Impact of Climate Change on Hydrological Cycle in a Humid Tropical River Basin in Sumatra, Indonesia

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Abstract: In Sumatra in Indonesia, large-scale plantations of oil palm and acacia trees have caused 50 % reduction of natural forests in the 25 years between 1985 to 2009. Both climate and land cover changes may impact on regional water cycle, which potentially leads to increase the risk of flood and drought. Therefore, hydrologic process understandings and their representations by hydrological models are important steps for achieving adequate water resources and water-related disaster management. Among various hydrological processes, rainfall-runoff processes in humid tropics, which is typically characterized by flow in a deep soil layer, have been poorly understood. This study conducts field investigations and modeling to simulate rainfall-runoff and flood inundation processes at the river basin scale in the Batanghari River basin in Sumatra, Indonesia. By reflecting such conditions in the model, it conducts a long-term hydrologic simulation with climate change projected based on MRI-AGCM (20 km resolution) and its dynamically downscaling by MRI-NHRCM (5km resolution) to estimate the impact of climate change on hydrological cycle in this region.

Keywords: climate change, rainfall-runoff, floods, Sumatra, humid tropics

1. Introduction

In Sumatra in Indonesia, large-scale plantations of palm and acacia trees have caused 50 % reduction of natural forests in the 25 years between 1985 to 2009. Deforestation of natural forest might have changed water cycle in the area including runoff and evapotranspiration, which may lead to possible changes in flood and drought conditions. Downstream parts of the river basins in Sumatra spread wetlands with rich ecosystems, though such environment have degraded due to land cover changes over the last few decades to agricultural areas. Drying the wetlands by drainage for rice cropping and other agricultures caused various issues including peatland fire and haze in surrounding regions. In addition to the land cover change, climate change may give significant impact on the hydrologic cycle in this region. Climate change in humid tropical region in South East Asia has been difficult to be projected due to local atmospheric cycle. Furthermore, hydrologic process understandings and their representations by simulation models are the important scientific step toward adequate assessment of land cover and climate changes. Among various hydrologic processes, rainfall-runoff processes in tropical climate conditions characterized also by deep weathered soil layers have been poorly understood. Hence our objective of our study here is to conduct field investigation with respect to rainfall-runoff processes in the mountainous hillslope in Sumatra to understand the fundamental characteristics of rainfall-runoff in this region, and to represent the feature particularly with a thick soil layer, in our hydrologic model. After the calibration and validation of the model at the river basin scale in the Batanghari River basin, we assess the impact of the climate change by inputting the rainfall projected by the AGCM as well as its regional downscaled product by NHRCM, both of which are provided by Meteorological Research Institute (MRI) in Japan. Based on the long term simulation, this study assesses the impact of climate change on hydrological cycle in this area.

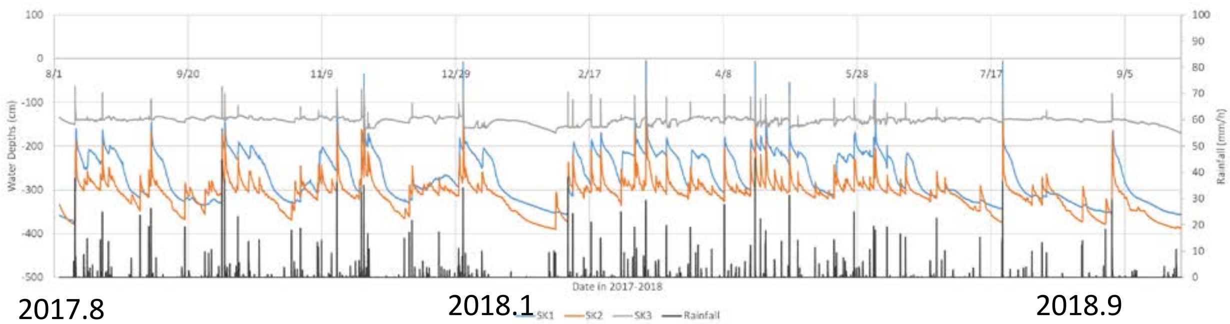

Figure 1. Observed ground water depths at a mountainous hillslope in the Batanghari River Basin
SK1: near stream (4.5 m), SK2: middle (2.3 m), SK3: near ridge (1.5 m) (soil depths)

2. Hillslope Monitoring in Sumatra

Our study site is the Batanghari River Basin, which drains for 42,960 km^2. The river basin is located in Jambi and part of West Sumatra Provinces in Sumatra Island. The rivers flow from western mountainous region to the eastern coast. In the downstream area of the basin, peat land area is spread with shallow water ponding throughout a year. Annual rainfall and temperature in the downstream part are 2,235 ± 381 mm and 26.7 ± 0.2 °C, respectively.

To understand the characteristics of rainfall-runoff from the mountainous hillslopes, we set our field monitoring site in the upstream of the basin. We installed some sensors to monitor rainfall, a creek water level, groundwater levels and soil moisture. We measured also basic soil characteristics and the soil depths. Here we mainly focus on the natural forest condition but we continue the monitoring in a palm oil plantation site to compare the two land cover conditions.

We summarize the main findings from the field monitoring. According to a simple cone penetration experiment, the soil depths in the hillslope were estimated to be about 1.5 ~ 4.5 meters. Furthermore, the soil sample experiment at surface, 30 cm and 60 cm depths showed that saturated hydraulic conductivities were as high as 7,200 mm/h while the volumetric water content maintain also high (0.45~0.50) with negative suction between 1~10 m. Such characteristics should be explained due to the aggregated soil in humid tropics. In our site, the foot of the slope (SK1) has thicker soil layer (4.5 m), while it is reduced to 1.5 m about 20 m upstream along the hillslope (SK3). Figure 1 shows the observation results of the groundwater monitoring. It shows that the groundwater table exists at the depths of about 3 ~ 4 m depth consistently at SK1 (bottom) and SK2 (middle) and the groundwater table responses rapidly (less than one hour) to rainfall. With the high saturated hydraulic conductivity and high infiltration rate, especially in the natural forest area, we conceptualize the rainfall-runoff in this region is dominated by fairly quick vertical infiltration into the thick soil layer and the recharge to the groundwater table.

3. Rainfall-Runoff-Inundation Modeling in the Batanghari River Basin

Based on the above process understandings, we apply the Rainfall-Runoff-Inundation (RRI) model (Sayama et al. 2012) to the entire Batanghari River basin. The model is a distributed hydrological model, which simulates for slope rainfall-runoff processes including vertical infiltration and lateral subsurface flows together with overland flow. Unlike the typical distributed rainfall-runoff models, which decides the flow directions according to the topography, the RRI Model simulates the lateral flow based on the diffusive wave approximation on the two dimensional basis. Together with the interaction between slope runoff and river routing, the model is also able to simulate both rainfall-runoff and flood inundation at the river basin scale.

To apply the RRI Model to the humid tropical river basin, we activate the groundwater module of the RRI model. The module of the RRI model was originally developed to simulate the bedrock groundwater in humid temperate river basins, but it could be applicable to the entire river basin in this humid tropical basin. The spatial resolution of the model was set as 30 arc-sec (about 900 m). The potential evapotranspiration was estimated by the Penman-Monteith equation with WFDEI climate dataset. This study used satellite rainfall data as the input of the model. After comparisons with ground gauged data, we decided to use GSMaP Reanalysis product for our simulation.

Figure 2 shows the simulation results at the downstream area of the basin. The model performance was evaluated by Nash Sutcliffe Efficiency (NSE) and shown in the figure. Although the model does not perform perfectly for the large river basin with limited information, we think it now can capture the general characteristics of the rainfall-runoff and also inundation processes for the entire river basin.

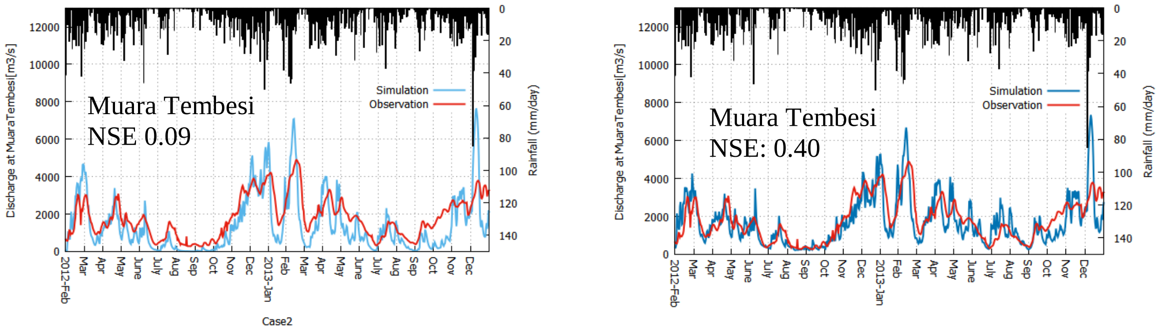

Figure 2. Simulated stream flow discharges at the downstream point (at Muara Tembesi). The left figure shows the result with the original RRI model and the right figure shows the one with updated with groundwater component.

4. Effects of Climate Change on Hydrologic Cycle

To project future climate conditions, this study used the outputs from AGCM and its dynamically downscaled product (NHRCM) by MRI. Figure 3 left panels show the change of annual rainfall between future and present climate conditions with two different SST increasing patterns. Generally, the precipitation over this region is projected to be increased (e.g. C1) but in case of C2 pattern, which has similar to El-Nino pattern, the regional rainfall over the basin is expected to be decreased. Figure 3 right panel shows the flow duration curves of stream flow discharges at the downstream based on observation, GSMaP input and NHRCM with and without bias correction. The continuous hydrologic simulation by NHRCM is currently undertaken and will be presented at the conference.

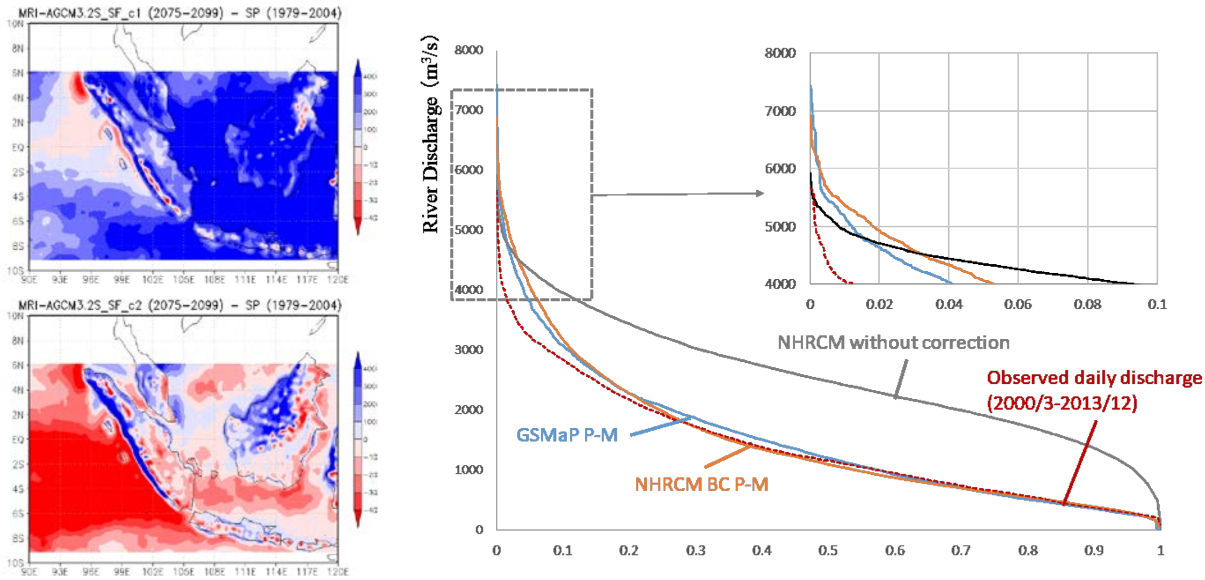

Figure 3. Projected changes of annual rainfall in the Sumatra Island by MRI-AGCM with two different SST scenarios (C1 and C2 under RCP8.5) (left). Simulated flow duration curves and their comparisons with the one based on observed daily discharge (right).

Acknowledgment

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