Estimating the spatial distribution of thaw depth in the Siberian tundra near Tiksi from micro undulation, vegetation and image color index

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INTRODUCTION

Siberian tundra occurs in a permafrost area that is overlaid with a layer that freezes and thaws annually, the so-called active layer. The depth of thaw of permafrost varies spatially and may further influence hydrologic processes in tundra watersheds. Watanabe et al. (2000) reported that the maximum thaw depth of tundra decreased with increasing thickness of the living plant layer. This implies that the spatial distribution of thaw depth in the tundra can be estimated from the spatial distribution of boundary conditions between the ground surface and atmosphere, i.e. vegetation and micro undulations of the ground surface. However, little is known about this relationship. In this study, we report the thaw depth, ground surface elevation, and vegetation in tundra. Then we develop a method for estimating the spatial distribution of thaw depth in a tundra watershed.

OBSERVATION SITE AND METHODS

The survey was carried out in tundra near Tiksi in the summer of 1999. A 100 × 100m area divided into a 10m grid was located at the southeast end of the CALM grid. Thaw depth, ground surface elevation, and vegetation were investigated at each intersection of the grid. The thaw depth was measured using a steel rod. The ground surface elevation was surveyed from a benchmark placed the previous year. The vegetation in each 10 × 10m grid square was classified by the typical species (Watanabe et al. 2000). To analyze the vegetation conditions and distribution in detail, an image of the ground surface at each observation site was captured by digital video camera.

ANALYTICAL RESULT

The slope direction of the ground surface and the gradient were calculated from the ground surface elevation using GIS analyzing software (GRASS). Figure 1 shows a map of the slope direction for gradients larger than 1°. The slope was separated into four directions. The solid lines are the thaw depth contour with a 10cm interval. The thaw depth ranged from 30 to100cm. The ground near a depression, where four slopes faced each other, thawed to a greater depth (more than 80cm) than the surrounding ground. The depressions were inundated and contained sedge. As seen in the southeast part of the figure, the thaw depth of ground that sloped continuously in one direction was shallower than 40cm.

Figure 2 shows a vegetation map with the thaw depth contours. The thaw depth of ground mainly covered by moss was shallow as seen in the southeast part of the figure. Since moss covers the ground surface more densely than sedge or other plants, it is thought that the moss prevents the soil from thawing. Where the ground was studded with frost boils, the thaw was deeper than in the surrounding area. Since the surface of a frost boil consists of clayey silt with a low albedo and no vegetation to prevent thawing, the thaw depth near frost boils is deep. Some areas of sedge-covered ground also had a deep thaw depth. These areas corresponded to the inundated depressions shown in Figure 1.

ESTIMATION

The analysis indicates that the thaw depth depends on the ground surface conditions. The proportion of vegetative cover on the surface varied, even when it consisted of similar plants. If an index of surface conditions can be determined from a quantitative estimation of the vegetative cover, the spatial distribution of thaw depth can be estimated using the index. Measuring the number of plants per unit area and the species is an effective way to quantitatively estimate the vegetative cover. However, it is difficult to measure an open watershed directly in a short time.

Therefore, we first captured images of the vegetative cover with a digital camera, and then analyzed the color of the image, which is related to the vegetative cover, to make an index.

Images of a 75 × 100cm area around each intersection were used. The color of each image was separated into four hues (CMYK). We used the yellow (Y) level, since it is strongly related to the vegetative cover and expressed the main color of vegetation. The yellow level of an image was defined as the mean value of all the pixels in the image; it has a range from 0 to 255. When an image has many yellow components, the yellow level is low. Figure 3 shows a map using the yellow level as an index of the vegetative cover. The yellow level was proportional to the thaw depth, as shown in Figure 4. Ground that thawed to a depth exceeding 80cm had a yellow level higher than 160. This indicates that if the proportion of vegetative cover is low, the ground thaws to a greater depth. Where moss covered the ground widely, the thaw was shallower than 40cm and the yellow level had a middle value (about 135). It seems necessary to add factors to the index in order to include differences in the insulating effect of each plant species.

SAMMARY

The following relationships were obtained from the analysis of micro undulation, vegetation, and thaw depth using GIS. (1) The ground thaws to a greater depth at or near meter-scale inundated depressions. (2) The thaw is shallower in moss-covered areas. (3) Ground studded with frost boils thawed to a greater depth than the surroundings. From these results, we developed a method for estimating the spatial distribution of thaw depth. The yellow level of digital images can be used to estimate the distribution of thaw depth, although other factors should be added. Applying the index to aerial photographs or satellite maps should prove useful for making a hydrological model of the tundra region.

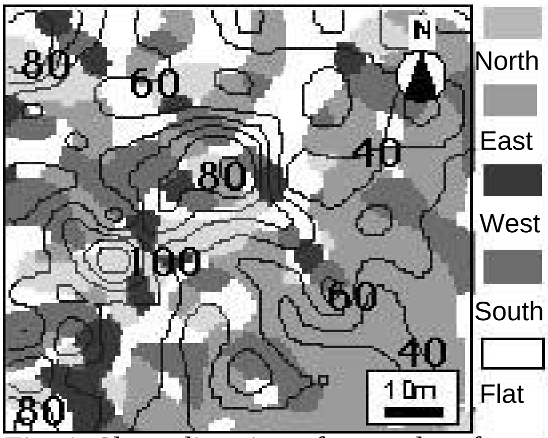

Fig. 1 Slope direction of ground surface

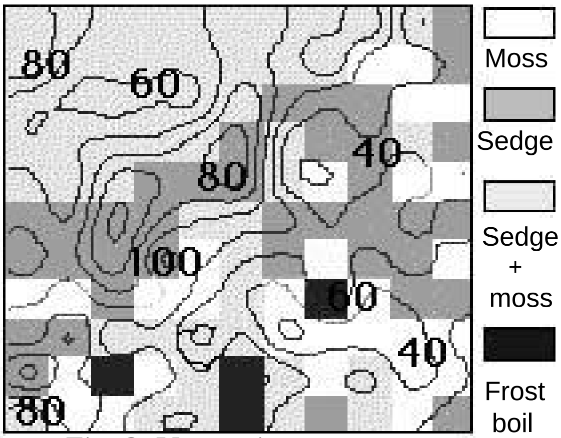

Fig. 2 Vegetation map

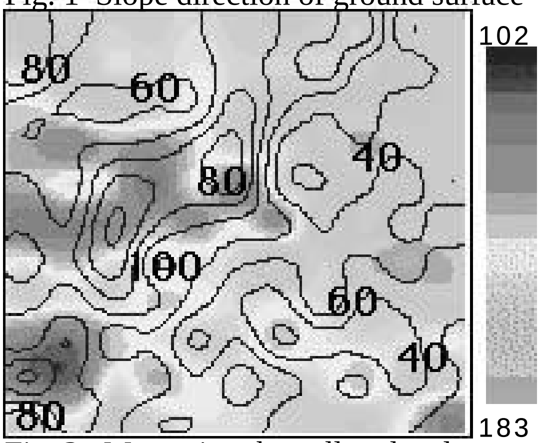

Fig. 3 Map using the yellow level

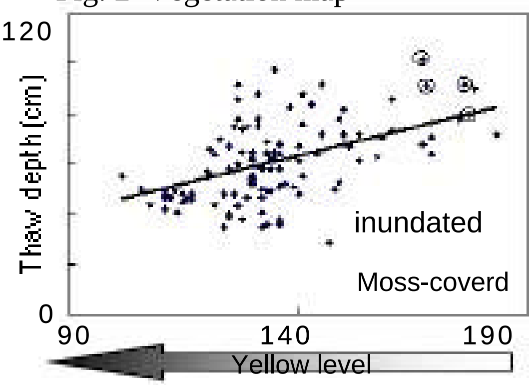

Fig. 4 Relationship between yellow level and thaw depth

REFFERENCES Watanabe et al. (2000) : Properties and horizons of active layer soil in tundra at Tiksi, Siberia, J. Japan Soc. Hydrol. & Water Resour. Vol. 13, pp 9-16