Characteristics of spring runoff in the Mogot experimental watershed, in the southern mountainous taiga of eastern Siberia

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Abstract: During the spring thaw in eastern Siberia, melt water sometimes causes avalanches and spring floods in mountain taiga permafrost regions. Thus, it is important to understand the spring runoff generation in the region. We analyzed data for the Mogot experimental watershed, which is located in this region and was the site of intensive observations by the State Hydrological Institute for 10 years from 1976 to 1985. The spring runoff ratio was smaller than the annual ratio, and the variation in the spring runoff ratio was larger than that in the annual ratio. This demonstrated that spring runoff is generated by a different mechanism. The variation in the spring runoff ratio depended on the maximum snow water equivalent and fall soil moisture. Furthermore, the effective parameters determining infiltration into frozen soil were soil temperature and the duration of the thaw. To evaluate snow ablation, sublimation is also important. The estimated sublimation from snowcover was significant and amounted to nearly 11.6 mm/month in April.

Keywords: Eastern Siberia, permafrost, sublimation, runoff ratio, soil moisture, snowmelt

1. Introduction

Avalanches and floods sometimes occur when warm air causes sudden snowmelt in spring. For example, in May 2001 there was a large avalanche and flood in a mountainous region of southern Siberia, near Krasnoyarsk. Therefore, it is necessary to determine how snowmelt runoff is generated, especially in permafrost regions. Woo and Winter (1993) showed that permafrost and seasonal permafrost are important for hydrological processes. However, knowledge of the effect of permafrost on snowmelt discharge is limited. The State Hydrological Institute carried out long-term observations of the water and energy balances in the Mogot experimental watershed, in the southern mountains of eastern Siberia, Russia, for 10 years from 1976 to 1985 (Sokolov and Vuglinsky, 1997).

In this study, our objectives were (1) to examine the inter-annual variation in runoff generation during and after the snowmelt period in Siberian mountainous taiga and (2) to evaluate the winter energy and water balances.

2. Methodology

2.1 Site description

The Mogot experimental watershed is located in the southern mountains of eastern Siberia (55.5°N, 124.7°E) approximately 60 km north of Tynda, in the Amur region of Russia. The site is the catchment of the Nelka River. The basin is 12 km long and 2.5 km wide, with a total area of approximately 30.8 km²; the slopes are exposed to the northeast and southwest. In this basin, altitudes range from 580 to 1130 m. Hydrometeorological observations were carried out in this region from 1976 to 1985 and from 2000 to 2002. The observations from 1976 to 1985 were made by the State Hydrological Institute (SHI) and those from 2000 to 2002 were made by the Frontier Observational Research System for Global Change and SHI.

Figure 1 shows the location of the study site. The dominant land cover is larch forest (Larix gmelinii), although ridges are partially covered by birch and pine forests. Forest covers nearly 90% of the watershed, and the remaining area is covered by grassland. Table 1 shows the properties of soils in the Mogot experimental watershed. The soils contain permafrost and are covered by a 10- to 15-cm-thick...
The soil porosity exceeds 85% in most of the watershed.

2.2 Data

We used daily data for hydrometeorological elements (air temperature, relative humidity, wind speed, cloud amount, surface temperature, air pressure, river discharge, soil moisture, thaw depth within the soil, and snow water equivalent) from 1978 to 1983. In this watershed, the annual maximum air temperature exceeded 30 °C, the annual minimum air temperature was below -45 °C, and the mean annual air temperature was about -7.7 °C. Maximum runoff occurred from July to September. The annual precipitation was approximately 580 mm and the winter precipitation was about 100 mm.

Yang and Ohata (2001) considered wind loss of winter precipitation important. Therefore, we adopted the bias-correction method for the Trecyakov precipitation gauge described by Yang and Ohata (2001) as:

\[ CR(\text{snow}) = 103.10 - 8.67 \cdot W_s + 0.30 \cdot T_{\text{max}} , \]
\[ CR(\text{mixed}) = 96.99 - 4.46 \cdot W_s + 0.88 \cdot T_{\text{max}} + 0.22T_{\text{min}} , \]
\[ CR(\text{rain}) = 100.00 - 4.77 \cdot W_s^{0.56} , \]

Where, CR is the catchment ratio of a Trecyakov precipitation gauge (%) for each type of precipitation. Here, we assumed that the boundary air temperature between snow and rain was 1.5 °C.

2.3 Estimation of snowmelt in the watershed

To evaluate the energy balance for snow-covered frozen ground, we used SNTHERM (Jordan, 1991) and the simple snowmelt model of Suzuki and Ohta (2002). The values estimated using this model were verified using the observed snow water equivalent, surface temperature, and thaw depth, and estimates agreed with the observed values.

Table 1. The properties of soil in the Mogot experimental watershed.

<table>
<thead>
<tr>
<th>Soil characteristics</th>
<th>Watershed divides and nearby areas</th>
<th>Shaded slopes</th>
<th>Exposed slopes</th>
<th>Deluvium solifluction gentle slopes</th>
<th>Valley bottoms</th>
<th>Steep slopes (pad)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil type: mountain, cryo-taiga, podzolized</td>
<td>Soil type: mountain, sod-taiga, long freezing, subbroun earth</td>
<td>Soil type: mountain, sod-taiga, long freezing, subbroun earth</td>
<td>Soil type: mountain, sod-taiga, long freezing, pit earth</td>
<td>Soil type: alluvial, with bedded structure, long freezing, alluvial, slightly sod, alluvial bog, pit bog</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (γ) g/cm³</td>
<td>0.32-0.36</td>
<td>0.17-0.18</td>
<td>0.22-0.30</td>
<td>0.28-0.56</td>
<td>0.42</td>
<td>0.16</td>
<td>0-20 cm layer</td>
</tr>
<tr>
<td>Porosity %</td>
<td>86</td>
<td>88</td>
<td>85</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Filtration coefficient cm/sec</td>
<td>0.04</td>
<td>2</td>
<td>0.01-0.04</td>
<td>0.01-0.003</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>% from basin area</td>
<td>15.1</td>
<td>30.1</td>
<td>32.3</td>
<td>16.2</td>
<td>5.1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Therefore, we believe that the model can estimate the winter energy and water balance above the snow and soil surface.

3. Results and Discussion

First, we discuss the spring runoff characteristics in the Mogot experimental watershed. Figure 2 shows the mean seasonal variation in discharge and precipitation for the watershed from 1979 to 1983. Here, we consider a water year to run from 1 October the previous year to 30 September in the current year. From November to April, the river was completely frozen. Runoff began in May and the maximum discharge occurred from July to September.

Figure 3 shows the inter-annual runoff ratio for an entire year to the thaw period (April to May) for 1979 to 1983. The runoff ratio is the ratio of discharge from the catchment to the water input into the ground in the watershed. The annual runoff ratio was around 0.6, while the spring runoff ratio was smaller and ranged from 0.2 to 0.5. In spring, most of the ground is covered by frozen permafrost, which begins to melt in early May. It is difficult to understand why the spring runoff ratio was so small compared to the annual runoff ratio, because we believe that infiltration into frozen ground is more difficult than infiltration into a thawed soil layer.

Figure 4 shows the relationship between the spring runoff ratio, and the maximum snow water equivalent and fall soil moisture. We used the data for the end of August or early September for the fall soil moisture. The spring runoff ratio increased with the maximum snow water equivalent and fall soil moisture. The large inter-annual variation in the spring runoff depended on the fall soil moisture and maximum snow water equivalent.

Next, we discuss the relationship between winter precipitation and snowmelt runoff. Figure 5a shows the temporal variation in snowmelt, soil moisture within 0 to 20 cm, discharge, and thaw depth when the winter precipitation and spring runoff ratio was greatest over a 5-year period. The peak of snowmelt agreed well with the peak of discharge, and soil moisture increased with the duration of snowmelt. The increase in soil moisture was about 23 mm during the snowmelt period and was equivalent to 26.6% of the melt water. Figure 5b shows the temporal variations in the same parameters when the winter precipitation and spring runoff ratio were lowest over the 5 years. There was a lag between the peaks of snowmelt and discharge, and the peak discharge was less than 1 mm d⁻¹. Nearly 47.8% of the melt water infiltrated into the frozen ground, and the soil moisture increased by about 31 mm during the thaw. We believe that this difference in the ability of melt water to recharge permafrost causes the difference in the spring runoff ratio.

One possible explanation is that if the soil
temperature is lower, then melt water entering frozen soil refreezes within the frozen soil and is caught within the permafrost. The estimated initial soil surface temperature just before the thaw was -4.6 °C in 1983 and -6.3 °C in 1981. The ability of water to infiltrate frozen ground depends on soil temperature. Furthermore, the duration of the thaw also affects the infiltration; the thaw lasted 22 days in 1981 and 15 days in 1983.

Using our model, we evaluated the energy and water balances in the snowpack in the catchment. The amount of evaporation from the snowpack was significant during the snowmelt and pre-snow accumulation periods. The mean sublimation in April was 11.7 mm and the total sublimation during the winter (October to April) was 25.7 mm; about 26% of the winter precipitation was lost to sublimation. The contribution of energy to sublimation differed during the snowmelt and pre-snow accumulation periods. During the thaw, net radiation contributed the most energy to sublimation, while during the early snow accumulation period ground heat flux contributed the most.

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References