LATITUINAL AND ALTITUINAL TRENDS OF SEASONAL SOIL THAW IN YAKUTIA

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Abstract

The change in calculated depths of seasonal soil thaw from north to south through central Yakutia (nearly 2500 km) was analysed for relatively dry and water-saturated sands and silty loams. For each of four soil types, three correlation relationships were obtained between the seasonal thaw depth and the geographic latitude and altitude of the area. The latitudinal gradients of change in seasonal thaw depth were found to be 0.05 - 0.08 m/°N.L. in the Arctic and 0.06 - 0.14 m/°N.L. in the continental sections of the transect. The depth of seasonal soil thaw for mountainous area (Southern Yakutia) decreased by 0.56 - 0.68 m/1000 m of altitude in silty loams and by 0.85 - 1.23 m/1000 m of altitude in sands.

Methods

The effect of site location (latitude, longitude and altitude of the area) upon seasonal thaw depth cannot be determined from any of the above works. It would be possible to obtain only by comparing the results of measurements carried out in soils with identical composition, moisture content and other properties, in different parts of the region. As finding such soils under natural conditions is practically impossible, we had to use analytical methods. The most probable ranges of moisture content and of all other soil characteristics were used in our calculations to obtain results close to the real ones.

Depth of seasonal thawing of soils was calculated based on long-term observation data from 166 weather stations in Yakutia. The calculations were made for two varieties of soils: for sands with moisture contents of 5 and 25% and for silty loams, with moisture contents assumed to be equal to 20 and 45%. Such moisture content ranges were selected in order to find the probable limits of seasonal thaw depths for relatively dry (maximum depth) and wet (minimum depth) soils.

Research work carried out over a 30-year period in the area of Northern Zabaikalye (Zabolotnik, 1967), in Mongolia (Zabolotnik, 1974), the northern part of the Amur river basin (Nekrasov and Zabolotnik, 1983) and...
in Yakutia (Zabolotnik, 1984, 1991) has shown that the depth of seasonal thaw on peatlands and under a moss cover is always less than that in silty loams. In sandy loams, it occupies an intermediate position between sands and silty loams. Thawing in gravel-pebble and crushed stone soils as well as in rocks is always deeper than in sands. Thus, the calculations of seasonal thaw depth for sands and silty loams are also useful for other soils.

Results

First, we considered the change in a depth of seasonal thaw from north to south. For this aim, the most extensive transect in this direction (about 2500 km) in central part of Yakutia was selected (Figure 1). Analysis of the results shows that a rate of change in a depth of seasonal soil thaw differs within the basin of the Arctic Ocean and the continental part of Yakutia.

In the New Siberian Islands and in the coastal areas of the Laptev Sea, where all weather stations are situated at altitudes of 5 to 50 m, most of the area is at altitude of less than 150 m and only a few locations exceed 200-300 m above sea level. The influence of relief is practically absent under such conditions, and changes in a depth of seasonal thaw are mainly due to an increase in incoming solar radiation at the ground surface.

The calculations show a variation in a depth of seasonal thaw from 0.3 to 0.8 m in silty loams and from 0.5 to 1.2 m in sands. It should be emphasized that there is only a very small increase southward despite the great extent (nearly 800 km) of this part of Yakutia (Figure 2). This is probably the result of the smoothing effect of the enormous water mass of the Arctic Ocean.

Quantitative estimates of the change in the magnitude of soil seasonal thaw were obtained from statistical processing made by mathematician N.I. Votyakova using the computer program Mathematica (Wolfram, 1993).

As noted above, the effect of relief has not been taken into consideration at the Arctic sites. When revealing the correlation relationships between the magnitudes of seasonal thaw depths and the terrain latitude, all relationships were assumed to be the linear ones and the regression coefficients were determined by method of the least squares (Fisher, 1958; Rumshinskiy, 1971).

Based on calculations the relationship between the seasonal thaw and the latitude of the area can be described as follows:

- silty loam, \( W = 45\% \) \( \xi_1 = -0.0485\varphi + 4.11, \) \( \rho = 0.89 \)
- silty loam, \( W = 20\% \) \( \xi_2 = -0.0550\varphi + 4.70, \) \( \rho = 0.89 \)
- sand, \( W = 25\% \) \( \xi_3 = -0.0719\varphi + 6.09, \) \( \rho = 0.89 \)
- sand, \( W = 5\% \) \( \xi_4 = -0.0816\varphi + 6.97, \) \( \rho = 0.89 \)


where \( W \) is the gravimetric water content in %, \( \xi \) is depth of soil seasonal thaw in m, \( \varphi \) is geographic lati-
tude of the area in degrees of north latitude, $\rho$ is the correlation coefficient.

Equations (1) - (4) show that a depth of seasonal thaw increases only by 0.05 - 0.06 m in silty loams and by 0.07 - 0.08 m in sands for each degree of latitude southward. In other words, the latitudinal gradient at the Arctic sites in Yakutia equals 0.05 - 0.08 m/°N.L.

The continental part of the region under study can be conditionally subdivided into 2 sections.

The northern section extends for more than 1100 km from the Laptev Sea coast to its crossing with the Lena River, about 64° N.L. (see Figure 1). It partially covers western spurs of Verkhoyanskiy Ridge where certain elements of relief are at altitudes of 1000 - 1200 m. However, there are no weather stations at elevations of more than 315 m and most of them are situated in the river valleys with altitudes from 8 to 110 m (Figure 3). Therefore, when finding the correlation relationships between the seasonal thaw depths for sands and silty loams and the latitude of the area, all relationships were assumed to be the linear ones.

Depths of seasonal thawing were found from calculations to vary in this section from 0.7 to 1.6 m in silty loams and from 1.0 to 2.6 m in sands and they increase southward per each degree of latitude by 0.06 - 0.08 m and by 0.10 - 0.14 m, correspondingly (see Figure 3, lines 5 - 8). Correlation between thaw depths and latitude of the area can be expressed through the following relationships:

$\text{silty loam}, W = 45\% \; \xi_5 = -0.0637\varphi + 5.40, \quad \rho = 0.97$

$\text{silty loam}, W = 20\% \; \xi_6 = -0.0783\varphi + 6.59, \quad \rho = 0.98$

$\text{sand}, \quad W = 25\% \; \xi_7 = -0.0969\varphi + 8.17, \quad \rho = 0.97$

$\text{sand}, \quad W = 5\% \; \xi_8 = -0.1431\varphi + 11.73, \quad \rho = 0.98$

It is seen from Equations (5) - (8) that the latitudinal gradient reaches 0.06 - 0.14 m/°N.L. in this part of the region, that is 1.3 - 1.8 times higher than in the Arctic section.

Southward of 64°N.L., the section under discussion first crosses the Prilenskoye Plateau, then the Aldan Upland and runs into the Stanovoi Ridge. The altitude of the area within the Prilenskoye Plateau increases up to 200 - 700 m. It varies from 500 to 1000 m in the Aldan Upland and increases up to 1300 - 1500 m at certain sites (see Figure 3).

Since there are weather stations practically within the entire range of latitudes, we managed not only to calculate the depths of seasonal thaw of soils in places of their occurrence, but also to establish correlations between the depths and the geographic latitude and the altitude of the area. The relationships obtained are the following:
where $H$ is the altitude in m.

When developing Equations (9) - (12), it was assumed that the latitudinal gradient for each variety of soil was the same as for northern and central parts of the continental section (see Equations 5 - 8). We took into account that incoming of solar radiation is mainly determined by the geographic latitude of the area. Such relatively low altitudes basically do not effect the air mass transfer at a global scale. The calculated depths of seasonal soil thaw should be close to those observed under natural conditions.

Values of latitudinal gradient close to real ones refer to the range from 60.7 - 74° N.L., where the effect of altitude is practically absent or insignificant. Thus, about 40% of extension of the southernmost site was considered in the calculation (see Figure 3).

From Equations (9) - (12) it follows that with altitude increase of 1000 m the depth of seasonal thaw decreases by 0.56 - 0.68 m in silty loams and by 0.85 - 1.23 m in sands in Southern Yakutia. The calculations considering the altitudinal gradients showed that the depth of seasonal thaw ranges between 1.0 and 1.8 in silty loams and from 1.5 to 3.0 m in sands in this part of the region.
(see Figure 3, curves 9 - 12). These values are within the limits of those determined under natural conditions and published in the above mentioned maps as well as in the book “Southern Yakutia” (Kudryavtsev, 1975).

Conclusions

Analysis of calculated data and the correlation relationships revealed allowed both qualitative and quantitative characteristics of the main parameters determining depth of soil seasonal thaw in the most extended central part of Yakutia from the north to southward to be defined. The results of this work can be applied for determining the thickness of seasonally thawing layer in different types of soils at any latitude within the region under discussion at altitudes up to 1500 m. Equations (1) - (12) likely can be used for evaluation of seasonal thaw depths in adjacent areas at significant altitudes, as well as to determine their potential values at sea level within mountainous areas (see dotted line in Figure 3).

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References


