The influences of climate on runoff: a case study of four catchments in Western Siberia

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Abstract. Currently, dynamic processes, affecting runoff in catchments, are poorly understood. Among all the elements of water balance calculations, the streamflow is the most accurately measured and largely reflects the current moisture content of the active layer. Devices for automatic measurement of water level and temperature of soil, water and air were installed in four small catchments with different climatic conditions. The studied catchments are located in a zone of oligotrophic swamps of the southern taiga, a zone of hilly swamps of the forest-tundra, a foothill zone of the southern taiga, and a mountain-glacial basin. Runoff in the mountain-glacier basin is determined using an acoustic level meter of the water flow. As a result: Site 1) We have revealed a change in the water-physical properties of the active layer in the marshy catchment, which resulted from the 2012 drought; Site 2) We have shown the linkages of the moisture content of the soil above the water table with extreme water discharge in active watersheds; Site 3) The increase in autumn runoff is due to thawing of seasonal permafrost and snow-melt in the tundra; Site 4) In the mountain-glacier basin, our studies are at an initial stage.

1. Introduction
Climate change can have significant impacts on hydrological processes, which are typically manifested in changes in the structure of the water balance and its annual distribution [1]. Regional responses to future environmental change may be equally individualistic [2]. However, actual observational data of streamflow for such statements are commonly lacking. Therefore, there is a need for empirical data to assess streamflow in catchments. Regionalization is a commonly used method for runoff predictions [3], in which model parameters calibrated from gauged catchments are transferred to ungauged catchments using various approaches.

The study addresses the poor understanding of how dynamic processes in landscapes affect the flow of streams in small catchments [4]. The conditions for the initiation of runoff are not only very diverse but also closely interconnected; therefore, they should be considered using integral parameters. The most common indicator of landscape changes is the change in the moisture content of the active layer of landscapes in periglacial environments due to the influence of natural factors at the regional and global level.

Among all the elements of water balance calculations, surface channel runoff of water is most accurately measured, reflecting the current moisture content of the active layer in the catchment. Soil moisture of the active layer, in addition to climatic factors, integrally considers the influence of vegetation and soil cover as well as the drainage conditions of the catchment area (relief). Previously,
it was assumed that observations at small representative catchments would lead to the emergence of new hydrological knowledge [5]. Unfortunately, this did not happen due to the lack of a guiding theory in organizing such observations [6]. Therefore, the ultimate goal of our work is to link landscape changes with runoff from representative catchments using the genetic method of runoff formation [7].

2. Objects, data and methods
Four representative catchments with different climatic conditions were identified in periglacial environments from the Altai Mountains to the forest-tundra in Siberia, Russia. Environmental (soil, air and water temperature) and runoff monitoring were conducted using automatic monitoring devices. Devices are designed and manufactured at IMCES SB RAS [8].

Environmental and runoff monitoring was initiated in 2011 in the oligotrophic swamps of the Korovinsky stream on the western slope of the Bakcharsky swamp adjacent to a culvert under the P-399 highway (site 1). The catchment is 22 km², with 70% of the surface area covered with bogs. The runoff calculation was carried out according to the scheme of a non-flooded spillway with a circular cross section with a wide threshold [9].

In the southern taiga piedmont zone, environmental and runoff monitoring was conducted on a stream with a catchment area of 1.99 km² in the well-drained Tom-Yai interfluve, 30 km east of Tomsk in the Kyrgyz River basin [10] (site 2). Runoff monitoring was carried out using a triangular spillway (weir) with a flooded lower pool [9].

In the forest-tundra zone of the Yamal-Nenets Autonomous District on the upper left tributary of the Sedeyakha River, observations have been conducted since August 2014 (Site 3). The catchment has an area of 19 km² and is a section of forest-tundra with a predominance of tuberous bogs on sandy soils and a great number of lakes. Within the riverine area, the most drained territory comprises an oppressed larch forest. Runoff was calculated using hydraulic formulas for uniform movement in natural channels with a roughness coefficient derived from instrumental measurements of water flow. The slope of the water surface was recorded using readings from two water level sensors [9].

In the Aktru glacier basin (the Altai Mountains) (Site 4), runoff has been recorded since May 2019 and is ongoing using an experimental acoustic flow meter (made at IMCES SB RAS).

3. Results and discussion
At Site 1 (in the zone of oligotrophic bogs), we organized timely observations were organized, which made enabled to obtain a runoff hydrograph for 2012 (from July / 2011 to May 2014). In Western Siberia, 2012 marked as an extremely dry year. The drought of 2012 (due to the snowy winter of 2011-12) led to drainage of the active layer of wetlands. This observation is significant since dry peat loses its water, holding capacity and water throughput, and the wetland (peat) then ceases to fulfill its water-regulating function. This scenario can form the prerequisites for the occurrences of mass movement processes manifested as landslides. This led to the cessation of monitoring on the culvert under the highway in May 2014.

The correlation between the measured and modeled runoff shows a positive trend in 2011 and 2012 but a negative trend in 2013 (figure 1). Hydrological-climatic modeling revealed that the most significant positive correlation ($R^2=0.96$) between the measured and calculated runoff occurred in 2011, with a weaker positive correlation ($R^2=0.74$) observed in 2012. This weakening of the correlation can be explained by the beginning of a change in water-physical properties of the peat deposit due to drying in this period. In 2013, the correlation of the measured and modeled runoff was negative ($R^2=0.70$).

In Western Siberia, in the winter of 2011-12, there was very little snow. In June 2012, the maximum evaporation rate for the observation period was 204 mm. This was due to high air temperatures and low rainfall of 12 mm at the Bakchar weather station. The active layer dried up to 0.46 (in the fractions of the smallest moisture capacity). Draining the active layer beyond the plasticity threshold led to a significant change in the water-physical properties of the active layer. For dry peat,
the smallest moisture capacity is 1.5-2.3 times less than in the wet state, which is how the mechanism maintains soil moisture and preserves mire ecosystems during the dry periods.

Figure 1. Dependences of measured and calculated runoff (mm / month) on the Korovinsky stream for 2011, 2012 and 2013 (oligotrophic bog zone).

The automatic monitoring data of water flow on the Korovinsky stream show a very low snow flood in 2012 compared to the autumn floods of 2011 and 2013. The nature of the runoff during the dry periods of 2011 and 2012 is similar. At the same time, in 2013, runoff from studied catchment was more intense, which indirectly indicates a change in the water holding capacity of the active layer. This is also observed by the autumn floods of 2013.

According to the results of model parameters optimization, the smallest moisture capacity 1.5 times decreased, and the parameter of water-physical properties increased from 1.7 to 2.5. If the plasticity limit soil was not violated and the parameters did not change, evaporation in 2013 would be 10 mm more (399 mm), and the runoff – 33 mm less (101 mm). In 2014, evaporation would be 26 mm more, and runoff – 6 mm less.

In the southern taiga piedmont zone (site 2), observations for 2015 indicate that the maximum rainfall intensity is 20 mm / 15 minutes. After a long dry period, this caused only a slight increase in the flow of water into the stream. At the same time, floods are possible in water-saturated soils even after the low intensity of rainfall since almost all precipitation goes to runoff formation.

In the forest-tundra (Site 3), the studied catchment shows significant intraday fluctuations in meteorological elements, which lead to significant intraday variations in the flow of water. Unfortunately, observations of meteorological parameters were interrupted in the spring of 2015 due to water entering the environmental monitoring datalogger. The total duration of the flood peak is less than a month, after which floods are possible due to rainfall superimposed on the base flow, consisting of lake-accumulative water and water from moisture-rich frozen soils (figure 2).

A comparison of the measured runoff with modeled runoff, based on data from the Nadym and Tarko-Sale weather stations for 2015-16, provides a good correlation (R² = 0.95). The largest differences between the measured and model runoff occur in May and September. In May, the difference in measured and modeled runoff may be due to incorrect operation of the water level sensor at negative water temperatures (degrees Celsius) as well as ice phenomena since freezing will alter the area of the channel living section. Therefore, such data are excluded, as their use would require special field observations to introduce correction factors into the calculation.

In the forest-tundra zone, we recorded no ice phenomena in September 2015. Therefore, the increased measured runoff in September, compared to the calculated runoff, can be due to the depletion of water reserves from lakes and the active layer. At depth, the active layer continues to thaw.
until the end of September. This is confirmed by the presence, in autumn, of a significant negative correlation ($R^2 = 0.64$) between the water flow and the temperature of the active soil layer.

In the Aktru (Site 4) mountain-glacier basin (the Altai Mountains), runoff has been recorded since May 2019 using an experimental acoustic flow meter. To construct curves of the dependence of the flow rate on the water level and the noise of the water flow during student practice, we performed runoff measurements by the hydrometric method. Experimental tests in July 2018 showed that the correlation coefficient of noise and water levels was 0.75. The values of the correlation coefficient between the water level and the measured discharges were higher and equal to 0.89.

![Figure 2. Flow hydrograph (m$^3$/s) of the Sedeyakha River (forest-tundra).](image)

4. Conclusion
Conclusions of our study are as follows:

- On the marshy watershed, we have revealed the change in water-physical properties of the water table as a result of the 2012 drought;
- For the piedmont catchment, we have shown the crucial role of the moisture content in the water table for the occurrence of extreme water discharge;
- In the forest-tundra zone, the increase in streamflow was due to the melting of the seasonal permafrost;
- In the glacier basin, our studies are at an initial stage. The first interesting results have already been obtained for presentation in a separate work.

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