DETECTION OF ALGAE BLOOMS IN THE NORTH SEA USING SUPERVISED CLASSIFICATION OF SEAWIFS REFLECTANCE IMAGERY*

R. Pasterkamp, S.W.M. Peters, H.J. van der Woerd
Institute for Environmental Studies (IVM)
Tel. +31 20 444 9552/9555 Fax. +31 20 4449553
e-mail: Reinold.Pasterkamp@ivm.vu.nl
Amsterdam, The Netherlands

H.J. Hoogenboom
Nat. Inst. for Coastal and Marine Management/RIKZ
The Hague, The Netherlands

ABSTRACT

In the Netherlands, on-going operational processing of SeaWiFS imagery has resulted in a time-series of images of total suspended matter concentration (TSM) in the North Sea of 1999 and 2000. The used TSM algorithm provides reliable results for this case II water, which is dominated by sediment from various sources. However, the algorithm tends to seriously overestimate TSM concentrations in areas with high reflectance values due to algal blooms. For this reason, blooms may be misinterpreted for areas with predominantly high sediment concentrations. In individual images, experts can easily recognize algal blooms because of the typically limited extend (50-100 km) and annually recurrent pattern in the North Sea. For operational monitoring however, a more reproducible and objective method is necessary. This paper presents the results from a study to design a method that discriminates between areas where high reflectance values are primarily due to high concentrations of suspended sediments, and areas where high reflectance values are due to algal blooms. The method is based on maximum likelihood classification of three spectral band combinations, where the classes (10 in total) are established by selecting characteristic regions of interest (including clear waters, turbid coastal waters and several algal blooms) in several SeaWiFS reflectance images (the training set). The method was applied favourably to the training set for consistency, and to a test set of other images where algal blooms are known to be present.

1.0 INTRODUCTION

Dutch coastal management authorities routinely monitor the quality of the North Sea system. The monitoring is required to check the current water-quality parameters against norms and detect long-term trends. Furthermore it is essential to verify if current policies have the desired effect (feed-back) and the data is used by scientists for a better understanding of the North-Sea system. An important physical parameter with respect to ecology is the total suspended matter concentration (TSM) or dry weight. The TSM directly influences the under water light field via the diffuse attenuation coefficient thereby limiting the available radiation necessary for the growth of algae. Micro-pollutants adhere to the suspended particles and are thus transported along with the sediments.

† The term ‘Suspended’ is here defined as not passing a Whatmann GF/F glassfibre filter.
Current routine monitoring by Dutch authorities is based on recurring field cruises (2-week intervals) visiting approximately 18 fixed sampling stations. Although this type of monitoring may be sufficient to detect long-term trends, and to compose spatial information on a course spatial scale by interpolation, it is insufficient to observe relevant smaller scale processes (coastal river, estuaries, river outflows, dredging/dumping activities) with higher frequency (daily or even more frequently). Remote Sensing offers the opportunity to increase the knowledge of sediment transport on a high spatial resolution.

Two years ago, the National Institute for Coastal and Marine Management/RIKZ commissioned the Institute for Environmental Studies (Netherlands) to produce an atlas of the North Sea for the total suspended matter concentration. The atlas consisted of maps on a 1 square kilometre resolution derived from SeaWiFS. Fifteen images were selected that showed typical patterns of TSM in the North Sea, during all seasons. The algorithm (van der Woerd et al., 2000) used to calculate the total suspended matter concentration was developed within the POWERS (Pre-Operational Water and Environment Regional Service) project and is based on the subsurface irradiance reflectance in waveband 5 of the SeaWiFS (nominal wavelength 555nm). A graphical representation of the algorithm is shown in Figure 1, together with the legend intervals used in the final atlas.

![Figure 1. Relation Between Subsurface Irradiance Reflectance In SeaWiFS Band 5 and the Total Suspended Matter Concentration.](image)

The algorithm provides reliable (accuracy estimated smaller than 30%) results for the North Sea, which is dominated by sediment from various sources. However, the algorithm tends to seriously overestimate TSM concentrations in areas with high reflectance values due to algal blooms. For this reason, blooms may be misinterpreted for areas with predominantly high sediment concentrations. In individual images, experts can easily recognize algal blooms because of the typically limited extend (50-100 km) and annually recurrent pattern in the North Sea. For operational monitoring however, a more reproducible and objective method is necessary. The problem is illustrated in Figure 2, showing a typical spring bloom in the North Sea and the resulting TSM map.

Two bright patches are visible in the centre of the left image (indicated by arrows). The left patch is caused by sediment originating from the Thames estuary, coastal erosion and/or resuspension of bottom material. The strong increase in total suspended matter concentrations in the accompanying TSM map (right image) thus is realistic. A highly reflective Phaeocystis bloom causes the right patch. This type of bloom is common in the Dutch North Sea in spring. Although the area will have an increased
concentration of TSM due to the augmented algal biomass, the derived TSM concentrations are seriously overestimated in the TSM image. These kinds of errors are of course not wanted in the final maps presented to the end-user. To improve the overall quality of the maps, it is desirable to 1) redesign the algorithm so that it can distinguish between areas with high (inorganic) sediment concentrations, and areas with high algae concentrations –or– 2) mask the algae blooms from the final maps.

Several algorithms exist to detect chlorophyll concentrations in case II waters by SeaWiFS (e.g. Althuis et al., 1996). However, these algorithms are not very accurate, because SeaWiFS was designed to detect chlorophyll concentration in ocean (case I) waters and misses essential bands in the red part of the spectrum necessary to detect chlorophyll in case II waters (e.g. Gons, 1999; Ruddick et al., 2000). Moreover, the chlorophyll concentration does not provide any information about the dominant algal species in the bloom. Because of these two drawbacks, it was decided not to try and develop a SeaWiFS chlorophyll algorithm for the North Sea, but to try to classify the algal blooms to be able to mask them in the final TSM image and even try to differentiate between several dominant algal species. The idea of using (multispectral) classification techniques was also initiated by the observation that differences in colour are visible between the algal bloom (greenish) and the area with high sediment concentration (brownish) in the ‘true’ colour image in Figure 2.

2.0 METHODS

1.1 IMAGE AND BLOOM SELECTION

The first step in setting up the classification method was to select SeaWiFS images covering the North Sea where algae blooms are visible. Images were considered from 1999 and 2000 where the North Sea was in the centre of the scan and with (almost) no cloud cover. The selection of the blooms was based on visual inspection of true colour images. Attention was paid to the typical (limited) extend of the blooms and the location where they are expected to appear in spring and summer. Additionally, other water types were also selected (e.g. several sediment types, canal water and clear ocean water) as input for the classification algorithms. The procedure resulted in 10 regions of interest (ROI’s). Four of them were identified as algae blooms: a Phaeocystis bloom close to the Dutch coast, two Coccolithophores

Figure 2. SeaWiFS Image Of 27 April 1999. True Colour Image Left And TSM Map Right. An Algae Bloom Is Visible In The Centre Of The Image.
blooms (*Emiliania huxleyi*) south of Norway and a *Chattonella verruculosa* bloom west of Denmark (pers. comm. G.H. Tilstone). The following table lists the SeaWiFS images used and the selected ROI’s.

<table>
<thead>
<tr>
<th>SeaWiFS image</th>
<th>date</th>
<th>time (UTC)</th>
<th>selected ROI’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1999117121456.L1A_HDUN</td>
<td>27-apr-99</td>
<td>12:14:55</td>
<td><em>Phaeocystis</em> bloom, UK sediment NL sediment, DK sediment, Canal, Ocean I, Ocean II</td>
</tr>
<tr>
<td>S1999191124408.L1A_HDUN</td>
<td>10-jul-99</td>
<td>12:44:08</td>
<td><em>Coccolithophores</em> bloom I <em>Coccolithophores</em> bloom II</td>
</tr>
<tr>
<td>S2000127120112.L1A_HDUN</td>
<td>6-mei-00</td>
<td>12:01:12</td>
<td><em>Chattonella verruculosa</em> bloom</td>
</tr>
</tbody>
</table>

**Figure 3. Ten Selected ROI’s In Three SeaWiFS Images**
The ROI’s are indicated as striped patches in the true colour images of the SeaWiFS images in Figure 3. Next the pixels were sampled for each region of interest. In classification terms, each ROI will result in one class. For a better understanding, the mean class reflectance spectra are plotted in Figure 4. The left graph shows the subsurface irradiance reflectance and the right graph shows the same subsurface irradiance reflectance, normalised at SeaWiFS band 5.

Noticeable are the large differences in absolute reflectance and the large differences in spectral signature. The Coccolithophores and Phaeocystis blooms demonstrate the highest reflectance in the blue. The sediment classes are somewhat lower in absolute reflectance, but have higher reflectance s in the red. Note that for instance the DK and UK sediment classes have virtually the same reflectance in band 5 as the Coccolithophores 1 class (thus the TSM algorithm would derive the same TSM value), but are spectrally totally different.

![Figure 4. Mean Class Reflectance Spectra. Left Graph: Absolute Reflectance, Right Graph: Reflectance Normalised at Band 5.](image)

### 1.2 CLASSIFICATION METHODS

These data were used as input to three candidate classification algorithms. All algorithms were implemented and tested under ENVI 3.2.

1. Spectral Angle Mapper (SAM);
2. Minimum Distance classification;
3. Maximum Likelihood classification;

Different input parameters were used to feed these algorithms. Absolute reflectance and two reflectance ratios were considered. The first ratio is based on the SeaWiFS Ocean Colour 4 version 4 chlorophyll algorithm and has a high correlation with chlorophyll concentration in ocean type waters. The ratio is defined as the maximum in SeaWiFS band 2 to 4 divided by SeaWiFS band 5. This ratio in the text is abbreviated with ‘OC4’, in graphs it is abbreviated with ‘R443>R490>R510 / R555’. The second ratio considered is a substitute for the red chlorophyll ratio used in case II waters and is defined here as the reflectance in band 6 divided by the reflectance in band 5. In the text it is abbreviated by ‘RG’, in graphs it is abbreviated by ‘R670 / R555’.
Three input combinations were tested:

1. Absolute reflectance in SeaWiFS bands 1 to 6;
2. Only the two ratios (OC4 and RG);
3. Combination of the two ratios and SeaWiFS band 5 (OC4, RG and R555).

The three classification algorithms and three input combinations result in nine potential classification 'methods'. The maximum likelihood classification is the only one that uses the covariance statistics for the input parameters (for instance the covariance between the OC4 and RG ratio in each class).

1.3 CLASSIFICATION VERIFICATION

Ideally, the devised classification methods should be validated using a test set of SeaWiFS images, with prior knowledge of the present classes on a pixel-by-pixel basis. For each classification method a User’s and Producer’s accuracy could be calculated which would allow a selection of the best classification method. This data was unfortunately not available. The methods were evaluated here by testing them on the same set of three SeaWiFS images, expanded with two test images. The following features were evaluated for each classification method:

1. For the three training SeaWiFS images, is the resulting classification consistent with the selected classes?
2. Is the classification conceptually in agreement with the true colour image?
3. How realistic is the classification in terms of expectancy of spring blooms, ocean water, etc.
4. How smooth is the classification, i.e. blooms and sediment plumes are expected to be limited to certain areas and have reasonably sharp edges.

The results from these four criteria were put into a matrix, which allowed selection of the best overall classification method.

3.0 RESULTS

It is outside the scope of this paper to discuss the performance of each method for each test image. It is sufficient to mention here that the maximum likelihood classification was superior to the spectral angle mapper and the minimum distance method. This is mainly caused by the fact that only the maximum likelihood classification uses the covariance between input parameters. Concerning the input parameters, the use of just absolute reflectances resulted in good discrimination between ‘bright’ and ‘dark’ (algae blooms and sediments classes but the discrimination between sediment classes and algae bloom classes was insufficient for the purpose of this study. On the other hand, the use of only band ratios resulted in good discrimination between sediment and classes and algae bloom classes, but ‘dark’ waters in e.g. the Canal and on the North-West North Sea were frequently misclassified as algae blooms. The overall best result was achieved by the combination of the two ratios and SeaWiFS band 5. Both the differences between spectrally different classes and ‘bright’ and ‘dark’ classes were correctly classified. Classification results for the three training images are presented in Figure 6.

The aim of this study was to correctly indicate the location of algal blooms in the TSM images, so that they can be recognised (or masked) by the end-user. For the final atlas an aggregate of classes was therefore proposed to make evaluation more straightforward. A scene of the final atlas is included here.
(Figure 5), with the original TSM map and with the classification aggregated to only three classes, i.e. ‘sediment dominated water’, ‘algae bloom’ and ‘other’.

4.0 CONCLUSIONS

Using SeaWiFS reflectance imagery, ten classes were selected as regions of interest for the supervised classification, consisting of four algae bloom classes, three sediment classes and three other classes. Three classification methods were tested and three types of input parameters were evaluated: absolute reflectances, band ratios and a combination of the two. After applying the resulting nine classification methods on the training set of images to test the consistency and on two additional images to test the between-image accuracy one classification method was selected. This method is based on the maximum likelihood classification where a blue-green ratio (indicating chlorophyll in ocean waters) a red-green ratio, (indicating chlorophyll in coastal waters) and the reflectance in band 5 were used as input. The classification of algae blooms in the North Sea proved successful, and allowed the generation of maps indicating areas with high sediment concentrations, algae blooms and ‘clear’ water areas. These maps can be used by an end-user to locate possible algae blooms and to identify regions were the current operational total suspended matter algorithm is likely to give overestimated TSM concentrations.

Figure 5. Total Suspended Matter Map and Accompanying Classification Result For The SeaWiFS Image Dated 27 April 1999.
5.0 REFERENCES


