ON THE POTENTIAL OF ROBUST SATELLITE TECHNIQUE FOR COASTAL WATER QUALITY MONITORING

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ABSTRACT

The coastal marine environment is a complex and dynamic ecosystem, strongly subject to environmental degradation, because of both natural and anthropogenic causes. In the last years several remote sensing-based approaches for coastal water monitoring and investigation have been proposed. Among the few satellite packages useful for these purposes, the Moderate-Resolution Imaging Spectroradiometer (MODIS), aboard the Earth Observing System (EOS) Terra (since 2000) and Aqua (since 2002) satellites is one of the most used. It is the only one, still operational, that assures a long historical series of data with a good trade-off between spatial and temporal resolution, as well as an adequate spectral resolution in the visible portion of the electromagnetic spectrum. One of the main limit of the MODIS-based Ocean Color (OC) products is their low sensitivity to the retrieved parameters in shallow waters, where the signal at the sensor is influenced also by bottom reflectance. To overcome these limits, as well as to better identify the actual sea water status for a specific region of the interest, in this work we implemented the Robust Satellite Techniques (RST) approach on long-term (i.e. ten years) historical series of MODIS OC products. In detail, the parameters investigated by RST was the Chlorophyll-a (Chl-a) concentration, while the region of interest was the Ionian sea water off the coast of Basilicata region (southern Italy), in the Gulf of Taranto. Achieved results shown in this paper confirm that RST, analyzing the historical behavior of the signal at pixel level, is capable to detect long term trend of the investigated parameter as well as its medium/short temporal changes, allowing for a recognition of the most exposed areas as well as for a timely identification of any possible critical situation.

INTRODUCTION

The marine coastal area environment is a primary resource for humans, as it often constitutes a source of transport, food, energy and materials, as well as of recreational and residential settlements for populations (1). This is why more than 40% of world's population lives within 150 kilometres of the coast (2). This high level of anthropogenic concentration coupled with natural hazards and climate changes caused strong pressures and situations of degradation for the coastal marine environment (3). In such a context, it is fundamental implementing a monitoring system able to guarantee continuous observation as well as a more rapid detection and timely predictions of the impacts of natural hazards, climate change and human activities on the health of marine and estuarine ecosystems (3). Considering that the main essential coastal ecosystem variables, which usually exhibit a broad range of time-space scales of variability, include variables of different nature, such as: geophysical (temperature, salinity, currents, waves, sea level, shoreline position, bathymetry), chemical (dissolved inorganic nutrients, dissolved oxygen, pCO2, pH), biological variables (fecal indicators, phytoplankton biomass, benthic biomass), and biophysical (bio-optical properties the need for a multi-scale, multi-disciplinary monitoring system is quite evident (3).

Water quality monitoring of shallow waters may be guaranteed both by in situ and satellite remote observations (4). While in situ measurements can provide accurate information but with a small spatial-temporal scale, satellite data (which are often free and easily accessible on the web) may assure large spatial and temporal scale, with less logistic and economical efforts. In addition, if appropriate analysis techniques are used, they will also be able to provide timely information on critical situations useful to reduce the vulnerability of the areas most exposed. Shallow waters quality depends on the interaction of three main important bio-optical parameters such as: the Chlorophyll-a (Chl-a), the dissolved organic matter (Cromophoric Dissolved Organic Matter - CDOM) and the solid suspended matter (SSM) (5). Among them the chlorophyll concentration will be analyzed in more detail in this paper, because, being strictly related to phytoplankton, it is the parameter most related to the water quality; in fact the excessive growth of phytoplankton biomass, produces eutrophication (e.g. anoxic conditions) causing damage to the marine environment (i.e. fish death).

Starting from the Coastal Zone Color Scanner (CZCS) different satellite sensors have been used for the estimation of Chl-a among other Ocean Color Products (4). At this moment, the one, still operational, assuring the best trade-off between spatial and temporal resolution is the Moderate-Resolution Imaging Spectroradiometer (MODIS) aboard the Earth Observing System (EOS) Terra (since 2000) and Aqua (since 2002) satellites. In addition, the large MODIS OC product archive allows for a long-term trend analysis of the produced outputs too. In the case of the MODIS OC product, the OC3M (Ocean Color 3 Bands Modis) algorithm (6) has been used for the estimation of Chl-a concentration. This algorithm exploits three MODIS bands differently related to the level of Chl-a concentration: R_{443}, R_{488}, R_{547} (where R_{xxx} refers to the Remote Sensing Reflectance at xxx MODIS wavelenght), looking for the the maximum of two band ratios MBR (Maximum Band Ratio): R_{443}/R_{547} and R_{488}/R_{547}. The main limitation of this algorithm is that, being developed to operate at a global scale, it often shows a low sensitivity when applied to the shallow waters, because in the coastal area intrinsic factors (hydromorphological and weather conditions) of the area of interest affect the measurements (6).

The Robust Satellite Techniques (RST – (7,8)) approach, taking into account of the historical behaviour of the signal at pixel level, may help in limiting these effects. RST is based on a preliminary analysis of a historical data set of this MODIS data/products, co-located in space-time domain, in order to characterize the expected behaviour of the signal under specific conditions of observation. Then any significant statistical deviation from this values, taken into account also the signal natural variability, is detected as an anomaly. In this way it is also possible to determinate the months of the year characterized by higher values of the parameter of interest and areas subject to greater potential risk of eutrophication.

In particular, the region investigated by RTS is the Ionian Sea along the Basilicata coasts in the framework of the IOSMOS (IOnian Sea water quality MOnitoring by Satellite data) project activities. IOSMOS is a project for European Transnational Cooperation, co-founded by Basilicata Region in the framework of ERDF (European Regional Development Fund) Operational Program 2007-2013. Preliminary results of this study will shown and discussed in this paper.

DATA AND METHODOLOGY

RST approach has been applied in this work on long-term historical series of MODIS OC Chl-a product. RST is a general change detection methodology, which has been already applied for the detection and monitoring of different natural and environmental hazards also in coastal areas, as for example for oil spills detection (9). One of the objective of RST is deriving the historical signal behavior (both in terms of expected values and natural variability) of each single pixel in the observed scene, by analyzing multiyear historical series of homogenous satellite data. Then, any possible anomaly is detected by implementing the ALICE (Absolutely Local Index of Change of the Environment) index:

$$\otimes_V (x,y,t) = \frac{V(x,y,t) - \mu_V(x,y)}{\sigma_V(x,y)} \qquad (1)$$

where V(x,y,t) represents the investigated signal (e.g. the *Chl – a concentration* product in this specific case) and, $\mu_V(x,y)$ is its temporal mean and $\sigma_V(x,y)$ its normal variability, both computed by analysing at pixel (x,y) level, historical series of satellite imagery co-locate in the space-time domain. For its construction, the ALICE index provides an identification of the deviation of the measured signal from its unperturbed condition, taking into account its natural variability.

During the analysis carried out in this work, the investigated signal, as already said, was the Chl-a concentration (mg/m3) derived applying the OCM3 algorithm to MODIS radiances. To implement such a methodology for the area of interest, the first activity carried out was the generation of the historical time series. About 11000 MODIS OC Level 2 data in the period 2003 – 2012 have been dowloaded from NASA OC archive (http://oceancolor.gsfc.nasa.gov/cgi/algorithms.cgi/). Such a product contains, among others, information about different the Chlorophyll-a (Chl-a) concentration at a spatial resolution up to 1 km. A spatial and "spectral" sub-set has been then performed on these data, extracting Chl-a maps for an area centered on the Gulf of Taranto (Ionian sea, Southern Italy). Specifically an area of 221 pixels x 171 lines (Corners: UL 40.7N16.4E; LR 39N18.6E) has been considered. Then, on these data-set, the Robust Satellite Techniques approach has been implemented, stratifying data on a monthly base. This means that, to compute the reference means (i.e. temporal mean and standard deviations) of August, all the MODIS Chl-a data computed for August 2003, August 2004, ..., August 2012, were collected together, and the same was performed for the other calendar months. In this way, the first results we achieved was the identification of the multi-year seasonal trend of chlorophyll concentration during the 2003-2012 period. Then a similar analysis has been performed for each of the considered years looking for any deviations from the detected trend. Finally, by implementing the ALICE index at different temporal scale, we moved from a long-term analysis to a medium/short term investigations.

RESULTS

By the long term analysis it was possible to determine the seasonal trend of the chlorophyll concentration for the investigated area. Following RST approach prescriptions, indeed, for each calendar month the temporal mean and the standard deviation of the Chl-a concentration product [mg/m^{3}] have been computed for the 2003 – 2012 period. For sake of brevity, in Figure 1 some Ionian sea monthly chlorophyll-a maps are shown. The maps show that the sea water in the Gulf of Taranto area are characterized by oligotrophic condition all over the year, except values greater than $1 mg/m^3$ near coastal areas, especially during the late winter. In addition, the analysis of these maps allows for an identification of the seasonal trend of the Chl-a for the investigated areas.. The highest Chl-a values occur during the winter season (Figure 1 a and d) when the enhanced vertical instability and run-off increase nutrients elements concentration and circulation (10); the lowest values occur during summer period ((Figure 1 b and c), when these effects are less present. These outputs are in line with those already achieved by other independent works (10).

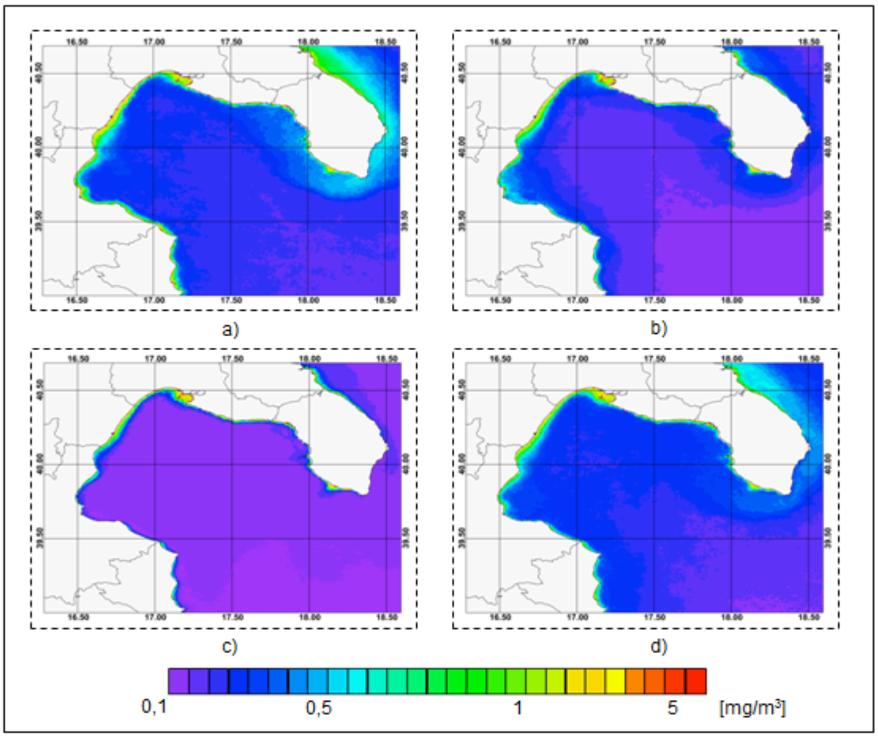

Figure 1: Temporal mean (RST-based) Chl-a maps for: a) February 2003-2012; b) May 2003-2012; c) August 2003 – 2012; d) November 2003 - 2012

The long term analysis allows us for a deeper investigation at different temporal scales. As an example, in figure 2 is plotted the trend of Chl-a values averaged over the investigate area for all the months of February from 2003 to 2012. To better understand the relevance of the signal fluctuations, on the same graph the RST multi-year February mean and the twice standard deviation interval are also reported.

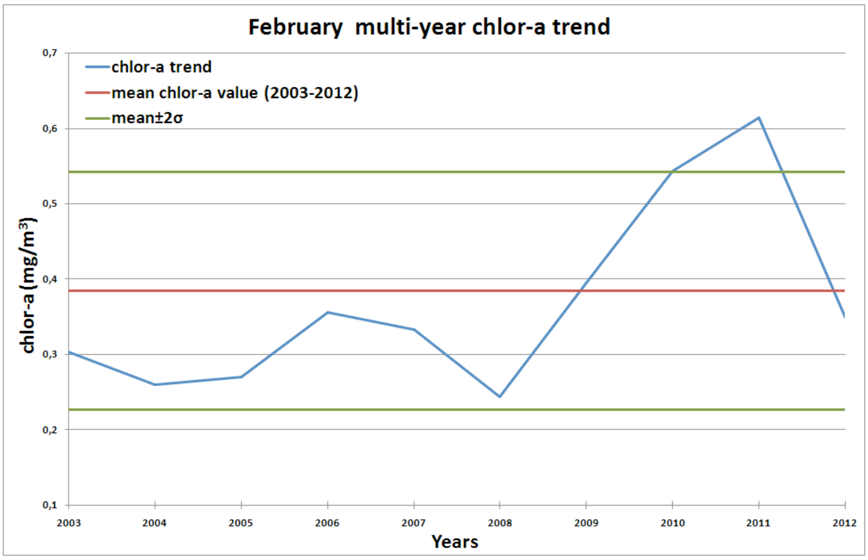

Figure 2: (Blue line) Yearly variations of the February Chlorophyll-a concentration value averaged over the investigated area. (Red line) The RST multi-year (February 2003-2013) Chlorophyll-a mean value averaged over the investigated area while the two green lines indicated the twice standard deviations interval.

From the analysis of figure 2, it is possible to note an increase of Chl-a February concentration starting from 2008, with a clear and significant statistical excess of the signal during February

2011. Such a result clearly explains both RST approach philosophy and capability. An anomaly, which usually represents a deviation from a normal condition, can be detected only if the actual "normal" condition have been previously identified together with the natural variability of the investigated signal. By such an study, we moved also to medium/short term investigation, computing first the ALICE index considering the February 2011 Chl-a map (Figure 3a) and then the daily February 2011 Chl-a maps as the investigated signal (Figure3b).

In figure 3a the ALICE Chl-a map of February 2011 is reported. As it can be seen large areas of the Gulf of Taranto show large deviation (in term of Signal/Noise ratio) from the normal conditions, with an effect more evident close to the coastlines, especially in the southern-western areas. Moving to daily ALICE maps, for sake of brevity in figure 3b is reported just that achieved for Chl-a maps of 05/02/2011 at 12:30, where again, extreme anomalous Chl-a values are detected, in agreement whit those detected in the monthly map.

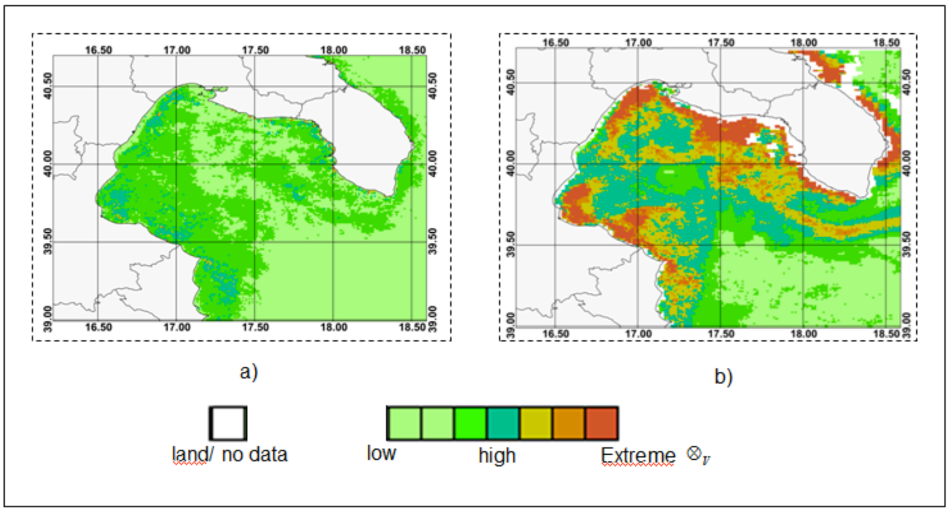

Figure 3: a) Chl-a ALICE map of February 2011; b) Chl-a ALICE map of 05/02/2011 12:30 GMT

Obviously, this is just a preliminary result, further investigation are in progress now to better understand both the nature of such a signal, which may be related to an excess of solid suspended matter as well as to an algal bloom, and if the same signal is present in other February 2011 data

CONCLUSION

In this work the potential of RST approach for the analysis of sea water quality parameters have been assessed. In particular, ten years of MODIS Ocean Color Chlorophyll-a concentration data covering the area of the Gulf of Taranto (Southern Italy) have been analyzed. This analysis, carried out in the framework of the IOSMOS project, have first allowed for the identification of the seasonal trend of chlorophyll concentration. In particular, it was possible to distinguish two phases characterized by an opposite behaviour: the highest values occur from November to April, because of the enhanced vertical instability and run-off increase nutrients elements concentration and circulation; the lowest values occur from May to October, when these effects are less present. Then, exploiting RST potential, we moved from the multi-year analysis towards a monthly and daily scale analysis, identifying several critical situations in terms of Chl-a concentration.

Such good results need to be further assessed by other investigations, also by comparing such an achievements with in situ measurements. Anyway, considering the intrinsic exportability of RST both on other parameters and geographic location, they seem to indicate that it could provide reliable and accurate information about sea water processes.

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