Sentinel-2 for monitoring coastal waters: valuable support to EU directives.

Giulio Ceriola, Paolo Manunta, Planetek Italia S.r.l, Bari (Italy);
Roberto Cossu, European Space Agency – ESA (ECSAT, UK)

The present study was performed under the ESA funded **Integrated Coastal Management for Mediterranean** (**ICWM for MED**) project, to perform a first evaluation of the Sentinel-2 capabilities in **coastal water monitoring**, in particular to exploit its spatial resolution near the shoreline for supporting monitoring duties for **European Union's Directives** and national legislation concerning water quality.

Effective and meaningful monitoring of coastal sea areas from satellite requires high resolution mapping with a regular time frequency, due to the reduced scale at which relevant phenomena occur. Examples are environmental agencies which really need a spatial resolution of <100m from remote sensing (Ceriola et al, 2013), or private engineering companies which need to monitor the effects of dredging narrow sea bottom. Successful applications with very high resolution (VHR) images have been performed for mapping turbidity and total suspended matter based on algorithms developed for medium resolution sensors further re-calibrated (e.g. Ceriola et al (2014). The present work included a preliminary evaluation of the performances of a set of algorithms for retrieving detailed maps of **Turbidity** and **Chlorophyll-a** (Chl-a) in two coastal areas in Italy.

EU directives on coastal areas

European Union issued several directives impacting directly or indirectly coastal areas:

- ✓ Water Framework Directive (WFD)
- ✓ Marine Strategy Framework Directive (MSFD)
- ✓ Recommendation on Integrated Coastal Zone Management
- ✓ Bathing Water, Habitats (Natura2000), …

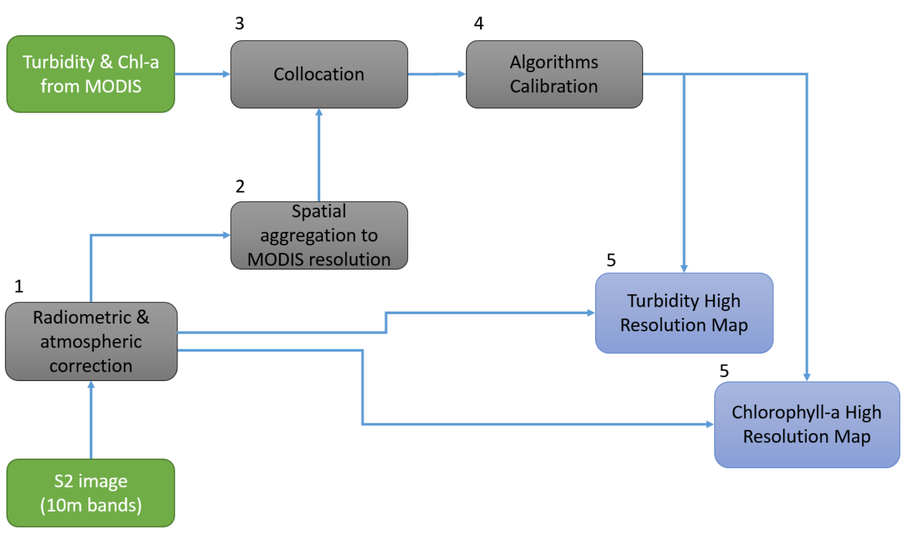
Such directives include the need to evaluate and monitor the water ecological and quality status e.g. by a series of indicators (WFD) and descriptors (MSFD) which in turns require a set of water quality (WQ) parameters to be regularly measured.

EU countries converted such directives into national laws assigning to national and regional authorities the duty to make such measurements which are mostly taken by traditional in situ campaigns with limited spatial and temporal capabilities.

Algorithms based on S2

Sentinel-2 (S2) provides an interesting trade-off between revisit time (5 days with full constellation at the equator) and a relatively high spatial resolution of 10m. In this case study we performed a preliminary analysis to evaluate the performance of S2 10m bands for obtaining Turbidity and chlorophyll-a concentration in the Ionian Sea (Italy).

A S2 MSI image acquired on 24/08/2015 was selected from the available dataset and a MODIS/AQUA L2 Ocean Colour product acquired about 1 hour before was also used for calibration/comparison. The illustrated methodology was applied.



Algorithms selected from literature for retrieving Turbidity and Chl-a

Nechad et al. (2009), Dogliotti et al (2015)

$$Turb = \frac{A * Red}{1 - Red/C} + B$$

A,B,C: calibration coefficients

Wong et al. (2008)

$$log(Chl\ a) = A_0 + A_1 * \left(\frac{\log(Blue)}{\log(Red)}\right)$$

A_0,A_1: calibration coefficients

The S2 image was converted to remote sensing reflectance and the Dark Object Subtraction method was used in order to perform a basic atmospheric correction (Chavez, 1988). The S2 red band were resampled at 1km and co-registered with a the turbidity maps obtained by applying the algorithms reported in the right box – validated in the Italian seas by Ceriola et al. (2013) – to the MODIS 667nm band. Then the original coefficients were tuned by means of a non-linear regression between the resampled S2 red band and the MODIS Turbidity. Finally they were used for applying the calibrated Nechad algorithm to the S2 red band at 10m.

A similar approach was used for Chl-a, considering an algorithm described by Wong et al (2008), applied to the red and blue bands of the S2 MSI. In this case the reference Chl-a map was the MODIS chlor_a L2 product.

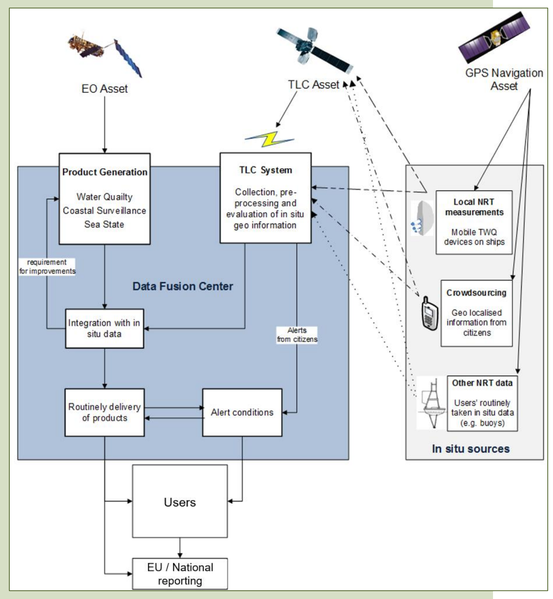
ICWM for MED project

ICWM integrated solution includes continuous monitoring for Integrated Coastal Water Management exploiting three space assets: Satellite Communication, Satellite Navigation and EO.

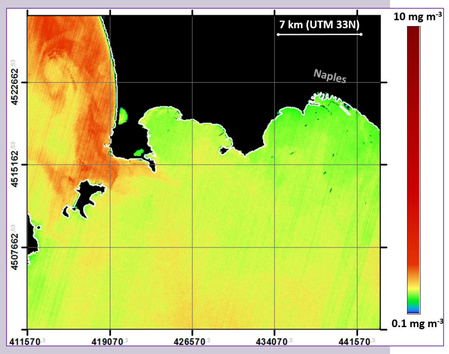
It includes 3 processing chains: WQ monitoring, Coastal Surveillance (illegal discharges activities from ships) and Sea State monitoring (ship detection and winds/wave motion).

Satellite Navigation asset is used by the Tracking Water Quality (TWQ) devices onboard small ships and by the mobile applications (crowdsourcing).

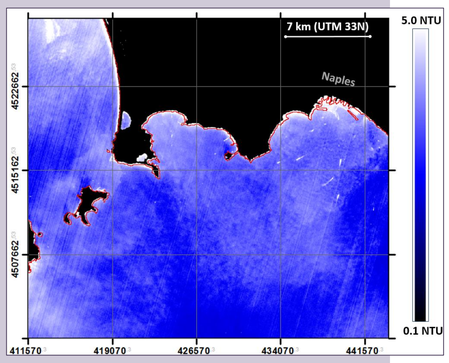
Satellite Communication is used for collecting information from the TWQ.

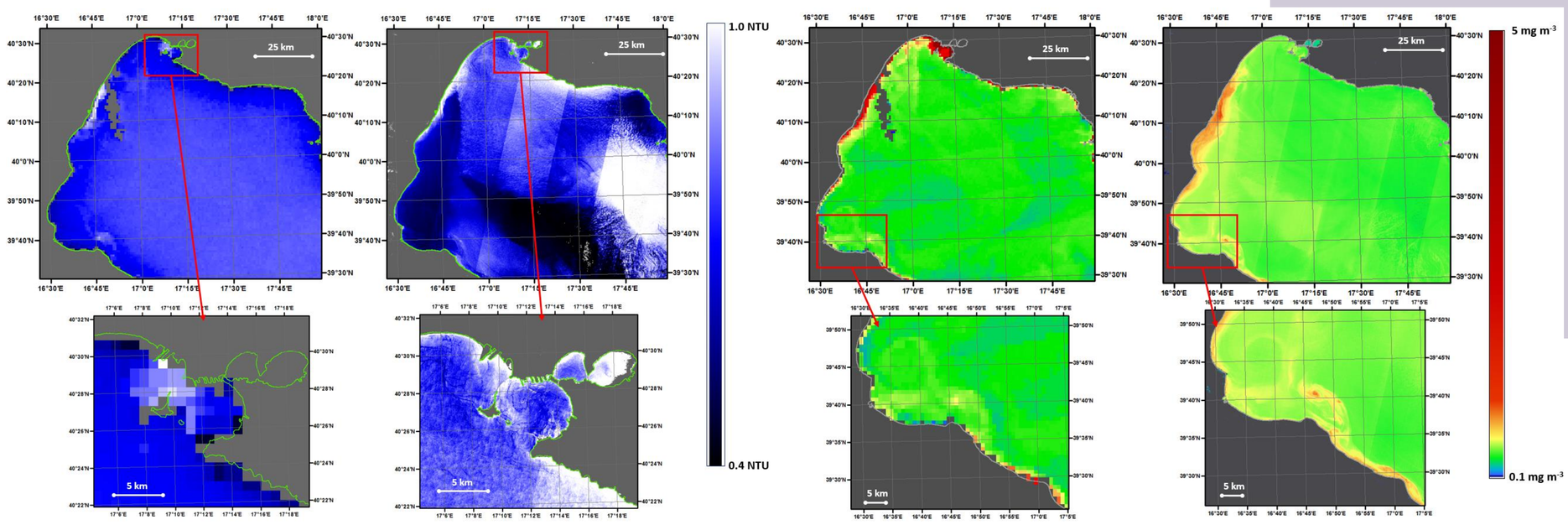


The depicted methodology is also implemented into the **ICWM for MED system** in order to enable automatic mapping over the area of interest of the project. During a Pilot demonstration validation of the algorithms will be applied using in situ measurements provided by regional authorities (ARPA Campania).



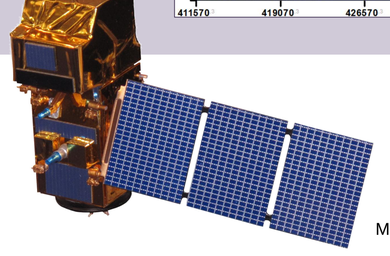
Chl-a (top) and Turbidity (bottom) maps in the north of the Naples Gulf at 10m generated from a S2 acquired the 18/12/2015. White/red lines: coastline.





Turbidity maps from MODIS AQUA and Sentinel-2
Left column: Turbidity map obtained applying the Nechad algorithm to a L2 MODIS/AQUA scene acquired the 24/08/2015 over the Gulf of Taranto (top), with a zoom on the Taranto harbour (bottom). The 1km resolution is not able to correctly map the sea area nearby the coastline (green).
Right column: Turbidity map obtained applying the recalibrated Nechad algorithm to the red band (10m) of the S2 image acquired 1 hour later (right), and the Taranto harbour (bottom).

Chlorophyll maps from MODIS AQUA and Sentinel-2
Left column: Chl-a map corresponding to the chlor_a standard product from a L2 MODIS/AQUA scene acquired the 24/08/2015 over the Gulf of Taranto (top), with a zoom on the south near a river mouth (bottom). The 1km resolution is not able to correctly map the sea area nearby the coastline (gray).
Right column: Chl-a map obtained applying the recalibrated Wong algorithm to the red and blue bands (10m) of the S2 image acquired 1 hour later (right). In the bottom inset, the plume originates from the river mouth.



Model of a Sentinel 2 satellite

Ionian Sea case study

The area of the Ionian Sea covered by the image is characterized by oligotrophic waters with usually very low chlorophyll and turbidity values. However there are some small rivers along the western and southern coast that regularly increase their values. In the northern part there is the harbour of the Taranto city which shows higher turbidity that in some cases can spread in the surroundings.

The S2 maps both for Turbidity and Chlorophyll in their complex show a good agreement to the MODIS ones - apart a sun glint that strongly affects some areas - catching areas with increased values. In particular the 10m spatial resolution of the S2 is able to better discriminate and characterize the areas in proximity of the shoreline both in the harbor and in the southern coast for a plume due to a small river after a rain event.

This case study clearly shows the **potential of Sentinel-2 MSI 10m bands** to provide higher spatial detail of **turbidity and chlorophyll**. Specific algorithms will be further improved in order to reduce the impact of sun glint and the striping effect (which is related to the geometry of the MSI detector configuration in which detectors are staggered on the focal plane array leading to real geometrical differences).

Currently such algorithms are implemented in the ICWM project for demonstrating the utility of Sentinel-2 derived maps at the spatial resolution of 10m.

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ICWM project: https://artes-apps.esa.int/projects/icwm-for-med