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The Sentinel-2A age for Earth and Ocean Observation: Preliminary implementation in the North-East Aegean Sea, Greece.

Abstract

The European Space Agency's (ESA) Sentinel-2A mission in 2015, opened the new era of high-resolution imagery of Earth's surface, evolving and enriching, among others, the near-shore and offshore oceanographic investigation. With this preliminary work we attempt to use, process and evaluate the Sentinel-2A product to estimate and map the distribution of sea surface suspended particulate matter (SPM), an important water quality parameter in coastal environments. More specifically, we present the characteristics and advantages of the new Sentinel sensor as well as the atmospheric corrections applied through ESA's processing tool SNAP, to compute remote sensing reflectance (R_{rs}) and, consequently, to quantify SPM surface concentrations. Two representative Sentinel-2A images (collected in 2016), one during the wet (November-April) and the other one during the dry (May-October) period, revealed moderate SPM seasonal distribution (1-30 mg/L) in the Gulf of Alexandroupolis, northeastern Aegean Sea (Eastern Mediterranean Sea). More precisely, the Sentinel-2A image of June 2016 showed SPM concentrations between <1 mg/L and 15 mg/L, whereas in December's image SPM reached up to 30 mg/L. Landsat-8 image processing (22/06/2016) has shown relevant SPM values to Sentinel-2A estimations (i.e. 1-16 mg/L). Simultaneous to Landsat-8 passage in situ SPM data comes to better agreement with the Sentinel-2A values (r=0.88); this indicates greater Sentinel-2A accuracy, although verification, with simultaneous to Sentinel crossing in situ data is needed. Additionally, the highest values appear in front of the Evros delta mouth, showing obvious influence from the river discharges, while the lowest values are estimated offshore. The new Sentinel-2A products of a 10-m spatial resolution and its 5-day revisiting period promise access to both a quantitative and qualitative remote sensing data flow to acquiring frequent satellite-derived SPM information, which can be accordingly validated in filling older data gaps and, thus, contribute to a cost-efficient way for continuous coastal monitoring.

Keywords: remote sensing, water transparency, Evros River, suspended particulate matter

Introduction

The Sentinel-2A mission of the European Space Agency was launched on 23 June 2015 and initiates a new era in high resolution Earth's monitoring from space, with two MultiSpectral Instruments (MSIs) onboard and a 5-day revisit time over terrestrial and aquatic areas. The purpose of the twin satellites (Sentinel-2A & Sentinel-2B) attempt to enable monitoring of land cover and land use at a global, regional or local scale, by measuring the reflected radiances in 13 bands of the visible and infrared spectrum (Drusch et al., 2012). However, the MSI instruments can also map near-surface water constituents, including the surface suspended particulate matter (SPM) in coastal areas, providing high quality of remote sensing products due to their additional spectral bands comparing to other sensors (Vanhellemont & Ruddick, 2015).

Recent studies in retrieving water parameters have been carried out by using the Sentinel-2 MSI data. Gernez et al. (2015) retrieved SPM values from a simulated Sentinel 2 MSI dataset in turbid estuary environment. Dörnhöfer et al. (2016) applied Sentinel 2 MSI to quantify water constituents over oligotrophic inland waters. Another interesting study conducted by Kutser et al. (2016) revealed the advantage of Sentinel-2 MSI over Landsat-8 OLI in SPM computing. Toming et al. (2016) resulted in high fitting accuracy between in-situ and remote-sensed reflectance data from Sentinel-2 MSI regarding chlorophyll-a (R^2 = 0.83) and dissolved organic carbon (R^2 = 0.92).

In this study we attempt to present the main characteristics of the Sentinel-2 imagery, to provide MSI-derived R_{rs} products and thus to retrieve SPM concentration in Alexandroupolis Gulf. More specifically, the aim within this manuscript is to demonstrate the Sentinel-2 initial imagery, the atmospheric correction procedure as well as the product quality of the final R_{rs} derived products. Furthermore, SPM concentrations were quantified in our defined area, from two representative Sentinel-2A images (collected in 2016), one during the wet (17/12/2016) and the other one during the dry (10/06/2016) period of the near Evros River discharge. Lastly, we compare the Sentinel-2 derived SPM results from June 2016 with simultaneous (02/06/2016) in situ sampling and similar Landsat-8 SPM retrievals.

Materials and methods

Study Area

The Gulf of Alexandroupolis is part of the inner continental shelf of the NE Aegean Sea (Samothraki Plateau) with Evros river debouching on its eastern coast. The drainage basin of the river is 52,500 km^2 being the largest in the Balkan Peninsula. Approximately 3.2 x 106 tones sediment are discharged from Evros river annually (Pehlivanoglou, 1989) into the Gulf, making the Evros river Delta very important environmental shelter (Karditsa et al., 2014). The seabed consists of sand (<10 m water depth) having a zonal distribution with the nearshore sediments, of fine-grained material (10-30 m water depth) and of muddy sands offshore (>30 m depth). This testifies a transitional zone to relict sandy deposits found at water depths >60 m (Karditsa & Poulos, 2013).

Human activities within Alexandroupolis Gulf such as agricultural discharge, sewage, industrial waste affect the natural environment of Evros river Delta by increasing the organic and inorganic concentrations in the water column (Angelidis & Athanasiadis, 1995). Moreover, the harbor of the city of Alexandroupolis combined with the existence of coastal stations of fuel loading may are expected to have a significant impact of the surrounding area.

Data & Methodology

We used and processed two Sentinel-2A imageries sensed on 10 June 2016 and 17 December 2016 respectively, at 09.09 am (UTC) (Table 1). Sentinel images have four bands with a spatial resolution of 10 m, six bands with 20 m, and three bands with 60 m. The Sentinels Scientific Data Hub site (https://scihub.copernicus.eu/dhus/) provides unlimited Sentinel-2 Level-1C (L1C) data for downloading with open access to remote sensing users. These products are called granules and represent a 100 km^2 orthorectified images with Universal Transverse Mercator (UTM)-World Geodetic System 1984 (WGS84) spatial projection.

Table 1. Sentinel-2A images used in this study and their characteristics.

Acquisition date	**Tile name**	**Sensor Altitude**
10 June 2016		786 km
	S2A_OPER_MSI_L1C_TL_MTI__20160614T160614_A005052_T35TMF_N02.02	
	S2A_OPER_MSI_L1C_TL_MTI__20160614T160614_A005052_T35TLF_N02.02	
	S2A_OPER_MSI_L1C_TL_MTI__20160614T160614_A005052_T35TLE_N02.02	
17 December 2016		
	S2A_OPER_MSI_L1C_TL_MTI__ 20161217T091648_ A007769_T35TLF_N02.02	
	S2A_OPER_MSI_L1C_TL_MTI__ 20161217T091648_ A007769_T35TMF_N02.02	
	S2A_OPER_MSI_L1C_TL_MTI__ 20161217T091648_ A007769_T35TLE_N02.02	

The downloaded Sentinel-2 L1C products contain the top of atmosphere reflectance (ρ_{TOA}) which is the sum of Reileigh reflectance (ρ_r), aerosol reflectance (ρ_α) and water-leaving reflectance (ρ_W) (Gordon & Wang, 1994). Thus, a preliminary atmospheric correction has already been applied to imagery, giving an advantage to MSI instruments comparing to predecessor sensors. Further, The European Space Agency's (ESA) Sentinel-2A has created the processing tool SNAP, where with the Sen2Cor processor we are able to perform atmospheric and solar illumination geometry influence correction on L1C data.

The output products are Level 2A Bottom-Of-Atmosphere (BOA) corrected reflectance images. The Level-1C images, which are the input for the Level-2A products consist of a series of granules, each one with a 100 km^2. Each granule consists of thirteen compressed JPEG-2000 images, each one representing one single band. The thirteen bands have resolutions of 10m, 20m and 60m leading to different image dimensions of the Level-1C input product (ESA-Sen2Cor Configuration and User Manual, 2016). Then, the atmospherically corrected images, and more specifically the near-infrared (NIR) band 8 (great water absorption) were used to mask out the land, to avoid terrestrial reflectance influence on the quantitative retrieval of SPM.

After retrieving the Sentinel-2A products with the corrected remote sensing reflectance values we applied the Semi-Analytical Algorithm (SAA) in the red spectral band proposed by Nechad et al., (2010), which is described by the formula (1).

$$\mathrm{SPM} = A^{\rho} * \frac{\rho_W(\lambda)}{1 - \rho_W(\lambda)/C} \qquad (1)$$

where $\rho_W(\lambda) = \pi \cdot R_{rs}(\lambda)$ is the water leaving reflectance.

A^{ρ} ($g \cdot m^{-3}$) is the ratio of non-algal particulate absorption to the specific particulate backscattering coefficient, b_{bp}/SPM, and C^{ρ} (dimensionless) is the ratio of b_{bp}/SPM to the specific particulate absorption, a_p/SPM. The tabulated values for Sentinel-2A band 4 (664 nm) used are A=355.85 g·m^{-3} and C= 0.1728 (Nechad et al., 2010).

Results

On 2nd June 2016 in situ sampling was conducted in Alexandroupolis Gulf, measuring surface remote sensing reflectance and SPM concentrations in 19 stations (Tsapanou et al., unpublished data). In addition, simultaneous Landsat-8 OLI passage above the study area generated Landsat-8 derived R_{rs} from which we then estimated surface SPM values at the same sampling stations, by applying the same algorithm proposed by Nechad et al. (2010) for the red band.

Here, the remote sensing reflectance values derived from Sentinel-2A products, R_{rs}(664) from June and December 2016, respectively, are shown along with the Landsat-8 OLI-derived R_{rs}(655) estimations and the in situ R_{rs} in Figure 1. The estimations of Sentinel-derived R_{rs} are very similar to the in situ R_{rs} measurements, with Landsat-derived estimations to show a slight overestimation from both Sentinel-2A and in situ measurements. We assume that this overestimation deviation is because of the general low SPM concentrations that prevailed in June 2016, since at the positions with the highest SPM values a convergence is observed.

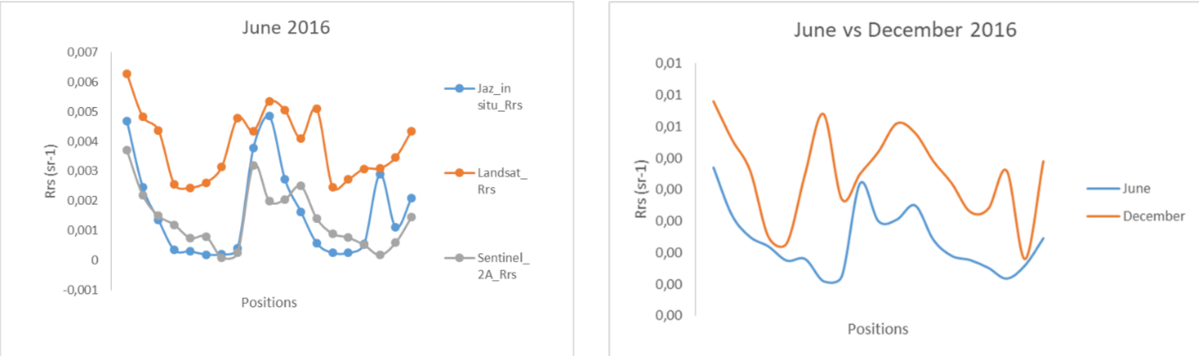

Figure 1. a) MSI-derived, OLI-derived and in situ R_{rs} values for the 19 sampling stations along the Alexandroupolis Gulf in June 2016 and b) MSI-derived R_{rs} values in June and December 2016.

Sentinel-2A image from June 2016 generated surface SPM concentrations between 1 mg/L and 15 mg/L, whereas in December's image surface SPM reached up to 30 mg/L. Landsat-8 image processing (22/06/2016) has shown relevant SPM values to Sentinel-2A estimations (i.e. 1-16 mg/L). The simultaneous to Landsat-8 passage in situ SPM data comes to better agreement with the Sentinel-2A values (R^2=0.88) (Figure 2); this indicates greater Sentinel-2A accuracy, although verification, with simultaneous to Sentinel crossing in situ data is needed. Additionally, the highest values appear in front of the Evros delta mouth, showing obvious influence from the river discharges, while the lowest values are estimated offshore.

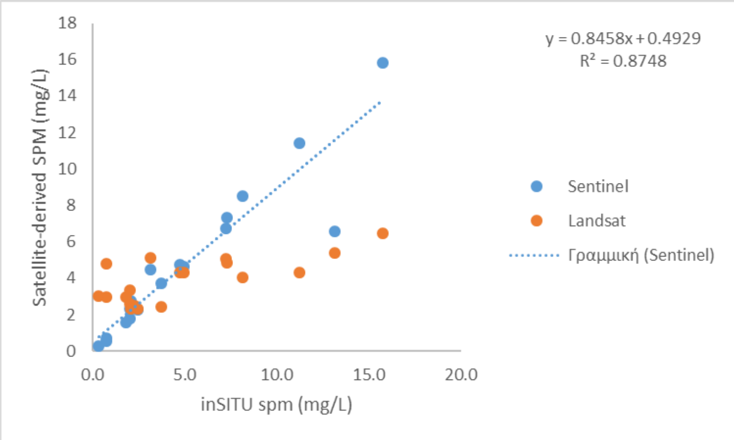

Figure 2. Satellite derived SPM concentrations against in situ SPM measurement in June 2016 in Alexandroupolis Gulf.

Conclusions

The new Sentinel-2A products of a 10-m spatial resolution and its 5-day revisiting period shown a good correlation with and in situ SPM measurements in Alexandroupolis Gulf, in June 2016, more accurate from the relative Landsat-8-derived values. These products promise access to both a quantitative and qualitative remote sensing data flow to acquiring frequent satellite-derived SPM information, which can be accordingly validated in filling older data gaps and, thus, contribute to a cost-efficient way for continuous coastal monitoring**.**

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