Optimized extraction of daily bio-optical time series derived from MODIS/Aqua imagery for Lake Tanganyika, Africa

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A B S T R A C T

Lake Tanganyika is one of the world's great freshwater ecosystems. In recent decades its hydrodynamic characteristics have undergone important changes that have had consequences on the lake's primary productivity. The establishment of a long-term Ocean Color dataset for Lake Tanganyika is a fundamental tool for understanding and monitoring these changes. We developed an approach to create a regionally calibrated dataset of chlorophyll-a concentrations (CHL) and attenuation coefficients at 490 nm (K490) for the period from July 2002 to December 2006 using daily calibrated radiances retrieved from the MODIS-Aqua sensor. Standard MODIS Aqua Ocean Color products were found to not provide a suitable calibration for high altitude lakes such as the Lake Tanganyika. An optimization of the extraction process and the validation of the dataset were performed with independent sets of in situ measurements. Our results show that for the geographical, atmospheric and optical conditions of Lake Tanganyika: (i) a coastal aerosol model set with high relative humidity (90%) provides a suitable atmospheric correction; (ii) a significant correlation between in situ data and CHL estimates using the MODIS specific OC3 algorithm is possible; and (iii) K490 estimates provide a good level of significance. The resulting validated time series of bio-optical properties provides a fundamental information base for the study of phytoplankton and primary production dynamics and interannual trends. A comparison between surface chlorophyll-a concentrations estimated from field monitoring and from the MODIS based dataset shows that remote sensing allows improved detection of surface blooms in Lake Tanganyika.

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1. Introduction

Lake Tanganyika is one of the world's most important freshwater ecosystems, providing fundamental resources for 10 million people living in its catchment's area as well as a unique reservoir of biodiversity (Mölsä et al., 1999). The lake, situated in the East-African rift, approximately at 773 m above sea level, covers a large transnational area of 32,900 km² with borders in Tanzania, Democratic Republic of Congo, Burundi and Zambia (Fig. 1). It is the second deepest freshwater lake in the world (after Lake Baïkal), and is characterized by deep basins in the north (max. depth of 1310 m) and south (max. depth of 1470 m) separated by a sill at 600 m deep.

The lake is oligotrophic and permanently stratified with an anoxic hypolimnion. During the dry season (from May to September), strong southerly winds induce upwelling of nutrient-rich deep waters in the southern part of the lake, and a tilting of the thermocline. In addition to this major hydrodynamic phenomenon, the depth of the mixed layer varies seasonally in all lake basins as a result of change in the temperature–density gradients and of variation of wind velocity (Naithani et al., 2003). Along with internal waves which enhance diffusion through the thermocline, these events are key drivers of phytoplankton growth and dynamics, as they determine nutrient availability in the euphotic zone. (Hecky et al., 1991; Plisnier et al., 1999; Naithani et al., 2007).

The plankton assemblages of Lake Tanganyika also show seasonal and spatial variations, with a chlorophytes–cyanobacteria (Chroococcales) assemblage in the wet season (October–April), when high light is combined with poor nutrient availability in the shallow epilimnion (Hecky and Kling, 1981). In the dry season (May to September), when deep mixing occurs, an increase of diatoms is observed, favoured by lower light levels and higher nutrient availability. Surface blooms of filamentous cyanobacteria (Anabaena sp.) develop frequently at the end of the dry season, when the water column re-stratifies. More recently, both algal pigment (Descy et al., 2005) and microscopy (Cocquyt and Vyverman, 2005) surveys updated the data on algal biomass, composition and dynamics in the pelagic waters of Lake Tanganyika, and underlined the cyanobacteria–chlorophyceae dominance in the most part of the year cycle, with particular prominence of...
the picocyanobacteria *Synechococcus* sp. (Vuorio et al., 2003; Descy et al., 2005; Sarmento et al., 2007, Stenuite et al., 2009). There is, however, significant spatial variation in Lake Tanganyika: the dry season diatom peak coinciding with the chlorophyll-a maximum in the water column (Cocquyt & Vyverman, 2005), is clearly visible in the northern part of the lake. By contrast, in the southern basin, where the temperature density gradient is usually weaker, diatom maxima has a less pronounced seasonal pattern, and picocyanobacteria tend to dominate at all times (Descy et al., 2005; Stenuite et al., 2009). The same recent investigations (Descy et al., 2005) report that green algae are far more abundant and diverse off Kigoma (northern basin) than off Mbulungu (southern basin).

Several authors have emphasized the risk of a decreasing primary productivity of the lake due to rising surface temperatures and decreasing wind speeds, in the context of global change (O’Reilly et al., 2003; Verburg et al., 2003; Verschuren, 2003). In this regard, Lake Tanganyika’s ecosystem and biodiversity, as well as the regional population which depends on lake resources, may face a critical situation in the near future. A better understanding of the lake’s mechanisms is essential to managing these resources to ensure their sustainable exploitation. However, the large size of the lake precludes the use of in situ measurements for the creation of a database with sufficient temporal and spatial resolutions (Naithani et al., 2007). In this regard, satellite data have a great potential for the study of the spatio-temporal variability of the Lake.

In the present paper, we describe and validate an approach for the development of a time series of chlorophyll-a concentration (CHL) and vertical attenuation coefficient (K490) based on daily MODIS Aqua calibrated radiances. Both bio-optical parameters have been directly linked to primary productivity and fisheries. In situ data from measurements on lake transects carried out in the same period were used to calibrate and validate the algorithms as well as to examine dominating optical components of the water column. Finally, we compare surface chlorophyll-a concentrations determined in two sites in the lake with the coincident data from the MODIS based time series. The results show the advantages of using remote sensing to detect surface blooms in Lake Tanganyika.

2. Data and methods

2.1. In situ data

Measurements in two permanent stations situated in the pelagic zone of the lake near Kigoma and Mbulungu were made each fortnight from 2002 to 2006 (Fig. 1). Major optical and physical parameters were measured at the water surface and every 20 m to a depth of 100 m: water temperature, conductivity, pH, dissolved oxygen, transparency, turbidity and chlorophyll-a. Water samples were obtained from each sampling depth for phytoplankton pigment analysis by HPLC; all methods were described in Descy et al. (2005). Chlorophyll-a concentrations were typically low in both stations (mean CHLsurface = 0.7 mg/m³, max. CHLsurface = 3.77 mg/m³ at Mbulungu and max. CHLsurface = 2.00 mg/m³ at Kigoma) with a higher temporal variability of the chlorophyll-a concentration in Mbulungu (Plisnier & Descy, 2005). The highest pigment concentrations were usually found in the 0–40 m layer and decreased sharply downward.

HPLC analysis was also used to estimate the contribution of different phytoplankton groups to total chlorophyll-a, using marker pigment
concentrations and a data processing based on marker pigment-chlorophyll-a ratios (see e.g. Wright & Jeffrey, 2006). All methods used for pigment analysis and subsequent processing by CHEMTAX, a software for calculating phytoplankton biomass at the class level (Mackey et al., 1996), were described in Descy et al. (2005). For Lake Tanganyika samples, the following phytoplankton groups were quantified with this method: Chlorophytes, cryptophytes, chrysophytes + diatoms, dinoflagellates, cyanobacteria T1 (pigment type 1 or "Synechococcus pigment type" according to Jeffrey et al., 1997) and cyanobacteria T2 (pigment type 2, according to Jeffrey et al., 1997, found in many filamentous cyanobacteria). In Lake Tanganyika, cyanobacteria T2 were found to correspond mostly to Anabaena sp. (Descy et al., 2005).

Besides the field data recorded at the permanent stations, limnological and pigment data were collected for nine other pelagic stations during three sampling cruises between Kigoma and Mpulungu (Fig. 1, crossed points). Two data series cover the dry season (July 2002 and 2003) and one covers the wet season (February 2004). All measurements and sampling treatments followed a similar protocol (Descy et al., 2005), except for the cruise 2002 during which samples were acquired for a mixed water column between 0 and 60 (these values were not used in this study).

The vertical attenuation of photosynthetically available radiation (PAR) was determined at all sites as in Descy et al. (2005). The PAR diffuse attenuation coefficient was calculated by assuming an exponential decay of solar radiation within the lake water column (Kirk, 1994). For examining the contribution of dominant optical components to light attenuation, chlorophyll-a concentration, turbidity and dissolved organic matter were measured at the Mpulungu station in August 2006. The PAR attenuation coefficient \(K_a\) was then divided into a set of partial attenuation coefficients, each corresponding to a different optical component of the medium (Eq. (1)):

\[
K_a = K_W + K_T + K_{PHY} + K_{CDOM}
\]

where \(K_W\), \(K_T\), \(K_{PHY}\) and \(K_{CDOM}\) are the partial attenuation coefficients due to water, tripton, phytoplankton and CDOM. Smith (Smith & Baker, 1978) proposed an average value of the specific attenuation coefficient for phytoplankton \(K_{PHY}\) of 0.016 m\(^{-1}\) (mg chl-a\(^{-1}\)) while the PAR attenuation coefficient for pure water is 0.027 m\(^{-1}\). \(K_{CDOM}\) values were estimated from spectrophotometric measurements of filtered (0.22 µm) water samples. In the partitioning of the PAR attenuation coefficient, we subtracted the estimated \(K_{CDOM}, K_{PHY}\) and the reported \(K_W\) from the measured \(K_a\) to determine contribution of the tripton fraction to overall attenuation. The contribution of phytoplankton to the attenuation of PAR was globally larger than 50% (Table 1), allowing us to consider Lake Tanganyika as Case 1. Furthermore, \(K_W\) was found to be generally well correlated with surface CHL, especially in non coastal areas.

2.2. Bio-optical parameters derived from MODIS Aqua

Several MODIS Ocean Color (MODIS OC) products distributed by the Biology Ocean Processing Group (OBPG) are freely available on the Ocean Color Web (http://oceancolor.gsfc.nasa.gov/). These products are processed following the methodologies built up by Gordon and Voss (1999), Gordon and Wang (1992, 1994) for the computation of normalized water-leaving radiance and by Clark (1997) for the bio-optical algorithms adapted to Case 1 Waters. Daily normalized water-leaving radiances and derived bio-optical parameters such as chlorophyll-a concentration, water attenuation, etc. are available with a 1 km nadir resolution as Level 2 data (MYD01CL2 and MYD02LA2) (Table 2).

For the present study, clear sky normalized water-leaving radiance images (MYD01CL2_V004) were acquired to coincide with the July 2003 cruise. These images were evaluated to observe how the standard MODIS OC products handle perturbation factors present in high altitude tropical lakes such as Lake Tanganyika. Normalized water-leaving radiances (nLw), extracted from MYD02CL2 products, were compared for different targets such as cloud, river sediment plumes (near the Malagarasi mouth and the Rusizi delta) and four pelagic stations within the lake (Fig. 2). The cloud target shows a consistent zero value for all the wavelengths (flagged pixels) while the other targets present normalized water-leaving radiance (nLw) in the 443 nm wavelength band. This is a clear sign that the pre-processing of the Ocean Color products is not appropriate for retrieving water-leaving radiances from Lake Tanganyika. Indeed, this is a logical consequence of the ocean based pre-processing adopted by the Ocean Color community. Atmospheric characteristics of the world’s oceans are clearly different from those found in the high altitude Rift Valley lakes of Eastern Africa. As such, standard pre-processing of the MODIS OC products does not take into account the thinner atmospheric layer above the lake, with a difference in atmospheric pressure estimated to be 112 hPa. The standard atmospheric correction will overestimate the aerosol layer above the lake and consequently the contribution of the atmosphere to the measured radiance. The result is a negative water-leaving radiance (flagged as zero value in the OC products) and significant errors in the estimation of bio-optical parameters. It is therefore necessary to create a regionally based MODIS CHL and K490 estimation approach. For that purpose, we used in situ measurements of 3 lake transects and Level 1B images (MYD02L1km) containing calibrated and geolocated radiances at-aperture for all 36 MODIS Aqua spectral bands at 1 km resolution.

The SeaWIFS Data Analysis System (SeaDAS) was used to generate level-2 geophysical products (mssl12 program of SeaDAS 4.6) (Fu et al., 1998). Required inputs are calibrated radiances, geolocation fields, NCEP meteorological data of the acquisition day at 6, 12 and 18 h and ozone data nearest the acquisition time. Ozone information was

| Table 2 |
| Description of the tested MODIS Ocean Color products. |
| **MODIS Ocean Color Products** | **Description** |
| **MYD01CL2** MODIS/Aqua Ocean Color radiance products 5-min L2 swath 1 km day | The MODIS Level 2 Ocean Color water-leaving radiance product, MYD01CL2, contains normalized water-leaving radiance for 7 of the 36 wavelengths/spectral bands (bands 8 through 14, 412 through 618 nm) of MODIS which are used to derive nearly all the ocean products, ocean aerosol properties and clear water epilimnion (parameter numbers 1–12). This Level 2 data collection has daily coverage with a 1-km resolution at nadir. |
| **MYD02LA2** MODIS/Aqua Ocean Color Derived Products Group 1 5-min L2 swath 1 km day | The MODIS Level 2 Ocean Color Derived Products Group 1, MYD02LA2, product contains the following ocean products: chlorophyll derived from several different algorithms, phycobilin pigment concentrations, chlorophyll fluorescence, suspended solids concentration, coccolith, calcite, coccolith corrected pigment concentration and ocean water attenuation (ocean parameter numbers 13–25). This Level 2 product has daily coverage with a 1-km resolution at nadir. |
obtained from: (a) EPTOMS data from the Earth Probe Total Ozone Mapping Spectrometer which measures backscattered UV radiances in the 310–380 nm spectral band and; (b) TOAST data (Total Ozone Analysis) which combines TOVS tropospheric and lower stratospheric ozone with SBUV/2 mid-to-upper stratospheric layer ozone retrievals.

Four algorithms for atmospheric correction with different aerosol multi-scattering models were tested. Three of them were fixed models with aerosol optical thickness parameters adapted to coastal areas characterized by relative humidity of 50%, 70% and 90%. The last model (SeaDAS default) is based on the 765/865 nm radiances ratio and uses a NIR correction for non-zero nLw. Two different bio-optical algorithms were tested for the estimation of CHL: the specific MODIS algorithm (Chl_OC3) (Eqs. (2) and (3)) and the algorithm proposed by Clark (1997) (Chl_Clark) (Eq. (4)).

\[
\text{Chl\_OC3} = 10^{0.2830 - 2.753R_{50} + 1.457R_{550} + 0.659R_{550} - 1.403R_{550}} 
\]

\[
R_{SM} = \log_{10}(R_{550} - R_{50}) 
\]

where Chl\_OC3 is the concentration in chlorophyll-a and RSM is the maximum ratio of water-leaving radiances at different wavelengths.

\[
\log \text{Chl\_Clark} = -1.4(\log R_{550}) + 0.07 
\]

where Chl\_Clark is the concentration in chlorophyll-a and \(R_{550}^{443}\) is the ratio between water-leaving radiances at 443 nm and at 550 nm.

K490 provides information on water column turbidity and is related to the concentration of scattering particles. The estimates of the diffuse attenuation coefficient at 490 nm (K490) were based on the atmospheric correction algorithm that was optimized for CHL and calculated according to Mueller (2000) (Eq. (5)).

\[
K490 = K_{W(490)} + 0.15645 \left( \frac{nLw(490)}{nLw(550)} \right)^{-1.5401} 
\]

where \(K_{W(490)}\) is the diffuse attenuation coefficient for pure water, \(nLw(490)\) and \(nLw(550)\) are the normalized water-leaving radiances at 490 nm and 550 nm.
3. Results

3.1. Atmospheric correction and chlorophyll-a concentration calculation

CHL estimates were computed using each aerosol model and each CHL algorithm for exploitable days (cloudiness lower than 20% of the lake and satellite view angle higher than 60°) during the transect cruises of 2003 and 2004. The reference points corresponded to the sampling sites and MODIS CHL pixels which were collocated (occurring within the same MODIS pixel) and nearly synchronous (occurring within a maximum delay of 2 days). Due to these strict selection criteria, the number of eligible points was rather low, notably due to high cloud cover during the wet season.

The results of the linear regression were analyzed using the significance test of $R^2$ ($F$—Snedecor), and conformity tests of the slope and the offset ($t$—Student). Comparisons of in situ data and derived CHL showed a range of results (Fig. 3a, b). The SeaDAS default atmospheric correction did not provide a significant correlation (Table 3). The regression obtained with OC3 algorithm and an aerosol correction model optimized for coastal regions with 90% of humidity provided the best correlation ($R^2$ and RMSE) and is the only alternative with an origin and a slope not significantly different from 0 and 1, respectively. The root mean square error, RMSE, expressed w.r.t. the mean in situ values, is around 20%.

3.2. Validation of the dataset

Daily MODIS/Aqua L1B images were used to compute a 5-year dataset (July 2002 to December 2006) of CHL and K490. Both time series were validated using independent in situ data from the permanent stations in Kigoma and Mpulungu. Constraints for the selection of validation points were more restrictive than those for the optimization phase: selected points were strictly collocated and synchronous. A linear regression between the measured in situ CHL concentrations and the MODIS based CHL estimates was found to have an offset not significantly different from zero (Fig. 4) but with a slope slightly different from 1 ($R^2 = 0.66$, $n = 17$, RMSE = 55.5% w.r.t mean in situ CHL). For K490, the relationship between in situ data and MODIS estimates was found to have an offset and slope not significantly different from 0 and 1, respectively ($R^2 = 0.56$, $n = 16$, RMSE = 21.9% w.r.t mean in situ $K_d$).

<table>
<thead>
<tr>
<th>Aerosol model</th>
<th>CHL algorithm</th>
<th>$R^2$</th>
<th>RMSE</th>
<th>RMSE (%)</th>
<th>$F$</th>
<th>Significance test——$R^2$</th>
<th>Conformity test——offset</th>
<th>Conformity test——slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal, 90% RH</td>
<td>OC3</td>
<td>0.64</td>
<td>0.23</td>
<td>20.26</td>
<td>14.25</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
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<td>0.66</td>
<td>0.28</td>
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<td>Yes</td>
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<td>0.42</td>
<td>0.44</td>
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<td>3.07</td>
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<td>Yes</td>
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<td>4.23</td>
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<tr>
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<td>59.32</td>
<td>0.57</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*H0 of the statistical tests (all tests were realized using $\alpha$ level = 0.05).

$^*$Does it exist a significant relationship between in situ data ($X$) and remotely sensed estimates ($Y$)?

$^**$Is the offset not significantly different from 0?

$^***$Is the slope not significantly different from 1?
3.3. MODIS CHL dataset and phytoplankton bloom detection

Fig. 5 shows the time series of chlorophyll-a data from field measurements and the MODIS based CHL dataset, corresponding to two in situ monitoring sites. Remote sensing estimates showed more frequent high concentration events (>3 mg m⁻³), with respect to field sampling. These high chlorophyll-a events were usually of short duration (~1–2 weeks) and may have been underdetected in our field sampling. When high chlorophyll-a concentrations were observed in the field survey, they usually corresponded to cyanobacteria T2 (pigment type 2), chiefly of N₂-fixing filamentous forms, with a dominance of Anabaena sp. (Descy et al., 2005). These surface blooms...
usually occurred near the onset of the rainy season or in the middle of the rainy season. They occurred mainly in the 0–30 m surface layer (Fig. 6), and reached maxima near the surface. Chlorophyll-a concentrations measured in the field when surface blooms occurred barely exceeded 3 mg m$^{-3}$, but when concentrated in the surface layer, following vertical migration of the cyanobacteria filaments, they may have reached or exceeded the range of 10–20 mg m$^{-3}$ estimated from MODIS-Aqua data. High surface chl-a in the dry season, as those which occurred between April and August 2004 in Mpulungu (Fig. 6b) were found to correspond mostly to diatoms, which developed in a deeply mixed water column, i.e. over 70–80 m (Descy et al., 2005). A higher correlation occurred between chlorophyll-a from field samples and the MODIS-Aqua based dataset ($r = 0.67, n = 99, P < 0.005$), when chlorophyll-a concentrations higher than 4 mg m$^{-3}$ are excluded.

4. Discussion

4.1. General discussion

Using the optimized algorithms, we found that the MODIS based CHL estimates provide an appropriate measure of the actual CHL concentrations in the upper water masses. A slight overestimate occurs, in particular in lake areas with lower water transparencies. Globally the validation results are satisfactory, even if a more complete dataset of validation points would have strengthened our conclusions. The low number of exploitable images available during the wet season may affect the quality of our bio-physical estimations during that period. This points to possible computation errors with a temporal variability.

The complete dataset built for Lake Tanganyika is composed of 662 daily images of CHL and 652 daily images of K490, beginning in July 2002 and ending in December 2006. The dataset was analyzed both spatially and temporally by plotting a grid of completeness (Fig. 7a). The completeness index ranges from 0 (no image available for grid cell) to 1 (the cell has total coverage of MODIS L1B data). The Northern part presents the lowest scores in terms of temporal coverage, partly due to high cloudiness (Fig. 7b). In contrast, the Southern part (Fig. 7c) is covered by the highest number of images. The seasonal effect of the movement of the inter-tropical convergence zone clearly affects the quality of the time series for the major part of the lake. The signature of the dry season is clear and similar for the years 2004 and 2005. The year 2003, classified as a post El Niño year, is atypical with lower values of maximum completeness and a 2-peak evolution. The relative frequencies observed for measured and
Fig. 7. (a) Spatio-temporal completeness of the MODIS CHL dataset computed for Lake Tanganyika for the period June 2002–December 2006; spatial completeness during the period June 2002–December 2006, respectively for (b) the northern part of the lake, (c) the Southern part of the lake and (d) the entire Lake. Black lines are 21-days moving averaged values.
calculated bio-optical parameters show comparable distributions (Fig. 8). This further indicates that the model used for the estimation of these bio-optical parameters performs well, as the data retrieved from remote sensing have the same range and distribution as those measured in situ. For the chlorophyll-a concentration, the mode is about 0.75–1 mg m$^{-3}$, even if the distribution resulting from MODIS data shows slight and nearly systematic shift towards higher values. High concentrations events (≥ 3 mg m$^{-3}$) appear to occur more frequently in the MODIS CHL dataset. Surface blooms in Lake Tanganyika are often short-time events, which occur more frequently in the dry season, during which clear sky situations favor satellite data acquisition (Fig. 7). Both the possible overestimation by the used algorithms as well as the temporal bias due to a higher frequency of dry season images will favor a shift to higher average values.

4.2. MODIS CHL dataset and phytoplankton bloom detection

Surface blooms in Lake Tanganyika are often short-time events, which occur both in the rainy season and in the dry season. They are generally linked to upwelling of deep water caused by strong seasonal winds. Southeast winds push surface waters northward in the dry season, resulting in a tilted thermocline (Plisnier & Coenen, 2001; Naithani et al., 2002, 2003). Reversing winds create oscillating internal waves with diminishing amplitude with an approximate period of 3 weeks. Upwelling is particularly strong when thermal stratification is low, allowing for a generalized and stable bloom over the Southern part of the lake. This is typically the case in 2002 where the bloom is dominant in the Southern part of the Lake and stable during 4–5 days (Fig. 9a). Similar seasonal surface blooms were observed during the same period (June–July) in all years of the dataset. The 1 km resolution of MODIS is, in the case of the Lake Tanganyika, sufficient to observe the development of patches of high concentration of chlorophyll-a and even to identify gyres (Fig. 9a and b). Therefore chlorophyll-a spatial distributions derived from our CHL image dataset, together with information regarding lake bathymetry and winds, could provide important information on lake hydrodynamics.

As the duration of surface blooms is often limited to few days in Lake Tanganyika, remote sensing, with daily data acquisition, is undoubtedly an appropriate tool to evaluate surface “blooms” frequency with respect to a field survey with a 2-week periodicity. Although this periodicity may be suitable to follow phytoplankton dynamics, given the range of population growth rates (Stenuite et al., 2007), it is clearly insufficient to detect and evaluate surface blooms of buoyant filamentous cyanobacteria. We have shown that several MODIS based high chlorophyll-a events corresponded to development of cyanobacteria T2 (as detected from marker pigments using HPLC analysis and CHEMTAX processing). In Lake Tanganyika, Anabaenopsis sp. blooms of relatively short duration have been reported; Anabaena filaments typically develop slowly at depth, exploiting water column stratification and adjusting their optimal depth by modulating their buoyancy with cellular gas vesicles. In addition, Anabaena sp. and other filamentous cyanobacteria (such as Anabaenopsis tanganyicae) are N-fixers, which allow them to outcompete other phytoplankton in DIN-depleted environments, typical of the surface waters of Lake Tanganyika during the rainy season. Blooms are expected to show high spatial and temporal variability, which renders them hard to quantify by in situ monitoring. Therefore, the use of satellite data with appropriate calibration and validation is fundamental for a comprehensive and reliable evaluation of these events in large tropical lakes such as Lake Tanganyika.

5. Conclusion and perspectives

The algorithms and models presently developed are shown to provide reliable CHL and K490 estimates for Lake Tanganyika. The resulting 4.5 year dataset allows us, for the first time, to explore the phytoplankton dynamics in a major Rift Valley lake, with the spatial and temporal resolution necessary for such an extensive ecosystem. With such a validated dataset, fundamental analyses of the lake are possible, including (i) analysis of the temporal dynamics of phytoplankton concentrations (day, season and year), (ii) identification of eco-regions inside the lake characterized by a similar temporal phytoplankton dynamics, (iii) the estimation of primary productivity, and (iv) a phytoplankton bloom analysis. Several of these have been explored in Bergamino el al. (this volume) while this dataset was used to examine the temporal and spatial variability of pelagic fish abundance by Plisnier et al. (2009).

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References


Fig. 9. Two sequences of MODIS daily chlorophyll-α concentration for Lake Tanganyika during the dry season: (a) from 05/07/02 to 10/07/02 and (b) from 23/06/04 to 30/06/04. The color scale ranges from 0 to 5 mg/m³, areas without data are in black.


