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Evapotranspiration Patterns for Tropical Rainforests in Southeast Asia: A Model Performance Examination of the Biome-BGC Model.

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1. Introduction

Southeast Asia tropical rainforest ecosystem is one of Asia's rainforest biome, but is not as well known for its important role in sustaining the global climatic system as compared to other rainforest biomes in Central America and Africa. Instead, it is a valuable source of raw materials needed to sustain the economies of the developing Asian region (BROOKFIELD and BYRON, 1990). During the period 1990 – 2000, tropical forests (47% of the total forest area) decreased by 14.2 million hectares per year, that is about 97% of the total deforestation. Maximal decrease of tropical forests was observed in South-East Asian countries, where areas covered by forest decreased from 53.9% in 1990 to 48.6% in 2000 (UN, 2005; OLCHEV *et al.*, 2008).

Deforestation reduces plant evapotranspiration, humidity, effective soil depth, water-table height and surface roughness, and increases soil erosion, soil temperatures and surface albedo (WRIGHT *et al.,* 1996; GASH and NOBRE 1997; MALHI and PHILIPS, 2005). Thus, the world community has been increasingly concerned about climatic change and its effect on the remaining forest ecosystem both globally and regionally. Three major changes in atmospheric composition are the increased concentration of atmospheric carbon dioxide, the increased rate of land surface temperature in tropical regions, and changes in rainfall pattern.

More studies show that there is still a lack of understanding about the contribution of tropical rainforests to global primary productivity. Indeed, there may be a causal link between the impact of drought on rainforest and global CO_2 concentrations because of the large contribution that rainforests make to global photosynthesis (CLARK *et al.*, 2003; MALHI and PHILIPS, 2005). Because tropical forests are the greatest global source of net primary production (NPP), they are the important contributors to global carbon cycling (International Panel on Climate Change IPCC, 2001). However, there is evidently considerable uncertainty about the magnitude of the terrestrial missing sink, and even larger uncertainty about the location (MALHI *et al.*, 1999). A combination of modelling and measurements of water (H_2O) and carbon (CO_2) from forest ecosystems can give possible estimates of water budget and carbon budget especially for Asian tropical rainforests.

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Ecosystem simulation models such as the Biome-BGC model are often used to integrate observed meteorological data in assessing water, carbon and nutrient cycling within a certain ecosystem. Other advantages of simulation models include providing alternative tools to assess observation, and developing a newer understanding or theories based observed and simulated results. It is a means of evaluating our lack of understanding (WAINWRIGHT and MULLIGAN, 2004). Component cycles of the Biome-BGC have previously undergone testing and validation, including the carbon (MCLEOD and RUNNING, 1988; KOROL *et al.*, 1991; HUNT *et al.*, 1991), nitrogen (RUNNING, 1994) and hydrologic cycles (KNIGHT *et al.*, 1985; NEMANI and RUNNING, 1989; WHITE *et al.*, 1997) in a natural ecosystem (WANG *et al.*, 2005). However, the Biome-BGC version 4.1.1 model has not been widely applied for tropical rainforest biomes in the Southeast Asia region.

In this study, we aim to examine further the application of the Biome-BGC model in estimating evapotranspiration and carbon budget to fit the study site's observational data. The paper focuses on evergreen broadleaf forests, specifically lowland evergreen tropical forest. We focus on the comparability of the model to generate modelled patterns of evapotranspiration (water budget) and the carbon budget at the study site.

2. Site and observed information

Site Description

The location of the study site was at Lambir Hills National Park (4º12'N, 114º02'E), south of Miri city, Sarawak, Malaysia, as shown in Figure 1. The park covers a strip of land 6,949 ha in area and is separated into two sections by the road traversing the park at its narrowest part, ca. 1.6km in width (YAMAKURA *et al.*, 1995). The climate around Miri including Lambir Hills is everwet but monsoonal due to distinct shifts in prevailing winds (YAMAKURA *et al.*, 1995). Daily rainfall data measured between 1968 and 2001 at Miri Airport showed a mean annual rainfall of 2740.5 ± 378.98mm (MANFROI *et al.*, 2006). The mean annual temperature is 27ºC at Miri Airport (MANFROI *et al.*, 2006).

The study site was established as a protected national park in 1975, in an undisturbed forest which is dominated by various dipterocarp species and vast biodiversity. The characteristic of the above mentioned undisturbed forest is large tall trees with high canopy height reaching up to 70m and is highly floristic diversified. As part of the project entitled 'Research and Observation on the Mechanisms of Atmosphere – Ecosphere Interaction in Tropical Forest Canopy', a large canopy crane with rotating jib was constructed on the research site that covers a 4-ha research plot in the national park. The function of the 80m canopy crane was to conduct *in-situ* eddy-covariance and micrometeorological measurements at the beginning of June 2001.

Biological measurements

In their previous research studies, they indicated that the leaf area index (LAI, m^2 leaf area per m^2 ground area) measured with pair of plant canopy analyzers (LAI2000, Li-Cor, Lincoln, NE) every 5m on a 30m x 30m subplot was approximately 6.2m^2m^{-2} with a seasonal fluctuation (KUMAGAI *et al.*, 2004) and the basal area was approximately 41.7m^2ha^{-1} (MANFROI *et al.*, 2004).

Micrometeorological and flux measurements using eddy covariance method

A 10m x 10m square grid on a 200m x 200m plot was established at the site (MANFROI *et al.* 2007). The 80m tall crane is situated in the centre of the study plot. (KUMAGAI *et al.*, 2005) Instruments used in measuring micrometeorological and flux measurements using the eddy covariance method were as mentioned in KUMAGAI (2004) and KUMAGAI *et al.* (2005). Appendix 1 shows the equipment and data acquisitions from the Lambir Hills National Park in Sarawak, Malaysia (KUME, 2005). Meteorological data like temperature, precipitation, shortwave radiation and vapor pressure deficit used in the model were observed and data collected for the period from July 2001 to June 2002 (Fig.2).

3. Modelling

The model work consisted of several stages, necessarily needed to tune up the parameters values of the model to fit the study site's natural environment before starting the simulation process.

It is important that, even at this early stage, the modules were tested so that the solution developed had a reasonable chance of producing consistent results (WAINWRIGHT *et al.*, 2004).

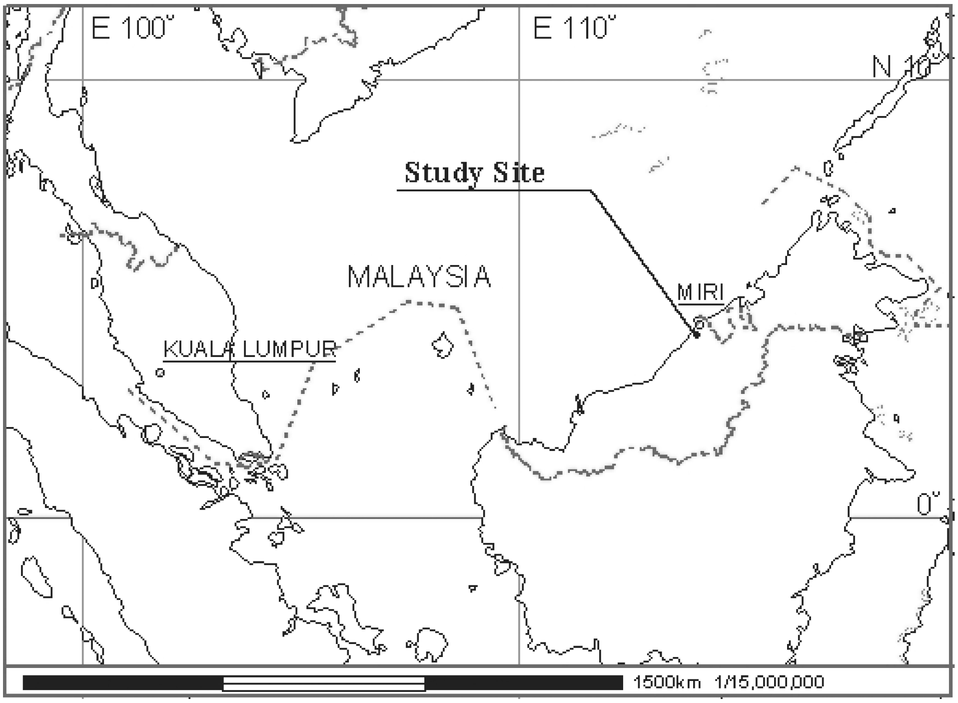

Fig. 1. Location of the study site at Lambir Hills, Sarawak, Malaysia.

Elements	Instruments		Data logger		Height		Measurement interval	Logging interval	Total measurement period (A)	No data period (B)	Ratio (%) =B/A x 100
					m		sec	min			
Rainfall	1. 0.5 Tipping bucket	Ohta keiki Co.	HOBO-event	Onset computer Co.	85.8	Crane	Event	Event	1827	0	0.00
	2. 0.5 Tipping bucket	Ohta keiki Co.	HOBO-event	Onset computer Co.	0	Crane	Event	Event			
	3. 0.5 Tipping bucket	Ohta keiki Co.	Kadec-PLS	Kona system Co.	49.5	Tower	Event	Event			
Downward short-wave radiation	1. Phyranometer	EKO Instruments Trading Co. Ltd MS 401	CR10X	Campbell Scientific Inc.	85.8	Crane	5	10	1827	66	3.61
	2. Phyranometer	EKO Instruments Trading Co. Ltd MS 401	CR10X	Campbell Scientific Inc.	49.5	Tower	5	10			
Upward short-wave radiation (refrection)	1. Phyranometer	Kippa & Zonen, CM06E	CR10X	Campbell Scientific Inc.	55.3	Crane	5	10	1812	179	9.88
	2. Phyranometer	EKO Instruments Trading Co. Ltd MS 401	CR10X	Campbell Scientific Inc.	49.5	Tower	5	10			
Downward long-wave radiation	1. Infrared radiometer	Eppley Model PIR	CR10X	Campbell Scientific Inc.	85.8	Crane	5	10	1812	61	3.37
	2. Infrared radiometer	EKO Instruments Trading Co. Ltd MS201F	CR10X	Campbell Scientific Inc.	49.5	Tower	5	10			
Upward long-wave radiation (refrection)	1. Infrared radiometer	Eppley Model PIR	CR10X	Campbell Scientific Inc.	55.3	Crane	5	10	1812	189	10.43
	2. Infrared radiometer	EKO Instruments Trading Co. Ltd MS201F	CR10X	Campbell Scientific Inc.	49.5	Tower	5	10			
Net radiation	calculation*								1812	189	10.43
Air Temperature	1. Themohygrograph	Vaisala Co., HMP35A	SQ1250	Grant Instruments Co.	76.3	Crane	600	10			
	2. Venyilated psychrometer	EKO Instruments Trading Co. Ltd MS020S	CR10X	Campbell Scientific Inc.	76.3	Crane	5	10			
	3. Venyilated psychrometer	EKO Instruments Trading Co. Ltd MS021S	CR10X	Campbell Scientific Inc.	60.2	Crane	5	10	1817	0	0.00
	4. Themohygrograph	Vaisala Co., HMP35A	SQ1250	Grant Instruments Co.	49.5	Tower	600	10			
	5. Themohygrograph	Onset computer Co. HOBO (H08032)			49.5	Tower	600	10			
Vapor Pressure Deficit	1. Themohygrograph	Vaisala Co., HMP35A	SQ1250	Grant Instruments Co.	76.3	Crane	600	10			
	2. Venyilated psychrometer	EKO Instruments Trading Co. MS020S	CR10X	Campbell Scientific Inc.	76.3	Crane	5	10			
	3. Venyilated psychrometer	EKO Instruments Trading Co. MS021S	CR10X	Campbell Scientific Inc.	60.2	Crane	5	10	1817	0	0.00
	4. Themohygrograph	Vaisala Co., HMP35A	SQ1250	Grant Instruments Co.	49.5	Tower	600	10			
	5. Themohygrograph	Onset computer Co. HOBO (H08032)	-		49.5	Tower	600	10			
Wind Speed	1. Anenometer	Makino Instruments Inc. AC750	CR10X	Campbell Scientific Inc.	76.3	Crane	5	10			
	2. Anenometer	Makino Instruments Inc. AC751	CR10X	Campbell Scientific Inc.	60.2	Crane	5	10	1812	70	3.86
	3. Anenometer	Makino Instruments Inc. AC752	CR10X	Campbell Scientific Inc.	93.2	Crane	5	10			
	4. Anenometer	Makino Instruments Inc. AC753	CR10X	Campbell Scientific Inc.	49.5	Tower	5	10			

Appendix 1 Appendix 1 showing equipments and data acquisitions in Lambir hills national park in Sarawak, Malaysia. (KUME, 2005.)

Biome-BGC Model background

The model was designed to be ultimately driven by remote sensing inputs of the surface climate and vegetation structure, in the framework of a geographic information system containing topographic and physical site characteristics (PETERSON *et al.*, 1985; RUNNING and COUGHLAN, 1988). Biome-BGC simulates the development of soil and plant carbon and nitrogen pools without necessarily using input of soil carbon information or LAI (WHITE, 2000). It is designed specifically to simulate physiological processes and soil biogeochemistry in more detailed and at a finer scale (WANG *et al.,* 2005). The model simulates the daily and annual output of water and carbon dynamics in different vegetation biomes.

Recent workshops on global ecological issues have identified LAI as the most important single variable for measuring vegetation structure over large areas and the use of LAI as a quantity unit when explaining energy flow and mass exchange in a forest structure (RUNNING and COUGHLAN, 1988).

In our study, LAI is used as the principal independent variable for calculating canopy interception, transpiration, respiration and photosynthesis, carbon allocation and litterfall (RUNNING and COUGHLAN, 1988). It is also our strongest point in understanding the compatibility of the model to fit with the observation of the study site.

Site specification parameters such as elevation and soil characteristics were set to the study site. The eco-physiological characteristic, (EPC) of the vegetation was set to 'evergreen broadleaf forest' parameters. It is the nearest eco-physiological characteristic to our study site. The EPC consisted of 34 parameters that have been identified and separated into different biomes: woody and nonwoody biomes.

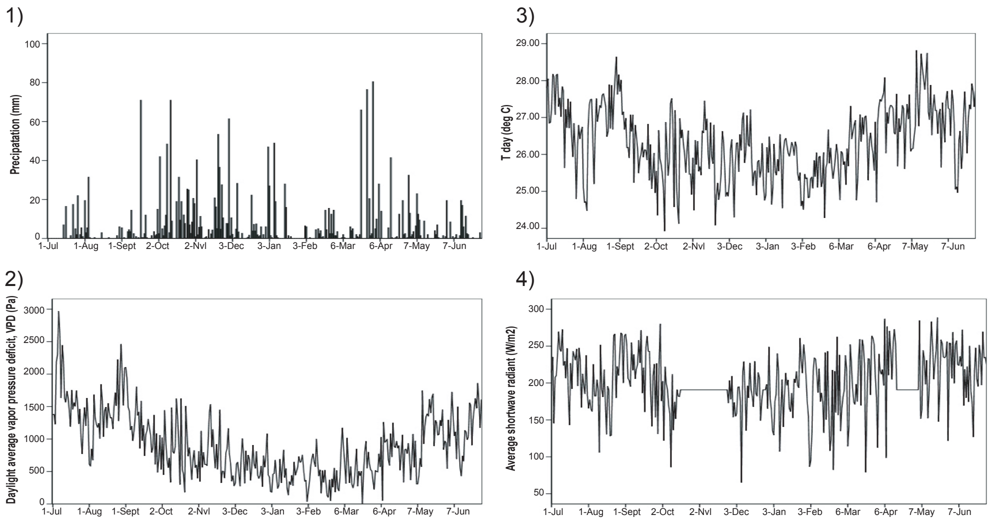

Fig. 2. Seasonal trend of the meteorological input from 1st July 2001 to 30th June 2002 as observed by eddy covariance measurements at the study site. From the top (clockwise)
1) Total daily precipitation
2) Daily average shortwave radiant flux density (W/m^{-2})
3) Daylight average vapor pressure deficit (Pa) and
4) Average daytime temperature.

Parameter Optimization Strategy

In order to achieve a better calculation of ET, test simulations were carried out as part of parameter tuning process. We later confirmed the modeled daily water evaporatranspiration (ET), evaporation of water intercepted on the canopy or canopy interception (Ewet), soil evaporation (Esoil), and transpiration (Edry) using eddy covariance measurements collected from the Lambir flux tower.

In Biome-BGC, seven different classes of vegetation can be modelled to describe their carbon and water exchanges in the atmosphere. Parameter groups include the following: 1) turnover and mortality; 2) allocation of carbon; 3) carbon to nitrogen ratios (C:N); 4) the percent of plant material in labile, cellulose and lignin pools; 5) leaf morphology; 6) leaf conductance rates and limitations; 7) canopy water interception and light extinction; and 8) the percent of leaf nitrogen in Rubisco (PLNR) (WANG *et al.*, 2005).

We chose the nearest suitable forest biomes parameter settings to our study site which is the evergreen broad-leaved forest (EBF) biome. We used the default parameters for EBF to simulate both water and carbon exchanges in a forest ecosystem.

Meteorological inputs such as precipitation, daily minimum and maximum temperature, shortwave radiation and vapour pressure deficit are the main inputs for the model. However, the eco-physiological parameters for 'evergreen broadleaf forest' needed to be changed. Among these allocation of carbon from new root to new leaf and new stem to new leaf, ratio for canopy water interception coefficient, maximum stomatal conductance and boundary layer conductance were changed to fit the observational data of the study site.

However, the original EBF parameters failed to achieve reasonable LAI size which is important in establishing the water dynamics of the forest ecosystem such as, transpiration and interception. We performed several sensitivity test trials on several parameters namely;

1) The carbon allocation ratio for new fine root: new leaf and new stem:new leaf
2) The canopy water interception coefficient (CWI)
3) The maximum stomatal conductance, g_s
4) The boundary layer conductance, g_b
5) The fraction of leaf N in Rubisco

We tested the effect of each individual parameter separately by increasing and reducing a certain percentage of the default value. We also noted that certain parameters have a different significant effect in simulated results for water dynamics factors. In particular simulated result for transpiration, interception and also carbon dynamics like gross primary production, GPP and seasonality. Thus, we focus in our parameterization strategy more on the simulated results for LAI, ET and GPP while comparing it with observation data.

Table 1. Site Input Parameter

		Range	Source
a) Soil content			
% of sand	*69.0	62.4 – 73.4	ISHIZUKA *et al*., 1998
% of silt	*12.2		
% of clay	*18.8	13.9 – 21.6	ISHIZUKA *et al*., 1998

* Mid range values were chosen for each parameter in the soil component.

Table 2. Eco-physiological parameters for original EBF and modified parameterization of LHNP with values: $C_{fr:leaf}$ is the allocation ratio of carbon to new fine root : new leaf; $C_{stem:leaf}$ is the allocation ratio of carbon to new stem : new leaf; CWI is the canopy water interception coefficient; $FLR_{rubisco}$ is the fraction of leaf N in rubisco; g_s and g_b are conductance values for the stomatal and boundary layer respectively.

	$C_{fr:leaf}$ (ratio)	$C_{stem:leaf}$ (ratio)	*CWI* (–)	$FLR_{rubisco}$ (–)	g_s (ms^{-1})	g_b (ms^{-1})
Evergreen Broad-leaved Forest (EBF)	1	1	0.045	0.033	0.006	0.01
Lambir Hill National Park (LHNP)	0.3	0.3	0.01	0.15	0.005	0.02

Input data for the Biome-BGC model

The running of the model required three major components: meteorological data, site parameter and type of forest biome eco-physiological characteristic. Any missing data would fail each normal run. Thus, it was necessary that any missing data should be filled in by interpolation.

The soils are red-yellow podzonic (Malaysian classification) or ultisols (USDA Soil Taxonomy), with a high sand content, a low pH and a high porosity (OHASHI *et al.*, 2007). (see Table 1)

4. Results and discussion

We finalized our modified parameters value for Biome-BGC which fitted the study site, Lambir Hills National Park. Table 2 shows the individual eco-physiological parameters that we changed when compared with the original EBF parameters.

The initial eco-physiological parameters for evergreen broadleaf forest were more focused towards temperate regions and were not suitable for the tropical climate, especially in Southeast Asia. Modifications of the initial eco-physiological parameters were necessary for the Biome-BGC model simulation to perform to a certain degree of agreement.

Comparison of model results with observations;

Leaf Area Index, LAI

Observed values for LAI mentioned in KUMAGAI *et al.* (2004), shows a good agreement with the model estimate after modification. Initial EBF parameters fixed by the model estimated a size of LAI of 2.26 m^2m^{-2}. It is interesting that by reducing the allocation ratio of carbon in eco-physiological parameters that controls the growth of new fine root, new leaf and new stem, the model estimated the size of LAI ~ 5.0 m^2m^{-2}. (Table 2) We realized how important LAI is in influencing the total ET in terms of interception and transpiration estimates. Our final modified parameter result shows that the size of LAI for our study site was 5.29 m^2m^{-2}.

Interception value controlled by CWI

The Biome-BGC model estimates the water budget ET both annually and monthly. The model water budget using the Penman-Monteith equation consisted of three components: evaporation, transpiration and evaporation from intercepted rainfall from the canopy, Ewet. With good estimated LAI, we found that the total canopy interception, Ewet, was slightly higher than the observed value. Both our initial EBF parameters and our newly modified allocation of carbon ratio showed high Ewet values ranging from 224.59mm to 391.26mm annually. It is logical to deduce that the high LAI would contribute significantly to higher Ewet values. However, MANFROI *et al.* (2006), states that interception evaporation at the same study site shows the mean annual Ewet for three years was 210mm/year. His research on Ewet was carried out starting from January 2002. This gave us a good comparison range for observation and model estimates for Ewet.

By reducing the canopy water interception (CWI) ratio in the model, we found that the total interception value reduced as shown in Figure 3. Run 1 shows the initial EBF parameter whereby CWI ratio was 0.045. Several runs showed that a reduced ratio causes the total interception Ewet value to reduce gradually. This shows a corresponding relationship between CWI and interception value, Ewet in the model. For our final modification, the total interception value was 197.57mm with CWI=0.01.

The effect of maximum stomatal conductance, (g_s) on transpiration and soil evaporation

KUMAGAI *et al.* (2005), computed using the Priestly and Taylor (PT) equation that total transpiration and soil evaporation was 1193.1mm for the study site. Our initial EBF parameter shows relatively low transpiration and low soil evaporation as shown in Figure 4. In order to achieve a better fit with eco-physiological parameters for the study site, it is crucial to identify a suitable g_s ratio for the study site. By increasing the ratio of g_s, it increases both, but it has a higher impact on transpiration than on soil evaporation.

The impact on transpiration (Edry) model estimate is influenced by the value of vapour pressure deficit (VPD). It constrains the process of transpiration, as stomata tend to be closed in response to high VPD (GRACE *et al.,* 1995; MALHI & PHILIPS, 2005). During our earlier model trials, we considered that the daily average value of vapour pressure deficit (VPD) observed at the study site but it was lower than the actual VPD in the forest. The calculation of daily average VPD used in this model include the measurement of hourly nighttime VPD which is nearly zero. Thus, we only considered daytime (6:00 - 18:00) average vapour pressure deficit. It is usual that VPD at the top of rainforest canopies can be remarkably high because of the high leaf surface temperatures (GRACE *et al.,3* 1995; MALHI & PHILIPS, 2005). However, at this study site, one of the special characteristic of Lambir Hills National Park forest is the high humidity surrounding the park. Thus, a modification of g_S value allows the model to generate suitable estimates compared with observed values. In the end, our final simulated total transpiration, Edry and soil evaporation, Esoil was estimated at 947.88mm.

Seasonality of total evapotranspiration

Figure 5 shows our final, modified parameter result, for modelled ET compared with observational ET. After several runs, we decided on the final modified parameter values as shown in Table 2. It shows the most promising fit to the observational ET (KUMAGAI *et al.*, 2004 modified). However, our annual modelled ET computed using Biome-BGC model shows a slightly low amount of 1145.47mm compared to observed annual ET which was equalled to

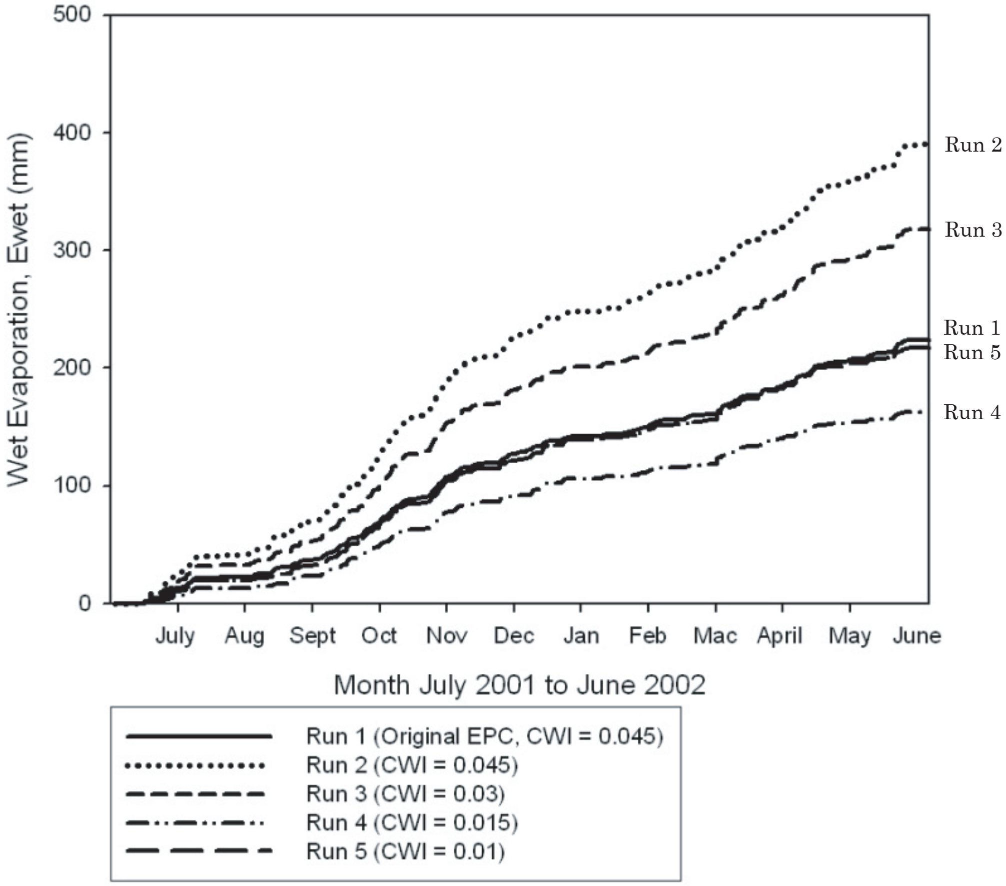

Fig. 3. The effects of CWI ratio in interception, Ewet values.

1401.1mm.

Although it is slightly low compared to the observational ET, it shows however a consistent pattern of seasonality with observed ET. This is clearly seen in the months of October 2001 and November 2001 with a large value of monthly ET, and low value of monthly ET in the months of December 2001 and January 2002.

In comparison, the first eleven months show that the total observational ET was higher than the modelled total ET. Only for the month of June 2002, did the modelled monthly ET exceed the monthly observed ET.

We also learned that the combination factor of boundary layer conductance, g_b and g_s could generate a higher modelled ET, as shown in Figure 5. Different g_b and g_s values can influence the total modelled ET in Edry and Esoil. Run 8 shows higher monthly modelled ET compared to the final modified parameters, but, however, failed to show similarities in the pattern of seasonality as mentioned above. This also applies to Run 9, whereby the month of July and August 2001 shows a higher monthly total ET, but subsequently declined when compared to both the monthly observed and final modified modelled ET.

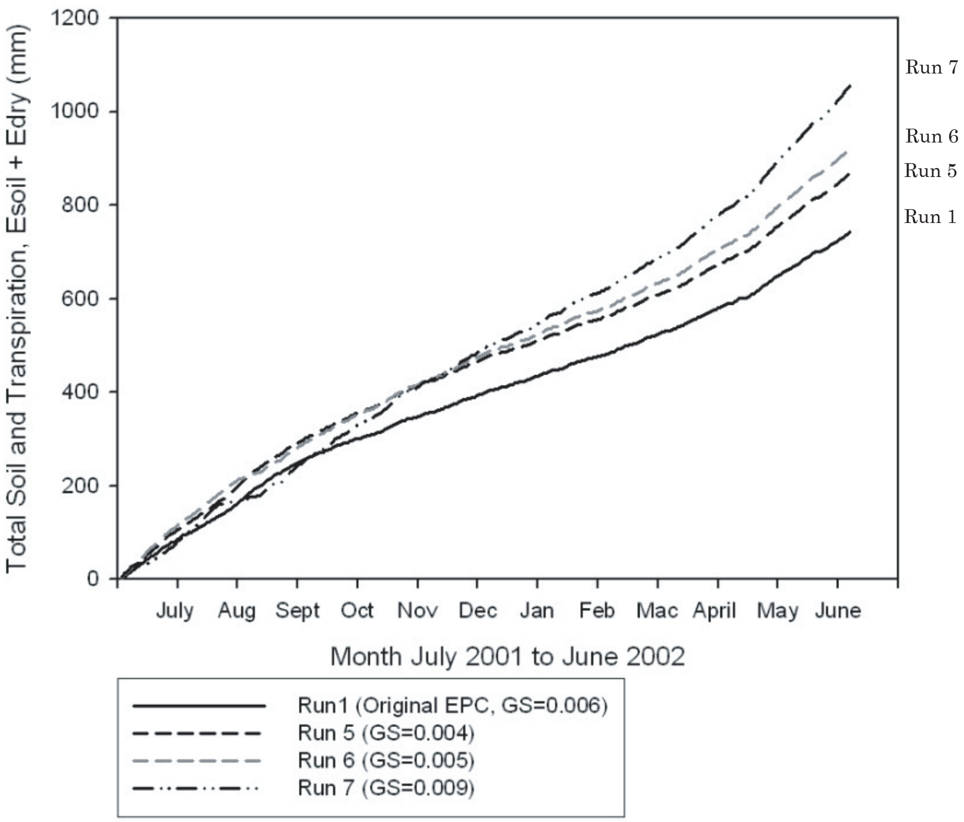

Fig. 4. The effects of g_s in soil evaporation, Esoil and transpiration, Edry values.

Gross Primary Productivity, GPP

In the process of simulation, the Biome-BGC model simulated the net primary production, NPP of the undisturbed tropical rainforest at an estimation of 4.19 tC ha^{-1} $year^{-1}$. For autotrophic respiration, R_a is the total of R_m (maintenance respiration) and R_g (growth respiration) which the Biome-BGC model simulated separately. The annual total R_a as simulated was estimated at 20.3 tC ha^{-1} $year^{-1}$. Meanwhile heterotrophic respiration, R_h, was estimated at the rate of 3.51 tC ha^{-1} $year^{-1}$.

In our simulation for the net carbon balance for the study site using the Biome-BGC model, the net ecosystem productivity (NEP) value was estimated positive at 0.68 tC ha^{-1} $year^{-1}$. Old-growth forests aged between 15 and 800 years of age usually were reported that the net ecosystem production, NEP is usually positive which means that the forests are CO_2 sinks (LUYSSAERT *et al.,* 2008). This indicates that in the model, the Lambir Hills National Park had reached a certain maturity point.

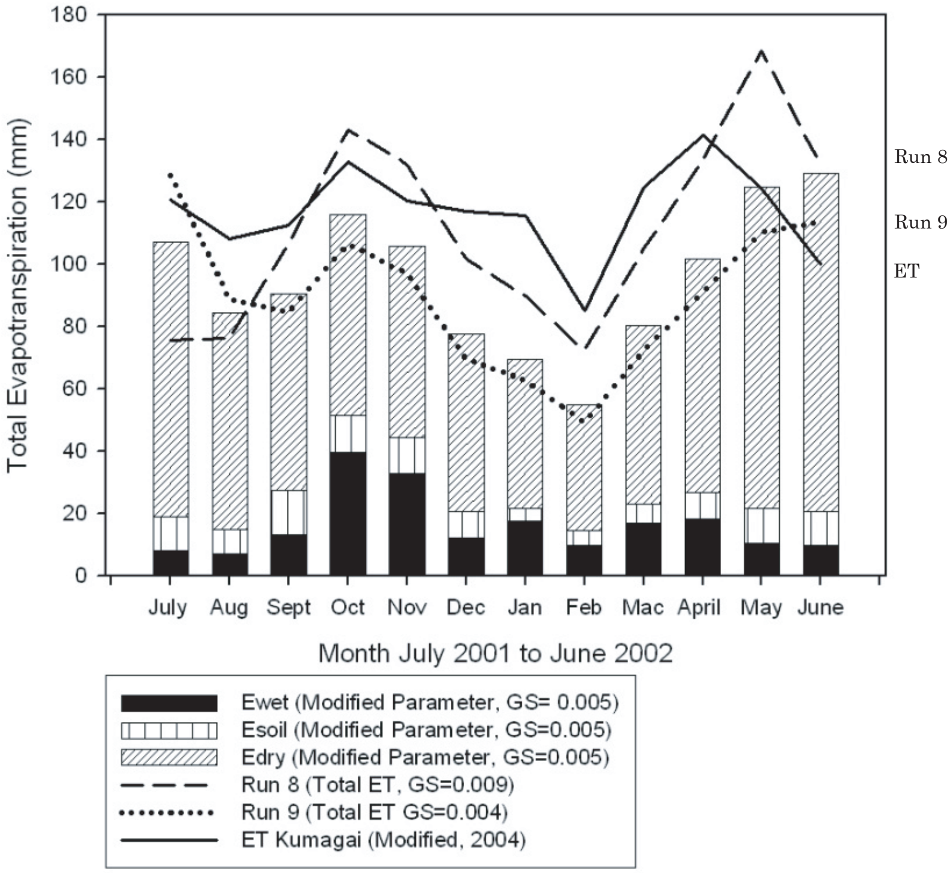

Fig. 5. Seasonal pattern of simulated and observed evapotranspiration, ET.

Table 3 shows the comparison of GPP values from published reports for tropical rainforest over modelled GPP using Biome-BGC. In comparing observational GPP from the Lambir Hills National Park, it is found to be a relatively smaller value with annual simulated GPP estimated at 24.5 tC ha^{-1} $year^{-1}$.

Table 3. Comparison of observed GPP, maintenance respiration values for a tropical rainforest with simulated GPP from using the Biome-BGC.

Gross Primary Productivitity	GPP Amazon, (Malhi 1999)	GPP Lambir (Saito, 2005)	GPP BIOME-BGC
Total Annual ($tCha^{-1}yr^{-1}$)	30.4	30.3	24.5

5. Concluding remarks

This study was first conceptualized to test the ability of Biome-BGC model to estimate evapotranspiration and carbon budget for an undisturbed lowland evergreen tropical rainforest in Southeast Asia. Using the meteorological data input from the observation site as our main input for the model, we found that the simulated results were not suitable or compatible with the observation result.

By tuning the eco-physiological parameters with Lambir Hills National Park's meteorological input, we were able to predict reasonable LAI values as high as $5.29m^2m^{-2}$. Reducing the allocation of carbon to new leaf, fine root and stem in effect increases the LAI values. The LAI is important in the evapotranspiration and NEE estimation. The modelled ET shows a consistence pattern of seasonality with observed ET in both annual and monthly estimations.

In our model, the carbon cycling estimates shows a mature forest ecosystem in the Lambir Hills National Park which is the same as observed data. However, the GPP was simulated at a lower estimation compared to observed data. We concludes that the proposed parameters in this paper shows positive outcome by using the Biome-BGC model in applying it to a tropical rainforest ecosystem in Southeast Asia. In the near future, further examination on the simulated biomass respiration estimation is greatly needed.

Acknowledgments

Biome-BGC version 4.1.1 was provided by the Numerical Terradynamic Simulation Group (NTSG) at the University of Montana. NTSG assumes no responsibility for the proper use of Biome-BGC by others.

Summary

Ecosystem simulations of tropical rainforest biomes can significantly lead to a better understanding of global primary productivity. Our study site was located at Lambir Hills National Park (4° 12' N, 114° 02' E) Sarawak, Malaysia. Our main objective was to examine the application of Biome-BGC in estimating evapotranspiration and carbon dynamics. Meteorological data collected in an undisturbed lowland evergreen tropical forest were used as the main inputs for a Biome-BGC model. Meteorological data, such as temperature, precipitation, shortwave radiation and vapor pressure deficit were used in the model. They were collected for the period from July 2001 to June 2002. Several modifications of individual ecophysiological parameters were necessary to obtain a reasonable modeled estimation and to corroborate the observational data. Our final modified parameter result showed that the leaf area index, LAI was simulated at an estimated value of 5.29 m^2m^{-2}, which was within the observational range of 4.8 – 6.8 m^2m^{-2}. The simulated annual interception value was 197.57mm with CWI=0.01. With the boundary layer conductance ratio, g_b and the maximum stomatal conductance ratio, g_s values 0.02 and 0.005, the simulated total transpiration and soil evaporation was estimated at 947.88, which was 20% lower than the observational result. However, our annual modeled evapotranspiration, ET, computed using the Biome-BGC model showed a slightly lower amount, 1145.47mm, compared to the observed annual ET which totaled 1401.1mm. A consistent pattern of seasonality was discovered in the modeled and observational results. This was clearly shown in the months of October 2001 and November 2001 with large values of monthly ET, and low values of monthly ET in the months of December 2001 and January 2002. In our simulation for the net carbon balance, the net ecosystem productivity (NEP) value was estimated to be positive and have a value of 0.68 tC ha^{-1} $year^{-1}$. The NEP is usually positive and indicates that, according to the model, the Lambir Hills National Park has reached a certain maturity point. The net primary production, NPP, of the undisturbed tropical rainforest was estimated at 4.19 tC ha^{-1} $year^{-1}$. Observational gross primary productivity, GPP, in Lambir Hills National Park, was slightly higher compare with annual simulated GPP estimated at 24.5 tC $ha^{-1}year^{-1}$ In conclusion, the proposed parameters in this paper shows a good correspondence with evapotranspiration and LAI, while GPP was slightly underestimated.

Key words: Biome-BGC model, evapotranspiration, interception, Net CO_2 ecosystem production (NEP), tropical rainforest

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東南アジア熱帯雨林の蒸発散量季節変化：Biome-BGCモデルによる再現性の試行

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要　　旨

生態系の水・炭素循環を再現するBiome－BGCモデルの東南アジア熱帯雨林への適用性をマレーシア，サラワク州ランビル国立公園（4º12’N, 114º02’E）の熱帯雨林で観測された各種の観測記録を用いて検討した。ランビル国立公園は，低地フタバガキ林で，蒸発散量，樹冠遮断量，NPP，地上部現存量などの観測値が蓄積されている。2001年7月から2002年6月のランビルの気象記録を用いて，温帯の常緑広葉樹林で得られたBiome－BGCモデルのパラメータセットによって求めた推定は，葉面積指数が小さく，蒸発散量が著しく小さい結果となった。光合成産物の地上部への分配割合，空気力学的コンダクタンス，気孔コンダクタンスのパラメータを変更すると，葉面積指数が観測結果に一致し，年間の蒸発散量とその季節変化をかなり再現する結果を得た。しかし，GPPと炭素蓄積量については水収支特性の再現性に比べて低い段階に留まった。

キーワード： Biome－BGCモデル・蒸発散・樹冠遮断量・正味二酸化炭素交換量・熱帯雨林