APPARENT WATER OPTICAL PROPERTIES AT THE CARIBBEAN TIME SERIES STATION

Roy A. Armstrong, Jose M. Lopez and Fernando Gilbes
Bio-Optical Oceanography Laboratory
Department of Marine Sciences, University of Puerto Rico
Mayagüez, Puerto Rico 00681

ABSTRACT

The Caribbean Time Series, located 28 nautical miles south of Puerto Rico, provides a temporal dataset of physical, chemical, and bio-optical variability in near-surface waters of the northeastern Caribbean Basin. Apparent optical properties such as, remote sensing reflectance and the diffuse attenuation coefficient of photosynthetically active radiation (Kd_{PAR}) were measured on a monthly basis at CaTS. These data are being related to inherent optical properties and to surface chlorophyll concentration. Seasonal changes in the climatic regime modulate upper water column properties of the northeastern Caribbean. SeaWiFS imagery shows large-scale ocean color (chlorophyll and colored dissolved organic matter) fields in the eastern Caribbean in the fall. These features have been detected at CaTS in the second half of the year as higher surface chlorophylls and lower salinities. Both apparent and inherent optical properties are being used for assessing the influence of seasonal South American river intrusions in the northeastern Caribbean, for developing regional SeaWiFS remote sensing algorithms, and for modeling ocean primary productivity.

INTRODUCTION

We maintain a monthly time series station denoted CaTS (Caribbean Time Series) at $17^{o}38'$ N 67^{o} W, approximately 28 nautical miles off the southwestern coast of Puerto Rico. CaTS provides an observing station for the assessment of the magnitude and periodicity of basin-scale phenomena affecting the optics and biogeochemistry of marginal seas. We have focused on characterizing the seasonal and inter-annual variability of near-surface water features of the northeastern Caribbean Basin as affected by seasonal riverine intrusions and its relationship to the biological productivity and carbon sequestration capacity of these waters. In the eastern Caribbean Sea, Orinoco River effluents have been detected as far north as Puerto Rico using satellite data (Müller-Karger et al., 1989) and have been shown to modulate salinity variations in near surface waters and controls vertical distribution of phytoplankton (Corredor and Morell, *in press*). In this region, an inshore-offshore gradient in apparent and inherent optical properties has been documented (Blough et al., 1993; Farmer et al., 1993).

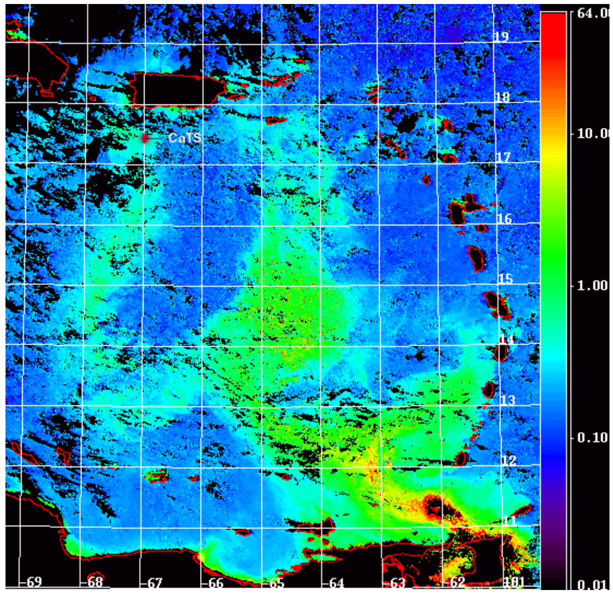

Figure 1. SeaWiFS mean chlorophyll-a composite for September 1999 depicting a large filament of Orinoco River water reaching the CaTS station.

Multi-year time series recorded at CaTS depict seasonal and inter-annual variability with associated phytoplankton biomass fluctuations. This paper describes the temporal variability of remote sensing reflectance and the attenuation coefficient of photosynthetically-active radiation (Kd_{PAR}).

METHODS

Apparent and inherent optical properties were obtained during monthly cruises to the CaTS station. In-water measurements of radiance and irradiance were made with a PRR-600 submersible radiometer (from Biospherical Instruments) at the SeaWiFS bands in addition to downwelling irradiance measurements of PAR. Profiles of PAR were used to calculate the diffuse attenuation coefficient (Kd_{PAR}), the first optical depth, and the depth of the euphotic zone. A CTD (Seabird SBE-19) measured temperature and salinity. A Sea Tech profiling fluorometer measured chlorophyll-a fluorescence. This instrument was periodically calibrated by filtering seawater, extraction in 90% acetone, and spectrophotometric analysis of the extract.

A Geophysical Engineering Research (GER 1500) portable spectroradiometer was used to obtain reflectance measurements in the 297-1095 nm region of the spectrum. However, only the wavelength region between 400 and 750 nm was used in the analysis. Three sets of triplicate spectral scans were obtained at each sampling station. Measurements were only made when clouds were not covering or near the sun. The upwelling signal from the water was measured with the sensor pointing perpendicular to the path of the sun and 45° to the water. This geometry minimized specular reflection and ship shadow or reflection. To account for a smaller component of specular reflection resulting from light reflecting off the water from either a cloud or from the sky, a second set of measurements was acquired with the sensor at 45° from vertical. This sky-light contribution was substracted from the water measurements. Remote Sensing reflectance (R_{rs}) was calculated from the ratio of skylight-corrected upwelling radiance to downwelling irradiance.

RESULTS

During the dry season (December trough May), oligotrophic waters with a deep mixed layer, low phytoplankton biomass, and large euphotic zone depths predominate at CaTS. The summer, and to a lesser extent the fall, are characterized by a shallow mixed layer and a reduced depth of the euphotic zone (Figure 2). Seasonal changes in Kd_{PAR} and the resulting changes in the depth of the euphotic zone (Zeu), are directly related to the observed patterns of primary productivity in these waters. Primary productivity integrated to 200 m increased with increasing optical depths (Lopez et al., 2000).

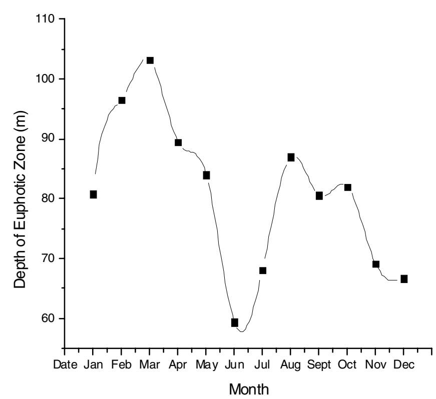

Figure 2. Bi-modal distribution of the depth of the euphotic zone (Zeu) at CaTS.

The depth of the chlorophyll maximum also varies seasonally between 50 to 100 meters. The chorophyll maximum occurs deeper between January and May, corresponding to low seasonal values of Kd_{PAR} and highest depths of the euphotic zone. The Orinoco River intrusions reach the northeastern Caribbean in the late summer reaching a maximum in October. However, the presence of meanders and filaments in this river plume (see Figure 1) causes a high variability in the observed surface chlorophyll and salinity fields at the serial station. Changes in bio-optical properties also respond to the presence and absence of the river plume.

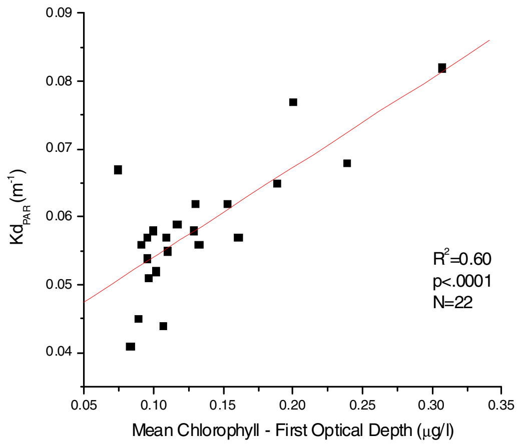

Figure 3. Relationship between Kd_{PAR} and the mean chlorophyll amount in the first optical depth.

The first optical depth varied between 12 and 24 meters with an average value of 20 meters. The mean chlorophyll concentration in the first optical depth was significantly correlated to Kd_{PAR} (R^2=0.60, p<0.0001). Since satellite ocean color algorithms estimate chlorophyll amount in the first optical depth, this relationship could provide a way of deriving Kd $_{PAR}$ from satellite data. Accurate estimates of Kd $_{PAR}$ and chlorophyll-a from satellite sensors are required for modeling primary production at regional and global scales.

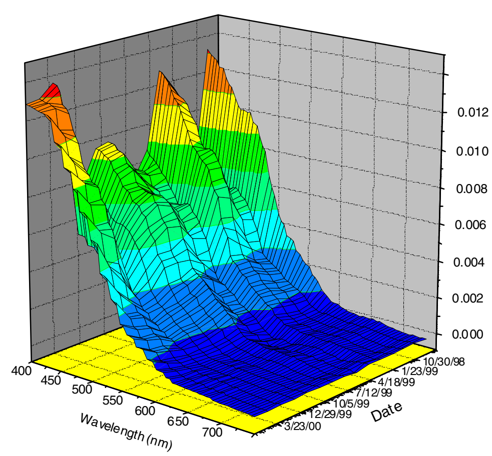

Figure 4. Time series of remote sensing reflectance measurements at CaTS.

Monthly remote sensing reflectance measurements in the visible region of the spectrum were obtained at CaTS (Figure 4). Low reflectances in the 400-475 nm region correspond to high absorbance by chlorophyll and/or colored dissolved organic matter (CDOM). This occurs during the fall due to the influence of the Orinoco River plume in the eastern Caribbean. Since SeaWiFS chlorophyll algorithms overestimate chlorophyll amount in the presence of CDOM, these spectroradiometric measurements are being used for developing more robust remote sensing algorithms for estimating chlorophyll amount in this region.

CONCLUSIONS

Apparent optical measurements at CaTS are being used to ascertain the influence of the Orinoco River plume in the northeastern Caribbean Basin, to develop algorithms capable of accurate estimates of chlorophyll-a in the presence of CDOM, and for providing some of the parameters needed to model primary production *in situ* and from satellite data. This ongoing program also contributes to the validation of SeaWiFS, MODIS and other future ocean color sensors.

ACKNOWLEDGMENTS

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