Changing Land Use in the Golden Triangle:

Where the Rubber Meets the Road

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Abstract

Land-use and land-cover change in Montane Mainland Southeast Asia (MMSEA) is changing dramatically as shifting cultivation gives way to commercial agriculture driven by domestic demand and by regional trade agreements. In Xishuangbanna, (the most southern prefecture in Yunnan Province), China, both semi-privatized state farms and minority farmers are planting rubber at rates that threatens to transform the landscape between 300 and 1,000 m into an unbroken carpet of rubber. In northern Laos and eastern Cambodia entrepreneurs have contracted farmers to grow rubber for the Chinese markets. While it has become all too apparent that this region is on the cusp of major changes in tree cover, there is much uncertainty about the direction of change and the impacts it will have both people's livelihoods and environmental variables such as biodiversity, carbon sequestration, watershed hydrology, and climate. This paper explores the hydrological impacts of this land-cover change at the basin scale. For this purpose, we collected climatic measurements and profiles of soil moisture data for two years in a rubber-growing basin located in Xishuangbanna Prefecture (22°N, 101°E), Yunnan Province, China. We monitored four vegetation covers: rubber and three native land covers (tea, secondary forest and grassland), and measured surface radiation above the tea and rubber canopies. Observations showed that root water uptake of rubber during the dry season is controlled by day-length, whereas water demand of the native vegetation starts with the arrival of the first monsoon rainfall. The different dynamics of root water uptake in rubber result in distinct depletion of soil moisture in deeper layers, with possible implications at local and regional hydrological scales.

Keywords: Rubber (*Hevea brasiliensis*), root zone water balance, evapotranspiration, land use change, hydrologic change, Montane Mainland Southeast Asia.

Introduction

Montane mainland Southeast Asia (MMSEA) is a large, ecologically vital region comprising approximately half the land area of Cambodia, Laos, Myanmar, Thailand, Vietnam, and China's Yunnan Province (Fig. 1). It is a region of great biological and cultural diversity that has come under close scrutiny in the last several decades as a result of both real and perceived deforestation, land degradation, and most recently, the conversion from traditional agriculture, including shifting cultivation, to more permanent cash crops driven by regional and global markets (Fox and Vogler 2005). The causes and consequences of these changes are many. Globalization of markets, wide diffusion of technical information favoring simplified production models, and similar agricultural and conservation policies concerning smallholder production are among the factors that have led to this region-wide phenomenon. Despite political borders and cultural differences that fragment the region, these trends are everywhere leading to the simplification of diverse landscapes, increased threats to food security, and limited access of farming households to traditional medicines, construction materials, and other daily necessities, as well as to loss of local ecological and agricultural knowledge and cultural diversity.

The Asian Development Bank along with the governments of China, Laos, and Thailand recently finished building a new highway corridor running from northern Thailand, through northwest Laos to Kunming (Yunnan Province, China). The Chiang Mai-Kunming Highway provides the first reliable land transport route connecting eastern China with central Thailand and the Malay Peninsula, and creates a "North-South Economic Corridor" through the heavily forested montane region formerly known as the Golden Triangle, and now called Golden Economic Quadrangle (the border regions of

Yunnan, Laos, Myanmar and northern Thailand). This is one of a series of major new highway routes (Thant and Nair 2002) currently being built to connect major population centers and markets. These highways are expected to increase trade and tourism. In addition to the economic and social changes they provide, however, highways such as these, traversing forested regions, promote rapid land-use and land-cover change by providing access to formerly isolated areas and facilitating transport of timber and other products to market (Schneider 1994).

The Chinese town of Jinghong lies on the Chiang Mai to Kunming corridor and provides a good example of the types of change this region has faced. In 1950, when the authorities of the newly-established People's Republic of China took control of Jinghong they found themselves the new rulers of the small but prosperous Southeast Asian principality of Sipsongbanna (transliterated as Xishuangbanna in Chinese) located on the banks of the Mekong river. Over the centuries, a number of peoples, few of whom were Han Chinese, had produced a complex landscape with paddy rice grown on the plain and in valley bottoms and where the surrounding forested hills were the source of an abundance of products ranging from tea to timber to elephants.

Some fifty years later, Jinghong is the political center of the Xishuangbanna Dai Autonomous Prefecture. The city is still surrounded by irrigated fields, which now also grow vegetables and other food crops for the city. The surrounding hills are now marked into large sectors planted with straight rows of rubber trees while red soil shows starkly through lines of pineapple planted down the slopes draining into the Mekong. A short-lived tourist boom has left a heritage of hastily built hotels where travel companies offer visits to exoticized ethnic minority villages and to nature reserves in the remaining patches of forest.

Xishuangbanna is not alone in witnessing the transformation of its landscape over the last fifty years. The shifting ideologies of ethnicity, frontier territories, national security, and economic development have remade the landscape of the whole montane mainland Southeast Asia region. These same ideologies can be expected to continue to reshape the landscape as Xishuangbanna, and the rest of MMSEA, moves from the political periphery to being a significant node for transportation, movement of people, and economic activity.

Rubber (*Hevea brasiliensis*) is the major commercial crop replacing traditional agriculture and secondary forests in the MMSEA region (Xu et al 2005, Thongmanivong et al 2005), a direct result of strong market demands from China, the world's largest consumer. Forecasts indicate global demand for natural rubber may outpace supply by 1.4 million metric tons by 2020. Asia accounts for 97% of the world’s natural rubber supply, with most from Thailand, Indonesia, and Malaysia. Entrepreneurs from China, Vietnam, Malaysia, and Thailand are investing heavily in rubber plantations in the less developed countries of the region—Laos, Cambodia, and Myanmar. Perhaps even more startling has been the pace at which small farmers have converted from subsistence agriculture to growing rubber for commercial production. Newspaper reports in Laos suggest that over 50,000 ha of rubber had been planted there in 2000. In Cambodia, the Ministry of Agriculture plans to expand the area under rubber cultivation from 50,000 ha to as much as 800,000 ha by 2015. In Myanmar, rubber is expanding into border areas in Kachin and Shan States. In Thailand, rubber has expanded to include over 48,000 ha in the north and 64,000 ha in the northeast. The Thai Rubber Board predicts total area of rubber in Thailand will increase from 1.9 to 2.4 million ha by 2020. Vietnam currently has ca. 500,000 ha of rubber and little is known about where new rubber trees are being planted or at what rate.

A native of the Amazon rainforest, rubber is physiologically unusual (but not unique, see Elliott et al. 2006) within MMSEA. It sheds its leaves in the middle of the dry season and flushes new leaves before the onset of the wet season. The characteristics of rubber are suspected of causing changes in local climate and watershed processes. For example, in Xisuangbanna District, Yunnan, China, where rubber cultivation began in the early 1950s, Liu (1990, cited in Wu et al. 2001) observed a dramatic downward trend in fog frequency between the mid-1950s and the mid-1980s, which he attributed to the effects of rubber expansion on atmospheric processes. Wu et al. showed that surface runoff increases by a factor of three, and soil erosion increases by a factor of 45 as a result of conversion from tropical forest to monoculture rubber in Xishuangbanna.

The phenology of rubber is typical of Amazonian forests, where Myneni et al. (2007) identify dry-season leaf flushing as a possible trigger of the onset of the wet season. In MMSEA, this phenological pattern represents a disruption of the land-atmosphere dynamics of native and other non-rubber vegetation, and implies that the explosive expansion of rubber cultivation may have serious consequences for water dynamics of the region. Conversion to plantation agriculture in other regions has already been shown to cause significant changes in aboveground (Bunker et al. 2005) and belowground (Guo and Gifford 2002) carbon stocks. Vegetation phenology, as well as possible differences in growth rates, and leaf turnover and decomposition rates of rubber, are likely to cause changes in carbon stocks and carbon exchange rates when rubber replaces other vegetation. The methods of plantation management for rubber (land terracing, control of understory growth, etc.) and harvesting (latex extraction) may further alter carbon dynamics in ways that are currently unknown.

The project "The role of land-cover change in MMSEA in altering regional hydrological processes under a changing climate" (http://research.eastwestcenter.org/mmsea) was funded by NASA in 2004. The project sought to simulate how LCLUC in MMSEA could affect local and regional energy and moisture fluxes, and to model the consequences of those changes for continental-scale atmospheric circulation and climate. To answer these questions the LCLU project: 1) developed a comprehensive, high-resolution database of historical and current land cover in MMSEA, 2) developed scenarios of future LCLUC in the region; 3) made field measurements of key hydrological variables within two representative watersheds for calibrating and validating hydrological and climatological models for the region; 4) simulated the climate and hydrology of the greater East and SE Asia region under scenarios of LCLUC; and 5) is currently modeling hydrological processes within each study watershed to establish the role of LCLUC in altering watershed function.

The MMSEA geospatial database is unique, consisting of regional to site-specific datasets acquired from government and commercial sources, our established network of regional/local collaborators in MMSEA, and products derived by the current project. Site-specific datasets have been obtained for study areas in northern Thailand, northern Laos, Xishuangbanna prefecture, China, northeast Cambodia, and northern Vietnam. Raster datasets include imagery dating to the 1960s (Corona) to recent collections of ASTER (NASA-JPL), NASA Orthorectified Landsat, IKONOS, Quickbird, and GeoCover LC products for selected sites. Aerial photographs at various scales/dates/locations have been acquired. Detailed LCLU maps of the Mae Sa watershed (northern Thailand) and Nam Ken watershed (Xishuangbanna, China) were created in the current project. A collection of country- and site-specific thematic feature datasets (e.g., roads, rivers, admin units, Censuses, GPS) have been acquired ranging 1965-2007 at scales from 1:25,000-1:250,000.

At the MMSEA level, a collection of 1-km resolution raster datasets, including 1992/93 IGBP land cover (Loveland et al. 2000), 2000/01 Terra MODIS land cover (Strahler et al. 1999), and other bioclimatic, biophysical, accessibility, and population datasets, have been assembled and used to drive 1-km resolution LCLUC simulations for the MMSEA region. Using this database, Fox and Vogler (in prep.) project that significant changes in LCLUC will occur by 2050. Changes will be mostly from evergreen broadleaf trees to deciduous broadleaf trees, reflecting changes from forest cover to plantation crops—especially rubber. Our climate model simulations using the regional climate model (RegCM3) suggest that under the projected 2050 LCLU scenario, changes in precipitation over MMSEA, the Indochina Peninsula, and eastern China, will result, primarily from significant differences in four vegetation parameters (roughness length, minimum stomatal resistance, range of LAI, and vegetation albedo) between evergreen broadleaf trees and deciduous broadleaf trees (Sen et al. in prep.).

This paper describes the hydrological effects of land-use change at the basin scale. In this respect, the hydrological implications of *Hevea brasiliensis* cultivation (rubber) are studied. Two years of climatological and soil moisture measurements in three native vegetation covers are compared with measurements in a rubber plantation. Differences in vegetation dynamics and possible implications within the hydrological cycle are then explored.

Hydrologic implications of land-use change at the basin scale

Rubber cultivation is expanding in larger areas within MMSEA. Xishuangbanna prefecture, a Chinese prefecture northern of MMSEA, is a Chinese example of this rubber cultivation expansion (Fig 2a). Towards the end of the 1950s, China introduced rubber in the southern region of Yunnan Province (Chapman 1991). Since then, native vegetation (mainly primary and secondary forest) has been rapidly replaced by rubber plantations. In 1963 rubber occupied 6,130 ha (Jiang 2003), which increased to 136,782 ha by 1998 (Wu *et al.* 2001) and to about 220,000 ha by 2004 (Li Haitao personal communication). This increase follows the global demand for natural rubber driven by the economic growth of China and other emerging countries.

Rubber (*Hevea brasiliensis*) is a tree native to the tropical rainforest of the Amazon Basin. Its habitat is characterized by small variations in air temperature (24˚C to 28˚C) and precipitation (1500 – 2000 mm) throughout the year. Rubber's natural habitat extends between 10˚ north and south of the equator and to at most 600 m AMSL. Rubber is being now cultivated at higher latitudes and altitudes in South America, South East Asia and Africa, despite the reduction of productivity (Chandrashekar *et al.* 1998; Devakumar *et al.* 1999).

In general, the effects of introducing a non-native species on the local and regional hydrologic cycle are poorly understood (Newman *et al.* 2006). Our study focuses on a humid environment with a distinctive dry season followed by a strong wet monsoon season. It characterizes root water uptake dynamics of three native vegetation types (tea, secondary forest and grassland) and compares them to rubber tree plantations (Fig 3). The analysis is based on 2 years (2005 and 2006) of hourly soil moisture observations and other hydro-meteorological variables measured in these four land covers.

Site description

The experimental catchment, Nam Ken (69 km2), is located in the Xishuangbanna Prefecture (22°N, 101°E), close to the Myanmar border (Fig 2a). The basin waters drain to the Mekong River (Lancang Jiang in Chinese). The region is characterized by a tropical monsoon climate. Topography strongly affects precipitation and temperature in the basin, creating pronounced altitudinal climate zones. The average precipitation for the lower part of the basin is 1100 mm at 800 m an increase to over 1700 mm at 2000 m. In this monsoon-dominated climate, most of the precipitation falls between May and October. Soils are typically dark red ultisols, developed over granite and gneiss bedrock (Cao *et al.* 2006).

Precipitation and temperature also affects land-cover distribution. The upper areas of the basin are dominated by montane rainforest (primary forest) with mostly broadleaf evergreen species (Zhu *et al.* 2004). Adjacent to the primary forest there are stands of disturbed or fragmented forest (secondary forest) (Zhu 2006). The lower areas in the basin are used extensively for agriculture. The primary crops include corn (planted on hillslope swidden fields) and paddy rice (in the proximities of the river). Grassland covers temporary most of the fields due to the traditional swidden agriculture system.

To simplify future modeling efforts and gain overall understanding of the basin vegetation dynamics, the vegetation in the basin has been grouped into five different categories based on their root characteristics and water demand. These five groups are: rice paddies, rubber, agricultural sites (e.g. tea), forest (primary and secondary), and grassland (Fig. 3). We have ignore rice paddies because growing area has remind constant for decades (Xu *et al.* 2005), and our focus is on land-covers that rubber is now replacing.

Data Acquisition Network

A hydro-meteorological data acquisition network was established in the basin in May 2004 and removed in February 2007. It consisted of two micrometeorological (MET) stations located in rubber and on a tea plantation; and two soil moisture/precipitation (SM/RF) stations in grassland, and in secondary forest (Fig 2b). Both MET stations recorded hourly energy and water fluxes. In each MET site daily albedo was derived (averaging the hourly radiation from 10:00 to 14:00 local time). The two SM/RF stations (and also the MET stations) recorded hourly soil moisture at three different depths (surface, 1 m, and 2 m) and precipitation above canopy.

Root zone water balance

During periods of zero precipitation with a deep ground water table and assuming no significant drainage to deeper layers or lateral inflows, soil evaporation and vegetation transpiration (root water uptake, *E*) are the only mechanisms for depleting the moisture content in the root zone. Under these circumstances, estimates of (combined) soil evaporation and root water uptake can be derived from soil moisture measurements at different depths. Therefore, root water uptake has been estimated at the three depths where soil moisture is measured (surface to 0.75 m, 0.75-1.50 m and 1.50-2.25 m depth). For each of these layers, we assume that the change in water content is uniform and contributes equally to *E*. To compare variability of root water uptake within the root zone, the actual E at each depth has been scaled with the total atmospheric demand (E_{max}) in what has been called an evaporation reduction factor (Williams and Albertsons 2004):

$$\lambda = \frac{E}{E_{max}} \tag{1}$$

where E_{max} is the maximal rate of evaporation (atmospheric demand), and E is the actual evaporation or root water uptake derived from soil moisture observations (Guardiola-Claramonte *et al. in review*).

Results and discussion

Profiles of calibrated water content at the tea, secondary forest and grassland sites shows very different patterns when compared with the soil moisture recorded within the rubber profile. Rubber soil moisture decreases and it is dampened with depth, and shows an important time delay (in depth) with respect the surface soil moisture content. The rest of the vegetation covers show opposite trends. Comparisons of root water uptake during 2005 show also distinct pattern for rubber. While tea, grassland and forest do not show increase in deep layers root water uptake during the dry season, rubber increases water uptake from the deeper layers towards the end of the dry season, a few weeks before the arrival of the first rains.

In Nam Ken *Hevea* is dormant from November to March and retains its foliage until the end of February, when leaves are shed within 2 to 4 weeks. Bud break and growth of new leaves start in late March, several weeks (2 to 4) before the arrival of the first monsoon rains. Shedding of old leaves results in an increase of albedo from 0.12 (typical value of evergreen forest) to 0.20 (a typical value for soil) in March; and flushing of new leaves decreases albedo back to 0.12 in April (Fig. 4). Rapid shoot growth during the late dry season (April) is accompanied by increased water uptake from deeper soil layers (Fig. 4). This subsurface water uptake is necessary to increase stem water potential above a certain threshold to allow bud break (Borchert *et al*. 2002). The causes of bud break and flushing of certain tropical species during the dry season (a phenomenon referred to as the *leaf flushing paradox;* Rivera *et al.* 2002; Elliott *et al.* 2006) is on debate (Renner 2007). These authors found that flushing is independent of climate conditions and associated with photoperiodic induction (increase in day-length) and the availability of deeper subsurface water. Flushing occurs around the equinox, which corresponds to the maximum increase in day length. Good correlations between changes in the albedo of rubber together with increase of day length and with root water uptake confirms that rubber is indeed a brevideciduous spring flushing species. It seems that water availability plays a secondary role in triggering rubber dynamics during the dry period, either for shedding or flushing new leaves. Rubber exhibits a distinct behavior compared to the other land use types. Secondary forest, tea, and grassland seem to depend primarily on water availability in the form of rain, and only activate once the rainy season has started.

Rubber currently (2005) represents over 16% of the land cover in the Nam Ken basin. Replacing 16% of the native vegetation by rubber could have important implications on the local and regional hydrological cycle. Based on long term observations, Liu (1990, reported in Wu *et al.* 2001) shows a negative relationship between the presence of fog and the increase of rubber plantations in the Xishuangbanna region. The author claims that the reduction of fog in the region is a direct consequence of replacing forest by rubber given that rubber trees shed their leaves during the dry season (Wu *et al.* 2001), with a consequent reduction of leaf interception and drip. Liu *et* *al.*, (2004) refer to this alteration of hydrologic partitioning by rubber as the main reason for the observed reduction in soil water content. This could also explain our observations of lower water content with depth for rubber, as compared to secondary forest. Soil moisture under grassland and tea does not decrease with depth because of the absence of deep roots to deplete the water content at deeper layers. We now know that rubber's water demand is concentrated around the equinox, when soil water availability is the lowest and atmospheric demand is the greatest. In similar settings (where precipitation and atmospheric demand are "out of phase") changes in native vegetation have resulted in dramatic changes in streamflow and/or groundwater levels (Wilcox *et al.* 2006).

Summary

Observations of vegetation dynamics and soil moisture time series analysis suggest a dramatically different behavior in terms of timing and rates of water consumption between the studied vegetation types. Albedo trends and field observations indicate that rubber sheds its leaves for a couple of weeks during the driest and hottest period in the region. Leaves fall to minimize water loss through evaporation and to allow the build-up of stem potential to initiate next season's bud break. The additional stem potential needed for flushing is acquired through deep subsurface water uptake. At the secondary forest site, root water uptake is linked to water availability in the form of rain. Native forest trees rehydrate after occasional rain events during the dry season or shortly after the start of the rainy season. Water extraction from deep soil layers was not observed under shallow-rooted tea and grassland covers.

Figure 1. MMSEA study region, study sites, and established and emerging rubber-growing regions.

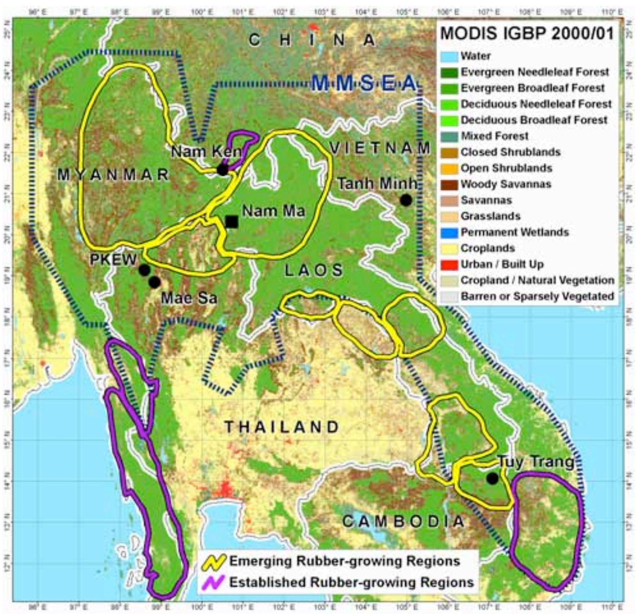


Figure 2. (a) Location of the experimental catchment Nam Ken. (b) Land-cover and location of the micrometeorological (triangles) and soil moisture stations (squares) in Nam Ken in Nam Ken land-cover.

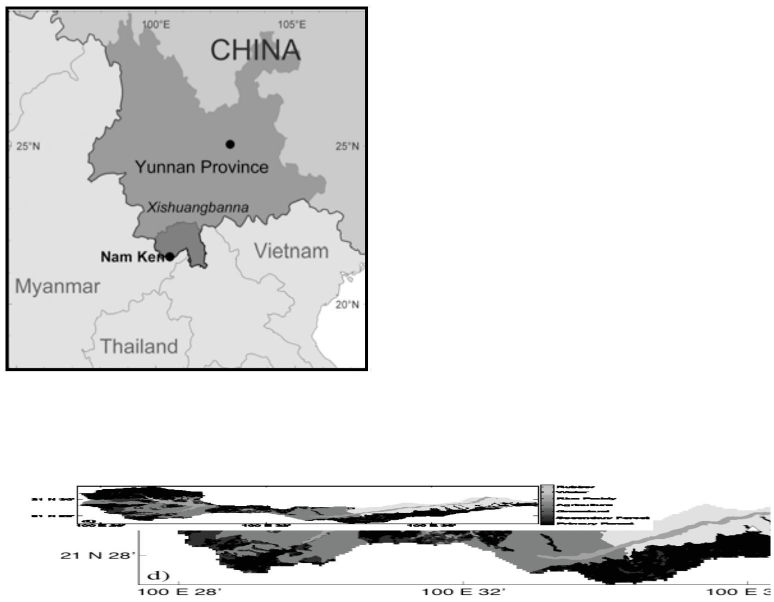
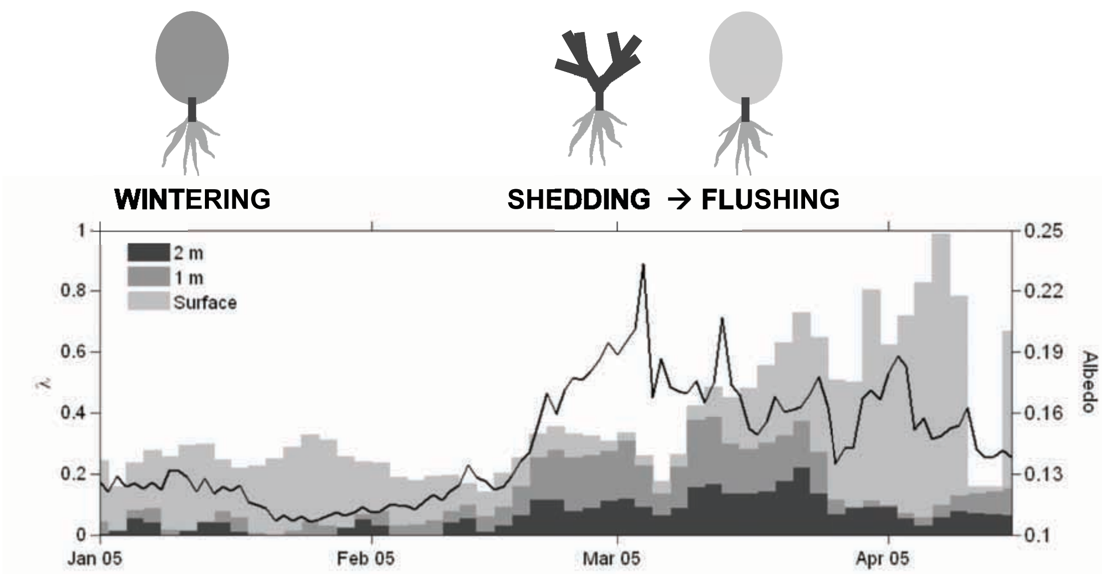


Figure 3. Studied land covers: (a) rubber, (b) tea, (c) secondary forest, (d) grassland.

Figure 4. Daily albedo values and evaporation fraction (λ) in the rubber plantation for part of 2005. The evaporation fraction is stacked in two days average values. The trees on top of the figure illustrate rubber dynamics.



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Acknowledgments

This research has been supported through NASA G rant # NNG04GH59G (Project ID: IDS/03-0365-0079), and the Asia Pacific Network (grants ARCP2006-06NMY, ARCP2007-01CMY). The authors thank Li Haitao and Dr. B. Nijssen for their support. We also thank the anonymous reviewers for their insightful comments.