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ESTIMATION OF FEASIBILITY OF SEA SURFACE TEMPERATURE SATELLITE DATA USE THROUGH COMPARISON AGAINST *IN SITU* MEASUREMENTS FOR THE WESTERN BLACK SEA REGION

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Abstract: *Sea surface temperature (SST) is an important indicator of the earth climate system state. Therefore, an accurate assessment of SST variability is essential for tracking and prediction of the climate change. In this paper monthly match-up data sets are produced using the Moderate Resolution Imaging Spectroradiometer (MODIS) SSTs and in situ sea water temperature measured in the Western part of the Black Sea during June cruises of the Institute of Oceanology at the Bulgarian Academy of Sciences for the period of four years 2003-2006.*

The analysis is based on computation of the root mean square deviation (RMSD) between satellite-derived and in situ SST data. Monthly and diurnal variations of the difference are estimated. Calculated deviation of SST differences between the infrared satellite data and in-situ data is within reasonable ranges (0.05 - 0.8°C). The results prove feasibleness of satellite data use for oceanographic and climate researches in particular in region of sparse in situ data such as the Black Sea.

1. Introduction

Sea surface temperature (SST) is one of the important geophysical parameters, providing the boundary conditions used in the estimation of heat flux at the air-sea interface. In order to monitor climate properly, it is necessary to obtain accurate SST data over the global oceans (Reynolds *et al*., 1987). On the global scale this is important for climate modeling, study of the earth's heat balance, and gives an insight into atmospheric and oceanic circulation patterns. On a more local scale, SST, can be use operationally to assess eddies, fronts and upwellings for marine navigation and to track biological productivity. In the past, SST could only be measured by ships and buoys, whose ranges were limited. This disadvantage was compensated with development on the satellite apparatuses for remote sensing observations on the sea surface. The satellite remote sensing methods provide frequently observation on the swath with height space and temporal resolution and accuracy of the measurements corresponding exactly to present oceanographic needs. One of the methods for determining SST from satellite remote sensing is the thermal infrared radiometry. Thermal infrared instruments that have been used for deriving sea surface temperature include Advanced Very High Resolution Radiometer (AVHRR) on NOAA Polar-orbiting Operational Environmental Satellites, Along-Track Scanning Radiometer aboard on ERS-2 and Moderate resolution Imaging Spectroradiometer (MODIS) aboard NASA Earth Observing System satellites.

The objective of this study is to estimate precision of MODIS SST, which is indispensable for oceanographic and climate researches in particular in region of sparse *in situ* data such as the Black Sea. Match-up data sets are produced using the MODIS SSTs and *in situ* sea water temperature measured in the Western part of the Black Sea during June cruises of the Institute of oceanology - BAS for the period of four years (2003-2006).

2. Data and methods

In situ data

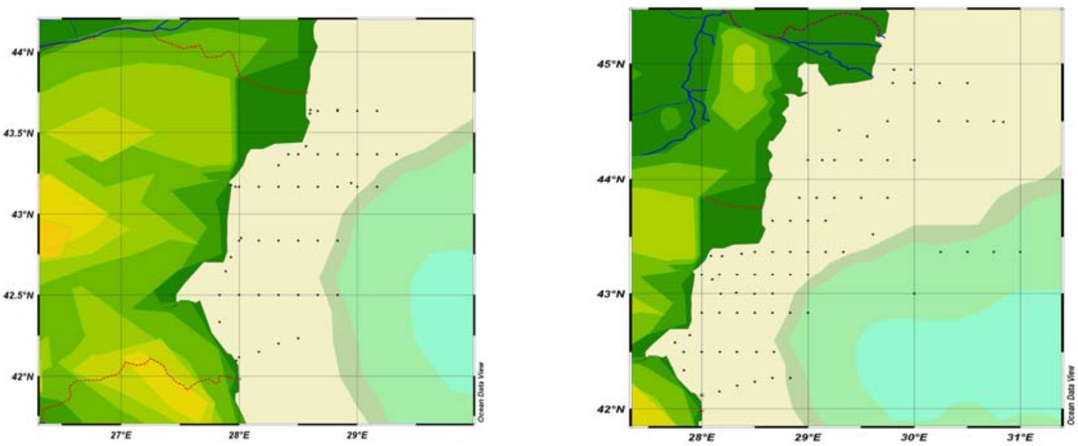
The *in situ* SST data are derived through the CTD casts performed in June during four successive years 2003-2006. They consist of one-meter-depth SST that are collected during the RV "Akademik" cruises in the Western part of the Black Sea. The spatial distribution of observations conforms to the monitoring scheme of the Institute of Oceanology (Palazov *et al*., 2006), except for the most recent cruise, performed in cooperation with the Joint Research Centre of the EC in 2006, during which a number of stations located in the Romanian territorial waters were implemented. Time duration and number of stations covered during the considered cruises are given in Table 1.

The raw data are processed with *SBE Data Processing* tool and are further submitted to standard quality control procedures. The analysis is based only on the high quality data.

Table 1. Details of the in-situ one-meter-depth SST measurements during the RV"Akademik" cruises

Cruise name	Duration	Number of stations
AK062003	07.06 – 11.06.2003	37
AK062004	31.05 – 04.06.2004	48
AK062005	07.06 – 11.06.2005	39
AK062006	01.06 – 17 .06.2006	80

Wind and air temperature data cited in this study are obtained from Weather Underground (www.wunderground.com) for Varna, Bourgas and Kaliakra stations.



a) b)

***Fig. 1**. Deployment of stations: a) Cruises in 2003-2005; b) Cruise in June 2006*

Satellite (MODIS) data

MODIS is designed to sense five different wavelengths, which are selected according to thermal (infrared) part of the spectrum with lowest atmospheric absorption of sea surface emission (atmospheric windows), for more accurate measurements of SST fields.

For the purpose in the present study daily MODIS –TERRA STT measurements are used, which are obtained from two far infrared channels at 11 - 12 µm. The data are derived from Ocean Color Web archive (http://oceancolor.gsfc.nasa.gov). The SST products have Level 2 with 1km spatial resolution. They are processed and distributed by NASA Goddard Space Flight Center's Ocean Data Processing Systems (ODPS) in Hierarchical Data Format (HDF). Each SST Level 2 product contains additional file for pixel quality which vary between 0 (best quality) to 3 (bad quality). Further, satellite data are processed with relevant algorithms and GIS applications using information about pixel geolocation.

Comparison between *in situ* and MODIS data

The method used consists in comparison of *in situ* one-meter depth SST from discrete water samples with those derived from daily MODIS images for each day of the corresponding survey location during four June expeditions. In the analysis are considered only pixels with quality level 0 (QL 0) and all other quality levels related to sun reflection, closely cloud and problems with atmospheric correction are discarded.

Several different methods for the satellite and *in situ* data error have been reported. Here absolute root mean square error (RMSE) and biases are estimated to give measure for the difference between the two different data sets .These estimates are defined as follows:

$$RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i)^2} \qquad (1)$$

$$bias = \left(\frac{1}{n} \sum_{i=1}^{n} x_i \right) \tag{2}$$

$$x_i = |S_i - I_i| \tag{3}$$

where *S* stands for MODIS data, *I* for *in situ* data, and *n* is number of matching pairs.

3. Results and Discussion

In order to investigate the differences between MODIS and one-meter-depth SSTs it should be taken into consideration that the satellite infrared sensor measures the infrared radiation emitted from the surface skin of the ocean. The skin between the sea surface and the lower turbulent 1m layer has a thickness of several millimeters and depends on many atmospheric and hydrological factors such as solar radiation, wind speed and salinity. Majority of days in warm (or cold) season are typified by strong sunshine (or radiative cooling) and low wind speed (less then 22km/h). This is in favour of large vertical temperature gradient within 0–1 m depth of the sea surface layer and can cause large positive (negative) differences between satellite and *in situ* SSTs.

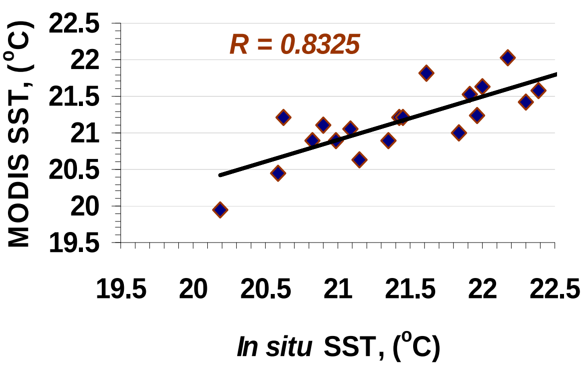
Table 2. *Statistical estimates of differences between MODIS and in situ SSTs*

Cruise ID number	Number of matching pairs	RMS Deviation	Correlation coefficient, R	Bias	Min Difference	Max Difference
AK062003	22	0.30	0.83	0.41	0.046	0.890
AK062004	13	0.18	0.89	0.28	0.037	0.579
AK062005	22	0.21	0.94	0.37	0.038	0.825
AK062006	27	0.26	0.90	0.45	0.012	0.789

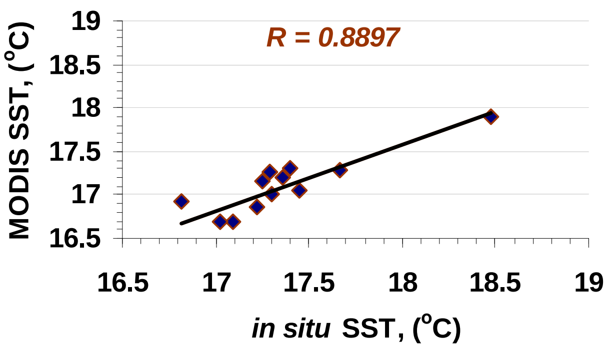
The June match-up data sets is created firstly because of the high quality of MODIS images for the late spring period as it is characterized with clear and cloud free sky. Clouds, atmospheric fog and water vapour cause interfere strongly the visible and infrared wavelength. Second reason is this is assumed as transitional period with not very intensive and continuous sunshine and moderate air temperature. These specific features specify less temperature differences between skin and one-meter-depth layers.

Table 2 and Fig. 2 show the results from comparison between in situ temperature based on discrete sample measurements (location shown in Fig. 1a, b) and daytime MODIS SST derived from far infrared channels for each day of the cruise surveys.

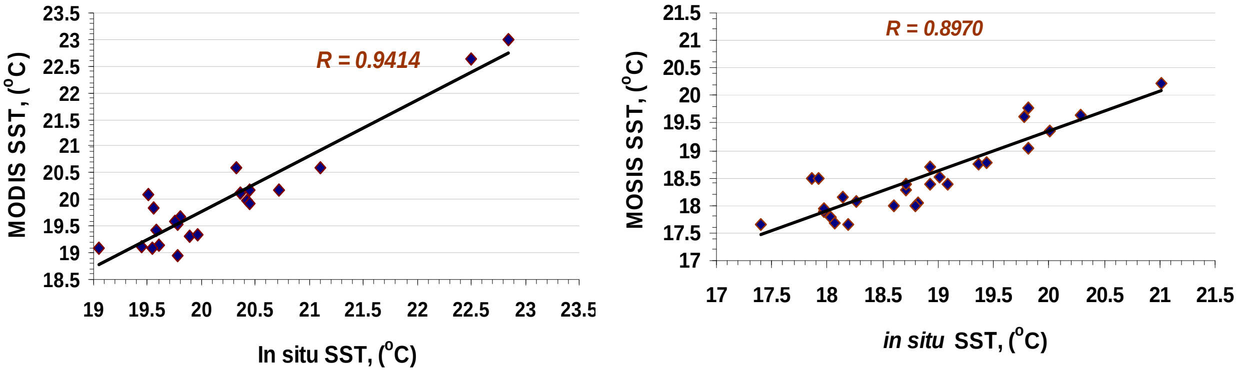
Estimates of likelihood between two types the observation periods are estimated as follows: RMS in range 0.18 - 0.30˚C, biases 0.28 - 0.45˚C and correlation coefficient 0.83 - 0.94. Absolute minimum and maximum difference between measurements vary from 0.012˚C to 0.890˚C. According to calculated statistical parameters two cases could be clearly distinguished. The first one is related to higher values of RMS and biases and corresponding lower correlation coefficient (June 2003, June 2006) while for the second one characteristics are the opposite (June 2004, June 2005).



a)



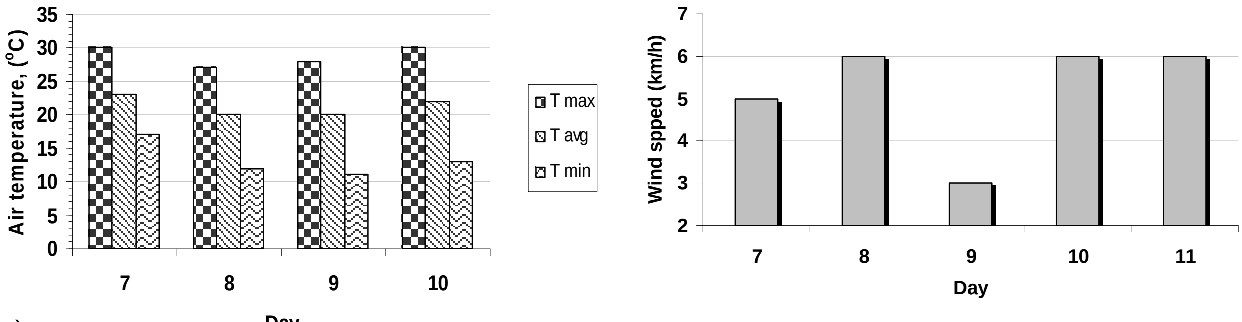
b)



c) d)

Fig. 2. *Scatter plots of all SST matching pairs obtained by in situ sampling and MODIS for the June cruises in 2003 (a), 2004(b), 2005 (c) and 2006 (d)*

Statistical parameters for the cruise performed during 07.06. – 11.06.2003 are RMS = 0.3˚C, bias = 0.41˚C and R = 0.83. This is the period with maximum absolute difference between two comparison temperatures. Only 22 ground stations with contact measurements out of 37 in total correspond to pixels with quality 0 from MODIS images. Analyzed periods are characterized with open sky, sunny weather and high atmospheric temperature amplitude – maximum 27- 30˚C and minimum 11 - 17˚C (Fig. 3a). Mean wind speed is up to 3 - 6 km/h (Fig. 3b). The day with maximum difference for entire observation period is 09 June 2003. It is distinguished with low mean wind speed (3m/h), which corresponds to still weather; sky is clear with intense solar radiation. Air temperature rises sharply from 12˚C at earlier hours of the day to 27˚C during noon and afternoon (Fig. 4a). *In situ* measurements are carried out at 3 p.m. when solar heating causes the surface temperature to increase. Described conditions favourite appearance of a diurnal thermocline with strong gradient of temperature, which contributes to larger temperature deviations and smaller coefficient of correlation for June 2003.



a) b)

Fig.3. *Weather conditions for the period 7-11 June 2003: a) air temperature; b) average wind speed*

The observed atmospheric conditions are similar for June 2006. Calculated statistical parameters are RMS = 0.26˚C, bias = 0.450˚C and R = 0.89. Mean wind speed is 5 km/h, except for 9 – 10 June 2006, when the reported wind value was 16 km/h. Air temperature vary in wide range from 8- 13˚C to 20 – 28˚C; at that, 10 June 2006 is described as day with absolute minimum temperature difference between the two measurement types. Wind speed and air temperature for 9 – 10 June 2006 are shown in Fig. 4a-b. Due to the significant mixing of surface and near surface layers the effect of diurnal thermocline is weakened and most of the solar heat is absorbed well down throughout the 1m layer. This is the reason for smaller temperature differences.

For June 2004 estimated RMS is 0.18 and bias is 0.28˚C, while for June 2005 these values are 0.21˚C and 0.37˚C, respectively. Correlation coefficients are 0.89 and 0.94 (Table 1, Fig. 2). During this time air temperature amplitudes are slight, as mean values barely reach 15 - 18˚C in contrast to the above discussed periods (Fig.5 a, d).

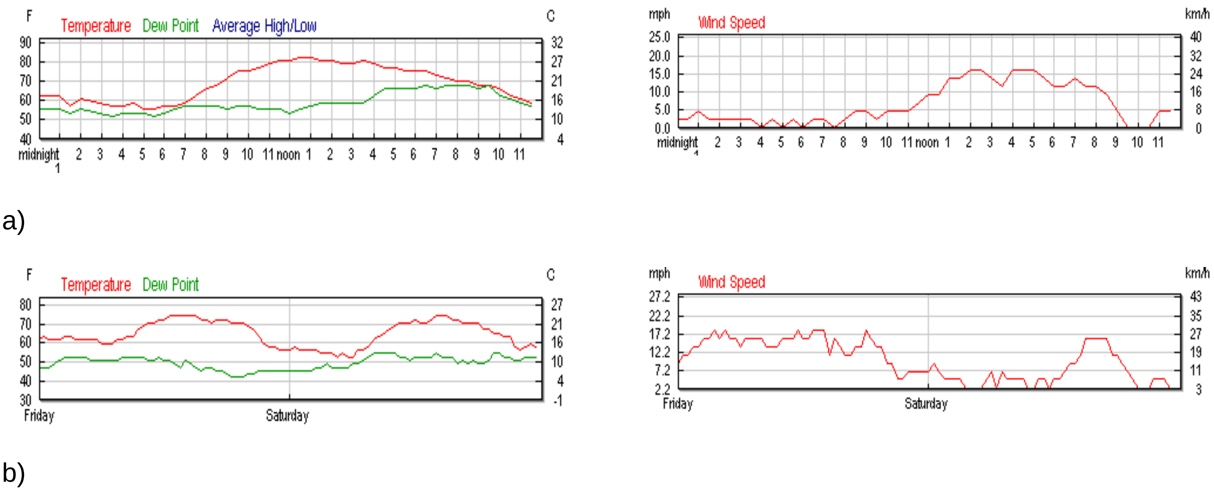


Fig. 4. Air temperature and wind speed for 09.06.2003 (a) and for 9 -10.06.2006 (b)

Average wind speed is also higher then in June 2003 and June 2006. The weather is changeable and is described with cloudy sky, rainfalls and weak sunshine. These atmospheric conditions are the reason for absence of diurnal thermocline and better correlation between *in situ* and MODIS SSTs.

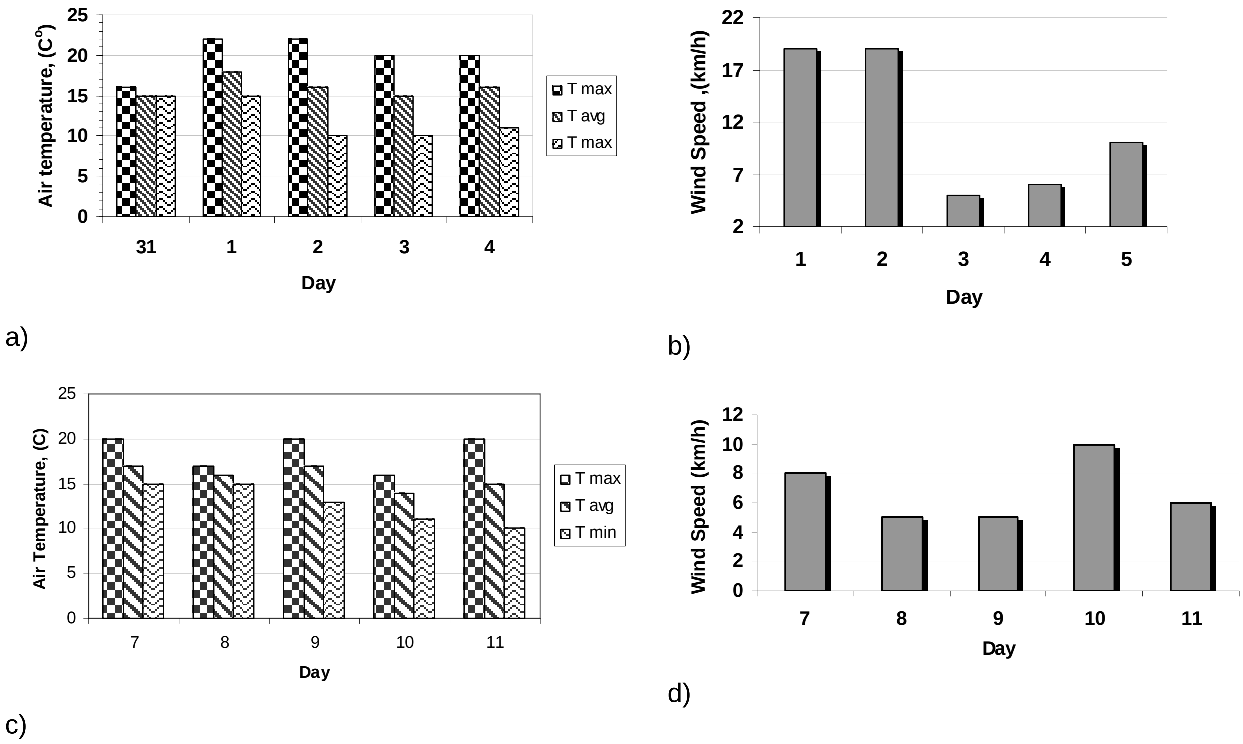


Fig. 5. *Air temperature and average wind speed for the cruises 31.05 – 4.06.2004 (a, b) and 07.0 – 11.06.2005 (c, d)*

It must be taken into account that MODIS represents instant values for the data, while the contact measurements are carried out at different hours throughout the day. Therefore, estimated differences could be associated also with this discrepancy. However, sea surface temperature is not quite dynamic characteristic and described effect may not lead to significant divergence between the two temperatures in comparison. Additional investigations are needed to substantiate this assumption.

4. Conclusion

A validation study between observed *in situ* measurement of the one-meter-depth and MODIS daytime 11µm SSTs have been carried out for the Western part of the Black Sea. It was found strong correlation dependence (R = 0.95) between the two types of data for the all observation periods. The RMS deviations and biases for separate cruise observations was found to vary in following ranges: 0.3 ÷ 0.18 C˚ for RMS and 0.28 ÷ 0.45˚C for bias, which are in good agreement whit those reported by EOS Data Product Handbook with absolute accuracy of 0.2 K.

The present study enhances the quality performance of the SST retrieval algorithm for MODIS far infrared channels. In view of sparse temporal and spatial coverage of *in situ* sea temperature measurements over the Black Sea, here the use of the MODIS satellite data is validated for different purposes such as better weather and sea state forecast.

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References:

1. R e y n o l d s R.W., L. R o b e r t s, 1987. A global sea surface temperature climatology from in-situ satellite and ice data, *Trop.Ocean-Atmos. Newslett.,* 37, 15-17.
2. P a l a z o v A., H. S l a b a k o v, H. S t a n c h e v, 2006. Monitoring programme of Western Black Sea, Proc. of Workshop on "*Black Sea Ecosystem in Support of Marine Conventions and Environmental Policies*", EUR 22176, European Communities, 40-46.
3. R o b i n s o n I., 2004. Infrared (IR) measurements of sea surface temperature (SST), In: Measuring the ocean from space, Chapter 7, *Springer*, 243 – 314*.*
4. A l o k e M., M. S u b r a h m a n y a m, B. G o h i l, K. R e d d y, V. A g a r w a l, 2005. In-situ validations of sea surface temperature derived from satellite microwave and infrared sensors: a case study of TRMM/TMI and TERRA/MODIS, *General Assembly of International Union Radio Sciences (URSI).*
5. EOS Data Products Handbook, 2000, NASA Goddard Space Flight Center Greenbelt, Maryland, Vol. 2.