REMOTE SENSING TO ANALYZE THE CHANGES OF SURFACE BIOPHYSICAL PARAMETERS IN VIETNAM'S URBANIZED AREA

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ABSTRACT

Hochiminh City, the biggest industrial, commercial center in Vietnam with population of more than 5 millions people, has experiencing rapid urban expansion during the last decade. A large amount of forest and agricultural land has been converted into housing, infrastructure and industrial estates. The resultant impervious urban surface alters the surface energy balance and surface runoff, which in turn could pose serious environmental problems for its inhabitants (e.g., urban waterlogged and thermal pollution). In this paper, we utilize satellite images (TM and ASTER) to derive surface biophysical parameters such as fractional vegetation cover (Fr), surface radiant temperature (T_s), surface moisture availability (M_0) and evapotranspiration fraction (ET/Rn) are derived for different years during 1989 – 2002 period. The changes over the years of surface biophysical parameters are, then, examined in association with land-use changes to illustrate how these parameters respond to rapid urban expansion in Hochiminh City and surrounding region. This study attempts to provide environmental awareness to urban planners in future urban development.

1. BACKGROUND

Hochiminh City, one of fast-expanding Asian Metropolis agglomerations with population of more than 5 millions, is the biggest industrial, commercial center in Vietnam. The population density in the urban area is reported as of 9,373 persons per square kilometers on April 01, 1999. High economic growth and increased employment opportunities caused substantial influx of labor immigration. The urban population has increased 1.5 times from 1977 to 1999 mainly due to immigration. Currently, the natural growth is 1.36% while the immigration growth is 0.77% annually. As the city expands, prime agricultural land and habitats such as forests and water basins are transformed into land for housing, roads, and industry. This has added more pressure on the land use demand and the drastic changes of land cover and land-use caused by urbanization could significantly affect social, economic and ecological conditions in a large urban footprint area. While effective urban land use planning can help guide urban development away from vulnerable ecosystems, it appears impossible without deep understanding of processes governing the change dynamics and their inter-relations in urban and sub-urban areas.

It is well recognized that the multi-spectral, multi-temporal satellite imageries provide the most reliable, up-to-date and consistent means of monitoring land cover changes associated with urbanization at the regional scale. The land cover information, properly classified, can provide a spatially and temporally explicit view of societal and environmental attributes and can be an important complement to in-situ measurements. In addition, Owen *et al.* (1998) noted that quantitative biophysical information could also be extracted from existing satellite data, thus adding a great potential for practical application to regional planning and urban ecology. Remotely sensed surface radiant temperatures were successfully used in the studies of the so-called urban heat islands, while various vegetation indexes have long been used in urban vegetation studies. Gillies *et al.* (1997) has described the characteristic triangular-shaped envelope of pixels as viewed on a scatterplot of vegetation cover and surface radiant temperature for satellite remotely sensed pixels. On the other hand, Soil-Vegetation-Atmosphere Transfer (SVAT) model can be used to predict changes in various meteorological variables, including substrate temperature, atmospheric temperature and surface moisture as a function of time. The remotely-sensed measured variables in terms of surface radiant temperature (T_s) and NDVI (after normalizing to minimize the effects of surface and atmospheric variability) could be then fitted to the model's simulated ones in order to solve the inverse problem of estimating fractional vegetation cover, surface moisture availability and evapotranspiration fraction (Gillies *et al.,* 1997).

In this paper, we attempt to utilize satellite imageries in association with existing ancillary data to monitor and analyze land-use dynamics in Hochiminh City and surrounding region during 16 years (1986-2002). Based on revealed urban development patterns, major land-conversion zones are delineated. We then have applied the "triangle method" to derive surface biophysical parameters such as surface moisture availability (M_0), evapotranspiration (ET/Rn) fraction and vegetation fraction (Fr) over the years from high-resolution TM, ETM+ and ASTER images. The main objective of this paper is to illustrate the expanded capability of remote sensing in studying the impacts of rapid urbanization on regional environment by analyzing the changes in the derived biophysical parameters associated with urban development in the Hochiminh City region between 1989 and 2002.

2. URBAN DEVELOPMENT PATTERNS BY REMOTE SENSING

The study area is located between $106^0 20'01''$ to $106^0 59'48''$ Longitude and $10^0 40'49''$ – $11^0 09'51''$ Latitude. Administratively, it composes of major part of Ho Chi Minh City and parts of surrounding Long An, Tay Ninh, Binh Duong and Dong Nai provinces, which is reported to have rapid built-up expansion since the last decade (Fig. 1). To provide temporal land cover and land use information, various satellite images such as MSS (1986), TM (1989, 1993), ETM+ (1999, 2001, 2002) and ASTER (2001) are obtained for the study area. Satellite images are corrected for atmospheric attenuation and geo-referenced to a common 1:50,000 UTM topographic map and re-sampled to 30m resolution. The image analysis is done on single-date images individually including ML classification and knowledge-based post-classification techniques incorporating texture, vegetation information and ancillary existing land-use maps of 1997. With biophysical characteristics of the land cover as the major focus of the study, the final analysis consolidates classified images into some major land-cover categories: built-up, paddy/irrigated agricultural land, plantation, forest, dry baresoil, wet baresoil, wasteland and water-body. Change detection is then applied based on overlaying classified images in order to understand the land-use conversion and to build time-series data for a particular land-use type for the 1986 – 2002 period.

As the result, the spatial patterns of urban development are found changing over the years (Fig. 2). Along with the continuing urban densification of highly urbanized areas in the inner city districts such as Quan 6, Phu Nhuan, the City significantly expands into northern and eastern suburban areas during 1989 – 2002 (e.g., Q. Go Vap, Quan 8, Q. Thu Duc, Q. 2 and southern part of Binh Duong province). The rate of urban expansion is observed of more than 7 percent per year in some neighborhoods of the Go Vap and Thu Duc districts. Figure 3 shows trend of urbanization of some representative districts in the inner city and suburban areas. The major to-urban-land conversion is observed from: 1) irrigated land (paddy fields, wetland) to built-up; 2) agricultural land (cash crops, orchards) to built-up; 3) bush land / range land to pre-construction wasteland and industrial estates areas; and 4) urban densification. Here, we select 5 sub-areas representing different patterns, type and degree of urban development (1 – inner city, 2 – dry suburb, 3 – wet suburb, 4 - industrial zones & 5 – agriculture as control zone) for more detailed analysis of the changes in surface biophysical parameters (Fig. 1).

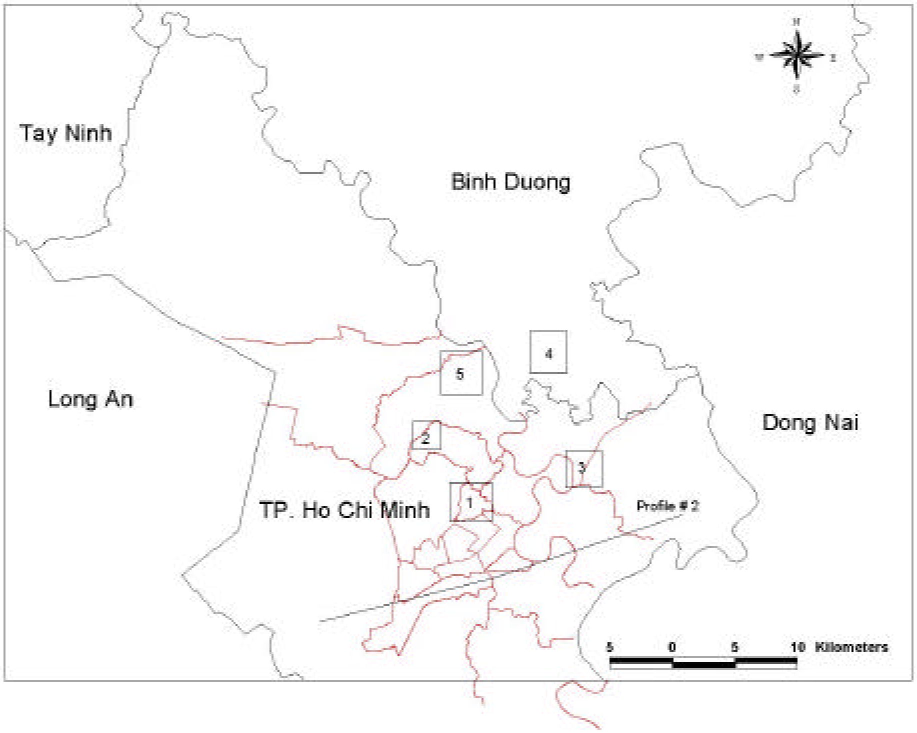

Figure 1 Map of the study area with some focus spots: for inner city – 1 (Q. Phu Nhuan); suburban - 2 & 3 (Q. Go Vap & Thu Duc); industrial zones – 4 (South of Binh Duong); agricultural area – 5 (H. Hoc Mon)

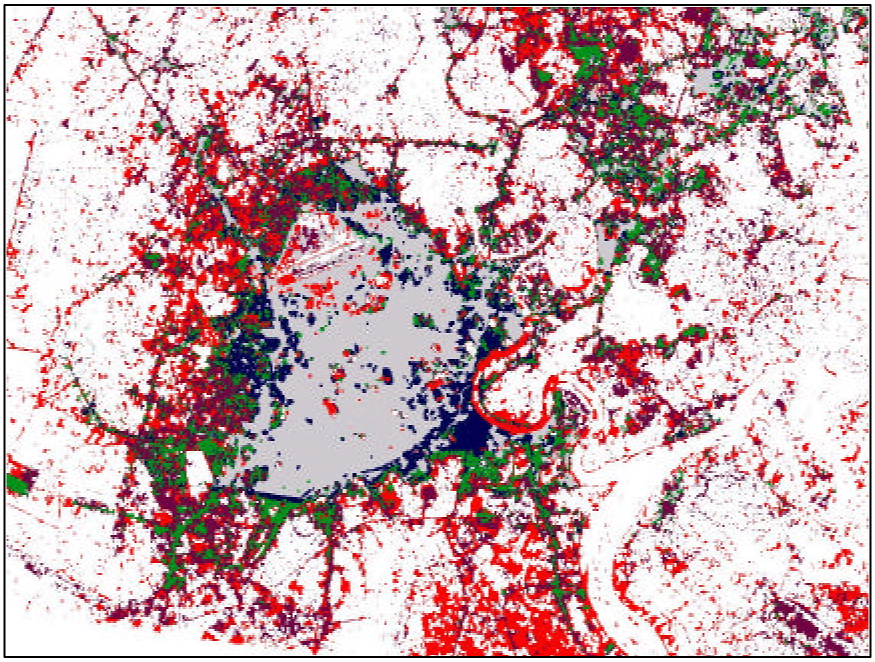

Figure 2 RS-derived urban expansion around HCM area during 1989 – 2002 (white color shows non-urban; gray - urban area before 1989; blue, green, brown and red show new urban land by 1993, 1999, 2001 and 2002)

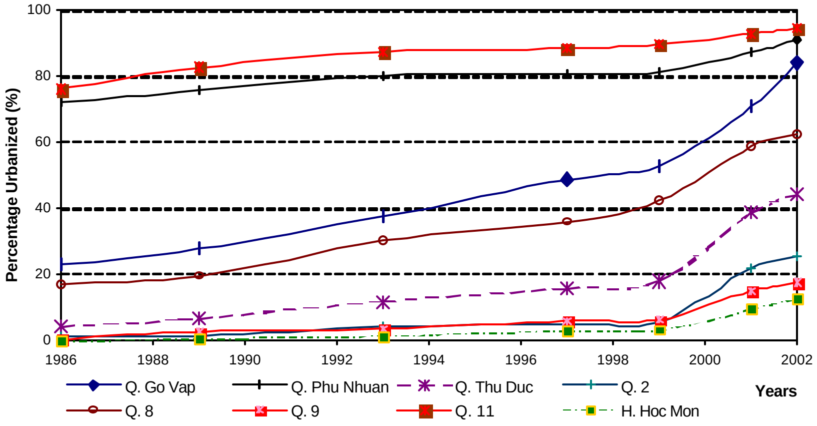

Figure 3 Increase in percentage of urbanized areas in selected inner and suburban districts of Hochiminh City during 1986-2002

3. REMOTELY-SENSED BIOPHYSICAL PARAMETERS

3.1 Surface temperatures and NDVI

The Landsat TM raw data of 1989 and 1993, ETM+ of 1999, 2001 and 2002 and Terra ASTER data of 2001 are used to extract biophysical surface parameters (more details could be found in Tran & Yasuoka, 2001). Thermal radiances at the original spatial resolution are converted to at-sensor temperatures via the Planck equation and then to at-surface temperatures based on the equations and calibrating coefficients developed by the National Aeronautics and Space Agency (NASA) and ERSDAC respectively. Normalized Difference Vegetation Index (NDVI) is calculated from visible red (TM Band 3 or ASTER B2) and near infrared (TM B4 or ASTER B3) reflectance by equation: NDVI = (NIR – R) / (NIR +R).

3.2 Universal triangle and biophysical parameters

We derive biophysical parameters from satellite images based on the triangle method (Gillies *et al.,* 1997). The water and cloud contaminated pixels, which tend to be localized at negative of NDVI and lower values of T_0, are excluded from the analysis. Firstly, we normalize the calculated NDVI and T_s, to reduce inter-scene variability in the state of the surface, the phenology of the vegetation and the condition of the atmosphere (e.g., haze, wind speed, humidity). Transformation of NDVI to a scaled NDVI (N^*) is accomplished using equation: $N* = \frac{NDVI - NDVI_0}{NDVI_s - NDVI_0}$ where $NDVI_0$ *is* limit for bare soil and $NDVI_s$ is limit for 100% vegetation cover are selected empirically for each image. Then, the fractional vegetation cover (*Fr*) is calculated as $Fr = N^{*2}$ according to Carlson & Arthur (2000). Temperature values are also scaled between the warmest (T_{max}) and coldest (T_0) surface temperatures corresponding to dry bare soil and wet soil at 100% of vegetation cover. The temperature anchor values are determined by inspection of the NDVI/T_s scatterplots (Owen *et al*., 1998) and observed ambient air temperature (T_a) recorded at the Tay Ninh, Xuan Loc meteorological stations at the time of satellite overpass. Normalization to a scaled surface temperature is done based on equation: $T* = \frac{T_s - T_0}{T_{\max} - T_0}$.

The normalized Fr/T* scatterplots are, then, constructed for the 1989, 1993, 2001 and 2002 images as the "universal triangle" as shown in Figure 4. With input parameters from observation data recorded from meteorological stations at Tay Ninh and Xuan Loc, the SVAT (soil-vegetation-atmosphere transfer) model of the Penn State University is used to derive fractional vegetation cover (Fr), surface soil water content (M_0) and evapotranspiration fraction (ET/Rn). The SVAT model output in forms of M_0 and *ET/Rn* isopleths are overlaid on the normalized Fr/T* scatterplots using third-order polynomial relations to compute the M_0 and *ET/Rn* from *Fr* and *T** for the 1989, 1993, 2001 and 2002 images in the study.

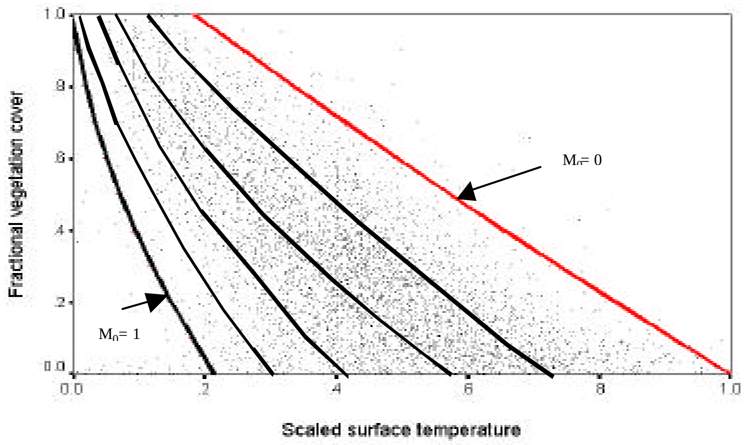

Figure 4 Universal triangle as scaled Fr/T* scatterplot for the February 04, 1993 TM scene and overlaid surface moisture availability isolines (M_0 = 0, 0.2, 0.4, 0.6, 0.8, 1) based on the SVAT model output.

4. URBANIZATION AND REGIONAL CLIMATIC PARAMETERS

With the derived biophysical parameters over the years, it is interesting to examine the relationship between them and the urbanization process. As TM/ETM+ pixels are of small size, T* and Fr have considerable large variations creating difficulties in tracing out representative changes over years, biophysical parameters are aggregated from 30x30m to 300x300m spatial resolution using average values. Examining the Fr/T* scatterplots, there is a clear distinction between dense urbanized pixels from other land cover types in terms of T* (> 0.6) and Fr (< 0.1), while suburban residential areas have large variability in T* (0.3 ÷ 0.6) due to variable vegetation covers. Statistically, it is found a significant negative relationship between % urbanized and Fr (*r = 0.473, p < 0.001 for 2001 data*) and significant positive correlation with T_s (*r = 0.491, p < 0.0001*).

The changes in T*, Fr, Mo and ET/Rn between 1993 and 2001 for 5 selected subgroups are summarized in Table 1, showing the study area in general tends to become warmer and drier. Figure 5 shows the trajectories for aggregated TM pixels representing 4 urban development classes from 1993 to 2001 & 2002, which suggests urbanization is the primary cause of the migration of the pixels in the Fr/T* scatterplot. However, the extent and direction of the path appeared to be governed by other factors such as the pixel's initial location in the triangle and pixel geographical neighborhood. It seems that the conversion from agricultural lands, especially from lowland irrigated areas to dense residential areas (e.g., Thu Duc, Q.2) leads to most regional microclimate changes (e.g., significant decrease in Mo, ET/Rn and significant increase in urban run-off).

Table 1 Comparison of mean migration of biophysical parameters from 1993 to 2001 for 5 distinct groupings based on urban development patterns

	Sample size	Mean ΔT*	Mean ΔFr	Mean ΔMo	Mean ΔET/Rn
1- Inner City (Phu Nhuan)	164	+0.1438	-0.0001	-0.1983	-0.0619
2- Suburban (Go Vap)	218	+0.2519	-0.2134	-0.3121	-0.1032
3- Suburban (Thu Duc)	113	+0.3213	-0.4673	-0.5217	-0.1527
4- Industrial Zones (Binh Duong)	322	+0.0942	-0.1425	-0.2025	-0.1382
5- Agricultural area	525	-0.0214	+0.2031	+0.0118	-0.0025

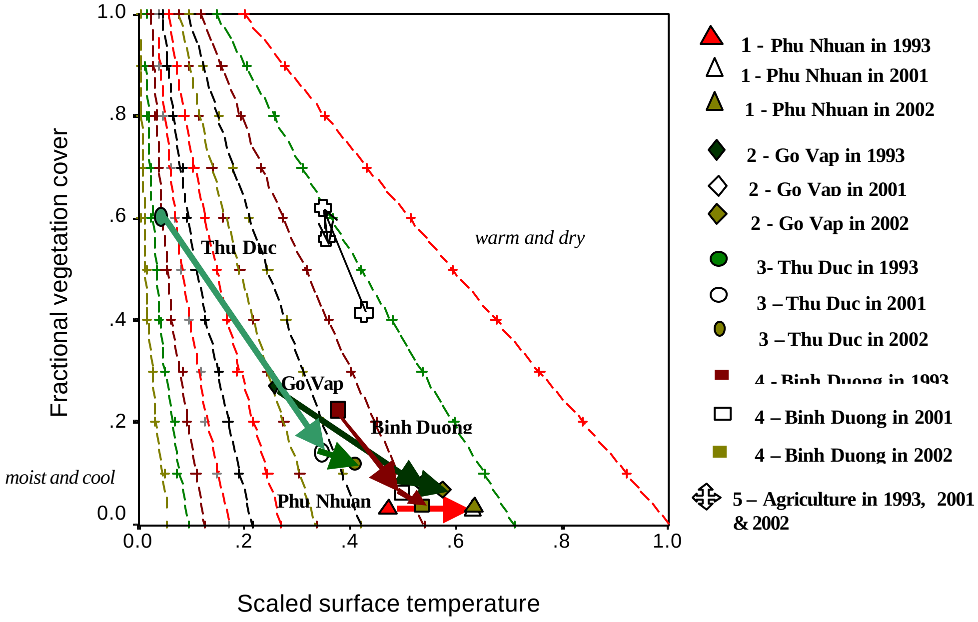

Figure 5 Migration of pixels (averaged for 5 focused sub-areas) on universal triangle between 1993, 2001 and 2002

5. CONCLUDING REMARKS

Primary results from this case study in Hochiminh City demonstrate the capability of satellite remote sensing not only in monitoring the surface development but also in determining useful climate and land surface parameters such as T_s, Fr, ET/Rn and Mo. Significant changes in these surface climate variables (ΔT*, ΔET/Rn) are found to depend on the speed of urbanization as well as the initial percentages of urban coverage and vegetation amount. Continuing works are carrying out to include more ground observations and factors such as sub-region's urbanized structure and stage of urban developments into modeling of microclimate changes. This study is a part of an on-going research at the Institute of Industrial Science, University of Tokyo focusing on using remote sensing to study urban growth in Asian cities and its impacts on regional climate. We wish to thank Prof. Carlson T. N. at the PSU (US) and Dr. Tran Thuc at the IHM (Vietnam) for providing SVAT model & meteorological observations data to use in this study. We also wish to acknowledge the Japan Science and Technology Agency for the funding of this research at the IIS, University of Tokyo, Japan.

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