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TOWARDS AN AUTONOMOUS TURBIDIMETER NETWORK FOR MULTI-MISSION OCEAN COLOUR SATELLITE DATA VALIDATION ACTIVITIES

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ABSTRACT

Satellite-based optical sensors such as MODIS/Aqua, Sentinel-2, Sentinel-3, Landsat-8, Pléiades, SABIA/Mar, PROBA-V, etc. can be used to map turbidity and suspended particulate matter in coastal, estuarine and inland waters as support for water quality monitoring, sediment transport applications such as dredging and fisheries science. However, data quality is a critical problem and *in situ* data must be gathered from a wide range of test sites in order to provide validation for the diverse range of conditions that can be encountered all over the world. In this context, a network to validate satellite turbidity products called TURBINET is proposed with the goal to establish a long-term (autonomous) international network of collaboration and data-sharing. Joint measurements of turbidity, reflectance and in-water side/back-scattering have been performed in Belgium and Argentina in 2015. Instrument comparisons showed that comparable values could be retrieved using different sensors and field measurements were used to validate a Pléiades high resolution image (2m). The results presented in this work demonstrate the feasibility and usefulness of setting up a network to validate satellite turbidity products.

1. INTRODUCTION

Sediments play an important role in biogeochemical cycling in the aquatic environment since they are responsible for transporting a significant proportion of nutrients and contaminants and also mediating their uptake, storage, release and transfer between environmental compartments. The study of riverine suspended sediments is becoming more important as the need to assess fluxes of nutrients and contaminants to lakes and oceans increases. In this respect, measurements of ocean color from earth-orbiting satellite sensors have demonstrated to be the most suitable tool available to monitor the transport of key biogeochemical substances such as suspended sediments in river plumes. In theory, algorithms to estimate suspended particulate matter concentration (SPM) from optical remote sensing need to be calibrated locally because the relationship between the mass of aquatic particles and their light scattering/absorption properties depends on the type and size of particles. However, recent results suggest that a single global algorithm can be used for remote sensing of turbidity (T) in different estuarine and coastal waters [1]. It was also suggested that SPM, the parameter of main interest in sediment transport studies, could then be retrieved by ocean color remote sensing if a region-specific relation between T and SPM is known. In this context, a network called TURBINET is proposed to establish long-term collaboration and data-sharing with the aim of generating a single multi-site dataset to validate multi-mission satellite ocean colour turbidity products. In the present work we present the first results obtained in the frame of the TURBINET project within which joint measurements campaigns have been performed in rivers and inland waters of Belgium and Argentina. Activities performed included harmonization of measurement protocols, setting of quality control criteria, and intercomparison and intercalibration of different instruments for measuring turbidity, as well as validation of high resolution satellite imagery.

2. METHODS

Two field campaigns have been carried out in the Scheldt and Zenne rivers in Belgium (28-29 May 2015) and in the Río de la Plata and inland waters in Argentina (16-24 November 2015) in the frame of the TURBINET project, focusing on *in situ* and satellite measurements of turbidity and marine reflectance. The location of the sampled sites are shown in Fig. 1 and 2.

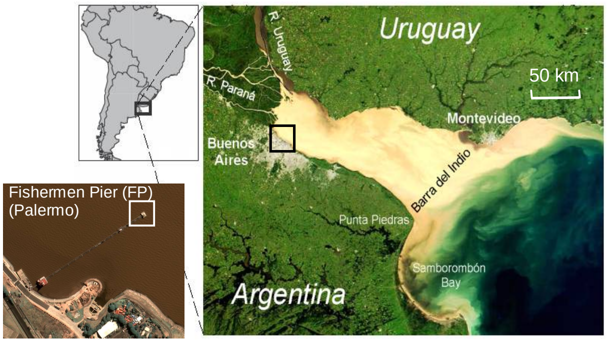

Figure 1. Location of the sampled site at the end of the Fishermen Pier (FP) in the Río de la Plata, Argentina.

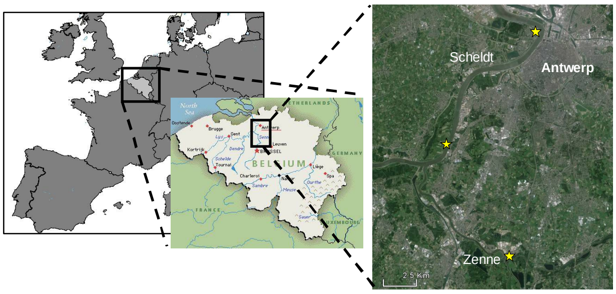

Figure 2. Location of the sampled sites in the Scheldt and Zenne rivers in Belgium.

Measurements were performed from pontoons using sensors from the two participating institutions, RBINS and IAFE. Water samples were collected at depth less than 1 m with a bucket and turbidity (~side-scattering) was measured in Formazin Nephelometric Unit (FNU) using two hand-held HACH 2100P/Q turbidimeters (BINS/IAFE). Turbidity was recorded in triplicates that were averaged. Turbidities of the STABLCAL Stabilized Formazin Turbidity 10 or 20, 100 and 800 FNU standards and that of pure water were recorded after each sampling campaign to check the instrument stability. Simultaneously, different in-water sensors measured continuously back- and side-scattering or turbidity (T) (Tab. 1). An OBS3+ was used to measure the optical back-scattering (b_{bB}) measured in Nephelometric Turbidity Unit (NTU), an OBS500 to measure the optical side-scattering and backscattering (b_{bB} in Formazin Backscatter Unit, FBU), and the Hydroscat-4 (HS-4) to measure backscattering (b_b) at 4 wavelengths (550, 700, 850 and 1020 nm). The protocols followed for the in-water sensors are in [5]. Two Trios/RAMSES radiometers were deployed simultaneously at the end of the Fishermen Pier in Buenos Aires during the Argentine campaign (Fig. 3).

Figure 3. Setup of the two Trios/RAMSES sensors at the end of the Fishermen Pier (Argentina). Radiance (left) and irradiance sensors (right).

The protocol described in [2] was followed except that a) the viewing azimuth angle relative to sun was set to 90° to minimize structure perturbations of the light field, and b) the wind speed was set to zero in the estimation of the Fresnel reflectance given that fetch-limited surface waves are expected in estuaries. The characteristics of the deployed instruments can be found in Tab. 1.

Table 1. Characteristics of the sensors deployed during the campaigns in Argentina and Belgium

Instrument	*Parameter*	*Unit / wavelength*
HACH	b_s (90°)	FNU (860 nm)
OBS3+	b_{bB} (90 to 165°)	NTU (850 nm)
OBS500	b_s (90°)	FNU
	b_{bB} (125 to 170°)	FBU (850 nm)
Hydroscat-4	b_b (141°)	m^{-1} (560, 700, 850, 1020 nm)
Trios/RAMSES	Reflectance	- (380 to 900 nm)

A Pléiades image was acquired over Buenos Aires region on 24 November 2015 at 11:01 hrs (local time). Pléiades satellite sensors are part of a constellation of four satellites (Pléiades-1A and -1B, and SPOT-6 and -7) combining a double daily revisit capability and high resolution imagery. Pléiades has 4 multispectral bands located in the visible and near infrared (NIR) regions at 2.8 m (resampled to 2m) resolution and a panchromatic band at 70 cm resolution (resample to 50 cm) (Tab. 2).

Table 2. Spatial and spectral characteristics of Pléiades imagery

Bands	*Spectral*	*Spatial*
Panchromatic	470-830	0.7 m
Blue	430–550	2.8 m
Green	500–620	2.8 m
Red	559–710	2.8 m
Near infrared	740–940	2.8 m

Pléiades image was processed using ACOLITE software [4] specially adapted for Pléaides imagery. Rayleigh reflectance was calculated based on sun and sensor geometry using 6SV [3]. The aerosol correction was performed assuming spectrally flat aerosol reflectance (ε=1) and a fixed aerosol reflectance (ρ_{am}) in the NIR. This value was determined from the clearest in-land waters observed and was fixed for the whole image. Given the viewing geometry, the water surface state (rough due to winds) and the sun position (high solar elevation angle close to austral summer solstice), the acquired image was highly contaminated with sun glint reflection (Fig. 4 left). A modified version of the method developed by [6] was applied to Pléiades imagery. This method estimates the sun glint correction factor for a given band based on covariance of radiance in each visible band and in NIR for a deep water area. Given that the NIR band in these highly turbid waters is of interest to estimate turbidity and there are no clear-deep water areas in the image, the relation between each band and the blue band was calculated instead and used to de-glint the image.

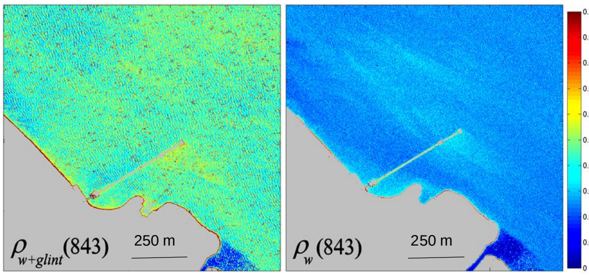

Figure 4. Pléiades image over the FP. Left: atmospherically corrected reflectance ($\rho_{w+glint}$). Right: de-glinted ρ_w as in [5], but using the blue band.

Turbidity was estimated using the switching-band semi-analytical algorithm described in [1], using the NIR band from the atmospherically corrected and de-glinted Pléiades imagery and the coefficients previously derived for MODIS bands [1].

Radiometric and in-water measurements were performed simultaneously with the image at the end of the pier (500 m from land) and water samples were also collected at this site and 20 other locations within 3 hours of the satellite image to measure turbidity using HACH instruments (Fig. 5).

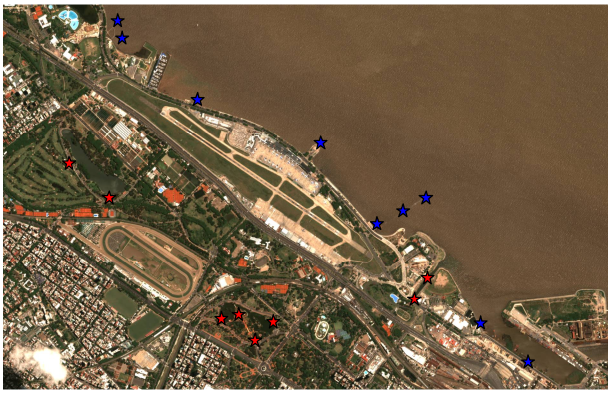

Figure 5. Location of the 13 sampling sites in the Río de la Plata (blue) and 8 sites in inland waters (red) super-imposed on the Rayleigh-corrected RGB Pléiades image acquired on 24 Nov 2015.

3. RESULTS

3.1 Instrument inter-comparison

In general a good correlation was found between the two HACH turbidimeters used (r>0.99, Fig. 6) and also between HACH and the other side and back-scattering sensors (Fig. 7). The turbidity values from both HACH sensors showed a low variability both within the three replicates (error bars in Fig. 5), with correlation coefficients CV<10%, and between the two instruments (Root mean square error RMSE=0.4 FNU).

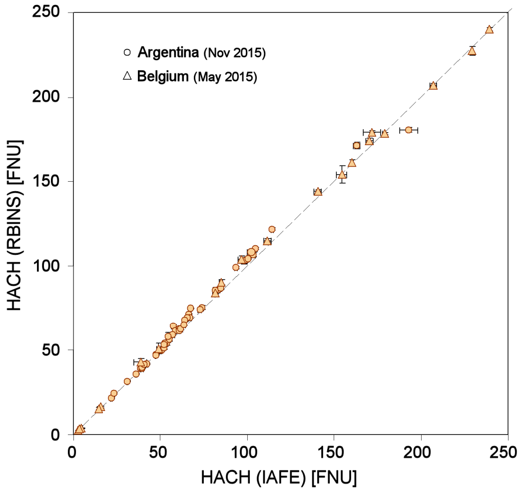

Figure 6. Comparison of turbidity measurements collected in Belgium (triangles) and Argentina (circles) for two HACH ISO hand-held turbidimeters. Error bars show the standard deviation (three replicates)

The HACH turbidity values were also well correlated with the OBS500 and HS4 backscattering values (r=0.97), as well as with the OBS500 and OBS3+ side-scattering values (r= 0.98 and 0.95, respectively) (Fig. 7).

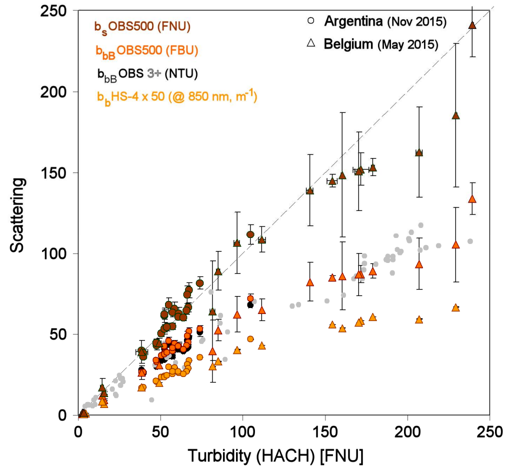

Figure 7. Scatter plot of HACH turbidity versus side- and back-scattering values measured with OBS3+, OBS500 and HS-4. Grey symbols show data collected in previous campaigns in the RdP with the OBS3+ sensor.

Fig. 8 shows the inter-comparison between water reflectance (ρ_w) from the two Trios systems at 6 different wavelengths. The data are highly correlated (r= 0.98) and close to the 1:1 line (slope = 1.03, intercept= 0.0006).

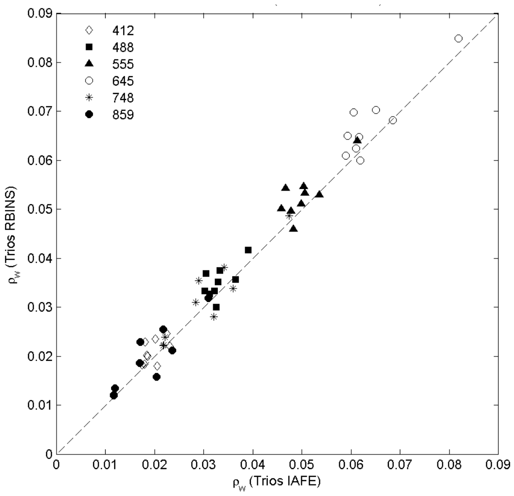

Figure 8. Intercomparison between two Trios ρ_w for wavelengths at 412, 488, 555, 645, 748, amd 859 nm.

3.2. Satellite validation

A total of 13 and 8 match-ups were obtained for the samples collected in the Río de la Plata and the inland waters, respectively. The scatter plots and statistics of the analysis for each region are shown in Fig. 9 and Tab. 3. An overall good correlation between field and satellite-derived turbidity was observed with high correlation coefficients for both regions (0.90 and 0.96 for the Río de la Plata and inland waters, respectively). On average, satellite-derived turbidity were higher than field measurements for the samples collected in the Río de la Plata with positive relative percentage difference (RPD= 11.4%) and relative low absolute percentage difference (APD=15.4%). In turn, Pléaides T values underestimated field measurements collected in inland waters, showing slightly negative relative errors (RPD= -7.3%), but higher dispersion (APD= 32.7%).

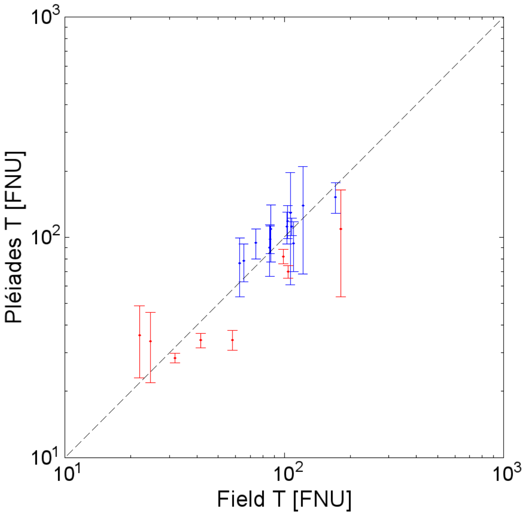

Figure 9. Scatter plot of field (HACH) & Pléiades derived turbidity for Río de la Plata (blue) and inland (red) water samples.

Table 3. Turbidity match-up statistics for the Río de la Plata and inland sampling sites and Pléiades imagery

Sites	*r*	*APD%*	*RPD%*	*N*
Río de la Plata	0.89	15.4	11.4	13
Inland	0.96	32.7	-7.3	8

4. CONCLUSIONS

Joint measurements in Belgium and Argentina have been performed in the frame of the TURBINET project. The harmonization of the instrumentation and protocols have enabled to combine datasets from the participating teams into a single multi-site dataset for satellite data validation. Common protocols have been developed for joint measurements of turbidity, reflectance and in-water side/back-scattering. Instrument comparisons showed that comparable measurements could be achieved using different sensors, demonstrating the capability to gather high quality and harmonized data set.

A Pléiades high resolution (2 m) image has been validated during the Argentine field campaign. Satellite-derived turbidity showed similar values to field measurements in the highly turbid waters of RdP, but less accurate estimates were found in the small inland waters probably due to adjacency effects and the influence of bottom reflectance in these shallow water bodies. Sun glint is an important factor limiting the quantity and accuracy of remotely sensed data from water bodies, especially for high spatial resolution imagery like the Pléiades image analyzed in this study. A modified version of a deglinting technique [6] has been applied here showing reasonable results.

The results presented in this work demonstrate the feasibility and usefulness of setting up a network to validate satellite turbidity products. The next steps include establishing autonomous and continuous in-water measurements in the test sites and to expand these activities to other regions based on the core methodologies already developed within TURBINET project.

5. ACKNOWLEDGEMENTS

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