Seasonal variability in the vertical attenuation coefficient at 490 nm (K490) in waters around Puerto Rico and US Virgin Islands.

William J. Hernandez[1] and Fernando Gilbes[2]

[1]Department of Marine Science, University of Puerto Rico Mayaguez Campus, Mayaguez, PR
[2]Department of Geology, University of Puerto Rico Mayaguez Campus, Mayaguez, PR
[1]Corresponding author: william.hernandez@upr.edu

ABSTRACT

Satellite sensors provide a valuable tool in understanding the seasonal variability of ocean color properties. The vertical diffuse attenuation coefficient (Kd) was evaluated for the waters around Puerto Rico and the US Virgin Islands. The MODIS K490 of Band 3 Level-2 daily images were processed with a resolution of 1 kilometer for the year 2008. The images were projected to WGS-84 geographic coordinate system and then compiled using the *Layer Stacking routine* to include all images within each month. A total of 184 were processed and monthly averages were developed using the *Sum Data Bands routine* for the study area to minimize cloud cover and seasonal averages were created from the monthly averages. Additional MODIS K490 Level-2 monthly and seasonal average products (euphotic depth, Lee et al., 2005), and (euphotic depth, Morel et al., 2007) were downloaded from the NASA's Ocean Color web site with a resolution of 4 kilometers. The values for the dry season (December-April) ranged from 0.206 (1/m) to 0.666 (1/m), with a mean of 0.482 (1/m) and for the rainy season (May-November) the values ranged from 0.516 (1/m) to 0.860 (1/m) with a mean of 0.698 (1/m). The monthly averages were higher for December (0.206 1/m) and lower for June (0.860 1/m). There is seasonal variability in the K490 values in the waters around Puerto Rico and the USVI the MODIS K490 product at 1 km provides the necessary resolution to evaluate the coastal land influence in the values of K490 at this geographic extent. Further development may include comparison of K490 additional products (Morel and Lee Kd algorithms) values at comparable spatial resolution to evaluate the overestimation of values derived from remote sensors. The data obtained from this project provides information on the seasonal variability of this parameter and the possible effects in the marine ecosystems.

KEYWORDS: Water Diffuse Attenuation Coefficient, Kd, Remote Sensing, Ocean Color, Puerto Rico, US Virgin Islands, MODIS Aqua, ENVI

INTRODUCTION

The vertical diffuse attenuation coefficient (Kd) provides information of how visible light in the blue-green region of the spectrum is attenuated by the water column. This parameter has wide applicability in ocean optics, as it is directly related to the presence of scattering particles in the water column, either organic or inorganic, and thus is an indication of water clarity (Lee et al., 2005). It is defined in terms of the exponential decrease with depth of the ambient downwelling irradiance Ed (z,λ), which comprises photons heading in all downward directions. The MODIS algorithm for deriving this product is $\mathbf{K(490) = K_w + A\ [\ L_w\ (\lambda_1)/\ L_w\ (\lambda_2)]^B}$**, where,** $\mathbf{\lambda_1}$**= 488/490** $\mathbf{\lambda_2}$**=551/555 A=0.15645 B=1.5401** (Lee et al., 2005).

For clear oligotrophic waters, the value of K490 is an integration of the first optical depth, or approximately the upper 20 m of the water column (Morel, et al., 2007). Several studies have used the K490 as an important parameter for the characterization of ocean properties. Lohrenz et al. (2008) evaluated the impacts of major tropical storms events on coastal waters in the Gulf of Mexico using MODIS Aqua K490 L2 images and Chorophyll-a concentration images. They focused on the water column mean conditions before and after the impacts of Hurricane Katrina and Rita and how this affected sediment resuspension, intense water column mixing, and increased delivery of terrestrial materials into coastal waters. The work of Gibbs, et. al. (2006) used chorophyll-a and k490 images to define the seaward extent of New Zealand's coastal zone (area of terrigenous influence) from remotely sensed ocean color and turbidity data. The coastal waters around Roatan Island, Honduras were characterized and mapped for the diffuse attenuation coefficients by Mishra et al. (2005) to evaluate the feasibility of mapping shallow water marine habitats. Corredor et al. (2004) used ocean color imagery to confirm the horizontal extent of mesoscale eddies from shipboard measurements in the Eastern Caribbean

basin. K490 and chlorophyll-a images from MODIS Aqua allowed characterization of such an eddy and it's interaction with the Orinoco River plume.

The values of K490 were obtained from the Moderate-resolution Imaging Spectroradiometer (MODIS). The MODIS instrument on EOS Aqua satellite provides data, and subsequent operational products, for the land, ocean, cryosphere, and atmosphere. MODIS sensor collects reflected and emitted energy from the Earth surface in 36 spectral bands from 400 to 14.400 nm. High sensitivity radiometric data (12 bits) are recorded at nominal spatial resolutions of 250 m (bands 1–2), 500 m (bands 3–7), and 1000 m (bands 8–36) and has a temporal resolution of 1-2 days. MODIS data are available without charge from several data archive and distribution centers. Specific data products can be selected for a given geographic region and time period using a web-based query and ordering system offered at several data portals (Feldman, et al., 2009).

The objectives of this project were to evaluate the differences in the vertical attenuation coefficient of waters around Puerto Rico and US Virgin Islands (Figure 1), compare seasonal changes in the vertical attenuation coefficient focusing on coastal waters, and evaluate differences in K490 products with other products from the MODIS sensor including KPAR, Euphotic depth (Lee), and Euphotic depth (Morel).

Figure 1: Study area that includes the surrounding waters around Puerto Rico and the US Virgin Islands.

METHODS AND MATERIALS

K490 is the diffuse attenuation coefficient of Band 3 of MODIS (490 nm) and MODIS Level-2 daily images were downloaded from the NASA's Ocean Color web site with a resolution of 1 kilometer (Feldman, et al., 2009). The daily images were evaluated for the year 2008. The year was selected because they correspond to other surveys made during that year and this project results will provide valuable information on this parameter of Kd. The selected images were evaluated to ensure that the study area will be included in the sensor's swath, and data was obtained in HDF format (Hierarchical Data Format).

For the image processing, the data was evaluated using ITT ENVI 4.5 software for the image processing. The *Ocean Color Tool Kit* was used to import and georeference images from HDF format. The K490 (diffuse attenuation coefficient at 490nm product) was selected and *Standard and Rigorous Projection routine* was performed to WGS-84 geographic coordinate system. The images were individually processed and compiled using the *Layer Stacking routine* to include all images within each month. Monthly averages were developed using the *Sum Data Bands routine* for the study area to minimize cloud cover. Seasonal averages were created from the monthly averages to evaluate possible rainy and dry season influences of the terrigenous sediments and other water column constituents in the Kd. The monthly and seasonal average data was exported to spreadsheet format and was evaluated statistically using Excel.

Additional MODIS K490 Level-2 monthly and seasonal average products (Euphotic depth (Lee et al., 2005), and Euphotic depth (Morel et al., 2007) were downloaded from the NASA's Ocean Color web site with a resolution of 4 kilometers.

RESULTS:

A total of 184 MODIS K490 (1 Km) images were processed for the 2008. The basic unit selected for analysis was the monthly average for each month of 2008. The seasons for the selected images were divided in dry season (December-April) and rainy season (May-November) The image total used for the averages are detailed in Table 1.

Table 1: MODIS Aqua (1 km) K490 Images Processed and included in the monthly and seasonal averages

Month (2008)	Images Total	Season	Season Total
Dec	17	Dry	
Jan	16	Dry	
Feb	13	Dry	**89**
Mar	15	Dry	
Apr	15	Dry	
May	13	Dry	
Jun	14	Rainy	
Jul	15	Rainy	
Ago	18	Rainy	**95**
Sep	14	Rainy	
Oct	18	Rainy	
Nov	16	Rainy	
TOTAL	**184**		

DISCUSSION

The seasonal variability was present in the K490 values for the study area in Puerto Rico and the US Virgin Islands. The K490 values derived from MODIS were higher in the rainy season and lower in the dry season. These values in the dry season for 2008 ranged from 0.206 (1/m) to 0.666 (1/m), with a mean of 0.482 (1/m). The values in the rainy season for 2008 ranged from 0.516 (1/m) to 0.860 (1/m) with a mean of 0.698 (1/m). Monthly averages of K490 values were lower for the month of December (0.206 1/m) and higher for the month of June (0.860 1/m) (Figure 2). The median values for the dry season was 0.644 (1/m) and for the rainy season was 0.744 (1/m).

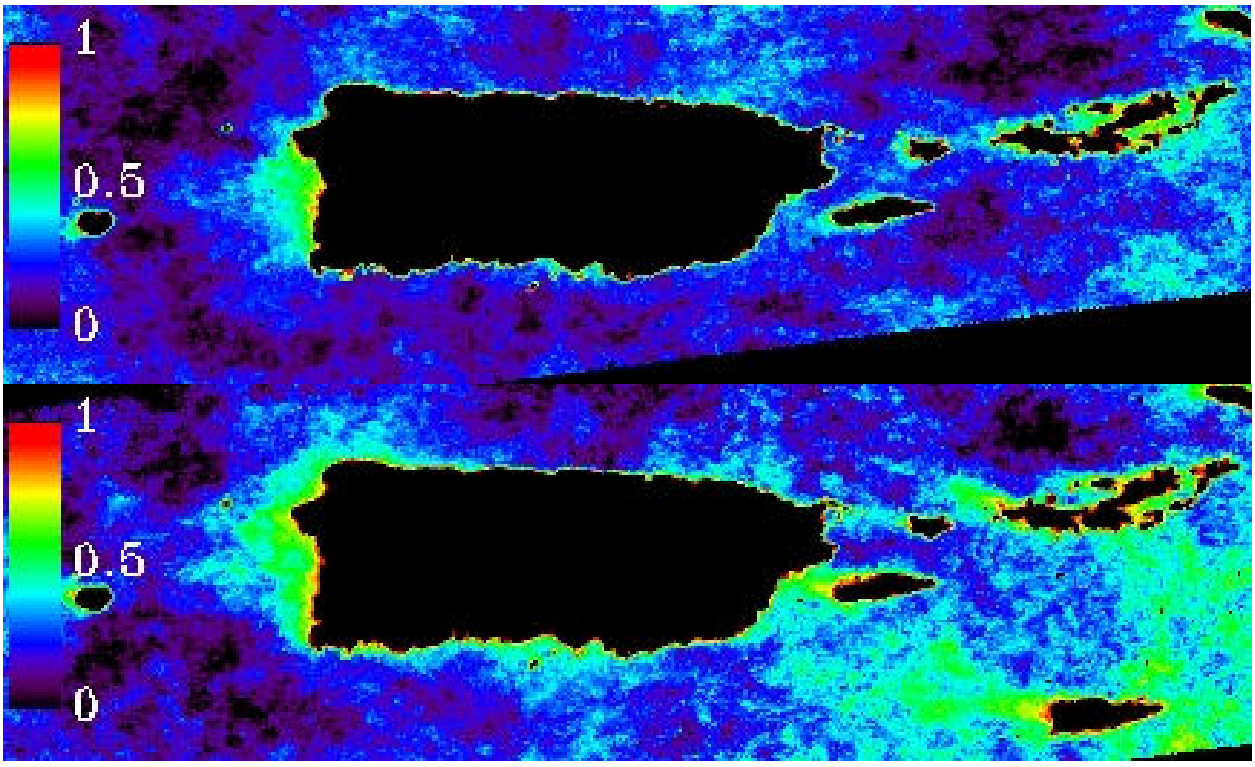

Figure 2: Seasonal averages from MODIS K490 values for Puerto Rico and the US Virgin Islands. The dry season (December-April) images (Top) from K490 and the rainy season (May-November) images (Bottom).

Comparison with Lee, Morel algorithms could not be assessed effectively due to the spatial resolution of these products (4 Km). To obtain comparable spatial resolution of 1 kilometer the images needed to be processed using Seadas software from Level-0 images. Morel et al., 2007 algorithm is not suitable for Case 2 waters, so overestimation of values is possible even with better spatial resolution, as is the case with Lee's algorithm (Lee et al., 2005).

CONCLUSIONS

There is seasonal variability in the K490 values in the waters around Puerto Rico and the USVI and the seasonal and monthly averages estimates demonstrate the rainy/dry season influences on the K490 values, especially in coastal waters. The MODIS K490 at 1 km provides the necessary resolution to evaluate the coastal land influence in the values of K490 at this geographic extent. The cloud cover can be minimized by using monthly averages as the minimal unit; however this approach diminished the temporal resolution of the K490 values and the ability to identify short term (daily) rain events. As with chlorophyll-a concentration values, MODIS sensor derived K490 values were overestimated for coastal waters, as this algorithm is not suitable for Case-2 waters (Morel, et al., 2007). The high median values confirms the overestimation of the MODIS K490 algorithm since the central (median) value is near or above the higher range of the values for K490.

Further development may include comparison of K490 additional products (Morel and Lee Kd algorithms) values at comparable spatial resolution. The integration of batch processing routines using IDL may provide the necessary tools to expand the image processing capabilities and extend the image analysis to previous years. The data obtained from this project provides information on the seasonal variability of this parameter in waters around Puerto Rico and the US Virgin Islands and possible effects in the marine ecosystems.

REFERENCES

Deepak R. Mishra, DR, Narumalani, S, Rundquist, D and Lawson, M. 2005. Characterizing the vertical diffuse attenuation coefficient for downwelling irradiance in coastal waters: Implications for water penetration by high resolution satellite data. ISPRS Journal of Photogrammetry & Remote Sensing 60 (2005) 48–64.

Feldman, G.C., *Ocean Color Web, MODIS Aqua Reprocessing 5, NASA Goddard Space Flight Center,* http://oceancolor.gsfc.nasa.gov/, Accessed September 15, 2009.

Gibbs, MT, Hobday, AJ, Sanderson , B, Hewitt, CL. 2006. Defining the seaward extent of New Zealand's coastal zone. Estuarine, Coastal and Shelf Science 66 (2006) 240e254

Lee, ZP, Du, KP, Arnone, R. 2005. A model for the diffuse attenuation coefficient of downwelling irradiance. Journal of Geophysical Research Vol.. 110, C02016, doi:10.1029/2004JC002275, 2005

Lohrenz, SE, Cai, WJ, Chen, X, Tuel, M. 2008. Satellite Assessment of Bio-Optical Properties of Northern Gulf of Mexico Coastal Waters Following Hurricanes Katrina and Rita. *Sensors 2008, 8, 4135-4150; DOI: 10.3390/s8074135*

Mobley, C.D., 1994. Light and Water: Radiative Transfer in Natural Waters. Academic Press, San Diego.

Morel, A, Huot, Y, Gentili, A, Werdell, PJ, Hooker, SB, Franz, BA. 2007. Examining the consistency of products derived from various ocean color sensors in open ocean (Case 1) waters in the perspective of a multi-sensor approach. Remote Sensing of Env.ironment 111 (2007) 69–88

Corredor, JE, Morell, JM, Lopez, JM, Capella, JE, Armstrong, RA. 2004. Cyclonic Eddy Entrains Orinoco River Plume in Eastern Caribbean. EOS, Transactions, American Geophysical Union .Eos,Vol. 85, No. 20, 18 May 2004