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APPLICATIONS OF SATELLITE REMOTE SENSING FOR MONITORING THE MARINE ENVIRONMENT IN THE BULGARIAN BLACK SEA ZONE

Violeta Slabakova, Atanas Palazov, Natalia Slabakova

Institute of Oceanology - Bulgarian Academy of Sciences
e-mail: v.slabakova@io-bas, palazov@io-bas.bg, n.slabakova@abv.bg

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Abstract: *Regular monitoring of the sea environment is exceedingly required for science, governmental organizations and private companies related to marine resource management, leisure activities and marine industry. The sources of point-based in situ observations that are commonly used for monitoring of marine environment can not always provide data with the required temporal and spatial regularity. These gaps can be filled in with data registered by satellite sensors which supply on operational basis measurements of many ocean geophysical parameters with great reliability and sufficient time frequency. Data from such observations can be used together with field measurements for sustainable exploration and exploitation of marine resources and for improving the accuracy of forecast of weather conditions, sea state and long-term climate changes. This paper aims to demonstrate the usefulness of some remote sensing techniques for monitoring of various marine processes and parameters, such as sea surface temperature, phytoplankton blooms, sea surface winds and marine pollution for the western Black Sea.*

Introduction

Bulgaria as a Black Sea nation had greatly depended on the marine natural (living and non-living) and economic resources. The coastal and offshore areas of our country are regions of a substantial importance from economical point of view as they are increasingly exploited for tourism, fishing, aquaculture, transport and other marine human activities. Different studies documented [1],[2] that during the past few decades the overutilization of coastal resources and anthropogenic pollution of the Black Sea have led to serious effects such as resource deterioration, environment pollution, ecosystem degradation. Comprehensive knowledge for the physical and biogeochemical processes of the sea, forecasting capacity, and the capability to assess environmental impacts is required in order to protect coastal and offshore waters. Moreover, it is necessary to understand ocean processes and properly assess the exploitable potential benefit of marine resources for long-term management and sustainable development of the Black Sea resources. This calls for regular observation and detailed study of the sea both spatially and temporary. The greater part of in situ observations that are commonly used for monitoring of the Bulgarian Black Sea waters are generally based on occasional ship measurements and in recent times – on the real-time measurements of the observing systems “Galata” [3] and “POMOS” [4] that can not always provide data with the required temporal and spatial resolution. These gaps can be filled in with data registered by satellite sensors which supply on operational basis measurements of many oceanographic parameters with considerable reliability and sufficient time frequency. Data from such observations can be used together with in situ measurements for sustainable exploration and exploitation of marine recourses and for improving the accuracy of forecast weather conditions, sea state and long-term climate changes. This paper aims to demonstrate the usefulness of some different remote sensing techniques for monitoring of various marine processes and parameters, such as sea surface temperature (SST), phytoplankton blooms, chlorophyll a (Chl a) distribution and sea surface winds for the Western Black Sea.

Satellite sensors and their potentials for marine research

Satellite remote sensing of the ocean has become available since late 1970s with the successful launch of the three NASA's satellites: the short live SeaSat (including mainly microwave sensors), Numbus-7 (carrying the first ocean color instrument - Coastal Zone Color Scanner) and TRITON–N, the first of NOAA series (carrying the Advanced Very High Resolution Radiometer which can measure SST). The success of these NASA’s missions led to demonstration how satellite data could be applied in oceanographic researches and to established “Satellite oceanography” as a specialism within the marine science [5],[6]. Nowadays, a great number of orbital satellites exist carrying different instruments for routine observations of the ocean surface and registration of the wide range of oceanographic parameters.

Global and regional scale weather and ocean features can be monitored by geostationary and polar orbiting satellites with sensors detecting radiation in several different portions of the electromagnetic spectrum. The satellite sensors used for monitoring the marine environment can be classified in respect to energy recourses as two basic types: active and passive (Fig.1). Passive sensors detect natural radiation emitted or reflected from the ocean surface in visible, thermal-infrared (IR) and microwave spectral windows. In contrast to passive sensors, active instruments use their own source of microwave energy for illuminating the water body and record “echo”.

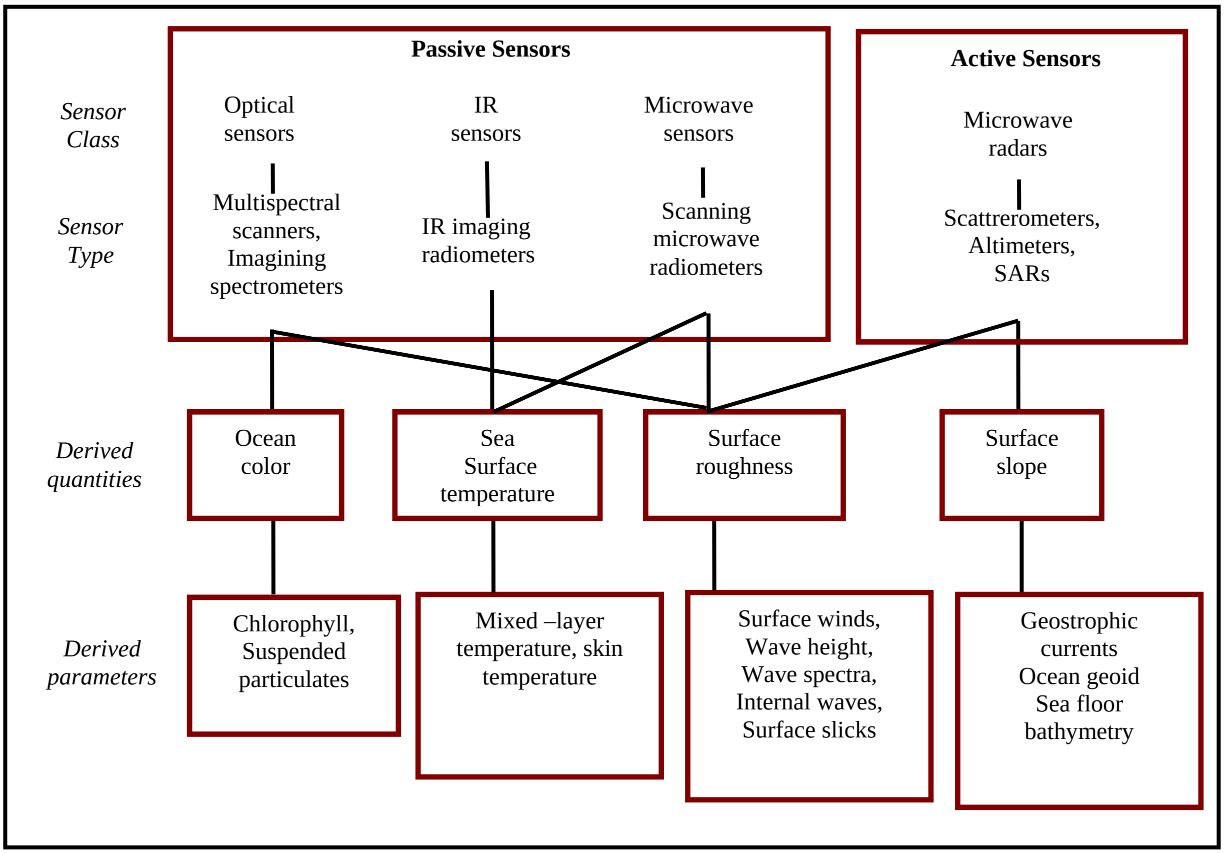

Fig. 1 Schematic illustration the different remote sensing methods and instruments used in marine research, along with their applications (after [7]).

In principle, there are four basic quantities of the ocean that can be observed from space using visible, infrared and microwave part of the electromagnetic spectrum (Fig. 1). These are:

- Ocean color, characteristic of the sea water optical properties. It is used to measure chlorophyll *a* concentration (the photosynthetic pigments of phytoplankton) considered as an index of phytoplankton biomass as well as suspended matter, yellow substance, marine pollution and water dynamics (currents, fronts).
- Sea surface temperature (SST*)*, one of the important geophysical parameters, providing the boundary conditions used for estimation of heat flux at the air-sea interface. Gyres, eddies, and upwelling regions can be detected using satellite derived SST measurements.
- Surface roughness, used to measure surface wind and wave from backscatter microwave power caused by wind on the sea surface.
- Surface slope, which derived from microwave altimeter measurements to study sea surface height anomaly (SSHA) and geostrophic currents.

This paper is focused on the part of the satellite remote sensing techniques for measurement of some of the above mentioned ocean parameters and respectively its applications for monitoring the Bulgarian Black Sea waters namely surface temperature, sea surface wind, phytoplankton blooms and chlorophyll a distribution.

Sea Surface Temperature

See surface temperature (SST) is one of the important geophysical parameters, providing significant information related to a wide range of the ocean marine processes and phenomena such as ocean currents, fronts, mesoscale eddies, and upwelling areas. Knowledge of the SST changes has been recognized as an important element of physical circulation and climate prediction models [8], [9]. SST is observed from space by infrared radiometry during cloudless conditions, using thermal infrared channels of the satellite sensor. The most widely used radiometers in oceanographic studies that can measure SST are: series AVHRR on POES satellites and MODIS both on EOS Terra/Aqua platforms. These sensors observed SST distribution at nominal spatial resolution at nadir 1.1 km and with accuracy of 0.5°C and better [10]. An example of an MODIS/AQUA scene is shown in Fig. 2.

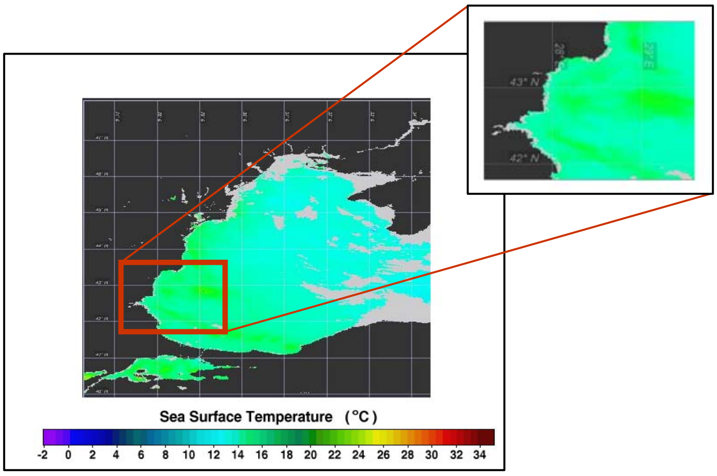

Fig. 2 MODIS/Aqua thermal infrared image of the Bulgarian Black Sea zone, 19 May 2009.

The in situ validation of the SST data derived from far infrared channels of the MODIS instrument was carried out for the Bulgarian sector of the Black Sea [11]. The obtained results indicated good agreement with MODIS mission requirements [10] and have been proved reliability of satellite data for future use and applications in various scientific researches and marine activities in the region (Fig 3).

One of the major advantages of the satellite remote sensing is its capability of ensuring the long-term observations of the ocean, land and atmosphere which are indispensable for monitoring and predicting climate changes. An example of digital data extracted from AVHRR imagery is a series of annual mean SST, illustrating the inter-annual variation of thermal structure over the Bulgarian Black Sea zone for the period of seventeen years (1991-2007). The data were clustered into two sub region in respect to the bathymetry and surface currents. The shelf region was defined with bottom depth less than 50m and offshore region was specified with bottom depth >200 m). The obtained results showed that SST increases in the both regions during the study period (Fig. 4, 5).

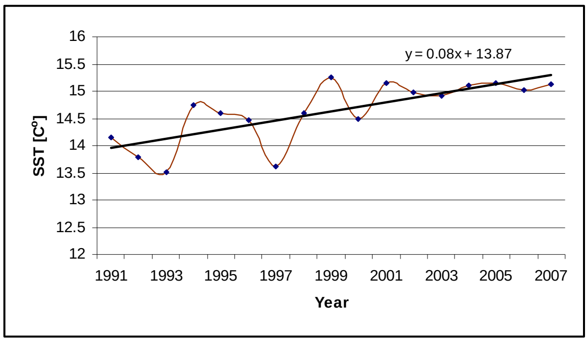

Fig. 4 Inter - annual observation of the SST variation in the Bulgarian shelf region from AVHHR data.

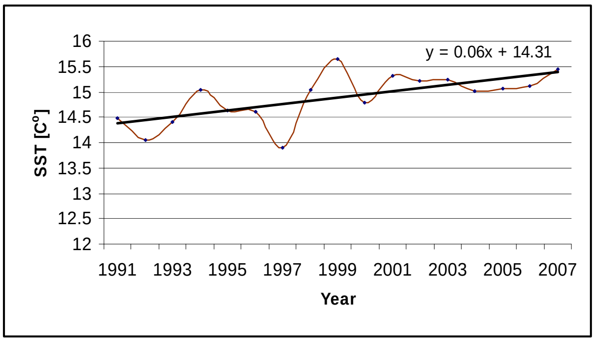

Fig. 5 Inter - annual observation of the SST variation in the Bulgarian offshore region from AVHHR data.

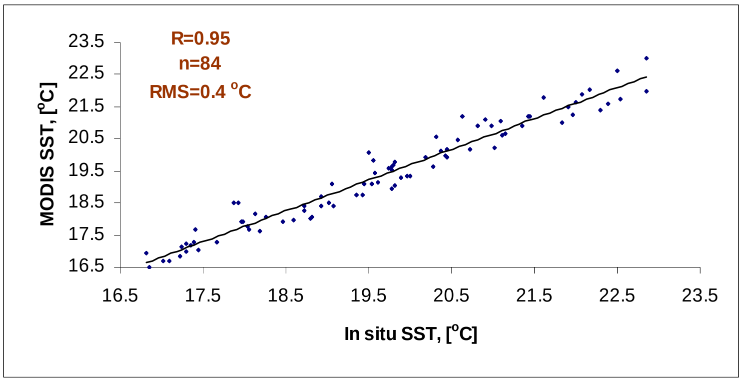

Fig. 3 Comparison between MODIS SSTs derived from split window algorithm and *in situ* measurements for the Bulgarian sector of the Black Sea.

Sea surface wind

Winds over the ocean play an important role in meteorology, oceanography and climatology. They affect air-sea variations in heat, humidity, gases and particles, regulating the crucial relation between the ocean and the atmosphere that establishes and supports the climate on regional and global scale. Therefore, the accurate forecasting of ocean surface winds contribute to good wave forecasts, which provide informativeness and safety in marine industry, navigation and other human activities in open and offshore seas. Wind speed and direction over the global ocean can be determined from space by radar scatterometers, such as SeaWinds on board the QuikScat and Midori -2 platforms and scatterometers on the ERS-1/2 satellites. Scatterometer observations estimate the wind vector at low spatial resolution of 50 km, 25 km and 12.5 km, with an accuracy of ±2 m/s in speed for the range 3-20 m/s and ±20° RMS in wind direction for wind speed ranging from 3–30 m/s. An example of QuikSCAT wind filed observation is shown in Fig. 6.

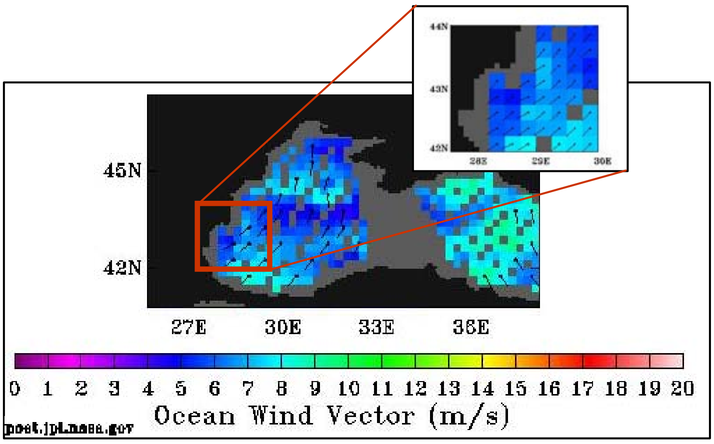

Fig 6. QuikSCAT wind vector filed observation for the study area 22 August, 2009 of the Black sea.

The performance of the latest QuikSCAT wind product (12.5 km) was evaluated by anemometer measurements acquired from meteorological station mounted on the earth gas exploration platform “Galata” in the study region [12]. For the moderate wind ranging between 3-15 m/s it was found that validation results correspond to the scatterometer mission requirements [13]. The values of the correlation coefficient and RMS error for the wind speed are 0.88 and 1.46 m/s, respectively (Fig.7). For the wind direction the good agreement is confirmed by high values of R = 0.96 and RMS error equal to 25° (Fig.8). Based on the performed analysis and obtained results, the assessment of the QuikSCAT wind product has been considered as successful and the scatterometer data reliable for further use and applications in various areas of scientific researches and marine industry in the region. However, ocean vector wind acquired by scatterometers has had too coarse resolution for some applications such as in coastal regions and in estuarine. In these regions only synthetic aperture radars (SAR) can provide high resolution images (30 m ground resolution) for quantitative measurements of mesoscale wind field [14], [15].

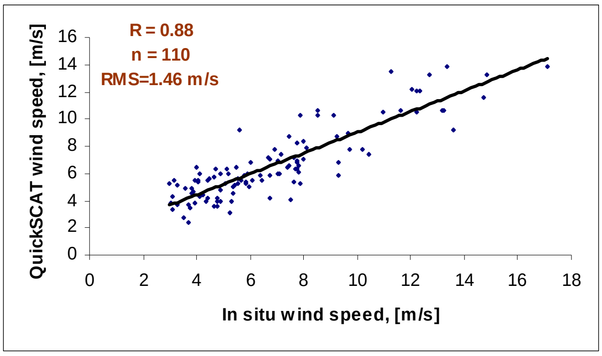

Fig 7. Scatter plots of QuikSCAT wind speed against in situ observations.

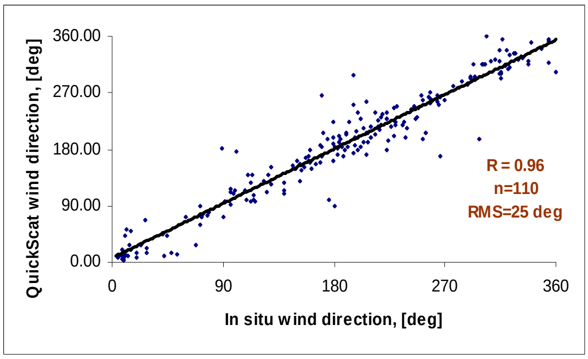

Fig 8. Scatter plots of QuikSCAT wind speed against in situ observations.

Chlorophyll a

An appropriate parameter for monitoring the marine ecosystems is a chlorophyll-a. It can be regarded as the total amount of phytoplankton biomass and measures of Chl a enables the monitoring of the mass generation of phytoplankton [16]. The ability of satellite sensors to extract plankton by imaging color of the sea water was established with launch of CZCS instrument in 1978. The most broadly used satellite optical systems by oceanographer that can measure marine optical properties are: SeaWiFS on OrbView 2 satellite, MODIS both on EOS Terra/Aqua platforms and MERIS instrument aboard ESA's satellite Envisat.

One of the main issue of studying distribution and concentration of Chl a is the operational monitoring of phytoplankton blooms. The blooms can color sea surface waters over large areas and can therefore be imaged from space. An example of intensive phytoplankton bloom registered by MODIS instrument over the Northwestern Black Sea during May, 2009 is shown in Fig. 9.

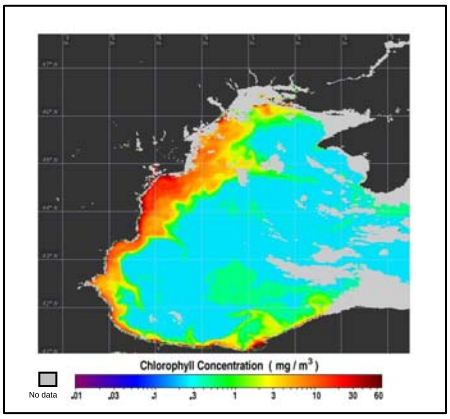

Fig. 9. Image of bloom event observed by MODIS over the Northwestern Black Sea on 09 May, 2009.

On the other hand, the remote sensing optical measurements are valuable tool for studying of the seasonal and inter-annual variation of the chlorophyll a concentrations [17]. An example of inter-annual variation of surface Chl a in the study area for the period of nine years (1998-2006) extracted from SeaWiFs imagery is shown in Fig.10.

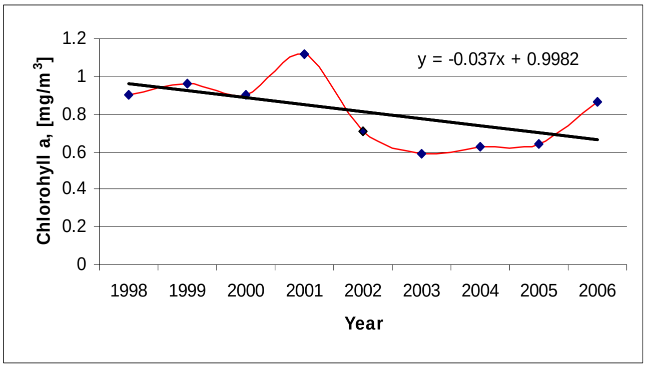

Fig. 10. Inter-annual observation of the Chl a in the study region from SeaWiFS data.

Likewise, the information about Chl a in global and regional scale is needed to improve and validate biogeochemical models, which are used for studying, e.g. the carbon cycle in the system ocean - atmosphere and its influence on the climate.

Conclusions

The present study provides a review of the part of satellite remote sensing methods, data and derived key oceanographic parameters, which can be useful for monitoring the marine environment in region of sparse in situ data such as the Black Sea. The most important advantages of satellite ocean remote sensing in comparison with standard in situ methods are as follow:

- Wide regional coverage and good spatial resolution;
- Sufficient time resolution;
- Continuous acquisition of data;
- Relatively cheep;
- Accurate data for information and analysis;
- Large records of historical data.

Combining remote sensing techniques with in situ measurements can be a valuable tool for environment protection and sustainable management of the marine resources in the Bulgarian Black Sea region.

Acknowledgment

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