Chlorophyll specific absorption coefficient and phytoplankton biomass in the Red Sea

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Abstract: The role of total particulate matter, the sum of phytoplankton and non-algal particles, is essential to understanding the distribution and pathways of particulate carbon in the ocean. Their relative contributions to light absorption and scattering are fundamental to understanding remotely sensed ocean color. Until recently, data regarding the contribution of phytoplankton and algal particles to the inherent optical properties of the Red Sea was nonexistent. Some of the first measurements of these inherent optical properties in the Red Sea including phytoplankton specific absorption coefficients ($a_{ph}^*(\lambda)$) were obtained by the TARA Oceans expedition in January 2010. From these observations, chlorophyll a was calculated using the Line Height Method (LHM) that minimizes the contribution to total and particulate absorption by non-algal particles (NAP) and CDOM. Bricaud and Stramski's (1990) method was then used to decompose hyperspectral total particulate absorption into the contributions by phytoplankton and non-algal particles.

Introduction

Red Sea is the narrow and one of the warmest and saltiest body of water on Earth (Marcos et al., 1970), which is one of the least explored sea in the world. Satellite remote sensing is one of the main source of data, which can be used to study the large-scale physical and biological processes in the Red Sea (Acker et al., 2008; Raitos et al., 2013; Brewin et al. 2013; Brewin et al., 2015). Several studies have been performed over the Red Sea to investigate the variation in chlorophyll concentration. These studies include ocean color data from SeaWiFS and MODIS-Aqua sensors. Raitsos et al. (2013) used data from MODIS-Aqua to describe the seasonal succession of chlorophyll and its relationship to the physical forcing.

Despite the potentially wide-ranging importance of chlorophyll concentrations to the upper ocean biogeochemical processes and optics, our present understanding of its spatial and temporal variability and factor affecting these variability are still limited. A difficulty with chlorophyll interpretation from satellite remote sensing occurs due to lack of in situ data, which is required for validation and calibration purpose (Brewin et al. 2015).

Data Description

TARA and for the Red Sea

ACS instrument has been used to measure hyperspectral absorption and attenuation coefficient during the R/V TARA Oceans expedition in the Red Sea in January 2010 (more detailed description about data collection and processing can be found in Boss et al. 2014; Werdell et al. 2014, Brewin et al., 2015, and references are therein). These in situ measurements were available at 5 nm intervals between the 404 nm to 737 nm and it was compared at selected wavelengths with satellite match ups (Werdell et al., 2014) for various ocean colour sensors (e.g, MODIS, MERIS, VIIRS). First four plots of Fig. 1 presents examples of absorption spectra obtain from these measurements.

During the TARA Oceans expedition, apart from total particulate absorption coefficients there were also extensive measurements of the temperature, salinity, and attenuation coefficient of particulate material in the upper layer of the Red Sea. Data of these measurements can be accessed at http://seabass.gsfc.nasa.gov/seabasscgi/search.cgi.

CDOM spectra are derived from data collected in the Red Sea during in 2014 and 2015.

Decomposition of total particulate matter

Bricaud and Stramski (1990) developed a numerical decomposition method based on spectral criteria. We have used this method to determine absorption coefficients of living phytoplankton and non-algal biogenous matter from the total particulate absorption spectra. Phytoplankton specific absorption coefficients were derived by dividing $a_{ph}(\lambda)$ by the chlorophyll a concentration (mg m^{-3}).

Estimation of phytoplankton biomass index

For the estimation of phytoplankton biomass index, the pigment absorption peak in the red waveband observed in phytoplankton and particulate absorption spectra are used (Roesler and Barnard 2013). We extracted the total particulate absorption coefficient values at at 650, 676 and 715nm. We have derived Chl-a using Line Height Method (LHM) developed by Roesler and Barnard (2013).

Computation of absorption line height

The absorption value of the baseline between 650 and 715 nm at reference wavelength is given by linear equation:

$$a_{BL}(\lambda_{ref}) = \frac{a_p(715) - a_p(650)}{715 - 650} \times (\lambda_{ref} - 650) + a_p(650)$$

of the form , where m is the slope and c is the intercept. The absorption line height at the red band absorption peak is computed from the difference of the baseline absorption from the observed absorption:

$$a_{LH}(676)(m^{-1}) = a_p(676) - a_{BL}(676)$$

The chlorophyll-specific absorption line height, a^*_{LH} value (≈ 0.0104 m^2 mg^{-1}) at 676 nm is adopted from Roesler and Barnard (2013) to derive the absorption based chlorophyll concentration as:

$$CHL_{LH} = a_{LH}/a^*_{LH}$$

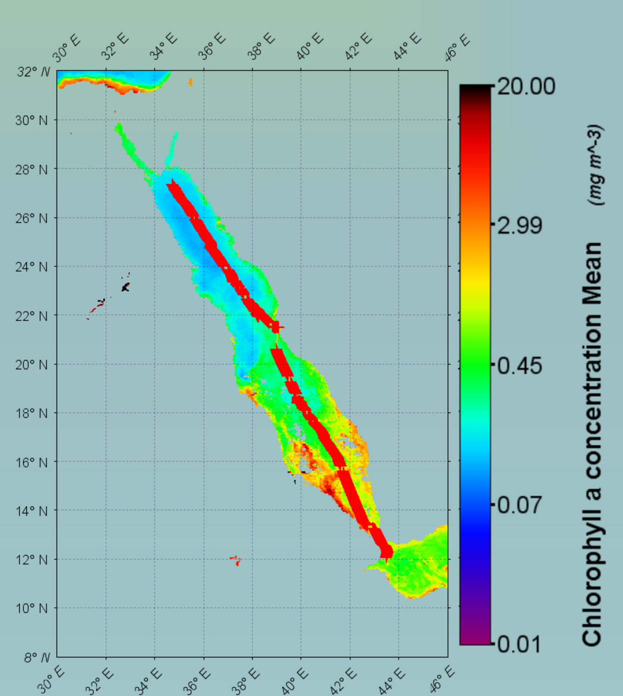

Fig. 1. Location map with station locations in the Red Sea.
Note that this region is always dominated by the atmospheric dust deposition and high CDOM.

Results

Variations of absorption spectra

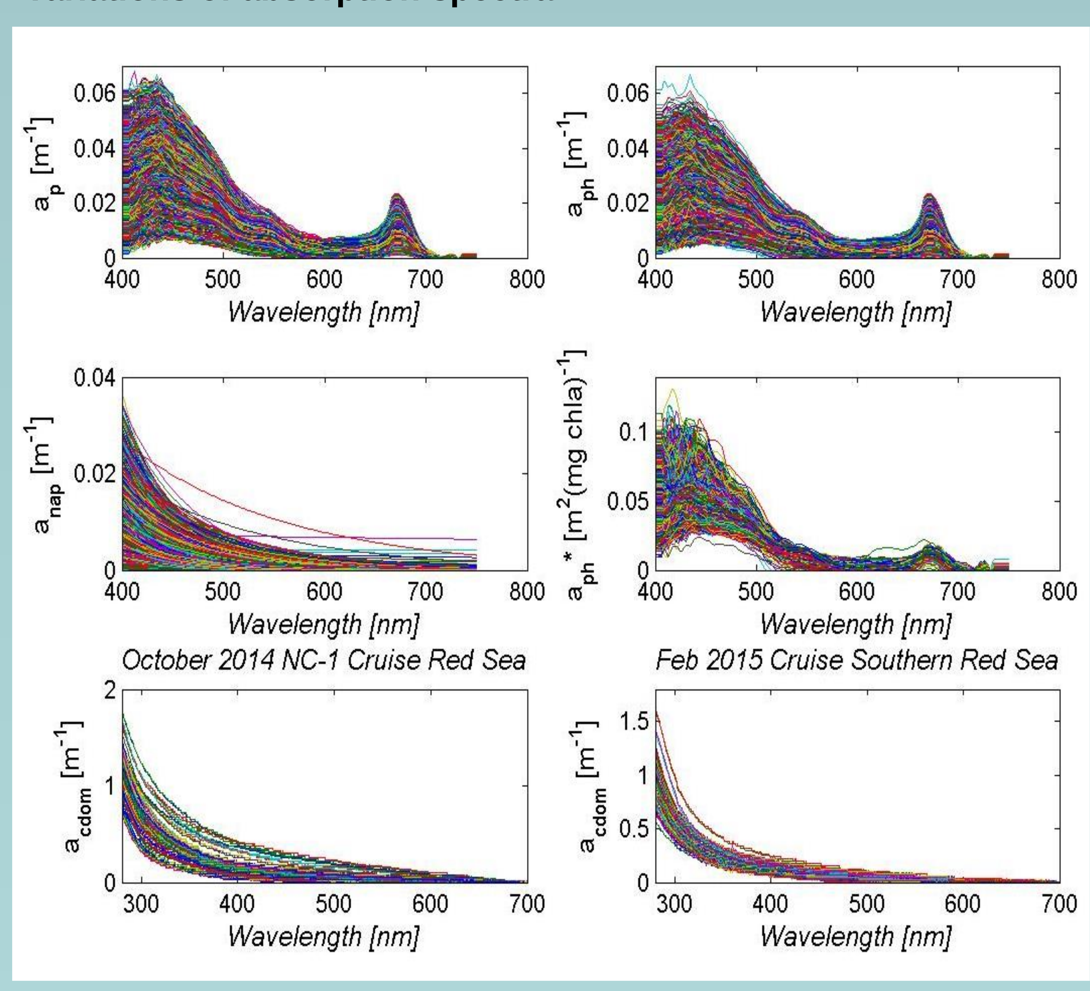

Fig. 2 shows the hyperspectral spectra for the different optical parameters such as total particulate absorption, phytoplankton absorption, non algal particles absorption, specific absorption by phytoplankton, and absorption by CDOM in the Red Sea. Two distinct peaks are observed from a_p, a_{ph}, and a^*_{ph} spectra a first peak at in the blue region (i.e., 443 nm) and the second peak in the red region (i.e., 676 nm) due to the fluorescence of light. CDOM spectra have shown a very high values of CDOM in the ultra violet region.

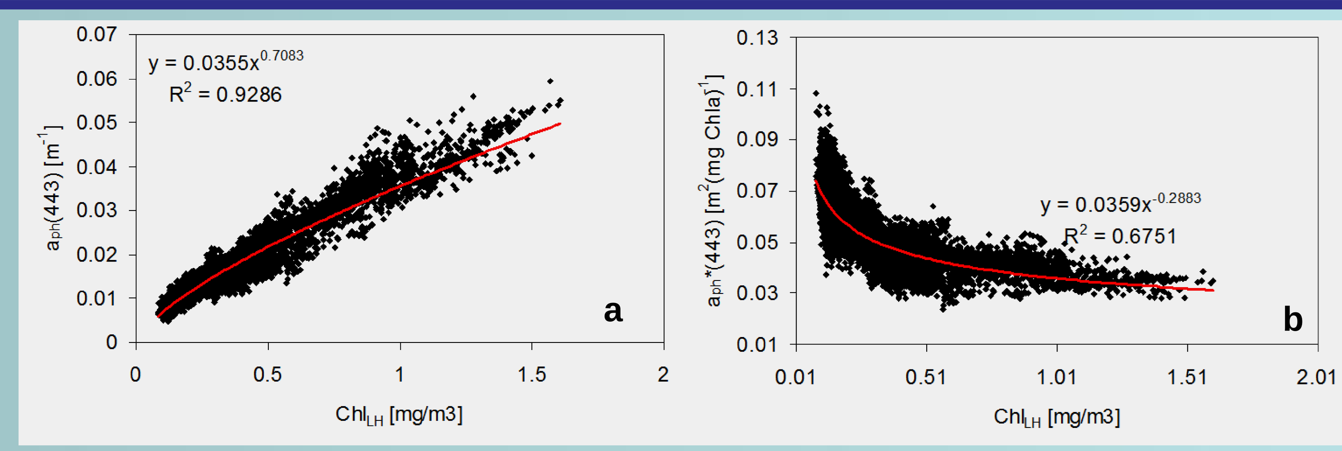

Fig.3 a and b shows the relationship of Chl_{LH} with $a_{ph}(443)$ and $a_{ph}^*(443)$ in the Red Sea.

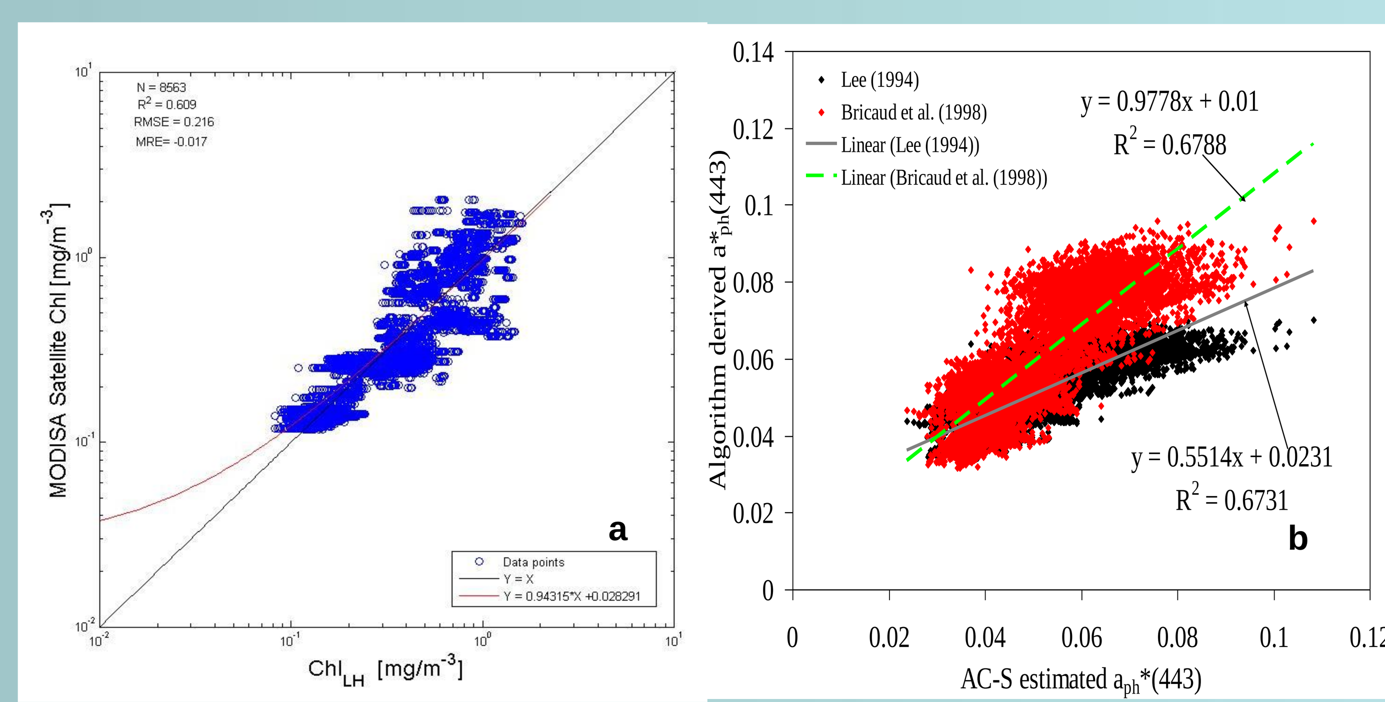

Fig.4 a shows scatter plot between the derived and ocean color estimated Chl in the Red Sea. MODIS-Aqua satellite image of January 2010 acquired over the Red Sea and Fig. 4(b) shows Bricaud (1998) and Lee (1994) algorithms fitted on the derived $a_{ph}^*(443)$.

- Overall, decomposed total particulate absorption (i.e., $a_p(443)$average = 0.01995 m^{-1}) was dominated by phytoplankton absorption (i.e., $a_{ph}(443)$average = 0.01743 m^{-1} with a smaller contribution by non-algal particles (i.e., $a_{nap}(443)$average = 0.002524 m^{-1}).
- High values of specific absorption coefficients are seen from derived spectra. It means that the Red Sea offshore waters are dominated by small cell phytoplankton. The small cell sizes are consistent with our understanding of the Red Sea where small cyanobacteria are thought to dominate the productivity where their small size contributes to efficient uptake at very low nutrient concentrations.
- Higher CDOM absorption observed from in situ measurements in the Red Sea which does not follow the global relationships between the CDOM and Chl in the oligotrophic waters.
- Our retrievals obtained from optical data were compared with estimated values using existing algorithms (e.g., Lee et al., 1994; Bricaud et al., 1998). There we found that over and underestimation by both algorithms, with almost same correlation coefficient (R^2 = 0.67).

Conclusions

- Results obtain from this study will be useful to study phytoplankton functional types and to avoid the bias between the satellite matchups and measured values of phytoplankton absorption coefficients.
- The contribution by NAP is revealed to be weak as compared to that by phytoplankton.
- Furthermore, our additional field measured data in the Red Sea showed high concentration of CDOM, since the TARA Oceans expedition was held in January 2010.
- Higher amount of CDOM significantly influence the retrieval of ocean color estimates
- Future study will be focused to understand the sources and sinks of the higher amount of CDOM in the Red Sea.

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