Value-added product generation for species image of mixed algal bloom in the Northern Arabian Sea using Remote Sensing technique

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Background

The bloom of *Noctiluca scintillans* (*N.sci*, a dinoflagellate), which appears in the form of a green tide covers a large area of the Northern Arabian Sea from the west coast of India to the coast of Oman. On time-scale, it is reasonably persistent; and sighted during winter-spring (Mid Feb-end Mar) that prevails at least for three months. Moreover, it has been found that it is not a mono-species bloom and more exactly it co-exists with diatoms. *N.sci* is characterized by the presence of the symbiont Pedimonas noctilucae. This organism shows a predominantly green coloration due to the presence of high chlorophyll b along with chlorophyll a. A massive event like this involving mixed-species eco system has motivated researchers in applying more time and efforts for studying its impact on fishery resources and bio geo chemistry of the area to understand fate of carbon in a cycle.

These blooms have been sampled in various phases by Indian research vessels like the Sagar Sampada and the Sagar Kanya from 2003 onwards. The bloom can be easily identified by SeaWiFS and MODIS chlorophyll images due to high chlorophyll pattern associated with it. However, generalized algorithm for chlorophyll retrieval breaks down in presence of algal bloom and provides unreliable estimates of the parameter. Besides this, the chlorophyll product does not reveal phytoplankton species/group level information. To enable this, an approach was developed for detection of the bloom forming algae *N.sci* and its discrimination from diatoms in a mixed species environment using ocean colour sensor of MODIS-AQUA. *In situ* remote sensing reflectance spectra were generated using Satlantic™ hyper spectral radiometer for the bloom and non-bloom waters. Spectral shapes of the reflectance spectra for different water types were distinct and were used for species identification. Scatter of points representing different phytoplankton classes on a derivative plots revealed four diverse clusters, viz. *N.sci*, diatoms, non-bloom oceanic and non-bloom coastal waters. The criteria developed for species discrimination were implemented on MODIS data and validated using inputs from a recent ship cruises conducted in March 2012-13. Water samples were collected during different stages synchronous with satellite over pass and were checked under microscope for species identification. Satellite derived information on species of the bloom matched with the microscopic observations.

Materials and methods

Data sets supporting this study are derived through ship cruises (FORV *Sagar Sampada* and ORV *Sagar Kanya)* during January-March 2001–2012. The study area and repetitive ship tracks were shown in Figure 1.

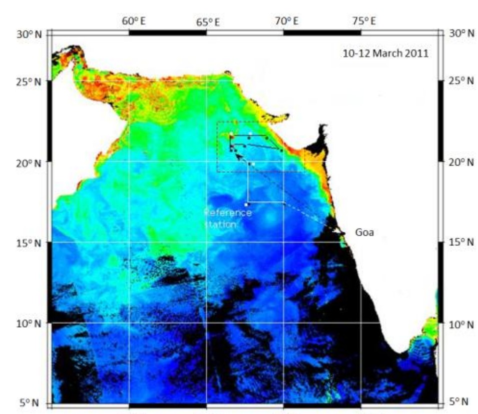

Figure 1. Site for intensive *in situ* measurements (dashed rectangle in red) in the NEAS waters during bloom season and ship track

Vertical profiles of in-water upwelling spectral radiance (L_u) and down welling irradiance (E_d) were measured using Satlantic[TM] hyper spectral free-fall optical profiler in 350-800 nm calibrated range at 1 nm interval. In-air surface irradiance (*Es*) was measured using deck reference sensor, SMSR (SeaWiFS Multi-channel Surface Reference- "reference").

Remote sensing reflectance, which is essentially the ratio of water-leaving radiance to down welling irradiance just above the surface (sr^{-1}), was derived from,

$$Rrs\ (\lambda) = \frac{Lw(0^+,\lambda)}{Ed\ (0^+,\lambda)}$$

$L_W\ (0^+,\lambda)$ = upwelling spectral radiance propagated through the surface
$E_d(0^+,\lambda)$ = down welling spectral irradiance extrapolated through the surface

The derived R_{rs} were used to generate derivative spectra for different water types. Water samples were collected from bloom as well as non-bloom waters and analyzed to identify phytoplankton species, concentration ($mg.m^{-3}$) and cell density (cells L^{-1}) for *N. sci* and diatoms.

Satellite data processing
MODIS-Aqua Level-3 HDF data were downloaded for the bloom period (January-March) through NASA Internet server: Ocean Color Web. The data were processed to retrieve remote sensing reflectance using SeaDAS for multi-dates during January-March 2009-2012.
Appropriate thresholds (range) were determined for R_{rs} derivatives at 488 nm corresponding to four distinct classes, viz. *N. sci*, diatoms, oceanic non-bloom and coastal non-bloom waters. Level-3 R_{rs} images, output from SeaDAS, were imported in ERDAS Imagine image processing software to have HDF file converted into band sequential image file. Subsequently, ERDAS Modeler was used to mask land / cloud and in the following step, class allocation was performed through checking the derivative value for each class on pixel by pixel basis. Five separate class images were generated corresponding to each scene. These were composited to a single classified image indicating distribution of the bloom species and non-bloom oceanic and coastal waters.

Results and discussion

Rationale for species discrimination
Different phytoplankton types (algal blooms) react to incoming electromagnetic radiation in a unique way in terms of reflectance, i.e. shape of the reflectance spectra is different for different phytoplankton classes. This information was inverted to detect the bloom as well as to identify its species from reflectance pattern obtained from satellite data. Spectral characteristics of the two phytoplankton types (*N. sci*, and diatoms) and non-bloom waters in the NEAS during winter can be seen from Figure 2.

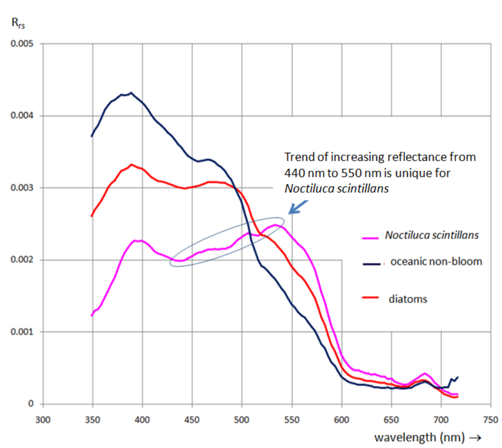

Figure 2. Remote sensing reflectance (Sr^{-1}) spectra for *N. sci*, diatoms and non- bloom oceanic waters generated for NEAS waters using under-water radiometer.

Difference in the spectral shapes can be noticed in case of diatoms, *N. Sci* and non-bloom waters. It can be seen that shapes of all the three spectra are different because of unique reflectance properties specific to phytoplankton species. Remote sensing reflectance can be seen increasing from 440 nm to 550 nm in case of *N. sci*. None of the other two phytoplankton types reveal this pattern. *N. sci* is a luminescent organism and emits light from 420 nm to 580 nm with maximum at 470 nm (blue). Further increase in reflectance that peaks near 550 nm (green) could be due to endosymbiont of green color. In case of diatoms; the spectral response is relatively flat in this slot (440-550 nm) and the plot for non-bloom oceanic waters reveals decreasing trend of reflectance in this region. The unique feature like increase in reflectance in case of *N. sci* differs from other classes and was utilized to recognize this species of dinoflagellate.

Threshold determination for class identification

The observed difference in shapes of the reflectance spectra as shown in Figure 2 was utilized for detection and identification of bloom and bloom forming species. Derivative analysis is one of the approaches to quantify spectral shape into a number, which also enhances small variability in spectral reflectance. First derivative of the MODIS derived reflectance was computed and plotted as a function of wavelength (Figure 3).

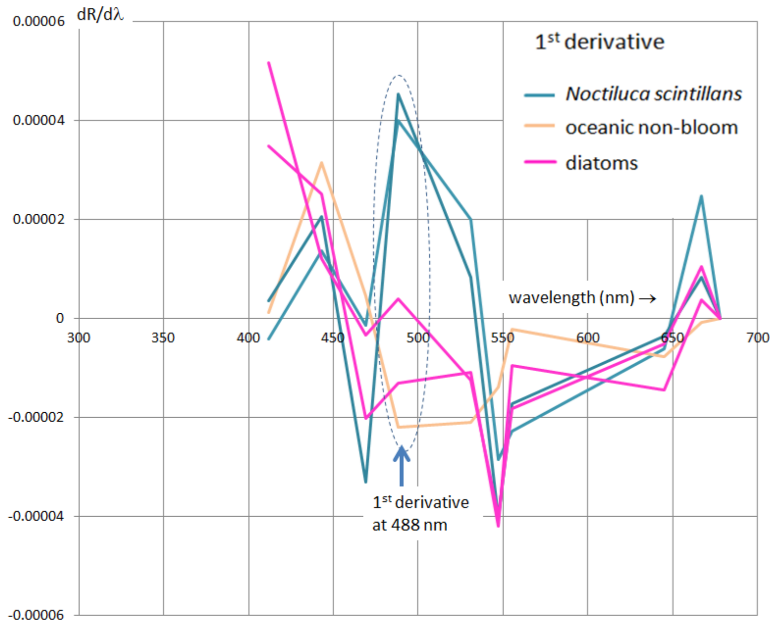

Figure 3. 1st derivative spectra generated from MODIS derived remote sensing reflectance (Sr^{-1}) for different water types in NEAS during dominance of the winter bloom

It can be seen that the three water categories; *N. sci*, diatoms and non-bloom (oceanic) are distinctly separated by first derivative at 488 nm. These classes can be seen either inter-mixed or closely located at other wavelengths in the derivative plot. Derivative for *N. sci* class is positive and of relatively larger magnitude at 488 nm. In case of diatom, this is of smaller magnitude and is distributed on either side of origin, where as in case of non-bloom pixel in oceanic waters, this value is of larger magnitude on negative derivative axis.

Implementation of classification criteria on MODIS data

Specific ranges of derivatives were used to determine phytoplankton class on pixel by pixel basis using MODIS data of 7 March 2013 and ERDAS' Model Maker. MODIS derived remote sensing reflectance images for 443, 488 and 531 nm band were used as input images and a color coded classified output image was generated. This can be seen in Figure 4(A).

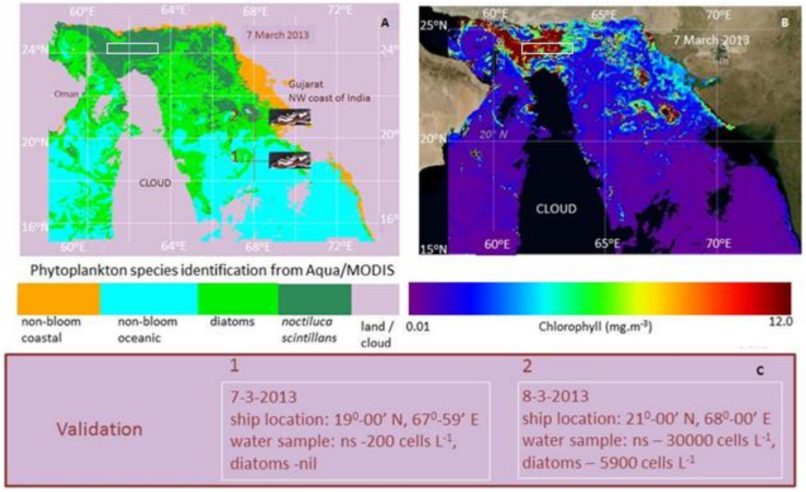

Fig 4(A) Image classified for phytoplankton class, (B) Chlorophyll image using MODIS/SeaDAS, (C) Phytoplankton analysis using water samples

The image provides information on distribution (spatial extent) of *N. sci*, diatoms and normal (non-bloom) waters in the basin with reference to the step wedge. Simon and Shanmugam (2012) have presented an approach to detect *Noctiluca milaris* bloom in the Gulf of Oman using MODIS-Aqua data. However, this bloom is not mono species bloom in this area and the approach does not detect diatoms bloom collocated with *Noctiluca miliaris*. *Noctiluca* does not exist in isolation and there are reports mentioning requirement of high concentration of phytoplankton/diatoms prey to support optimal growth of *Noctiluca* (Lee & Hirayama 1992, Kiørboe & Titelman 1998, Kiørboe 2003). Thus, it is reasonable to expect diatoms in vicinity of *N.sci*. The approach presented in this paper discriminates among *N.sci*, diatoms and non-bloom pixels.

It is noticed from Figure 4(B) that pattern of chlorophyll closely matches with phytoplankton species as seen in the adjacent image (Figure 4(A)).

iv. Validation

Ship cruise FORV314 was conducted during March 2013 to validate the classified phytoplankton species image. It can be seen from Figure 4(C) that *N. sci* concentration was 200 cells L^{-1} and diatoms nil at 19^0-00’ N, 67^0-59’ E on 7-3-2013 indicating non-bloom waters.

Location of corresponding point marked as ‘1’ in classified image (Figure 4(A)) is seen in cyan colour. Step wedge at the bottom shows this colour as oceanic non-bloom class, which is in agreement with ship observation.

N. sci and diatoms concentrations were 3×10^4 and 0.59×10^4 cells L^{-1} respectively at 21^0-00’ N, 68^0-00’ E on 8-3-2013 indicating that the waters are dominated by *N. sci*. Optical response of the water is influenced by *N. sci* and location marked as ‘2’ in phytoplankton class image (Figure 4(A)) shows dark green colour. It is *N. sci* class according to the step wedge and thus complies with the water sample analysis.

There is a point to notice that when the two species co-exist as in this case, optical response is dictated by the dominating species, for instance *N. sci* suppressed influence of diatoms.

Conclusion

NAS holds the bloom waters of mixed species, which co-exist. Remote sensing based approach to detect algal blooms in the Northern Arabian Sea during winter and species discrimination has been developed

and proven here. Synchronous *in situ* water sample analysis from bloom and non-bloom waters were found matching with the classification results from MODIS derived product. The classified output image provides knowledge of distribution of *N. sci* and diatoms in space and time. A product like this would facilitate study of various biological aspects of the bloom.
Development of the approach and availability of MODIS data with one day repeat cycle would enable implementation of satellite based harmful algal bloom monitoring system in the NAS.

References

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