OPTICAL DETECTION OF A *NOCTILUCA SCINTILLANS* BLOOM

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ABSTRACT

Noctiluca scintillans blooms are often observed as reddish patches in Belgian waters in June-July in calm weather. The possibility of mapping these blooms is investigated here. In June 2005 a dataset of *in situ* measured reflectance spectra, airborne hyperspectral images, experimental reflectance and absorption spectra of *Noctiluca scintillans* was collected. The strong optical signature of dense *Noctiluca scintillans* blooms suggests that mapping these blooms should be feasible. A detection algorithm is proposed based on a combination of a high reflectance threshold with a condition of sharp increase in reflectance in the range 520-580 nm. This algorithm will detect only intense blooms but should distinguish between *Noctiluca scintillans* and both intense phytoplankton blooms and very turbid water. *Noctiluca scintillans* detection by optical sensors mounted on ships and airplanes has been confirmed for the June 2005 bloom in Belgian waters. Detection from satellites should also be feasible but only if suitable wavelengths are available and only if the spatial resolution is sufficiently high. The optical properties of this species are thought to be related to gut content. The applicability of this algorithm to other regions and situations therefore remains to be tested.

Keywords: *Noctiluca scintillans* detection, remote sensing of phytoplankton blooms.

INTRODUCTION

Noctiluca scintillans is a heterotrophic, bloom forming dinoflagellate. It is a cosmopolitan species distributed world wide in cold and warm water (1), which contains a gas vacuole that enables the creature to float and to move between surface and bottom of the ocean (2).

Although the cell is mainly colourless and non-photosynthetic on its own, it appears pink, red or green in colour because of symbionts (3) and probably because of ingested material which depends on its geographical location. Evidence shows that *Noctiluca* blooms are green in The Philippines (4). They are observed as red tomato soup like patches in Belgian waters, during calm, warm weather in June-July (Figures 1, 3). However the definitive explanation for their colour is not clear. *Noctiluca scintillans* feeds on particles, mainly diatoms, and its growth requires large amounts of food suggesting that its nature may be limited by food availability (5,6). *Noctiluca* abundances have been found greater in coastal waters than in estuaries or offshore areas (5). Because of its strong colour, it should be possible to discriminate *Noctiluca* optically from other components in the sea.

In some regions blooms of *Noctiluca scintillans* have been linked to massive fish and marine invertebrate kills (1,7). While the species is itself not toxic, intense blooms may generate high levels of ammonia in the surrounding waters (1). These blooms have not been shown to be harmful in Belgian waters, but their role in clearing the water of other plankton is thought to be an important element of the trophic chain (8). The possible impact on mussel farms is unknown.

The objective of this study is to design an algorithm to map *Noctiluca scintillans* in the "easy" case of a high concentration (spatially resolved) surface bloom. Various algorithms have been designed for detecting specific taxa or functional groups from optical data and are reviewed in a harmful algae bloom context (9). Such algorithms generally exploit optical properties of the target taxa which are distinctly different from other taxa. Usually this relates to a pigment which is present in only the target taxa and which contributes significantly to the absorption spectrum, e.g. (10). Backscattering properties may

also provide a means to distinguish between taxa in some circumstances (11), but are unlikely to be useful in waters with significant backscatter from non algae particles.

This paper describes reflectance and absorption spectra recorded during an intense bloom in Belgian waters. Based on these optical properties a detection algorithm for intense *Noctiluca scintillans* blooms has been designed and tested. Limitations and future application to satellite data are also described.

DATA

On 23 June 2005 a benchmark dataset including seaborne, airborne and satellite optical data was collected in turbid waters just offshore of Oostende. This is a region of shallow water (depth <20 m) with strong tides (~1 m/s maximum current) and high suspended matter concentrations (typically 10-100 g/m^3) as described in more detail in (12).
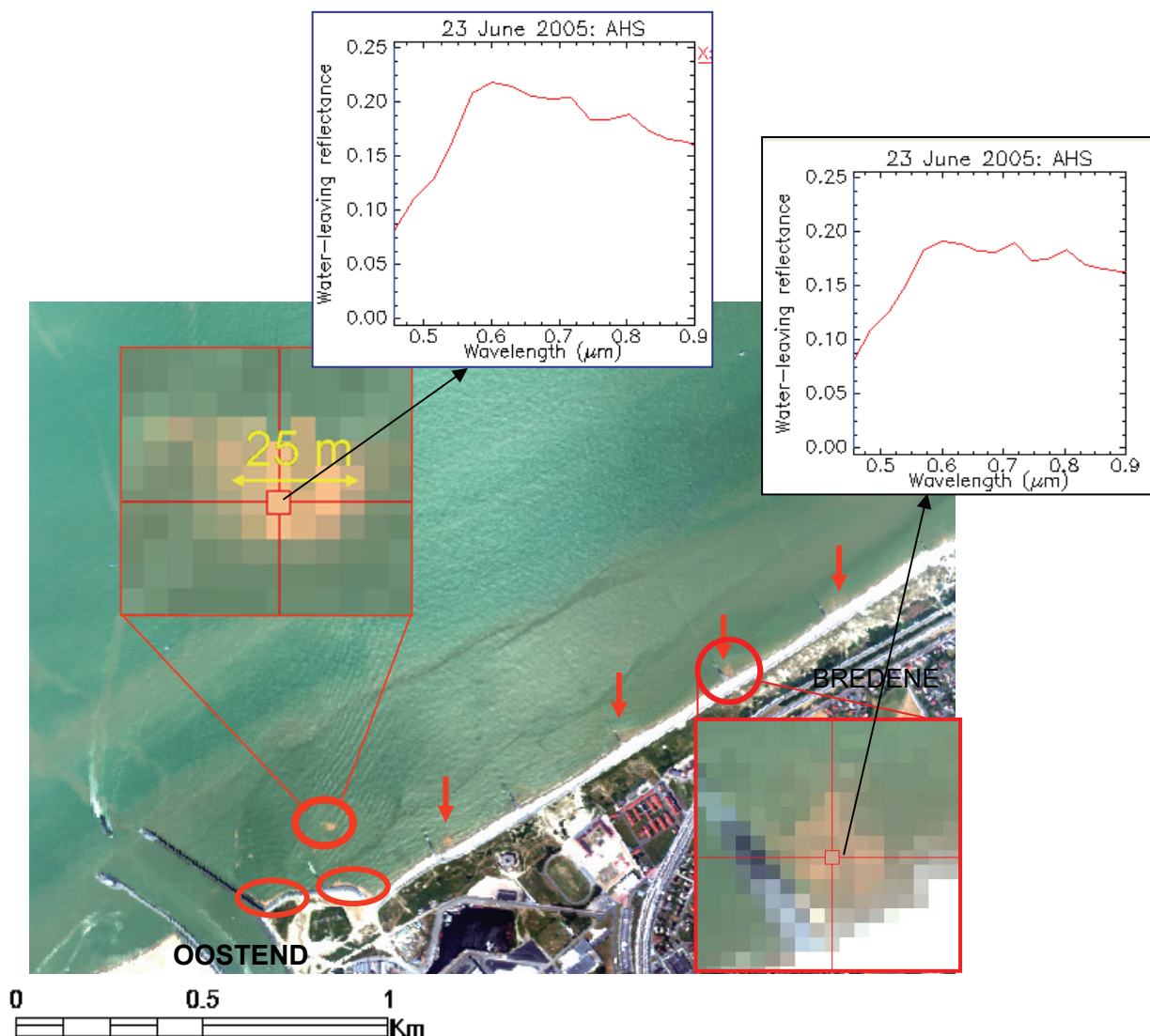

Figure 1: Water-leaving reflectance spectra extracted from the AHS image at a pixel identified as Noctiluca. Red-Green-Blue composite generated from wavelengths 630, 542 and 455 nm.

On the way to the measurement points, *Noctiluca* was visually observed in high concentrations near the harbour of Oostende and at the coast of Bredene between the jetties. Simultaneous air-

borne hyperspectral images were made with an AHS[1] sensor. The resulting AHS images were atmospherically corrected by VITO[2] with software based on Watcor (13). The visually observed *Noctiluca* patches as well as some other patches are located on the AHS image and spectra of water-leaving reflectance – defined (14) as π times the above-water water-leaving radiance divided by downwelling irradiance – are extracted from pixels identified as *Noctiluca* (Figure 1). A more dispersed patch was crossed during the *in situ* water-leaving reflectance measurements made in point BRC4 and at the beginning of transect BRCT3, before crossing a sediment front (Figure 2).
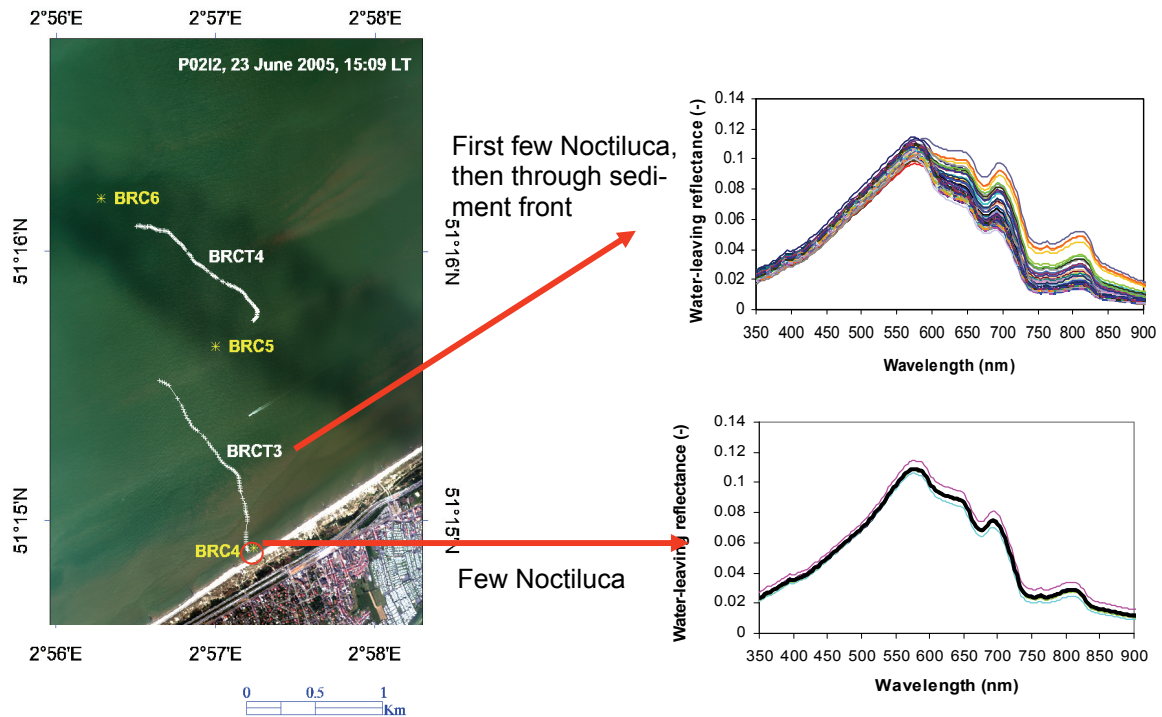

Figure 2: Water-leaving reflectance measured by TriOS-RAMSES on 23 June 2005 at point BRC4 and during transect BRCT3 (scans every 10 seconds).
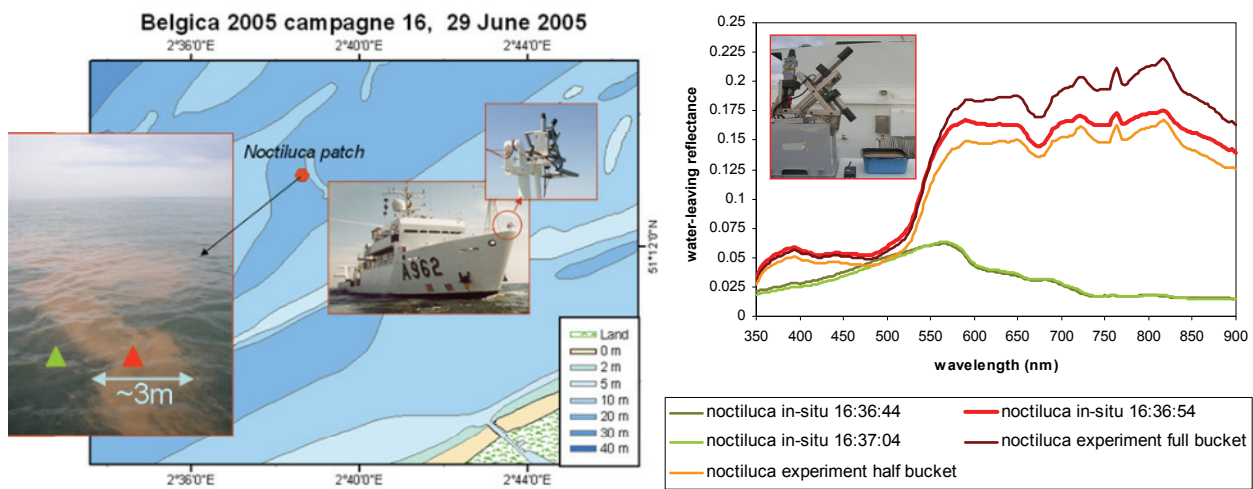

Figure 3: Water-leaving reflectance measured by TriOS-RAMSES on 29 June 2005 in the middle of the Noctiluca patch (red), just before and after entering the patch (green) and measured on board in a bucket full (mauve) and half full (orange) with Noctiluca.

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[1] Airborne Hyperspectral System. Information about the AHS sensor can be found at http://www.crepad.rcanaria.es
[2] http://www.vito.be

Six days later, on 29 June 2005 water-leaving reflectance measurements were made in the middle of a *Noctiluca scintillans* patch (Figure 3). Additional buckets of *Noctiluca* were taken from the patch for absorption and experimental reflectance measurements on board.

The *in situ* water-leaving reflectance measurements are made using a system of three TriOS-RAMSES sensors mounted at the bow of the ships (a rigid inflatable boat on 23 June, the Research Vessel *Belgica* on 29 June 2005). A detailed description of the measurement protocol is given in the text and Web Appendices of (15) and is based on the protocol of (16).

RESULTS

Reflectance spectra

On the quasi true colour images of the AHS data, reddish patches are visible and, based on *in situ* observations, were identified as *Noctiluca* (Figure 1)*.* Despite the greater spectral smoothing of the AHS sensor (Full Width at Half Maximum 27 to 29 nm for the spectral bands between 450 and 1000 nm) (17), similarities are found between the water-leaving reflectance extracted from AHS pixels believed to be *Noctiluca* (Figure 1) and the *in situ* measured water-leaving reflectance spectrum of *Noctiluca* recorded by the TriOS system on 29 June 2005 (Figure 3).

The reflectance spectra recorded at point BRC4 and for the transect BRCT3 (Figure 2) are less reflective between 600 and 900 nm than the spectra measured for very high concentrations of *Noctiluca* (Figure 3) because of reduced scattering. Similarly the sharp rise in reflectance between 450 and 590 nm found for the more intense bloom is not found in Figure 2 because at lower concentrations the optical characteristics of *Noctiluca scintillans* are masked by the optical properties of other particulates.

The reflectance spectra of *Noctiluca* blooms are compared with spectra for a bloom of *Phaeocystis globosa* and for water with very high non-algal suspended matter in Figure 4. Clearly a *Noctiluca* detection algorithm must distinguish between such spectra.
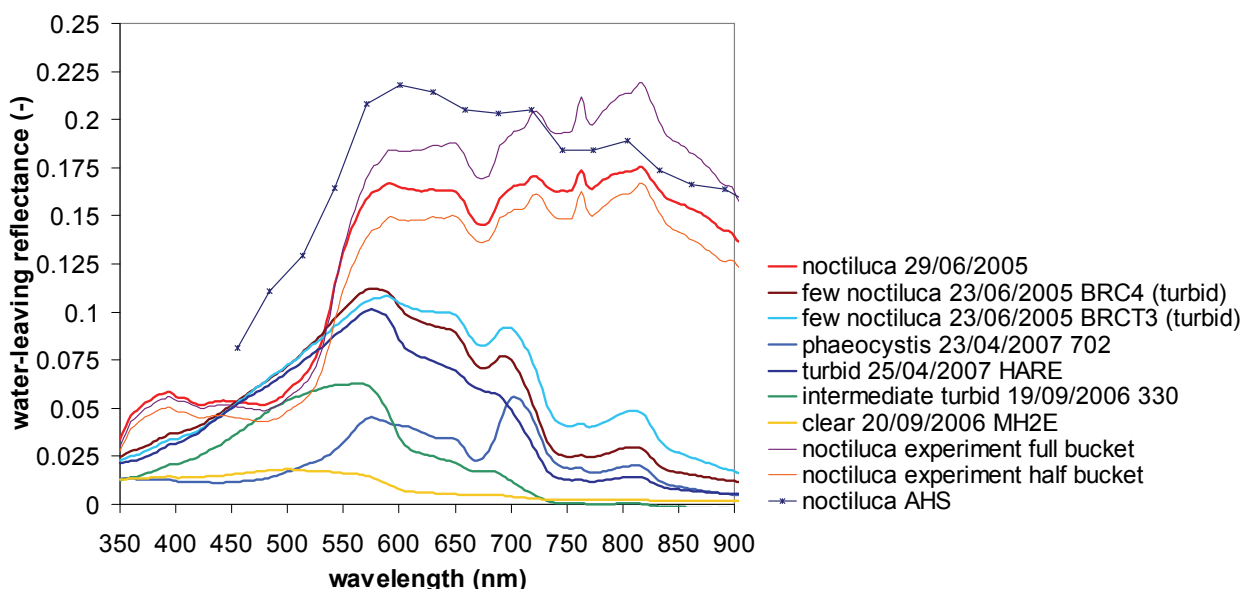

Figure 4: Comparison of different water-leaving reflectance spectra.

Detection algorithm

For the detection of *Noctiluca scintillans* in turbid coastal waters the reflectance data of Figure 3 suggests the possibility of using either the red and near infrared reflectance (600-900 nm), which is very high and spectrally rather flat, or the sharp increase in reflectance observed in the range 520-580 nm. Considering first the red and near infrared range, it is striking that the reflectance shown in Figure 3 is nearly constant despite the large spectral variation in pure water absorption (15,18).

This implies that the backscattering is so high that a maximal "saturation" reflectance has been reached. While highly unusual, this feature derives essentially from the extremely high near-surface concentrations of scattering particles reached in this bloom and not from the nature of the particles. An extremely high concentration of non-algae particles (NAP) could give a similar reflectance spectrum, see Figure 5 of (19). A detection algorithm based on this feature alone will be prone to false detection in high NAP conditions.

An important difference between the *Noctiluca scintillans* reflectance spectrum and a typical high NAP reflectance spectrum is the rate of increase of reflectance from 520 to 580 nm which is much smoother in the case of NAP. This can be related to the corresponding absorption spectra shown in Figure 5 – taken from (20), where *Noctiluca scintillans* shows a sharper decrease in absorption from 520 to 580 nm compared to the exponential decrease in absorption that can be expected of NAP (and of coloured dissolved organic matter). While this feature would allow to distinguish between *Noctiluca scintillans* and NAP it is also necessary to distinguish between *Noctiluca scintillans* and phytoplankton species which may also occur in bloom conditions. Comparison of the absorption spectra with typical phytoplankton species in Figure 5 shows that significantly higher absorption is found for *Noctiluca scintillans* in the range 500-550 nm. HPLC analysis of a water sample shows a high proportion of carotenoids compared to photosynthetic pigments. In particular one carotenoid, found at high concentration, accounted for 36% of the pigments but has not yet been clearly identified (Astoreca, unpublished results).
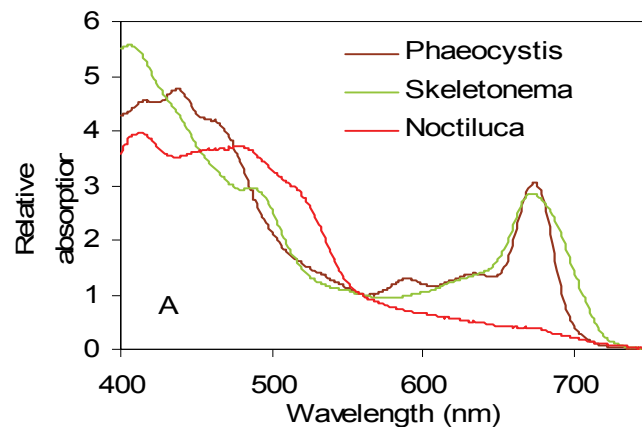

Figure 5: *Absorption spectra normalised to 560 nm for pure cultures of Phaeocystis globosa (brown) and Skeletonema costatum (green) isolated from Belgian waters and a natural sample of Noctiluca scintillans (red) taken from Belgian waters.*

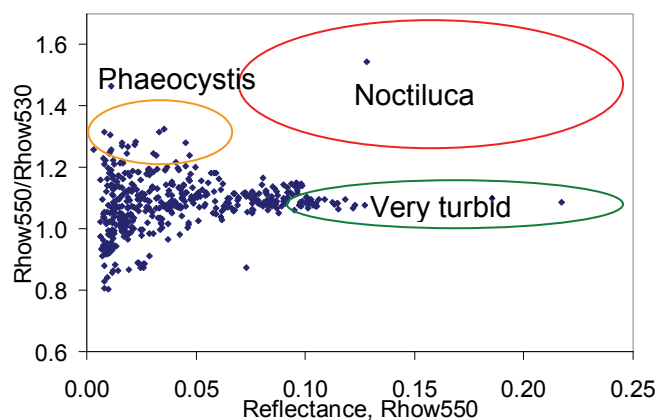
Figure 6: *Ratio of water-leaving reflectance at 550 nm over 530 nm to the water-leaving reflectance at 550 nm of all the in situ measurements made in Belgian and adjacent waters over the period 2001-7. See (9) for a description of measurement conditions.*

To allow discrimination between *Noctiluca scintillans* and both NAP and other phytoplankton species, it is proposed to combine conditions of both high backscatter and a sharp decrease in absorption from 520 to 580 nm. In a first detection algorithm, the wavelengths 530 nm and 550 nm are chosen. Plotting the ratio of water-leaving reflectance at 550 nm, Rhow550, to that at 530 nm, Rhow530, against Rhow550 of all the *in situ* measurements made in the Belgian and adjacent waters over the period 2001-2007, shows that most ratios are between 1 and 1.2 (Figure 6). The measurement made in a *Noctiluca* bloom takes a completely different niche from the other measurements. From this plot we propose that *Noctiluca scintillans* blooms will be best detected by Rhow550/Rhow530>1.25 and Rhow550>0.06.

A detection algorithm suitable for the AHS wavelengths is then given by Rhow542/Rhow513>1.24 and Rhow542>0.06. Figure 7 shows that the ratio Rhow542/Rhow513>1.24 can pick up *Noctiluca scintillans* blooms of very high concentration. However, because of the greater spectral smoothing of the AHS sensor the threshold of 1.24 may need to be reduced with respect to TriOS. Similar algorithms can be designed for other sensors, such as MODIS (531 nm and 551 nm) which have bands in this range, although it is unclear whether the 510 nm and 560 nm bands of MERIS are suitable.
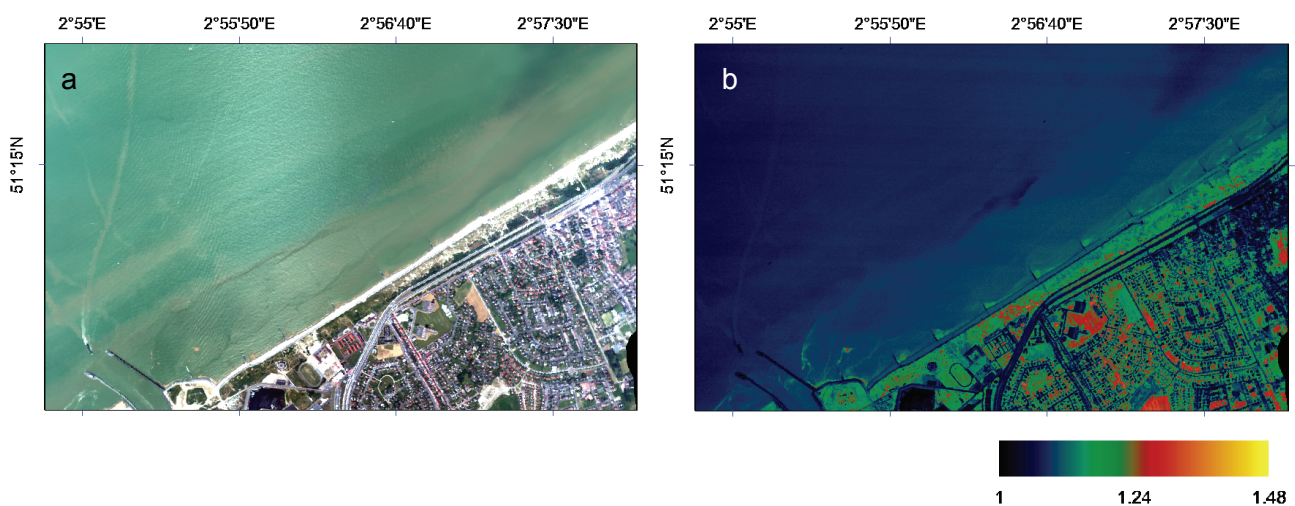

Figure 7: a) Quasi true colour image of AHS data ; b) Ratio Rhow542/Rhow513

Limitations

The high concentrations of *Noctiluca* in Belgian waters occur in small patches or lines, ranging from less than half a metre to 50 m. In satellite images like MERIS and MODIS, where the highest resolution is 250 m, the *Noctiluca scintillans* reflectance will be averaged with the water-leaving reflectance of the water in the same pixel. Figure 8 is an example of how the water-leaving reflectance spectra changes when averaging adjacent spectra. Detecting *Noctiluca* from satellite images will be possible only if the pixel size of the images is smaller then the highly concentrated *Noctiluca* patches.

Detection of less intense blooms is limited because the distinct features used to identify *Noctiluca* become smoothed into the reflectance spectrum resulting from the other water constituents. In conditions where vertical mixing prevents very high surface concentrations from occurring it will be difficult to distinguish between *Noctiluca scintillans* and other algal and non-algal particles.

Since the optical properties of this species are probably related to their gut content (4,20), and hence diet, there may be considerable variation in reflectance spectra, especially between this and other regions. The global applicability of this detection algorithm is thus uncertain and needs to be further investigated.

The very high near infrared reflectances observed for intense blooms will cause failure of atmospheric correction algorithms which use the near infrared for estimation of aerosol properties (21-24).

Moreover *Noctiluca* is often found near to ports and jetties, where the water is calmer but where the proximity to land causes extreme atmospheric correction problems relating to adjacency effects.
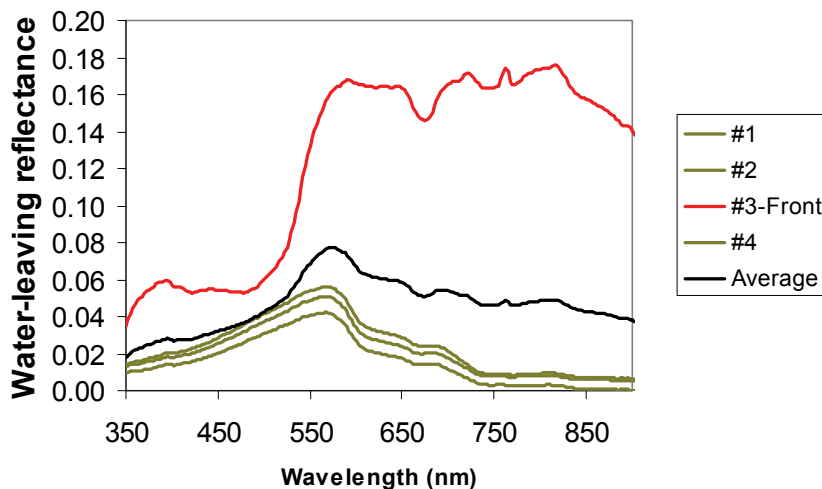

Figure 8: red: Noctiluca; green: next to Noctiluca patch; black: average of Noctiluca scan and three adjacent scans.

CONCLUSIONS

Intense blooms of *Noctiluca scintillans* are characterised by a high reflectance for wavelengths higher than 580 nm and a sharp increase in reflectance from 520 to 580 nm. An algorithm is proposed for the detection of such intense blooms and has been tested for a bloom in Belgian waters. Detection by remote sensing is possible if the concentration is sufficiently high and if the spatial resolution of the sensor is fine enough to resolve patches.

ACKNOWLEDGEMENTS

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