

Development and application of an algorithm for detecting undesirable *Phaeocystis globosa* blooms

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CONTEXT AND OBJECTIVES

Detecting phytoplankton species from space is a challenge particularly relevant for mapping undesirable algal blooms in eutrophicated coastal waters. Such is the case in the turbid waters of the Southern Bight of the North Sea, where high concentrations of chlorophyll *a* corresponding to blooms of the colonial haptophyte *Phaeocystis globosa* in the presence of diatoms have been reported. To explore the possibility of detecting *Phaeocystis* colonies in these coastal waters also characterized by large concentrations of CDOM and non-algal particles (NAP), we conducted laboratory and field experiments aiming to:

- ❖ identifying specific differences in the absorption signature in order to discriminate *Phaeocystis* from diatoms in pure cultures and field samples
- ❖ retrieving these differences in the reflectance spectra in field samples dominated by *Phaeocystis* or diatoms
- ❖ using these differences, to develop an algorithm to detect the presence of *Phaeocystis* in the field.

METHODS

Cultures - Pure strains of the diatoms *Thalassiosira rotula* and *Dietylum brighwellii* and the haptophyte *P. globosa* were grown in a culture room at 8°C under two light intensities (10 and 100 μmol quanta m⁻² s⁻¹).

Field samples - Sampling was conducted in Belgian and adjacent coastal waters during several campaigns at different seasons from 2004 to 2007 aboard RV Belgica. Sampling area is reported in Fig. 1 in red.



Pigments - HPLC pigment determination following Wright et al. (1991).
Light absorption - Particle absorption (a_{part}) on filters was measured with the Transmittance-Reflectance method (Tassan & Ferrari 1995). Filters were bleached with NaOCl to obtain NAP absorption (a_{NAP}). Phytoplankton absorption (a_{ph}) was obtained from $a_{ph} = a_{part} - a_{NAP}$. Pathlength correction was performed following Tassan & Ferrari (1998). CDOM absorption was measured using a 10cm cuvette. Total absorption was calculated as:

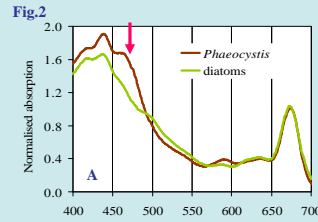
$$a_t = a_{part} + a_{CDOM}$$

Water-leaving reflectance (ρ_w) - measured above water using TriOS-RAMSES hyperspectral spectroradiometers, "Method 1" of the NASA protocols (Ruddick et al. 2006).

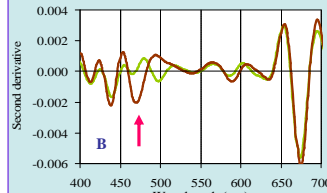
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1-Absorption differences between *Phaeocystis* and diatoms in cultures.

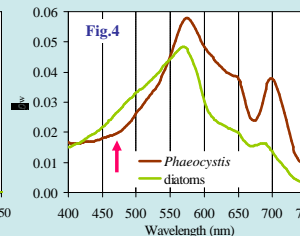
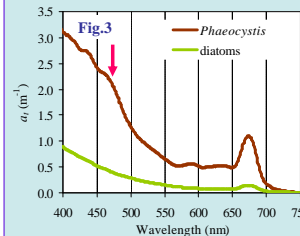


The absorption spectra of diatoms and *Phaeocystis* grown under 2 light conditions showed no overall significant differences thus average spectra were calculated for each taxa (Fig. 2A). The mean absorption spectra of diatoms and *Phaeocystis* show significant differences at 412, 440, 467 and 500 nm (ANOVA). The largest difference is obtained at 467 nm ($F=61.5$, $p<0.001$) corresponding to absorption of chlorophyll *c3* (chl *c3*).



The second derivative analysis (Fig. 2B) of the mean absorption spectra of both taxa shows that *Phaeocystis* present a minimum at 467 nm which is less evident in diatoms, making this wavelength appropriate for discrimination between taxa.

2-Retrieval of 467 nm absorption in reflectance spectra of *Phaeocystis* and diatom-dominated field communities.



The enhanced absorption at 467 nm, corresponding to absorption of chl *c3*, is also retrieved in field samples of total absorption (Fig. 3) and reflectance (Fig. 4) dominated by *Phaeocystis*.

RESULTS

3- Development of the three-band retrieval algorithm for chl *c3* from absorption or reflectance data.

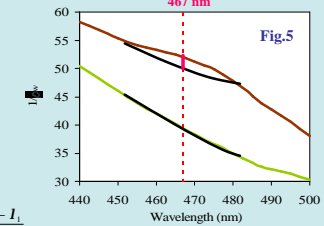
The algorithm for retrieval of chl *c3* is based on the difference between baseline and the measured absorption/reflectance (Fig. 5 thick red line), normalised by the product of reflectance and pure water absorption at a NIR wavelength. The algorithm uses 3 bands: $\lambda_1=450$ nm and $\lambda_2=480$ nm chosen at either side of the expected chl *c3* absorption band ($\lambda_{c3}=467$ nm). The extra absorption at λ_{c3} , that can be attributed to chl *c3* alone, can be approximated by an exponential interpolation of the total absorption a_t between λ_1 and λ_2 :

$$a_{c3}(\lambda_{c3}) = a_t(\lambda_{c3}) - a_t(\lambda_1)^{(1-w)} * a_t(\lambda_2)^w \quad (1) \quad \text{where } w = \frac{I_{c3} - I_1}{I_2 - I_1}$$

$$\text{Assuming: } a_i(I_i) = a_w(I_{NIR}) \frac{r_w(I_{NIR})}{r_w(I_i)} \quad \text{for } i = 1, 2, c3 \quad (2)$$

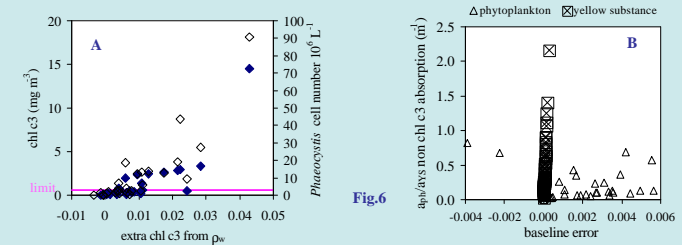
Substituting (2) into (1) gives the retrieval algorithm based on reflectance (ρ_w):

$$a_{c3}(I_{c3}) = \left[\frac{1}{r_w(I_{c3})} \right] - \left[\frac{1}{r_w(I_1)^{1-w}} \right] * \left[\frac{1}{r_w(I_2)^w} \right] * a_w(I_{NIR}) * r_w(I_{NIR}) \quad (3)$$



The reciprocal of water-leaving reflectance (Fig. 5) is compared to baselines obtained by exponential interpolation between 450 nm and 480 nm (bold lines).

4- Validation of the *Phaeocystis*-detection algorithm based on reflectance



A significant regression is obtained between extra chl *c3* absorption from water-leaving reflectance (ρ_w) and measured chl *c3* concentrations ($r^2 = 0.66$, $p < 0.0001$) (Fig. 6A, filled diamonds) and between extra chl *c3* absorption from water-leaving reflectance and *Phaeocystis* cell number ($r^2 = 0.72$, $p < 0.0001$) (Fig. 6A, open diamonds).

The algorithm uncertainty was calculated by applying the algorithm to non-chl *c3* containing phytoplankton absorption on the one hand and to yellow substance (YS=CDOM+NAP) absorption on the other hand. This correspond to the error, expressed in absorption, calculated by the algorithm for samples with absence of chl *c3* (Fig. 6B). The YS baseline error is nearly zero. The baseline error for non-chl *c3* phytoplankton has a maximum value of 0.006 meaning that below this value the algorithm is not able to detect extra chl *c3* from *Phaeocystis*. Thus, the limit from which the *Phaeocystis* bloom can be quantified is 0.6 mg chl *c3* m⁻³ equivalent to 5.5x10⁶ cells L⁻¹.

CONCLUSION: Is detection of *Phaeocystis* from remote-sensing feasible?

The proposed algorithm is capable of detecting the presence of *Phaeocystis* from the information retained in water-leaving $\rho_w(467)$ or total $a(467)$, when no other chl *c3* containing species are present and could serve for providing *Phaeocystis* information from remote sensing images.

The yellow substance (CDOM+NAP) interference is eliminated from the algorithm by using an exponential baseline which fits the exponential form of the yellow substance absorption. In this way, the algorithm can be used in very turbid (case 2) waters, i.e. Southern Bight of the North Sea.

The detection of *Phaeocystis* from space could be possible if the appropriate wavelengths are available in satellite sensors and if no atmospheric effects are interfering with the water leaving reflectance.

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