Environmental Monitoring of Southeast Asia using MODIS Direct Broadcast Data

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Abstract – The direct broadcast of MODIS data from the TERRA and AQUA satellites provides new opportunities for realtime and precision environmental monitoring of the Southeast Asia region. In this paper, we describe our centre's efforts to set up a regional environmental monitoring system making use of the direct broadcast data. The system will automatically processes any MODIS DB data to level 2, and performs near-realtime detection of impending environmental disasters, such as fire hot spots, algal blooms, smoke haze and floods. The extracted information is disseminated immediately to interested stakeholders via emails. Besides the near-realtime products, cloud-free composite products such as land surface reflectance, coastal sea suspended sediments and chlorophyll distribution are produced to study the spatial and temporal changes in the states of the environment.

Keywords: MODIS DB, hotspot detection, flood, environmental monitoring.

1. INTRODUCTION

The MODIS sensor onboard the TERRA and AQUA satellites with its direct broadcast capability is providing new opportunities for near realtime and precision environmental monitoring of the Southeast Asia region. Its wide swath coverage of 2300 kilometres with moderate resolution means two adjacent passes of one satellite is sufficient to image the whole Southeasat Asia region. Since there are 2 satellites, namely TERRA and AQUA equipped with the MODIS sensor, the region can be imaged up to four times a day(fig 1).

2. DB RECEPTION AND PROCESSING

CRISP started receiving MODIS direct broadcast data in March 2001 (Lim et al, 2001a) when the Direct Broadcast Reception and Processing system was established. This is a fully automated system that acquires MODIS direct broadcast data via a 6-metre X-band antenna. An in-house developed software creates browse images from the incoming DB data which can be previewed at the CRISP catalog webpage (http://www.crisp.nus.edu.sg). Another reformatting software converts the raw data to MODIS Level 0 or Production Data Sets (PDS) format.

The MODIS processing system comprises a network of Linux workstations (Low et al, 2003). The first workstation receives the MODIS PDS and produces geolocated and calibrated top-of-atmosphere radiances using the NASA MODIS Level 1 Processing Software. A single MODIS pass usually results in several 5-minute HDF data files. On completion of Level 1 processing, the data granules are sent to the second Linux PC via a gigabit network.

Whenever new MODIS data is available, a processing script will activate relevant NASA science algorithms (institutional algorithms) and inhouse-developed algorithms to retrieve geophysical land, ocean and atmospheric parameters (to be explained in the next section). The retrieved geophysical parameters are used to detect and monitor the onset of anomalous events in the Southeast Asia region. The interpreted results are despatched to stakeholders and interested users immediately via Internet protocols like email and the web. Simultaneously, the analysed information is also transmitted to the third workstation which hosts a web server. The information on the web server is currently only accessible by internal users. Public access is being considered at a future date.

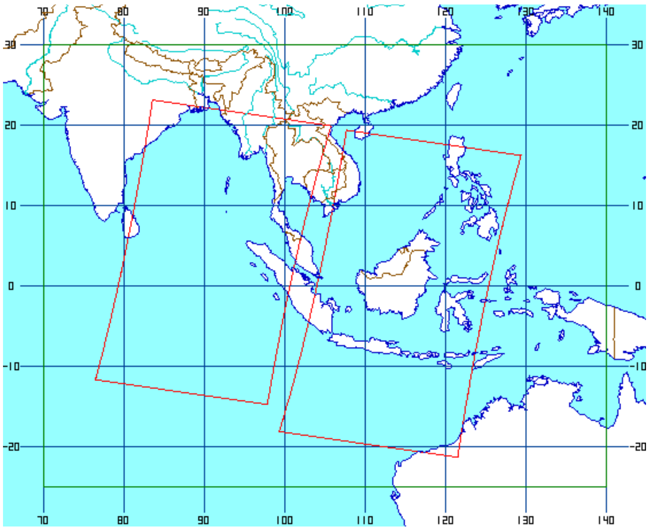

Figure 1a. Typical spatial extent of TERRA MODIS received by CRISP (coverage for morning pass on 4 Feb 2005).

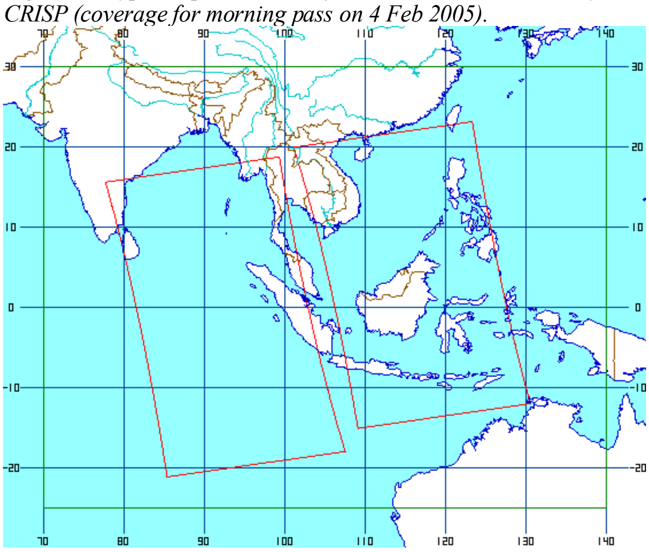

Figure 1b. Typical spatial extent of AQUA MODIS received by CRISP (coverage for afternoon pass on 4 Feb 2005)

The environmental monitoring activities at CRISP specifically using the MODIS DB data can be divided into two categories. The first category are events of short time scales such as forest fires, floods and sea water chlorophyll anomalies. The second category are events of much longer time scales and spatial extent like land cover changes. The following sections is an attempt to describe the more significant environmental monitoring activities in greater detail. However, more specific and implementation information can be obtained from the respective references.

3. ENVIRONMENTAL MONITORING

3.1 Forest Fire and Haze Monitoring

Forest fires are a common occurrence in the region during the dry season. Unlike forest fires in the subtropics, the fires in the region produces much more smoke and haze (fig 2), and this have severe social, health and economic impacts. The MODIS sensor has 2 3.9 micron thermal bands (Bands 21 and 22) which are very sensitive to high temperature targets. Before the advent of MODIS, CRISP was actively detecting fires using NOAA satellite data. When the MODIS DB reception and processing system was established, CRISP developed the software to detect forest fires using MODIS (Lim et al, 2001b) data.

In 2003, CRISP installed the NASA fire detection algorithm as part of its efforts to operationally run selective NASA's Level 2 institutional algorithms (http://directreadout.gsfc.nasa.gov/download_technology/inst_algorithms.cfm). Since then, the fire detection algorithm has been upgarded following NASA's release of their enhanced global contextual fire detection algorithm for the MODIS sensor (Giglio et al, 2003). In our continuing efforts to develop a regional fire detection algorithm, Lim et al, (2004) have developed a fire detection technique based on subpixel retrieval of fire temperature. At the same time, CRISP has done extensive studies to validate the accuracy of the NASA-detected hot spot locations in the region (Liew et al, 2003).

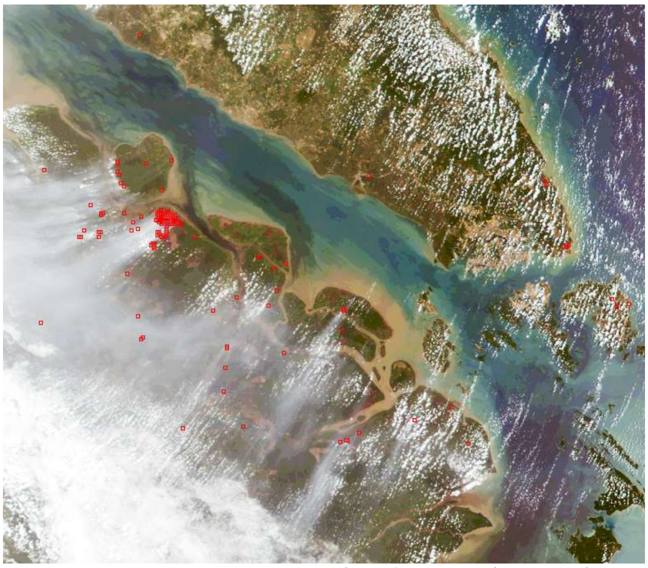

Figure 2. TERRA MODIS in true colour (RGB Bands 1, 4 and 3 respectively) with hot spots detected by NASA algorithm (ver 4.3.2) superposed. This image was taken on 9 March 2005. Smoke plumes emanate from active fires burning in Sumatra. Red spots are hot spots detected by NASA's fire detection algorithm.

The fire detection programs are activated whenever new MODIS Level 1 data is available. The hot spot information is placed on the web server upon completion of the run. Internally, the hot spot information is required urgently for target selection of high resolution SPOT4 imagery (Lim et al, 2000). Since MODIS thermal bands have a resolution of one kilometre (even coarser away from the satellite nadir), it is unable to provide thelocation of the fires at the required precision for ground activities. SPOT4 imagery has a resolution of 20m and therefore, is highly suited for this purpose. The MODIS hot spot information is used to identify areas with persistent forest fires and minimal cloudiness. The SPOT4 target planning system requires the geographic coordinates of these areas are registered into the system before the cut-off time each day for image acquisition the next day.

As soon as new MODIS hot spot data is available, it is also sent by email to stakeholders and government agencies at their request. From the onset, the subscribers to this service would have indicated an area of interest for monitoring, which can range from a plantation area to the whole country. The email message containing the hot spot information will contain only the hot spots over their area of interest.

3.2 Flood Monitoring

Many countries in the region experience seasonal flooding, in particular Thailand, Laos, Cambodia and Vietnam during the Southwest Monsoon which begins around June and ends in November. The Philippines experiences floods from tropical storms and typhoons which tend to occur about the same period.

In late 2004, a series of tropical storms and typhoon struck the Philippines in close succession, causing widespread flooding and loss of lives. The last storm to strike was Typhoon Nanmadol on December 2, 2004. The skies cleared on December 4, 2004 and AQUA MODIS was able to capture a view of the flood extent (fig 3).

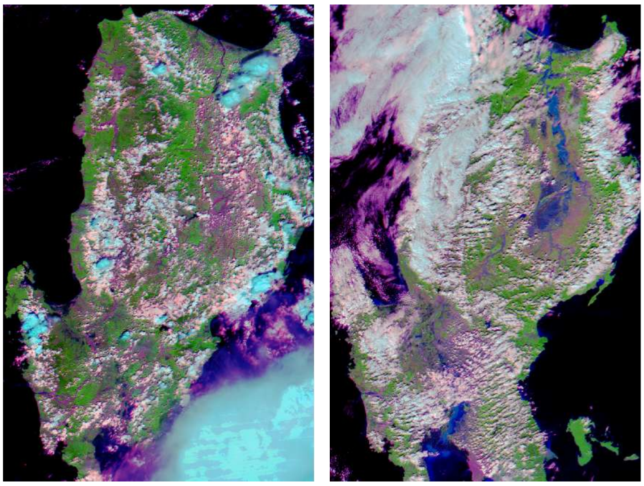

Figure 3. AQUA MODIS in false colour (RGB Bands 7, 2 and 1 respectively) showing the island of Luzon in the Philippines. The left image (without flooding) is taken on 1 October 2004 and the right image (flooding shown in dark blue shades) is taken on 4 December 2004. Note that the images have been stretched artificially to show contrast.

In fact, MODIS may not be the best instrument for near-realtime flood monitoring (Low et al, 2004) because of predominant cloud activity in the region. However, because of its high temporal coverage, a composite of several days' images may be used to map the flood extent in the aftermath of the event.

In Low et al, (2004), a prototype of a flood monitoring system was evaluated over the Cambodia region during the wet season of 2004. Essentially, the flood detection is done by change detection of two classification maps over the area of interest. For simplicity, an area of interest is classified into three classes, namely, water, forest and an 'others' category. One classification map is made for the period of interest whilst another is made during the dry season of the same area. The classification map is obtained by applying a supervised maximum likelihood scheme to a composite image consisting of seven shortwave MODIS bands at 250m resolution. The dry season composite is built by selecting cloudfree pixels from up to 30 days' MODIS passes. A classification map to be evaluated for flooding may be derived from a composite of any number of days, provided sufficient cloudfree pixels are available. The compositing algorithm to choose the cloudfree pixels is explained in more details in the mentioned paper.

3.3 Regional Sea Water Chlorophyll Distribution

MODIS has 7 ocean viewing bands at a resolution of 1 km. These bands are used by the NASA PGE09 (version 4.2.2) program to derive several ocean colour products such as chlorophyll concentration, sediment and dissolved organic matter concentrations. Liew and Heng, 2003 described how daily TERRA MODIS data is used to obtain daily chlorophyll charts of the regional waters. The daily charts are averaged over a month to produce a grid of regional chlorophyll data. The monthly averaged values can be used to study the seasonal variations of chlorophyll conectration in the regional waters. On a daily basis, we can test for anomalous changes of chlorophyll concentration at each grid point against the corresponding monthly averaged concentration. A prolonged and sustained anomalous increase of chlorophyll concentration may indicate an impending algael bloom event.

3.4 Coastal Plumes

Coastal plumes are plume-like features usually observed at mouths of rivers. They are precursors of how land-use changes affect the drainage basin. In remotely sensed images such as MODIS, the sediment-laden waters reflect strongly in the visible bands, and is clearly distinguishable from relatively clearer waters. Heng et al (2004) describe how MODIS shortwave bands (250m and 500m resolution) are used to retrieve the absorption and backscattering coefficients of coastal waters. These backscattering and absorption coefficients maps give an indication of the extent of suspended sediment and dissolved organic matter discharge from the inland drainage systems. The variation in colour among the different types of waters is essentially the result of absorption and scattering by particulate and dissolved substances in the waters (fig 4).

3.5 Land Cover Change Detection

The seven shortwave bands of the MODIS sensor are designed primarily for remote sensing of the land surface. The spatial resolution is 250m for Bands 1 and 2 and 500m for Bands 3 to 7. With such spatial resolution, many kinds of land cover changes can be discerned and studied over time. An example of short time scale land cover change is caused by floods as described earlier. Forest fires result in burnt scars which may persist for weeks to months. The burnt scars can be mapped by change detection of composited MODIS images. Longer term changes such as those due to urban development, deforestation can similarly be monitored using MODIS.

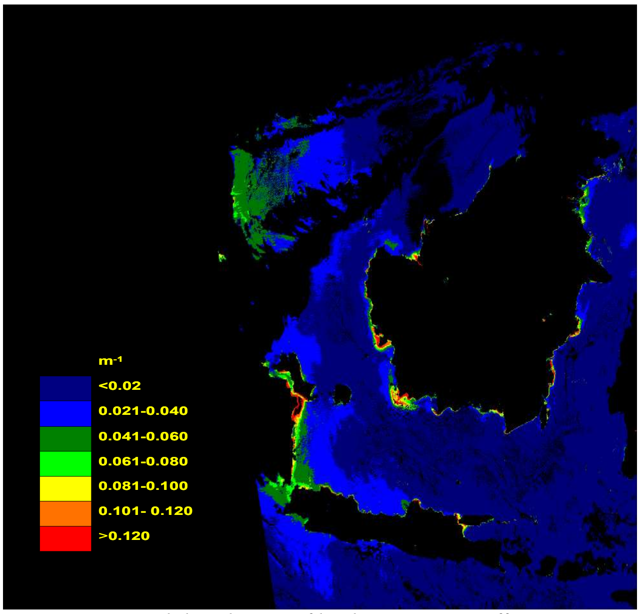

Figure 4. Spatial distribution of backscattering coefficients, 10 August 2004 (Heng et al, 2004).

One example of MODIS land cover change is seen in the recent Indian Ocean (26 December 2004) earthquake cum tsunami which resulted in devastating tidal waves sweeping the coasts of many Asian countries. The western coast of Sumatra, particularly, was severely impacted and damaged as can be observed from the change detected on MODIS images (fig 4). The image after the event shows much of the vegetation has been stripped off along the coast and extends upto a few kilometres inland.

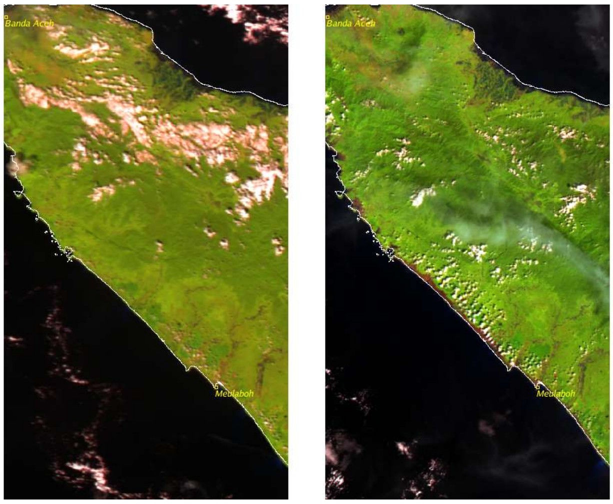

Figure 5. A noticeable land cover change on the western coast of the island of Sumatra caused by the Indian Ocean tsunami on the 26 December 2004. TERRA MODIS images acquired by CRISP on 17 December (left) and 29 December 2004 (right) respectively. Both images shown in false colour (RGB Bands 7, 2 and 1 respectively) and at 250m. Note that a significant area on the western coast has changed from green (left) to brown (right).

Many of the Southeast Asia countries experience persistent cloudiness throughout the year. One of the challenges to do land cover change detection in the region is the treatment of such cloud. Besides the NASA cloudmask algorithm MOD35, several other in-house algorithms have been developed based on commonly-known cloud tests. The cloud thresholds, however, are customised to detect clouds in the region. The MODIS Level 1 data is first converted to surface reflectances using the NASA MOD09 science algorithm. The seven atmospherically-corrected bands are subsequently screened for clouds and shadows. In this way, it is possible to accumulate a month's worth of cloudfree data over a fixed area. One 'good' pixel from each area is finally chosen via a compositing scheme. The choice of compositing methodolgy depends on the study purpose (Zerbe et al, 2003). In another study, Zerbe et al (2004) proposed a new vegetation index for this region using MODIS and discussed its merits versus the traditional NDVI.

4. CONCLUDING REMARKS

MODIS direct broadcast has contributed significantly to enhancing the near-realtime monitoring of the region. It is an invaluable tool to track and monitor the development of numerous man-made or natural phenomena. With regard to monitoring of forest fires, a system has been setup to automatically process new available data and disseminate the final product to stakeholders and interested users through the Internet. A regional flood monitoring system has been prototyped and will be put to the test during the flood season later this year.

For longer term monitoring of the environment, MODIS direct broadcast data is being processed to output products like chlorophyll concentration, backscattering coefficients, cloudfree composites of surface reflectance, etc. These products are being composited on a daily basis to form a monthly distribution map of the parameter of interest. The spatial and temporal changes of these monthly maps are being studied to better understand the regional environment as well as to map out seasonal variations. On a day to day basis, the daily maps are compared against the monthly distribution maps to sieve out anomalous changes which may be precursors of impending environmental hazards.

5. ACKNOWLEDGEMENTS

I would like to acknowledge the work of the CRISP's MODIS team for the setup the NASA Level 2 processing system which is able to operationally run many of NASA's institutional algorithms including MOD35 (cloumask), MOD07 (atmospheric profile), MOD04 (aerosol retrieval), MOD05 (water vapour), MOD09 (surface reflectance), MOD10 (sea surface temperature), PGE09 (ocean colour) and MOD14 (fire detection).

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