Forecast of avalanche danger for the intracontinental regions of Northeast of Eurasia

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ABSTRACT. The research area includes the Kolyma riverhead with tributaries. For this territory the extreme continental climate with very frost winters is common. The duration of snow cover is 200-230 days. The domination of low temperatures with small thickness of snow cover causes strong recrystallization of snow pack. On the other hand the intensity of this process often is not high. Significant loosening determines an unstable condition of snow on mountain slopes. Under certain conditions even the small increase of loading is capable to cause avalanching. The origin of the majority of avalanches (more than 60 %) is connected with fresh snow fall on the friable base. A network of avalanche research and meteorological stations in this area is scarce. In such conditions only background (area) forecast is possible. At the creation of the forecast technique the analysis of large number of the factors of avalanching process in the region was carried out. The forecast includes computation and an expert estimation of snow-avalanche situation. The data of meteorological station Kulu, located at the center of area, are used as the basis of the technique. The sum of precipitation, its intensity, temperature of air and its change during the snowfall are distinguished as predictors. The final forecast and definition of possible places of crashing of avalanches occurs with the improvement of the data of other avalanche research and meteorological stations. The character of winter is also taken into account. The forecast is made on nearest 12 hours 2 times per day. It has an alternative character.

INTRODUCTION

The Northeast of Russia almost half territory of which is covered with mountains, is equal to square of France, Great Britain and Germany taken together. About 20-th years of our century it was occupied by not numerous local tribes and Cossacks engaging in a herd of deers, hunting and fishing.

Economic development of Northeast began due to the mineral deposits of gold and tin. The creation in 30-th of an extensive network of GULAG camps with the use of slavish labor of prisoners has allowed expanding considerably the extraction of minerals. Together with construction of large mines the rather intensive infrastructure including settlements of miners with numerous auxiliary services, and line of the communications, including even railways build on a permafrost was created. Much of created in those years was maintained and developed further, something was kept about our days.

The first fixed avalanche incidents that have caused human victims also concern to 30-th of our century. Some cases of mass loss of prisoners in the avalanches, which have occurred per different years and in different places in Northeast, are known. However they did not promote the beginning of researches of avalanche danger in region. Only the death in 1966 of the road worker, who has cut an avalanche with clearing of a road from snow, has forced to pay steadfast attention to a problem of snow avalanches. By 1985 in avalanches perished annually 1 of 100 thousand of the local population. The avalanching is regularly occur on highways, blocking settlements from the world and from each other. In the avalanche-prone areas there are inhabited buildings and places of rest, transmission lines and oil pipelines, sites of extraction of minerals.

To the middle of 80-th in the region the network of the specialized stations for study of avalanches was created. The monitoring of avalanche danger happened with the use of ground-based stationary and routing observations, planes and helicopters also were used. The accumulation of the meteorological and snow-avalanche information has allowed approaching to the creation of techniques of the forecast of avalanching for some areas in Northeast of Russia.

CONDITIONS OF AVALANCHING

The area of researches includes basins of the rivers Kulu and Ajan-Jurach and riverheads of the river Kolyma. The mountains of Verchnekolymskoje nagorje consist mainly of small massifs and short ranges with flat tops. The prevailing absolute heights make 600-1400 m. Average

relative heights are 200-300 m and sometimes reach 500-600 m. The most widespread forms of the avalanche sites are the erosional hollows, in which occur channeled avalanches and flat slopes, where the formation of slides happens. The narrow gorges in riverheads transform to wide valleys, where the meanders press highways against a foot of dangerous mountain slopes.

Proceeding from the analysis of geomorphologic conditions of region, it is possible to state that the avalanches evidently have small volumes. Experience shows that even on extended rather flat slopes, the avalanching seldom occurs on all of their area. The presence on these slopes even of insignificant protuberances produces the formation in a snow cover of zones with considerably distinguished properties. Alongside with action of other factors this circumstance produces a gradual unloading of slopes from snow as avalanches.

The steepness of mountain slopes at a level of avalanche fracture line makes up 35-45^0. The surface of them is often composed of fine- and medium-detrital rocks. Such character of surface provides the presence of air cavities in the lower part of a snow pack, under some conditions the water vapor from snow to a ground can promote migrations. It conducts to acceleration of growth of crystals of a depth hoar on boundary of snow with ground. A corollary can become formation of dangerous layers. The detrital material on a surface of slopes by first snowfalls already completely becomes covered by snow. It is possible to make a conclusion, that the character of surface in the research area is favorable for avalanching.

Climate of region is extreme continental. The annual radiation balance is small and in winter period has a negative value, that causes significant duration and severity of winters.

In the winter dominate the anticyclonic processes. Two types of weather are possible: a little-cloudy, frost, windless; or cloudy weather, with the weak snowfalls accompanying with a weak wind. An increase of snowfalls and raise of air temperature are observed with approach to the region of deep cyclones. The more often their trajectories are shown in Figure 1. With presence above intracontinental areas of an anticyclonic core, there occur significant barometric gradients, that cause the strengthening of wind.

The pass of mean day temperature of air through 0^0 C to the negative values is marked in the second decade of September. The coldest month of year is January. Mean monthly temperature of air reaches at this time -38,2 ^{0}C in Susuman and -37,0 ^{0} C in Kulu. The absolute minimum makes accordingly -63 ^{0}C and -61 ^{0}C. In a winter period within the limits of region the inversion of temperature develops. The data of observations show that by December - January the high-altitude gradients of air temperature reach -1,7 ^{0}C per 100 m. In March - April the radiation balance becomes positive and the temperature inversion collapses. In a last decade of May there the pass through 0 ^{0}C to the positive values happens.

The first snow happen in September, and earliest occur in the beginning of August. The insignificant heights and synoptic conditions promote that the snow cover in the whole territory is established practically simultaneously in the first decade of October. The mountains located along the coast of Okhotsk Sea take over a significant part of precipitation. Therefore, in the intracontinental areas, to which the research area concerns, not enough snow falls out. Since October till May the amount of precipitation makes 88 mm in Susuman and 125 mm in Kulu. The maximum of precipitation in a cold period of year falls out in October: 17 and 22 mm accordingly. The monthly amount of precipitation gradually decreases and reach a minimum in March - April -. 5-9 mm. The maximum quantity of precipitation per day is marked in October - 6 mm. The intensity of snowfalls seldom exceeds 0,1 mm hour^{-1}. An increase of a snow cover depth during several-days-snowfall makes only 3-5 cm. The interruptions between snowfalls make 5-10 days. The amount of precipitation is increased with a raise of height, however reliable data on a high-altitude gradient of precipitation are absent. The high-altitude gradient of precipitation of 10 mm per 100 m for a winter period is calculated using the data of observations of 50-th years and casts serious doubts.

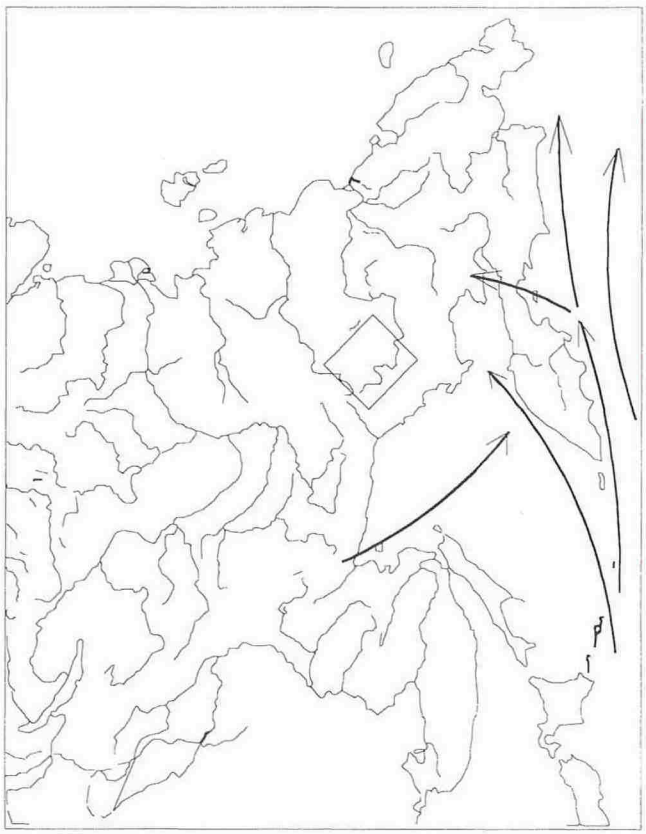

Fig.1. The trajectories of cyclones that cause avalanching in the intracontinental regions of Northeast of Eurasia.

□ - area of research

The maximum depth of a snow cover is reached at the end of March - beginning of April. The mean maximal depth of snow is low - in Kulu it makes 45 cm. In the middle of May the destruction of a snow cover happens. The number of days with snow cover makes about 220.

The average velocities of wind during the winter are small: 1,5 m sec^{-1} in Kulu and 2,0 m sec^{-1} in Susuman. Thus the maximum velocities of a wind are marked in spring months. With a height the velocity grows and reaches 3,0 m sec^{-1} on meteorological station Butygychag

(1408 m). The number of days with blizzard is insignificant and makes 29 in Susuman and 20 in Kulu. At the same time the area of research is characterized by a small snow transport. On the data of S.A.Rakita (unpublished materials) the maximum intensity of a snow transport does not exceed 300 m^3 m^{-1}. In a winter period the winds of northern quarter (about 80 %) dominate.

The avalanching in area of research can be connected both with a cyclonic activity, and with development of interior processes in a snow pack. The latter factor can be exhibited as a fracture of avalanches of long development (the classification, accepted in USSR). Low air temperature with insignificant depth of a snow cover even with low temperature of surface (up to -20 ^{0}C in January - February) ensures significant gradients in a snow pack strengthening processes of a recrystallization. However the data of some researchers show that the domination of low air temperatures produces their restraint. Blizzards are displayed in a structure and character of a snow cover not frequently. The wind crusts with thickness up to 1 cm, small cornices and sastrugi on a surface of snow occur only in the upper part of slopes above than 1000 meters above the sea level. The overwhelming dominance of northern winds with an insignificant thickness of snow cover causes the transposition of snow from windward northern slopes to leeward southern. The originality of conditions of snow metamorphism produces the smoothing of physic-mechanical properties of snow on all depth. The boundaries of layers with transition from a layer of new snow to a layer of a depth hoar are uncertain. The size of crystals of a depth hoar by February - March reaches 6-8 mm. Density of snow near the ground makes 160-180 kg m^{-3}. In the upper layers it is seldom exceeds 200 kg m^{-3}. The development of inversion promotes that the maximum gradients in a snow pack must be in middle and bottom parts of slopes. It is possible to assume on these sites the maximum development of processes of a loosening. The climatic conditions as well as geomorphologic promote development of small avalanches.

Transition to a positive radiation balance in March in a combination with insignificant depth of a snow cover promotes intensive evaporation of snow on southern slopes with negative temperature. The formation of wet avalanches caused by action of solar radiation does not occur. And already before an establishment of positive air temperature there is not enough snow on slopes.

The character of vegetation is uniform. The larch-tree forest rises up to height of 800 meters above a sea level. Higher the slopes are covered with a bush, nestling under snow weight to ground. At height 1000 m and above mountain tundra belt develops. As observations show, the vegetation does not hinder avalanching. The zone of a fracture of an avalanche can pass even between the trees remote less than on 10 meters from each other. Some years in succession such cases were registered on one of sites of a highway in the river Kulu basin.

DATA ON AVALANCHES

The outcomes of observations show that the avalanches of volume less than 1000 cubic meters prevail. Not more than 10 % of avalanches have volume from 1 up to 10 thousand cubic meters. Volume of few avalanches exceeds 10 thousand cubic meters.

The fracture of majority of avalanches (more than 60 % from general number) happens during snowfalls. Frequently even insignificant masses of snow suffices for violation of stability of the loosened layer. The amount of the registered avalanches is in direct dependence on a snowiness of winters. In multisnow winters occur more avalanches and their volumes are larger than in few low-snow winters. In 70-th and 80-th years the fact of direct dependence of winter snowiness from amount of precipitation of the first cold month - October is marked. However confirmations of the given regularity need a significant series of observations. The absolute majority of the registered avalanches have fallen from southern slopes (Fig.2). Only in multisnow years the avalanching occurs on different slopes. As a rule, the fracture of avalanches happens in the bottom layer consisting of a depth hoar. The sizes of crystals in this layer can reach 6-8 mm. The

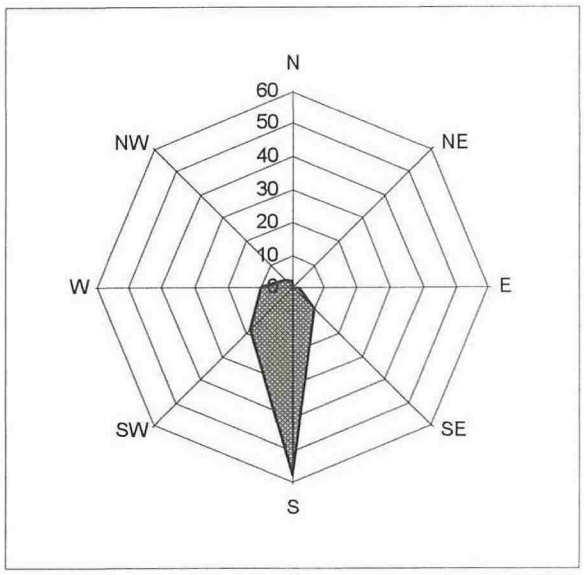

Fig.2. Frequency of avalanches on different slopes.

fracture of first avalanches frequently occurs already after the establishment of snow cover during intensive October snowfalls. Last avalanches are fixed long before a loss of a snow cover - in the beginning of April.

THE FORECAST TECHNIQUE

With the analysis of snow-avalanche information some indications of avalanche danger in the regions were defined:

- The fracture of the first avalanches occurs after the depth of snow cover reaches 18 cm at meteorological station Kulu;
- Formation of avalanches cause snowfalls during which more than 1 mm of precipitation fall out;

50 snowfalls adequate to such conditions are selected from a ten years' series of observations.

The following stage has become searching defining predictors. It is supposed to use:

1. Intensity of snowfalls (i). Measurements of precipitation happen two times per day in 0 and 12 hours on Moscow time. The account of all characteristics is conducted for these terms. However not all snowfalls (3-4 mm for 12 hours) conduct to avalanching. And, on the contrary, the can occur with intensity of snowfalls of 0,05 mm hour^{-1} and less. It is required the account of other factors capable to characterize change of snow- meteorological situation.

2. Data of meteorological stations show the insignificant increase of snow cover. It is supposed that it is better to use the sum of precipitation from a beginning of snowfall (x). Load of fresh snow on the friable base grows slowly during a snowfall. A settling of snow pack is insignificant.

3. It is supposed that the course of processes in snow pack, the change of its properties can be characterized by air temperature and its change during snowfall (dt). During avalanche-danger snowfalls the raise of air temperature happens. The snowfalls frequently begin with temperature -40 ^{0}C and below. For one-two days the raise of air temperature can reach 20 -25 ^{0} C. Form and size of crystals, density of fresh snow varies during a snowfall. With the raise of temperature the density of fresh snow is increased. The upper layers have higher density, than lower. The air temperature difference in time of observation and in time before snowfall is calculated each 12 hours.

4. At the same time the unit measurement of temperature in meteorological terms can deviate from the general tendency. The change of temperature during the snowfall describes as a predictor by mean temperature (t_s) during the snowfall.

As the base information for accounts the data of meteorological station Kulu located closer to the centre of area of researches and having the average meteorological characteristics in a sparse network of observant stations are used.

The discriminant function for the forecast is following:

$$D = 0.89i - 1,15x - 0.47dt - 0.32t_s + 0.36$$

The forecast has an alternative character. With negative values of function there are conditions favorable for avalanching. For the immediate 12 hours the prognosis is made: "in the territory of regions avalanching is possible".

The reliability of a technique with use of independent data has exceeded 70%.

The forecast obtained with the help of the calculated equation is specified by an expert evaluation. Thus the most probable places of an avalanching are determined. With realization of an expert estimation the following conditions are taken into account:

- A blizzard in area of meteorological stations located in region, can promote to an avalanching when $D > 0$ and strengthen probability of a fracture, when $D < 0$;
- The improvement of the forecast can be promoted by the data on observations of snow cover depth in the avalanche sites and physic-mechanical properties of snow near to them, carried out once a week. It is necessary to pay attention to their essential changes;
- A sum of precipitation for winter essentially exceeding a common value (as a rule it is possible to judge about a snowiness of winter already on the data of October); show a possibility of avalanching from different slopes;
- There can be a fracture only of one avalanches from one avalanche site per one year (significant weight of snow could not be accumulated once more). Only extended slide slopes unload gradually during all winter.
- Over long-term observations after April 1 avalanching is not registered.

The given technique is accepted for prognosis of avalanche danger in intracontinental areas of Magadan area in Hydro-Meteorologic Survey of Magadan City.

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