COMPARISON OF MODIS AND LANDSAT-8 RETRIEVALS OF CHLOROPHYLL-A AND WATER TEMPERATURE OVER LAKE TITICACA

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ABSTRACT

Chlorophyll-a concentration ([Chl-a]) and Lake Surface Temperature (LST) were retrieved in Lake Titicaca (Peru-Bolivia) using MODIS and Landsat-8 images. The lake was chosen as a case-study for evaluating the feasibility of Landsat-8 images for [Chl-a] and LST monitoring in oligotrophic and mesotrophic water bodies. The big size of the lake and its spatial and temporal variability, allowed the comparison of MODIS and Landsat-8 products for a wide range of [Chl-a] and LST. The atmospheric correction of the images was facilitated by the very high altitude of the lake. MODIS images were processed with standard ocean color algorithms whereas for Landsat-8, specific algorithms were tested and validated

The results show that Landsat-8 is capable of retrieving [Chl-a] and LST with an accuracy comparable to that of MODIS and with a finer spatial resolution, revealing surface patterns in greater detail. The combined use of both sensors allows monitoring the eutrophication and temperature trends of Lake Titicaca, which is a water body of the highest ecological interest, increasingly affected by human activities in its watershed and very sensitive to climate changes.

Index Terms— Water Quality, Lake Titicaca, Landsat-8, MODIS, Chlorophyll-a.

1. INTRODUCTION

So far, satellite remote sensing of lake water quality has been limited by the lack of sensors combining the required spatial, radiometric and spectral resolution for the detection of the optically active constituents of the water bodies. The recent launch of Landsat-8 opens new possibilities in this area, thanks to its increased radiometric resolution and its new specific bands for the study of water bodies and atmospheric correction.

With the objective of exploiting the Landsat-8 capabilities for limnological studies, specific algorithms for the retrieval of Chlorophyll-a concentration ([Chl-a]) [1] and lake surface temperature (LST) [2], were tested in a singular tropical water body: Lake Titicaca. This high-altitude lake was chosen, besides its intrinsic interest, because its large size allowed the comparison of the Landsat-8 retrievals with those of MODIS, the water and temperature retrieval algorithms of which have been extensively validated.

The two chosen variables ([Chl-a] and LST) are of the greatest importance in the inland water quality monitoring. [Chl-a] is a proxy for phytoplankton biomass and therefore an indicator of the trophic state of lakes, while LST allows detecting surface spatial patterns linked with lake hydrodynamics, as well as detecting trends associated with climate changes.

2. DATA AND METHODS

2.1. Study area and satellite data

Lake Titicaca is a tropical high-altitude lake (around 3809 m above sea level) located in Central Andes (15º 47’ S, 69º 22’ W), transboundary between Peru and Bolivia. The lake is composed of two almost independent sub-basins, connected by the Strait of Tiquina. The larger sub-basin (6450 km^2), called “Lago Mayor”, is deep, with a mean depth of 135 m and a maximum depth of 284 m, whereas the smaller sub-basin (2112 km^2), called “Lago Menor”, is shallow, with a mean depth of 9 m and a maximum depth of 40 m. Lago Mayor is a tropical monomictic lake (with one mixing period each year) whereas Lago Menor is a tropical polymictic lake (mixing almost daily) [3, 4]. The (weak) stratification period occurs during the rainy and relatively warm season (November-April). During this period, Lago Mayor is turbid because of the suspended solids coming from erosive processes in the watershed. The mixing period occurs during the driest and coldest season (May-October), when the vertical gradient of temperature vanishes and the water column has a uniform temperature [5].

In this work, we used Landsat-8/OLI & TIRS (30 m of spatial resolution), and Terra-Aqua/MODIS (1 km of spatial resolution) images in order to study the lake water properties. Landsat-8 images, which include the standard level-1 processing (orthorectification), were downloaded from the USGS Earth Explorer interface (http://earthexplorer.usgs.gov). Digital Counts (DC) were converted to Top of Atmosphere (TOA) reflectances using radiometric coefficients included in the metadata. Taking into account the high altitude of the lake and the small atmospheric interference expected, at-surface reflectances were obtained from TOA reflectances using a simple approach based on the Dark Object Subtract (DOS) method [6, 7]. TIR bands were converted to brightness temperatures, and water surface temperature was retrieved using the single-channel algorithm developed by Jiménez-Muñoz et al. [2]. In the case of MODIS data, the standard products MOD09 (at-surface reflectances) and MOD11 (surface temperature) were used. For a preliminary comparison, a single Landsat-8 image acquired on 16-August-2013, and a single MODIS image acquired on the same date, but 4 hours later, were selected. MODIS daily global products (5-km spatial resolution) were also used to extract temporal series along the year 2013. In this case, thresholds on reflectance were applied to avoid cloud or sun-glint contamination.

2.1. Algorithms

The improved radiometric resolution (better signal-to-noise ratio) and spectral resolution (new added bands) of Landsat-8 opens new possibilities for water quality studies [8], which require the adaptation of existing algorithms or the development of new methods. In this work, we used the algorithm proposed by Tenjo et al. [1] to retrieve [Chl-a] from Landsat-8 OLI data:

$$[\mathrm{Chl-a}] = 4.46\left(\frac{R560}{R440}\right) - 0.55 \qquad (1)$$

where [Chl-a] is expressed in µg/L and R is the at-surface reflectance at bands 560 nm and 440 nm. This algorithm is based on the HydroLight radiative transfer model, and it was validated using an exhaustive water reflectance spectra dataset and in situ measurements of [Chl-a] over different lakes and reservoirs in the Iberian Peninsula.

In the case of MODIS data, [Chl-a] was estimated using the empirical algorithm OC3-M (Ocean Chlorophyll three-band algorithm for MODIS), which is an adaptation of the algorithm developed for SeaWiFs. It is based on the ratio between the green (minimum Chl-a absorption) and blue (maximum Chl-a absorption) bands. This algorithm has been widely validated from in situ data [9]. Water Surface Temperature was estimated with the single-channel algorithm proposed by Jiménez-Muñoz et al. [2] using Landsat-8 TIRS band 10 (around 10.9 µm). In the case of MODIS data, the standard MOD11 product was used.

3. RESULTS AND DISCUSION

Figure 1 shows the [Chl-a] map obtained after application of the algorithm (1) to the Landsat-8 image acquired on 16-August-2013. It also shows the results obtained with the MODIS image using the OC3-M algorithm. The highest values of [Chl-a] are observed near the coast, in agreement with results described by Blanco [4]. This result can be attributed to the nutrients supply coming from different sources, although suspended sediments could lead to an overestimation of [Chl-a]. The lower [Chl-a] are found in the pelagic zone, showing a spatial pattern governed by the surface currents. [Chl-a] is higher in Lago Menor than in Lago Mayor. Mean values over the two lakes were extracted from both the Landsat-8 and the MODIS image. For Lago Mayor, values were (3.80 ± 0.24) and (2.48 ± 0.36) µg/L for Landsat-8 and MODIS, respectively. For Lago Menor, values were (4.80 ± 0.18) and (3.55 ± 0.44) µg/L, respectively. Mean values obtained from MODIS data are approximately 1 µg/L lower than the mean value obtained from Landsat-8, although the spatial pattern is similar in both cases. Values are also within expected range of variation according to other authors [3, 4, 10, 11].

Maps of LST were also obtained from Landsat-8 and MODIS images (Fig. 2). In this case, significant differences between the two products were observed, although these differences could be attributed to the different acquisition time between the two images (9:43 local time for Landsat-8, and 13:35 local time for MODIS). These differences are also consistent with the expected spatial pattern for August (winter), when the lake is in the mixing period, combined to a light thermal stratification at the surface due to the daytime sunshine [11].

The temporal analysis of [Chl-a] and LST along the year 2013, using MODIS global products, captured the seasonal variations on both parameters (Fig. 3). In the case of [Chl-a], several short episodes of high concentrations were also observed, corresponding to phytoplankton blooms associated with river nutrient supply during the rainy periods. For a more robust comparison of MODIS and Landsat-8 retrievals, a series of concurrent images of both sensors was analyzed for spatially averaged areas of both sub-lakes.

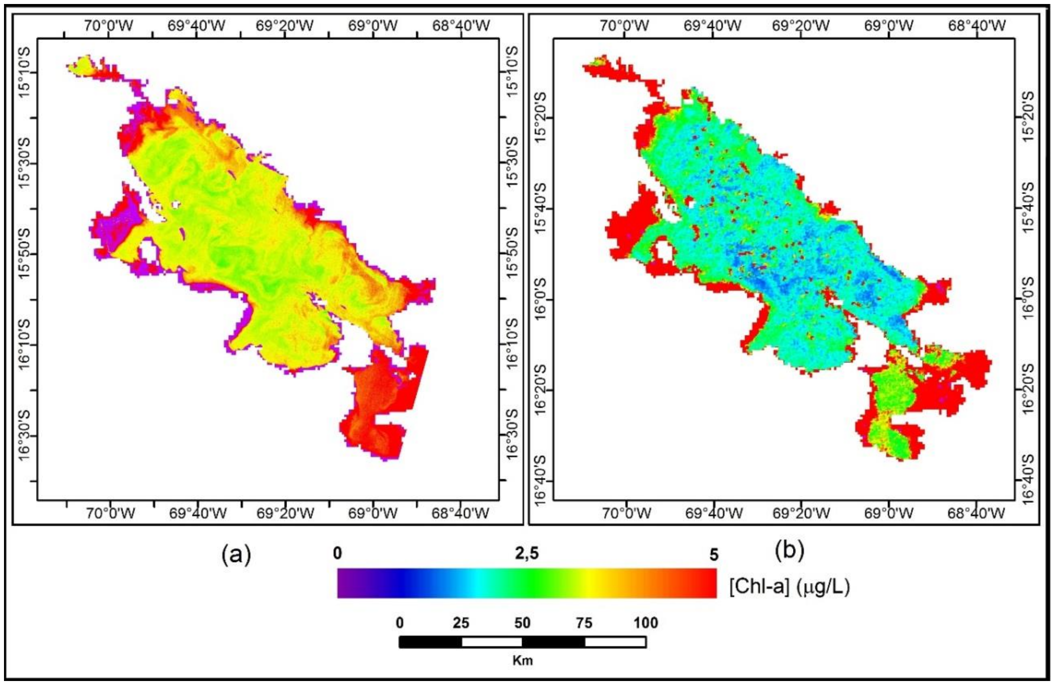

Figure 1. Map of [Chl-a] obtained from (a) Landsat-8 and (b) MODIS data. Images acquired on 16-August-2013.

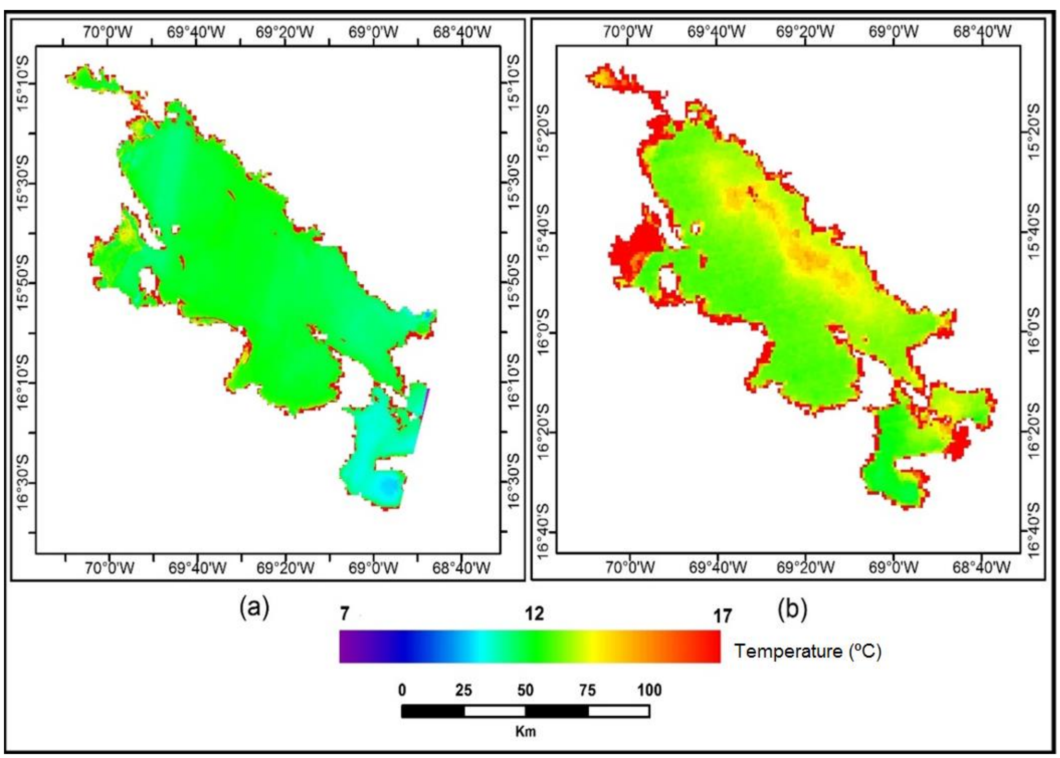

Figure 2. Map of LST obtained from (a) Landsat-8 and (b) MODIS data. Images acquired on 16-August-2013.

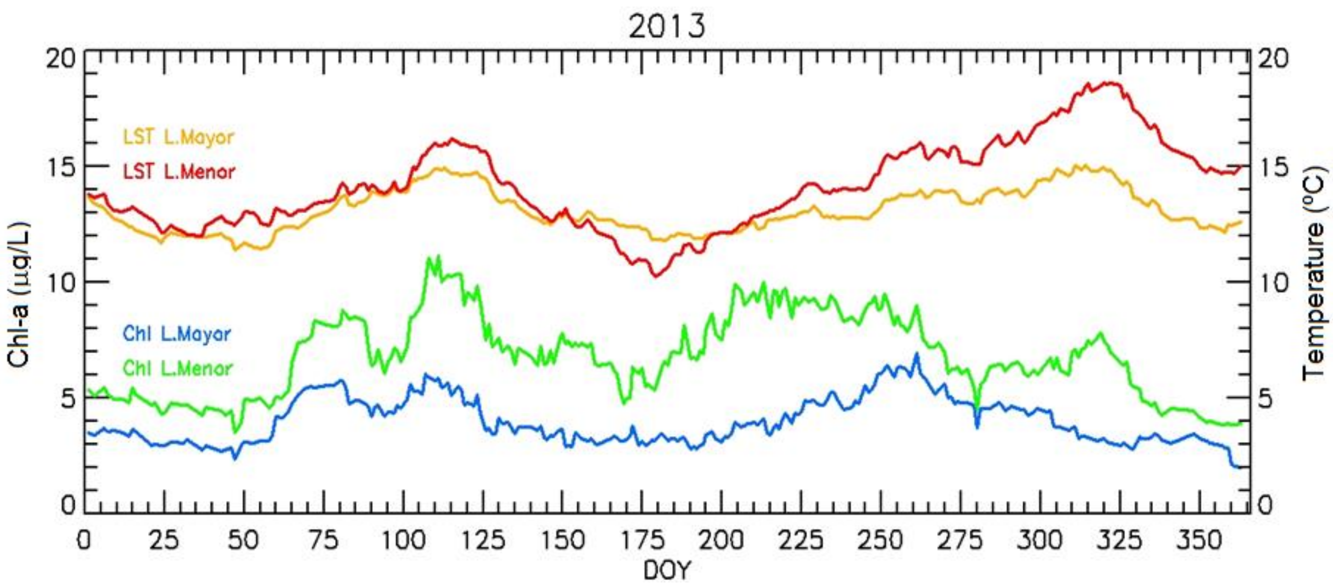

Figure 3. Evolution of MODIS LST and [Chl-a] during 2013 for spatially averaged areas covering lakes Mayor and Menor.

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