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EVALUATION OF TWO SITES FOR OCEAN COLOR VALIDATION IN THE TURBID WATERS OF THE RÍO DE LA PLATA (ARGENTINA)

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ABSTRACT

The Río de la Plata (RdP) is a large and shallow estuary carrying large amounts of dissolved and suspended particulate matter (100-300 g m^{-3}). The site is deal to a) test turbid water atmospheric correction algorithms for current and future OC missions, like S3-OLCI, and b) to validate 1020nm OLCI band and test it's usefulness to estimate turbidity [1]. With the aim of choosing the location to setup an autonomous validation site, like AERONET-OC, two possible sites are characterized in terms of temporal, spatial and spectral variability of optical properties based on information from high (Landsat 8/OLI) and medium (MODIS-Aqua) spatial resolution satellite sensors.

1. INTRODUCTION

The Río de la Plata (RdP) is a large and shallow funnel-shape estuary which drains the second largest basin in South America carrying a large amount of nutrients, particulate and dissolved organic matter to the adjacent shelf waters (Fig.1). High values of suspended particulate matter have been reported in this region with mean values ranging from 100 to 300 g m^{-3} and extreme concentrations of up to 400 g m^{-3} [2], representing a challenge as well as an ideal site to test atmospheric correction algorithm performance. Strong efforts have been put into the collection of field measurements and to make the RdP an international site for ocean color (OC) validation of current and future OC missions, like S3-OLCI and the future Argentina-Brazil ocean color mission SABIA-Mar. Measurements of optical properties have been carried out from a fixed pontoon since 2012 and from ships since November 2013 in the upper part of the RdP estuary (Buenos Aires, Argentina). This provides a basis for setting up an automatic measuring system, for example combining radiometry from a AERONET-OC system with continuously measuring in-water sensors, to obtain high-frequency and high-quality data for validation of satellite products and specifically for testing atmospheric correction algorithms in turbid waters. With the aim of choosing the location to setup such an autonomous validation site in the RdP, two possible sites are here characterized in terms of temporal and spatial variability of optical properties based on information from high (Landsat-8/OLI) and medium (MODIS/Aqua) spatial resolution satellite sensors and available *in situ* data.

One of the site is located at the end of a Fishermen's Pier (FP) in Buenos Aires, very close to the city and with easy access. The pier is 500 m long and water height is continously measured. The other site is a pole called "Pilote Norden" (PN) which is located downstream of the city of Buenos Aires, in the middle of the river, and around 19.5 km from land (Fig.1).

Figure 1. Location of two possible sited to set up an AERONET-OC station in the Río de la Plata, Argentina. Fishermen Pier (FP) and Pilote Norden (PN)

This pole already has sensors that are continuously measuring water height, wind and current intensity and direction. Both sites are located in the upper part of the estuary and show high suspended sediments concentrations. The characteristics of the two sites are summarized in Tab. 1

Table 1. Summary of the two sites analyzed the setup an autonomous validation site

Name	Location	Water depth	Distance to land
Fishermen pier	34°33'38.8"S 58°23'55.6"W	2 m	500 m
Pilote Norden	34°37'46.2"S 57°55'10.9"W	5 m	19.5 Km

2. METHODS

For the two sites the temporal and spatial variability of optical properties from MODIS-Aqua and Landsat-8/OLI data have been analyzed.

Ten years of Level 1A MODIS-Aqua images covering the RdP region for the period 2003 to 2014 have been obtained from the Ocean Color webpage (http://oceancolor.gsfc.nasa.com). They were processed using SeaDAS 7.02 to obtain remote sensing reflectance (R_{rs}) at all bands using the NIR-SWIR switching atmospheric correction [3, 4] and masking clouds using the 2130 nm band. The STRAYLIGHT and HILT flags were not used as masks given that the highly reflective (turbid) waters and sensor saturation erroneously mask most of the RdP estuary. Turbidity (T) was estimated using the switching band semi-analytical algorithm [5]. Thus, time series of water reflectance ($\rho_w = R_{rs} . \pi$) and T (FNU) were extracted for each site using the median value in a 3×3 pixel box centered at the location of each site if at least 6 out of the 9 pixels were valid pixels according with the standard flags.

The spatial variability of T was analyzed using Landsat-8/OLI data. Orthorectified and terrain corrected Level 1T OLI imagery was obtained from USGS EarthExplorer (http://earthexplorer.usgs.gov/). The atmospheric correction applied uses the shortwave infrared (SWIR) bands at 1609 and 2201 nm for the aerosol correction as described in [6] using ACOLITE software (http://odnature.naturalsciences.be/remsem/software-and-data/acolite). Then the switching single-band algorithm using the 655 and 865 nm bands [5] is applied to retrieve turbidity.

Simultaneous radiometric and turbidity measurements were performed at the FP during six cruises between 2012 and 2014. Water reflectance (350-2500 nm) was measured with an ASD Fieldspec FR spectrometer. The methodology used is described in [7]. Turbidity (T) was measured with a portable HACH 2100P ISO turbidimeter. Three replicate measurements were recorded for each sample.

3. RESULTS

3.1. Temporal variability

Time series of turbidity have been extracted for the two sites (Fig. 2) showing the temporal variability of this optical property.

The T time series at the two sites show a maximum around March-April reaching values higher than 1000 FNU and lower values the other months of the year. At the FP, seasonality is less marked, though still showing a maximum (T>1000 FNU) and highly variable values between 10 and 400 FNU the rest of the year. On the other hand at the PN the seasonality and inter-annual variability can be clearly observed with maximum values in February-April and T values not higher than 200 FNU at other times.

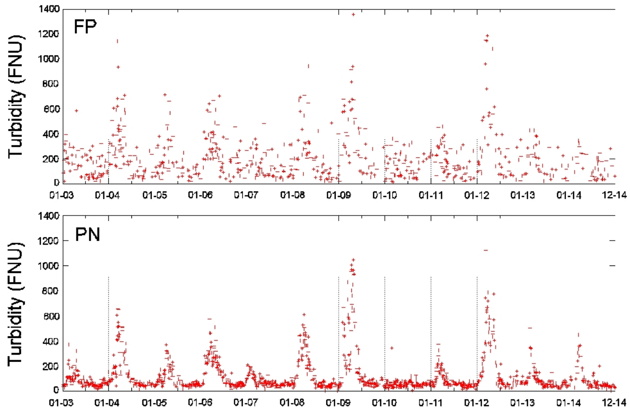

Figure 2. Time series of T at the Fishermen Pier (top) and Pilote Norden /bottom) from MODIS-Aqua for the period 2003-14

3.2. Spectral variability

The water reflectance from MODIS-Aqua have been extracted at the two sites and are shown colour-coded according to turbidity in Fig. 3. Both sites show a similar feature, for most of the time no data is available for the 547 nm band, and the ocean red (667 and 678 nm) and NIR (748 and 869 nm) bands due to saturation. Also, reflectance at the blue bands (412 nm) is sometimes lacking, because of problems with the atmospheric correction (negative values).

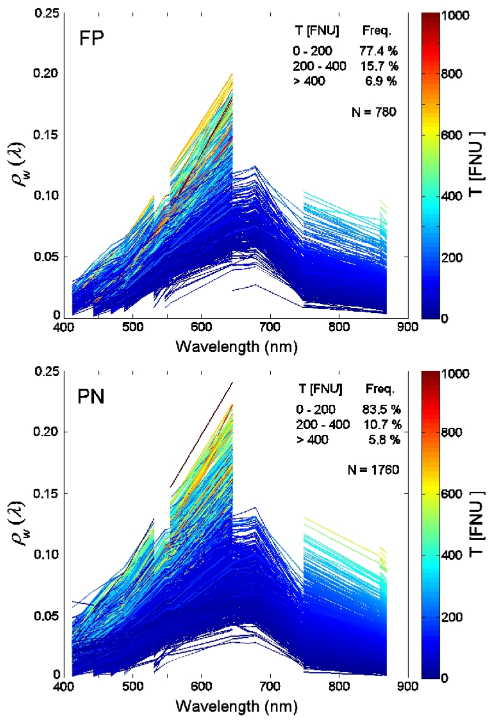

Figure 3. Water reflectance from MODIS-Aqua for the period 2003-14 at Fishermen Pier (top) and Pilote Norden (bottom)

The total number of spectra extracted at FP site was low (N=780 out of 2140) and maximum values at 645 nm reached 0.2. On the other hand higher number of spectra were retrieved at PN (N=1760 out of 2140) and higher values of reflectance at 645 nm could be observed. The frequency of T values retrieved at the two sites was higher for values between 0 and 200 FNU (77,4% and 83.5% at FP and PN respectively). While higher frequencies for 200-400 FNU and > 400 FNU ranges was found for FP (15.7% and 6.9%) compared to PN for FP (10.7% and 5.8%). Field measurements collected at the FP between 2012 and 2014 (N=60) show a similar shape (Fig. 4). It should be noted that the measured T range was much lower (65-160 FNU) than the range found using the MODIS-Aqua ten years dataset.

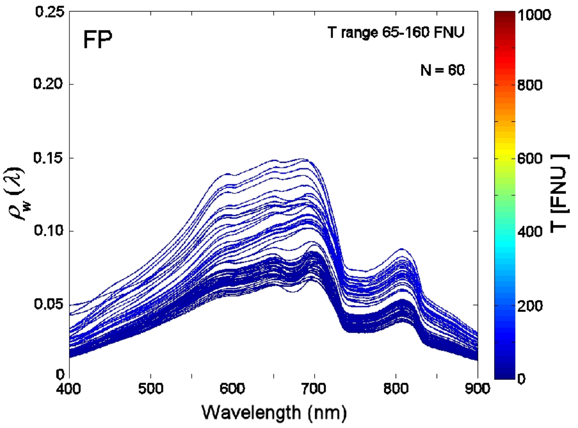

Figure 4. Water reflectance spectra collecting during six campaigns over the period 2012 and 2014 at the Fishermen Pier

A more detailed analysis of the variability of the spectra at the two sites was performed. In Fig. 5 and Fig. 6 spectra have been grouped for different months.

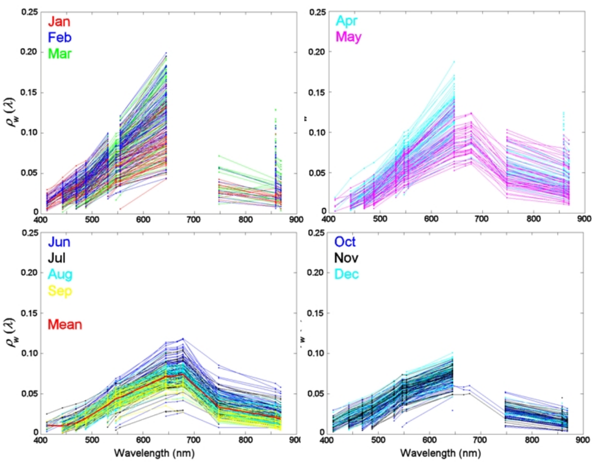

Figure 5.Water reflectamce MODIS-Aqua for the period 2003-14 at Fishermen Pier grouped by month.

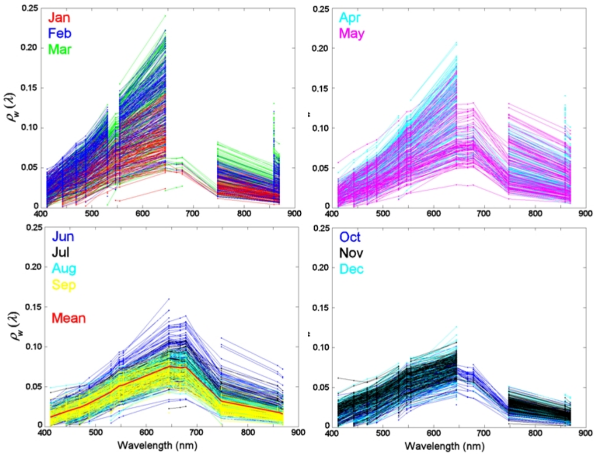

Figure 6.Water reflectamce MODIS-Aqua for the period 2003-14 at Pilote Norden (bottom)

It is clear that for both sites saturation of the previously mentioned bands occurred mainly from January to April and from November to December, while May and October are less affected. On the other hand from June to September complete spectra with only a few saturation conditions can be observed. Again, lower number of spectra for FP and higher reflectance values for the PN could be observed. The frequency of invalid pixels for the saturating bands for PN are shown in Fig. 7.

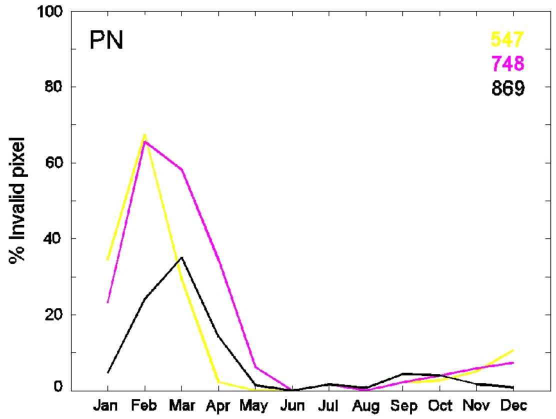

Figure 7. Percentage of invalid pixels (excluding clouds) per month at Pilote Norden for 574, 748 and 869 nm bands.

Percentage of invalid pixels were high between January and April, reaching 30% for the 547 nm band in March and 70% for the 748 and 869 nm bands in February. These peaks coincide with the months of maximum turbidity found in the time series analysis (Fig. 2). Similar results were found for the FP site (not shown).

3.3. Spatial variability

The spatial variability of reflectance and turbidity in the vicinity of the FP and PN was analyzed using high spatial resolution imagery (Landsat-8). Data from windows of variable pixel size were extracted and compared to the one pixel (30m) where measurements will be made for each of the selected sites. The Landsat-8 imagery for 23 April 2015 shown in Fig. 8 shows the spatial variability of T in the proximity of the FP.

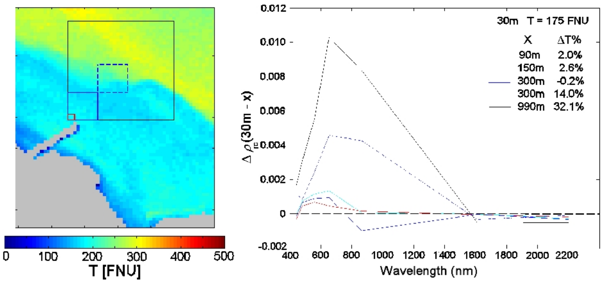

Figure 8. Turbidity map from L8 image at FP for 23/4/2015 with different window sizes in colours (left). Rayleigh-corrected reflectance spectral difference between different window sizes (color coded as in the map) and a single L8 pixel (30m) (right).

The plot in Fig. 8 clearly shows the effect of reducing the spatial resolution from 30 to 990 m in the reflectance and turbidity retrieved values. The difference of Rayleigh-corrected reflectance (ρ_{rc}) of the different window sizes and the one at 30m increases with the window size, being maximum at for the 990m spatial average and reaching 0.01 at 655 nm. The difference of different spatial resolution could lead to a relative percent difference (RPD) of 32% in the retrieved T value. When selecting a nearby 300m pixel in the vicinity of the validation site to evaluate its possible use for validation purposes (dashed blue square), it can be observed that the averaged values differs even more and that the RPD increases from -0.2 to 14%, mainly due to the presence of a coastal current that generates a turbidity front close to the FP (~500 m). A similar analysis was performed on the PN site for the 22 March 2014 Landsat-8 image (Fig. 9).

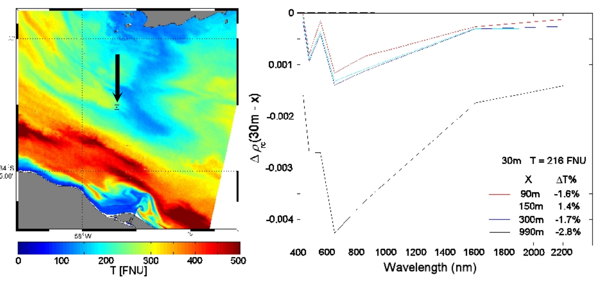

Figure 9. Turbidity map from L8 image at PN for 22/3/2014 (arrow) with different window sizes in colours (left). Rayleigh-corrected reflectance spectral difference between different window sizes (color coded) and a single L8 pixel (30m) (right).

The spatial variability in reflectance also increased with increasing spatial averaging, but the difference between the different windows and the one pixel value was much lower compared to FP, reaching -0.004 at 655 nm and leading only to a RPD of -3% in the retrieved T.

4. CONCLUSIONS

The Río de la Plata is an international ocean colour test site which would be greatly enhanced by installation of an autonomous system to gather continuous measurements from above and below the water in order to obtain a large amount of data for match-up comparisons with satellite data. The high amount of sediments and large scale of the estuary represents an ideal scenario to test atmospheric correction algorithms and the suitability of the Sentinel 3/OLCI and AERONET-OC 1020 nm band to estimate total suspended sediment concentration [1].

Considering the two sites here proposed, the FP is logistically more convenient since it is close to the city and can be easily and frequently accessed. Moreover, given it is located in shallow waters it presents a high temporal variability of turbidity mainly due to re-suspension and wind mixing. However, it is located close to land (500 m) and in a region of high spatial variability due to the presence of a coastal current which produces a turbidity front with variable position, making this region less reliable for validation of moderate resolution satellite images, even if a close-by pixel is chosen for the comparisons.

On the other hand, the PN is located far from land and shows high number of valid pixels for match-up analysis and a clear seasonal T variability with T>400 FNU 6% of the time in March-May. The pole probably does not contaminate the 30m pixel (not identified in Landsat images), and the spatial variability of estimated T is generally low reaching up to 3% at 990m.

The existence of other sensors on the pole (wind, currents and water height) as well as the current plans for using this pole as a monitoring site in the frame of a bi-national initiative between Argentina and Uruguay, makes this the ideal place to locate an AERONET-OC site for ocean color validation of current and future OC missions, like S3-OLCI and the future Argentina-Brazil ocean color mission SABIA-Mar in the highly turbid waters of the Río de la Plata. The FP is relevant for validation of higher resolution sensors and other (non-validation) ocean colour measurements.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

1. Knaeps, E., Ruddick, K.G., Doxaran, D., Dogliotti, A.I., Nechad, B., Raymaekers, D., and Sterckx, S. A SWIR based algorithm to retrieve Total Suspended Matter in extremely turbid waters. Remote Sens. of Environ. (accepted).

2. Framiñan, M., and O. Brown (1996), Study of the Río de la Plata turbidity front, Part 1: Spatial and temporal distribution, *Cont. Shelf Res.*, 16, 1259–1282, doi:10.1016/0278-4343(95)00071-2.

3. Wang, M. (2007). Remote sensing of the ocean contributions from ultraviolet to near infrared using the shortwave infrared bands: simulations. Applied Optics, 46, 1535-1547.

4. Wang M & W Shi (2007). The NIR-SWIR combined atmospheric correction approach for MODIS ocean color data processing. Optics Express, 15: 15722-15733

5. Dogliotti, A., Ruddick, K., Nechad, B., Doxaran, D., Knaeps, E. (2015). A single algorithm to retrieve turbidity from remotely-sensed data in all coastal and estuarine waters. Remote Sens. Environ. 156, 157–168.

6. Vanhellemont, Q., Ruddick, K. (2015). Advantages of high quality SWIR bands for ocean colour processing: examples from Landsat-8. Remote Sens. Environ. 161, 89-106.

7. Knaeps, E., Raymaekers, D., Sterckx, S., Ruddick, K., Dogliotti, A. I. (2012). In-situ evidence of non-zero reflectance in the OLCI 1020 nm band for a turbid estuary. Remote Sens. of Environ., Sentinel Special issue, 120: 133-144.