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Satellite Based Monitoring of Turbidity around Hai Phong Bay, Vietnam

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This paper develops a satellite-based monitoring system for observations of spatial and temporal variations of turbidity of the sea surface around Hai Phong Bay in the northern part of Vietnam. The monitoring system is based on MODIS and consists of sub-tools required for the monitoring, such as cloud masking and turbidity estimations based on multiple band data. The developed system is validated through comparisons of estimated and measured turbidity patterns around Hai Phong Bay. The system is then applied for monitoring of turbidity patterns around the bay over the past sixteen years and it was found through the monitoring that observed turbidity shows decreasing trend after the construction of dams along the upstream of the rivers around the area.

Key Words : *turbidity, remote sensing, MODIS, Hai Phong, Vietnam*

1. INTRODUCTION

Hai Phong is located in the northern part of Vietnam and is highly affected by complex sediment discharge from multiple branches of the Red River system. The Red River discharges significant amount of sediments and the Red River Delta is known to have the fourth largest delta plain in Southeast Asia[1]. Significant sediment discharge around Hai Phong Bay and Cam Estuary has significant economic impact not only by deposition[2] of Hai Phong Harbour, one of the main economic hub in the northern part of Vietnam, but also by high turbidity along the surrounding coastal resorts.

Although some residents claim increasing trend of turbidity especially after the construction of reclaimed land in the bay, there is no quantitative evidence to justify their claims. Besides such reclamation in the bay, constructions of dams and reservoirs along the Red River System may also have significant impact on the sediment discharge and turbidity around the bay. Since the turbidity around the bay dynamically changes in different temporal and spatial scales, the better understandings of the behavior of turbidity require monitoring of spatial and temporal variations of turbidity patterns around the bay. This study aims to develop a satellite-based monitoring system of turbidity patterns and test the developed system to Hai Phong Bay and surrounding coast.

2. STUDY AREA

Fig.1 shows the study area. The Cam River and Bach Dang, the most northern tributaries of the Red River system, are the primary rivers that flows into Hai Phong bay. The study area also covers the Van Uc River located at the south side of Hai Phong Bay because this river may also have certain influence on the turbidity around Hai Phong Bay. Ha Long Bay, known as one of world heritages, is located just north side of Hai Phong Bay. Since Ha Long Bay is well known to have clear sea water, i.e., little turbidity, the contrast between Hai Phong Bay and Ha Long Bay can be a good indicator for validation of the devel-

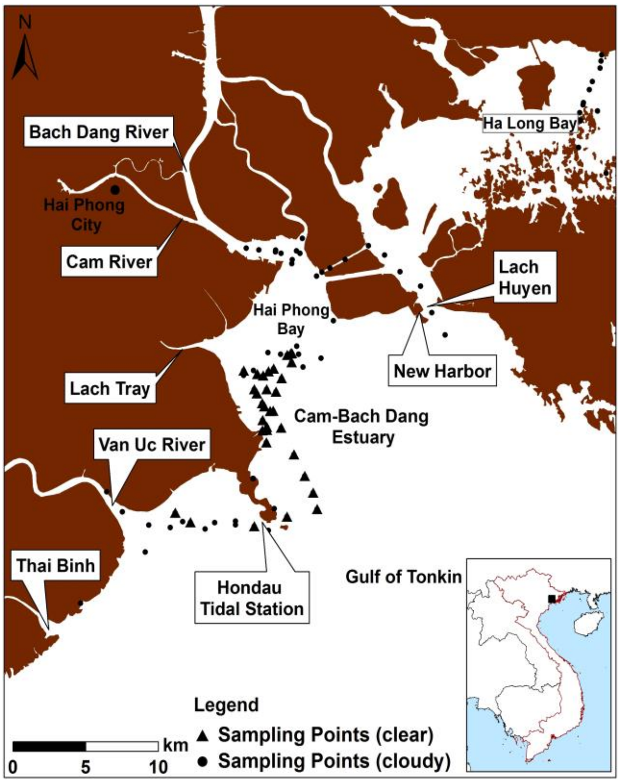

Fig.1 A map of study area and sampling points when the sky was clear (triangles) and cloudy (circles)

oping turbidity monitoring system.

3. FIELD SURVEY

Field surveys were conducted around Hai Phong Bay and around the Van Uc River mouth to obtain the in-situ turbidity data, which is used for validation of the developing satellite-based turbidity monitoring system. These field surveys were carried out at the time when the MODIS is recorded around the target area. To cover both rainy and dry seasons, we carried out two field surveys in dry season, Mar 2015 and Feb 2016 and four field surveys in rainy season, July 2014, July 2015, Sep 2015 and Nov 2015. Extent of data collection coverage highly depends on weather conditions at the study site although it was not easy to forecast the cloud-free day on which MODIS is also recorded. We could not use some of the turbidity data since these sites were covered by cloud and no reliable reflectance data was obtained from MODIS. Turbidity was measured by the turbidity meter, INFINITY_CLW ACLW2-USB, which can measure the turbidity within the range from 0 to 1000 FTU (Formazin Nephelometric Unit).

A tourist boat was used for the data collection and we stopped the boat at each survey point to avoid the influence of turbulence on the turbidity measurements. At each point, the turbidity meter was dropped to the water by a rope and kept around the water surface with water depth of less than 50cm during the measurement. Coordinates of each point were recorded by GPS. At each location, the turbidity was recorded for more than two minutes and recorded turbidity was averaged over the time. **Fig. 2** shows photographs during the field work when turbidity front was clearly observed. Sampling locations were selected so that the measured turbidities are distributed in the wider range. Prior to the field work, we synchronized the clocks of sensor and GPS so that we can easily match the measured turbidity and coordinates of measured locations through the recording time.

Fig.2 Pictures of sampling surveys

4. MONITORING SYSTEM

This section outlines the development of satellite-based monitoring system of spatial and temporal variations of the turbidity around Hai Phong Bay. Since the turbidity patterns were expected to change dynamically with tide, the river flows, waves and some other factors, monitoring frequency and the number/duration of available data are one of primary features for selections of appropriate satellite for the present monitoring system. This study selected Moderate Resolution Imaging Spectroradiometer (MODIS, hereafter), which records each site twice a day and archives the data over the past sixteen years.

Two MODIS sensors are installed on two satellites; Terra and Aqua. Terra orbits around the Earth from February 2000 to the present and it passes the study area in the morning (10:30am). Aqua, on the other hand, was launched in July 2002 and it passes the study area in the afternoon (01:30pm). Two satellites respectively provide a separate image of the target site every day. MODIS sensor consists of 36 multispectral bands with different spatial resolutions; 250m (2 bands), 500m (5 bands) and 1000m (29 bands). **Fig. 3** shows the visual images of MODIS and estimated turbidity patterns, which are discussed in the following section.

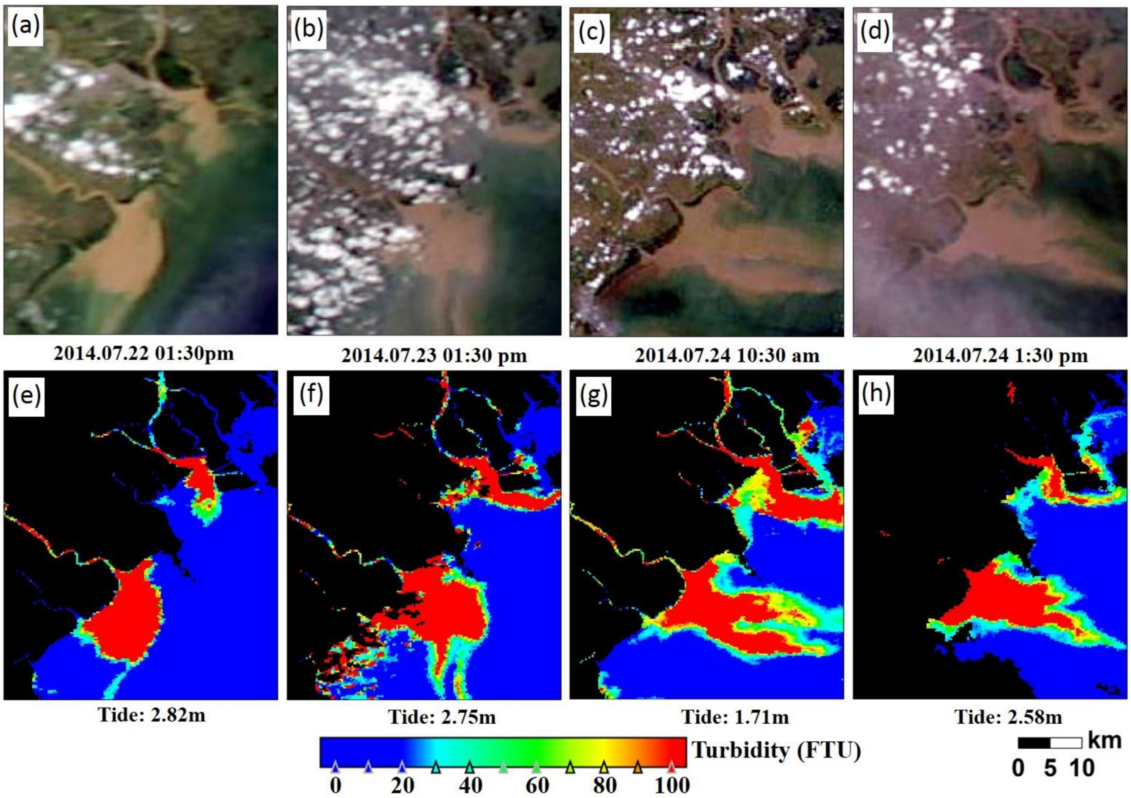

Fig.3 (a)~(d) Visual images of MOIDS around the study site; (e)~(h) derived turbidity maps from MOD09 images

MODIS data can be freely downloaded from several websites and ftp servers in different processing scales (http://modis.gsfc.nasa.gov/). This study used daily level 2G (L2G) surface reflectance products (250m resolution) from both Terra (MOD09GQ) and Aqua (MYD09GQ). Those daily products are atmospherically corrected for the effects of atmospheric gases and aerosols to yield surface spectral reflectance[3),4)]. These products consist of surface reflectance for two bands: band 1 with the range of wave length from 620 to 670 nm and band 2, from 841 to 876 nm. Band 1 and 2 respectively represents Red and Near-Infra-Red (NIR) range in the electromagnetic spectrum. This study used the band 1 for estimation of the turbidity and combinations of band 1 and 2 for detection of the cloud, which is masked out from the monitoring of the turbidity.

All the archive data from the year of 2000 to December 2015 were utilized for the analysis. Data processing, such as downloading, reprojection, mosaicking and resampling, were automated in Linux environment by using two libraries; pyModis and GDAL. Following sections outline the developed methodologies for estimation of the turbidity and cloud masking.

(1) Turbidity estimation

As discussed in the previous section, this study applies the surface reflectance of red band data of MODIS for estimations of the turbidity of the sea water surface. Several existing studies demonstrate that reflectance of the wave band between 600 and 800 nm are well correlated with the turbidity of the open water surface[5)] and suggest that the observed relationship between turbidity and band data can be applied for estimations of the surface water turbidity at any locations. This study introduces a new fitting formula for estimation of the turbidity based on the in-situ turbidity data measured around Hai Phong Bay.

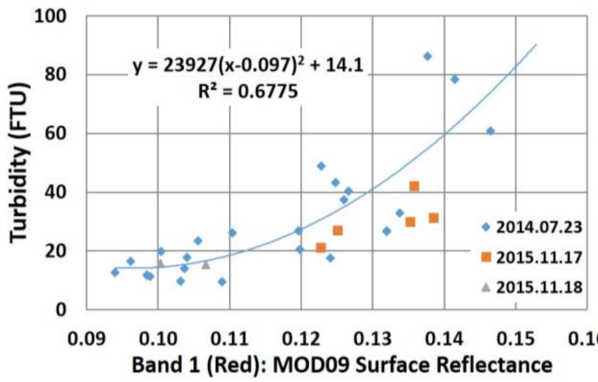

Fig.4 Relationship between redband reflectance of MODIS and corresponding in-situ turbidity measurements.

Daily MODIS images on the days of the field surveys were obtained and the red band reflectance was extracted from the cloud-free pixels where the turbidity was measured in the field survey. **Fig. 4** shows the relationship between MODIS red band surface reflectance and in-situ turbidity measurements. In the Figure, the solid line indicates the following fitting curve of the relationship between the red band reflectance and the turbidity.

$$T = 23927(x - 0.097)^2 + 14.1 \quad (0.097 \le x \le 0.15) \tag{1}$$

Here, T is the modelled turbidity (FTU), x is the Red band (band 1) reflectance of of MODIS. It should be noted that this fitting formula can be applied within the range of $0.097<x<0.15$. Applicability of the present formula in the range of higher turbidity need to be validated with additional data.

(2) Cloud masking

One of unique and challenging features of this study is that we aim to use all the available MODIS data over the past sixteen years for understanding of spatial and temporal behaviors of the turbidity patterns. Some of MODIS data, however, are fully/partially covered by clouds and the present monitoring system needs to exclude the influence of the cloud on the analysis of turbidity patterns.

While the red band has high reflectance both from cloud and high turbidity, the band 2, NIR band, shows low reflectance from the turbid water but high reflectance from the cloud. This study thus utilizes this characteristics and determine the threshold value for detection of the cloud by the difference of band 1 and band 2. While thick cloud is easy to mask, haze, i.e., transparent clouds, is quite difficult to mask out. By trial and error method, haze was removed by locally changing the threshold value but it should be noted that a part of cloud free turbid pixels are also masked out. Validity of the cloud masking is discussed in the following section.

(3) Turbidity map

Bottom panels of **Fig. 3** (from (e)~(f)) show examples of turbidity maps based on MOD09 images in three consecutive days of July 2014. Black color area represents the clouds and land which are masked out. As seen in the area around the left-bottom corner of these panels, the area covered by haze was reasonably detected and masked out. It is also seen that estimated turbidity distributions reasonably represent the spatial patterns of turbid water observed in corresponding top panels.

(4) Cell system

As seen in **Fig. 3**, many of obtained turbidity maps partially contain pixels with no turbidity estimations. On the other hand, observed horizontal length scale of the turbidity variation appears to be much larger than the pixels size, 250m. Based on these findings, this study introduces unique cell system to represent spatial temporal turbidity patterns. **Fig. 5** shows the developed cell system in the study area. Each cell contains more than 16 pixels and averaged turbidity can be obtained even if the cell is partially covered by cloud. Alongshore boundaries of the cell were determined parallel to the shoreline so that selected cells are aligned about the same distance from the shoreline. Several Matlab scripts were developed to automatically process the daily images to estimate the average turbidity in each cell, in which the pixels covered by cloud were excluded.

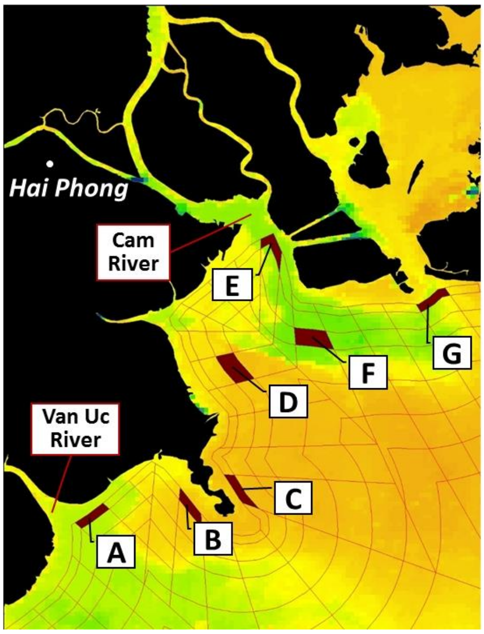

Fig.5 Developed cell system and seleted cells for the comparision of long-term turbidity trend.

5. DISCUSSIONS

Finally, the developed monitoring system is applied to the area around Hai Phong Bay to investigate the characteristic behavior of turbidity patterns, which may be affected by various external factors such as tide, wind, waves, river discharge, and bathymetry change of the bay. This section discusses the overall influence of some of these external factors on behavior of spatial and temporal variations of the turbidity pattern around Hai Phong Bay.

(1) Tidal influence

While all the MODIS images shown in **Fig.3** were recorded within two days, observed turbidity patterns significantly differ from each other. **Fig. 6** shows the time series of tide recorded at Hondau station inside the study area during these two days and also in the entire year of 2014. In the figure, black dots indicate the tide when either Terra or Aqua acquired MODIS data at the target site; red squares indicate the tide when images in **Fig.3** were acquired. Images in

Fig.3 (a), (b) and (d) were recorded around the peaks of high tide while (c) was recorded during the flood tide. The area of high turbidity was larger during the flood tide (c) rather than the one at the high tide (d). The difference between (a) and (d) may be due to some other external factors since tidal conditions are nearly the same in these two images. Further analysis needs to be carried out to extract the turbidity behavior due to tide. As seen in the bottom panel of **Fig.6**, tidal conditions at the MODIS acquisition time widely vary in the tidal range.

(2) Long-term trend of averaged turbidity

This section focuses on long-term trend of the turbidity through observations of the turbidity averaged over the year. **Fig.7** (a) shows the time-history of the spatial and temporal average of the turbidity in the selected cells and each year. **Fig. 7** (b) also shows the time series in each cell and year but values are based on the standard deviations of the turbidity.

As seen in the figure, the cells A and B show the highest average turbidity among other locations until 2009 and this feature indicates dominant influence of Van Uc river. The turbidity at cell E, around Cam river mouth, was relatively lower than those in A and B but turbidities at these cells nearly equal to each other after 2009. Low and stable turbidity at the cell G indicates that high turbidity around Hai Phong Bay has little influence on Ha Long Bay. It is interesting to note that relatively high standard deviations are observed at cells C and D where are away from the river mouth and the turbidity level may also be affected by some other external factors.

Overall decreasing trend of the turbidity was observed in **Fig.7** especially after 2005. Along the Red River system, two dams, Thac Ba and Hoa Binh dams, were constructed from 1989 to 2006 and three other dams, Tuyen Quang, Son La and Lai Chau dams were constructed from 2007 to 2014. **Fig.8** shows the decreasing trend of total volume of sediment fluxes at different locations[6]. Dominant decrease of sediment discharge is observed at the Van Uc river mouth and this feature is consistent with the observed decreasing trend of turbidity by MODIS data.

Fig.9 shows spatial distribution of normalized average (top) and standard deviations(bottom) of estimated turbidity from 2000 to 2005 (left) and from 2006 to 2015(right), respectively. Significant decrease of the turbidity is also observed around the Van Uc river mouth. Standard deviations of the turbidity tend to be larger in the offshore cells. Relatively high turbidity is spread on both side of the Van Uc River mouth while slightly higher turbidity is observed on the southern side of the river mouth. It is also interesting to note that, along the east side of

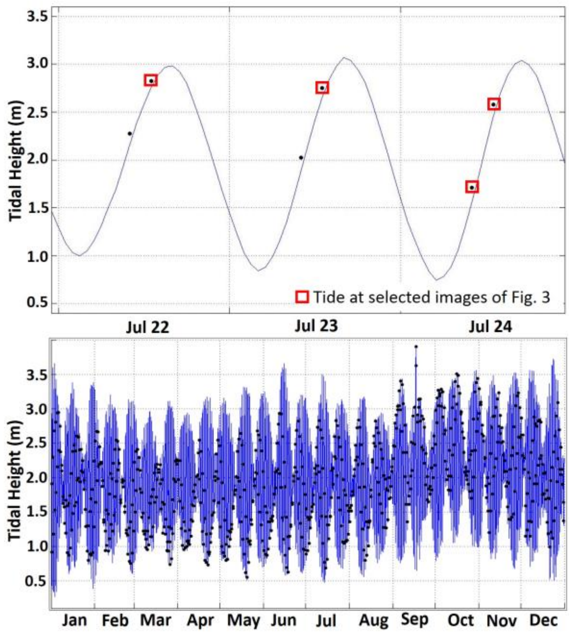

Fig.6 Tide at Hondau station from July 22 to 24, 2014(top) and in the entire year of 2014 (bottom). Black dots indicate the tide at me at which MODIS was recorded.

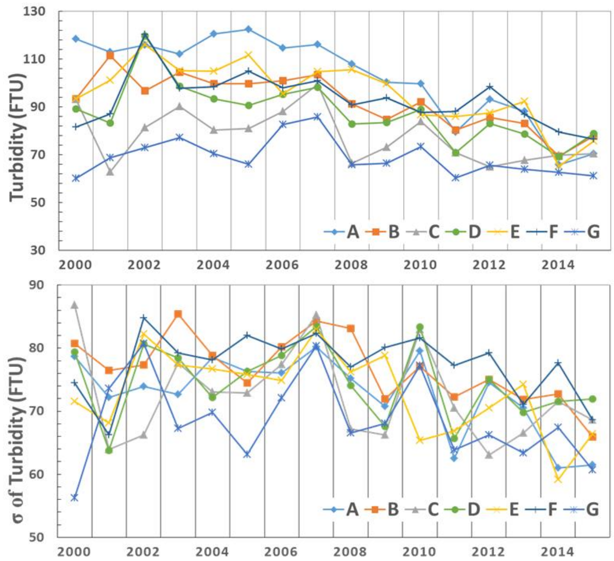

Fig.7 Time series of the turbidity characteristics in each selected cells indicated in Fig.5 ((a) yearly average and (b) standard deviation)

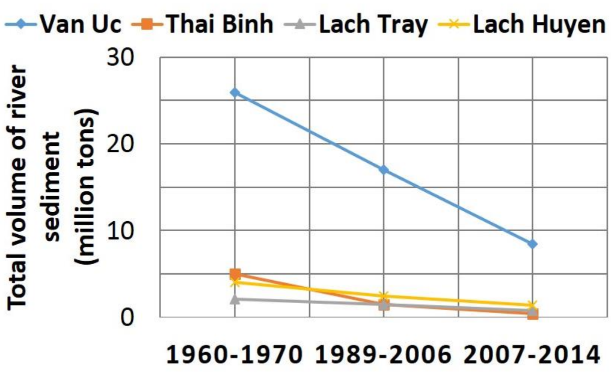

Fig.8 Total volume of river sediment discharge over the three time periods

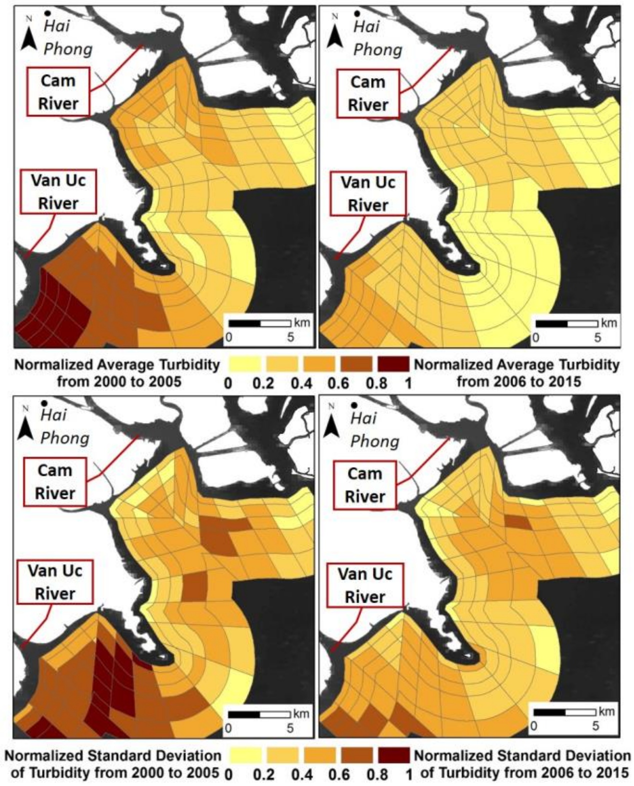

Fig.9 Spatial distribution of normalized average turbidity from 2000 to 2005 and from 2006 to 2015 (top); standard deviation of turidity in those periods (bottom)

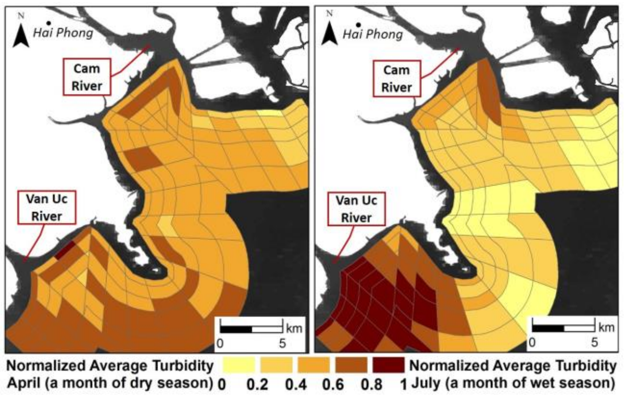

Fig.10 Spatial distribution of normalized average turbidity in dry (left) and wet (right) seasons

Don Son resort (peninsula), the patterns of turbidity both in average and standard deviations appear to be more affected by the turbidity on the west side of the peninsula. This feature indicates that the influence of turbid water from Van Uc River reaches over the peninsula.

(3) Seasonal Variations

To evaluate the seasonal patterns of turbidity, two months were selected in dry (April) and rainy (July) seasons and spatial distributions of the normalized average turbidity in each month were compared in **Fig.10**. As seen in the figure, the rainy season shows clearly higher average turbidity around the river mouth while relatively high turbidity is widely expanded in the dry season. Further analysis needed for understanding of the behavior of turbidity affected by various external factors.

5. CONCLUSIONS

This study developed a satellite-based monitoring technique for observations of temporal and spatial variations of turbidity especially around the river mouth based on MODIS data. The developed technique was applied to the area around Hai Phong Bay where suffers turbidity problems. Field surveys were carried out to obtained the in-situ turbidity and suspended sediment concentration. Obtained in-situ turbidity and corresponding MODIS red-band reflectance showed good correlations and empirical formula for estimation of the turbidity based on the red-bad reflectance of MODIS was obtained. Based on the observed turbidity data, we found the dominant influence of Van Uc river beyond the peninsula located on the north side of the river. It was also found that yearly-averaged turbidity showed clear decreasing trend especially around Van Uc river after 2005 and this trend also corresponds to the timings of dam constructions.

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REFERENCES

1) Hori, K., Tanabe, S., Saito, Y., Haruyama, S., Nguyen, V., and Kita- mura, A.: Delta initiation and Holocene sea-level change: exam- ple from the Song Hong (Red River) delta, Vietnam, Sediment. Geol., 164, 237–249, 2004.
2) Lefebvre, J. P., Ouillon, S., Vu, D. V., Arfi, R., Panche, J. Y., Mari, X., Chu, V. T., and Torréton, J. P.: Seasonal variability of co- hesive sediment aggregation in the Bach Dang-Cam Estuary, Haiphong (Vietnam), Geo-Mar. Lett., 32, 103–121, 2012.
3) Vermote, E. F., El Saleous,N. Z., & Justice, C.O. (2002). Atmospheric correction ofMODIS data in the visible to middle infrared: First results. Remote Sensing of Environment, 83,97–111.
4) Vermote, E. F., & Vermeulen, A. (1999). MODIS algorithm technical background document, atmospheric correction algorithm: Spectral reflectance (MOD09). NASA, contract NAS5-96062
5) Doxaran, D., Froidefond, J.M., & Castaing, P. (2002). Areflectance band ratio used to esti- mate suspended matter concentrations in sediment-dominated coastal waters. International Journal of Remote Sensing, 23,5079–5085.
6) National research project (code KC08.34/11-15). (2015). Science-based research and proposed solutions to improve the phenomenon of sedimatation in Do Son estuary, Hai Phong City, Vietnam. Center for river hydraulics engineering, Vietnam Academy for Water Resources.

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