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Meteorological and climatic conditions of dynamics of the Anmangynda icing size

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Abstract The Anmangynda icing is located in the central part of the Magadan region, in the headwaters of the Kolyma River. The maximum length of the icing reaches 7 km, its average thickness is about 2 m and the maximum thickness reaches 8 m. Observations of the icing regime were organized in 1962, and continued with short interruptions until 1992. A well-expressed statistically significant trend has been found in long-term dynamics of the maximum size of the icing. It has been shown that the maximum annual volume of the icing decreased by half during the 30-year period as a result of changes of climatic characteristics.

Key words icing; northeastern Russia; climate change

INTRODUCTION

Icings are characteristic hydrological features of the rivers of the continental part of northeastern Russia. Icings are the massifs of ice formed by freezing of ground, surface and atmospheric water on the surface of the ground or ice. Icings, created as a result of freezing of ground and river waters, are the most hydrologically important. The results of the numerous research which has been carried out in different regions demonstrate the intensive degradation of long-term ice (mountain glaciers, polar ice sheets, etc.) due to global warming. Concerning water objects such as icings, this conclusion is complicated because observations are occasional. An exception is Anmangynda icing where measurements in the period of its maximum development were carried out practically without interruption over 30 years.

In the territory of Russia icings annually accumulate about 94 km^3 of river and groundwaters (Alekseev, 1974). The hydrological role of icings is that they re-distribute surface and ground flows within a year, reducing their contribution during winter and, otherwise, increasing it during summer (seasonal regulation by icing). In the territory of the northeastern part of Russia, groundwater icings contribute up to 15% to the annual river runoff. In river basins with a large number of icing massifs, this contribution reaches 30–40% (Sokolov, 1986).

During the warm season of the year, the hydrological role of icings formed by groundwaters is most noticeable in spring when river networks collect the main part of melt water. According to Sokolov (1980), the part of icing component in spring flood runoff of rivers with a large number of icings reaches 20–30%. The effect of groundwater icings is not so noticeable in the summer/autumn period because of high river runoff and relatively small discharge of the icing flow. In most cases icings contribute about 5–15% of water inflow into rivers during the summer/autumn period, but for some rivers this contribution reaches 20–35% (Sokolov, 1980).

The objective of the study was experimental investigation and generalization of the special hydrometeorological observation data to find the governing factors of icing formation for the purpose of icing forecast under climate change.

DATA

The Anmangynda icing is located in the central part of the Magadan region, in headwaters of the Kolyma River, within the basin of the Anmangynda River. The length of the icing at its maximum extension reaches 7 km. The average thickness is about 2 m and the maximum thickness reaches 8 m. The climate is continental. Mean annual air temperature is –11°C, annual precipitation is about 300 mm. The average temperature of the coldest month (January) is –36°C, the minimum falls to –60°C. The severe climate results in extensive prevalence of permafrost of thickness from 150 to 200 m under the bottoms of valleys, to 500–600 m under mountains (Kalabin, 1960).

Data of the evaporation from soil, evaporation from snow and water surface, dynamics of melting of an active soil layer, heat balance and gradient observations, different special and experimental studies were collected on Kolyma Water Balance Station (KWBS), which is situated near Anmangynda River basin (see Fig. 1). The necessity of using KWBS data arose due to the absence of a gauging station (with comprehensive data of hydrometeorological observation) in the immediate region of Anmangynda icing.

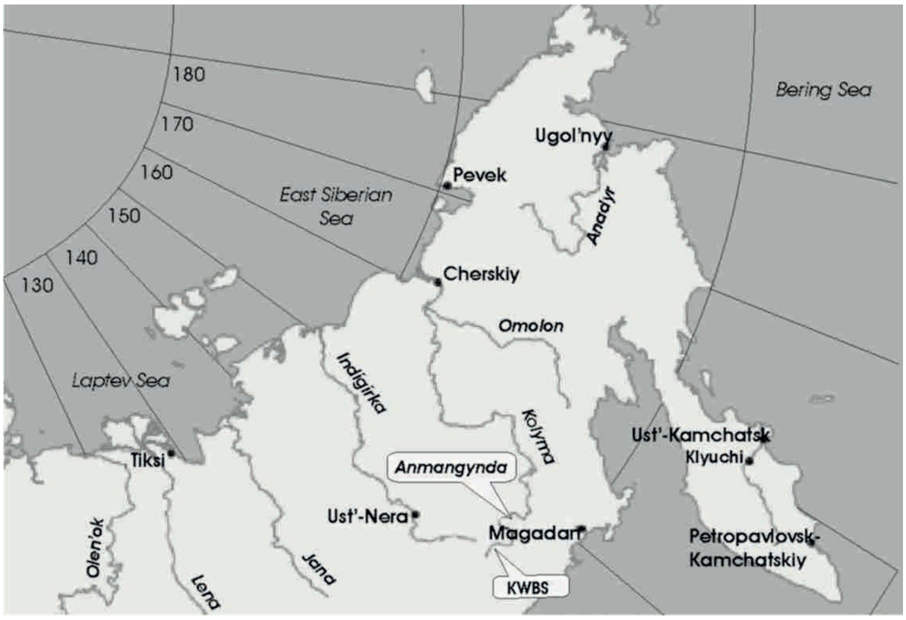

Fig. 1 Location of the Anmangynda River basin.

ANMANGYNDA ICING: GENESIS AND HYDROLOGICAL REGIME

Observations of the icing regime were organized in 1962. A special hydrographic department, which existed until 1977, was created for this purpose. Further observations proceeded with short interruptions until 1992, measuring only the volume of the icing in the period of its maximum extension. The programme of works also included hydrological observations (the water discharge and icing size) in the cross-section of the Anmangynda River (159 km) located 500 m lower from the icing glade, and the closing water-collecting area of 376 km^2. Measurements there were carried out from 1962 to 1987.

The formation of groundwater icing needs a source of water and special conditions when groundwater rises up to the surface and freezes in rather thin layers. Anmangynda icing is created by the blowout of alluvial waters at the upper bound of the icing where a sharp reduction of the slope and valley expansion occurs. Alluvial waters flow out in the form of non-freezing sources, with discharge constantly decreasing to spring (Lebedev, 1969). Alimentation of these sources is provided by gravitational unloading of taliks located above permafrost under the beds of the Anmangynda River and the Sloptsevoi Stream. The catchment's surface upstream of the sources is completely composed by stone talus. Light larch forest is only located in a narrow strip along the main riverbed. The width of the valley does not exceed 400–500 m. In the summer, groundwaters discharge into the main riverbed as sub-aquatic, and occur above the shore line only during the late autumn period, after steady transition of average daily air temperature to negative values.

According to Bukayev (1966) and Lebedev (1969, 1980), the discharge of sources is reduced from 1.2 m^3/s in October when surface flow completely ceases, and the flow is provided only by unloading of the river and above permafrost taliks, to 0.2–0.3 m^3/s by the end of winter. Blowout of water masses on the surface occurs in the form of two flows above the merge of the main riverbed and Sloptsevoi Stream, which at a distance of 200–300 m break up to the separate streamlets, which are often flowing in the alluvial layer. This part of the river does not freeze during the whole winter, and in the period of hard frosts, clouds of water vapour over it are visible from a distance of several kilometres.

The surface of the icing bed represents the tussock land with well expressed hilly microrelief, overgrown with low shrubs of an osier-bed, cowberry and blueberries. During the prewinter period, the main flow is divided within the icing glade into the separate streamlets running in depressions between tussocks. They are often covered by turf.

When negative air temperatures set in the first, preliminary phase of icing formation occurs. This period is characterized by the maximal discharge of sources. Thus water passes across the icing field en route, bank-freezing and freezing-over on some parts of the river are noted. This phase finishes when the temperature falls down to –15 to –20°C, when at some parts channels become entirely frozen, and water starts spreading over the glade width, filling micro depressions and directly creating the icing body. During this period both an increase of icing body and water transit downstream occurs.

The icing glade during the winter period accumulates an amount of water in solid form, corresponding to the difference of total flow of sources and runoff fixed at the hydrometric cross-section Anmangynda – 159 km, i.e. runoff which left the limits of the icing field. Termination of flow in the lower cross-section means that all input from sources is used for formation of the icing body. Because the greatest discharges of sources occur in the prewinter period, it is possible to assume that fluctuations of meteorological factors have an essential impact on the intensity of increase of the icing volume. The stronger the cooling of the icing glade in autumn and in the early winter, the more intensive will be the ice increase, and less water will leave the limits of the icing.

To investigate the dynamics of growth and destruction of the icing, its glade was divided into 34 cross-sections with 200 m distance between them. Each cross-section was equipped with graduated landmarks through every 100 m. Zero point of landmark corresponded to the Earth surface at this point. Mapping of the icing and measurements of ice thickness of were made on 10th, 20th and last day of the month.

RESULTS

Influence of pre-winter hydrometeorological conditions on the extension of the Anmangynda icing

Hydrogeological research conducted at the Kolyma Water Balance Station showed that in the case of seasonal freezing of alluvial deposits, lowering of groundwater level occurs prior to freezing (Ogaryov, 1975). This fact, along with a smooth character of unloading of sources during the winter period, mean that winter temperature regimes can have an essential impact on the topography of icing surface, development of specific cryogenic processes – formation and rupture of hillocks, of soil heaving and hydro laccoliths, pouring out of water on the ice surface, ice cracks, etc. but not on the size of the icing body. Here the determining factor is water discharge.

As noted above, hydrometeorological factors of the pre-winter period have a great impact on the extension of icing. Snow cover has the most essential impact. Snow cover is accepted as a factor of thermal control of the icing glade. Thin snow layer promotes intensive cooling caused by a sharp increase of albedo of the surface of icing glade. In contrast, high snow cover is a good heat insulator, which slows down cooling of soils and their freezing. The influence of snow cover on the temperature regime of active soil layer is studied in this paper using observational data obtained at the Kolyma Water Balance Station. Figure 2 presents the course of hydrometeorological elements in the autumn/winter periods of 1972 (a) and 1973 (b).

The dynamics of average daily temperature of the soil surface were rather similar in these years: there was decrease of temperature from –10°C at the end of October to –40°C at the end of the year. But the regime of snow accumulation had important differences. In 1972 permanent snow cover started to form only in the second 10 days of October, and by the end of the year its thickness reached 30 cm. Soil temperature at the depth of 0.2 m gradually decreased during this period from –0.1°C to –15.2°C, and at 1.2 m depth was close to zero until the first 10 days of November, and by the end of the year fell to –5.0°C.

Conditions of snow accumulation in autumn/winter period of 1973 significantly differed from those described above. In the first 10 days of October, snow cover reached 30 cm, and by the end

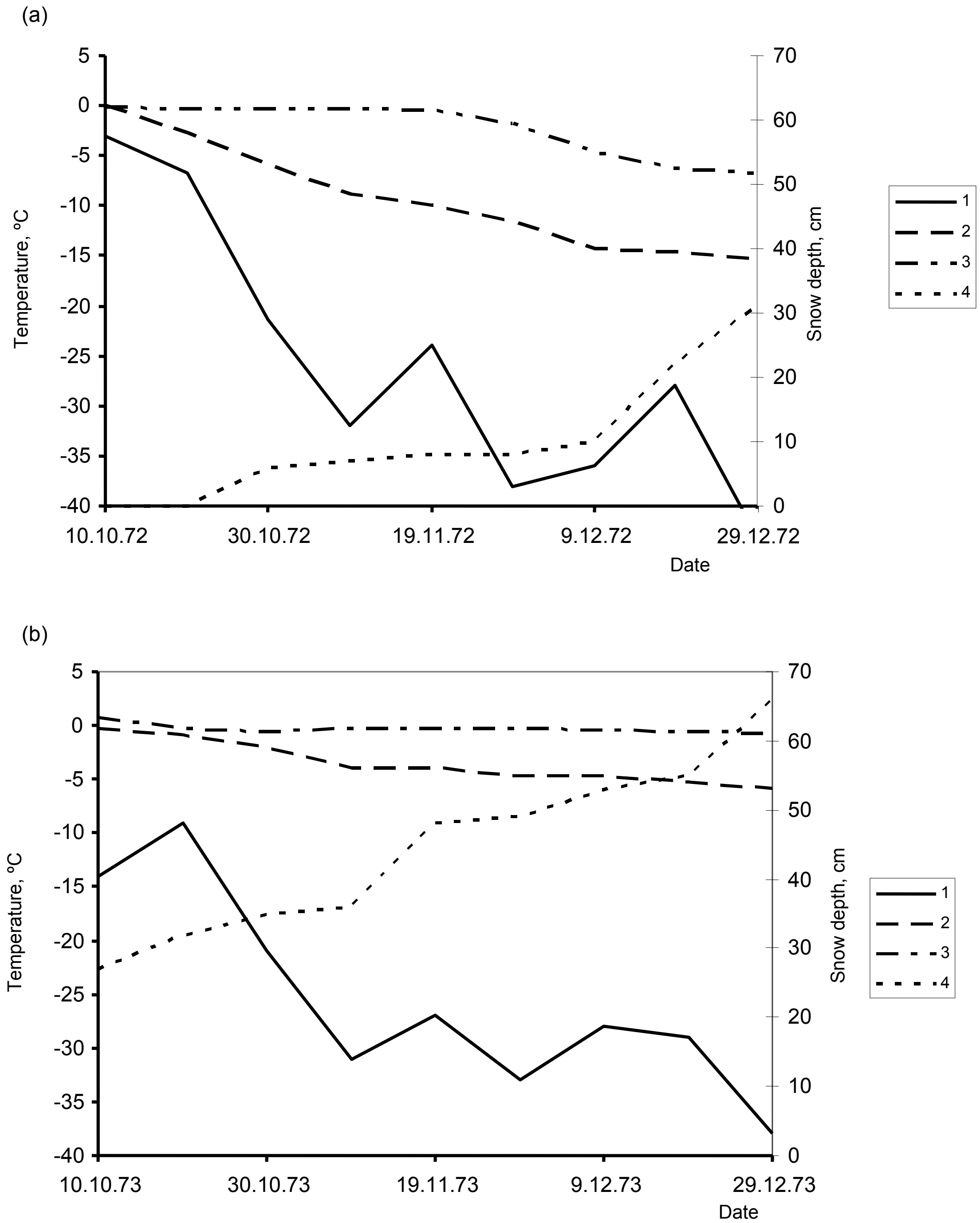

Fig. 2 Temperature of the soil surface (1), soil temperatures at depths 0.2 m (2) and 1.2 m (3), and snow depth (4) at the Kolyma Water Balance Station in 1972 and 1973.

of the year increased to 70 cm. At the same time soil temperature at 0.2 m depth decreased from –0.10°C to –5.0°C, and at the depth of 1.2 m was close to 0°C during the entire period.

Thus, it is possible to expect that in the autumn/winter of 1973–1974 transit of water from sources out of limits of the icing glade will occur more intensively than in 1972. Figure 3 presents hydrographs of runoff in the autumn/winter period of Anmangynda River. It can be seen from Fig. 3 that runoff volume in 1973 (4.15×10^6 m^3) exceeds that of 1972 (0.80×10^6 m^3), as well as duration of runoff is 30 days more in 1973. The volume of icing body during the period of its maximum extension in spring of 1973 reached 9.4×10^6 m^3, and in 1974 it was close to the smallest one for the period of observations ($5.54 \times 10^6 m^3$). The difference in volume of icing is 3.86×10^6 m^3, in other words this difference is close to the difference of runoff volumes (3.35×10^6 m^3) transited through the icing glade.

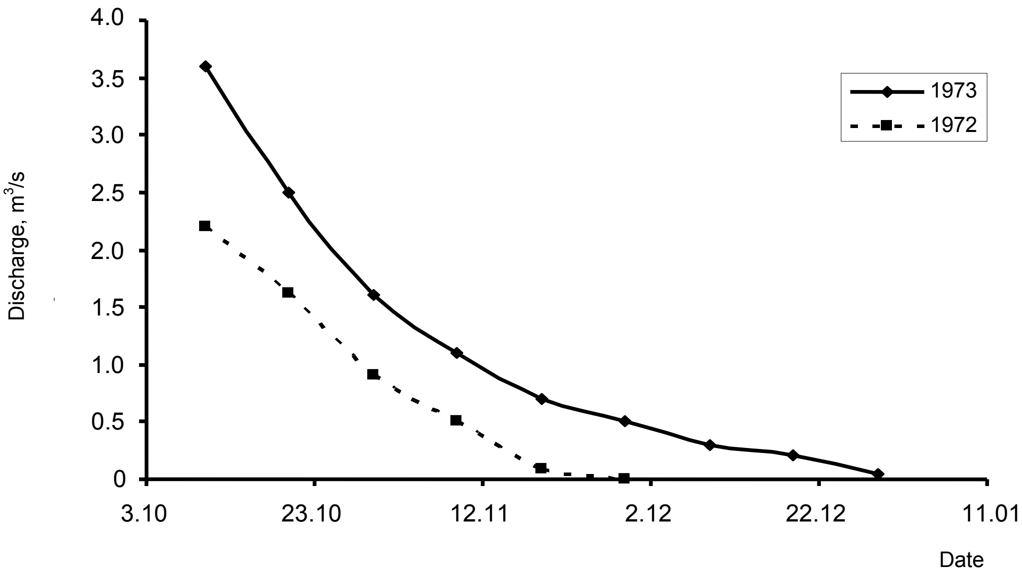

Fig. 3 Runoff of Anmangynda River in autumn/winter period.

If the snow cover is higher, then most of the river runoff will discharge from the icing field at the initial stage of icing formation, and the volume of icing during the period of its maximum development will be less. In fact, there is a steady negative correlation dependence between total precipitation for October and November of the previous year and maximum volume of icing (see Fig. 4).

The performed analysis confirms that long-term variability of the icing volume depends substantially on the meteorological conditions in autumn of the previous year.

Long-term changes of the icing volume

Long-term changes of the maximum annual icing volume is characterized by a well-expressed negative trend (see Fig. 5). The greatest volume of icing body 11.68×10^6 m^3 was reached in 1967, the smallest volume was 5.33×10^6 m^3 in 1974 and 1992. We made an attempt to explain this trend by changes in climate factors. An analysis of long-term changes of annual precipitation and air temperature was carried out using data of meteorological observations at the KWBS from 1949 to 2011. Mean annual air temperature has increased by 1.80°C since the beginning of the 1970s; annual precipitation has increased from 270 to 370 mm during the whole period of observations.

Changes of climatic characteristics within a year happen unequally. The highest increase of mean monthly air temperature was in October (from –12.3°C to –8.5°C), November from –28.5°C, (to –24.5°C). In other months, there were no significant changes.

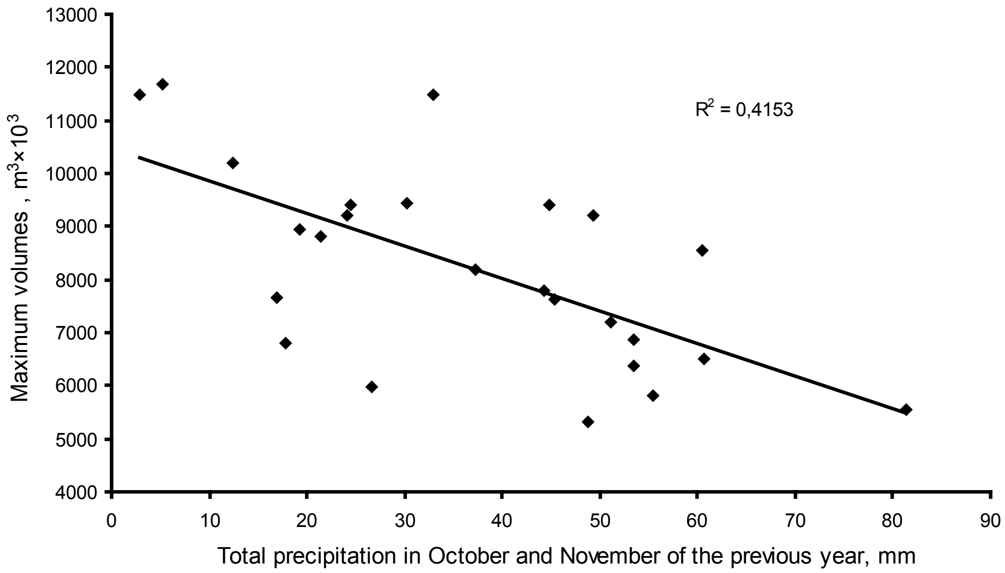

Fig. 4 Dependence of maximum volume of Anmangynda icing from total precipitation of October and November of the previous year.

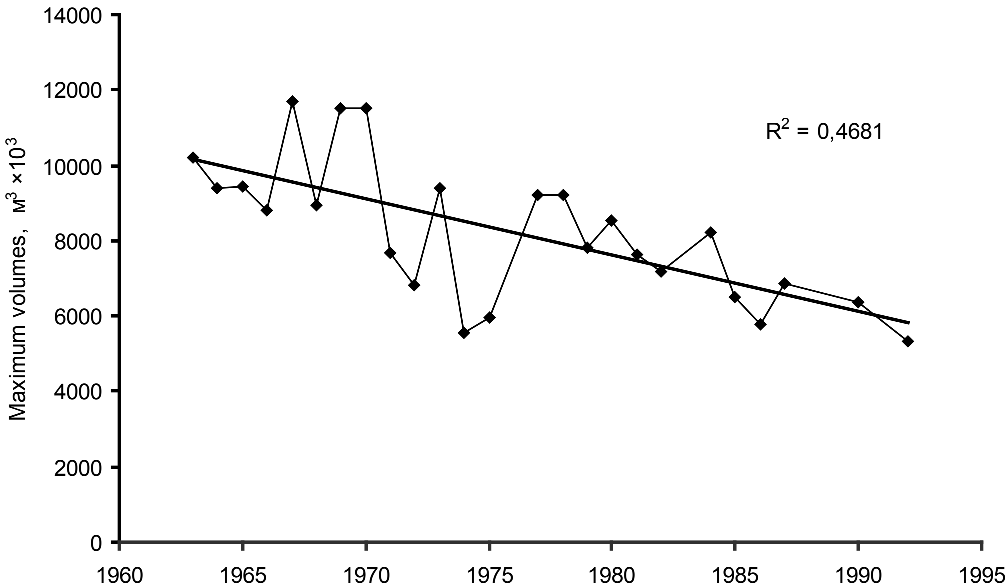

Fig. 5 Long-term dynamics of maximum volumes of Anmangynda icing (1962–1992).

The period from 1961 to 1992 when observations of the icing regime were carried out, coincided with the period of the most intensive changes in average monthly temperature and precipitation in October and November. On average, during this period temperature increased from –20.8°C to –17.0°C and the precipitation increased from 20 to 62 mm. This led to increasing water outflow from the icing field from 0.2 to 0.7 m^3/s in November. Thus, one can assume that the negative trend in icing volume illustrated above (see Fig. 5) can be caused by changes in the pre-winter climate characteristics.

CONCLUSION

As a result it is possible to draw a conclusion that in a long-term time series of the hydrometeorological variables under consideration, a statistically significant linear trend takes place. Trends in time series of annual temperature are generally caused by availability of trends in time series of average monthly values for October, November and March. Trends in time series of annual precipitation are generally caused by trends in time series of average monthly values for October and November.

The causes of degradation of icing volume lie in the indicated change in climatic characteristics which determine the intensity of increase of icing body in autumn/winter period.

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