Tsunami Reconnaissance Survey in Thailand Using Satellite Images and GPS

Fumio YAMAZAKI*, Masashi MATSUOKA, Pennung WARNITCHAI,
Supapis POLNGAM, and Shubharoop GHOSH

* Department of Urban Environment Systems, Chiba University
1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan n
yamazaki@iis.u-tokyo.ac.jp

Abstract

This report summarizes the results of tsunami reconnaissance survey in south Thailand conducted by a team consisting of researchers from Thailand, Japan, and USA. The area was hit by a series of tsunamis caused by the 26 December, 2004 North Sumatra Island earthquake with magnitude 9.0. The primary objective of the survey is to gather geo-referenced tsunami inundation and damage information with enhanced use of satellite images and GPS. Digital still photos and videos were taken in the hard-hit areas and they were linked to the satellite images. Using a hand-held spectrometer, measurement of spectral reflectance for surface materials in tsunami effected areas was also conducted to gather ground truth data of satellite images. Using all the data gathered in the survey and satellite imagery, the present authors plan to develop tsunami hazard/inundation maps in Thailand.

Key Words : the 2004 Indian Ocean Tsunami, Thailand, Field Survey, Remote Sensing

1. Introduction

A moment-magnitude 9.0 earthquake struck the area off the western coast of northern Sumatra on 26 December, 2004, at 7:58:53 local time (00:58:53 GMT). The magnitude is registered as the forth among the earthquakes worldwide after 1900. The epicenter was located at 3.307°N, 95.947°E and the depth is 30 km by location program (USGS, 2005). The slow slip likely occurred over the entire 1,200 km length of the rupture zone shown by aftershock distribution (Stein and Okal, 2005). This gigantic earthquake triggered massive tsunamis, which inundated coastal areas in countries all around the Indian Ocean rim – from Indonesia to East Africa. Tsunami related deaths have been reported in 11 countries, including Indonesia, Sri Lanka, India, Thailand, Malaysia, Myanmar, Maldives, Bangladesh, Somalia, Tanzania and Kenya. The death toll including missing is approximately 280,000 according to United Nations and governments (ReliefWeb, 2005).

In Thailand, provinces facing Andaman Sea, notably, Phang-Nga, Phuket, and Krabi, were attacked by repeated tsunamis. The death toll in Thailand reached 5,395 and 2,932 people were listed as missing as of March 9, 2005. Nearly half of those confirmed dead, and half of those missing were foreign tourists who were spending their holiday season in the resort areas.

As the scale of this tsunami disaster became unveiled, the present authors have decided to form an international survey team to gather geo-referenced tsunami inundation and damage information with the enhance use of satellite images and GPS. A similar joint survey team supported by Earthquake Disaster Mitigation Research Center (EDM), Japan, and the Multidisciplinary Center for Earthquake Engineering Research (MCEER), USA, was formed after the 1999 Kocaeli, Turkey earthquake for the first time (Eguchi et al., 1999; EDM, 2000). The joint reconnaissance survey was also conducted after the 2004 Mid-Niigata earthquake (Huyck et al., 2005). It was almost impossible to cover the large tsunami-affected areas by a small group. Thailand was selected as our primary survey area because of existing research collaboration and accessibility to the sites at an early stage. Geo-Informatics and Space Technology Development Agency (GISTDA), Thailand, provided various satellite images for this joint survey.

Damage detection using high-resolution satellite imagery has been conducted by the present authors and others for recent earthquakes, e.g. the 2001 Gujarat, India earthquake (Saito et al., 2004), the 2003 Boumerdes, Algeria earthquake (Adams et al., 2003; Yamazaki et al., 2004), and the 2003 Bam, Iran earthquake (Adams et al., 2004; Yano et al., 2004).

Figure 1(a) shows the members of the international survey team. The team was formed by Chiba University (Japan: F. Yamazaki), EDM (Japan: M. Matsuoka), ImageCat Inc./MCEER (USA: S. Ghosh), Asian Institute of Technology (Thailand: P. Warnitchai), GISTDA (Thailand: S. Polngam and S. Lawawirojwong), and Japan International Cooperation Agency (Japan: M. Honzawa). The primary objective of our survey is to gather geo-referenced tsunami inundation and damage information, and hence we brought several digital video cameras and digital still cameras. Figure 1 (b) shows a scene of geo-referenced video shooting using three video cameras.

The team members gathered in Bangkok, Thailand on 7 January, 2005 and a meeting and information collection were conducted. The field survey was carried out from 8 to 11 January, 2005, covering hard-hit areas, e.g. Khao Lak, Phuket Island, Phi Phi Island. This article reports the results of the field survey with the special emphasis on the use of satellite images and GPS in damage survey. The preliminary survey report has been found in MCEER homepage (Ghosh et al., 2005).

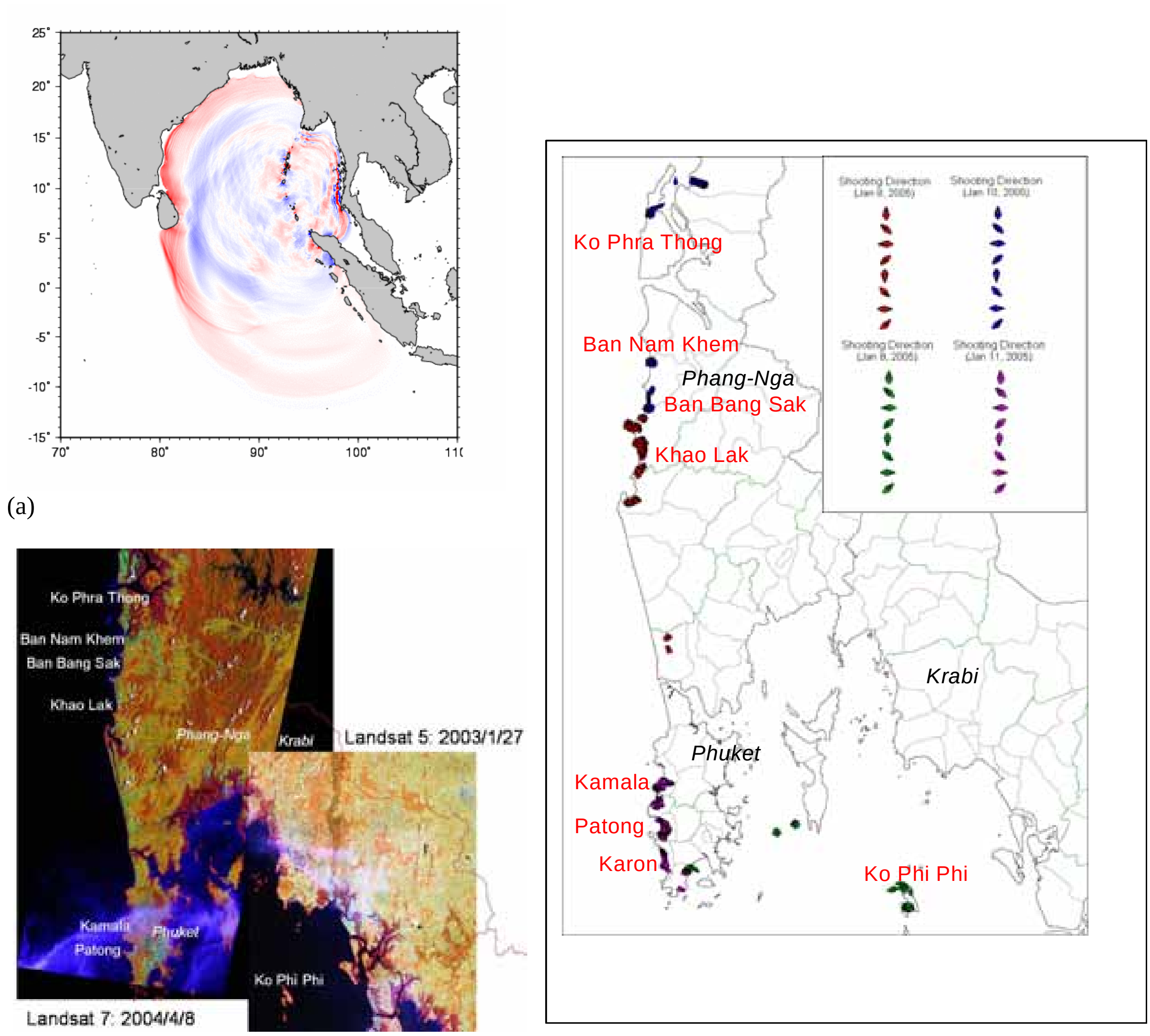

(a)


(b)

Figure 1: (a) Members of the international survey team and (b) video shooting with three videos synchronized with GPS

2. Survey Area and Schedule

As seen in Figure 2(a), southern provinces of Thailand were hit by gigantic tsunamis at about 10 AM (local time), about 2 hours after the occurrence of the magnitude 9.0 earthquake. Landsat image of the tsunami affected areas in Thailand is shown in Figure 2(b). The first day of the field survey (8 January), after arriving Phuket airport in the morning, we looked around Khao Lak, Phang Nga Province, by a car. On the second day, we visited Phi Phi Island, Krabi Province, and two small islands in the west of Phuket by a high-speed boat. The third day, we went to Phang Nga Province again and surveyed the north and central areas of the province, e.g. Ban Nam Khem, Ban Bang Sak. Hiring a small boat, the team visited a small fishery village on Phra Thong Inland also. On the forth day, we surveyed several beaches along the west shoreline of Phuket Island, e.g., Kamala, Patong, Karon, Kata beaches. Tsunami inundation and runup heights in south Thailand have been surveyed by a survey team supported by a research grant of Japanese Government (Matsunami, 2005). According the survey, tsunami height was 6-10 m in Khao Lak, 3-6 m along the west coast of Phuket, about 6 m on the beach facing south in Phi Phi Island. Initially, we planned to add tsunami height data to this Matsunami's database. But since we did not have level surveying instruments, we concentrated on gathering geo-referenced videos and photos of tsunami damage. After this January survey, F. Yamazaki conducted another field survey in mid February and M. Matsuoka in mid March to gather additional information.



(a)

(b) (c)

Figure 2: (a) Tsunami simulation result 120 minutes after (http://staff.aist.go.jp/kenji.satake/animation.gif), (b) Landsat image of tsunami affected area in south Thailand, (c) location and direction of GPS-synchronized still camera shooting in the field survey

3. North and Mid Phang-Nga Province

Phang-Nga Province is the most heavily affected area in Thailand by the gigantic tsunami. The northern part of Phang-Nga Province is a rural area with fishery and agricultural villages while the central part has several resort hotels. Figure 3 shows ASTER image of north and mid Phang-Nga Province and photos taken during the field survey. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is the optical sensors of Japan on board TERRA satellite of USA. The spatial resolution of bands 1-3 (0.52-0.86μm) in visible and near-infrared regions is 15m, that of bands 4-9 (1.60-2.43μm) in short-wave infrared region is 30m and that of bands 10-14 (8.125-11.65μm) in thermal infrared region is 90m.

Figure 3(a) is the false color image of ASTER taken 6 days after the tsunami attack for north and mid Phang-Nga Province, which is put on the web site of Earth Remote Sensing Data Analysis Center (ERSDAC), Japan (http://www.ersdac.or.jp/todayData/EDS/00.1/pict_j.html). The areas depicted as red are those with dense vegetation. Comparing this post-tsunami image with one before tsunami, the red area is seen to recede along the shoreline hit by tsunamis.

Figures 3(b) and (c) show the port and village of Ban Nam Khem, respectively. In this area,

Figure 3: ASTER image of Phang-Nga Province and photos taken during the field survey. (a) false color image of ASTER on 2004/12/31, (b) Port of Ban Nam Khem, (c) Ban Nam Khem village, (d) a hotel under-construction hit by tsunami, (e) boundary of tsunami runup shown by yellow dot line, (f) debris remains on beach, (g) devastated Princess Resort

tsunami attacked the populated village and many residents were killed. Figure 3(d) shows a hotel under-construction hit by tsunami, (e) shows the boundary of tsunami runup, identified by the condition of vegetation and remaining objects brought by tsunami, (f) shows debris on the beach, and (g) is cottages in Princess Resort, which was completely devastated by tsunami, all in Ban Bang Sak area of mid Phang-Nga Province.

4. Khao Lak

Khao Lak is located in the south of Phang-Nga Province with many luxurious hotels. The area was quite popular to foreign tourists, especially from Europe. Khao Lak was hit by the gigantic tsunami after 10 AM and the death toll in Khao Lak was the largest in Thailand. Three days after the killer tsunami (2004/12/29), IKONOS satellite captured a clear image of Khao Lak area. Pan-sharpened images of Khao Lak are posted on web pages, e.g. the Centre for Remote Imaging, Sensing and Processing (CRISP) at National University of Singapore and Center for Satellite-Based Crisis Information at German Aerospace Center (DLR).

Figure 4 shows the post-tsunami IKONOS image of Khao Lak and photos taken during the field survey. Blue dots in IKONOS images are the location of geo-referenced photo shooting. Figure 4(a) is IKONOS image of Phakarang cape area with 1m resolution, (b) is the photo of devastated Bamboo Orchid Resort on the Phakarang cape, (c) shows a car thrown on the roof by tsunami. If we enlarge the IKONOS image, several black pixels corresponding to this car can be identified. Figure 4(d) is

Figure 4: Post-tsunami IKONOS image of Khao Lak and photos taken during the field survey. Blue dots show the location of geo-reference photo shooting. (a) Phakarang cape area, (b) devastated Bamboo Orchid Resort on the Phakarang cape, (c) a car on the roof, (d) mid Khao Lak area near Weather Station, (e) a collapsed bridge by tsunami, (f) destroyed cottages in a resort, (g) Nang Thong Beach area in lower Khao Lak, (h) & (i) Similana Resort devastated by tsunami

IKONOS image of mid Khao Lak area near a weather station, (e) is a collapsed bridge by tsunami near the weather station, and (f) shows destroyed cottages in a resort. Figure 4(g) shows Nang Thong Beach area in lower Khao Lak, and Figures 4(h) and (i) are photos taken at Similana Resort, which was devastated by tsunami of about 5m high.

5. Phuket Island

Phuket Island was attacked by repeated tsunamis about two hours after the occurrence of the off Sumatra Island earthquake. The scene of tsunami attack was recorded by several videos of tourists. The height of tsunami was reported to be highest in Kamala and Patong Beaches, about 5m, and that of Karon and Bang Thao Beaches was about 4m.

Figure 5 shows Landsat image of Kamala and Patong Beaches in Phuket Island and photos taken during the tsunami attack and in the field survey. Photos (b), (d) and (f) were taken by a resident from the third floor of a reinforced concrete building in Kamala Beach on 26 December, 2004 while the corresponding photos (c), (e) and (g) were taken during the second field survey on 20 February, 2005 from the same building. Comparing photos (b) and (c), we can see that a wooden house which was covered by tsunami to the roof has been washed away. The houses in photo (f) are located behind the third story building, and thus the speed of tsunami might be reduced. Together with the fact that they are made of reinforced concrete, the houses remained as shown in photo (g) although they were also covered by tsunami up to the roof level.

Patong Beach, which attracts the largest number of tourists in Phuket Island, was attacked by

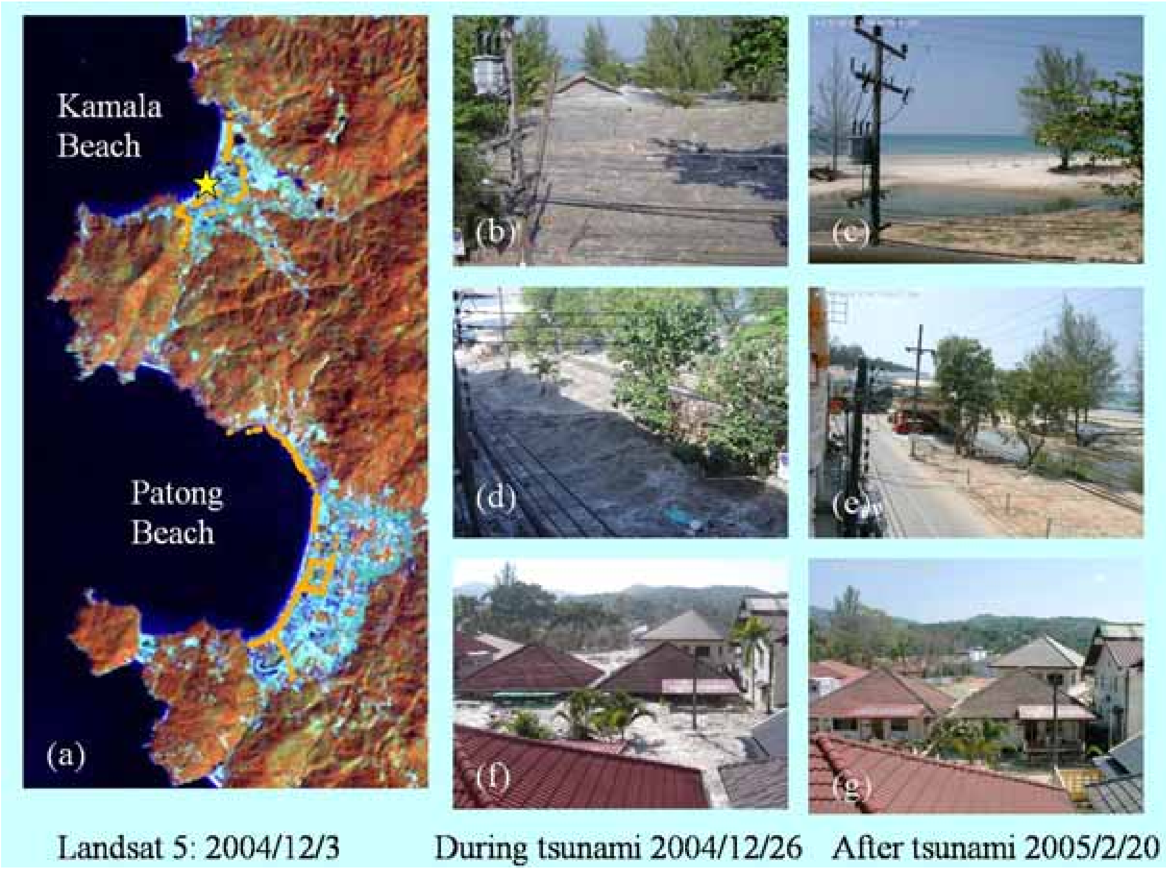


Figure 5: Landsat image of Kamala and Patong Beaches in Phuket Island and photos taken during the tsunami attack and in the field survey. Photos (b), (d) and (f) were taken by a resident from the third floor of a reinforced concrete building on Kamala Beach while the corresponding photos (c), (e) and (g) were taken during the second field survey on 20 February, 2005.

tsunami with the height of about 5m. Although shops and restaurants along Thaweewong Road (beach street) were severely damaged and many people were killed, the elevation of the area goes up gradually from the beach to inland, and thus the tsunami lost power and runup was up to 200-300 m distance from the shoreline.

Recovery of Patong Beach was very quick. When we visited there on 7 January, many restaurants and bars have already opened and some tourists were seen on beach.

Probably due to cloud cover, the number of good quality high-resolution satellite images is very small for Phuket. QuickBird, the highest resolution commercial satellite, captured the area including Patong Beach on 2 January, 2005, but its quality was not so good. QuickBird shot the area again on 5 January, 2005, and this time, the image including Patong, Karon and Kata Yai Beaches was obtained with less cloud cover. The present authors purchased this image together with a pre-event image covering Patong and Karon Beaches on 2002/3/23. We plan to compare these images in detail and to validate the area of tsunami inundation based on the changes in reflectance characteristics in four spectral bands.

6. Phi Phi Island

Phi Phi Islands consist of two islands, the main island: Ko Phi Phi Don, and the no inhabitant marine sports island: Ko Phi Phi Le. The survey team visited Phi Phi Don Island on 9 January, 2005 by a high-speed boat from Phuket Island. Seeing from the tsunami source area, Ko Phi Phi Don is located outside the shadow of Phuket Island. Thus the island was hit by large tsunamis of about 6 m maximum height. The number of casualties in the island was 691 and that of missing was 951 according to the emergency response center of Thai government as of 8 January.

Figure 6: Landsat image of Phi Phi Island and photos taken during the field survey. (a) Ko Phi Phi Don and survey points (green dots), (b) & (c) Laem Tong area and destroyed cottages, (d) Ton Sai Bay from the south, (e) burning of debris, (f) main shopping street filled with debris, (g) water mark remaining inside a completely destroyed shop.

Figure 6 shows Landsat image of Phi Phi Don Island and photos taken during the field survey. As seen in Landsat image (a) on 2003/1/27, Ton Sai area, the center of the island, has been developed on a thin sand belt between two mountainous islands. The elevation of Ton Sai area is only 2-3 m from the sea level. From the topographic condition, there is no place to evacuate in the area, other than higher stories of several reinforced concrete hotel buildings. Tsunami first came from the north bay, and then the higher tsunami attacked the area from the south bay. The scene of tsunami attack was recorded by a foreign tourist from the third story of Phi Phi Cabana Hotel. It is seen that the tsunami came up to the roof of the first story of the hotel.

Photos (b) and (c) show Laem Tong area in the north of the island with several destroyed resort cottages. Although the area was also hit by tsunami, the height and resultant damages were smaller than those in Ton Sai area. Photo (d) is Ton Sai seen from the south bay, photo (e) burning of debris, and photo (f) the main shopping street of Ton Sai filled with debris. The buildings in this area were mostly wood-frame of one or two-storied, and thus the most buildings were collapsed or partly collapsed. Photo (g) shows a water mark remaining inside a completely destroyed shop, showing that the inundated water was sustained at this level.

After surveying Ko Phi Phi Don, the team visited two small islands, Ko Khai Nai and Ko Khai Nok, between Phuket and Yao Yai Islands. These two islands are located behind Phuket Island seen from the tsunami source, and thus the effect of tsunami was minimal. Dozens of foreign tourists have already been on the beach when we visited there two weeks after the tsunami.

7. Panoramic VIEWS: GPS Synchronized Multiple Video Shooting

VIEWS (Visualizing the Impacts of Earthquakes With Satellites) has been developed by ImageCat, Inc. with the financial support from MCEER. VIEWS is a notebook-based system, which integrates GPS-registered digital video footage, digital photographs and observations with high-resolution satellite imagery, collected before and after a disaster (Adams et al., 2004). VIEWS was

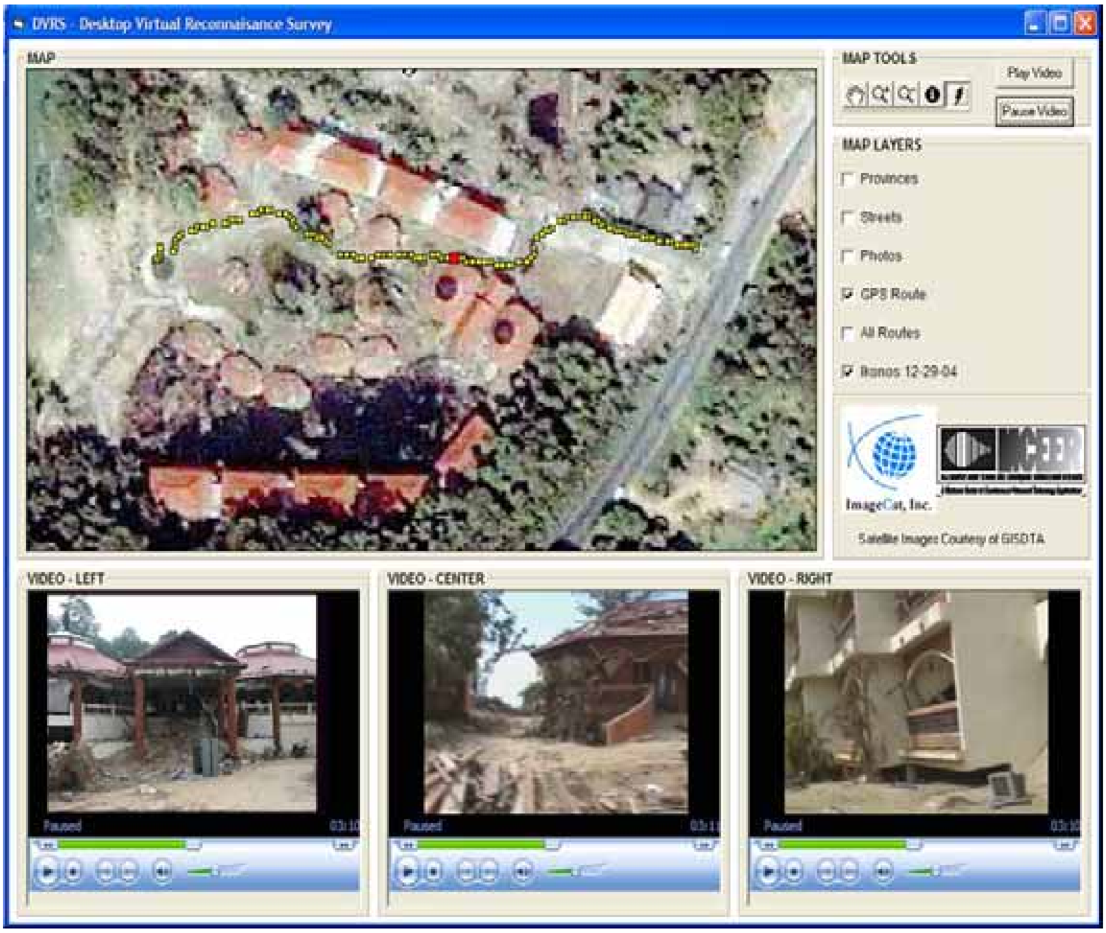


Figure 7: Screen shot from the virtual reconnaissance system (D-VRS), showing satellite imagery (IKONOS on 2004/12/29) with GPS readings and video footage from three video cameras collected in Khao Lak, Thailand (Ghosh et al., 2005).

previously used in reconnaissance activities following the 2003 Bam, Iran earthquake, the 2004 Hurricanes Charley and Ivan that hit the Mexico Gulf coast of USA, and the 2004 Mid-Niigata, Japan earthquake (Huyck et al., 2005).

In this tsunami survey in Thailand, the field-based damage assessment was conducted using VIEWS. These ground-based observations can be later used to validate damage characteristics identified on satellite imagery. It is envisioned that such perishable data will be invaluable for future research in evaluating damage from tsunami hazards. We brought several video cameras in our field survey in Thailand. Thus, a new data collection approach was adopted (Figure 1(b)) by deploying three video cameras that simultaneously captured footage for three directions (front, left, and right) in some heavily affected areas. This streamlined the video collection process and provided a wider view of the area. We named this new system as “Panoramic-VIEWS”.

In order to integrate, share, visualize, and ultimately analyze post-disaster reconnaissance field data collected using VIEWS, MCEER funded the development of tandem internet- and desktop-based “virtual reconnaissance systems”, referred to as D-VRS (Ghosh et al., 2005). Figure 7 shows a screen shot from the virtual reconnaissance system, showing satellite imagery (IKONOS on 2004/12/29) with GPS readings and video footage from three video cameras collected in Khao Lak. Users have an option to toggle between multi-temporal and multi-source satellite images, and to explore these images in detail using zoom in and zoom out functions. These images are overlaid with GPS routes collected during the survey. By selecting a GPS point, users can view corresponding video footage and scroll through the photographic archive in the adjacent windows.

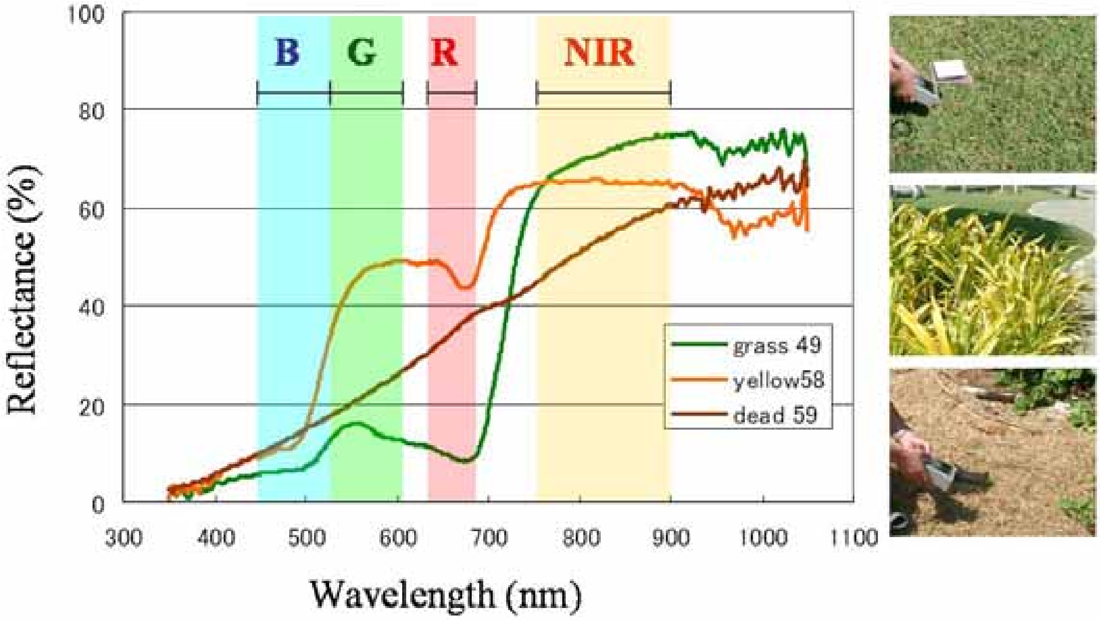


Figure 8: Reflectance of vegetation measured on Kata Beach, Phuket Island on 2005/2/20. Green loan (top) was planted after the tsunami attack, and yellow plant (middle) and dead loan (bottom) were inundated by tsunami.

8. Reflectance Characteristics of Surface Materials in Tsunami Affected Areas

Both moderate resolution satellites, e.g. Landsat and ASTER, and high resolution satellites, e.g. IKONOS and QuickBird, have optical sensors in visible and near-infrared regions. To gather ground truth data of satellite images, measurements of spectral reflectance of surface materials were conducted during the second field survey by the first author on 19 and 20 February, 2005. A hand-held spectrometer, MS-720 made by Eko Instruments Co., Ltd., Japan, (http://www.eko.co.jp/eko/a/index.html), was used. Figure 8 shows an example of data obtained in the field measurement: the reflectance of vegetation on Kata Beach, Phuket Island on 2005/2/20. The area for measurement was inundated by tsunami, and hence vegetation in the area was dead or in unhealthy condition. We measured the reflectance of vegetation in three different conditions: healthy (re-planted), seriously suffered (yellow), and dead, as shown in Figure 8. A clear difference is seen among three reflectance curves: a rapid increase in reflectance between visible red (R) and near-infrared (NIR) bands is observed for the healthy plant (top) while this characteristic is reduced for the unhealthy plant (middle), and it was lost for the dead plant (bottom). As can be seen in this example, the change in reflectance of vegetation is significant and thus it can be used to judge the effects of tsunami. The Normalized Difference Vegetation Index (NDVI) can be calculated for various multi-temporal satellite images and the difference of NDVI before and after the tsunami attack may show the area of inundation by tsunami.

9. Conclusions

A reconnaissance survey was carried out in south Thailand by a team consisting of researchers from Thailand, Japan, and USA. The area was hit by tsunami caused by the 26 December, 2004 North Sumatra Island earthquake of moment-magnitude 9.0. The primary objective of the survey is to gather geo-referenced tsunami inundation and damage information with the enhanced use of satellite images and GPS. Digital still photos and videos were taken in the hard-hit areas, e.g. Khao Lak, Phuket Island, Phi Phi Island, and they were linked to the satellite maps. It is envisioned that such perishable data will be invaluable for future research in evaluating damage from tsunami hazards. A new data collection approach was adopted by deploying three video cameras that simultaneously captured footage for three directions (front, left, and right) in some heavily affected areas. This provides a wider view of the survey area and we named this new system as “Panoramic-VIEWS”. Using a hand-held spectrometer, measurement of spectral reflectance for surface materials in tsunami effected areas was also conducted to gather ground truth data of satellite images. Using all the data gathered and satellite imagery, the present authors plan to develop tsunami hazard/inundation maps in Thailand.

References

Adams, B.J., Huyck, C.K., and Eguchi, R.T., 2003, The Boumerdes (Algeria) Earthquake of May 21, 2003: Preliminary Reconnaissance Using Remotely Sensed Data, http://mceer.buffalo.edu/research/boumerdes/default.asp

Adams, B.J., Huyck, C.K., Mansouri, B. et al., 2004. The Bam (Iran) earthquake of December 26, 2003: Preliminary reconnaissance using remotely sensed data and the VIEWS system, *MCEER Earthquake Reconnaissance Investigation Report*, 10p. http://mceer.buffalo.edu/research/Bam/page1.asp

Earthquake Disaster Mitigation Research Center (EDM), 2000, Report on the Kocaeli, Turkey Earthquake of August 17, 1999, The 1999 Turkey Earthquake Report, *EDM Technical Report* No. 6, p. 67.

Eguchi, R.T., Huyck, C.K. Houshmand, B., Mansouri, B., Shinozuka, M., Yamazaki, F., and Matsuoka, M., 2000, The Marmara Earthquake: A View from Space, The Marmara, Turkey Earthquake of August 17, 1999: Reconnaissance Report, *Technical Report* MCEER-00-0001, pp. 151-169.

Ghosh, S., Huyck, C.K., Adams, B.J., Eguchi, R.T., Yamazaki, F., and Matsuoka, M., 2005, Preliminary Field Report: Post-Tsunami Urban Damage Survey in Thailand, Using the VIEWS Reconnaissance System, http://mceer.buffalo.edu/

Huyck, C.K. et al., 2005, Reconnaissance Technologies: Lessons from Niigata Ken Chuetsu Earthquake, *Earthquake Spectra*, (submitted for review).

Matsutomi, H. et al., 2005, The December 26, 2004 Sumatra Earthquake Tsunami, Tsunami Field Survey around Phuket, Thailand, http://www.drs.dpri.kyoto-u.ac.jp/sumatra/thailand/phuket_survey_e.html

ReliefWeb, 2005, http://www.reliefweb.int/rw/RWB.NSF/db900SID/EVIU-6AJJ3C?OpenDocument&rc=3&cc=tha

Saito, K., Spence, R.J.S., Going,C., and Markus, M., 2004, Using High-Resolution Satellite Images for Post-Earthquake Building Damage Assessment: A Study Following the 26 January 2001 Gujarat Earthquake, *Earthquake Spectra*, Vol. 20, No. 1, pp.145–169.

Stein, S. and Okal, E., 2005, Ultra-long period seismic moment of the great December 26, 2004 Sumatra earthquake and implications for the slip process, http://www.earth.northwestern.edu/people/seth/research/sumatra.html

United States Geological Survey (USGS), 2005, http://earthquake.usgs.gov/eqinthenews/2004/usslav/

Yamazaki, F., Kouchi, K., Matsuoka, M., Kohiyama, M., and Muraoka, N., 2004. Damage Detection from High-Resolution Satellite Images for the 2003 Boumerdes, Algeria Earthquake, *13th World Conference on Earthquake Engineering*, CD-ROM, Paper No. 2595, 13p.

Yano, Y., Yamazaki, F., Matsuoka, M., and Vu, T.T., 2004, Building Damage Detection of the 2003 Bam, Iran Earthquake Using QuickBird Images: *Proceedings of 25th Asian Conference on Remote Sensing*, CD-ROM, pp. 618-623.