Mapping Net Primary Productivity of Peninsular Malaysia Forest Using Satellite Data

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The main objective of this project is to estimate and map the Net Primary Productivity (NPP) of Peninsular Malaysia forest using NOAA AVHRR satellite data. The production of this NPP map is very important and serves as background information for the overall project, the mapping of ecosystem services and goods for the tropical rain forest that is still on-going. For this purpose, series of NOAA satellite data for the year 2004 have been pre-processed, first to precisely co-register each image through geometric correction and secondly the radiometric corrections were performed to eliminate the radiometric distortions mainly caused by incidence angle different of sun light. As most of the images obtained were covered with cloud, cloud free image was then generated by combining and mosaicking images of difference dates. Apart from satellite image, meteorological parameters such as surface solar irradiance, surface temperature and rainfall were obtained from Malaysian Meteorological services as an input into the model Results of the analysis indicate that the annual values NPP are within the range of 50 to 6,000 gC/m^2/year, while the values of Normalized Differential Vegetation Index (NDVI) are within the range of 0.04 to 0.7.

1. Introduction

Forest plays a very significant role as a source and sinks for CO_2. An understanding of this process in is thus important as continuing increases of CO2 in the atmosphere are most likely to contribute to future changes in global climate. Among aspect of climatic change are an increase in mean annual air temperature and alterations in patterns of rainfall and cloud cover. Plants assimilated CO_2 through the process of photosynthesis, and the total amount of CO_2 assimilated by plants over a given time period is known as Gross Primary Productivity (GPP). This assimilated CO_2 will then be converted by plants to heat or mechanical energy, or used in the growth and life process of the plants. Parts of assimilated CO2 use in the maintenance and growth of the plant minus loss to respiration is known as the Net primary productivity (NPP). Thus NPP can be defined as the net flow of carbon from the atmosphere into plants (Christopher et al., 1995). It represents the net carbon (C) input from the atmosphere into the vegetation (Kimmins, 1986) and for this reason it is widely used as an indicator for sequestration of atmospheric CO_2 by the terrestrial ecosystems.

From the theoretical perspective, the concept of NPP is very simple. However, to measure the value of NPP accurately can be very difficult. There are lots of challenges that have to be confronted in the measurement of NPP using various techniques. The measurement of NPP based on biomass as an example will need the quantification of below ground processes, including root production and exudation Sala et al., 1988), and this has found to be a great challenge. Measurement based on gas exchange are also very complicated and many of the reports in the literature are tentative and incomplete (Christopher et al., 1995).

Various strategies have been developed to improve the method of estimating terrestrial net and gross primary productivity and it has become possible to investigate the magnitude and geographical distribution of primary productivity on a global scale by a combination of ecosystem process modelling and monitoring by remote sensing. The main objective of this report is to derive and map the NPP for Peninsular Malaysia forest using remote sensing data.

2. Background of Peninsular Malaysia Forest

Malaysia covers an area of about 32.86 million hectares, including Peninsular Malaysia, as well as the states of Sabah and Sarawak. For Penisular Malaysia, almost half of the area is under forest cover (Shaharuddin, 2004). Malaysia is one of the most biodiversity-rich countries in the world with about 8,000 species of flowering plants, 2,680 tree species, more than 200 species of mammals, 600 species of birds, 110 species of snakes, 80 species of lizards and thousands species of insects. However, mining activities in the middle of 19^{th} century and the development of agricultural activities with the development of rubber and oil palm cultivation in the 20^{th} century have led to the decline in forested areas in the lowlands. Various efforts have been carried out to keep the Malaysian forest intact, and Peninsular Malaysia retains 6 million hectares of forested area, that is about 45 per cent of the total land size. Of this, about 4.8 million ha are permanent forest reserve. Figure 1 shows the distribution of forest area in Peninsular Malaysia, and Figure 2 shows forested area overlaid with Digital Elevation Model (DEM).

3. Methods

3.1 Modelling NPP using remotely sensed data

Satellite data used in this project are series of NOAA-17 AVHRR *Local Area Coverage* (LAC) for the month of April 2004. AVHRR Orbiting Environmental Satellites. The satellites makes 14 passes each day, viewing a 2,399-km swath. The system provides complete coverage of the earth from pole to pole. At nadir, the system provides an IFOV (Instantaneous Field of View) of about 1.1 km. For recent versions of AVHRR scanner, spectral channel are as shown in Table 1.

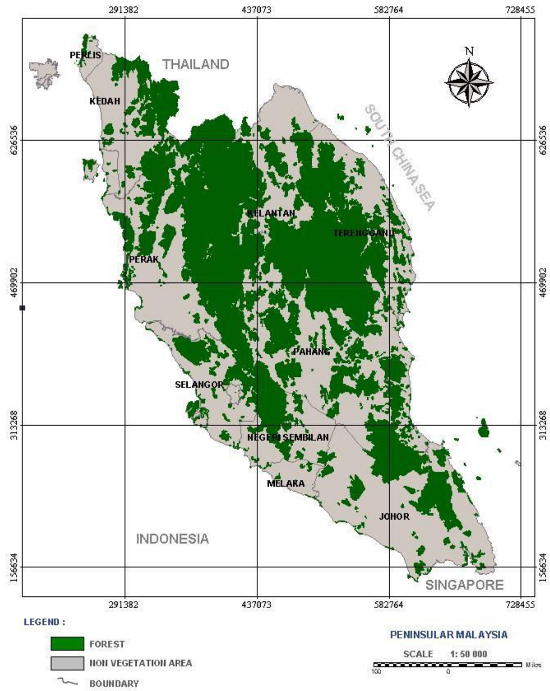

Figure 1 Forested Area of Peninsular Malaysia

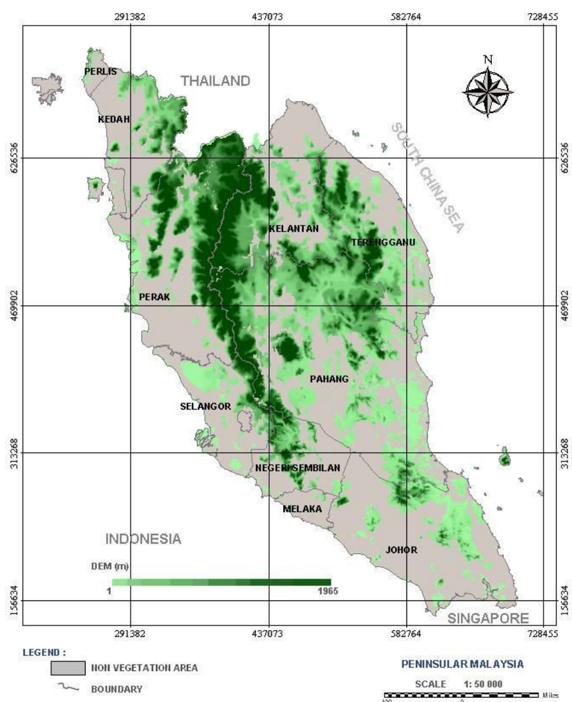

Figure 2 Forested Area with Digital Elevation Model

Table 1: Recent Version of the AVHRR Spectral Channels.

Band	Spektral Resolution (μm)
1 (red)	0.58-0.68
2 (near Infrared)	0.72-1.10
3 (mid-infrared)	3.55-3.93
4 (thermal infrared)	10.3-11.3
5 (thermal infrared)	11.5-12.5

The near infra-red (NIR) and red (R) wavelengths of the electromagnetic spectrum have been used extensively to estimate LAI (Peterson and Running 1989), the fraction of Photosynthetically Active Radiation absorbed by the plant canopy (*f*PAR) (Prince and Goward, 1995, Goward and Dye 1997) and Net Primary Productivity (NPP) (Running *et al.* 1994). In the NIR region of the spectrum, scattering within-leaf is high and the radiation from the canopy is therefore generally high. On the other hand, pigment absorption is high in the R component of the spectrum resulting in a low radiation reflection. As a result, LAI is usually positively related to an increase in the difference between NIR and R radiation.

One of the most common vegetation indices derived from remotely sensed data and is NDVI and it is calculated by dividing the two electromagnetic wavelengths (near infrared - red)/(near infrared + red).

Sellers (1985, 1987) derived an important relationship between LAI, Absorbed Photo-synthetically Active Radiation (APAR) to NDVI. Research found that under specified canopy properties APAR was linearly related to NDVI and curvilinear related to LAI. Sellers therefore showed that:

$$NDVI = f\,(APAR) = f\,(LAI)$$

The NOAA AVHRR data were used to calculate the normalised difference vegetation index (NDVI), which uses a comparison of the vegetation signatures in different spectral bands (Diallo et al., 1991). The AVHRR chanells, most sensitive to variation and growth dinamics of vegetation, are the red channel and infrared channel part of the electromagnetic spectrum; these two channels are commonly used to monitor the status of vegetation photosynthesis (Curan, 1980). NDVI has been shown to be highly correlated with vegetation parameters such as grean leaf biomass and green leaf area. It is calculated as;

$$\text{NDVI} = (\text{CH2} - \text{CH1})/(\text{CH2} + \text{CH1})$$

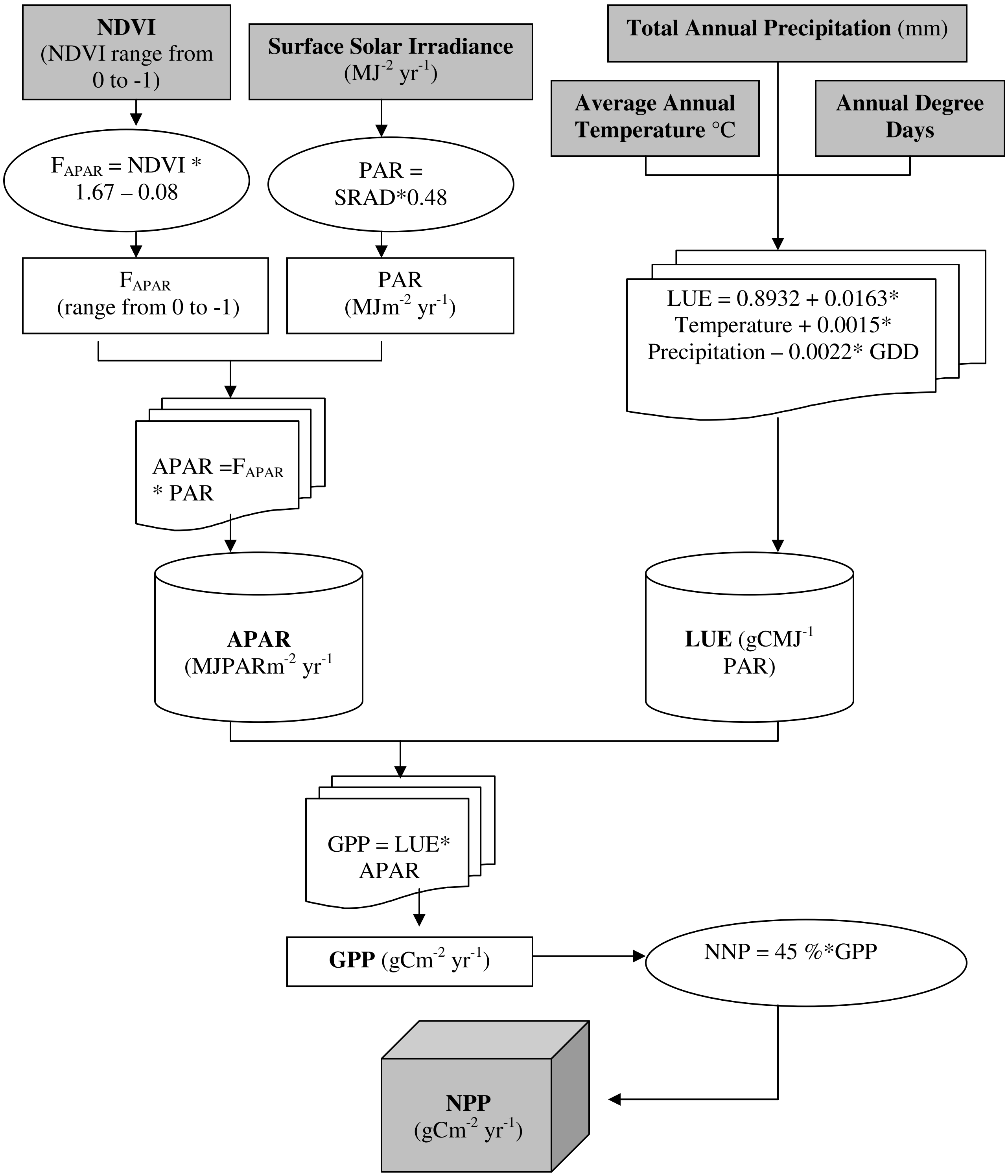

Figure 3 Flowchart of NPP Model Using NOAA AVHRR data

All the raw NOAA AVHRR data have to be pre-processed to improve the image quality and this is the basis for later analyses that will extract the information from the image. Typical preprocessing operation could include (1) radiometric processing to adjust digital values for the effect of a hazy atmosphere and, (2) geometric preprocessing to bring an image into registration with a map or another image (Campbell, 2003). As most of the images are covered with clouds, cloud free image were generated by combining and mosaicking images of various dates. Spatial estimate of NPP were calculated using NPP model as shown in Figure 3.

NDVI is an important input into the model and NDVI map produced from NOAA AVHRR image is as shown in figure 4.

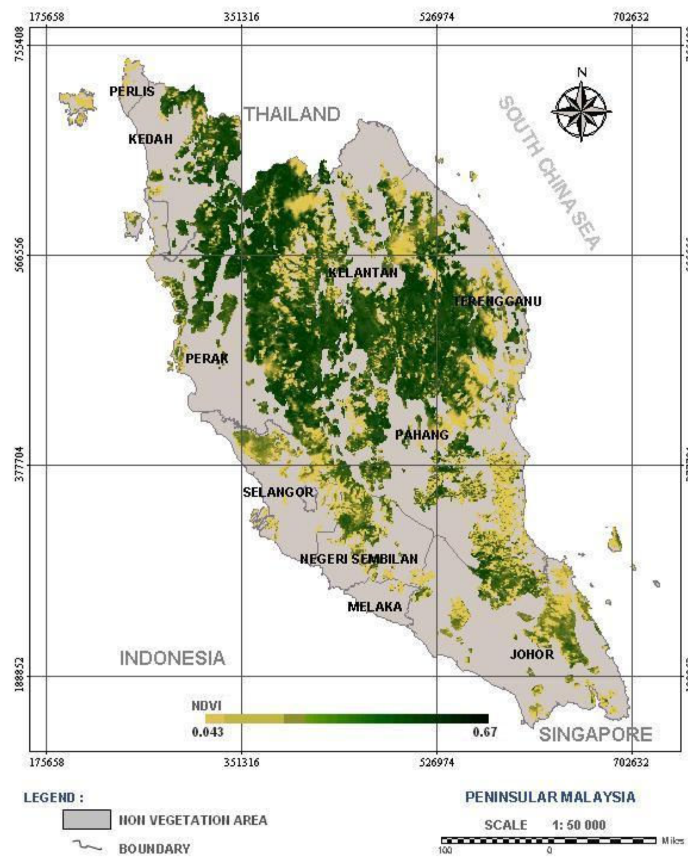

Figure 4 NDVI Map of Peninsular Malaysia

3.2 Forest Distribution Maps

Forest distribution map of Peninsular Malaysia is required to show the forested area in Peninsular Malaysia. This was later been used for the purpose of comparison with the NPP values derived from the satelite image. The forest distribution map was digitised from the landuse map obtained from the Malaysian Department of Agriculture. Figure 1 shows the forest distribution map of Peninsular Malaysia and Figure 2 shows the forested area overlaid with the digital elevation model (DEM). This forest distribution map is used to subset the forest area from the satellite image. Figure 5 shows the forest area that has been substracted from satellite image.

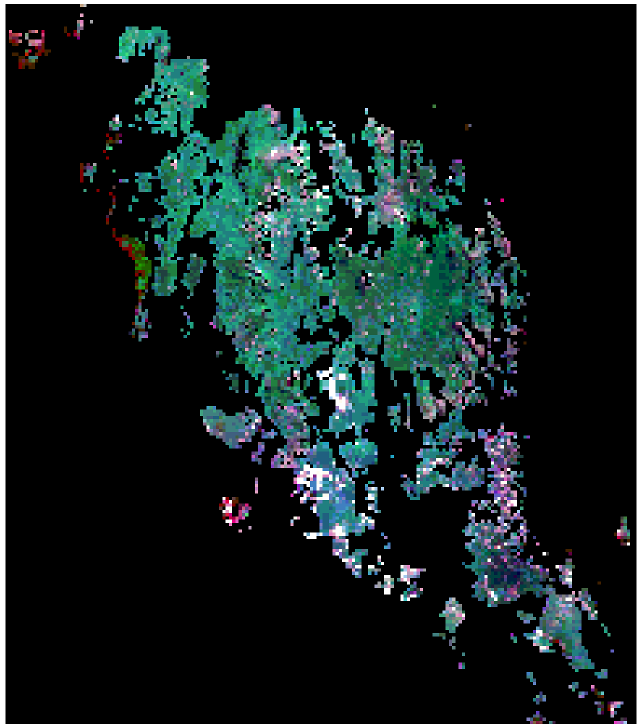

Figure 5 Subset of Forest Area from NOAA AVHRR Image

3.3 Meteorological Parameters

As indicated in the model, various meterological parameter such as rainfall, temperature and solar radiation were needed as an input. All this data have been obtained from the Malaysia Meteorological Service.

4. Results and Discussion

Using the forest distribution map of Peninsular Malaysia as a base, the NPP estimates were incorporated into a geographical information system (GIS, ARC/INFO, and ARCVIEW) to perform a spatial analysis of the distribution pattern of NPP in the Peninsular Malaysia forest. The spatial pattern of NPP of Peninsular Malaysia forest is shown in Figure 6. The value of NPP range from 50 to 6,000 gC/m^2/year with an average value of 3650.86 gC/m^2/year. The highest value of NPP is concentrated along the main range which stretches along the central part of the Peninsular. NPP is found to be sensitive to many factors such as climate, soils, plant characteristics, disturbance regime, and a number of other natural and anthropogenic factors. This current spatial pattern of NPP distribution in the Peninsular Malaysia forest is resulted from combination of those environmental aspects such as the variation in the hydrological regimes and also the land use changes which is associated with long-term human activity.

An analysis of the NPP values for forest area in different states showed that the annual values of NPP also varies among various. The state of Perlis that is located in the North western part of Peninsular Malaysia has the lowest value of NPP with an average of 1,776.01 gC/m^2/year, followed by Malacca with an average value of 2018.11 gC/m^2/year respectively (Figure 7). States with highest value of NPP is Kedah with an average of 4,650.43 gC/m^2/year. It is quite difficult to explain and justify the variation of NPP distribution in various states as no detailed information regarding the controlling factors.

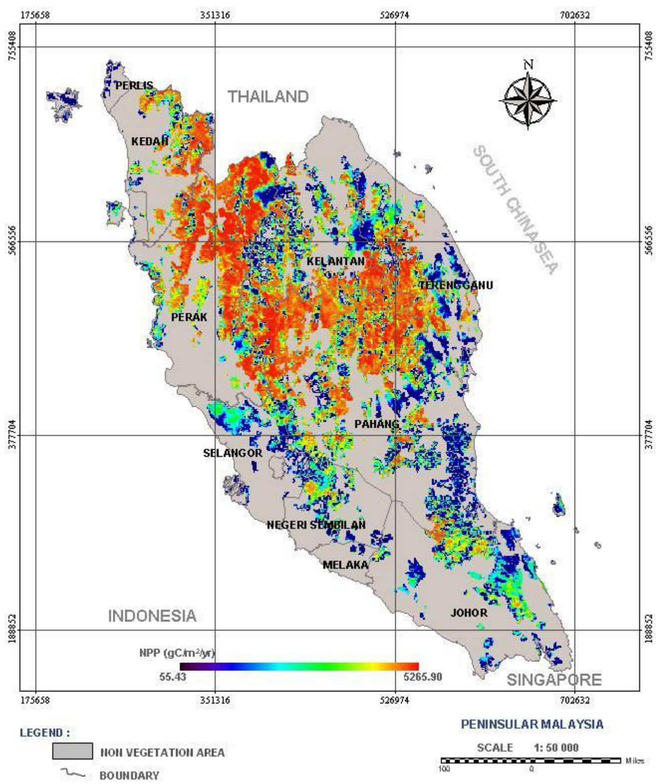

Figure 6 The Spatial Pattern of NPP Distribution of Peninsular Malaysia Forest

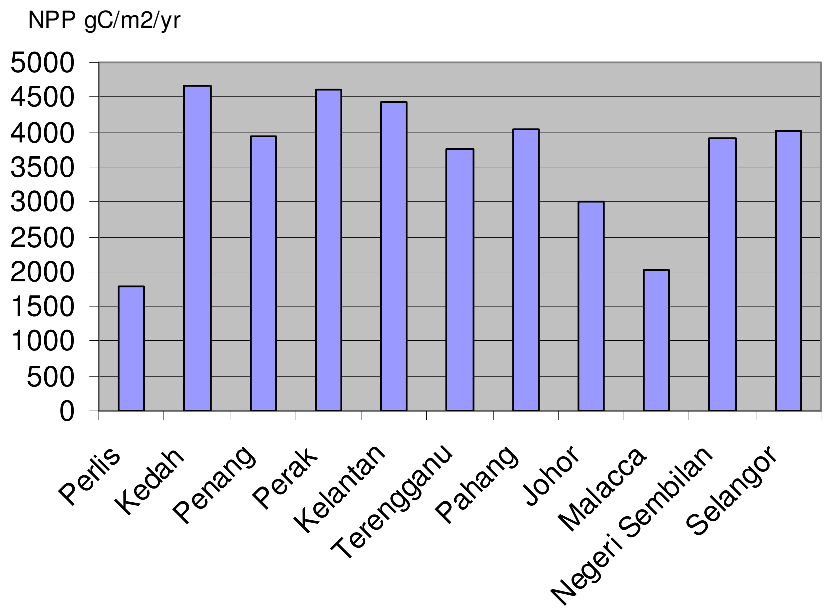

Figure 7 Average Value of NPP for Various State

5. Conclusion

Improved NPP data and understanding of the spatial pattern and dynamic processes that influence NPP will increase our ability to manage forest ecosystems and maintain their sustainability under a changing environment. In the past, the estimation of NPP in many forested areas including tropical forests have been based on direct measurement of only one or very few NPP components. Therefore accurate data on NPP are extremely limited. The emergence of remote sensing technology that allow remote sensing measurements and related modeling in forest ecosystem analysis can be very useful in providing fundamental understanding of energy interactions within the vegetation-soil complex. Remote sensing application can also provide a link between the energy environment and ecosystem processes. Apart from that, changes in the forest ecosystem can also be easily observed and quantified using remote sensing data**.** The combination of this technique and spatial analysis by GIS will continue to be strong areas of development in the modeling of forest NPP.

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