Water and Energy Budget in the Southern Mountainous Region of Eastern Siberia

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Abstract

To understand water and energy cycle in Siberia, an intensive field campaign was carried out at a small watershed on the watershed-divide of the Lena and Amur rivers. The amounts of precipitation, discharge, evapotranspiration and interception loss, in the warm period from April 19 to October 13, 2001 (178 days) were 434.5mm, 204.7mm, 127.5mm, and 55.2mm, respectively. The contribution of the evaporation from forest floor was significant, around 80% of the total. The Bowen ration after the snowmelt, in the middle of April, was around 2.0. Just after the opening leaves at the beginning of June, it decreased due to transpiration, and then began to increase at the end of August with falling leaves.

Keyword: Siberia, water and energy budget, seasonal change

1. Introduction

Siberia, which is located in the northern part of the Eurasia continent, has the widest permafrost area on earth. Discharges by big rivers in Siberia play an important role as fresh water supply to the Arctic Sea, affecting not only the hydrological and thermal conditions of the Arctic Sea, but also the polar region climate. At the same time, the southern mountainous region is important as the main source of the Lena River (Ma et. al., 2000). To understand water and energy cycle in Siberia, an intensive field campaign was carried out at a small watershed on the watershed-divide of the Lena and Amur rivers in the southern mountainous region. Both the catchment scale hydrological observation including time and spatial distribution of thawing depth and soil moisture and the observation of water and heat exchanges between land surface and atmosphere on several surface conditions within the watershed, including snow processes, were carried out from August 2000 to June 2002.

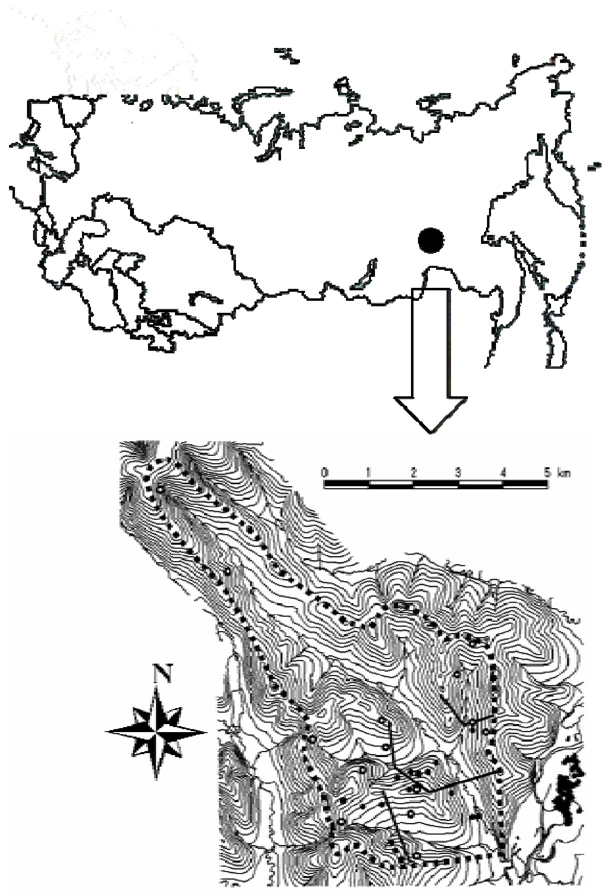

Fig. 1: Map of the study area

2. Methods

2.1 Site description

The Mogot experimental watershed (55°36’ and 124°53’) is located in the southern mountainous region in eastern Siberia (Figure 1). The watershed is a headwater of the Nelka River, which is a tributary of the Amur River. It belongs to discontinuous permafrost region. The basin area is 30.8 km^2. The elevation ranges from 550 m to 1130 m a.s.l. The average annual precipitation and discharge from 1976 to 1985 were 572 mm and 303 mm, respectively. The average annual air temperature was –7.7 °C from 1976 to 1985. It belongs to a continuous permafrost region with depth varying from 100 m to 250 m. Mountainous permafrost taiga podzolized soil formed with a podzol layer on the upper part of slopes. Turf taiga long-term permafrost loamy soils covered approximately 64% of the middle and lower slops. On slope sectors covered with thick moss, on plains and high flood plains there were wide spread peat bog permafrost taiga soils underlined with a close permafrost ground layer. There were intermontane depression soils of sub brown, alluvial laminated, weakly sod or sod-gley which met only in the lower part of the valley. Alluvial bog soils were spread in lowland swampy river and creek flood plains. Larch (*Larix gmelinii*) is dominant on the lower part of slopes and birch

(*Betula platyphylla*) and red pine (*Pinus sylvestris*) are dominant in other areas. Forest stand density and mean tree height at a main flux observation plot were 4128 trees/ha and 4.3 m, which trees were more than 5 cm in diameter at breast height, respectively The LAI was from 0.32 to 0.36 and Plant Area Index (PAI) was 0.45.

2.2 The measurements

We carried out an intensive observation in the Mogot experimental watershed from mid-August 2000 to the end of May 2002. Observation included both meteorological and hydrological elements.

An 18m-high observation tower was installed. An ultrasonic anemometer (KAIJO, DA-600) and a water vapour analyser with clothed path (Li-COR, LI-6262) were operated with a sampling rate of 10Hz at 18.6 m. The outputs of these instruments were recorded by a personal computer directly. Latent and sensible heat flux were calculated every 30 minites.

Downward and upward long-wave radiation above the canopy was measured using radiometers (Eiko, MS-201F) at 16.8 m. Also, Downward and upward short-wave radiation was measured using radiometers (Kipp and Zonen, CF-&F) at 16.8 m. The net all-wave radiation above the canopy was calculated as the sum of these four components. When these data were lacking, we used data obtained by a net radiometer (REBS, Q7) at 16.8 m. Surface temperature of the canopy was measured by infrared thermometer (Everette, 4000). Air temperature and humidity were measured using humicap sensors (VAISALA, HMP-35D and 45D) at 18.0 m and 13.8 m. Wind speed was measured with three-cup anemometers (Makino, AC-750) at 18.0 and 13.8 m). Wind direction was measured (Makino, WS-104) at 18.6 m. Ground temperature was measured with Pt sensors at six depths (0.05, 0.15, 0.25, 0.35, 0.45, 0.55 m). Soil moisture was monitored by TDR sensors at three depths (0.1, 0.3, 0.5 m). Most of these variables were recorded by data loggers every 10 minutes (Hakusan, Datamark 3300).

In order to consider the effect of plant phenology, sap flow velocity and growth rate of tree trunks were measured every 30 minutes in warm season. The understory evapotransipiration was estimated by weighing lysimeters with 0.2 m in diameter and 0.05 deep, containing undisturbed soil samples.

Precipitation was measured using a tipping bucket rain gauge with 0.5-mm resolution and storage type rain gauge twice a day. Throughfall was measured using 4 plastic gutters with 2 m long and 0.2 m wide, and stem flow was measured with six trees. River discharge was observed at the mouth of the Nelka River, by a floating water level gage. Discharge was calculated by the stage discharge curve obtained by current observations using both automatic water level and direct flow measurement

3. Results and discussion

3.1 Seasonal variation in the energy balance

Figure 2 shows the seasonal changes in the daily energy balance components. The data for rainy days were excluded. As it has been reported that the sum of turbulent fluxes was underestimated compared with available energy flux in many cases (e.g. Kelliher et. al., 1997, Ohata et. al., 2001), turbulent fluxes accounted only 60% of the available energy flux. Figure 3 shows the seasonal change of the Bowen ratio. Compared with the result of the larch forest at the central plain taiga forest in Eastern Siberia, the latent heat flux from the end of April to the middle of May before opening leaves was rather large. After opening leaves, the Bowen ratio decreased due to transpiration of larch. From the end of August, the Bowen ratio began to increase because of falling leaves.

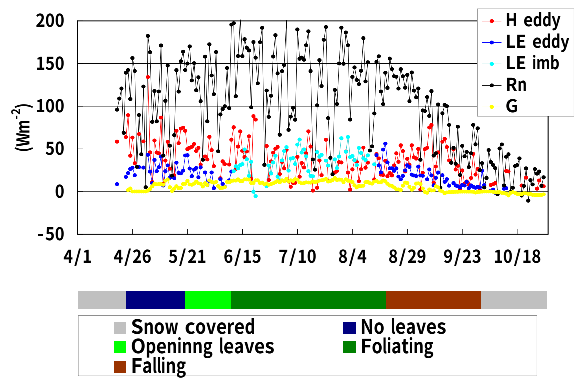

Fig. 2: Seasonal changes in the daily energy components

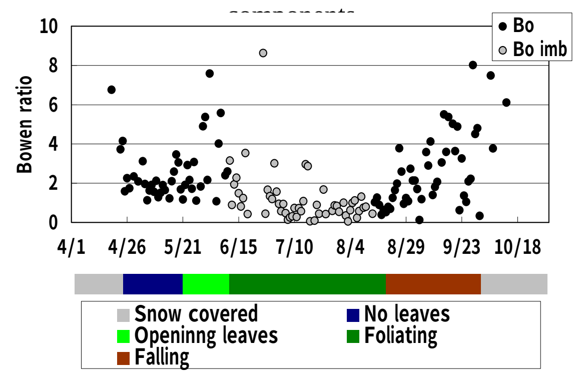

Fig. 3: Seasonal Changes in the Bowen ratio

3.2 Short-time water-budget method (SWB)

we used the short time-period water-budget method proposed by Suzuki (1985). According to this method, the evapotranspiration is defined as the difference between rainfall and discharge in a certain period, assuming that the change in water storage is nearly zero when values of discharge at the beginning and the end of analysis periods are equivalent. The amount of evapotranspiration E (mm) during the analysis period is described with the amount of precipitation P (mm) and discharge Q (mm) via equations (3), (4) and (5), assuming watershed storage is constant during the period (t_2-t_1)

$$P = \int_{t_1}^{t_2} p(t)dt \qquad (3)$$

$$Q = \int_{t_1}^{t_2} q(t)dt \qquad (4)$$

$$E = P - Q \qquad (5)$$

where p (t) (mm day^{-1}) is precipitation, q (t) (mm day^{-1}) is discharge, and t (day) is time.

The three following criteria were applied to choose a set for the beginning and the end of the analysis period. These criteria were determined by trial and error to formulate a sample.

1) There was no antecedent precipitation on a corresponding day and the 2 days before the beginning (t_1) and the end (t_2) of the analysis periods as to prevent water storage from including direct runoff.

2) Differences in discharge between the beginning, q (t_1) and the end, q (t_2) of the analysis period should be within 2%.

3) Periods within 8 days and over 60 days are omitted to prevent fluctuations when periods are too short or too long to see seasonal changes.

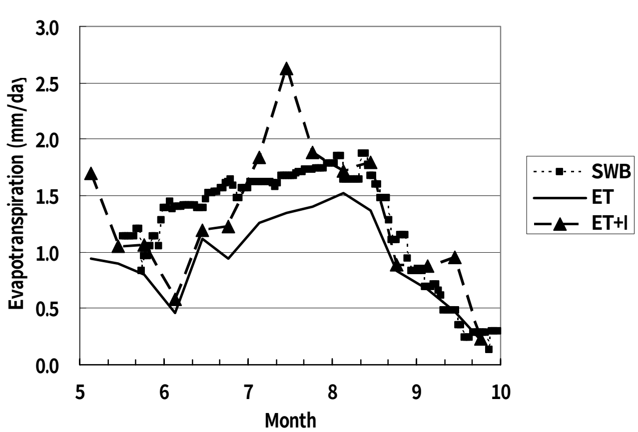

Fig. 4: Comparison of seasonal change in evapotranspiration

Figure 4 shows the comparison of estimated evapotranspirations. SWB indicates the seasonal change in evapotranspiration by the short-time water-budget method, using daily precipitation and discharge from 1975 to 1984. ET and ET+I mean 10-days moving average of latent heat flux at the tower site, and interception loss. Seasonal trends of evapotranspiration by flux measurement and SWB are similar. Total amounts of these two methods are also similar.

3.3 The role of understory evapotranspiration

In order to clarify the role of understory evapotranspiration to the whole fluxes above the canopy, we measured understory evapo-transpiration by lysimeters, and estimated transpiration by larch trees. Figure 5 shows the comparison among understory evapotranspiration measured by lysimeters, transpiration of larch trees estimated by sap flow velocity and latent heat flux by eddy correlation technique above the canopy. Figure 5 indicates that the sum of understory evapotranspiration and transpiration was almost same as total latent heat flux. Also, understory evapotranspiration accounted for about 80% of total fluxes.

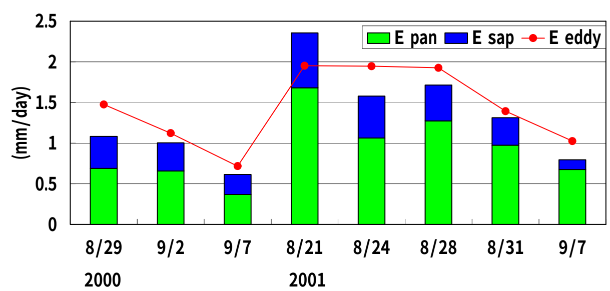

Fig. 5: Comparison among understory evapo-transpiration measured by lysimeters, transpiration of larch trees estimated by sap flow velocity and latent heat flux by eddy correlation technique above the canopy

3.4 Water budget

Table 1 shows the water budget of the Mogot experimental plot during the warm seasons. Evapotranspiration was estimated as the sum of latent heat flux by eddy correlation technique above the canopy and the interception loss estimated by the measurement of throughfall and stemflow. Interception loss accounted for 12.7% of the total of precipitation. As to the water budget during winter period, we have not finished analysis at the moment.

4. Summary

Water and energy budget of an small water shed in the mountainous region of eastern Siberia was investigated. The summary of the obtained result of this study were as follows;

The amounts of precipitation, discharge, evapo-transpiration by flux measurement and interception loss, in the warm period from April 19 to October 13, 2001 (178 days) were 434.5mm, 204.7mm, 127.5mm, and 55.2mm, respectively. According to measurements of transpiration by the sap flow method and the evaporation from forest floor by the pan method, the contribution of the evaporation from forest floor was significant, around 80% of the total. The Bowen ration after the snowmelt, in the middle of April, was around 2.0. Just after the opening leaves at the beginning of June, it decreased due to transpiration, then began to increase at the end of August with falling leaves.

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Table 1 Water budget of the Mogot experimental plot from April 19 to October 13, 2001

Year	2000	ratio	2001	ratio
Period	8/22-10/25		4/19-10/23	
Number of days	65		178	
Precipitation(mm)	81.00		434.50	
Discharge(mm)	60.94	75.2%	204.70	47.1%
Evapotranspiration(mm)	18.69	23.1%	127.54	29.4%
Interception loss(mm)	12.64	15.6%	55.18	12.7%
		113.9%		89.2%
dS(mm)	-11.27		47.08	