6th International Conference on Water Resources and Arid Environments (ICWRAE 6): 365-369
16-17 December, 2014, Riyadh, Saudi Arabia

Analysis of Historical Meris and Modis Data to Evaluate the Impact of Dredging on Monthly Mean Surface TSM Concentration

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Abstract: We studied the changes of total suspended matter (TSM) distribution in Estonian coastal sea with special focus on Paldiski harbour at the Pakri Bay (SW Gulf Of Finland). The purpose of current study was to examine the suitability of remote sensing data for detection of turbidity differences caused by dredged sediments on monthly mean surface TSM concentration, retrieved from satellite images. The MERIS (FSG) products with 300m resolution and MODIS band 1 data with 250m resolution from years 2006-2010 were used in the analysis. MERIS images were processed using the Case-2 water processors available in BEAM software. Validation of the two processors (C2R and FUB) with in situ measurements of TSM gave reliable correlation between satellite data and in situ TSM measurements: r2 was 0.43 for FUB processor and 0.47 for C2R processor. An empirical algorithm was established for conversion of MODIS band 1 reflectance (620-670 nm) data to TSM concentration. We found reliable (r2=0.43) relationship between MODIS reflectance at band 1and TSM concentration measured from water samples. The monthly average TSM maps in the harbour region were calculated from MERIS and MODIS data using validated conversion algorithms in order to describe TSM variability and to analyse environmental impact of dredging.

Key words: MODIS · MERIS · Total suspended matter · Dredging

INTRODUCTION

Coastal sea is primary receiver of suspended matter from rivers and other land-based sources. As a result, transparency of the coastal waters decreases, less solar radiation reaches marine biota in euphotic zone and therefore intensity of photosynthesis declines. Dredging operations in coastal waters affects water quality through an increase in suspended matter concentration. Also, waves and currents can cause re-suspension of sediments in shallow coastal sea. Monitoring of the re-suspended sediment load is mandatory during the dredging operations for evaluation of environmental impact caused by dredging operations. Optical remote sensing images from different satellite sensors have been used for monitoring TSM concentration for a few decades. Implementation of remote sensing in monitoring of commercial harbour areas can give much wider understanding of ongoing processes in marine environment. The launch of Moderate Resolution Imaging Spectrometer (MODIS) on board of Terra and Aqua satellites and Medium Resolution Imaging Spectrometer (MERIS) on board of Envisat satellite have opened new possibilities for near real time monitoring of coastal sea. Objective of the this study was to evaluate the increase in TSM concentration on monthly mean TSM maps from MODIS and MERIS images during dredging operation in Pakri Bay Gulf of Finland Baltic Sea in summer/autumn 2008.

Data

Satellite Data: MERIS instrument provided images with spatial resolution of 300 m (known as FR product) and 1200 m(known as RR product) at 15 bands in visible and near infrared wavelength region. The European Space Agency launched the Coast Colour project to fully exploit the potential of the MERIS instrument for remote sensing near the coastal zone. Under the CoastColour project the development, validation and intercomparison of different algorithms for Case-2 waters has been performed over a global range of coastal water types. In our analysis we used the CoastColour data archive of MERIS FR data from years 2006-2010.

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Multiple channels of MODIS Terra/Aqua satellites provide data for ocean studies at 1 km spatial resolution. Two additional bands with 250 meter spatial resolution, 620-670 nm (band 1) and 841-876 nm (band 2), can be used to monitor the sediment concentration in coastal and inland waters. MODIS Level 1 data is available through NASA archive http://rapidfire.sci.gsfc.nasa.gov/cgi-bin/imagery/realtime. Historical MODIS images from field campaign days were downloaded and used for empirical algorithm development.

Total Suspended Matter Determined from Water Samples: The water samples collected during field works were filtered through pre-weighted Millipore membrane filters (pore size 0.45 μm, diameter 47 mm, Millipore Corporation, Bedford, MA) and the filters were dried to constant weight at a fixed temperature (103-105° C) in order to determine the total suspended matter (TSM) concentrations. The increase of filter weight indicates the suspended matter concentration in the water sample.

Methodology

Satellite Algorithm Validation and Development

MERIS Algorithm: We validated and compared satellite TSM concentrations obtained by BEAM processors Case2Regional and FUB with our field measurement data. After revision of satellite data we obtained 5 days of cloud free images with simultaneous field measurements from years 2008-2011 in Pakri Bay, located on the SW coast of Gulf of Finland.

Table 2.1: Validation results for different MERIS processors

	SD%	r2(linear)
TSM (FUB)	78	0.43
TSM (C2R)	53	0.47

In Table 2.1 and on Figure 2.1 are presented the validation results. Both processors C2R and FUB represent the changes in TSM concentration adequately (Table 2.1). The correlation (r^2) between in situ measurements and FUB TSM retrievals was 0.43 while in case of the C2R processor the corresponding value was 0.47 (Table 2.1). However, figure 2.1 indicates that both processors underestimate the TSM. FUB processor underestimates the TSM concentrations more than C2R processor. The mean standard deviation was 78% in the case of FUB processor and 53% in the case of C2R standard processor (Table 2.1). These results are in same range as obtained by [1] for the northern coast of the Gulf of Finland. In their study the best coincidence between turbidity and satellite TSM was obtained for adjusted C2R and EUT processors (corresponding SD 50% and 48%). Taking into account on our validation results and on previous studies we processed the historical MERIS data using C2R standard processor. The monthly mean maps were calculated from MERIS archived imagery in order to describe the TSM levels at the dredging site. Reference monthly mean TSM maps were also calculated to describe the TSM content in the water during non-dredging conditions.

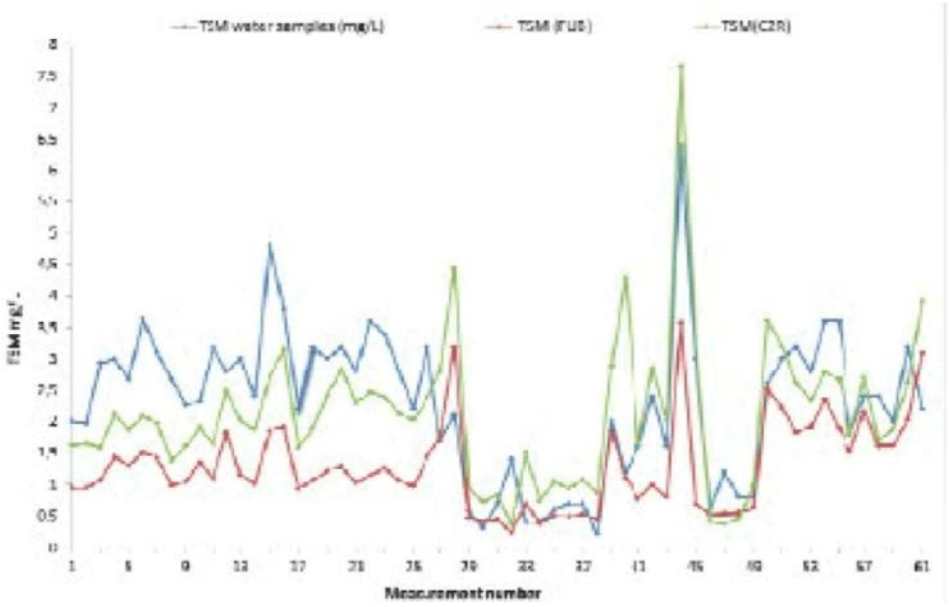

Fig. 2.1: TSM estimated with C2R processor (green line); TSM estimated with FUB processor (red line); TSM determined from water samples (blue line).

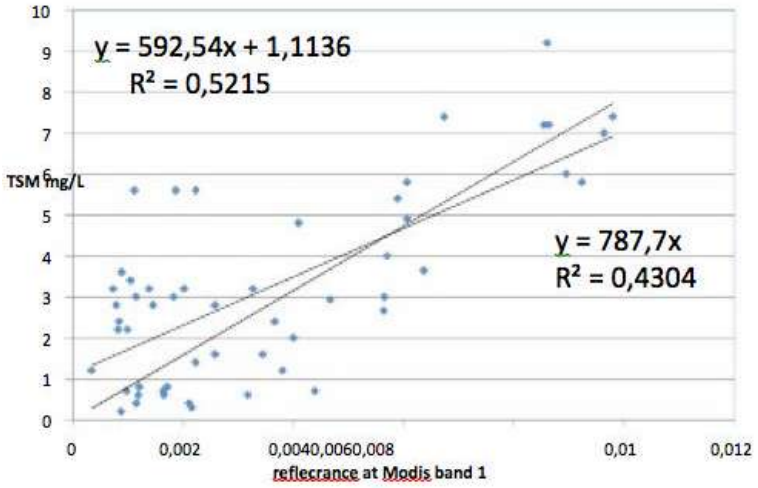

Fig. 2.2: Scatter plot: TSM (water samples) vs. MODIS reflectance.

Table 2.2: Algorithms for estimation of TSM concentration using MODIS reflectance data at band 1 (R1) or band 2 (R2) from previous studies

Reference	Empirical Relationship
5	SPM = 12.996 x e w2/R2 /0.189
9	In(ssc)= (43.233 x R2) + 1.396
9	In(ssc) = 50.171 x R1 - 1.523
2	Turbidity = 1203.9 x $R1^{1.087}$
7	TSM = -1.91 + 1140.25 x R1
3	R = 7.5 x log (ssc) + 1.6
8	Cspm = 110.3 R1 + 2.0

MODIS Algorithm: There are no standard processors available for retrieving TSM concentration from MODIS 250 data. However in literature several empirical relationships between MODIS reflectance at band 1 or band 2 and TSM concentration have been established.

The algorithms from previous studies using MODIS reflectance data at band 1 (R1) or band 2 (R2) for estimation of suspended sediments concentration are presented in Table 2.2.

All these relationships have been found using different methods for elimination of atmospheric disturbances. The most crucial in MODIS 250 m data analysis is the atmospheric correction because no standard procedure exists for these two bands and therefore these published algorithms are case specific. We used our dataset to establish the relationship between TSM concentration and MODIS reflectance at band 1. Firstly we used "dark pixel" methodology i.e. reflectance value of the darkest pixel was subtracted from each image for correction of atmospheric disturbances. For conversion of the MODIS band 1 reflectance values to TSM concentration the correlation between these parameters were found. In total, we had 77 data pairs from the following dates 17.04.2004, 11.08.2004, 18.04.2005, 20.02.2009, 9.09.2009, 28.04.2010, 18.07.2011, 2.05.2013. The correlation (r^2) between water sample TSM and MODIS band 1 reflectance for the entire dataset was 0.43 (Figure 2.2). Monthly mean TSM maps were calculated from MODIS imagery using the developed empirical algorithm.

RESULTS

On Figure 3.1 are presented the monthly averaged TSM maps for July, August and September 2008 which were calculated from MERIS and MODIS images. On all TSM maps the area with increased concentration of TSM can be observed near the harbour and also in southern part of the bay. However, the area of the TSM bloom is different (Figure 3.1). To evaluate the area where TSM has increased due to dredging we compared the monthly mean TSM with background TSM that describes the corresponding non-dredging period monthly mean TSM in years 2006-2010.

The TSM differences (monthly mean 2008 minus reference monthly mean 2006-2010) from background TSM values for dredging period in July, August and September 2008 are shown on figure 3.2. We considered the TSM increase of 3.5 mg/L from background level as the threshold value for indicating the impact of dredging operations. We calculated the area in km^2 near the harbour where monthly mean TSM increased more than 3.5 mg/L (Table 3.1). Comparison of MERIS and MODIS results showed that MODIS images had systematically higher

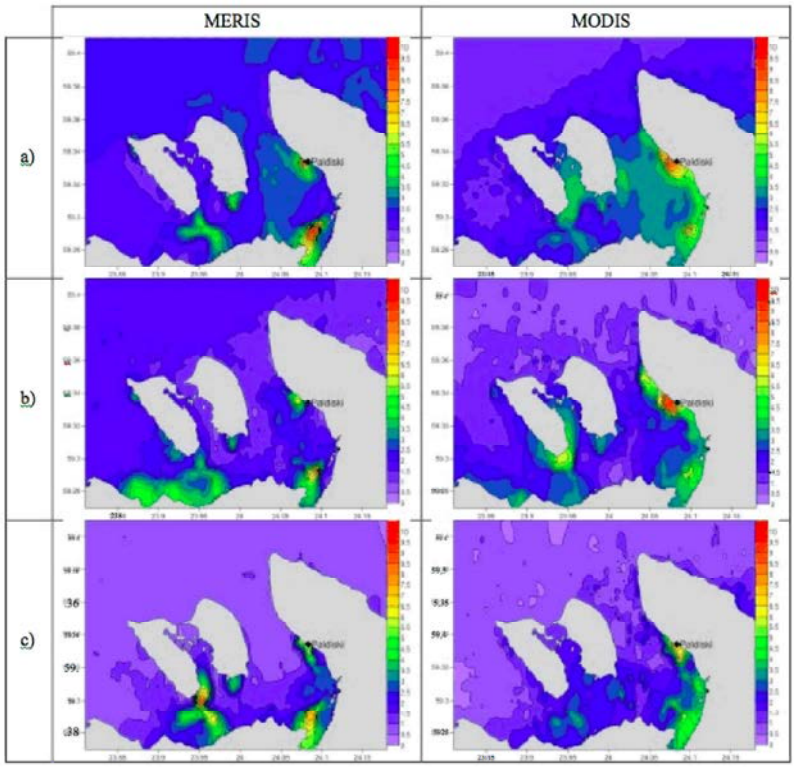

Fig. 3.1: Monthly averaged TSM concentration obtained from MERIS and MODIS images in a) July, b) August and c) September 2008.

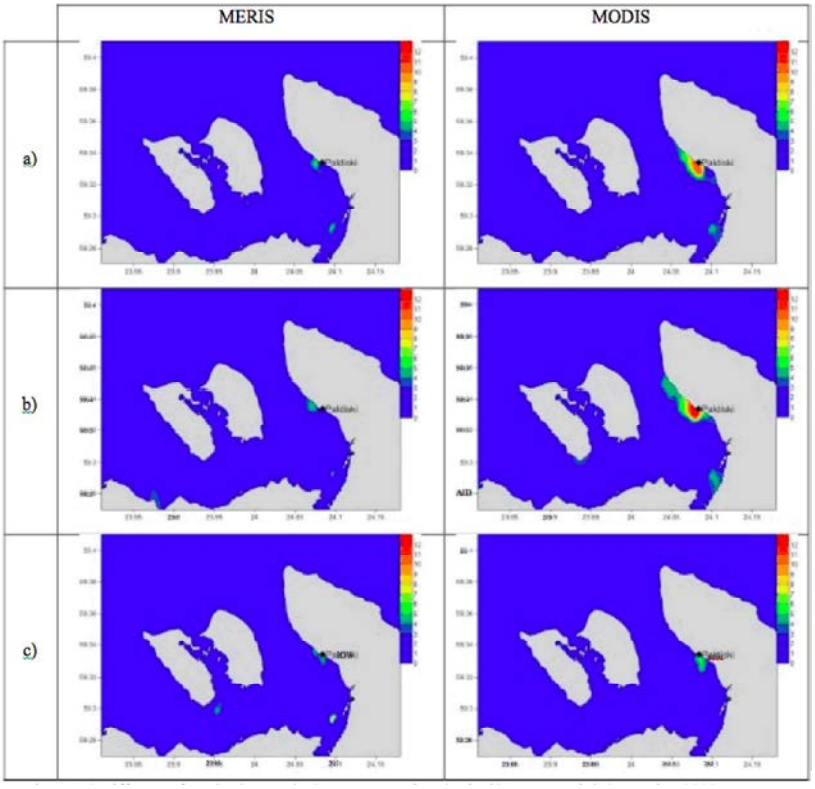

Fig. 3.2: Difference from background TSM concentration a) July, b) August and c) September 2008.

Table 3.1: Averaged area (km2) with increased TSM concentration obtained from MERIS and MODIS images during dredging operations in 2008

	Meris	Modis
July	0.375	0.875
August	0.375	0.938
September	0.188	0.563

TSM levels. The environmentally affected area by increased TSM level was smallest in September ~0.6 km^2 from MODIS and ~0.2 km^2 from MERIS images. In July and August it was about the same size ~0.9 km^2 from MODIS images and ~0.4 km^2 from MERIS images. Pakri Bay is environmentally sensitive area: most of the bay is covered by Natura 2000 Special Protection Area and Site of Community Importance (SPA and SCI, EU Birds and Habitats Directive). Analysis showed that the area with increased TSM concentration did not reach the sensitive NATURA 2000 region.

CONCLUSIONS

Comparison of MERIS C2R and FUB processors showed that both processors represent the changes in TSM concentration adequately. The correlation coefficient was 0.43 for FUB and 0.47 for C2R. However, both processors underestimate the TSM concentration compared to water samples. The SD in case C2R was 53% and in case FUB processor 78%, therefore we used C2R processor for calculations of historical monthly mean TSM maps for non-dredging period. Site specific algorithm was developed for converting the MODIS reflectance data to TSM concentration. Our dataset of 77 match ups between water sample TSM and MODIS band 1 reflectance had correlation (r^2) of 0.43 which can be considered statistically reliable. Conversion algorithm was used to calculate monthly mean TSM maps from MODIS data for dredging period in 2008 over the Pakri Bay area. TSM maps calculated from MERIS and MODIS during the dredging period in 2008 showed increased concentration of TSM near the harbour, however the area of the bloom detected from the two sensors varied. The bloom area obtained from MODIS images was systematically larger compared to the one obtained from MERIS images. Analysis still showed that the TSM bloom did not reach the environmentally sensitive NATURA 2000 area at the time of dredging operations in 2008.

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