Peat fire, air pollution and hydrological processes in a tropical peatland, Central Kalimantan, Indonesia

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Summary

Dense haze emitted from peat/forest fires in 1997/98 and 2002 damaged not only the peatland and forest themselves but also the social activity and human health in many countries of South-east Asia. Several components of air quality, such as carbon monoxide, ozone and particulate matter less than 10 µm in diameter (PM_{10}) etc. have been monitored since 2001 by the Environmental Impact Agency of Palangka Raya at three sites in Palangka Raya, Central Kalimantan. Peat moisture of the surface layer, which is a very important factor for surface peat to be ignited by sparking fire, was estimated with the one-dimensional bucket model of hydrological processes in the peat layer from surface to one metre in depth. The seasonal changes of concentrations of carbon monoxide and PM_{10} clearly coincided with changes of peat moisture of the surface layer.

Key index words: peat fire, soil moisture, groundwater level, air pollution, bucket model

Introduction

Long-term observation of the groundwater level in a tropical peat swamp forest has provided much information on the hydrological conditions of such a forest. The daily actual evapotranspiration from a tropical peat swamp forest was estimated from the daily change of groundwater level in a forest (Takahashi *et al.*, 1998). Takahashi *et al.* (2003) pointed out the importance of groundwater regulation for prevention of peatland fire. Some behaviour and mechanism of tropical peat fire were clarified by Usup *et al.* (2004). They mentioned that the surface peat should be dry to less than 100 gr.% to be ignited. Those results show the importance of the groundwater level and the surface peat moisture for forecasting the peatland fire and making a plan to extinguish the fire. The air pollution caused by peat fire is also a big problem in tropical peatlands (Limin *et al.*, 2006). Therefore, this study focuses on the the following three objectives: (1) air pollution and hydrological condition of peatland in 2002; (2) hydrological processes, such as the surface peat moisture, groundwater level during the dry season in tropical peatland; and (3) hydrological modelling, which can represent the moisture of surface peat in tropical peatland.

Study site and methodology

Air pollutants such as carbon monoxide, sulphur dioxide, nitrogen oxide, nitrogen dioxide, ozone and particulate matter less than 10 □ in diameter (PM_{10}) were monitored in the city area of Palangka Raya by the Air Quality Management System Regional Centre of Palangka Raya (Limin *et al.*, 2006). The concentration of PM_{10} was used in this paper. The field observation on the hydrology and meteorology in the tropical peatland was carried out at farmland near the University of Palangka Raya and in a peat swamp forest in the catchment of the River Sebangau. Soil of the study site was peat about 1 m deep, which was well decomposed but contained some wood fragments in the layer deeper than about 40 cm. The total area of the farm land was 1 ha with several small trees and a small residential house in northwest edge. An experimental site of 20 m square was set up on the central part of the farmland. The experimental site was divided into five blocks. Soybean (*Glysine max(L) Merril*) was planted in two blocks. The soybean seeded on 26th April, 17th May and 7th June. When the measurements of evapotranspiration in the soybean block were carried out on the middle June, middle July and the begging of August, the heights of plants reached 70-80 cm. One block, the bare soil block, was kept without planting and used for monitoring of such climatic and hydrological elements, as air temperature and humidity at 1.5 m height in shelter, integrated solar radiation with one hour interval at 1.2 m high and wind speed and direction at 3.5 m high. Groundwater level was measured at the same monitoring block by using a pressure sensor (Druck Ltd, PDCR830) and a data logger. Hourly rainfall was measured with a tipping-bucket rain gauge and a data

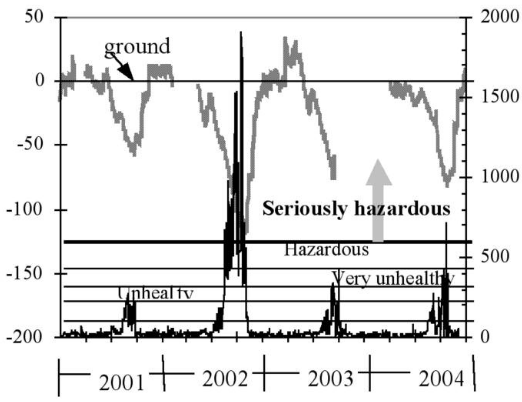

Figure 1. Seasonal changes of PM_{10} values in Palangka Raya and the ground water level in a forest.

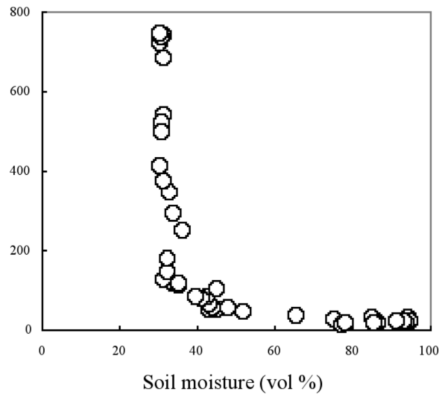

Figure 2. Relationship between soil moisture of surface peat and concentration of PM10 in the atmosphere in Palangka Raya during the dry season in 2002.

logger. Soil moisture from ground surface to 11 cm deep at the monitoring block and the soybean block were measured manually twice a day at 0900 LT and 1700 LT (Indonesia West Standard Time) by using a TDR sensor and logger (TRIME-3P).

Results

Air pollution and hydrological conditions of peatland

The seasonal changes of PM_{10} concentration and groundwater level in a forest are shown in Fig. 1. The PM_{10} concentration clearly increased during the dry season coinciding with lowering of groundwater level in the forest. Especially, the PM_{10} concentration increased to seriously hazardous levels for two months during the dry season in 2002. Groundwater level in the forest also dropped to 1 m below the ground surface. This means that the lowering of groundwaterlevel in peatland makes the surface peat layer dry and easy to ignite. The moisture of surface peat layer measured in the soybean field in Palangka Raya had clearly a relationship with the concentration of PM_{10} (Fig. 2). The PM_{10} concentration increased sharply with drying of the surface peat layer less than 40 vol %.

Model of peat moisture estimation

Water budget in different layers

The soil layer from surface to 100 cm in depth was divided into 20 layers of 5 cm thickness (Fig. 2). The upper surface of the first layer is ground surface with or without plants. Water budget through this surface are rain and evaporation. When the ground surface is covered by plants, transpiration from the first and second layers are added to the surface water budget. Soil water exceeded the field capacity in the first layer and flows out from the first layer and flows into the second layer. Capillary water flows into the first layer from the second layer with a water vapour deficit caused by evaporation and/or transpiration from the ground surface. Water budgets in the deeper layers than the third layer are in and out flows of gravity water and capillary water. Water budget by vapour is neglected in this model.

The water budget in the first layer in unit time is shown in the equation.

$$\Delta W_1 = P + E + T_1 + F_{o1} + C_{i1} \qquad \text{Eq. 1}$$

where, ΔW_1: the change of water in the layer and subscript means number of layer, P: Rain, E: evaporation from the ground surface, T_1: transpiration through plant, F_{o1}: flow out to lower layer by infiltration, C_{i1}: flow in from lower layer by capillary.

The evaporation E in Equation 4-1 is replaced with water flowing into the first layer by capillary C_{i1} from the second layer. The rain P is replaced with the water F_{o1} flowing out from the first layer. Transpiration T_2 becomes active when the second layer is unsaturated by water.

$$\Delta W_2 = F_{o1} + F_{o2} + C_{i1} + C_{i2} + T_2 \qquad \text{Eq. 2}$$

Water budgets in the layers deeper than the second layer are follows to next equation.

$$\Delta W_n = F_{on-1} + F_{on} + C_{in-1} + C_{in} \qquad \text{Eq. 3}$$

where the subscript n: number of layers changed from 3 to 20.

Soil structure of peat layers

The solid part of peat is composed of mineral, humus and plants undergoing decomposition. Contents of lignin and protein are very high in humus but plant decomposing in the ground contains a lot of cellulose and hemicellulose. Such organic materials in peat can contain water easily in the texture. According to Kamiya and Kawabata (2002), the surface peat at Kalampangan located about 20 km south-east from the study site had such physical properties as ignition loss of 96%, specific gravity of 1.46, water content of 391 gr%, degree of saturation of 61% and void ratio of 5-14, and dry density of 0.1-0.2. The void ratio was used in this study. Then solid space of 0.167 and the pore space of 0.833 were derived from the void ratio 5. Soil moisture was represented by volumetric percent of water in the layer.

Suction water by root and water flow by capillary

The root system of soybean penetrates to deeper soil layers with growing of plants and lowering of groundwater table.

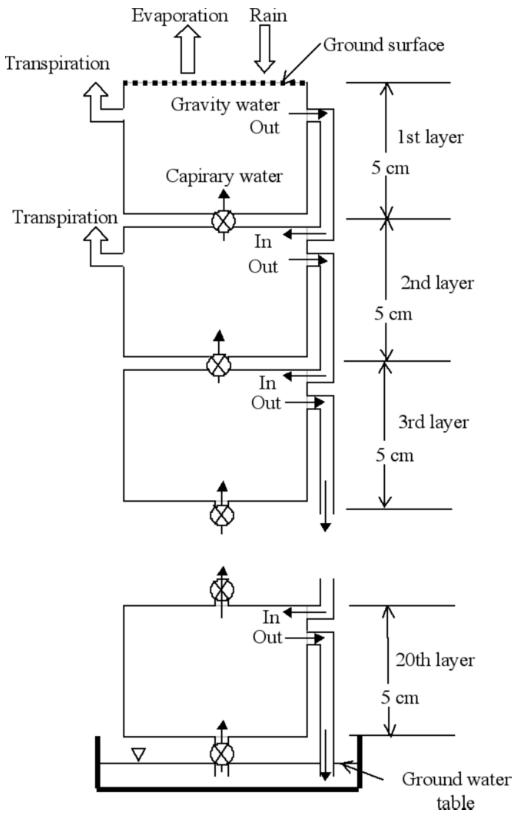

Figure 3. Bucket model for water budget in peat layers

In this model, it was supposed that the soybean block was covered by the soybean leaves. Then evapotranspiration was sheared by the transpiration from soybean, and most of the water budget from the ground flow through the roots of soybean. If the soil moisture in the first layer is lower than the field capacity of the soil, the suction by roots is controlled by the deficit of the soil moisture to the field capacity. The next empirical equation was used to control the suction of roots by water deficit in the soil layer.

$$U_r = E_t(1 - a(F_c - M_e)) \qquad \text{Eq. 4}$$

where U_r: suction flow through roots, a: empirical coefficient, 1.1 was used, F_c: field capacity of soil, 0.75 vol.% was used, M_e: moisture equivalent of soil, 0.45 vol.% was used in this study.

When the moisture of a soil layer is lower than the field capacity, the capillary water is sucked up from deeper soil layer. The strength of capillary water flow should be proposed with the moisture deficit between upper and lower soil layers. Then the empirical equation as shown in following was used in this study.

$$P_{cn} = b(M_n - M_{n+1}) \qquad \text{Eq. 5}$$

where P_{cn} : water flows into n soil layer from n+1 layer by capillary, b: empirical coefficient,
0.2 was used, M_n,M_{n+1}: Soil moisture vol.% at n and n+1 layers.

Field observations

Groundwaterlevel and surface soil moisture

The groundwater level fluctuated but kept high due to several heavy rainfalls until 26 June. After that the groundwater level dropped continuously till the end of August excepting two small rises with the small amount of rainfall on 22nd and 30th July. The specific productivity, which represented the response of groundwater level against the rain, was determined to be 3.0 mm mm^{-1} using the data of groundwater level and rain in June. The seepage rates in the site were obtained from the deviation of the groundwater level without rain events from 1900 LT to 0500 LT in the next morning (Fig. 4). The seepage rates in lower groundwater level than 15 cm in depth were small with 2-12 mm day^{-1}. On the other hand, those of higher groundwater level than 15 cm in depth increased sharply to around 110 mm day^{-1} at the ground surface level of groundwater. This relationship between the groundwater level and the infiltration rate was represented by the equation of the 5th degree with R^2=0.97. The surface soil moistures in the Soybean and the bare soil blocks fluctuated largely but kept in much more moist condition than 60 vol.% during June. The soil moisture in the soybean block were relatively higher than those in the bare soil block. But the surface soil moistures in the soybean block decreased more quickly than those in the bare soil block, then the surface moisture in the soybean block became drier than those in the bare soil block. This was caused by the larger evapotranspiration rate in the soybean block than the bare soil block. The decreasing processes of the surface soil moisture became gentle at around 40 vol % of moisture in both blocks. Following this result, the lower limit of the soil moisture in each layer was determined to be 45 vol %.

Evapotranspiration from the ground

Evaporation from the bare soil surface was estimated from the diurnal changes of groundwater level with the infiltration rate in the study site following the methods proposed and applied by Umeda and Inoue (1985) and Takahashi *et al.* (1998). The daily evaporation from the bare soil block is shown in Fig. 5.

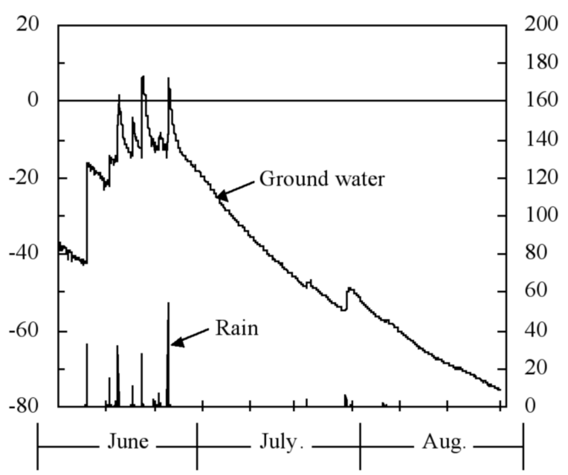

Figure 4. Change of ground water level and rainfall at the study site in Central Kalimantan during dry season in 2002.

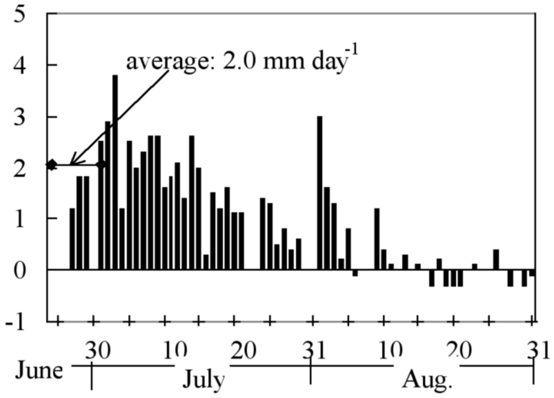

Figure 5. Evapotranspiration estimated from ground water level at the study site.

The daily evaporation rate at the beginning of the dry season in 2002, from 26th June to 1st August, was 2.0 mm day^{-1} on average. Evapotranspiration from the soybean block and the bare soil block were measured simultaneously by the chamber method (Sato, 2003). Unfortunately, the duration of measurements on the evaporation from the bare soil block were not same in both methods, the groundwater method and the chamber method. But the evaporation measured by the chamber method in the end of wet season, 10th –20th June, were from 1.2-2.1 mm day-1, which roughly coincided with the results obtained from the groundwater level analysis. Evapotranspiration from the soybean in the end of the wet season was around 2 mm day^{-1} and decreased gradually to around 1.7 mm day^{-1}. The evapotranspiration rates from the soybean block and the decreasing process were used in the estimation of the peat surface moisture.

Results from the simulation model

Drying process of the surface soil during dry season in 2002

The initial condition of groundwater was on the ground surface level in the model, which was equivalent to that in the field on 24th June. Soil moisture in the surface 11 cm layer was 83 vol.% in the model and decreased day by day with the transpiration through the soybean leaves (Fig. 6). The simulated surface moisture increased slightly with the rain of 3.4 mm day-1 on 21st July, and largely with the rain of 11.0 mm day-1 on 30th July. But such increases of the surface moisture in both days are not clear owing to luck of the field measurement. However, the simulated surface soil moistures reproduced well those in the field with the coefficient of determination R^2=0.9.

Moisture profile in the peat layers

The vertical profile of simulated moisture on 8th August is compared with the field data sampled at the fire event site in the secondary forest of Kalampangan on same day. The soil moistures from surface to 50 cm deep in Kalampangan were around a half of the simulated moisture for the study site. The large differences of the soil moisture in two sites were due to differences in the vegetation, the quality and structure of peat layers, and the hydrological system of two sites. Groundwater level in the study site was 58 cm deep on 8th August, which was corresponded to the depth of unsaturated layer of 60 cm in the simulated soil moisture profile (Fig. 7).

Conclusion

Air pollution caused by peat fire during the dry season is a very serious disaster in tropical peatlands. The seasonal change of the concentration PM_{10} in the city area of Palangka Raya clearly coincided with the groundwater level

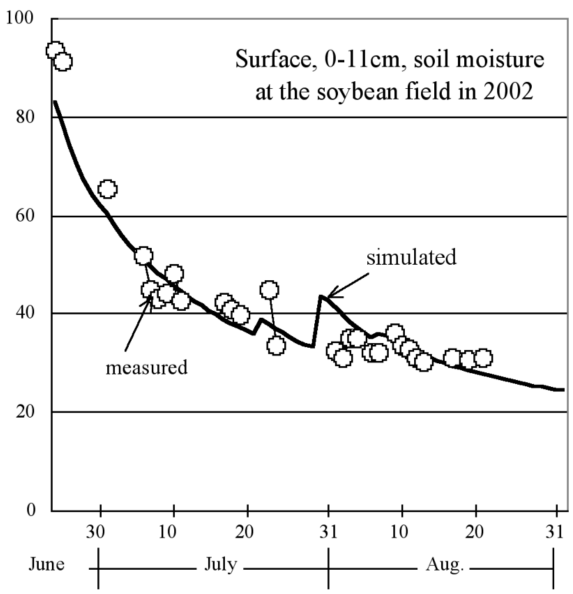

Figure 6. Observed and simulated soil moistures in the surface layer of the soybean block of study site during the dry season in 2002.

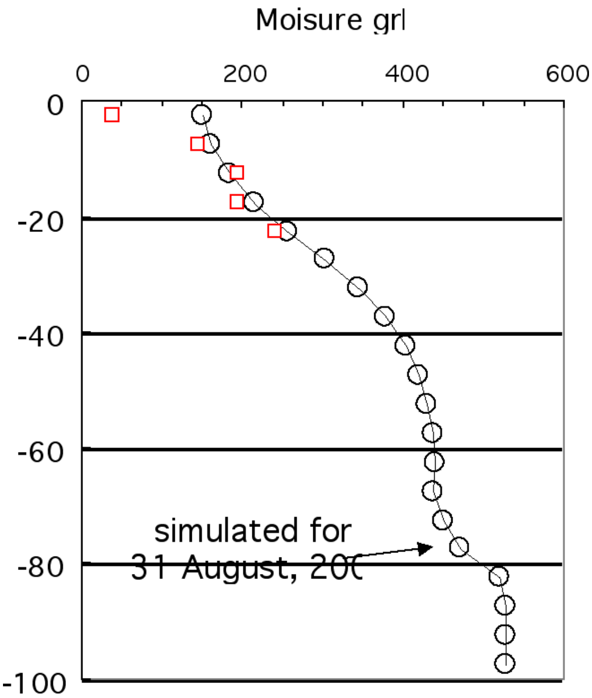

Figure 7. Simulated and measured soil moisture profiles in the peat layer on 30 August in 2002.

in the forest. The soil moisture of surface peat layer measured in farmland also had a clear relationship with the concentration of PM_{10}.

The moisture of the surface soil layer and groundwater level at farmland in tropical peatland was measured from the end of rainy season to the end of dry season. A bucket model was constructed to estimate the moisture of the surface soil layer. The drying process of the estimated by the model coincided with high similarity to the process observed in the field.

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