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Removing of Sediment and Bottom Reflectance Contribution from MODIS Imagery over Bright Coastal Water

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Abstract: Remote sensing image acquired over a turbid coastal area shows high reflectance in green and red wavelengths. The heightened of reflectance in these wavelengths are due to the contribution of sediment and bottom reflectance in the water and the present of aerosol in the atmosphere over that area. In this paper a simple method to remove sediment and bottom reflectance contribution from remote sensing data over turbid coastal waters for MODIS 0.55, 0.66 and 0.86 μm channels is proposed. We utilized first seven MODIS solar channels centered at 0.47, 0.55, 0.66, 0.86, 1.24, 1.64 and 2.13 μm originally designed for remote sensing over land and cloud properties. This algorithm is based on the excess reflectance at 0.55, 0.66 and 0.87 μm wavelength using the power law model that can be associated to the presence of sediment. The excess value of the reflectance was discarded, to obtain the atmospheric contribution in the data. The sample results from applications of the algorithm to several MODIS datasets acquired over the Gulf of Martaban were presented. This study shows that the sediment and bottom reflectance that influence remote sensing data over turbid coastal water are successfully removed.

Key words: MODIS, remote sensing, sediment, power law, turbid water.

INTRODUCTION

Imaging spectrometry has important applications in a variety of fields, including mineral explorations, vegetation studies, and coastal monitoring. Since the mid 1980's, the concepts of imaging spectrometry and hyperspectral imaging have become increasingly popular. Moderate Resolution Imaging Spectrometer (MODIS) instrument, onboard the Earth Observation System's (EOS) Terra and Aqua satellites. Both satellites are polar-orbiting, with Terra on a descending orbit (southward) over the equator about 10:30 local sun time, and Aqua on an ascending orbit (northward) over the equator about 13:30 local sun time. From a vantage of about 700 km above the surface and a ±55° view scan, each MODIS views the earth with a swath about 2330 km, thereby observing nearly the entire globe on a daily basis, and repeat orbits every 16 days. MODIS performs measurements in the visible to thermal infrared spectral region from 0.41 to 14.235 μm (Salomonson *et al*., 1989). MODIS instrument was designed with 36 spectral channels to support observation of clouds and land as well as oceans.

The atmospheric absorption and scattering effects in the MODIS imagery must be removed in order to get useful information about the Earth's surface. This process is known as atmospheric correction. The main goal of atmospheric correction over the ocean is to remove these contributions in order to retrieve water leaving reflectance in those areas. Water leaving reflectance obtained will be used as input to retrieve ocean color parameter. Water leaving reflectance is at most 10 percent of the top of atmosphere (TOA) reflectance in the visible part of the spectrum (Gordon and Morel, 1983), so accurate atmospheric correction is therefore required. The presence of high sediment concentration in a bright coastal water area not only saturate the MODIS ocean channel but also contributes to the systematic error in MODIS level 2 ocean and atmosphere products over that area. MODIS ocean color products are being used to derive estimation of products such as chlorophyll in oceanic waters. Two main steps involved in the processing of ocean color satellite data are the atmospheric correction to remove the atmospheric contribution to the radiance measured by the satellite sensor and the use of bio-optical algorithms that relate water leaving radiance to the in water constituents (D'Sa *et al*., 2002).

Currently, NASA standard ocean color products have been routinely derived using the two MODIS near infrared (NIR) channels (0.75 and 0.87 μm) for atmospheric correction (Gordon, 1997; Gordon and Wang, 1994). The atmospheric aerosols information is derived from channels centered near 0.66, 0.75, and 0.86 μm, where the water leaving radiances are close to zero. The aerosol information is derived by extrapolation from the near infrared to the visible part of the spectrum. In the turbid and shallow coastal waters, water leaving radiances for channels near 0.66 and 0.75 μm may be significantly greater than zero because of backscattering by suspended materials in the water and bottom reflectance (Mobley *et al*., 2004). Hence, these channels cannot be used for deriving information on atmospheric aerosols. The applications of the algorithm developed for case

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1 water (Morel and Prieur, 1977) to the turbid coastal waters (case 2) often result in negative water-leaving radiances over extended areas.

Numerous investigators shows that the atmospheric correction algorithm that currently apply for MODIS operational works well over case 1 water, whereas phytoplankton is the dominant water constituent but can give invalid results over brighter coastal waters or case 2 water (Gao *et al*., 2007; Wang and Shi, 2005; Lavender *et al*., 2005; Ruddick *et al*., 2000; Siegel *et al*., 2000; Stumpf *et al*., 2003). The impact of this erroneous atmospheric correction will lead to the large errors in the MODIS derived ocean color products (Wang *et al*., 2007). This is due to the turbid water areas are not dark for the two atmospheric correction channels centered near 0.75 and 0.86 μm. The other reason is the ocean color channels (0.488, 0.531, and 0.551 μm) often saturate over bright coastal waters (Gao *et al*., 2007). Atmospheric correction algorithms that currently apply to multichannel remote sensing for open ocean regions in order to retrieve water leaving radiances cannot easily be modified for retrievals over turbid coastal waters (Gao *et al*., 2000). At present, operational products over optically shallow waters are not produced. Therefore, improved atmospheric correction algorithms must be developed for the remote sensing of Case 2 waters (Gao *et al*., 2007).

The fact that suspended sediments increase the radiant emerging from surface waters in the visible and near infrared region of the electromagnet spectrum has been made since late 1970's (Ritchie *et al*., 1976). Studies by researches using a large range (i.e.,0-200 mgl^{-1}) of suspended sediment concentrations have found a curvilinear relationship between suspended sediments and radiance or reflectance (Ritchie *et al*., 1976 ; Curran and Novo, 1988). This is because the amount of reflected radiance tends to saturate the respected channels used for detection as suspended sediment concentrations increase. The point of saturation is wavelength dependent, with the shorter wavelength channels saturating at lower concentrations (Ritchie and Cooper, 1988). High concentrations of organic and inorganic suspended matter in case 2 waters may cause the water leaving signal in near infrared (0.865 and 0.950 μm) to be significantly greater than zero (D'Sa *et al*., 2002; Arnone *et al*., 1998; Hu *et al*., 2000; Hu *et al*., 2001). As a result, the aerosol optical thickness that is derived from this signal in the near infrared, may be over estimated and this lead to an over correction in the visible part of the spectrum (D'Sa *et al*., 2002).

In order to overcome this problem, the effect of sediment or inorganic suspended matter in the signal measured by satellite sensor should be removed. In this paper a simple method to remove the sediment and sea floor reflectance from MODIS imagery over bright coastal waters for MODIS visible and near infrared channels is proposed. This technique can solve the problem of the contribution of sediment and bottom reflectance in the top of atmosphere data. The objective of this study is to remove the contribution of sediment and bottom reflectance in the data and to obtain aerosol contribution for atmospheric algorithm over bright coastal water. This algorithm based on power law (Li *et al*., 2003) utilizing the first 7 MODIS channels centered at 0.47, 0.55, 0.55, 0.86, 1.24, 1.64 and 2.13 μm originally designed for remote sensing over land and cloud properties. The results of this algorithm then validates by histogram method. The peaks that indicates the presence of sediment and bottom reflectance in the top of atmospheric data was successfully removed.

Theoretical Background:

MODIS channels centered at 0.55, 0.66, 0.86, 1.24, 1.64 and 2.13 μm, are commonly being used with aerosol retrieving algorithms. As an assumption, water leaving reflectance in the aerosol algorithm is to be zero in the 0.86, 1.24, 1.64, and 2.13 μm channels due to strong absorption by the water mass (Gao *et al*., 2007; Gordon and Wang, 1994 ; Li *et al*., 2003 ; Reza, 2008). The water leaving reflectance at 0.55 and 0.66 μm channels were assumed to be the typical clear water or case 1 reflectance. An increment of the water leaving reflectance values in the turbid waters area were interpreted as an increase in the optical thickness of the fine aerosol particles. Over bright and shallow coastal water, sediments and shallow waters provided such unaccounted high reflectance and resulted in systematic overestimate of the aerosol optical thickness (Li *et al*., 2003).

The turbid water has significantly larger reflectance than the clear water. Over that area, the reflectance in each of the visible channels shows an increment. The main differences between the case 1 and case 2 waters are located in the 0.4-0.7 μm spectral range (Li *et al*., 2003; Reza, 2008). The effect of sea floor on the reflected radiance even in the shorter region of the spectrum is minimal when suspended sediment concentration (SSC) is high enough (Reza, 2008). The penetration depths in clear water at the level of 90% light attenuation is as high as 40 meters for 0.55 μm channel and as low as a millimeter for 2.13 μm channel (Hu *et al*., 2000). This turbidity in water can affect reflectance in the visible channels and even at 0.86 μm (Li *et al*., 2003; Wang and Shi, 2005). This means that the higher values of SSC may limit the depth of penetration of 0.55 μm channels to a few centimeters and increase the amount of scattering in this channel as a consequence (Hu *et al*., 2000; Reza, 1995). It is not easy to distinguish sunlight signal reflected by turbid waters or from that caused by aerosols using infrared wavelengths.

Because of the small water penetration depths of sunlight for the longer wavelengths (1.24, 1.64 and 2.13 µm), the possibility of the reflection by sea floor is negligible. On the other hand, the blue channel, 0.47 µm is very sensitive to atmospheric molecular scattering, but less sensitive to the additional reflection by sediments (Li *et al*., 2003). Thus, the contribution of sediment in the reflectance of 0.47 µm channel also can be neglected. As discussed above, the MODIS channels centered at 0.47, 1.2, 1.6, and 2.1 µm are mainly influenced by aerosol scattering and water vapor absorption and can be used to derive the atmospheric spectral power law. The 0.55-0.86 µm channels measurements are influenced both by the aerosol and the sediments. The excess reflectance at 0.55-0.86 µm beyond the power law values can be associated to the presence of sediments and used for their detection. The 0.55 µm channel reflectance can be used to detect the presence of sediment and sea floor due to the high penetration (up to 40 m) in the clear waters area. Meanwhile, the 0.66 µm channel is more suitable to discriminate the sediment reflectance and atmospheric contribution from the signal measured by the sensor because of this channel is not much influence by the sea bottom due to the low penetration in the water.

Data And Study Area:

MODIS Terra Level 1B (MOD021KM) during the period of 1 January 2008 to 30 November 2008 have been used in this study. The MODIS Level 1B granule consists of calibrated radiances or reflectance. The product can be downloaded from the MODIS website. The study area covers roughly the latitude range of 14^0N-18^0N and the longitude range of 94^0E-98^0E Gulf of Martaban is located at the northern Andaman Sea Gulf of Martaban is located at the northern Andaman Sea. Annually more than 350 million tons of sediment deposited into this area by the Ayerrarwady, Salween and Sittang rivers. Seafloor in the Gulf of Martaban and adjacent inner shelf is generally smooth whereas the outer shelf has a rough surface with relief of 2-20 m and has topographic features such as pinnacles, highs and valleys, buried channels and scarps. Surface suspended sediment concentrations (SSC) values in the Gulf of Martaban can be from less than 0.1 mg l^{-1} to over 500 mg l^{-} (Ramaswamy *et al*., 2004). Figure 1 shows the map of study area.

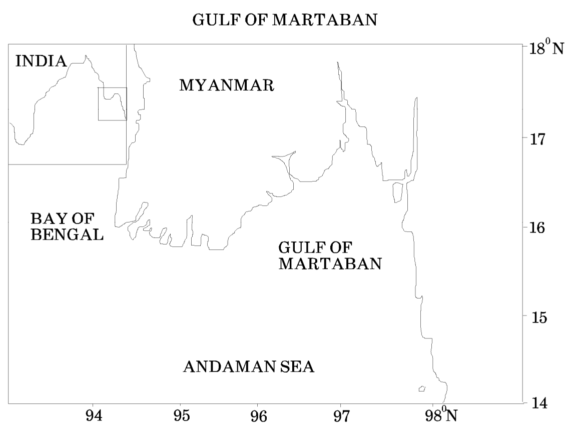


Fig. 1: Study area.

Methodology:

The cloud mask was applied to each scene covering the study area to ensure that no cloud obstruction that can affect the result of the study such as miss interpret of reflectance for high aerosol and cloud. MODIS cloud mask algorithms over water was applied. Normalized difference vegetation index (NDVI) algorithm is applied to differentiate between land and water. NDVI values above 0.1 were discarded from the image. Cloud and land masking process mentioned above retains pixels with only aerosol and sediment contributions in the study image.

After cloud and land covered pixels were masked, log-log graph for first seven MODIS channels was constructed. Three different area based on visual inspection have been classified. The three areas are aerosol and sediment free area, sediment free but contaminated by aerosol area and sediment area. From the log-log graph, the main different within sediment area and free sediment area is heighten of reflection in 0.55, 0.66 and 0.86 µm channels. For sediment free area, all seven channels are in line. Even at high aerosol concentration area, the graph still in straight line but with different slope. The objective of this study is to discard the excess reflectance due to sediment contribution of 0.55, 0.66 and 0.86 µm and fixed it in line with four others channel. This objective achieved by the construction of power algorithm with 0.47, 1.24, 1.64 and 2.13 µm channels as a based for this algorithm. This algorithm will discard all the excess reflectance and leave only aerosol contribution in the image.

RESULT AND DISCUSSION

In this discussion, MODIS image acquired on 7 January 2008 is used as an example. Figure 2 shows an image of 0.55 µm channel of the study area for the date of 7 January 2008. Three areas were selected and categorized based on visual inspection according to their conditions. Areas 1 is less turbid and was referred as clear water area. In this area, water is appears darker than surrounding area. This indicates that the reflectance values from this area are small compare to the other two areas. Area 2 is visually influenced by aerosol and is referred as hazy area. They have higher reflectance value than those in area 1 and located in deep water region (greater than 40 m) where the reflectance effects from sediment and bottom material were very small. Therefore these high reflectance water pixels are mainly caused by aerosol. The corresponding aerosol optical thickness (AOT) map (MODIS Level 2) distributed by NASA's Ocean Biology Processing Group (OBPG) also indicated the presence of aerosol (AOT values 0.100 to 0.310) in these areas. Meanwhile, area 3 is visually turbid water areas with suspended sediment. The existence of this area in the image can be detected easily in the true color image whereas this area shows apparently greenish to grayish color and high reflectance value.

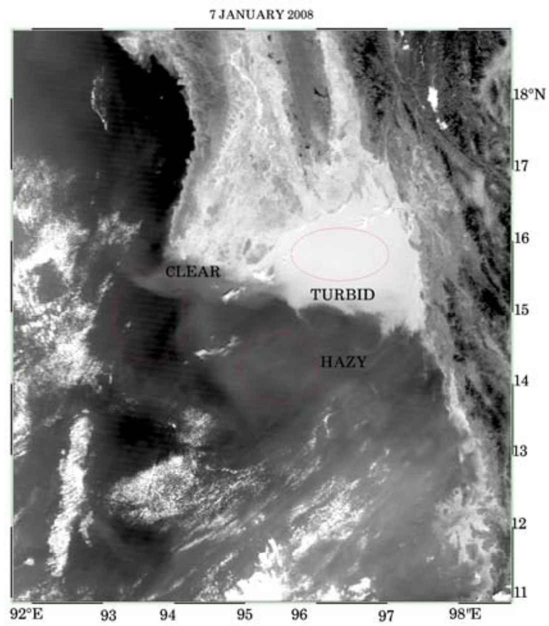


Fig. 2: An image of MODIS 0.55 µm channel represent clear, hazy and turbid water areas.

Figure 3 below shows the histogram build for the areas indicated in the Fig. 2 above. In this figure, three peaks have been identified at different reflectance values that represent three different areas in the scene. The first peaks with the lowest reflectance value indicate the clear water area. The reflectance value of 0.55 µm channels in this area are range from 0 to 0.45. The second peak indicates the hazy area. The apparent reflectance value that represents this area is range from 0.5 to 0.9 for 0.55 µm channels. The last peak is the sediment influence area. This peak exists due to the contribution of sediment reflectance in the data. This peak only exist in the coastal area that the contribution of sediment reflectance are strong. So, in the free sediment area the histogram only shows clear and hazy peak. The present of reflectance by sediment in the MODIS data over bright coastal water as shown above, contribute to the over estimating of aerosol optical depth over coastal area. The objective of this study is to clean up the data from sediment influence by removing the sediment contamination in the data. An influence of sediment reflectance in this data can be removed by applying power law algorithm as discussed below.

In order to have more understanding about the reflectance characteristics in the clear, aerosol influence and sediment influence waters, the apparent reflectance against center wavelength graph have been plotted. Figure 4 show the graph for the three type of scenes mention above. The apparent reflectance for each area shows that, the shorter wavelengths provides high value of reflectance compared to the longer wavelength. In the aerosol influence but free sediment area, a slight increment of reflectance value for each channels. These are due to the aerosol contribution, but the values are still fit in line. In the area with sediment influence, the 0.55, 0.66 and 0.86 reflectance increased drastically and is out of line.

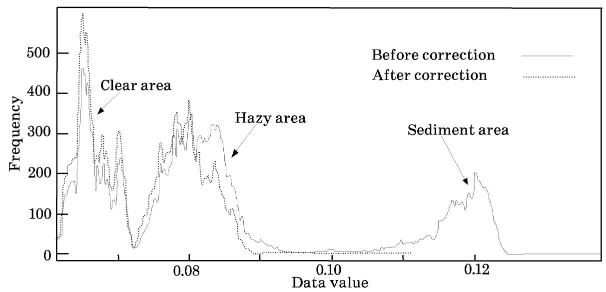


Fig. 3: Histogram of clear, hazy and sediment influence areas.

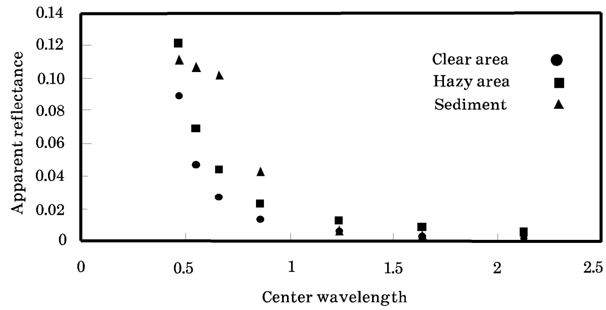


Fig. 4: Linear graph for clear and turbid waters area.

The comparisons between the spectral properties of regions with and without sediments are shown in Fig. 5. Figure 5 show a typical log-log graph of apparent reflectance against center wavelength of seven MODIS band for sediment free and sediment influence area. Based on visualization, hazy area is influenced more by aerosol compared to clear area. The spectral reflectance for hazy area and clear area fitted well with power law formula line, which illustrated by straight line of the graph. The R square value for both areas is 0.997 and 0.995 respectively. Spectral reflectances for clear area are lower than hazy area with steeper slope due to smaller aerosol concentration. The difference between the slopes is due to contribution of aerosol. It is means that, for an area with high aerosol contribution, the higher the increment of the slope.

In the sediment water area, the values of 0.55, 0.66 and 0.86 µm reflectance are above the power law line. Increment reflectances in these channels are due to the effect of sediment in that area. Meanwhile, the 0.47, 1.24, 1.64 and 2.13 µm reflectance fitted very well with the power law line. The R square value for the each area is given as 0.934. The correlation of sediment area is the lowest among the others two area. The reflectances in that area are higher in the grayish area compared to greenish area. This indicated that, grayish area contribute more reflectance than greenish area. After sediment effect have been discard from the image, the value of 0.55 and 0.66 µm channels will be fitted in line with others channels.

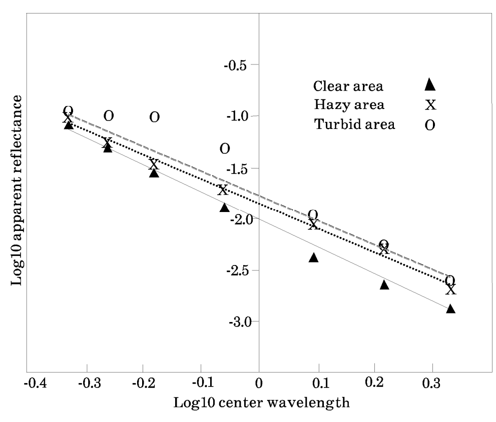
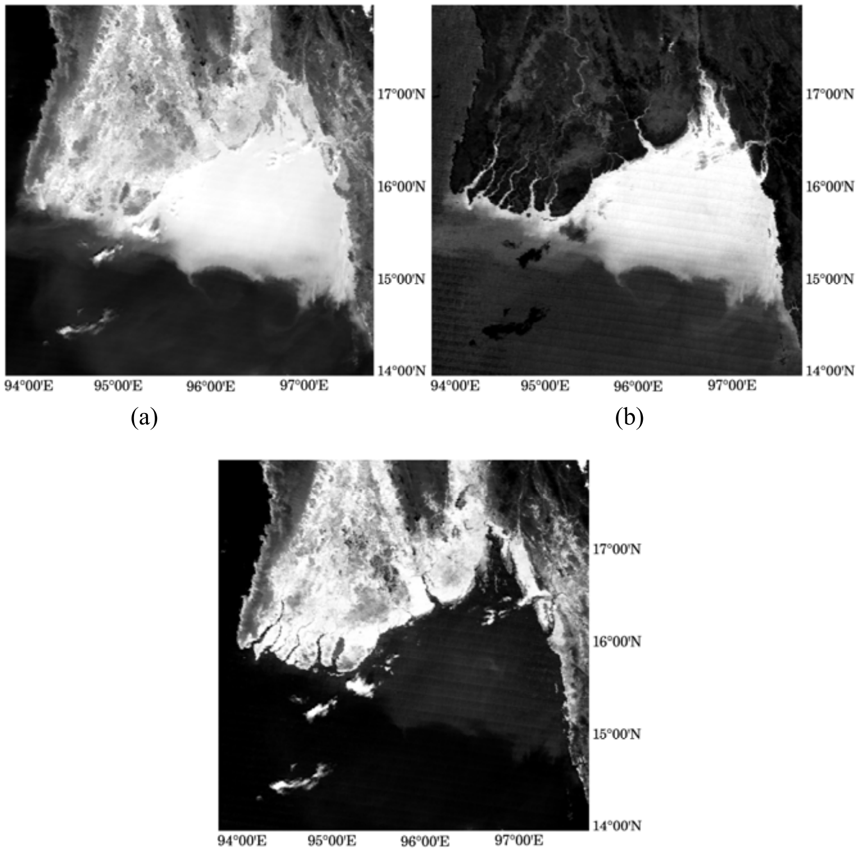


Fig. 5: Log-log plot for clear, hazy and sediment area.

Figure 6(a) shows the contributions of aerosol and sediment reflectance in the 0.55 µm channel. Figure 6(b) show the contribution of sediment in absent of aerosol. Meanwhile Fig. 6(c) shows the contributions of aerosol in the image after the sediment reflectance have been removed. It is clearly seen that in the Fig. 6(a), the present of bright area along the gulf are due to the contribution of sediments in the image. Figure 6(c) shows that the bright color that exists before the correction applied was successfully removed. It is also true for 0.66 and 0.86 μm wavelength.



(c)

Fig. 6: Image of 0.55 μm channel over Gulf of Martaban on 7 January 2008. (a) Image of 0.55 μm represents aerosol and sediment contributions. (b) Image represents sediment contributions. (c) Image represents aerosol contributions after sediment contributions have been removed.

In order to validate this algorithm, the histogram for the three areas discussed above, was build in Fig. 3. This figure shows the third peak whereas represents the sediment reflectance peak that exists before the correction applied was successfully removed.

Conclusion:

A simple algorithm to discriminate sediment and atmospheric contribution over bright coastal waters has been proposed. The method is based on analyses of MODIS dataset above Gulf of Martaban. The contributions of the sediment in the image have been discarded and leave only the contribution of the aerosol. This algorithm also can be applied to remove the sediment contribution in the ocean color channels that used to retrieve water leaving radiance over ocean (0.75 and 0.86 μm). In the near future, a study of aerosol optical thickness over bright coastal area will be conducted. Hopefully this proposed method can overcome the band saturation and improve the detection of aerosol optical depth and normalized water leaving radiance over bright coastal waters area.

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