MANIPULATION, USES AND BENEFITS OF GLACIERS, ICE AND SNOW

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Summary

The snow-ice resources are widely used in the human economic activity. Different principles make bases for impact upon snow and ice: mechanical, energetic, chemical and complex ones. In an engineering building snow is used in three basic forms: as bases for foundations, as a building material to make different constructions and their details, and as a medium in which trenches, ditches, mines, tunnels or under-snow rooms are made. The energetic principle is used at artificial ice freezing and blackening, and the chemical one is needed to cause or enhance snowfalls by spraying chemical reagents in unstable cloudiness, and the complex principle is used to transport icebergs to low latitudes and utilization of huge storage of fresh water in the icebergs. To make an artificial ice freezing a continuous water supply in a form of thin film is usually used; in such a case, an ice layer of several tens of centimeters thick can be made for a day. Intensity of such freezing can be an order increased by means of artificial sprinkling when the main heat exchange is transferred from the plane of freezing into volume of the drop plume. This technique can be also used for desalination of sea and salt underground waters. At blackening of their surfaces, glaciers absorb additional solar energy that results in enhancement of their melting and increases the glacier-derived runoff. Successful experiments for artificial enhancement of the glacier melting were carried out in 1940-1960s in USSR, China, and Chile. On the basis of experiments aimed at enhancement of the glacier melting and results of observations of their external

mass and energy exchange, estimates of such impact efficiency was obtained and rough calculations were made for all glacier regions in Central Asia and Kazakhstan (see Appendix). There are several prospects to transport icebergs from Antarctica to shores of South America, Australia, the Near East so that to obtain great volumes of fresh water. In this case cold oceanic currents can make significant part of the work since they are to be used to lay off courses of the iceberg transportation. But it is important to emphasize that all impacts upon the nival-glacial processes should be complex that is in addition to enhancement of the glacier melting special measures for increase of the snow storage should be foreseen.

1. Introduction

Until the present time, people most often face negative effects of the snow and ice phenomena, i.e. the snowdrifts, avalanches, spring floods on rivers, etc., and struggle against them needs significant expenses. That is why they were negatively thought, but in epoch of scientific-technical progress with a skillful control and management the snow-ice resources may be very useful in habitable «warm» regions of the Earth. The snow-ice resources are natural and nature-technical phenomena, objects, and processes which are used or may be used in the economy in the foreseeable future.

2. Engineering-glaciology problems

Effects upon snow and ice may be based on different principles: mechanical, energy, chemical and complex ones (Table 1). The energy principle is used at the ice blackening, while chemical one is applied when snowfalls are modified or enhanced by means of seeding of chemical substances in unstable cloud systems; complex principle means transportation of icebergs into low latitudes and utilization of huge stores of fresh water in them. We consider first the ***mechanical principle of effect*** upon snow cover and natural ice.

Objects	Goals	Methods	Results
Mechanical principle			
Snow cover	Snow reclamation of agricultural lands	Agricultural and forest management measures snow tillage	Positive with alternating success
	Snow retention	Forest bands, sheets and ditches	Positive at moderate storage
	Snow removal from roads and building sites	Snow-clearing machines	Positive at moderate storage
	Artificial avalanching and snow stabilization on slopes	Explosions, cutting, shock waves from aircraft	With alternating success
	Building of winter roads, runways and others	Loosening of snow with following compacting and wetting	Steadily positive
Glaciers	Mining works	Mechanical drilling with explosions	Steadily positive
Water ice	Prolongation of navigation	Ice-breakers, self-moving ice-cutters and ice-tillers	Positive at moderate thickness
	Control of ice dam and ice jam	Explosions, flashes from water reservoirs	With alternating success
	Control of ice impact upon the hydraulic-engineering constructions	Ice-breakers, synthetic shells	With alternating success

	Increase of the ice load-carrying capacity	Snow-clearing	Steadily positive
Aufeises	Control of icing of roads, ships and the hydraulic-engineering constructions	Manual and machine spalling of ice	With alternating success
	Creation of aufeises for reclamation and building purposes	Low-pressure dams on water streams	Steadily positive
Thermal-physical principle			
Snow cover	Snow reclamation of agricultural lands	Promotion of melting by dusting of the surface Retarding of melting by heat insulation of the surface	With alternating success Steadily positive
	Snow removal from roads and building sites	Flame snow-melters, heating of construction sites	With alternating success
Glaciers	Enhancement of water runoff	Promotion of melting by dusting of the surface	Experiments
Water ice	Prolongation of navigation	Increasing of the heat emission from the water by convection with air bulbs from perforated tubes Increasing of heat flux from the solar radiation by dusting of the surface Input of hot water from power-and-heating plants in ports	Positive under moderate frosts With alternating success Steadily positive
	Control of ice impact upon hydraulic-engineering constructions	Heating of constructions	Steadily positive
Aufeises	Creation of artificial aufeises for building, cooling and desalination	Thin-layer water spreading Water spraying and Raining	Steadily positive Steadily positive Experiment
Chemical principle			
Snow and ice	Dissolving of snow and ice on roads, runways, and building sites	Addition of chlorides, non-chlorides, mainly organic ones	Positive, but causing corrosion of metals
	Avalanche control	Chemical retarding of ice crystal growth of deep hoar-frost	Experiment
Complex principle			
Snow and ice	Snow control on roads, runways, and building sites	Gas-turbine snow removers for blowing-off and sublimation of snow and ice	Steadily positive
	Transportation of icebergs	Towing, melting	Project, small experiments

Table 1. Principles and methods of engineering-glaciology impacts

2.1. Mechanical principle of the effect

Even now, scales of snow land improvements are extremely large. Snow cover of agricultural lands is a part of agrotechnical system where specialists try to get an optimal use of its heat-insulating properties in winter, and its water-producing properties in spring; in this case, the largest addition to a harvest takes place in steppe, and particularly dry-steppe zones. Snow accumulation and retention of snow on the fields near roads provide also a complex solution of the other problem which is a decrease of snow-drifting on roads. Artificial «snow-out» from an air mass approaching a large city gives the double economic effect because it increases the snow accumulation on fields and decreases expenses for snow cleaning in a city streets.

In northern regions, as they were rendered habitable, the problem of a snowdrift without accumulation has arisen, when no retention of snow could form near constructions. Such conditions may be created by means of the wind intensification using snow-blowing devices, and thus making special forms and decreasing a surface roughness of constructions, arranging them in zones of enhanced snow-blowing out. But, it should be taken into account also that, as a rule, such snowdrift without accumulation is effective only under a certain direction of a snowdrift flow since after a wind direction changed such snow-blowing devices frequently turn into the snow accumulators. Because of this, it is very important to provide a condition of eddy-free flow by a snowdrift around constructions, but it is rather difficult to be realized.

In cold regions, where winter lasts for several months in a year, and the frosts are very severe, snow and ice serve as a good building material. Among engineering constructions from the ice, ice dams and barriers, i.e. ice massifs in a form of truncated pyramid, are increasingly used for protection against high floods, ice movements and aufeises.

Stone-cast dams with an ice core play the same role. Creation of ice platforms, i.e. artificial ice plates at a surface of water or ground, aimed at loading-and-unloading works and drilling of boreholes, are in common practice. There are also designs for creation of large ice platforms to bring the Arctic shelf into use, but there is still no good way to protect such ice massif against a wave-cut destruction.

To build up the ice massifs, the reinforced ice is frequently used. Mechanical strength of ice is increased by means of introduction into a freezing water of different substances, i.e. sawdust, chips, brushwood, papers, cotton, glass fibre, fabric, sand, gravel and others. Efficiency of the reinforced ice depends on a congelation of the ice crystals and on strength of the additions. The reinforcing is usually carried out by means of the layer-after-layer deposition of foreign materials onto an ice surface, earlier prepared, and the succeeding flooding of them by relatively thin water layers.

Several types of the reinforced ice are known: the wooden ice which is the frozen water with introduction of a sawdust mass, brushwood or chips; the cement ice which is the frozen mixture of water and sand-rubble, crushed rock or gravel material, characterized by the high strength; the foam ice which is the frozen water-air foam with very low density, only of 40-80 $kg\ m^{-3}$. For building in the severe regions, the ice constructions are widely used, they are made by laying of ice or snow-ice blocks, the layer-after-layer water freezing on horizontal or sloping bases, or by the spray freezing of water on rigid grid surfaces.

As a building material, snow is widely used at building of snow-ice roads and temporary runways which are very important for bringing up of high-latitude regions. Such roads are usually built on packed snow embankments which rise by several tens of centimeters above the surrounding snow cover. The road construction is started at freezing of ground down by 10-15 *cm*, so that to facilitate passing of light bulldozers through boggy areas. The snow embankments are built from previously loosened snow which is then compacted by rollers or vibrating tampers up to density of 550 $kg\ m^{-3}$ and greater. Such roads are used for many months.

In the engineering building, snow is used in three main ways: as a basis of foundations, as a building material for making constructions and details of them, and also as a medium where trenches, pits, tunnels and under-snow rooms are arranged. To build snow constructions, the snow bricks and blocks are cut from snow by special machines. Previously crushed snow is packed into special forms which are taken off not earlier than in 2-3 hours after the snow is frozen. Snow houses and freezing store-rooms may serve for a long time if the snow construction is well isolated from a heat income from both outside and inside.

Wetted and frozen snow is sufficiently strong for constructing temporary engineering structures, i.e. bridges, piers, ware-houses, etc., while a loose snow, being a natural heat insulator, can be used to prevent freezing of soil and water basins, to warm buildings and greenhouse complexes. For a long time, Eskimos of Alaska build igloo which is a hut from snow bricks. Two skillful men can build this for 45 minutes. A temperature of 5°C, and sometimes up to 15 °C, is permanently kept inside an igloo.

Snow structures are continuously distorted under any loads, even under own weight, and, unlike a ground, inside a snow, their plastic deformations are not damped with time. They are going on for uncertainly long time and, under great loads, may cause catastrophic consequences. Because of this, a pressure onto a snow must not exceed 100 *kPa*. The use of reinforcing material such as wood ships enable ice to tolerate greater forces. Snow much better resists to compression than to stretching. That is why, the best constructive snow elements are arches and cupolas, for example, igloo.

2.2. Thermal physical principle of the effects

This principle is much more power-intensive than the mechanical one, therefore it is used either locally, or with use of the heat, coming from the Sun, or stored by natural objects. Permanent struggle against the floating ices is carried out on rivers and seas, terms of navigation are prolonged, and clearings in an open water are created. But, along with that, people should more and more often build up ice to support ice piers and bridges.

River and lake ice is sharply different from a glacial one by its high transparency and large pyramidal crystals with their vertical axes up to several tens of centimeters long. Blackening of such ice with the purpose to intensify its melting, and then, after its full melting, to make a navigable channel, was successfully carried out in Asian Arctic in June, when morning frosts are already rare, the Sun shines continuously and the total radiation is rather great. The situation is drastically changed during a cloudy weather, when snowfalls and spring cold spells often decrease efficiency of the blackening so much that it becomes impossible even to weaken the ice. The reason is that the blackening layer, promoting the melting from above, at the same time, prevents the radiation propagation into the ice thickness. But, precisely this process promotes melting on boundaries of the crystals, their separation one from another, and practically complete loss of mechanical strength of the ice in water basins and streams.

A method of local impact on ice in water basins and weakening the ice along the ice-breaker routes has been developed. A special V-shaped furrow is made in an ice by the

purposely designed ice plough, its depth is not large, but not less than 0.1 of the total ice depth, and it is simultaneously blackened. Firstly, the water, appeared in the furrow, intensively absorbs the solar radiation, and, secondly, owing to inverse thermal convection it concentrates the heat in the narrow lower part of the furrow, thus, promoting its self-deepening.
This technology was first proposed in the USSR in 1960s. It was rather efficiently used on rivers of Siberia (the Lena River for example). The channel formed in the river ice remained open for several days.

A problem of ***artificial water freezing onto ice*** is of great practical importance. With continuous water feed by a thin film, it is possible to freeze up in a day an ice layer with its depth of only of several tens of centimeters even under a strong frost. An average rate of freezing is 1 *mm* per day per degree Celsius below freezing point. This is so called potential freezing-up. It indicates how much of ice one may produce under existing climate conditions. Potentiality of such icing is rather high both in Eurasia and in the North America territories.

A potential ablation which is the opposite indicator is a specific ice mass which can melt and evaporate in a year under a given climate. Comparison of both indicators gives potential ice balance of a territory, i.e. a mass of ice which could be annually built up without a heat insulation.

However, it is often needed to have the freezing-up intensity by an order higher than it is under the ice-formation by the method of a thin-layer water feed. Such rates of the ice-formation are possible to be achieved by the artificial sprinkling when the main heat exchange is transferred from the plane of freezing into a volume of the torch or a plume of drops which can be easily frozen. It has been experimentally shown that under a moderate frost of -18°C, for 19 hours one can produce a massif of the hard firn with its volume of 3 thousand m^3. Similar intensity of artificial freezing-up under natural conditions has been achieved for the first time.

The artificial firn thus obtained turns after its complete freezing into the dry granulated ice with its density of 450-600 $kg\ m^{-3}$, which is similar in appearance to a snow cover. In a course of the metamorphism, individual granules of the ice are caked, and its density increases with time. When partly frozen water drops fall onto a hard base and are completely crystallized there, that is attended with breaking of the ice spheres and with pouring out of liquid water from them, then a wet granulated ice is formed. Its density is 500-800 $kg\ m^{-3}$, but, after its impregnation and freezing-through, it turns into a monolith ice with its density of 850-900 $kg\ m^{-3}$. Both forms of the granulated ice are widely used: the first one for make ski routes and for water-heat improvement of the soil, while the second form is needed to build ice bridges, ice platforms, piers and dams.

Method of the torch freezing-up is used to desalinate the sea waters and salt underground waters as well. Under a frost, these waters are passed through sprinkling device, near of which a massif of artificial firn is formed. Since it is well-filtering the water, the salt water runs down from this, and it can be carried away by artificial or natural channel. The firn remained is practically fresh. Using of modern water-jet facilities makes it possible to improve a very continental climate in places where the artificial freezing-up is carried out since in winter a latent heat of the ice-formation is released there, while in summer it is absorbed. Of course, it is right for small territories and only in very continental climate. There is also another way to use the method discussed which is a feed of such water-firn pulp into a cooling system of a thermal or atomic power station to improve its efficiency and decrease a wear of the equipment. And at last, this method could be used for making of ice sculptures.

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Biographical Sketch

Vladimir Mikhailovich KOTLYAKOV (born in 1931) is a member of the Russian Academy of Sciences (elected in 1991). He is Director of the Institute of Geography, Russian Academy of Sciences. With particular interest in glaciology and physical geography in polar and mountain regions, he directed the twenty-year project resulted in the World Atlas of Snow and Ice Resources (published in 1997).

V.M. Kotlyakov participated in many expeditions. He worked and wintered in the Arctic, the Antarctica, at the slope of the highest summit of Europe, the Elbrus, headed the high mountain glaciological expeditions to the Pamirs.

The main theoretical results of V.M. Kotlyakov`s works consist in elucidation of laws of snow and ice accumulation of the Antarctic ice sheet as well as ice sheets in general (1961), the snowiness of the Earth and its fluctuations within time and space (1968), the tasks and abilities of the space glaciology (1973), the application of isotope and geochemical methods to the study of the environment and its evolution (1982), the study of the past for four glacial-interglacial cycles (1985 and further on). During the last years, V.M. Kotlyakov dealt with the global changes of the environment, geographical aspects of global and regional ecological problems, the problems of interaction between the Nature and society.

V.M. Kotlyakov is the vice-president of the Russian Geographical Society and the President of the Glaciological Association. In 1983–87, V.M. Kotlyakov was elected the President of the International Commission of Snow and Ice, in 1987–93, he was the member of the Special, and later Scientific, ICSU Committee of the International Geosphere-Biosphere Programme, in 1988–96, the vice-president of the International Geographical Union. Now he is a member of the Earth Council.

V.M. Kotlyakov is elected a member of the Academia Europaea and the Academy of Sciences of Georgia, a honorary member of the American, Mexican, Italian, Georgian, and Estonian Geographical Societies.