MODIS APPLICATIONS IN ENVIRONMENTAL CHANGE RESEARCHES IN THE INDOCHINA REGION

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ABSTRACT

This paper reviews some theoretical background on improved MODIS sensor characteristics and MODIS data products in order to demonstrate the application potential as well as difficulties in utilizing MODIS data for environmental monitoring. Brief description of the MODIS acquisition, processing and archiving system at the Institute of Industrial Science, University of Tokyo and our experience in using MODIS data for the last 4 years will be given. The main focus of the paper is on scientific applications of MODIS data in 3 environmental change researches in the Indochina region: vegetation mapping with MODIS NDVI time series; urban heat island mapping with MODIS & ETM Land Surface Temperature (LST); and agricultural drought monitoring with the MODIS-based Temperature-Vegetation Dryness Index (TVDI).

1 INTRODUCTION

In addition to the existing satellite receiving systems of NOAA HRPT and GMS S-VISSR, in May 2001, two new X-band satellite reception facilities were installed in the Komaba Research Campus (University of Tokyo, Japan) and in the AIT campus (Bangkok, Thailand), which are used to collect data from MODIS, an electro-optical sensor aboard the TERRA and AQUA satellites. The Yasuoka Lab at the Institute of Industrial Science (IIS) is directly managing the MODIS station at the Komaba campus and regularly archiving MODIS data transferred through network from the AIT station. In near real-time, IMAPP software from the Wisconsin University is used to process routinely the level 0 data producing calibrated and geolocated radiances (level 1b) for archiving (Tran *et al.*, 2000, 2001). In addition to providing raw and level 1b data to research community, we also operationally produce selective high-level products such as cloud mask, fire/burned area, 500m-resolution NDVI, 1km-resolution LST, reflectance products and its 8-days and monthly composites for specified regions. MODIS level 0 and level 1b data in the IIS archive are available freely for registered users/ researchers. The Yasuoka lab has developed the WebMODIS, a web-based MODIS processing system to distribute rectified level 2+ MODIS data for user-specified rectangular area-of-interest on request through www. In summary, the MODIS receiving facilities make it possible to continue and expand our AVHRR-based continental-scale terrestrial ecosystem change researches as well as upgrade our capability for near-real-time data distribution for disaster warning and extreme weather events forecast in the South / East Asian (including Indochina) region.

2 MODERATE RESOLUTION IMAGING SPECTRORADIOMETER (MODIS)

The Moderate Resolution Imaging Spectroradiometers (MODIS) on board the TERRA and AQUA satellites provide information about the Earth's surface in 36 wavebands including visible and near-infrared spectra, SWIR and in thermal range. The TERRA launched (in December 1999) and AQUA satellites (in May 2002) into near-polar sun-synchronous orbits, pass in view of any point on earth 4 times daily at approximately 10:30 &

21:30 and 13:30 & 0:30 local time respectively. The design for land imaging combines and improves upon the strengths of the existing AVHRR sensor including finer spatial resolution as well as high-spectral resolution allowing significantly better atmospheric profiling, atmospheric correction and more accurate LST computation. The frequent and synoptic characteristics together with specially designed atmospheric bands of MODIS offer the alternative to lessen the cloudiness problem in monitoring environmental changes, which is especially helpful in case of tropical climate zone of the Indochina. As improved MODIS time series data are accumulated at the IIS archive over 4-years of operations, numerous environmental researches / environmental monitoring have been carried out at the Yasuoka lab, University of Tokyo (*previously utilized AVHRR data*) including:

- *Near Real-time and Short-term Applications:* For near real-time forecast and warning of extreme events such as volcanoes, forest fire, surface flooding we are generating and distributing (over Internet) fire/burned area product and snow/ice cover.
- *Ecosystem change researches for specified regions of interest:*
    - Monitoring forest fires disturbances and their effects to carbon cycle with RS & ecosystem modeling (SimCycle);
    - Methane emission estimation from wetlands and paddy fields;
    - Estimation of terrestrial carbon fluxes by integrating RS with ecosystems modeling (SimCycle);
    - Agricultural crop evapotranspiration estimation with MODIS and modeling;
    - Asian water distribution / flooding mapping using MODIS data;
    - Land cover/vegetation mapping & monitoring for continental Asia;
    - MODIS for comparative urban environmental changes study (long-term urban land cover changes, urban heat islands, urban climate modeling);
- Regional MODIS DB network cooperation for data exchange and in monitoring the large-scale disasters or extreme weather events.

We are also experimenting the combined use of high-temporal-resolution MODIS data with high-spatial-resolution satellite data: ETM, ASTER in environmental monitoring and integrating RS data with environmental/ecological/climate modeling. As our system is still ever evolving, some preliminary results of the environmental researches in the Indochina region are presented as follows.

3 SOME PRELIMINARY RESULTS

3.1 Vegetation mapping with MODIS time series data

Vegetation mapping at the regional and global level is very important for understanding the regional and global environment. The availability of high temporal resolution MODIS NDVI data is very useful for mapping the vegetation cover based on dynamic analysis of the temporal patterns of NDVI data. From the IIS MODIS archive, monthly cloud-free composite MODIS NDVI data in the Bangkok region in the dry season (August 2001 – April 2002) are generated and then, a time series is constructed where the seasonal agricultural lands are clearly distinguished from other land cover types as seen in Fig. 1. The index for temporal signature similarity (TSS) is calculated from patterns of temporal variability of MODIS NDVI values over different months and then, is used in a classification scheme to produce the vegetation map for the area with reasonable accuracy as shown in Fig. 2. For more information on the TSS classification please see Pahari and Yasuoka (1999).

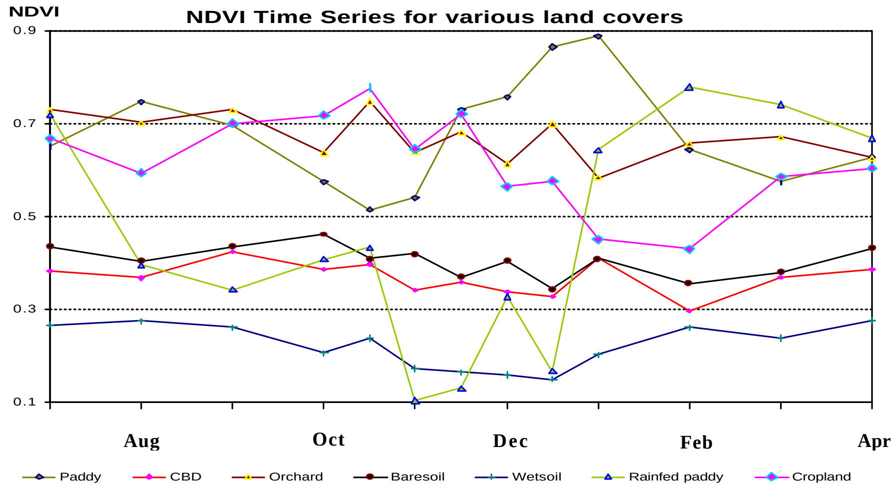

Fig. 1 Monthly NDVI time series (August 2001 – April 2002) data for the Bangkok region.

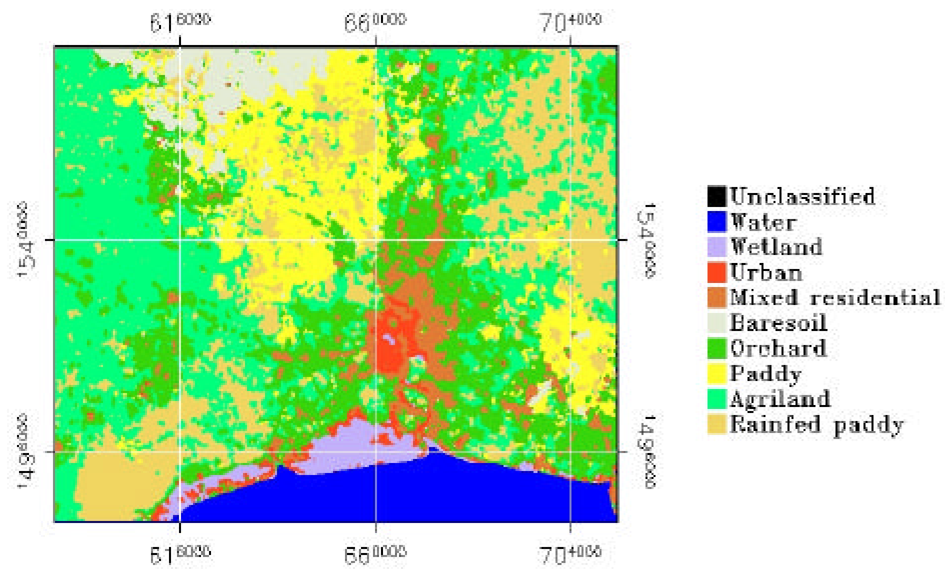

Fig. 2 Vegetation cover map of Bangkok classified based on MODIS NDVI time series.

3.2 Monitoring Urban Heat Island with MODIS LST data

Rapid urban development involving a large volume of population with increased energy consumption and dense urban infrastructure leads to an inevitable decline in the quality of life as well as urban environment. One of the most well known forms of anthropogenic modification is the phenomenon of urban heating or urban heat island (UHI) effect, causing the local air and surface temperatures to rise several degrees higher than the simultaneous temperatures of the surrounding rural areas. Satellite TIR sensors measuring top of the atmosphere (TOA) radiances, from which brightness temperatures can be derived using Plank's law provide accurate information on the urban canopy layer (UCL) heat island with much higher spatial resolution as compared to in-situ measurement. MODIS is particularly useful for the land surface temperature (LST) product because of its global coverage, radiometric resolution and dynamic ranges for a variety of land cover types, and high calibration accuracy in multiple thermal bands designed for retrievals of SST, LST and atmospheric properties (Wan, 1999). For 3 selected Southeast Asian cities of Bangkok, Manila and Ho Chi Minh City, urban heat island measurements are monitored from surface temperature maps at 1-km resolution derived from MODIS thermal data of selected day and night scenes acquired during dry season (September 2001 – April 2002). MODIS LST is derived from the atmospheric corrected 2 thermal bands (bands 31 and 32 in the 10.5-12.5μm spectra) using view-angle dependent split-window LST algorithm for MODIS (Wan, 1999) with reported accuracy of better than 1^0K.

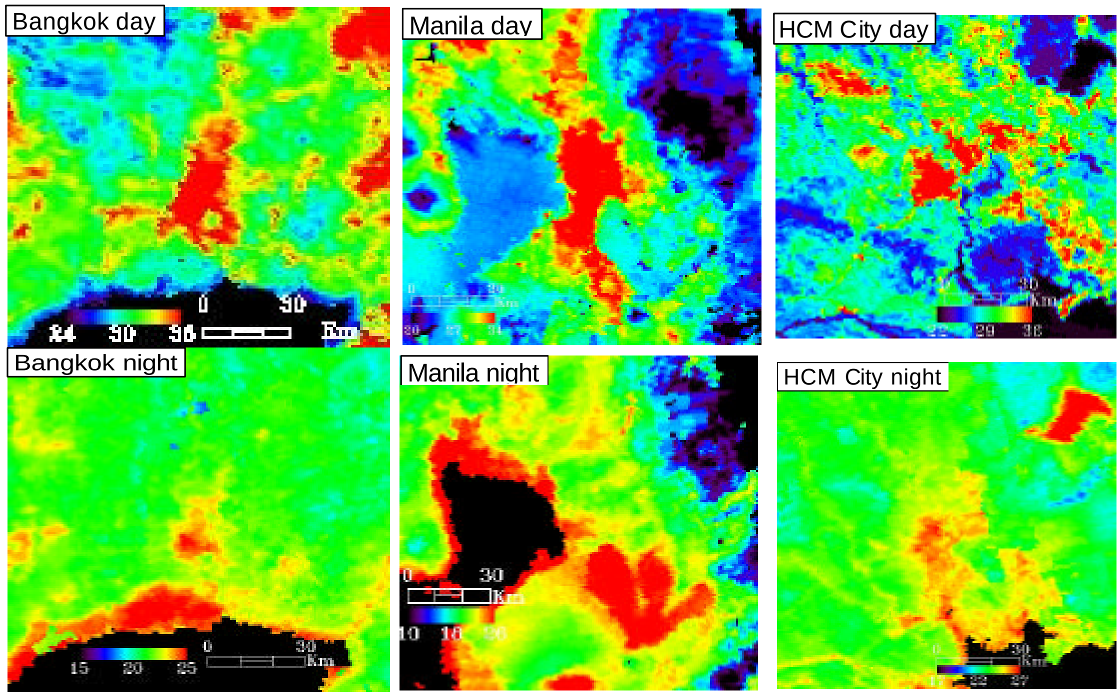

Fig. 3 Diurnal variations of the surface UHIs for Bangkok, Manila and Ho Chi Minh City in dry season

It is observed that satellite-based surface UHIs are greatest in the daytime with a maximum in areas of large buildings or paved surfaces and smallest at nighttime due to due to different surface properties and cooling rates (Fig. 3). The urban areas, which are characterized by high albedo and dry (built) surfaces, have significantly higher daytime surface temperature as compared to those of the surrounding rural moist vegetated areas. Using the statistics of LST images derived from MODIS day and night scenes, the surface UHIs patterns and its seasonal and diurnal variation are explored in both magnitude and spatial extent. The mean rural temperatures are 29.5^0C for Bangkok in February, 26.5^0C for Manila in November and 30^0C for Ho Chi Minh City in February. Bangkok has the highest daytime surface UHI intensity of 8^0C followed by Manila 7^0C and Ho Chi Minh City 5^0C in dry season. Close associations found between city size (in terms of population) with the UHIs magnitude and spatial extent indicates significant impacts of urbanization on the UHIs problems in the tropical Asia. During the night, the mean rural temperature is cooling down significantly to 22^0C in Bangkok and land-sea breeze circulations coupled with differences in surface cooling rates weaken surface UHI magnitude significantly to 3^0C as well as affect the UHI shape. At the first-order generalization, spatial variability of UHIs is a function of surface properties, which in turn is characterized by land-covers: most importantly by vegetation cover and built-up density. Strong negative correlations between day-time LST and NDVI are seen for all images as the moisture availability from vegetation allowing a larger fraction of the net radiative flux to be balanced by evapo-transpiration and by the latent heat flux, thus lowering the sensible heat flux, hence LST. This again confirms the classic patterns of surface UHIs in tropical humid cities and indicates the universal cooling impacts of vegetation. It is also found the difference in heating and cooling rates for various land covers types over the diurnal cycle where wet paddy fields and perennial vegetations have smaller average day-night fluctuation (4 and 4.9^0C respectively) in surface temperature than urbanized areas (more than 5.5^0C) mainly due to high moisture availability. In the Bangkok city center, it is found a significant daytime thermal contrast between parks (Chatuchak and Lumpini parks) and its urban surroundings reaching $5\text{-}6^0$C in February 2002 (for more details please see Tran and Yasuoka, 2003a; Tran *et. al.* 2003). The natural progression of this work involves a continued monitoring of UHIs in Asian cities with multi-sensor data (e.g., AVHRR on board the NOAA-12, NOAA-14 and MODIS on AQUA satellites) to better assess the diurnal cycle of urban climates.

3.3 Monitoring agricultural drought with MODIS TVDI

It is well recognized that drought is one of the most damaging environmental phenomena leading to sharp decrease in agricultural productions and increases the risk for wild fire. Since droughts cover large areas, it is difficult to monitor them using conventional systems, especially for developing countries with little infrastructure and few resources for continuous monitoring of environmental variables. It is obvious that use of Earth Observation Satellite (EOS) data is potentially of great interest in such contexts. The complementary information in the thermal and the visible/near infrared wavelengths has proven to be well suited to monitoring vegetation status and stress, specifically in relation to water stress (Sandholt *et al.,* 2002). The T_s/NDVI slope is related to the evapotranspiration rate of the surface, to the stomatal resistance of vegetation and areal averaged soil moisture conditions. The location of a pixel in the Ts/NDVI space is influenced by many factors, and a number of studies have been done to provide interpretations and here, isolines can be drawn in the triangle defining the T_s/NDVI space. A dryness index (TVDI) having the values of 1 at the ‘‘dry edge’’ (limited water availability) and 0 at the ‘‘wet edge’’ (maximum evapotranspiration and thereby unlimited water access) can be defined:

$$TDVI = \frac{T_s - T_{s\,\min}}{a + b * NDVI - T_{s\,\min}}$$

where T_{smin} is the minimum surface temperature in the triangle, defining the wet edge, T_s is the observed surface temperature at the given pixel, NDVI is the observed normalized difference vegetation index, and a and b are parameters defining the dry edge modeled as a linear fit to data (T_{smax} = a + b*NDVI), where T_{smax} is the maximum surface temperature observation for a given NDVI.

Using the MODIS NDVI and LST time series over the Indochina, the TVDI for selected scenes are computed as shown in Fig. 4. Then, TVDI time series for specified areas (e.g., Dac Lac forest; dry agricultural area in Binh Thuan) are constructed to monitor the surface moistures over the dry seasons and over three years. Comparatively, the TVDI is much higher for the agricultural cropland than that of forest area over time. Fig. 5 shows the temporal evolution of the TVDI, where the index is increasing toward the end of the dry season. Between the years, the TVDI are observed significantly higher during the 2002 dry season than that of the 2001 and 2003 dry seasons, indicating the possibility of using this index in monitoring not only short-term but also long-term agro-climatic variations (Tran and Yasuoka, 2003b). More detailed results as well as continuing research will be discussed at the conference.

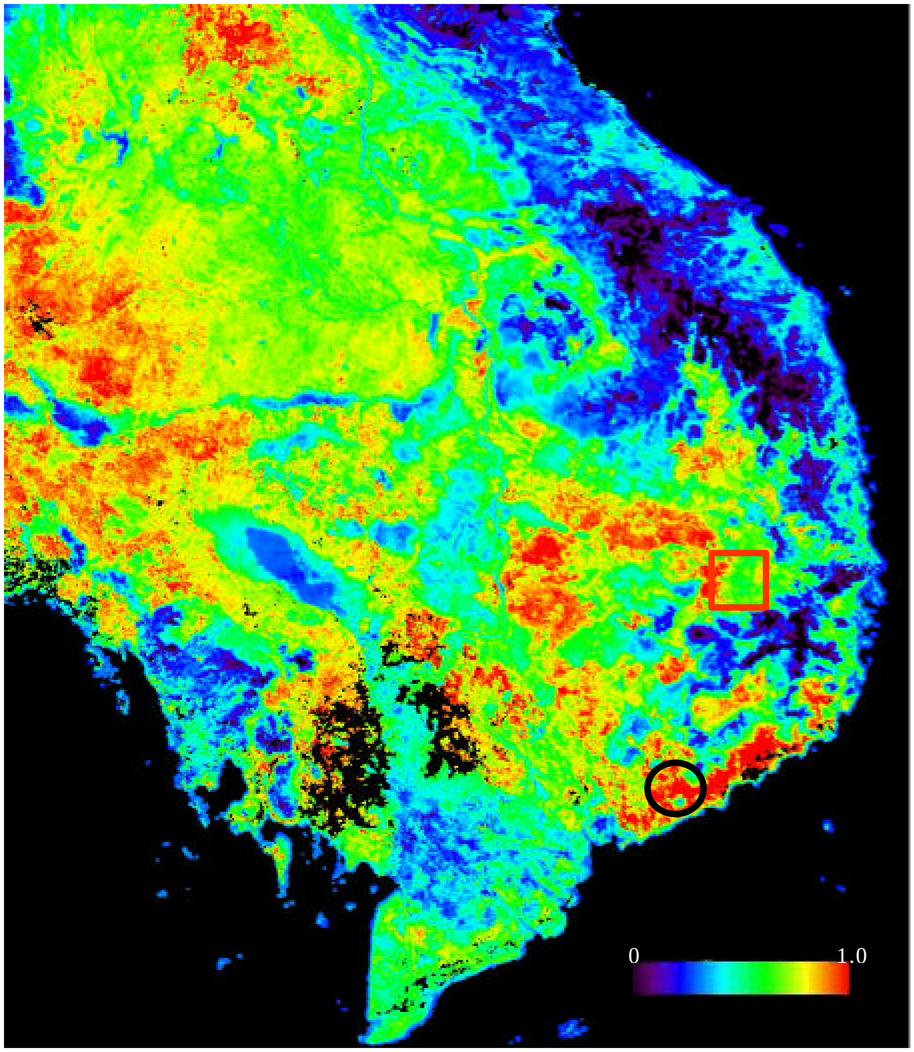

Fig. 4 The TVDI image (February 02, 2002) for Eastern Indochina: Rectangular indicates Dac Lac forest area and Circle – Binh Thuan cropland sample area.

4 CONCLUDING REMARKS

It has been demonstrated though these several application case studies that MODIS data is very useful and effective in monitoring the environmental/ecosystems change at the regional scale in the tropical Indochina. Furthermore, MODIS represents the beginning of a new family of ever-evolving sensors for monitoring the Earth dynamics, which will continue on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) satellites. It is, therefore, very encouraging and worthwhile to develop an effective scheme to utilize MODIS data in this rapid-developing, dynamic and environmental vulnerable Indochina region. There is still a number of difficulties/limitations hammering the utilization of the MODIS data (e.g., large data volume, complexity of data format, computing algorithms, cloud coverage in the tropics, etc.) to be addressed. However, it is a firm intention of the authors to work toward the full realization of MODIS application potential (especially in operational applications) for various environmental problems in the region in the framework of the Institute of Meteorology and Hydrology (Vietnam), the Institute of Industrial Science (Japan) and other collaborative organizations.

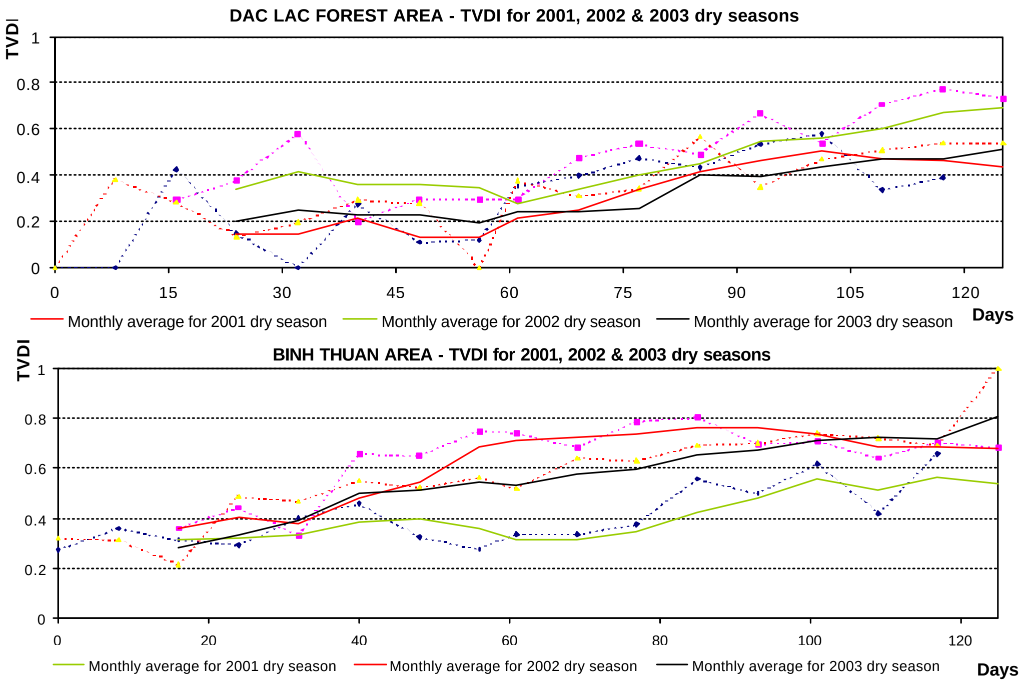

Fig. 5 Temporal evolution of the TVDI for the Dac Lac forest and Binh Thuan agricultural areas over 3 dry seasons 2001 - 2003

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