Validation of Landsat-8/OLI for ocean colour applications with AERONET-OC sites in Belgian coastal waters

by Dimitry Van der Zande [1*], Quinten Vanhellemont[1], Liesbeth De Keukelaere[2], Els Knaeps[2], Kevin Ruddick[1]

[1]Royal Belgian Institute of Natural Sciences, OD Nature, Belgium;
[2]Vlaamse Instelling van Technologisch Onderzoek (VITO), Belgium;
*Corresponding author: d.vanderzande@naturalsciences.be

Abstract

The sensors Landsat-8/OLI (L8-OLI) and Sentinel-2/MSI (S2-MSI) are mainly designed to provide information on land surfaces for applications in agriculture, geology, forestry, mapping, global change research, etc. However, their performance in terms of signal-to-noise ratio (SNR) is sufficient to be used for marine applications, especially in turbid coastal waters. Compared to the mainstream ocean colour sensors (MODIS-AQUA, VIIRS and Sentinel-3/OLCI) these sensors offer great advantages in terms of spatial resolution enabling the development of the new generation of coastal water quality products. Monitoring of water quality by satellite requires high quality atmospheric correction to separate the aerosol and marine contributions to the top of atmosphere radiance observed by the satellites. Determination of the marine part of the observed signal, i.e. the normalized water-leaving radiance (Lwn), is crucial as this parameter is the basis of all derived marine parameters, including total suspended matter (TSM) and chlorophyll *a* (CHL-a).

In this work, the performance of ACOLITE is validated in the Belgian coastal waters for the L8-OLI sensor.The validation is based on "matchup" data from simultaneous measuring sea-based instruments. The Belgian strategy for ocean colour validation has focused on the use of two continuously measuring AERONET-OC stations: the Zeebrugge-MOW1 site located in the turbid nearshore water and Thornton_C-Power site located in the clearer offshore waters. A validation protocol will be presented providing information on the acceptable time and space difference between *in situ* and satellite observations.

1. Introduction

The mainstream ocean colour remote sensors (MODIS-AQUA, VIIRS and Sentinel-3 OLCI) require "matchup" data from simultaneous sea-based instruments for validation. In particular validation of the normalized water-leaving radiance (Lwn) is crucial as this parameter is the basis of all derived marine parameters, including total suspended matter (TSM) and chlorophyll a (CHL-a) (Morel and Mueller, 2003; Zibordi et al, 2015). Belgian waters have been a key site for validation of satellite ocean colour radiometry since the launch of MERIS in 2002. Ship-based measurements have been regularly compared with satellite-derived marine reflectance to indicate any performance weaknesses. However, the ship-based measurements provide only a limited number of matchup measurements per year. The Belgian strategy for ocean colour validation has consequently shifted focus to the setup of continuously measuring systems in

order to provide early validation feedback to missions such as Sentinel-3/OLCI. AERONET-OC is instrumental in satellite ocean colour validation activities through standardized measurements sites with a single measurement system and protocol. All AERONET-OC sensors are calibrated with an identical reference source and method, and the data is processed with the same code (Zibordi et al. , 2009, 2015). In addition to the expanding range of mainstream ocean colour sensors, there is a growing interest in exploiting data from high-resolution sensors on polar-orbiters originally designed for land applications, such as Landsat-8 OLI giving 30m spatial resolution, Sentinel-2 MSI (10-60m) and Pléiades (2m). A single validation site can thus provide information for validation of a large number of space borne missions. In this work, the performance of ACOLITE, an atmospheric correction approach for the L8-OLI and S2-MSI sensors, is validated in the Belgian coastal waters. The validation is based on "matchup" data from two continuously measuring AERONET-OC stations: the Zeebrugge-MOW1 site located in the turbid nearshore water and Thornton_C-Power located in the clearer offshore waters. A study was performed to determine the acceptable time and space difference between *in situ* and satellite observations.

2.   Materials and Methods

2.1   Belgian AERONET-OC stations

The radiometric validation of ocean colour data is presented here in a multi sensor perspective with a focus on Belgian waters and the use of two AERONET-OC sites, one in turbid nearshore waters, one further offshore in clearer waters (Fig 1.). The systems are based on a standard CIMEL SeaPrism instrument but are equipped with a redesigned data acquisition and transmission system using a low-power embedded computer suitable for harsh environments with a time switch, router and GPRS antenna. This approach has multiple advantages compared to the traditionally used satellite data transmission system: (1) remote access to PC system, (2) added level of data security as data is locally stored in case of data transmission malfunction and (3) reduced physical footprint (+/- 35%) of the system on the offshore platforms.

Data products acquired by the CIMEL-SeaPrism system are transmitted on a daily basis to the AERONET-OC center managed by NASA for near real time processing. The products determined at different center wavelengths λ in the 412-1020nm spectral range (nominally, 412, 443, 488, 531, 551, 667, 870 and 1020nm) are available at three levels of quality control: (1) Level 1.0 represent complete sequences of SeaPrism measurements; (2) Level 1.5 data is obtained after cloud screening and applying a series of quality tests designed to remove the measurements affected by significant environmental perturbations or artifacts, (3) Level 2.0, comprising fully quality-controlled data generated after post-deployment calibration and checks of individual data records. Level 1.0 and Level 1.5 are accessible in almost real time through the web interface (http://aeronet.gsfc.nasa.gov/). Level 2 data products are only accessible after each deployment period lasting 6-12 months (Zibordi et al, 2015)

The Thornton-Cpower site is installed on the Offshore Transformation Station (OTS) of the C-power windpark located 26 km offshore in 19m water depth. The SeaPrism is installed on the upper platform rail corner and has been actively collecting ocean color data since April 2015.

Up to Oct 16th 2015 it has collected a total of 1319 water leaving radiance spectra of which 370 spectra have passed the level 1.5 quality control of NASA/JRC.

The Zeebrugge-MOW1 station is mounted on a measurement pole near the Zeebrugge harbour in 10m water depth, 3.65km from land. The SeaPrism instrument is installed on the platform rail. The system has been actively collecting ocean colour data between February 2014 and February 2015 when it was dismounted for maintenance and calibration. In this one year period the CIMEL/SeaPrism has collected a total of 1865 water leaving radiance measurements. After a first quality control by NASA/JRC 222 level 1.5 water leaving radiance measurements were retained for use in calibration/validation efforts of satellite data.

2.2 Atmospheric correction: ACOLITE

Imagery from higher resolution sensors, such as Landsat-8 and the upcoming Sentinel-2, with an appropriate turbid water atmospheric correction, is of great interest to coastal and inland water quality monitoring in general (Vanhellemont & Ruddick, 2014a, b). Atmospheric correction of satellite imagery over turbid waters requires separation of aerosol and marine contributions from the top of atmosphere signal observed by the satellite. Here we use the atmospheric correction approach ACOLITE developed by Vanhellemont et al. (2014a,b). ACOLITE (Atmospheric Correction for OLI 'light') is a binary distribution of the Landsat-8(L8)/Operational Land Imager (OLI) and Sentinel-2/ MSI processing. It allows simple and fast processing of L8 and S2 images for marine and inland water applications. Features include generation of RGB images before and after Rayleigh correction, atmospheric correction of water bodies and extraction of rectangular regions of interest (defined by bounding coordinates). Level 2 outputs are marine reflectance (ρ_w=Rrs·π) and multiple scattering aerosol reflectance (ρ_{am}), that can be saved as PNG maps and geolocated datasets in a NCDF (NetCDF) file.

The atmospheric correction is image based and needs no external inputs. TOA radiances are derived for the L1T files. TOA reflectance (ρ_{TOA}) is computed by normalizing the TOA radiance to the band averaged solar irradiance. These images are corrected for scattering by molecules (Rayleigh) and aerosols to retrieve water-leaving radiance reflectance, ρ_w. The Rayleigh correction uses a lookup table generated using 6SV (Vermote et al., 2006) and is based on the illumination and viewing geometry (sun and sensor zenith and azimuth angles) with a correction for atmospheric pressure as ancillary data. Cloud and land masking is performed using a threshold on reflectance in the 1609nm SWIR band. Pixels are classified as non-water when the Rayleigh-corrected reflectance ($\rho_c = \rho_{TOA} - \rho_r$), $\rho_c^{1609} > 0.0215$. Aerosol reflectance is estimated using an approach similar to Ruddick et al. (2000) where the aerosol type (ϵ) is determined from the ratio of reflectance in the SWIR band pair, over water pixels in the region of interest where the water contribution of those bands is assumed to be zero. The ϵ is considered constant over the region of interest and is used to extrapolate the observed aerosol reflectance from the SWIR bands to the visible channels. The remote sensing reflectance can be determined by subtracting Rayleigh and aerosol reflections from the TOA reflectance. For more information on ACOLITE processing consult Vanhellemont and Ruddick. (2015).

2.3   Validation protocol

The protocol for "match-up" validation notably specifies the acceptable time and space differences between in situ and satellite measurements and the quality control steps for pre-filtering of both in situ and satellite data. In this study we describe the variability in space and time of the optical properties of the water around the Belgian AERONET sites as a guideline to determine optimal match up conditions between in situ and satellite observations.

3.   Results and Discussions

3.1   Spatial and temporal dynamics of marine optical properties

As a demonstration of the variability of Lwn in the Belgian part of the North Sea, a time series of a single day is presented in figure 2. These spectra were collected by the two AERONET-OC stations in Belgian waters (i.e. Zeebrugge-MOW1 and Thornton-CPower) on the 13th of March and 12th of May 2014. Table 1 shows statistical parameters providing an estimate of the impact of the hydrodynamics in these locations on the Lwn measurements. For Zeebrugge-MOW1 the Lwn measurements vary in average between 6 and 15% per hour for the green and blue bands and up to 32% for the red band. The maximum percentage difference per hour was between 16% and 56% for the blue and green bands and up to 167% for the red band. The Thornton-CPower site is an offshore station located in more clear waters and in figure 2 the Lwn observations of 12th of May 1014 are shown. The hourly differences vary between 11% and 16% for the green and blue bands and more than 25% for the red band. The maximum percentage difference per hour was between 25% and 42% for the blue and green bands and up to 90% for the red band. These numbers show that the temporal variability of Lwn measurements can be quite high in Belgian waters and from these results it is advised to match the in situ measurements as close as possible to the actual satellite overpass, i.e. less than one hour time difference.

The spatial variability of TSM concentration near the Belgian coast based on L8-OLI imagery for 7/10/2013 is illustrated in figure 3. The L8-OLI image was processed with ACOLITE (v20160120) using the TSM algorithm of Nechad et al. (2010) to generate the TSM product with a spatial resolution of 30m/pixel. A transect was extracted perpendicular to the coast line to illustrate the spatial variations in TSM. High TSM values can be observed close to the coast line (section 1) with a strong decrease at the deeper shipping route to the harbor of Zeebrugge. Near the more shallow Vlakte van Raan (section 3) a strong increase in TSM can be observed due to resuspension of sediments. Behind the Vlakte van Raan the TSM values decrease rapidly due to an increased depth. It then remains rather stable at a value of 5 mg/l. In this transect of approx. 19km in length we observed a mean change in TSM of 0.32 mg/l between two adjacent pixels (i.e. 30m) and 0.85 mg/l between positions located three pixels apart (i.e. approx. 90m). Near the TSM fronts (figure 18b zones 1 and 3) a maximal difference of 2.75 mg/l for adjacent pixels and 7.18 mg/l between positions located three pixels apart were measured. Near the Zeebrugge-MOW1 measurement pole (location 2) an OBS-5 sensor monitored turbidity at 5 minute intervals with results shown from 1/10 to 10/10 and during the day of 7/10. Figure 18C

shows a typical diurnal pattern with a mean and maximum change in TSM of 4.52 mg/l and 33.3 mg/l respectively over a 30 min time span.

3.2   Match up analysis

To demonstrate the use of AERONET-OC sites for validation of non-ocean colour sensors, match-ups between the Belgian Zeebrugge-MOW1 site and L8-OLI were extracted and compared. The L8-OLI scenes were processed with ACOLITE delivering Lwn maps with a spatial resolution of 30m. Standard processing settings were selected. For a match-up a maximum time difference of one hour was allowed and the actual satellite pixel of the location of the AERONET-OC station was considered. Here we assume that there is no significant impact of the measurement tower on the reflectance signal of the pixel. The AERONET-OC data delivered 13 match-ups with L8-OLI data for the period February 2014-February 2015 for the level 1 data (NASA quality control). After level 1.5 and level 2 quality control only 1 match-up remained pointing to the severe quality control performed by NASA. In this study the level 1 AERONET-OC data was considered to enable a statistical comparison between the in situ and satellite data. Figure 4 shows the correlation for the L8-OLI bands 443nm, 490nm, 670nm and 870nm. For the 443nm band we observe an overestimation of the Lwn values by 14.09% (R^2 = 0.41). The 490nm band correlates well with the AERONET-OC observations with an overestimation of 10.34% (R^2 = 0.72). The best correlation can be observed for the 670 nm band with R^2 = 0.92. There is still an overestimation of 15.42% observed but this can be contributed to the difference in band characteristics between the two sensors. The AERONET-OC 670nm band is a quasi-squared 10nm wide band while the L8-OLI band shows an irregular spectral response function for the 670nm band (data not shown) with a width of 60nm. Finally, comparing the NIR-band (i.e. 870nm) showed L8-OLI underestimating Lwn with 43.24% (R^2 = 0.62).

4.   Conclusions

The AERONET-OC network enables the generation of standardized data relevant for the validation of primary satellite ocean colour products (i.e. Lwn) in coastal regions (Zibordi et al (2009). The standardization of measurements through the application of identical instruments, measurement protocols, processing and quality assurance schemes is a viable solution to increase the consistency of data sets and make them more applicable to the assessment of satellite data products. This work aims to add to this endeavour by studying the applicability of the AERONET-OC data for validation efforts of multiple satellite missions, including missions designed for land applications (i.e. L8-OLI and S2-MSI).

5.   Future work

Advanced results will be presented at the Ocean Optics 2016 Conference including validation of S2-MSI data using the AERONET-OC stations and inter-comparison analysis of ACOLITE atmospheric processing with OPERA. OPERA is an atmospheric correction procedure developed by VITO which can also be applied to a wide variety of sensors (Hyperspectral, Sentinel-2, Sentinel-3, MERIS) and scenes (land, coastal waters, inland waters, and macrophyte dominated

waters). The OPERA atmospheric correction scheme accounts for surface elevation variation, adjacency effects and for inland water targets, also the non-Lambertian reflection of water surfaces. Through the use of a single atmospheric correction implementation discontinuities in the resulting reflectance between land and the highly dynamic water areas (such as turbid, tidal, shallow waters or macrophyte dominated waters) are reduced.

Acknowledgments

References

Morel, A., & Mueller, J. L. (2003). Normalized water-leaving radiance and remote sensing reflectance: Bidirectional reflectance and other factors. In J. L. Mueller, G. S. Fargion, & C. R. McClain (Eds.), Ocean optics protocols for satellite ocean color sensor validation, revision 4, volume III: NASA/TM-2003-21621/Rev-Vol III (pp. 32–59). Maryland 20771: National Aeronautical and Space Administration, Goddard Space Flight Space Center Greenbelt.

Nechad, B., Ruddick K.G., Park, Y. (2010). Calibration and validation of a generic multisensor algorithm for mapping of Total Suspended Matter in turbid waters. Remote Sensing of Environment, 114 (4): 854-866.

Ruddick, K.G., Ovidio, F., & Rijkeboer, M. (2000). Atmospheric correction of SeaWiFS imagery for turbid coastal and inland waters. Applied Optics, 39, 897–912.

Vanhellemont, Q., & Ruddick, K. (2014a). Turbid wakes associated with offshore wind turbines observed with Landsat 8. Remote Sensing of Environment, 145, 105–115.

Vanhellemont, Q., & Ruddick, K. (2014b). Landsat-8 as a precursor to Sentinel-2: Observations of human impacts in coastal waters. ESA Special Publication SP-726. Presented at the 2014 European Space Agency Sentinel-2 for Science Workshop, Frascati.

Vanhellemont Q. & Ruddick K. Advantages of high quality SWIR bands for ocean colour processing: Examples from Landsat-8 (2015) Remote Sensing of Environment, Vol. 161 pp. 89–106.

Extended abstract for submission to Ocean Optics Conference to be held in Victoria, BC., Canada, 23-28 Oct. 2016

Vermote, E., Tanré, D., Deuzé, J., Herman, M., Morcrette, J., & Kotchenova, S. (2006). Second simulation of a satellite signal in the solar spectrum-vector (6SV). 6S User Guide Version 3.

Zibordi, G., Berthon, J. F., Mélin, F., D'Alimonte, D., & Kaitala, S. (2009). Validation of satellite ocean color primary products at optically complex coastal sites: Northern Adriatic Sea, Northern Baltic Proper and Gulf of Finland. *Remote Sensing of Environment*, *113*(12), 2574-2591.

Zibordi, G., Mélin, F., Berthon, J.-F., and Talone, M. (2015): In situ autonomous optical radiometry measurements for satellite ocean color validation in the Western Black Sea, *Ocean Sci.*, *11*, 275-286, doi:10.5194/os-11-275-2015.

Figure 1. Belgian waters and the location of the two AERONET-OC sites: 1) Thornton-CPower and 2) Zeebrugge-MOW1. RGB composite from Landsat-8 on 2.9.2015 generated using ACOLITE.
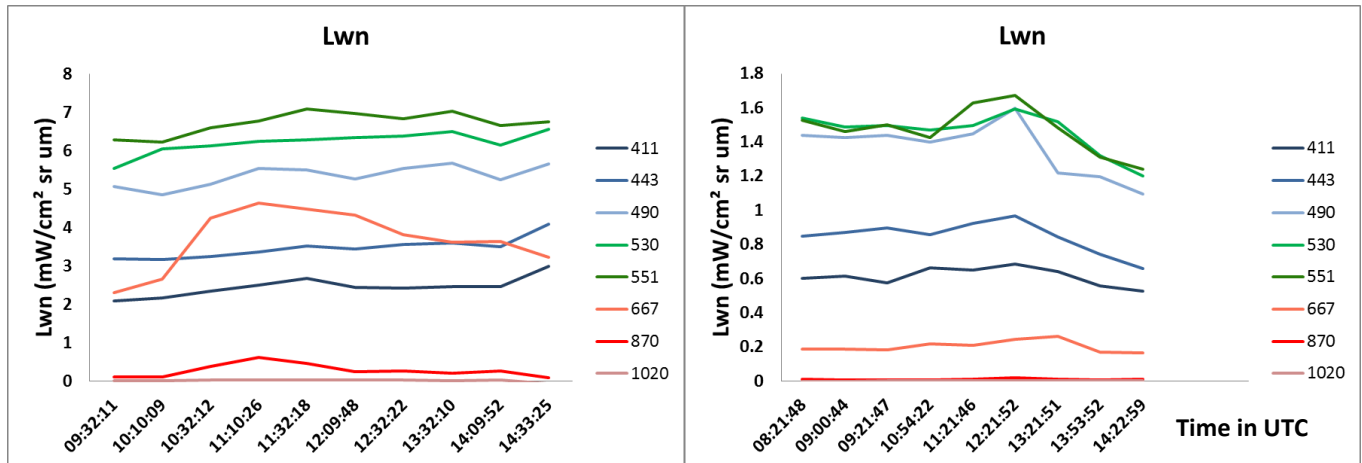
Figure 2. Normalized water leaving radiance (Lwn) values plotted per wavelength (in nm) collected by the AERONET-OC station Zeebrugge-MOW1 on the 13th of March 2014 (left) and the AERONET-OC station Thornthon-Cpower on the 12th of May 2014 (right)

Table 1. Statistical description of the variability of the Lwn measurements collected at the AERONET-OC station Zeebrugge-MOW1 on the 13th of March 2014.

	Lwn411	Lwn441	Lwn491	Lwn530	Lwn551	Lwn667	Lwn870	Lwn1019
Mean(Lwn)	2.46	3.46	5.35	6.21	6.72	3.69	0.28	0.02
Stddev(Lwn)	0.24	0.25	0.26	0.27	0.28	0.74	0.16	0.03
mean % diff/hour	14.89	10.15	10.46	6.17	6.57	32.53	179.62	126.26
max % diff/hour	56.89	43.91	20.59	17.74	16.26	162.59	637.15	414.50

Table 2. Statistical description of the variability of the Lwn measurements collected at the AERONET-OC station Thornthon-Cpower on the 12th of May 2014.

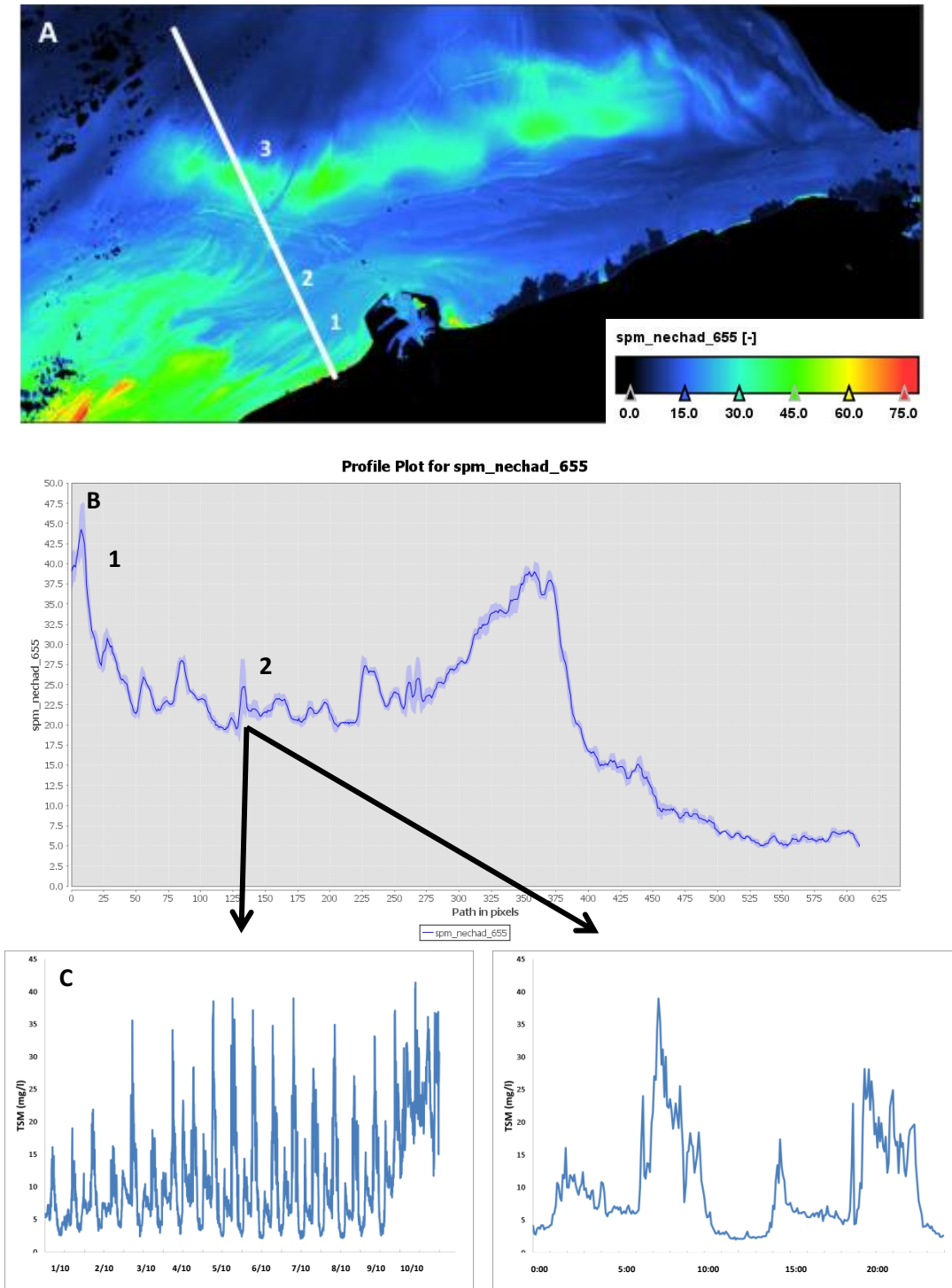|	Lwn411	Lwn441	Lwn491	Lwn530	Lwn551	Lwn667	Lwn870	Lwn1019
Mean(Lwn)	0.61	0.85	1.36	1.46	1.47	0.20	0.01	0.00
Stddev(Lwn)	0.05	0.09	0.15	0.11	0.13	0.03	0.00	0.00
mean % diff/hour	15.62	14.85	13.02	11.34	13.92	26.29	99.26	559.40
max % diff/hour	42.31	33.17	31.48	25.50	23.08	89.98	247.46	2157.03

Figure 3. (A) SPM product for the Belgian part of the North Sea (7/10/2013 10:41h) based on L8-OLI image with a resolution of 30 m showing the spatial patterns of suspended matter. (B) A transect from the coastal to the offshore region presents the spatial variability of SPM: 1) SPM front near the coast, 2) location of Zeebrugge-MOW1 measurement tower and 3) SPM front near the Thornton bank. C) Continuous in situ measurements of TSM collected at the Zeebrugge-MOW1 location for a 10 day period (left) and one day (right).
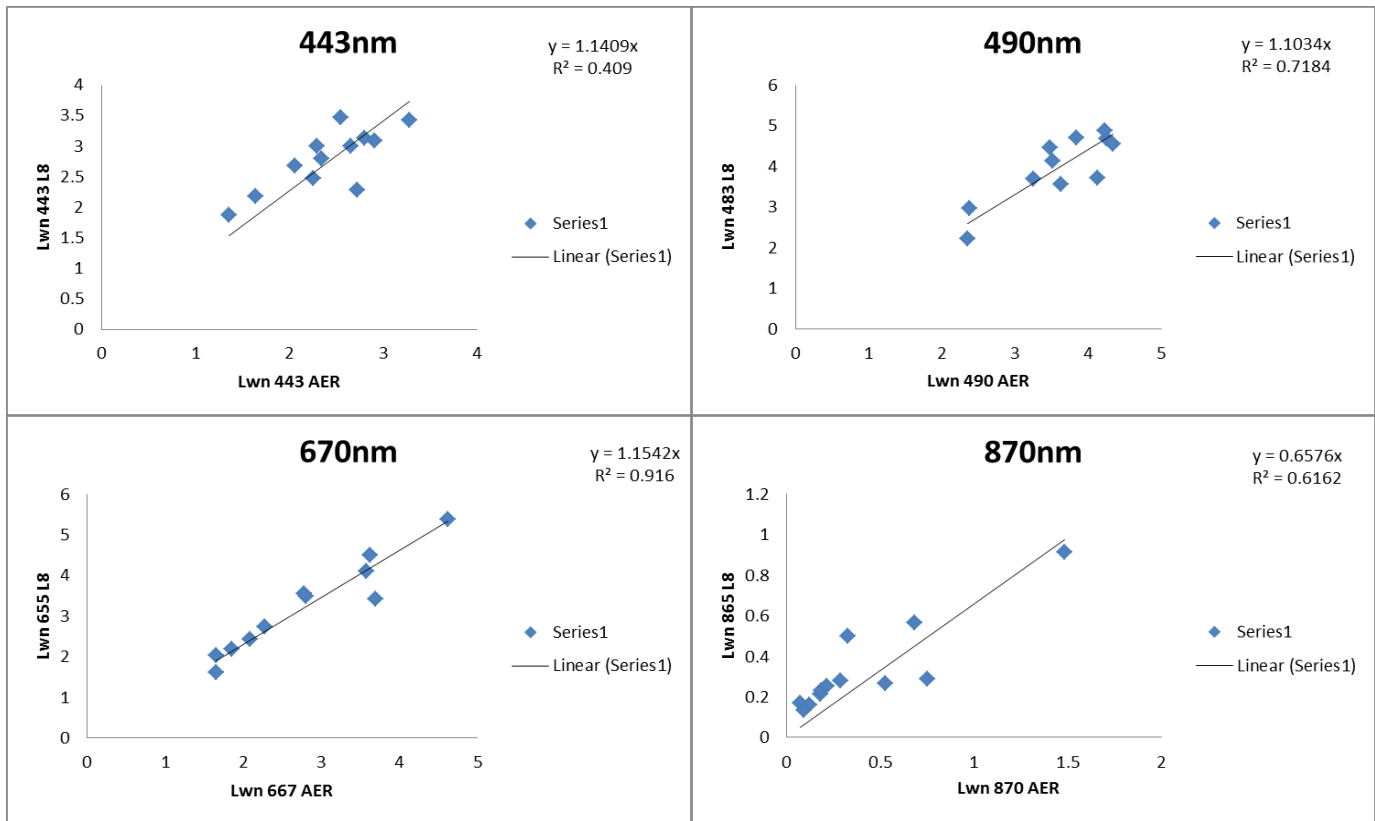
Figure 4. Match-ups between satellite-derived (L8-OLI) (1x1 pixel) and AERONET-OC Lwn values at 443, 490, 670, 870nm for theZeebrugge-MOW1 site.