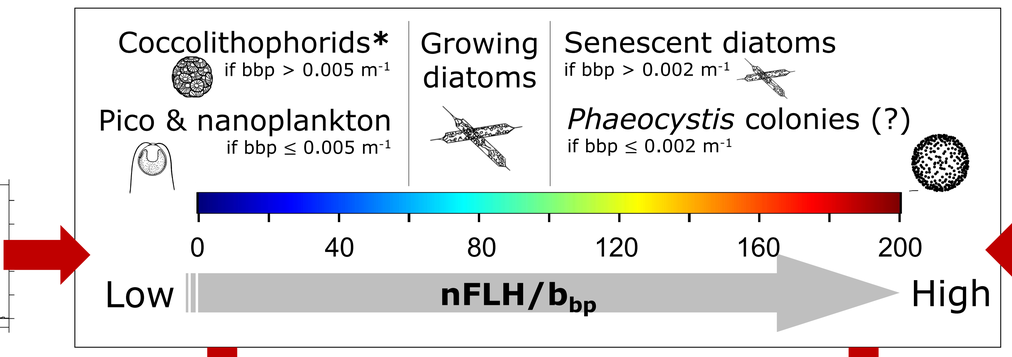
Aqua-MODIS, May 15th 2008, west of Ireland.

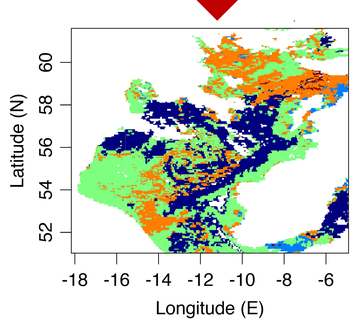


Pixels where **nFLH/b_{bp} < 50**





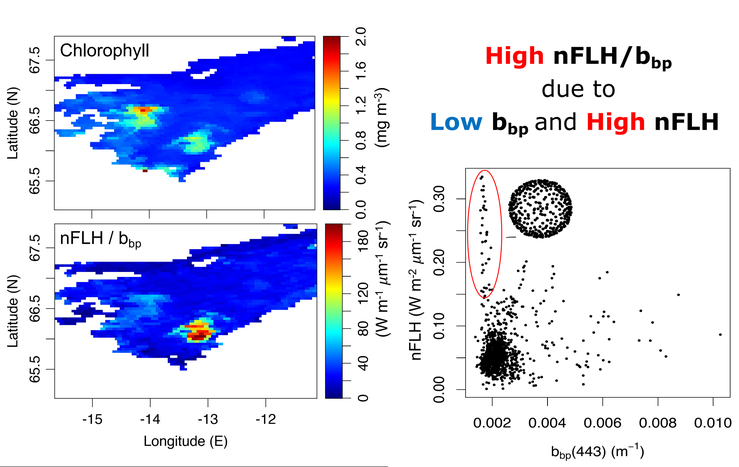




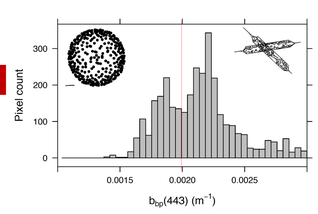
1) Coccolithophorids*
2) Phaeocystis colonies (?)
3) Pico- and nanoplankton (e.g., flagellates, *Synechococcus*)
4) Growing diatoms
5) Senescent diatoms

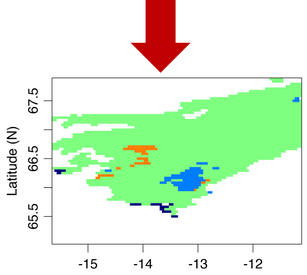
Blooms of different taxa or in different stages?

Aqua-MODIS, May 8th 2008, north of Iceland.



Pixels where **nFLH/b_{bp} > 100**





* Dinoflagellates can also present high backscatter, thus decreasing the nFLH/b_{bp} ratio.

Conclusions

- The **nFLH/b_{bp} ratio** implemented using satellite data can be used to infer different **stages of a phytoplankton bloom**, considering physiological changes and shifts in phytoplankton assemblages;
- The method can also be used to **distinguish blooms** of diatoms from coccolithophorids and *Phaeocystis*;
- However, although this method was proven efficient during the NAB08 experiment, further **validation with in-situ observations** is necessary to demonstrate the performance of this method to detect blooms of coccolithophorids, diatoms, or *Phaeocystis*. Further assessment is also required to discriminate dinoflagellates from other phytoplankton;
- It was not possible to assess the **influence of photochemical quenching** on the nFLH signal as a source of uncertainty, which needs investigation;
- The **b_{bp} of *Phaeocystis* colonies** is **low** when measured by instruments, with **occasional spikes**. The effect of this b_{bp} behavior on the satellite b_{bp} product is unclear.

References

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