Evaluation of derived total suspended matter products from Ocean and Land Colour Instrument Imagery (OLCI) in the inner and mid-shelf of Buenos Aires Province (Argentina)

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Abstract

The Ocean and Land Colour Instrument Imagery (OLCI) sensor provides moderate spatial and temporal resolution of marine data, becoming a promising tool for monitoring environmental changes in coastal waters. Therefore, it is fundamental to test and validate the resulting products from diverse algorithms to ensure the quality of the data. The complex waters of southern Buenos Aires Province inner and mid-shelf, characterized by the presence of estuaries and river inputs, are highly influenced by total suspended matter (TSM) variability. In this study, we evaluate the performance of three TSM products in different waters (estuarine, coastal and mid-shelf waters) with in situ data. Two products were obtained using neural networks (NN), i.e. OLCI L2 ESA standard product (TSM_NN) and Case 2 Regional Coast Colour processing (C2RCC_STD); and one product using the combination of an alternative Baseline Residual Atmospheric Correction approach and the Nechad 2010 TSM algorithm (BLR_NCHD). In general, TSM match-up results indicate that the OLCI TSM_NN and CR2CC_STD products are acceptable (R2 of 0.79-0.74, n=17, RMSE= 21-20 mg/L). The best results were obtained for BLR_NCHD product (R2=0.86, RMSE=7 mg/L). Future efforts needed to improve TSM retrieval involves the evaluation of the conversion factor between backscattering to TSM for the NN approaches and the evaluation of the atmospheric correction using in situ water reflectance measurements.

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Abstract

The Ocean and Land Colour Instrument Imagery (OLCI) sensor provides moderate spatial and temporal resolution of marine data, becoming a promising tool for monitoring environmental changes in coastal waters. Therefore, it is fundamental to test and validate the resulting products from diverse algorithms to ensure the quality of the data. The complex waters of southern Buenos Aires Province inner and mid-shelf, characterized by the presence of estuaries and river inputs, are highly influenced by total suspended matter (TSM) variability. In this study, we evaluate the performance of three TSM products in different waters (estuarine, coastal and mid-shelf waters) with *in situ* data. Two products were obtained using neural networks (NN), i.e. OLCI L2 ESA standard product (TSM_NN) and Case 2 Regional Coast Colour processing (C2RCC_STD); and one product using the combination of an alternative Baseline Residual Atmospheric Correction approach and the Nechad 2010 TSM algorithm (BLR_NCHD). In general, TSM match-up results indicate that the OLCI TSM_NN and CR2CC_STD products are acceptable (R^2 of 0.79-0.74, n=17, RMSE= 21-20 mg/L). The best results were obtained for BLR_NCHD product (R^2=0.86, RMSE=7 mg/L). Future efforts needed to improve TSM retrieval involves the evaluation of the conversion factor between backscattering to

TSM for the NN approaches and the evaluation of the atmospheric correction using in situ water reflectance measurements.

Introduction

The southern continental shelf of Buenos Aires Province is a complex oceanographic and ecological system, characterized by large inputs of turbid continental run-offs and winds that dominate the physical dynamics (Piccolo et al., 1998; Lucas et al., 2005). This area is habitat of commercially valuable fish species and important for local artisanal fisheries (Carroza et al., 2009; Lopez Cazorla et al., 2014). The particulate matter dynamics combined with dissolved nutrients inputs from rivers and marshes is a key factor in primary production of coastal zones, thus it is important to understand and know their behavior (Davies-Colley et al., 1993; Marques et al., 2007).

Remote sensing retrieval of physical and biological variables appears as a valuable tool, providing information at a high spatial and temporal resolution and thus allowing the study of processes that cannot be comprehended based only on *in situ* data (Loisel et al., 2007). Ocean and Land Colour Instrument (OLCI) on board Sentinel-3A lunched in February 2016 has been designed to provide continuous long-term data flow to allow monitoring of environmental parameters with high accuracy (Toming et al., 2017). Furthermore, it has been designed for coastal waters for its high spatial resolution (300 m). However, the quality of remote sensed data strongly depends on their ground-truthing using discrete *in situ* measurements. In this frame, the objective of the present work is to evaluate TSM products derived from OLCI imagery in three contrasted waters of southern Atlantic Ocean: the Bahia Blanca estuary, the inner shelf and the outer shelf.

Study area

The study area is located in a temperate region of the Argentinean Sea (Figure 1). The Bahía Blanca Estuary (BBE) encompasses about of 2300 km^2 and it is composed by a series of NW-SE tidal channels separated from each other by an intertidal flats, salt marshes and islands (Piccolo and Perillo, 1990). It has been described as an ebb-dominant system, with surface tidal currents over 1.3 m s^{-1} (Cuadrado et al., 2005). Accordingly, there is an enhanced erosion of intertidal flats and channel banks, along with a net outward sediment transport (Perini, 2007). Once eroded, cohesive sediments (silt and clay) are transported as suspended load, producing the high turbidity that characterizes BBE waters (Cuadrado et al., 2005). The balance between resuspension and deposition, and the amount of suspended particulate matter (SPM) is controlled by current velocities, with higher concentrations commonly observed during ebb tide (Menéndez et al., 2016). Further, it has been addressed that the estuarine waters are exported to the inner shelf arriving to the nearby beaches, containing relatively high turbidity, salinity and temperature (Delgado et al., 2017).

The inner-shelf of the southwestern Buenos Aires Province, is a highly complex oceanographic and ecological system, characterized by large inputs of continental run-offs, locally-generating cells of high-salinity, and winds that dominate the inner-shelf dynamics (Piccolo, 1998; Lucas et al., 2005). Finally, the mid-outer shelf is influenced by the sub-Antarctic waters, which are relatively cold and saline, because of the presence of the Malvinas current (Palma et al., 2008).

Approach

In situ data was obtained from different cruises and oceanographic campaigns between September 2017 and March 2018. Total suspended matter concentration (mg l^{-1}) was estimated by filtering between 150 and 1000 ml of seawater, depending on sample turbidity, through pre-combusted (500 °C, 4 h) and pre-weighed Whatman GF/F filters (pore size 0.7 µm). Filters were oven dried at 60 °C until constant weight and re-weighed.

OLCI-Sentinel 3 Daily level 1 (full resolution) and L2 (water full resolution) data at 300 m spatial resolution were downloaded from the Eumesat web page (https://coda.eumetsat.int/). The extracted L1A files for the study area were processed using SNAP software to obtain L2 TSM product. The performance of three TSM products in different waters were evaluated. Two products were obtained using neural networks (NN), OLCI L2 ESA standard product (TSM_NN) and Case 2 Regional Coast Colour processing chain (C2RCC_STD); and one product using the combination of an alternative Baseline Residual Atmospheric Correction approach (Gossn et al., 2018) and the Nechad 2010 TSM algorithm (BLR_NCHD).

The match-up procedure consists in extracting a box of 1 pixel (Bahia Blanca Estuary) or 3 x 3 pixels (Inner shelf and mid-outer shelf), centered at the location of the *in situ* measurements. The high spatial variability of the Bahia Blanca estuary does not allow to use a multipixel spatial box, since the sediment is transported in plumes (Arena et al., submitted). In the case of the 3 x 3 pixel box,a match-up is accepted only if more than 6 out of 9 pixels of the box are valid (Bailey and Werdell, 2006; Jamet el al., 2011). Then, a spatial uniformity criterion is applied based on the coefficient of variation (cv), defined as the ratio of the standard deviation to the mean pixel value of the box (cv< 0.3 were discarded) (Bailey and Werdell, 2006). The time window applied is of 12 hs from the satellite overpass. In addition, a manual quality control procedure is done, checking whether the pixels are located in cloud or land borders in order to avoid failures in validation results due to cloud or land contamination.

In order to evaluate the performance of the algorithms, a statistical analysis was performed comparing the *in situ* to the satellite data. A linear regression was carried out and the slope, intercept, and coefficient of determination (R^2) were computed.Also, the root-mean-square error ($RMSE = \sqrt{\frac{1}{n}\sum[y-x]^2}$) was calculated to evaluate the estimated error, where x is the measured parameter, y the satellite estimates and n the number of match-ups.

Resultsand Discussion

From the 30 total samples collected in the BBE, the inner and outer shelf (August-2017 till March-2018), only 17 remained as valid match-ups after applying the previously mentioned criteria. Results varied according to the atmospheric correction and the algorithm used to obtain TSM data. Although all of them had a high correlation coefficient (R^2> 0.74), errors varied from 7 mg l^{-1} to 21.3 mg l^{-1} (Table 1). Generally, the neural network algorithms tend to overestimate TSM in estuarine waters and underestimate the parameter in mid- and outer shelf waters.

The standard TSM_NN presented a high R^2 (0.79) but estimations are far from the 1:1 line (Figure 2), with an RMSE of 21.3 mg l^{-1} (Table 1). The atmospheric correction used in this product is the Baseline Atmospheric Correction algorithm (BAC) combined with the Alternative Atmospheric Correction Algorithm (AAC) (neural network) (EUMESAT, 2018) which may not be appropriated for the estuarine waters for not being built for very turbid waters. TSM is further derived from a trained neural net, which is based in the knowledge of the relationship between water constituents (their optical activity, i.e. absorption and backscattering properties, and spectral remote sensing reflectance), which would not represent the complexity of waters in the studied area.

TSM derived from C2CCR, which has been developed for coastal turbid waters, with the standard neural network, did not improve the accuracy. The C2CCR_STD results were similar to standard TSM_NN, with R^2= 0.74 and RMSE = 20.7 mg l^{-1} (Figure 3) (Table 1). The C2RCC algorithm first retrieves inherent optical properties (total scattering products at 443) and further uses those parameters to estimate the concentration of optically active substances, such as TSM, thus any error derived in that process will lead to a TSM estimating error. Furthermore, it has been reported that in coastal waters the satellite reflectance in the blue portion of the spectrum is higher than measured reflectance (Toming et al., 2017) and since all spectral bands are considered by neural network processing chains, failures in accurately retrieving blue reflectance do affect results obtained by neural network algorithms.

Finally, the algorithm developed by Gossn *et al*. 2018 combined with TSM algorithm of Nechad (2010) (BLR_NCHD) produced the most accurate estimations compared to the *in situ* data obtained for this study (Figure 4). This scheme is composed of: i) the BLR-AC algorithm, which is an atmospheric correction designed to be applied over turbid waters, and which uses OLCI spectral bands centered at 620, 709, 779, 865 and 1016 nm and ii) the TSM algorithm developed by Nechad 2010, for which the 620 nm band was chosen. The R^2 is of 0.86 and the slope and intercept are closer to the 1:1 line (Table 1). Also, the RMSE is considerably lower (7.95 mg l^{-1}). A good performance was expected using this scheme, since BLR-AC is particularly robust at retrieving water reflectances in the red/NIR bands, and the Nechad algorithm is based on the red band.

Most algorithms tend to overestimate TSM in estuarine and inner shelf waters, except BLR_NCHD, which produced estimates both higher and lower than *in situ* values. Nevertheless, the overall error for this algorithm was considerably lower than for the others. It is important to highlight that in the Bahia Blanca Estuary optical components of water are tightly related to the physical forcing of the environment (tides and tidal currents), resulting in significant spatial (firstly) and short-term (secondly) variations, which have a large influence in the spatial box used for the pixel extraction and the time-difference window (Arena et al., *submitted*). A relatively large difference (20 %) observed between TSM values from stations located only 40 m apart and sampled within a few minutes, suggests that suspended sediment distribution is not homogeneous but forms sediment plumes driven by tidal forces (Arena et al., *submitted*). In this frame it could be possible that even the 1 pixel box (300 m) will not represent the ground truth.

In the case of mid-shelf waters all algorithms failed in reproducing *in situ* values, not only the absolute ones but also failed to represent their relative variability (Figures 2-

4).This is expected to occur with BLR_NCHD and C2CCR since they were built for turbid coastal waters.

It is also important to highlight that *in situ* TSM acquisition is not trivial in our study area and we are aware of this. There is a strong need in improving the consistency of *in situ* data in calibration and validation of satellite products. We are dealing with different kinds of waters from different origins (*e.g.,* riverine, estuarine and oceanic), composed by organic and inorganic matter, with different colors, *e.g.* the Bahia Blanca estuarine waters present high variability in water color derived from human cloacal discharges (*e.g*. black from high iron concentrations, Fernandez Severini *et al*., 2017), which may affect the absorption and backscattering properties.

Conclusions

A first evaluation of Sentinel 3 OLCI TSM products has been performed in the Bahia Blanca estuary and the continental shelf of Argentina. So far, the BLR atmospheric correction (Gossn et al., 2018) combined with the TSM algorithm developed by Nechad et al. (2010) is the most accurate option for estimating sediment matter in the estuarine and coastal waters of the studied area (Figure 5). TSM_NN and C2CCR_STD present a good approximation of sediment variability but overestimating absolute values, thus they could be applied to study the temporal and spatial variability of TSM concentration. In turn poor results have been obtained with all the analyzed products for the mid-outer shelf.

Further efforts are focus on obtaining more in situ data with the objective of obtaining more statistically significant results. Also work directed to improve TSM retrieval should consider the evaluation of the conversion factor from backscattering to TSM used in NN algorithms. Additionally, atmospheric correction procedures should be evaluated using *in situ* measurements of water reflectance.

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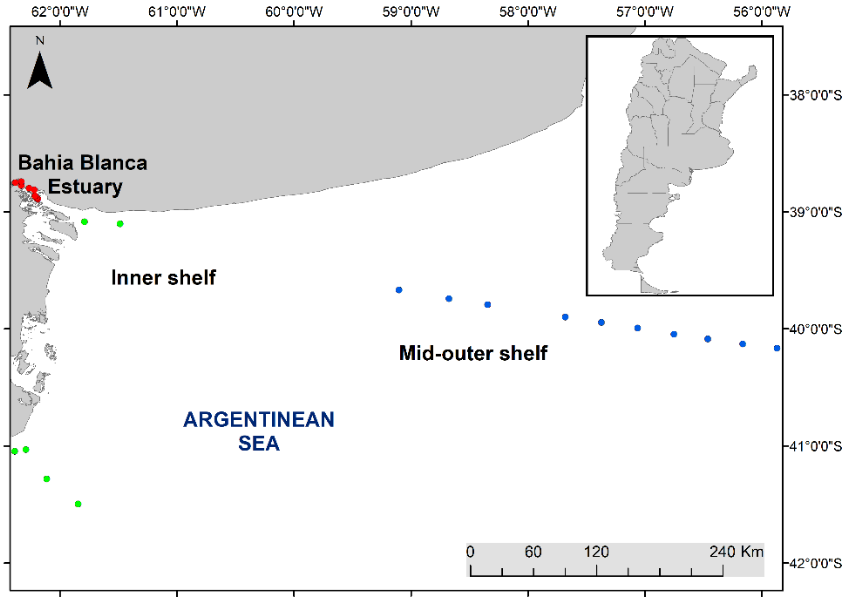

Figure 1. Location of the study area and in situ sampling sites. Red spots stand for estuarine waters; green spots for inner-shelf waters; and blue spots for mid and outer shelf waters.

	TSM_NN	C2RCC_STD	BLR_NCHD
R^2	0.79	0.74	0.86
Intercept	-17.22	-16.5	-4.5
Slope	2.17	2.04	0.89
RMSE	21.3	20.7	7.95
n	17	17	17

Table 1. Statistical results of the performance of TSM OLCI products in the Bahia Blanca Estuary, the inner and mid shelves of Buenos Aires Province, Argentina. RMSE = root mean square error; n = number of match ups.

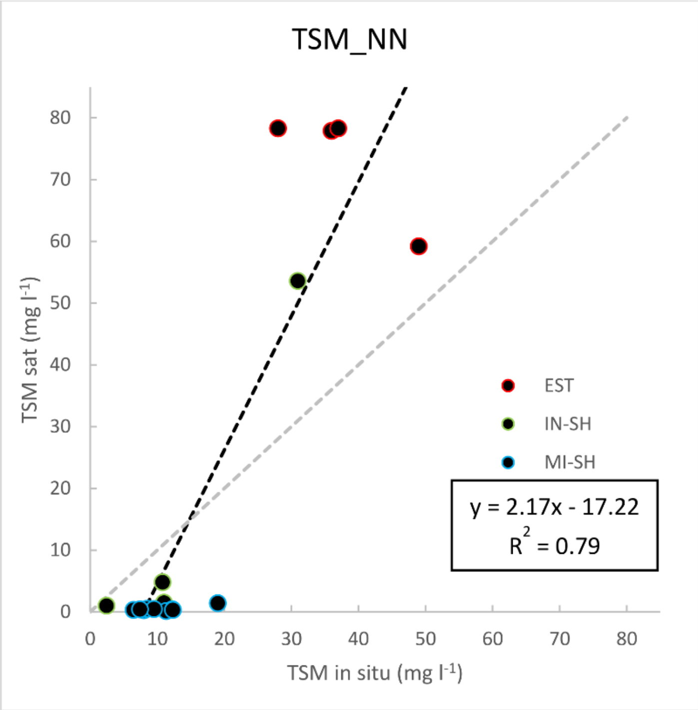

Figure 2. Comparison between in situ measured and satellite-derived TSM with OLCI standard neural network. EST, estuarine waters (red spots); IN-SH, inner shelf waters (green spots); MI-SH, mid and outer shelf waters (blue spots).

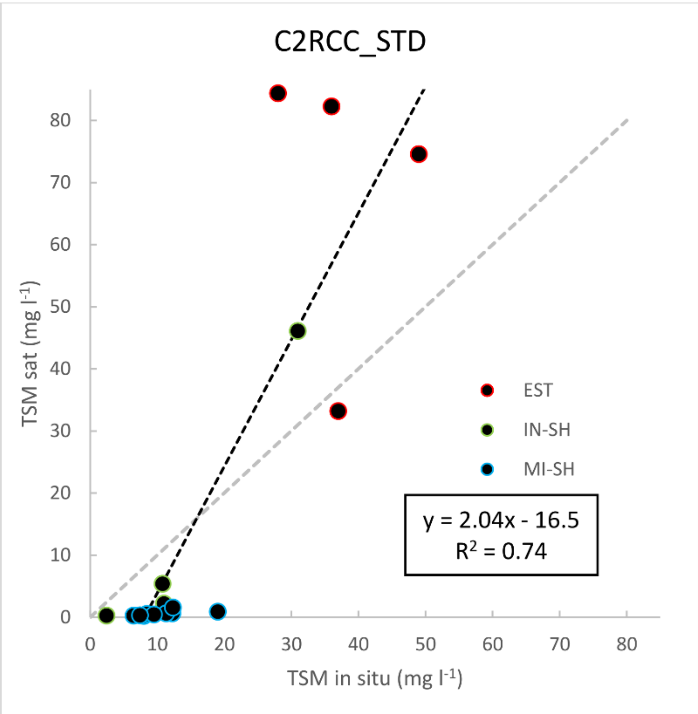

Figure 3. Comparison between in situ measured and satellite-derived TSM with OLCI C2RCC atmospheric correction algorithm with standard neural network a. EST, estuarine waters (red spots); IN-SH, inner shelf waters (green spots); MI-SH, mid and outer shelf waters (blue spots).

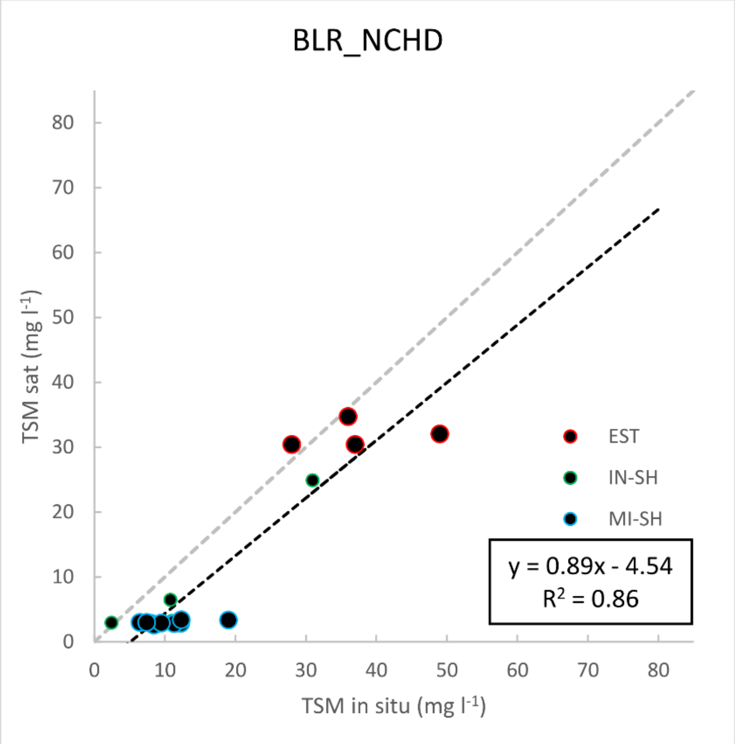

Figure 4. Comparison between in situ measured and satellite-derived TSM with OLCI BLR atmospheric correction algorithm and Nechad (2010) TSM algorithm. EST, estuarine waters (red spots); IN-SH, inner shelf waters (green spots); MI-SH, mid and outer shelf waters (blue spots).

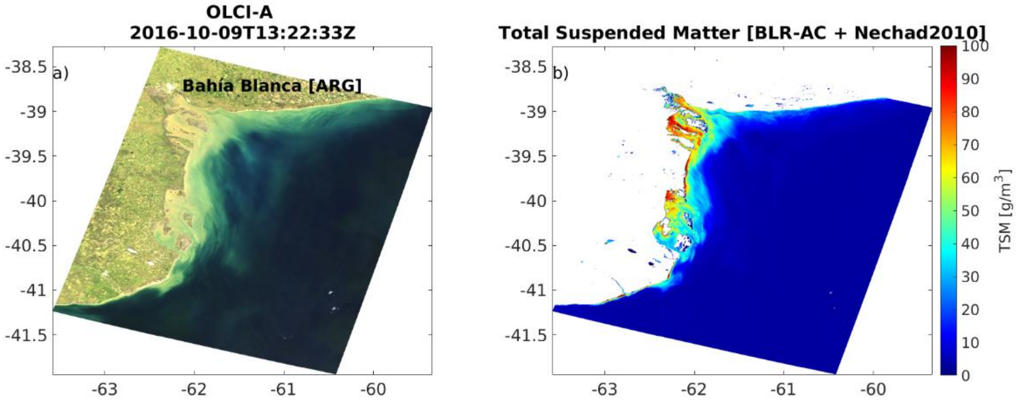

Figure 5. Example of OLCI TSM BLR_NCHD product at 300 m resolution in the studied area.