Sediment Detection by Means of Atmospherically Corrected MODIS Data

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Abstract: The present paper describes the impacts of atmospheric correction of MODIS (Moderate Resolution Imaging Spectroradiometer) data for detecting sediment concentration. The efficiency of applying time-consuming atmospheric correction processes for increasing accuracies versus applying top of the atmosphere signals will be analysed.

The code applied for calculating surface reflectance is called 6S code (Second Simulation of the Satellite Signal in the Solar Spectrum). It is able to simulate gaseous absorption, scattering by molecules and aerosols, correct for adjacency effects, and take into account the directional properties of the observed surface [21]. The data used for atmospheric correction are radiance values retrieved at the satellite altitude from the MODIS sensor (MOD02 product). On three field trips in the mouth of Chao Phraya River, Thailand, ground truth data for reflectance values were recorded using a Spectro Coop. Spectrometer. Furthermore, sediment concentrations were collected on these study trips.

In a first approach MOD02 data were atmospherically corrected using inherent models in the 6S code. In a second step MODIS atmospheric data (MODIS aerosol product MOD04, MODIS water vapour product MOD05, and MODIS atmospheric profile product MOD07) were used to model the atmosphere conditions. A comparison is made between own calculated surface reflectance data, MODIS surface reflectance data calculated from the MODIS land science team, and reflectance values obtained from field trips. Furthermore, it was analysed, which of the data is most suitable for detecting sediment concentration.

The research showed that MODIS surface reflectance values are more suitable to detect sediment concentration than MODIS top of the atmosphere data. For example using band 1, the correlation between sediments and satellite data was increased from 28 % for top of the atmosphere data to 63 % using atmospherically corrected data. This effect was only noticed for calculations that used atmospheric MODIS data, not for tests that were done with inherent models in the 6S code.
Keywords: Remote Sensing, MODIS, Atmospheric Correction, 6S Code, Sediment Detection

1. Introduction

Among large number of satellite sensors that are available for local, regional and global resource management studies, MODIS sensors housed in Terra and Aqua plays very important role. The abbreviation MODIS stands for Moderate Resolution Imaging Spectroradiometer. This sensor was carefully developed and therefore has many advantages to previous sensors. One of the biggest progresses made was to enable MODIS for detecting aerosol loading and aerosol optical thickness derivation due to the presence of seven channels in the spectral interval 0.41-2.1 µm. Especially the 1.38 µm channel was designed for detecting stratospheric aerosols and thin cirrus. The influence of water vapour could be reduced due to smaller reflectance channels, especially for the 0.659 µm and 2.1 µm channel. Due to high radiometric sensitivity data in 36 spectral bands and the availability of two overpasses for the same area on daily basis, MODIS can be used very efficiently for various remote sensing applications in general and for water quality detection in particular.

But as for all sensors working in the visible range of light, different kinds of substances among the source of radiation, the earth surface and the satellite sensor influence the light passing by or through them. As a result the information about the earth surface is changed. Substances that influence the radiation are gasses, aerosols and clouds by the processes of absorption and scattering.

In several cases it is required to work with surface reflectance data and not with radiance values recorded at the satellite sensor. Possible land parameters that can be generated after atmospheric correction are bidirectional reflectance distribution function (BRDF), albedo, vegetation indices (VIs), leaf area index (LAI) and land use & land cover change mapping. Furthermore, a comparison between different sensors and multi-temporal analysis is possible after performing atmospheric correction.

The main aim of this study is to determine the influence of the atmosphere on detecting sediment concentration. To monitor sediments is important because an excessive amount of sediments creates harmful conditions for plants and animals. Suspended sediments can smother bottom-dwelling plants and animals, cloud the water, and prevent light from penetrating to the leaves. Furthermore, toxic materials can be carried by sediments, which further contaminate waterways. Accretions of sediments are responsible for blocking waterways and ports, making traffic difficult or hazardous.

Initially the 6S code is used to convert the satellite signals received at the MODIS sensor (MOD02) into surface reflectance. A comparison between manual calculated reflectance values, downloaded reflectance values from the MODIS sensor (MOD09), and in situ measurements will be made. It will be analysed, which of the following sources (manual calculated surface reflectance, MOD09 surface reflectance data, in situ measurements, and MOD02 top of the atmosphere radiance) is most suitable for sediment detection. With this research it will be shown that using surface reflectance MODIS data, which are atmospherically corrected using MODIS atmospheric products, will lead to better results for sediment detection than signals received at the sensor altitude. Another important part of investigation is the determination of the atmosphere content that influences the flux of radiation at the most. Therefore atmospheric parameters in the 6S code were modified to distinguish their impact on the calculated outcome. This test will be called 6S input parameter test in this paper.

Field data were collected in the mouth of Chao Phraya river, Thailand. This area was chosen because the level of pollution increased over the past years [15], [24]. A research carried out by the Pollution Control Department of Thailand found that the water quality in the lower parts of the Chao Phraya river is not in a good condition. Most parameters that have been analysed were below the surface water quality standards. Beside low dissolved oxygen, high ammonia-nitrogen, high fecal coliform bacteria, the problem of high turbidity was mentioned [15]. The research [24] came to the following conclusion: "In the lower Basin there was evidence of heavy pollution in the Chao Phraya River." Therefore new tools and sensors have to be applied for monitoring the decrease of water quality.

The sensor MODIS (Moderate Resolution Imaging Spectroradiometer) is installed on the satellites Terra and Aqua. This research only applied MODIS-Terra data. For atmospheric correction the MOD02 product was used. This product contains MODIS radiance values received at the top of the atmosphere. Data about atmospheric conditions came from MODIS atmospheric products. Information regarding aerosol condition was gathered from the MODIS aerosol product MOD04, water vapour was collected from the MOD05 water vapour product and ozone information from the atmospheric profile product MOD07.

2. Materials and Methods

1) 6S Code

The 6S code was developed in 1997 and can predict the satellite signal in the range from 0.25 to 4.0 µm, but a cloudless atmosphere is assumed. It is able to simulate gaseous absorption, scattering by molecules and aerosols, corrects for adjacency effects and takes into account the directional properties of the observed surface [21].

Absorption is the process by which incident radiation is taken in by aerosol and atmospheric gases such as oxygen, carbon dioxide, methane, nitrogen, ozone, and water vapour. It causes a loss of radiation energy by molecular absorption by converting this energy into excitation energy of the molecules. The effect by aerosols is assumed to be small and satellite bands are constructed to avoid molecular absorption bands. The biggest unknowns for absorption are ozone and water vapour in the lower atmosphere because they vary between space and time. The effect of absorption by atmospheric gases is computed in the 6S code by multiplicative factors. Therefore the two processes of scattering and absorption must be separated and then absorption can be calculated for each scattering path.

Scattering is referred to all elastic interactions between molecules or non-absorbing aerosols and the electromagnetic radiation. The result will be photons that are reemitted in different directions and therefore redirected from their original path. The intensity of scattering depends on the wavelength of the radiation, the quantity of the particles or gases in the atmosphere, and the distance the radiation travels through the atmosphere. The process of scattering is taken into account by the 6S code using the successive orders of scattering method. This scheme solves numerically the equation of transfer for upward and downward radiation at any optical thickness τ by iteration. Furthermore, it accounts for a mixing of aerosol and gaseous molecules and allows the user of the 6S code to increase the number of atmospheric layers to a discrete number. It also enables exact simulations of airborne observations.

The adjacency effect is caused by a variation of land cover. It occurs when a different but adjacent land cover influences the target pixel radiance at sensor altitude due to atmospheric scattering. Therefore the signal at the top of the atmosphere (TOA) must be decoupled into photons that come from the target and those coming from surrounding areas [22]. The adjacency correction procedure was worked out by Tanré et. al. (1981). It will be carried out in a simplified way in the 6S code up to a distance of 10 pixels, each weighted by their distance from the target. The function that is applied for correcting the adjacency effect is the atmospheric point spread function. Because the computational time for this function is very high, precomputed tables as a function of viewing angles will be used in the 6S code.

BRDF or Bidirectional Reflectance Distribution Function is defined as an intrinsic property of a surface, which describes the angular distribution of radiation reflected by it, for all angles of exitance and under given illumination geometry. Therefore it gives the reflectance of a target as a function of illumination geometry and viewing geometry. Although it can not be measured directly as it is defined for all angles, it can be estimated using models of surface scattering in addition with a limited number of angular reflectance samples [2]. The output has dimensionless quantity such as ratio or reflectance. BRDF is dynamic in space and time, varies under different conditions, and can be used for deriving albedo, land cover classification, cloud detection, and atmospheric correction. For correcting the measured BRDF values a ratio between estimated BRDF coupled with the atmosphere and actual surface BRDF is calculated in the 6S code. Two solutions are possible to obtain modelled BRDF inputs while working with MODIS data. The first one is to use the Bidirectional Reflection Distribution Function from the previous 16-day period. The second choice is to use a general BRDF Look-Up-Table. BRDF and coupling terms will be precalculated and stored as a function of zenith angles, aerosol optical thickness, biome type and LAI. The biome is acquired from land cover maps and the LAI from different MODIS bands.

In order to run the atmospheric correction code, an input file is required. This file gives the necessary parameters to model the predominant conditions when the image was taken. It defines geometrical conditions, like solar and viewing azimuth and zenith and altitude of the target and sensor. Atmospheric information is given such as ozone and water vapour content. Furthermore, information about aerosol conditions are defined. Spectral conditions, such as wavelength range and recorded signal in the used band, are fixed by the input file. Finally ground conditions will be defined. Those are information regarding ground reflectance type and information about the surrounding pixels. At each of the previous mentioned steps, you can either select some proposed standard conditions that are given by the 6S code or define your own conditions.

2) Data Collection

Data used for this research stems from two different sources. Beside MODIS satellite data, ground truth data were collected on several visits along the river. Surveys were carried out on 26 February 2005, 8 March 2005, and 10 May 2005. Water samples were collected in a depth of one meter using a Ratner sampler. The water was filtered in a laboratory through a standard glass fibre filter. The residue retained on the filter was dried at 103°C to 105°C for one hour. The filter was weighted before and after filter process. The increase in weight of the filter represents the total suspended solids. Sediment concentrations for 65 samples were ranged from 17 mg/l to 2234 mg/l.

Ground surface reflectance data were collected on these three study trips using a spectrometer from the company Spectra Co-op. The wavelength range of this instrument is from 304 nm to 1135 nm, in 1 nm steps. The spectrometer was connected with a fibre-optic cable that has a measurement angle of 50 degree. It should be acknowledged, that on the three days of fieldwork only ordinary white paper as a white target reference was used. This paper did not undergo any calibration.

MODIS radiance data (MOD02 product), MODIS geo-location data (MOD03 product), MODIS aerosol product (MOD04 product), MODIS water vapour product (MOD05 product), MODIS atmospheric profile product (MOD07 product), and MODIS surface reflectance data (MOD09 product) were downloaded from the following source (DAAC): *http://edcimswww.cr.usgs.gov/pub/imswelcome/*.

A problem on 10 May 2005 was a thin cloud area that covered the field area. Although the MOD02 data from that day was usable, the required atmospheric MODIS data did not contain information for the field site. Because atmospheric information is necessary for the 6S code, the data set from 6 May 2005 was used. The time gap is 4 days to the measurement day and it was presumed that the collected sediment concentration did not change within that time period.

3) Workflow

The workflow of this study is shown in Fig. 1. After downloading the required MODIS data, the satellite images had to be georeferenced. All MODIS products are stored in the file format HDF file format. These HDF files contains scientific information that are different for different MODIS products. Some products contain a projection (MODIS gridd data), whereas others are not projected or gridded (MODIS swath data), which makes it difficult for softwares to reproject MODIS data.

At first, commercial software packages such as ENVI 3.1 and ERDAS 8.7 were used for reprojection. Results were compared with software tools MRT (MODIS Reprojection Tool), MSRT (MODIS Swath Reprojection Tool), HEG Tool (HDF-EOS to GeoTIFF Conversion Tool), and HDFLook. All these tools are available free of charge. To check the accuracy of these results a comparison between the coordinates of a specific pixel, which is already reprojected, before and after atmospheric correction, were made. That means the coordinates of one pixel in the MOD02 product and the same pixel in the MOD09 product after reprojection were compared. After these analyses it was decided to use HDFLook for reprojection, because it produced better registering accuracy among different MODIS products. After reprojection, the GPS coordinates from the field trips were used to detect the required MODIS pixel in the different MODIS products.

Using the radiance value from the MOD02 product, atmospheric correction was started. In a first step, the inherent models of the 6S code were applied. A model to predict aerosol optical thickness is not included in the code. But because of clear sky condition on the days of measurement it was decided in a first approach to use an aerosol optical thickness of 0. The calculated surface reflectance values from this step are called 6S01. In a next approach, the aerosol optical thickness was changed to 0.25, which is equal to an aerosol visibility of 20 kilometres. Results are named 6S02. In a second step MODIS atmospheric data (MOD04, MOD05, MOD07) were used to model the atmosphere conditions appropriate. Results are named 6S03.

A comparison is made between manual calculated surface reflectance data (6S01, 6S02, and 6S03), the MOD09 surface reflectance product, and reflectance values obtained using a spectrometer. With the help of calculated correlation coefficients it was figured out which of the data is most suitable for sediment detection. Finally this formula was applied for calculating sediment maps for all three days of measurement.

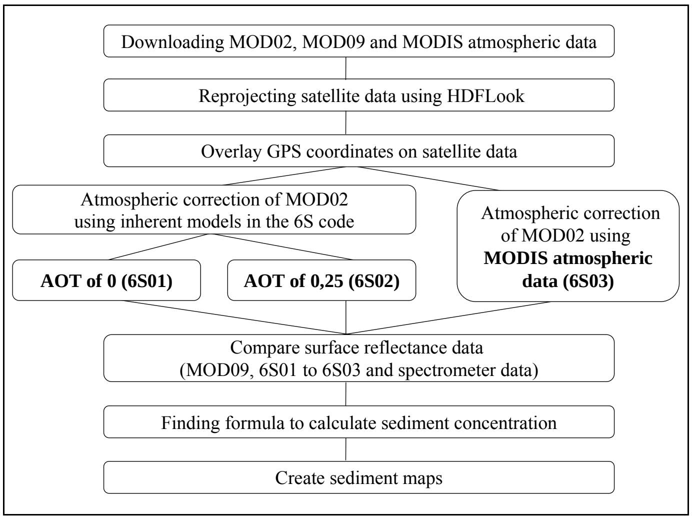

Fig. 1. Workflow of analysing data

Further test were undertaken after these analysis. One of the tests was carried out to detect the influence of the 6S parameters on the calculated surface reflectance. In this test, attempt was made to identify which parameters need to determine more accurately to get results that are close to ground truth values. Therefore this test is called 6S parameter test.

The second test was undertaken for analysing the influence of an ‘ordinary’ white paper in comparison to a calibrated reference board for collecting white reference target values. Furthermore, the influence of changing distances and angles between spectrometer sensor and white reference target were examined. Consequently this test is named white reference test. Results are presented in the following chapter.

3. Results

1) Reflectance Analysis

In a first step MOD02 data from the top of the atmosphere is used and converted to surface reflectance data. It was done using the previous explained 6S code. The result was compared with MOD09 surface reflectance data (table 1) and in situ measurements (table 2).

Table 1. Correlation results between manual calculated surface reflectance data and MODO9 product

	MOD09-6S01	MOD09-6S02	MOD09-6S03
Band 1	51 %	51 %	96 %
Band 2	54 %	52 %	77 %
Band 3	7 %	11 %	76 %
Band 4	45 %	46 %	95 %

It can be seen in table 1, that the correlation between MOD09 and 6S01 and 6S02 is not significant. After including atmospheric data from the MODIS products (6S03), the correlation was improved. This was to be expected because the MOD09 product is calculated from the MOD02 product using the 6S code and MODIS atmospheric products as well. The only difference for calculated MOD09 data is that more atmospheric information is used, which can be downloaded from worldwide meteorological stations.

In a second step surface reflectance data from MODIS were compared with ground truth data obtained from fieldwork. Results can be seen in table 2. All corrected values are very low. Even if atmospheric conditions are included in the atmosphere correction process, the correlation reached only a maximum of 37 %.

Table 2. Correlation results spectrometer data (spectro.) and satellite data

	MOD09-Spectro.	6S01-Spectro.	6S02-Spectro.	6S03-Spectro.
Band 1	37 %	5 %	5 %	29 %
Band 2	18 %	14 %	14 %	20 %
Band 3	25 %	3 %	4 %	15 %
Band 4	18 %	4 %	4 %	16 %

2) 6S Input Parameter Test

In order to distinguish their impact on the calculated outcome, atmospheric parameters in the input file were modified. Minima and maxima values for the parameter were adopted from the atmospheric MODIS products. Each product has its own defined valid range which was used as a guide line. The results showed that the water vapour content is not that relevant for an accurate reflectance calculation. Especially band 3 and 4 were not affected from water vapour concentration of any content. In general the reflectance changes lay within 2 % of reflectance.

Results for ozone changes were similar. Band 2 does not change for any ozone content and band 3 fluctuates within a small range of 0.2 % in reflectance. Band 1 and 4 alter within a range of around 2.5 %.

An analysis of aerosol impact on the reflectance change was conducted. Striking changes in calculated reflectance values were noticed after changing aerosol content. This was observed for all bands, but especially for band 3 and 4. Unlike the previous experiment with changing ozone and water vapour content the reflectance value decreased with higher AOT input value. It can be explained by the fact that a higher AOT will increase the atmospheric intrinsic and background reflectance. Those higher values have to be removed from the TOA value. In case of gases a higher input value leads to higher output reflectance. This is because higher gas concentration absorbs more radiance on the surface-sensor path. This radiance has to be added to the TOA data to get surface reflectance.

Furthermore, the influence for the target height and the sensor altitude was analysed. The output showed that the values did not change significantly for different target heights. Finally the reflectance type was changed. It was seen that there is no influence for the calculated reflectance value.

The conclusion is that aerosol impact has the biggest influence on the calculated reflectance value as a small change in aerosol concentration results in a big reflectance change.

3) Sediment Analysis

Here the analysis was carried out to identify, which kind of surface reflectance data is most suitable for sediment detection. Table 3 gives the correlation values between total suspended sediment concentration (TSS) and different sources of surface reflectance. These data showed that surface atmospherically corrected reflectance values from MODIS are more suitable to detect sediment concentration than MODIS top of the atmosphere data. This is the case for all 4 bands, but only if MODIS atmospheric products were included in the correction process (6S03 and MOD09 data).

Table 3. Correlation results between TSS and satellite data

	TSS-MOD02	TSS-6S01	TSS-6S02	TSS-Spectro.	TSS-6S03	TSS-MOD09
Band 1	28 %	26 %	28 %	29 %	63 %	63 %
Band 2	41 %	40 %	40 %	33 %	56 %	53 %
Band 3	0 %	0 %	1 %	20 %	40 %	61 %
Band 4	10 %	12 %	13 %	12 %	52 %	57 %

To understand the reason for an increase of the correlation coefficient before and after atmospheric correction it must be looked at the trend lines between satellite data and sediment concentration (Fig. 2, Fig. 3., and Fig. 4). It can be observed from the graph in Fig. 2, that the three days of measurement are separated into three groups. This should not be the case, because first and second day, highlighted in blue and green, have a similar sediment concentration and therefore should have similar radiance values. Because of this separation the correlation coefficient is with an R^2 value of 28 % not significant. After performing atmospheric correction on the data set using the inherent models of the 6S code, the results were not improved as it can be seen in Fig. 3. R^2 is only 26 % and the first and second day of measurement are still separated into two groups.

After analysing Fig. 4, which shows surface reflectance data calculated with the MODIS atmospheric products, it can be observed that the reflectance values of the first and second day merged together and can not be distinguished any more. Therefore the correlation value increased to R^2 = 63 %.

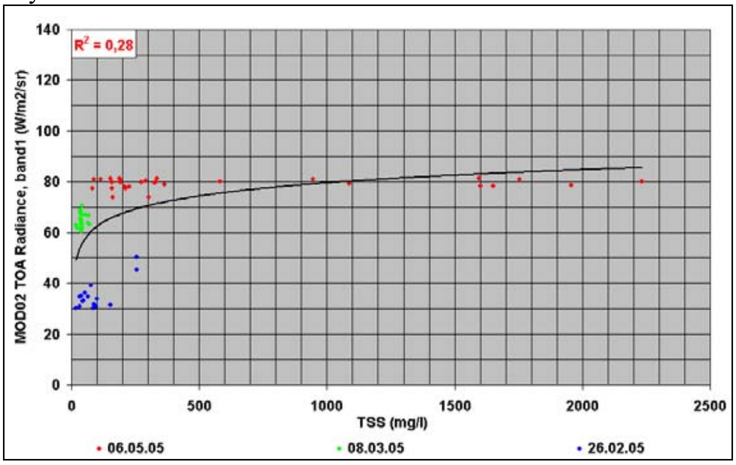

Fig. 2. Trend line between TSS and MOD02 top of the atmosphere radiance data

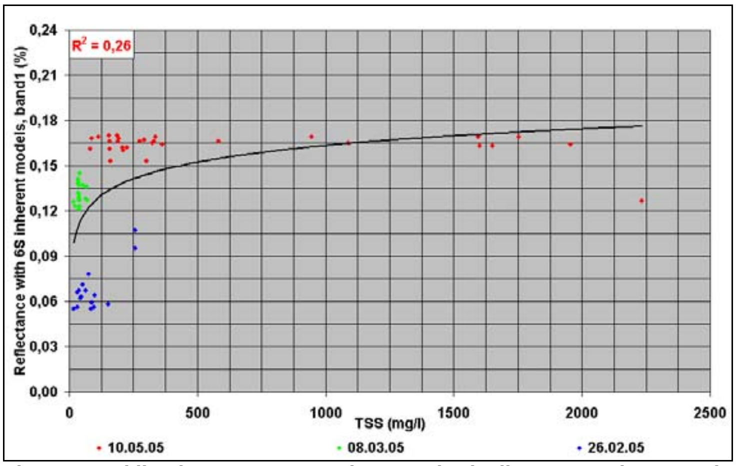

Fig. 3. Trend line between TSS and atmospherically corrected MODIS data using 6S code and included inherent models

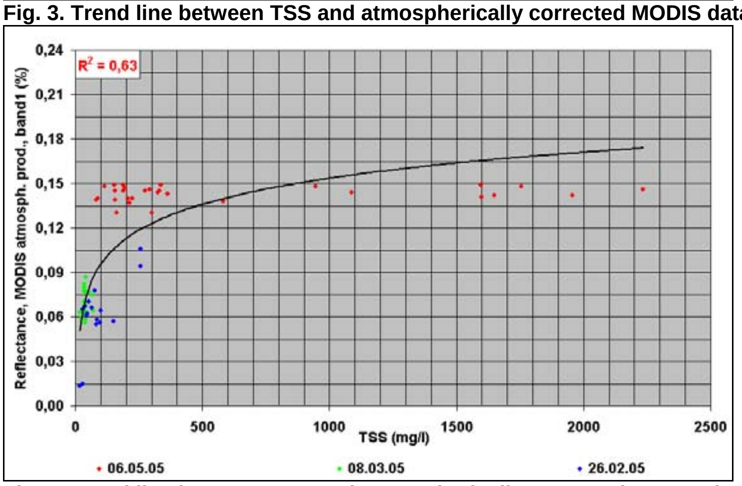

Fig. 4. Trend line between TSS and atmospherically corrected MODIS data using 6S code and MODIS atmospheric products

A look at the MODIS atmospheric data showed, that on 8 March 2005 a high aerosol concentration was existing. The data from 26 February 2005 gave an aerosol optical thickness (AOT) between 0,511 and 0,585. The MOD04 product on 6 May 2005 showed and AOT of around 0,666. But on 8 March 2005 an AOT of 0,925 was measured. This high aerosol loading caused an increase of the radiance value in the MOD02 product, because aerosols tend to scatter radiation back to space as figured out in the 6S input parameter test. This influence of the aerosols on the satellite date was removed by the 6S code that has MODIS atmospheric data as input parameters. It can be seen from Fig. 3 that the inherent model of the 6S code is not able to predict such an high aerosol condition.

The reason for low sediment concentrations (from 83 mg/l to around 250 mg/l) in the samples collected on 10 May 2005 with a high spectral response might be the time difference of 4 days between sediment collection and data of satellite acquisition. During that time low sediment concentration, that seems to be existing on 6 May 2005, might have shifted. Therefore a higher sediment concentration could be collected on the field trip on 10 May 2005.
Another possibility is that the obtained water samples for each pixel is not true representative. It means either in deeper water a high sediment concentration is present or the surrounding water areas within the same pixel have a higher TSS concentration. Both assumptions need to be proved with further analysis and test measurements.

Furthermore, it can be seen from table 3 that the correlation between band 1 and sediment concentration is most significant. Therefore this band was used to calculate sediment maps. Eq. (1) together with MOD09 surface reflectance data was applied to calculate total suspended sediments (TSS).

$$TSS = e^{\frac{(Band\,1+0.09)}{0.04}} . \qquad (1)$$

Fig. 5 shows the results of the TSS concentration of all measurement days using band 1 of MOD09. A previous land sea masking was done using a mask included in the MOD03 geo-location file. It can be observed that sediment concentration increased in between the 8 March 2005 and the 10 May 2005. This can be explained by the fact that the rainy season started in this time. It surely contributed to a higher sediment concentration.

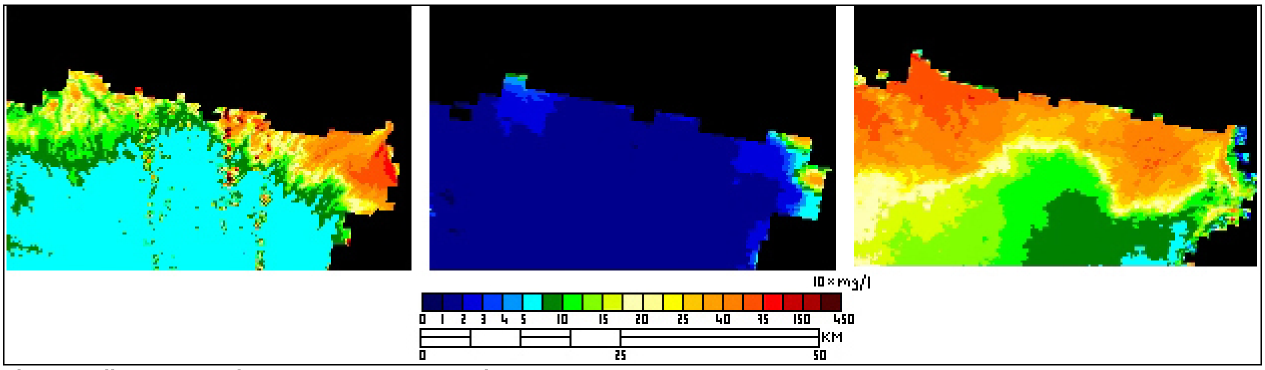

Fig. 5. Sediment maps for 26.02.05, 08.03.05 and 06.05.05

4) White Reference Test

As mentioned previously, only an ‘ordinary’ white paper was used for collecting reference values on the field trip. In order to detect the difference to a calibrated reference board, a white reference test was carried out. The following aspects regarding the measurement setup were considered. At first as already acknowledged an ‘ordinary’ white paper for collection surface reflectance was used. Therefore the difference in the results between white paper and a calibrated reference board were analysed. Furthermore, it was tried to find the influence of a changing distance and angle between the sensor and the white reference board. Because it can be assumed that those two parameters are difficult to keep constant on the fieldwork. For this test the reference board ‘Spectralon Reflectance Target’ (instrument number SRT-99050) from the company Labsphere was applied to seek out for possible sources of errors.

The test gave three results. At first it was noticed that there are enormous reflectance differences in the range from 300 to 400 nm between normal white paper and a calibrated reflectance board. In the rest of the wavelength range the reference curves have a similar shape, but differences still can reach only a maximum of 5 %.
Further it was found, that the calculated surface reflectance only slightly changes with different distances to the sensor. Finally it was studied that a change of the angles between sensor and board will lead to high differences of the calculated reflectance values.

After this test it was decided not to use spectrometer data for validation MODIS data because the spectrometer measurement setup seems not to be suitable for obtaining reliable ground truth values. In order to make it more useful, you have to use a calibrated reference board, include a bubble level in the setup and ensure a fixed distance between sensor and board.

4. Discussion

After the forgoing analysis the following conclusions can be drawn. When using MODIS data for estimating and monitoring sediment concentration, it is advised to perform atmospheric correction. In all 4 analysed bands the correlation between sediment concentration and satellite data could be improved by correcting them for atmospheric attenuations. Two possibilities for the use of MODIS surface reflectance data are given. The first and easier choice is to use MOD09 data, which is freely available. The MOD09 data is free of charge and no software environment for atmospheric correction is required. Because the producers of MOD09 have sometimes problems with their software, the data is not always available.

The second choice is to produce surface reflectance data manually. In this case MOD02 data must be used and parameters of 6S code should be decided. Especially the aerosol content has to be detected very accurate because it has been found that aerosols have a great influence on the radiance. Atmospheric gases (ozone, water vapour) seem to have less impact on the correcting process.

Those input parameters about atmospheric conditions can be chosen from different satellites or ground measurements. The second option is difficult for permanent monitoring. A further problem while converting MOD02 data is the need for a program that runs the 6S code for the whole image efficiently.

The research shows further that from the first 4 MODIS bands band 1 is most valuable for detecting sediments. This was observed for MOD09 data and manual calculated surface reflectance using atmospheric MODIS data. An R^2 value of 63 % was reached between surface reflectance and sediments. It could be shown that MODIS is capable of permanent sediment monitoring due to a significant correlation with sediments and high temporal resolution of the data. The daily coverage of the study area makes it possible to map changes in sediment concentration.

This work might be useful as a starting point for permanent sediment monitoring of the Bight of Bangkok. Using the MODIS sensor as a tool for the detection of sediment concentration, TSS maps could be calculated on daily or weekly base.

To find a better correlation between the satellite signal and the sediments it is recommended to include MODIS-Aqua data. The accuracy for TSS detection might be increased by combining different MODIS bands. More reference measurements at different areas in the bight should be carried out and included in the research. It is suggested to take water samples monthly to ensure a wide range of sediment concentration. And it should be analysed if more water samples in each pixel and in different water depths are necessary to increase R^2. This is especially the case if 1km resolution data should be included in the analysis. The calculated formula could finally be used to compute sediment concentration in the whole Bight of Bangkok. The sediment results could be used for following applications:

(a) Defining the watershed sources, transport, and delivery of sediment to the Bight of Bangkok.

(b) Understanding the relation between sediment sources, deposition, transport, and water clarity in the Bight.

(c) Building up a decision-support system, which can be helpful for creating sediment reduction strategies.

Such a system could be a guideline for actions reducing sediment loads in the bight that have negative impacts on water clarity and aquatic vegetation.

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