Chapter 14
Coastal Marine Environment Monitoring Using Satellite Data Derived from MODIS Instrument

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Abstract The quality of marine environment has a vital importance for the sustainable future of the Earth. On the other hand, the human activities, the sea commerce and transportation, affect significantly the marine environment especially in coastal areas, port areas, and the sea corridors. These induced activities impose contiguous and accurate methods for marine environment monitoring. Nowadays, modern satellite instruments gather data and the relative products derived from them can be used as an alternative, robust, and accurate way to monitor many basic marine parameters such as chlorophyll, sea surface temperature (SST), euphotic depth, dissolved organic matter and examine their long-term (climatic) tendencies. This study comprises an effort to assess the accuracy of satellite products, comparing them with relative ground-based measurements and it also focuses on provision of satellite-based mean variations on monthly basis regarding two important marine parameters (Chlorophyll-a and SST). In this study, available measurements of two different ports are used, i.e., the port of Bar in Montenegro and the port of Burgas in Bulgaria, which are partners of Transnational ENhancement of ECOPORT8 network (TEN ECOPORT) project.

14.1 Introduction

The quality of marine environment affects importantly the quality of natural life in many direct and indirect ways. It is essential and for this reason many physical parameters and indices are used to monitor changes and tendencies in different spatial and time scales. Additionally, estuaries and coastal waters (especially when they are

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located nearby cities and/or port areas) can be considered as the most highly vulnerable marine areas (Urquhart et al. 2013).

Nowadays, the satellite remote sensing of the marine environment provides unique information and large datasets of a wide variety of parameters in many different spatiotemporal scales even in areas (such as sea areas), where in-situ measurements are sparse and difficult or almost impossible to perform. But, it is possible to monitor many sea areas and calculate variations of their basic physical parameters using satellite produced datasets. In this study, we examine sea surface temperature (SST) and Chlorophyll-a concentration using such data.

More specifically, the SST is considered as an important factor that affects the physical, chemical, and biological characteristics of the sea. The SST is highly dependent on the solar energy, the dynamics of the sea water, the precipitation, and the season.

The other parameter, Chlorophyll-a, is the main indicator of eutrophication and high concentration, which indicates increasing organic production. Chlorophyll is the green pigment located in chloroplasts and thylakoids and it has an important role in the process of the photosynthesis.

There are two basic scopes of this study. Firstly, we assess the accuracy of selected satellite derived products about SST and Chlorophyll-a comparing them with available relative datasets from the ground-based stations of the ports of Bar and Burgas. A second basic scope is to calculate mean monthly variations of the examined marine parameters using satellite-based datasets for a period between the years 2000 and 2012 for both SST and Chlorophyll-a because it is well known that the long-term interannual variability of basic physical parameters is of crucial importance in climatic studies (e.g., Mesias et al. 2007; Rivas 2010).

14.2 Data and Methodology

14.2.1 Ground-based Measurements

Quality checked datasets of SST and Chlorophyll-a on a monthly basis are available thanks to the Institute of Marine Biology, University of Montenegro (BIOKOTOR) and Port Authority of Burgas, partners of TEN ECOPORT project.

More specifically, BIOKOTOR in collaboration with the Port Authority of Bar (Montenegro) provided monthly data from May 2011 to February 2012. These data were selected from two different stations, one inside the marine of the port of Bar and the other one mile outside the port; every month and their mean value is considered representative on monthly basis for each one of the examined parameters. The second dataset of ground-based measurements at the area of Port Authority of Burgas is coming from three different stations (their mean monthly values) for the period between February and December of 2012.

14.2.2 Satellite Data

For the needs of the study we collected and used satellite products about SST and Chlorophyll-a. The original satellite datasets came from NASA's MODerate resolution Imaging Spectroradiometer (MODIS) instrument on board of Terra and Aqua satellite platforms and they are widely used in a great variety of studies (e.g., Shang et al. 2011; Urquhart et al. 2013; Li et al. 2013; Brewin et al. 2013). We preprocessed the initial data so that to be on monthly basis in the spatial analysis of 9 km at 11 μm (day and night) in degrees of Celsius (°C) for SST and for Chlorophyll-a estimations (in mg/m^3) at 4 km spatial resolution.

14.2.3 Accuracy Assessment of Satellite Data Using Ground-based Measurements

To compare the two different types of data, the first important procedure is to identify the accurate spatial and temporal correlation between the two main types of data (satellite and ground based) so that to conclude about the accuracy of the satellite datasets. Both types of data are spatiotemporally correlated and the results of these correlations are provided in Fig. 14.1.

It is mentioned that the available measurements are coming from two ground-based stations in the port of Bar where both stations are inside the pixel dimensions of satellite data (9 km for SST estimations and 4 km for Chlorophyll-a). For this reason, the pixel values of the satellite data are correlated with the mean values of the relative ground-based measurements. In the case of the port of Burgas, the data come from three ground-based stations with valid measurements and their mean values are correlated with the relative satellite ones. The validation period for the port of Burgas is from February to December 2012 and for the port of Bar is from May 2011 to February 2012. It is mentioned that both the monthly values of SST and Chlorophyll-a satellite are satisfactorily correlated with the ground-based ones (Fig. 14.1). The correlation is higher in the case of SST monthly values than in chlorophyll concentration. It is concluded that the range of values for SST has the same order of magnitude in both the port areas but for the Chlorophyll-a concentration there is almost one order of magnitude higher in the port of Burgas relatively to the port of Bar. Table 14.1 presents that the correlation coefficient (R^2) for the SST is higher for Burgas compared to the relative value at the port of Bar but both of them can be characterized satisfactory enough. The mean absolute error (MAE) is calculated at about 1.8 °C in both the port areas. The root-mean-square error (RMSE) is also below 1 °C (about 0.5 °C) amplifying the conclusion about the satisfactory correlation among satellite and ground-based monthly SST values.

Regarding Chlorophyll-a, the correlation coefficients (R^2) are lower than the case of SST. For Burgas port, the correlation coefficient is significantly higher

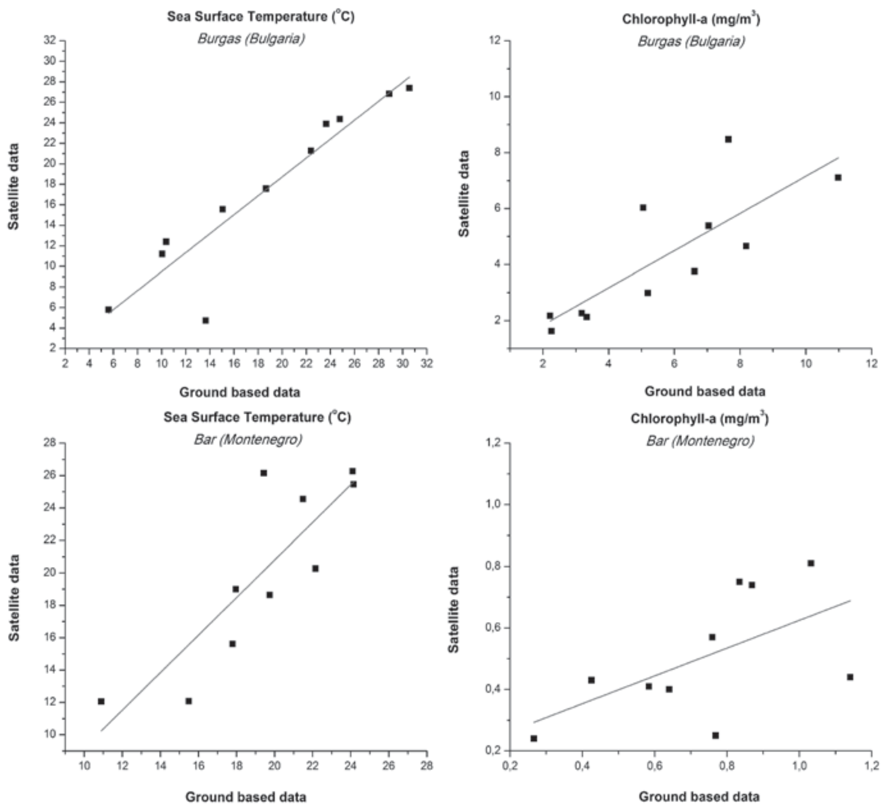

Fig. 14.1 Comparisons between satellite estimations and ground-based measurements in two port areas (the port of Burgas, Bulgaria, and the port of Bar, Montenegro)

Table 14.1 Basic statistics regarding the correlation between monthly satellite values and ground-based measurements for SST and Chlorophyll-a in both the examined ports

Location	Parameter	Adjusted R^2	MAE	ME	RMSE
Burgas (Bulgaria)	Chlorophyll-a	0.61	7.42	6.19	2.24
	SST	0.86	1.89	1.59	0.57
Bar (Montenegro)	Chlorophyll-a	0.26	0.71	0.71	0.22
	SST	0.69	1.85	0.28	0.59

than the port of Bar (Table 14.1). It is also noted that the MAE is slightly below 2 mg/m^3 in both the ports but the RMSE is higher for the port of Burgas, which means larger monthly deviations of ground-based monthly values in comparison with the relative satellite based.

14.3 Mean Monthly Variations

Considering the satisfactory accuracy of satellite data for SST and Chlorophyll-a, there are used monthly time series (from 2000 to 2012) to produce the mean monthly variations. Figure 14.2 concludes that the SST follows strictly the well-known-monthly changes of the incident solar radiation.

The same order of magnitude variations at the port of Burgas was also found in the study of Ginzburg et al. 2004, who used AVHRR satellite data to reveal interannual variations of SST for the whole Black Sea. It can also be noticed (Fig. 14.2) that there is a significantly smaller minimum for the SST in the case of Burgas port in comparison to the port area of Bar and the minimum temperature for the both ports is reached at the same month (February). There are higher mean monthly variations in the case of the port of Burgas than the relative variations in the port of Bar (Fig. 14.2). Regarding Chlorophyll-a, it is noted that there is a small decrease in mean concentration levels of Chlorophyll-a during summer and the first month of

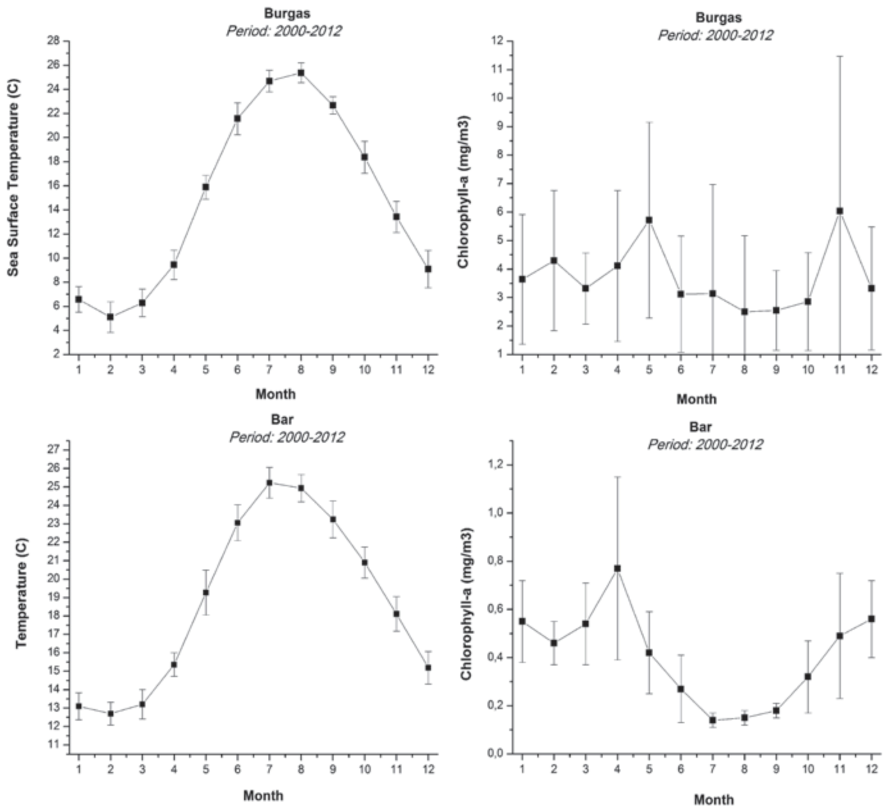

Fig. 14.2 Mean monthly variations for the period from 2000 to 2012 for the SST and Chlorophyll-a in the port areas of Bar (Montenegro) and Burgas (Bulgaria) using MODIS satellite datasets

autumn. It is also seen (Fig. 14.2) that the mean monthly Chlorophyll-a values are one order of magnitude higher for the port of Burgas relatively to the port of Bar.

It is important to mention the almost opposite monthly behavior of the two examined parameters. More specifically, in summer, the SST has the higher values annually but the concentration levels of the Chlorophyll-a are lower annually in the same season. Similar results have been found for other regions (e.g., Van De Poll et al. 2013) but it is mentioned that the type of the relationship between these two parameters is not always the same and affected importantly by local features of an area (Katara et al. 2008). The correlation coefficient (R^2) of these two parameters is 0.286 for Burgas and 0.76 for Bar, depicting a notable negative correlation although the small number of samples.

The statistical significance of the monthly differences (in the median values) for the two examined parameters is also tested. The analysis of variance (ANOVA) (Kruskal–Wallis test) hypothesis tests is implemented and the *p*-values (confidence interval: 99 %) and the results are provided in Table 14.2.

It is concluded that all the median monthly values in both of the examined parameters and ports are statistically different at a confidence level of 99 %. This conclusion indicates that there are important monthly variations of the examined parameters that can be owe to the changes of physical conditions (e.g., solar radiation) but also to the port traffic or sediments.

14.4 Conclusions

Firstly, this study is an effort to evaluate the accuracy of satellite-based products regarding two basic marine parameters (the SST and the Chlorophyll-a) using ground-based measurements for two case study areas (the port of Bar in Montenegro and the port of Burgas in Bulgaria). At a second stage, this study aims to provide the mean monthly variations of the examined parameters for a 13-year period (2000–2012) in the two study areas.

The main findings of this study are that the values of the statistical parameters (Table 14.1) regarding the correlation between monthly satellite estimations and ground-based measurements provide an overall satisfactory correlation for both the examined parameters (SST and Chlorophyll-a). This conclusion can be used as a robust argument that satellite products are characterized by enough accuracy to provide—at least—information about spatial and temporal tendencies and variations of these parameters.

Using the satellite-based data products, mean monthly variations of the SST and Chlorophyll-a are calculated and presented (Fig. 14.2). All the monthly differences are checked regarding their statistical significance using ANOVA nonparametric test and it is concluded that all the mean monthly values (in both of the parameters) are statistically different at 99 % confidence level.

It is also concluded an almost opposite monthly variation between chlorophyll and SST for both the port areas. More specifically, during the summer season the

Table 14.2 Results of ANOVA regarding the median values of the monthly satellite-derived datasets for the SST and Chlorophyll-a in the ports of Bar and Burgas

Location	Parameter	ANOVA (*p*-value)
Burgas (Bulgaria)	Chlorophyll-a	0.000
	SST	0.000
Bar (Montenegro)	Chlorophyll-a	0.000
	SST	0.000

SST reaches its maximum values annually but in the same season the Chlorophyll-a concentration is in their lowest levels for both of the port sea areas.

In the near future, we intend to analyze—for other subareas in the Mediterranean basin—spatiotemporal variations of the same parameters in order to identify how their spatial distribution can be affected by seasonality and large-scale circulations. We will also investigate the reasons of any interannual changes, the type, the intensity, and the nature of possible relationships among parameters that define the quality of the marine environment like SST and chlorophyll.

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