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Temperature conditions of snow mass and snow melting features in urban environments

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Temperature conditions of snow mass and snow melting features in urban environments

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Abstract. The paper presents the features of the snowmelt dynamics of snow mass in the urbanized area in different altitudinal zones, with different regimes of anthropogenic load. The temperature distribution in the snow layer data analysis is carried out. The capabilities of snow mass monitoring system analysis according to the periods of active water loss prediction is carried out.

1. Introduction

Temperature distribution in the snow layer and the speed of its melting issue is one of the most urgent problems of modern snow management. The temperature in snow layer is unevenly distributed. People distribute zones of temperature leaps confined to the boundaries of layers with different densities and zones with relatively stable temperature regime. These conditions lead to some difficulties with predicting the beginning of water loss period.

Mass water loss periods prediction allows to plan and carry out activities during the flood period in the most effective way. It's essential that the intensity of snowmelt in areas with varying degrees and type of anthropogenic load significantly differs from melting intensity of the unstrained snow cover.

The aim of the paper is to identify snow melting dynamics in urban areas for territories with varying degrees of anthropogenic load, as well as development of a mass water loss of snow layer periods prediction method, based on the interpretation of data from the system of constant monitoring of the snow mass temperature.

The characteristics of snow in an urbanized area and outside it significantly differ from each other. For example, the albedo of urban snow cover is lower than outside the city, it ranges from 0.8 for fresh dry snow to 0.4 for sleet; in central parts of cities albedo drops to 0.2 [1].

In addition, utilities, buildings and transport have a significant impact on the energy balance of urban snow cover. Anthropogenic snow settlement within the city line slows down the process of snowmelt.

The paper analyzes the dynamics of snow melting at different altitudes of the city, in areas with natural and disturbed snow cover, as well as the dynamics of snow melting process at snow landfills. The process of snow melting is explored on the case of the city of Yuzhno-Sakhalinsk (Sakhalin Region, Russia) and its environs.

2. Problem review

There are a lot of studies on the snowmelt modeling, however, almost all of them do not take into account snowmelt conditions in cities and on snow landfills. The main approaches used to model snowmelt are energy balance models (ESCIMO; SnowMelt-R) [2,3] and empirical models (SRM, MIKE SHE) [4,5] in which air temperature is used to notate the flow of energy.

Empirical models are commonly used to simulate snow cover in open and forest areas in snowmelt calculations.

On one hand empirical methods require less input data. However, snow melting rate for inhomogeneous urban area cannot be adequately determined via empirical techniques, since this type of model suggests homogeneous snow mass. There is regular redistribution of snow cover due to anthropogenic factors in urban areas.

On the other hand energy balance models require a lot of input data to describe the physical processes of each component of energy balance, but they are considered to be more accurate than empirical models [3]. However, differential of incoming energy flow varies greatly and depends on built-up level of the territory, proximity of heating mains and highways in urban areas.

Regular field observations of snow mass state in different parts of the city are necessary to calibrate any of the models.

3. Methodology

All the analyzed methods for snowmelt rate estimating do not take into account peculiarities of urban environment or require a large amount of initial data. Due to the fact it is necessary to identify the distinctive conditions of snowmelt within urban territories and beyond them. Authors of the paper set up monitoring sites in the city of Yuzhno-Sakhalinsk in two high-altitude zones of 20 and 100 m to do this. The snow landfill where snow from the territory of the city is stored was also under observation.

In the study of snowmelt rate, special attention is paid to its thermo-physical properties. However, compilation of temperature data package during field work is still a difficult task.

During the study authors used and analyzed various ways of obtaining correct value of snow mass temperature.

1) Mercury thermometers have high accuracy, but it takes people long to work with them, the result should be read instantly, as the results begin to change roughly when changing environment. In addition, these thermometers are very fragile, which must be taken into consideration when they are placed in packed snow or between snow crusts of different genesis.

2) Electronic thermometers break down quickly and after the season of active field work begin to give discrepancies at sub-zero temperatures, uptake of corrections does not change the situation, because, the degree of distortion varies depending from air temperature.

3) Pyrometers and thermal observation devices take readings from the wall of the dug hole, but after opening hole wall quickly melts and the actual data varies from readings taken from exposed surface.

Authors used a thermistor chain to observe snow layer temperature. The thermistor chain was installed on one of the observed sites (Site A). Temperature sensors on the thermistor chain are located every 2 cm from the surface of the soil.

Site A is located on the territory of the Sakhalin Botanical Garden (eastern border of the city, datum level of 65 m), site observations have been carried out since 2002. The thermistor chain was used in winter seasons of 2017–18 and 2018–19.

After installing and turning on the thermistor chains the continuous recording of readings from sensors to the electronic media was made. Observation was held from the second decade of December to the third decade of April. Inaccuracy of temperature measurement sensors is not more than $\pm\,0.1\,°\,C$. This system made it possible to determine the proceeding time of active snow melting and the layers of active water loss accurately.

Standard observations of snow mass characteristics in the dug hole were made on site A. The structure of observations includes determination of snow-cover height from snow surveys data,

permanent snow stake, description of snow section stratification, temperature measurement at the boundaries of snow layers, layer-by-layer density measurement, structure and texture determination [6].

Site B is located in the central part of the city (datum level 20 m), in the area of the hydrometeorological station (HMS) "Yuzhno-Sakhalinsk". The data from HMS "Yuzhno-Sakhalinsk" open access sources (https://rp5.ru/) was also used in the paper.

Sites A and B are located in the upper and lower altitude zones of the city of Yuzhno-Sakhalinsk. Elevation changes within urban areas leads to uneven precipitation and affects their redistribution.

Site C is located on the "Severny" snow landfill in the northern part of Yuzhno-Sakhalinsk (datum level 45 m), in the area of Central Heating and Power Plant. The landfill covers an area of 3.8 hectares. The morphometric characteristics of the snow landfill were determined via aerial photography; the surface temperature of the snow landfill was determined with a thermal observation device Testo 871.

4. Results and their analysis.

Analysis of perennial observations of snow-cover height at sites A and B for the period of maximum snow cover showed that annually the height of snow at site A is average 15% higher than at site B (Figure 1.).
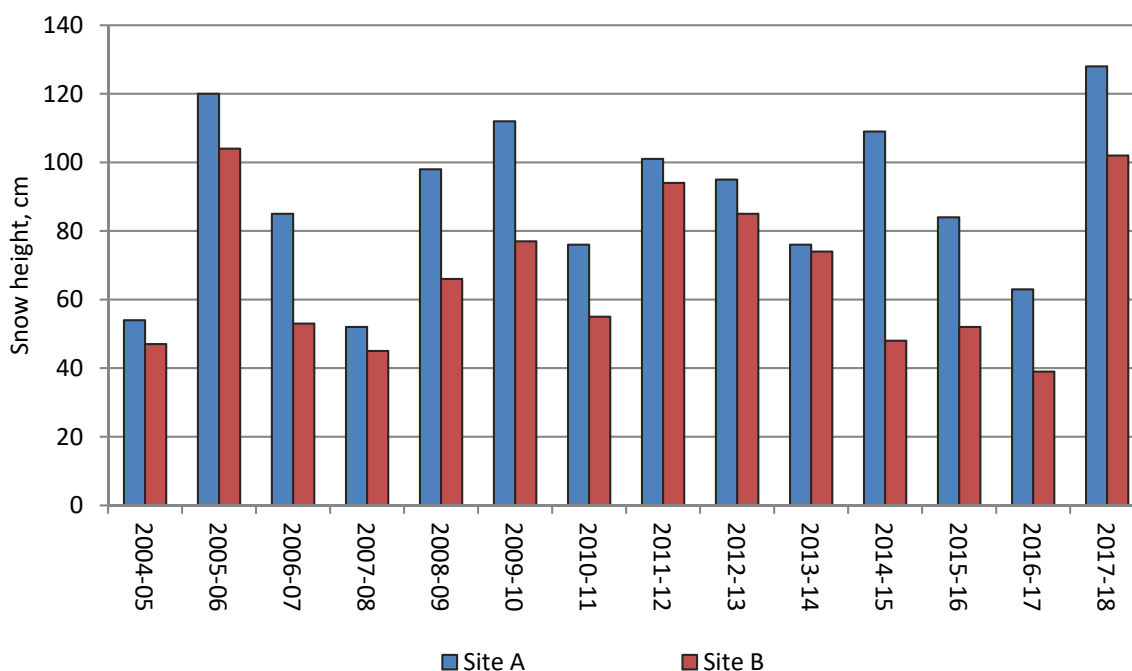

Figure 1. The dynamics of changes in snow-cover height at sites A and B in different altitudinal zones of the city.

The most intensively snowmelt took place on the site with undisturbed snow cover within the urbanized area (Site B). At the site located outside the built-up area (Site A), snowmelt intensity was lower. Duration of complete snow cover occurrence was, on average, 15 days longer there. The lower intensity of snowmelt is due to a smaller albedo, large amount of snow cover and smaller arrival of short-wave radiation reflected from urban areas.

The process of snow melting at the snow landfill (Site C) begins in April, work on redistribution and compaction of snow mass is completed at the site at the same period. However, in early May, the intensity of snow melting at the landfill slows down [7], despite the increase in average daily air temperature (Figure 2). This phenomenon is explained by the formation of a sand and soil layer on the surface of the landfill which appears from the snow during the first period. Then this layer acts as a thermal insulator and retains the ice core of the landfill, while increasing its depth. The temperature

sensor installed in the body of the snow landfill at a depth of 0.5 m showed stable temperature, during the entire measurement period.
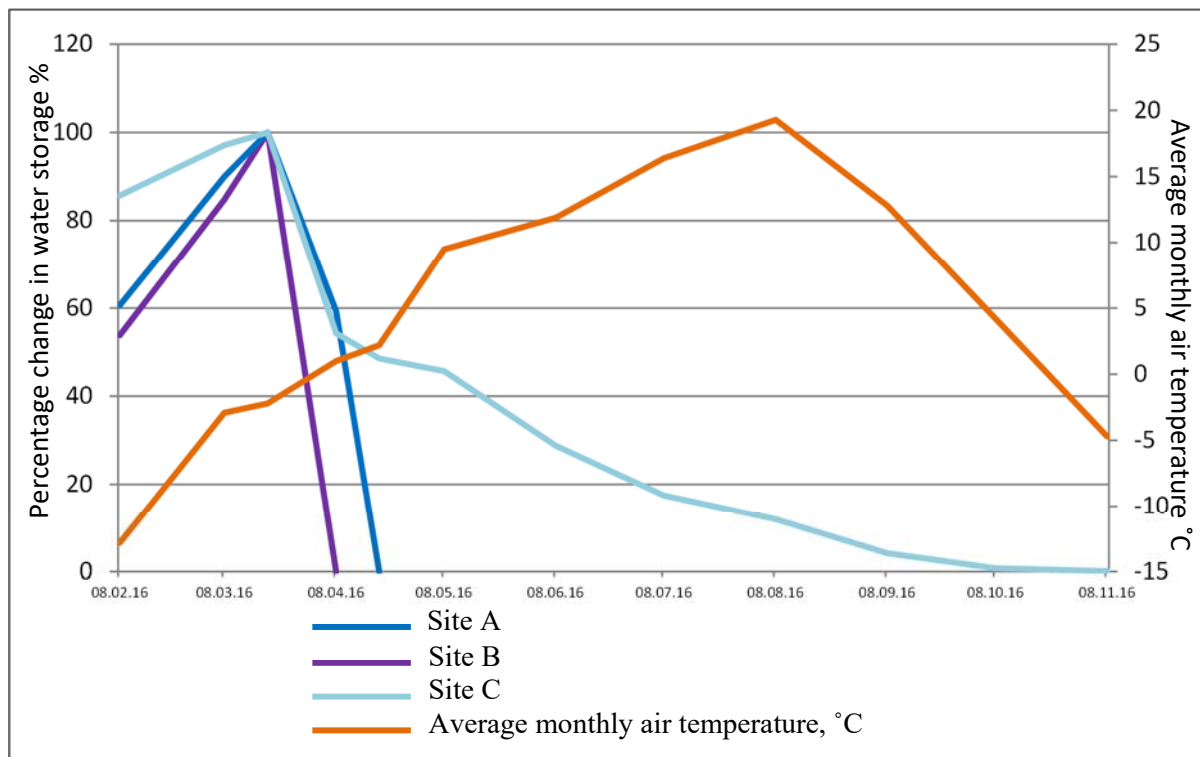
Figure 2. Dynamics of changes in the amount of water in the observation sites A, B, C in comparison with the average daily air temperature.

Intensive snowmelt at the landfill (Site C) continued until it lost 55% of its mass (late May-June), and then slowed down again. During the warm period of the year, the snow landfill does not melt every year. For example, in seasons of 2010-11, 2011-12, 2012-13, 2014-2015, 2015-16, 2017-18 snow landfill did not melt completely.

Snow landfills formed with snow taken out of streets during winter period preserve water supply in themselves. These events lead to increasing snowmelt period and smoothing of the spring flood peak. The rest of snow is conserved around the ice core of the landfill (Figure 3), which contributes to the cooling of the surrounding landscape and undersoil.
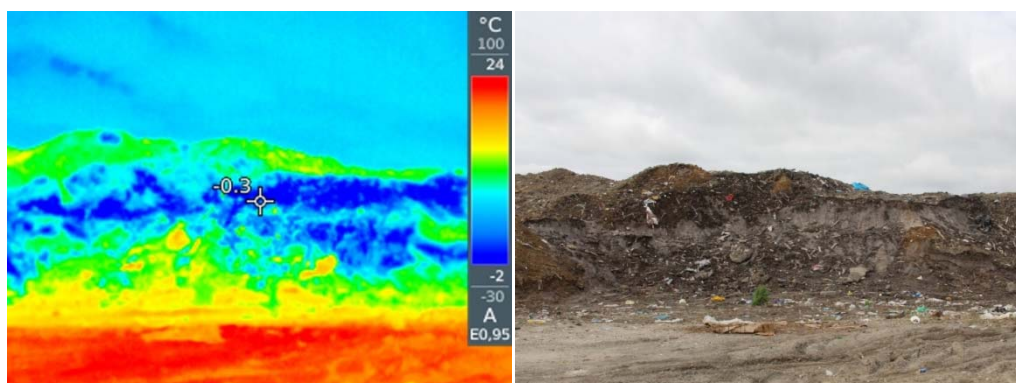
Figure 3. Site C Heat shot, 07.06.19.

Analysis of the data read from the thermistor chain (Site A) allows us to set the period of active snowmelt onset by sharp temperature fluctuations in the snow layer. Authors of the paper think that these shifts are explained by infiltration and subsequent freezing of melt water in the snow (Figure 4). This infiltration is significant for the period of maximum water loss of snow cover. Then the graph shows daily air temperature fluctuations throughout the snow layer, which indicates the destruction of snow cover. These shifts were observed in both winter seasons in which the thermistor chain was used.

This method can be used to predict the onset of water loss periods and inform interested ventures.
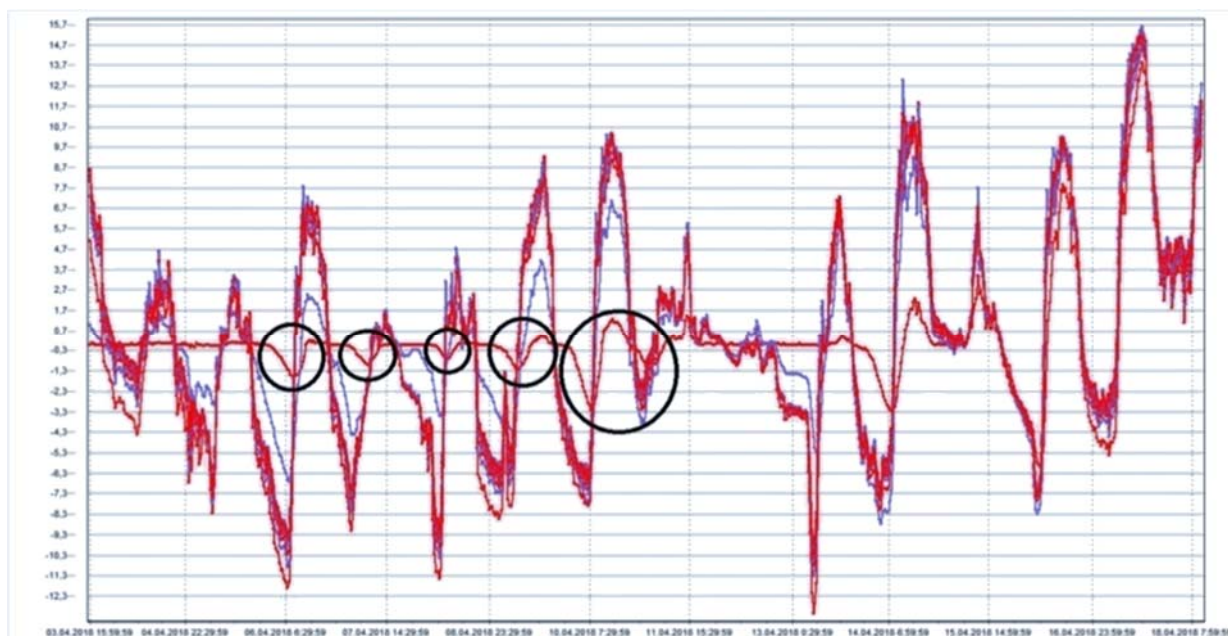
Figure 4. Temperature change inside the snow mass. Selected areas of the graph show the snow melting process onset.

5. Conclusions.

Use of thermistor chain as an element of snow mass temperature monitoring system allows determining time and intensity of snow melting, as well as active layers of water loss.

More intense snowmelt takes place in the high-altitude zone of Yuzhno-Sakhalinsk (up to 20 m). This regularity is associated with higher albedo, and more intensive surrounding built-up environment contributing to an increasing proportion of the reflected long-wave radiation arrival, as well as lower snow depth.

The sharp snowmelt speed decrease at snow landfill (Site B) is associated with the compaction of snow stored there with special transport and pouring sand to increase its bearing capacity. After thawing out litter accumulated on the landfill body created additional thermal resistance preventing snow from melting and led to ice core storing.

A differential approach for areas of strained and unstrained occurrence is recommended for current prediction and creation of snowmelt intensity operational maps. Use of snow mass temperature monitoring systems (thermistor chain) will allow real-time monitoring of active water loss areas.

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