Temporal characterization of the diffuse attenuation coefficient in Abrolhos Coral Reef Bank, Brazil

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Abstract. Coral reefs are ecosystems sensitive to high sedimentation rates. Remote sensing provides different products for the monitoring of these environments, as for example, the diffuse attenuation coefficient (Kd_{490}) which can be used as a proxy for water turbidity. Our aim in this work was to characterize the temporal variability of water transparency, here indexed as MODIS-Aqua Kd_{490} in the Abrolhos Coral Reef Bank (ACRB), which is the largest and richest coral reef area in the South Atlantic Ocean. Daily MODIS-Aqua Level-2 images were obtained between July/2002 and October/2012. Kd_{490} data was derived from the satellite time-series, and reprojected for the study area. Monthly averages and monthly climatology were calculated in a pixel-by-pixel basis and for two sampling boxes, one in the coast and the other one in the archipelago. Kd_{490} showed a seasonal variation, with maximum values in austral autumn-winter and minimum in austral spring-summer, as can be seen in monthly Kd_{490} images and in monthly climatology. Coastal waters showed a smoother climatologic curve, while waters from the archipelago showed a more evident peak in the winter. The 10 year time-series showed a noisier pattern in the coastal area, with some increases and decreases out of phase with the seasonal pattern. Waters of archipelago, on the contrary, showed a clear seasonal pattern along time. Different behavior of both series agrees with the influence of cold fronts which causes resuspension of sediments in the ACRB region and with additional contribution of terrestrial discharges in coastal waters.

Key-words: Abrolhos Coral Reef Bank, water turbidity, time-series, MODIS, Banco de corais de Abrolhos, turbidez da água, séries-temporais.

1. Introduction

Coral reefs are sensitive ecosystems that can be considered as biological indicators of environmental and climate changes (Holden and Ledrew, 1998). Thus, the monitoring of their status in regional and global scale becomes relevant and remote sensing provides an effective tool for this purpose. According to Andrefouet and Riegl (2004), two different approaches can be proposed to study this ecosystem by remote sensing. One of them is direct and it is focused in the reefs by themselves (i.e., habit mapping, geomorphologic structures). The indirect approach, on the contrary, is focused on the environment around the reefs that can be the water column, the atmosphere or the neighboring lands. Even when the target is the benthic bottom, understanding spatial-temporal variability of water column constituents is demanded. Bottom and water column signals are coupled in optically shallow areas and it is indispensable to apply any technique to correct water column effect from reflectance spectra. Therefore, water column characteristics must be known.

Remote sensing has become a tool nearly indispensable for the study and monitoring of marine and oceanic ecosystems across time. Nowadays, imagery from Moderate Resolution Imaging Spectroradiometer-Aqua (MODIS-Aqua) has completed more than 10 years providing data for the development of climatologic profiles and time-series analyses. Our aim in this work was to characterize the temporal variability of the Diffuse Attenuation Coefficient at 490nm (Kd_{490}), derived from MODIS-Aqua data, as an index of water transparency in the Abrolhos Coral Reef Bank. Kd_{490} is a measurement of vertical decay of download irradiance (E_d). In ocean color remote sensing it is an integer in the surface mixed layer and can be used as proxy of water turbidity and, reciprocally, of water visibility.

Water turbidity in coral reefs is ecologically relevant. This is because corals are bio-filtering organisms that obtain carbon and other nutrients from particulate phase to support their own production, and consequently, the biodiversity of reefs. For this reason, variations in sedimentation rates and increases of nutrients concentration can leave to changes in biological community structure and they are recognized as a strong threat for coral reefs ecosystems (Rogers, 1990; McCook, 1999).

2. Materials and methods

2.1. Study area

The Abrolhos Coral Reef Bank (ACRB) is located in the tropical Atlantic ocean, in the Brazilian continental shelf (Figure 1). It is considered the largest and richest coral reef area in the south Atlantic ocean (Leão, 1982). In this area, the coral reefs are distributed in different depths. The deeper reefs are located between 2-25m depth at approximately 60 km from the coast, near the Archipelago. The shallower ones are at 6-7km from the coast and are found between intertidal areas until 10m depth.

Sedimentation rates in the Abrolhos Bank are relatively higher than other recifal areas (Segal-Ramos, 2003). This sedimentation flux is greater in austral winter due to polar front migration in the area, when surface winds from SE, S and SW are predominant and produce turbulent processes with sediments resuspension (Segal et al 2008). There are also some rivers discharging in this oceanic region. Among them, the most important terrestrial discharge is from Doce River, which mean caudal is 1,140 m^3 sec^{-1} (Source: ANA, 2010). Maxima rivers discharge season is from November to April due to the rainfall regime in the interior of the region, with maximum between December and February (Segal et al., 2008). Terrestrial inputs affect mainly shallow waters in the continental shelf and there is an effect of dilution to open sea (Segal et al., 2008). At the coast maximum precipitation rate occurs during the austral autumn (March, April, and May).

2.2. Data sets and images processing

Daily MODIS-Aqua images, acquired during more than 10 years between July/2002 and October/2012, with low cloud cover and covering our interest area were downloaded from http://oceancolor.gsfc.nasa.gov/. A total of 2,688 Level 2 images were obtained with a spatial resolution of 1km. Diffuse Attenuation Coefficient at 490nm (Kd_{490}) is a standard product included in Level 2 data. Kd_{490} is estimated as a band ratio according to Equation 1:

$$Kd_{490} = A\left[\frac{nLw(490)}{nLw(555)}\right]^{B} \qquad \text{Eq. 1}$$

where $nLw(490)$ and $nLw(555)$ are normalized water leaving radiance at 490 and 555nm, respectively. A and B are constants ($A = 0.1853$; $B = -1.349$) (Werdell, 2005).

Figure 1. Localization of Abrolhos Coral Reef Bank in the Brazilian coast, Southwestern South Atlantic Ocean. Points 1 and 2 indicate the localization of a 2x2 pixels box where daily satellite Kd_{490} time-series were extracted. Main rivers in the study area are also indicated.

The Kd_{490} data set processed using SeaDAS software, and reprojected to cylindrical proyection between coordinates 15°46’12’’- 20°S and 36°51’36’’- 42°W, such as images from different orbits resulted co-registered allowing a temporal analysis. In all images, clouds and land were masked out not-a-number (NaN). Kd_{490} higher than $1m^{-1}$ were considered as spurious values and also masked as NaN.

2.3. Data analyses

Monthly averages and monthly climatology were calculated for Kd_{490} in a pixel-by-pixel basis. In turn, Kd_{490} monthly averages and monthly climatology were screening and all mean values higher than $0.5m^{-1}$ were eliminated. This threshold was chosen to enhance little differences and because values higher than $0.5m^{-1}$ were only adjoining the coast. Monthly climatology of Kd_{490} values were plotted, to describe the spatial pattern of distribution.

Two time-series of monthly Kd_{490} data were extracted form a 2x2 box located in the coastal (point 1 in Figure 1) and the archipelago (point 2 in Figure 2) areas. Monthly climatology was calculated for each sampling point.

3. Results and discussion

The attenuation coefficient Kd_{490} was used in this work to study water visibility temporal variability. Since substrates in this area are shallower than 20m, they might have contribution in the remote sensing signal depending on optically active constituents present in water column and on the wavelength considered. Nevertheless, considering the present effort as an exploratory analysis, we interpreted the results under the premise that bottom contribution is ~constant across time.

Considering this, Kd_{490} showed a seasonal variation, with maximum values in austral autumn-winter (May-September) and minimum in austral spring-summer (October-April) (Figure 2). During autumn-winter, it is possible observe an increase in spatial distribution of more turbid waters, especially to the south of the ACRB. This patter responds to polar front migration which causes sediments resuspension and carries material transport northward. Spatial pattern follows the continental shelf shape in this area, which has an extension where coral reefs are located.

When we observe water turbidity around the coral reefs, it is possible to note that both areas –coastal and archipelago– are submitted to the same seasonal regime (Figure 3). Nevertheless, while coastal box shows a smoother curve along the year, the archipelago time-series shows a more evident peak between May and July in its climatologic Kd_{490} data. This imply that whether the focus of work is to study submerse benthic coverage inside the bank (i.e., bottom mapping), images from spring-summer are recommended. Light penetration is higher when water column has low concentration of optically active constituents and then, remote sensing signal carries more information about bottom features.

Observing the ~10 year time-series, waters of coastal reefs showed a noisier pattern, with some increases and decreases out of seasonal pattern (Figure 4). This can be a consequence of influence of terrestrial discharges which can incorporate sediments and organic matter in other periods. On the other hand, waters from the archipelago seem to be affected only by instability process caused by cold fronts in winter and their material transport (Figure 5).

Some peaks were present in the archipelago but not in the coastal zone, during June/2003, June/2009 and June/2010 (Figures 6, 7 and 8). Observing of images from these three months presented some oceanic features which could correspond with local phytoplankton blooms. Chlorophyll images could help to reaffirm this hypothesis.

Next steps of this work will involve analyses of the time series in the frequency domain, application of some algorithms to know contribution of each constituent for water turbidity and study their relationship with wind pattern, to better understanding of mechanisms that causes turbidity behavior along time.

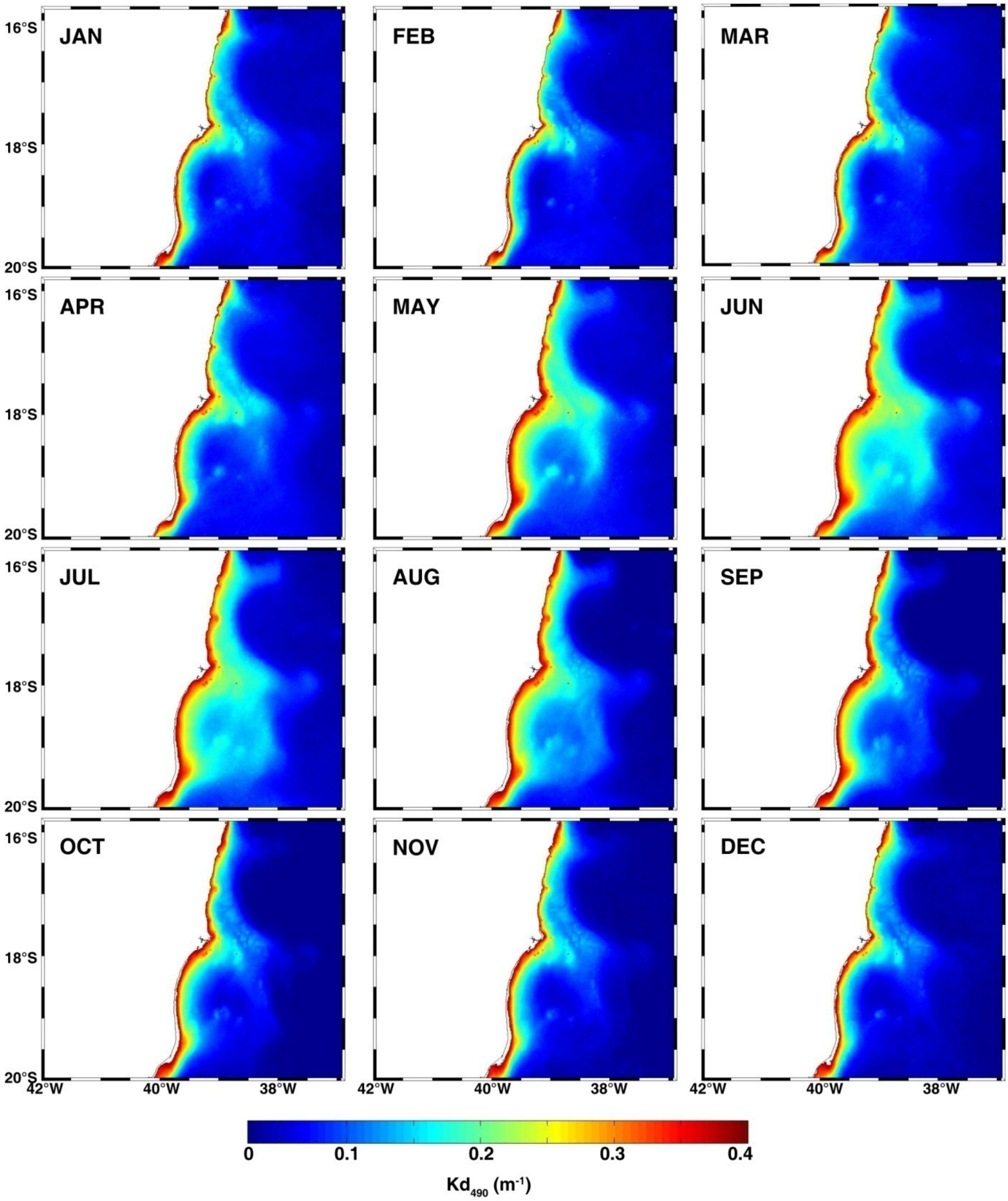

Figure 2. Monthly climatology of Kd_{490} (m^{-1}) from 10-years MODIS-Aqua data.

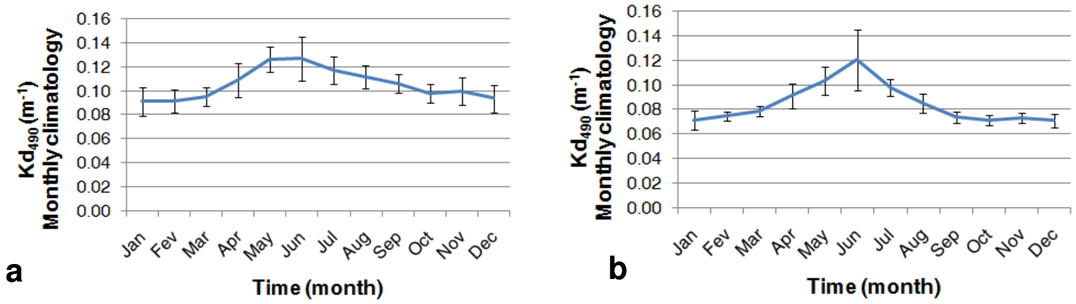

Figure 3. Monthly Climatology (± standard deviation) of Kd_{490} of coastal coral reef (a) and archipelago (b).

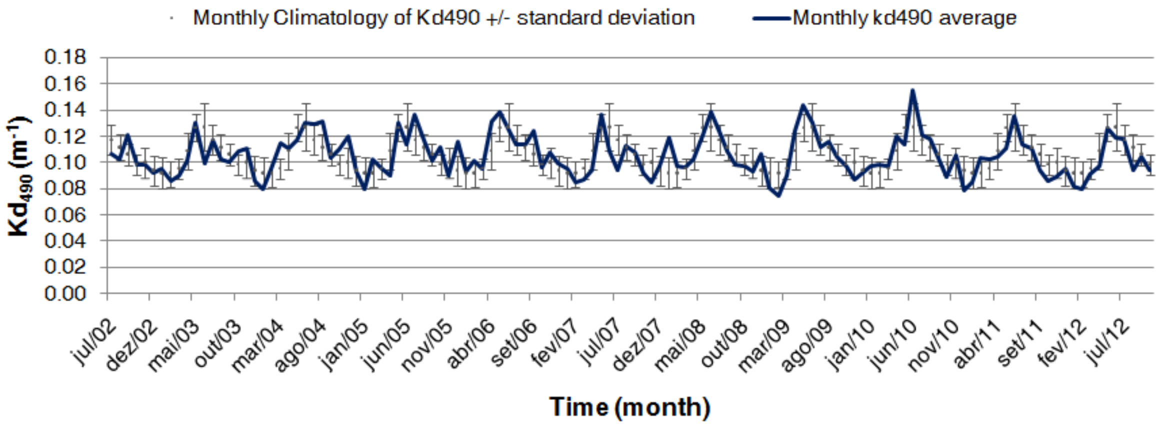

Figure 4. Monthly Kd_{490} average from MODIS-Aqua vs time, between July/2002 and October/2012 (in blue) in coastal waters. Grey points and error bars represent monthly climatology ± standard deviation.

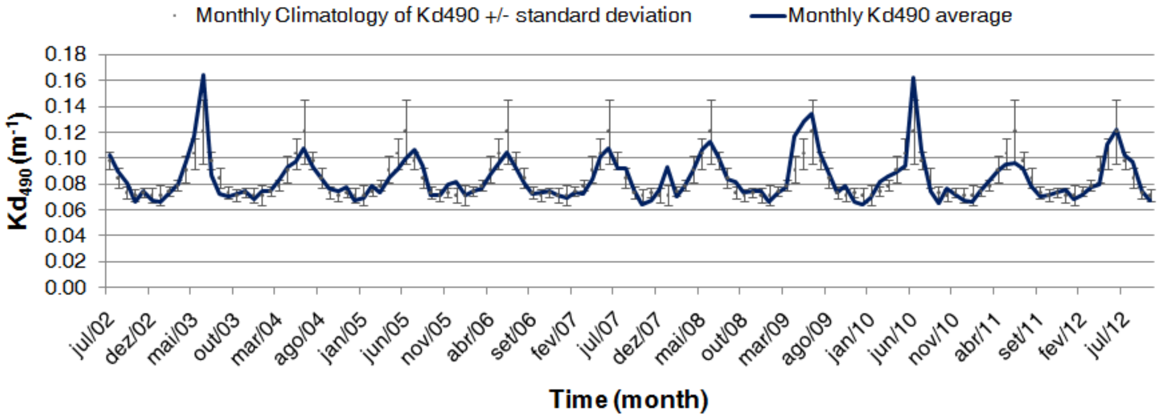

Figure 5. Monthly Kd_{490} average from MODIS-Aqua vs time, between July/2002 and October/2012 (in blue) in archipelago waters. Grey points and error bars represent monthly climatology ± standard deviation.

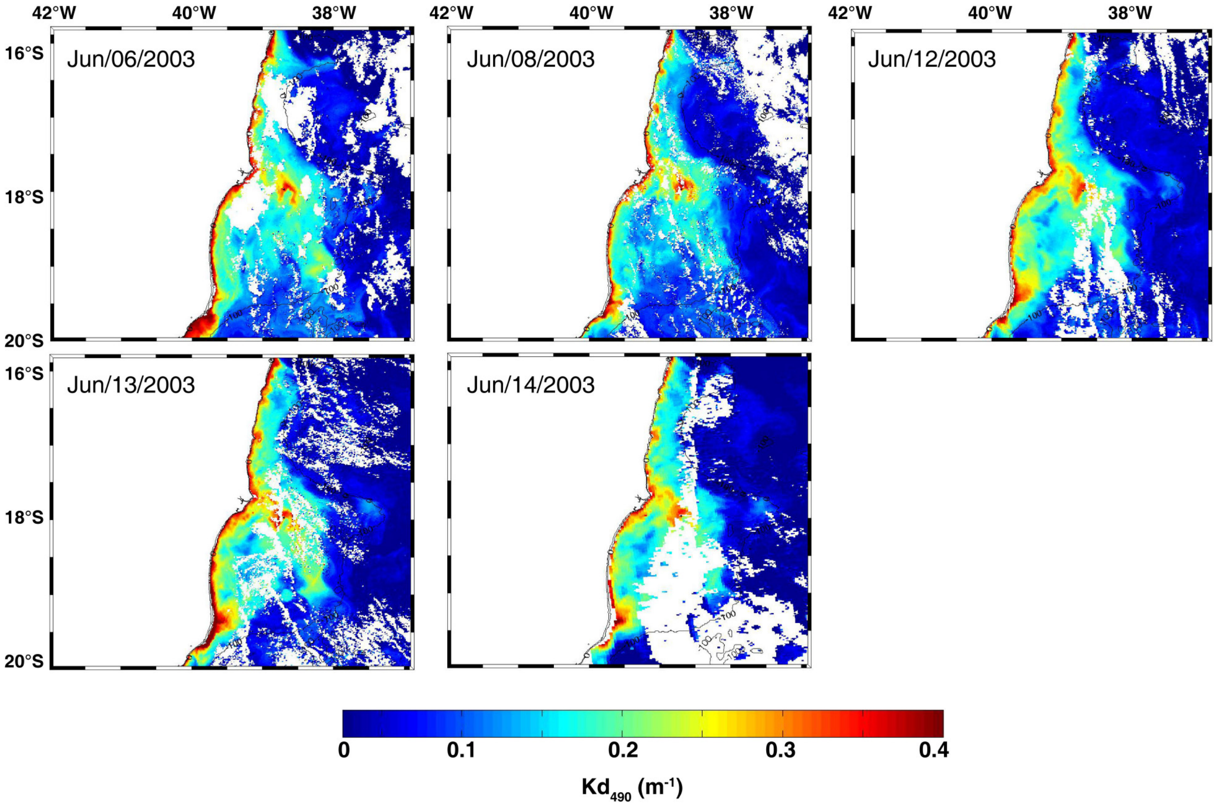

Figure 6. Daily images of Kd490 of several days in June/2003. A phytoplankton bloom can be observed around the archipelago.

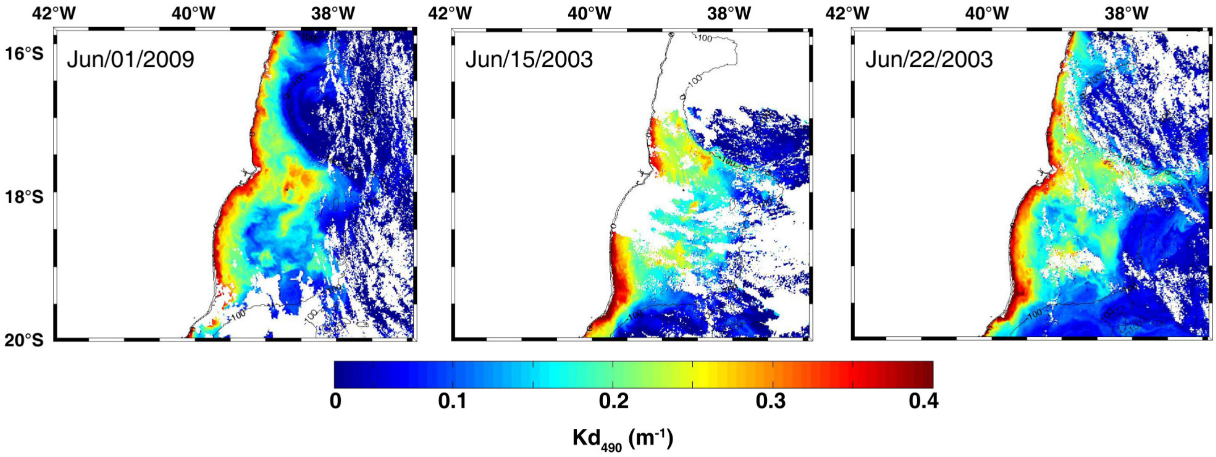

Figure 7. Daily images of Kd490 of several days in June/2009. A phytoplankton bloom can be observed around the archipelago.

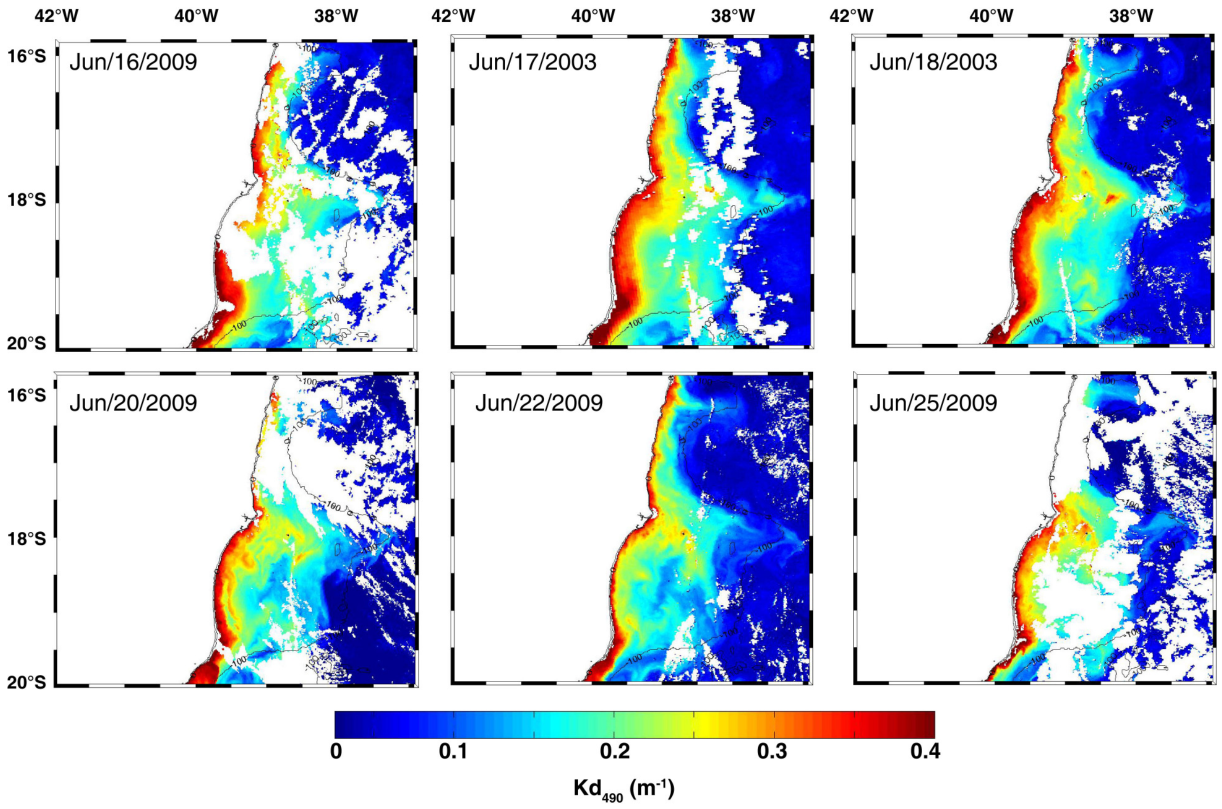

Figure 8. Daily images of Kd_{490} of several days in June/2010. A phytoplankton bloom can be observed around the archipelago.

4. REFERENCES

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