Identification of the climate control factors on carbon cycle variations of tropical forests combined analysis of ground and satellite observations

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Abstract
An estimation of the responses of tropical rainforests for climate changes is important problem to evaluate the terrestrial global carbon cycle. In the present study, we analysed the cross-correlation functions of vegetation indexes to climate parameters for the satellite-based global scale data in the southeastern Asia and the ground-observed point data at Bukit Soeharto, Borneo. Cross-correlation functions show various signals for the regional and temporal scale. Our conclusion is that tropical rainforests in the southeastern Asia have spatio-temporally various responses for climate variations.
Keywords: NDVI, tropical rainforests, climate change, southeastern Asia, cross-correlation function

1. Introduction
Tropical forests play an important role in the global terrestrial carbon cycle. Identification of the response of vegetation activities for climate changes needs to estimate the tropical ecosystem. In special, tropical rainforests are significant. There are three methods to evaluate the relationship, that is, (1) terrestrial ecosystem model (e.g. Nemani *et al*. 2003), (2) field measurement study (e.g. Potts 2003) and (3) analysis using satellite-based data (e.g. Nagai *et al*. 2005). Nemani *et al*. (2003) show that radiation is the most important climate factor. On the contrary, Potts (2003) presents that a severe drought due to strong El Niño events restricts vegetation activities. Nagai *et al*. (2005) detect that interannual variations in NDVI (Normalized Difference Vegetation Index) are inclined to decrease in El Niño events due to dryness. A reason for different interpretations is that tropical rainforests have no distinct phenology and the climate system consists of various time scale modes. Although ground-based data provide a good explanation, there are few field stations. Therefore, we need an analysis using the satellite-based global scale data.

In the present study, we evaluated the responses of tropical rainforests for climate variations in the southeastern Asia using the cross-correlation functions for the satellite-based global scale data, and compared with the analysis of ground-based point data.

2. Data
2.1 Study area
Our target area is the tropical rainforests in the southeastern Asia, where includes the field station Bukit Soeharto (0°51’41″S, 117°02’41″E) (Figure 1). We made two conditions to select tropical rainforests that the vegetation map of DeFries *et al*. (1998) shows evergreen broadleaf forests and monthly mean precipitation from 1971 to 2000 is over 100 (mm). We roughly divided the southeastern Asia into seven areas as shown in Figure 1.

The flora of Bukit Soeharto is secondary tropical rainforests recovered from the forest fires in 1983 and 1998 due to severe droughts. There is a dry season from July to October (Gamo 2003).

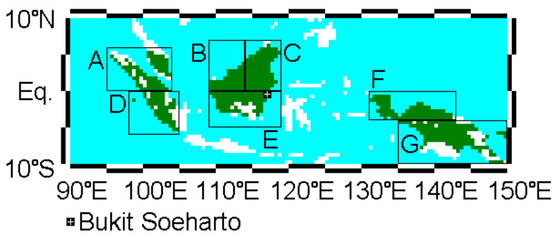

Figure 1. Our study areas in the southeastern Asia (A: 4°N-Eq., 95°E-104°E, B: 7°N-Eq., 109°E-114°E, C: 7°N-Eq., 114°E-119°E, D: Eq.-6°S, 98°E-105°E, E: Eq.-5°S, 109°E-119°E, F: Eq.-4°S, 131°E-143°E and G: 4°S-10°S, 135°E-150°E).
The selected tropical rainforests colour black. A cross marker shows the field site Bukit Soeharto.

2.2 Global scale data

We used the Global Inventory Modeling and Mapping Studies (GIMMS) NDVI data (Pinzon 2002, Pinzon *et al*. 2004, Tucker *et al*. 2005) distributed by the ISLSCP Initiative II data archive (Hall *et al*. 2005) with a 0.25° spatial resolution. Precipitation and temperature data based on ground observations are the Climate Research Unit (CRU) TS 2.0 data with a 0.5° spatial resolution (Mitchell *et al*. 2004). Incoming surface solar radiation data derived from satellites is the Goddard Institute for Space Studies (GISS) downwelling shortwave full sky at surface radiative flux data with a 2.5° spatial resolution (Rossow and Schiffer 1999). We used monthly composite data from January 1984 to December 2000.

2.3 Ground observation data

The LAI (Leaf Area Index) calculated from attenuation of PAR (Photosynthesis Active Radiation), soil water content at 10 (cm) underground, air temperature at 30 (m) above ground, and PPFD (Photosynthesis Photon Flux Density) data from January 2001 to December 2004 with a 30 minute temporal resolution were used. We reconstructed weekly composite data from the daily average of soil water content and temperature, and the daytime (8:15-17:45) average of LAI and PPFD. Deficit data were complemented by an autoregressive model.

3. Method

The cross-correlation functions of NDVI to climate parameters were calculated as shown in equation (1) after applying three month moving average for each data to remove high frequency components.

$$C_{\mathrm{NDVI-climate\ parameter}}(k) = \frac{1}{N}\sum_{t=k+1}^{N} \mathrm{NDVI}(t)\ \mathrm{climate\ parameter}(t-k) \quad (1)$$

where N is the length of time-series.

In the same way, we evaluated the cross-correlation functions of LAI to climate factors for the ground-based point data after applying four week moving average.

4. Results and discussion

We compared the monthly average of NDVI with the ground-observed LAI at Bukit Soeharto to test the seasonal variation in the satellite data. Although NDVI data in tropical rainforests include noise components due to cloud contamination (e.g. Kobayashi and Dye 2005), the seasonal cycle of NDVI coincides with those of LAI well.

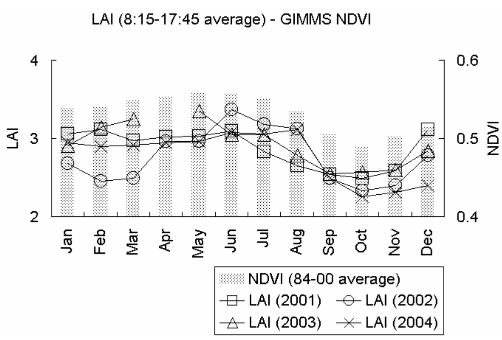

Figure 2. The monthly average of NDVI from 1984 to 2000 (bar) and ground-observed LAI (thin line) from 2001 to 2004 at Bukit Soeharto. We extracted the NDVI data from a grid (0°50' S-0°75' S, 117°00' E-117°25' E). The LAI data show daytime (8:15-17:45) average.

Figure 3 shows the cross-correlation functions of NDVI to climate parameters. Tropical rainforests have various responses for climate factors with different lag time and there are regional differences. We can roughly divide five groups, that is, (1) Malaysia (area A, B and D), (2) the northern Borneo (area C), (3) the southern Borneo (area E), (4) the northern New Guinea (area F) and (5) the southern New Guinea (area G). NDVI has higher positive correlations with temperature and radiation with no lag time in Malaysia and the northern Borneo. On the contrary, NDVI has a higher positive correlation with precipitation with some lag time in Malaysia, the southern Borneo and the northern New Guinea. In the northern Borneo, precipitation has no correlation with NDVI. NDVI-temperature and radiation show higher positive correlations with some lag time in New Guinea. These results mean as following sensitivities of tropical rainforests to climate parameters. Temperature and radiation are important at a point of time in Malaysia, which coincides with Nemani *et al*. (2003). However, precipitation is significant with some lag time in Malaysia, the southeastern Borneo and the northern New Guinea. It presents that water stress restricts vegetation activities, which is consistent with such as Gamo (2003), Potts (2003) and Nagai *et al*. (2005).

Similarly the cross-correlation functions of LAI to climate parameters at Bukit Soeharto are shown in

Figure 4. The correlation of LAI-soil water content denotes the same tendency of the NDVI-precipitation in the southern Borneo (area E), while those of LAI-temperature and PPFD are different from the NDVI-temperature and radiation respectively. It's assumed that ground-based point data include the local meteorology, in special, variations of amount of cloud cover. However, this result means that water stress limits vegetation activities, and agrees with the estimation of the satellite-based global scale data.

We detect that tropical rainforest in the southeastern Asia have different responses to climate parameters spatio-temporally. However, we should be concerned that the climate of southeastern Asia has variations due to the interaction between ENSO and Asian monsoon. More detailed analysis is necessary.

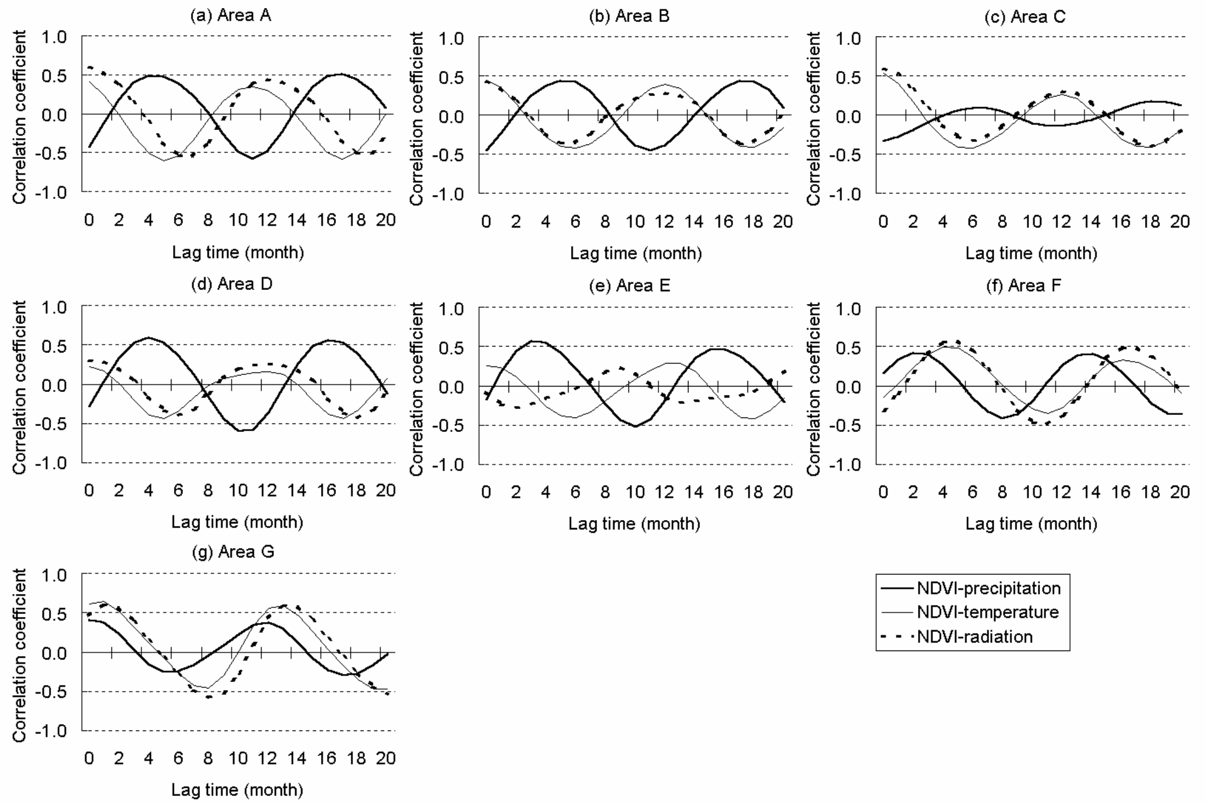

Figure 3. Cross-correlation functions of NDVI to precipitation (bold line), temperature (thin line) and radiation (dotted line) for selected tropical rainforests regions (a: area A, b: area B, c: area C, d: area D, e: area E, f: area F and g: area G).

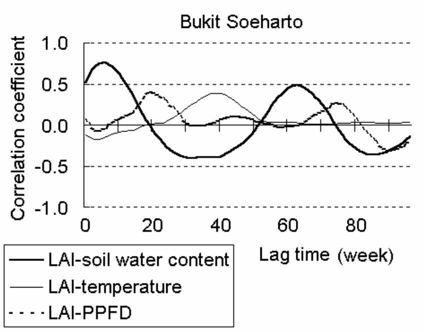

Figure 4. Cross-correlation functions of LAI to soil water content (bold line), temperature (thin line) and PPFD (dotted line) at Bukit Soeharto.

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