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Measurements of ground temperature and soil moisture content in the permafrost area in Tanggula Mountains, Tibetan Plateau

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Abstract

Ground temperature and soil moisture content in the permafrost region were measured at sites located from 4800 m to 5206 m a.s.l. in the Tanggula Mountains, Tibetan Plateau in October 1992–September 1993. There was a correlation between the first freezing and thawing dates and the freezing period and altitude at sparsely vegetated sites, and these relations lay on a straight line. The first freezing and thawing dates become later and earlier with decrease of altitude respectively. The surface frozen period becomes shorter with decrease of altitude. A densely vegetated site did not fit on this correlation obtained at sparsely vegetated sites. The average values of soil moisture content at 40 cm depth at sparsely vegetated sites were from 18 to 30 %, at the densely vegetated site this value was around 48 % in October 1992 and May 1993. Soil moisture content at the densely vegetated site was larger than that at sparsely vegetated sites. The thicknesses of the active layer at sparsely and densely vegetated sites were 234 cm and 93 cm respectively even though air temperature conditions were similar.

1. Introduction

Permafrost exists extensively on the high altitude Tibetan Plateau even though it is located at low latitude. There have been many investigations of permafrost in this region by the Lanzhou Institute of Glaciology and Geocryology. It is said that permafrost thickness ranges from 20 to 130 m in the loosely packed sediment region, and from 130 m to 200 m in the mountainous rocky region, and the active layer from 1.1 to 3.2 m in the former region (Tong and Li, 1983).

There has been no observation of spatial distribution of the active layer on seasonal variation of thawing depth of the active layer in the Tanggula Mountains, Tibetan Plateau. The active layer depth and the seasonal variation of frost table depth are said to depend on air temperature and surface layer conditions such as vegetation, soil texture, soil moisture and so on. The seasonal variation of thawing depth of this active layer may be controlled by evaporation from the surface, soil moisture and the water table in the active layer, and surface conditions. This report describes ground temperature, soil moisture and active layer depth, in the Tanggula Mountains, Tibetan Plateau.

2. Observation Sites

Field investigations were conducted at four sites located in the altitudinal range from 4800 m a.s.l. to 5206 m a.s.l. in the Tanggula Mountains, Tibetan Plateau (at locations of 4 sites in Fig. 1 in Ageta *et al.* (1994)). These sites were selected according to the following conditions :

1) Sites at different altitude with similar vegetation.

2) Sites at similar altitude with different vegetation.

The sites which fit the first condition were D100

(4800 m a.s.l.), D105 (5020 m a.s.l.) and Tanggula Pass (5206 m a.s.l.), at which vegetation was similar at the sites and sparse. The sites which fits the second condition, that is, sparse/dense vegetation but similar altitude, were D105 and Wetland (5100 m a.s.l.). At Wetland vegetation was dense and earth hummocks with diameter of 30−50 cm developed.

3. Observation methods

Observation items were ground temperature, soil moisture and heat conductivity of soil. The ground temperature was measured with platinum resistance sensors every hour at depths of 0, 5, 10, 20, 40 and 80 cm at D105 and Wetland, every 2 hours at depths of 0, 10, 20, 40 and 80 cm at D100 and every 2 hours at 0, 5, 10, 20, 40 cm at Tanggula Pass. The data were stored

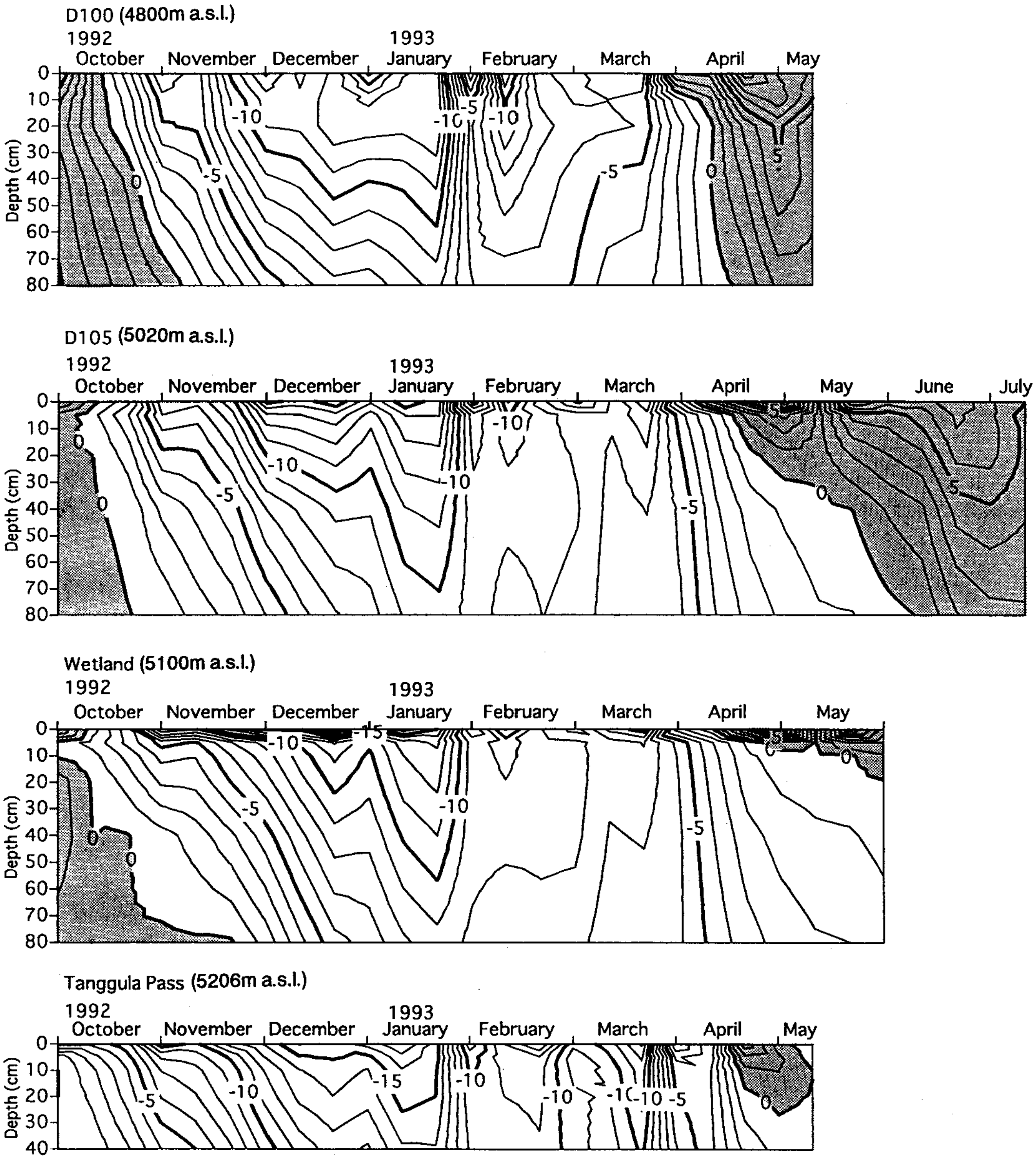

Fig. 1. Isopleths of ground temperature in the time domain at D105, Wetland, D100 and Tanggula Pass. The parts higher than 0 ℃ are shaded.

in LS3000Ptv on data logger (Hakusan Co.) at D105 and Wetland and on LT2001 (Hakusan Co.) at D100 and Tanggula Pass, respectively. These observations were carried out through a year from October 1992 to September 1993 at all 4 sites. Data used in the following sections are the daily mean values.

Soil samples for direct measurements of soil moisture content were taken with a 100 cc sampling tube in October 1992 and approximately once a week from May to July 1993 at all sites. Soil moisture content was obtained at site by weighing samples before and after drying.

Soil moisture content was also measured indirectly by measuring heat conductivities. Heat conductivities were measured with heat probe sensors every 12 hours (06 : 00 and 18 : 00 Beijing Standard Time) from October 1992 to April 1993 and from July to September 1993, and every 2 hours in May and June 1993, at depths of 5, 10, 20, 30, 45, 60 and 80 cm at D105. They were measured every 12 hours (06 : 00 and 18 : 00 Beijing Standard Time) from October 1992 to April 1993 and from July to September 1993 and every 2 hours in May 1993 at 10, 20, 40, 80 cm at Wetland, and every 12 hours (06 : 00 and 18 : 00 Beijing Standard Time) from October 1992 to May 1993 at D100. All data were stored in data loggers (IDL-1600, North Hightech Co.).

The water table was observed approximately once a week from May 1993 to July 1993 at D105 and Wetland.

4. Results

4.1. Ground temperature

4.1.1. Seasonal variation

Isopleths of ground temperature in the time-depth cross section at all sites are shown in Fig. 1. The parts higher than 0 °C are shaded. It can be seen from the Figure that the temperature gradient in the surface 10 cm layer at Wetland was very large. Temperature variations were rapid at the end of January and the end of March at all sites and were very slow at February at D105, Wetland and Tanggula Pass. The 0 °C isotherm in the freezing season moved very fast at D100 and D105, and very slowly, particularly at around the 40 and 70 cm levels at Wetland. The freezing at 80 cm depth occurred one month later at Wetland than at D105, even though air temperatures were similar. The 0 °C isotherm in the thawing season moved very fast at D100, particularly from 10 to 80 cm, and moved faster at D105 than at Wetland. The 0 °C isotherm moved slowly from the end of April to the middle of May at Wetland.

4.1.2. Altitudinal difference of surface freezing and thawing

The altitudinal differences of the first freezing and thawing dates and freezing period which is determined from daily mean ground temperatures at 0 and 10 cm depth at 4 sites are shown in Fig. 2. The first freezing and thawing dates are defined as the first day when ground temperature decreased and inc reased to 0 °C respectively. The duration of the freezing period is the number of days between the first days of freezing and thawing. The first freezing dates at these four sites were in the middle to the end of October, and the first thawing dates were in the middle to the end of April. The first freezing and thawing dates became later and earlier respectively with decrease of altitude. The duration of freezing periods at D100, D105, Wetland and Tanggula Pass were 198, 210, 221 and 225 days, becoming shorter with decrease of altitude in general. The thawing dates and durations of freezing periods at D100, D105, and Tanggula Pass with similar sparse vegetation conditions lay on a regression line, but the values at Wetland with dense vegetation do not lay on it. This difference can be considered to be due to the difference in soil moisture which will be explained later.

4.1.3. Thickness of active layer

The variations of 0 °C depth at D105 and Wetland in the thawing season are shown by squares and circles respectively in Fig. 3; these values were obtained by interpolation and extrapolation of ground temperature data. The depth could not be calculated after July 29 because of the small gradient of ground temperature at D105. No data were obtained at Wetland from the middle of June to the middle of July. The solid lines in the figure are the calculated depths, which are given below.

In order to obtain the 0 °C depth after July 29, the following equation giving the relation between 0 °C depth and thawing index of accumulated daily mean air temperature is applied :

$$Z = a\sqrt{\Omega_T} \qquad (1)$$

Z : thawing depth (cm)
a : coefficient
Ω_T: thawing index (degree·days)

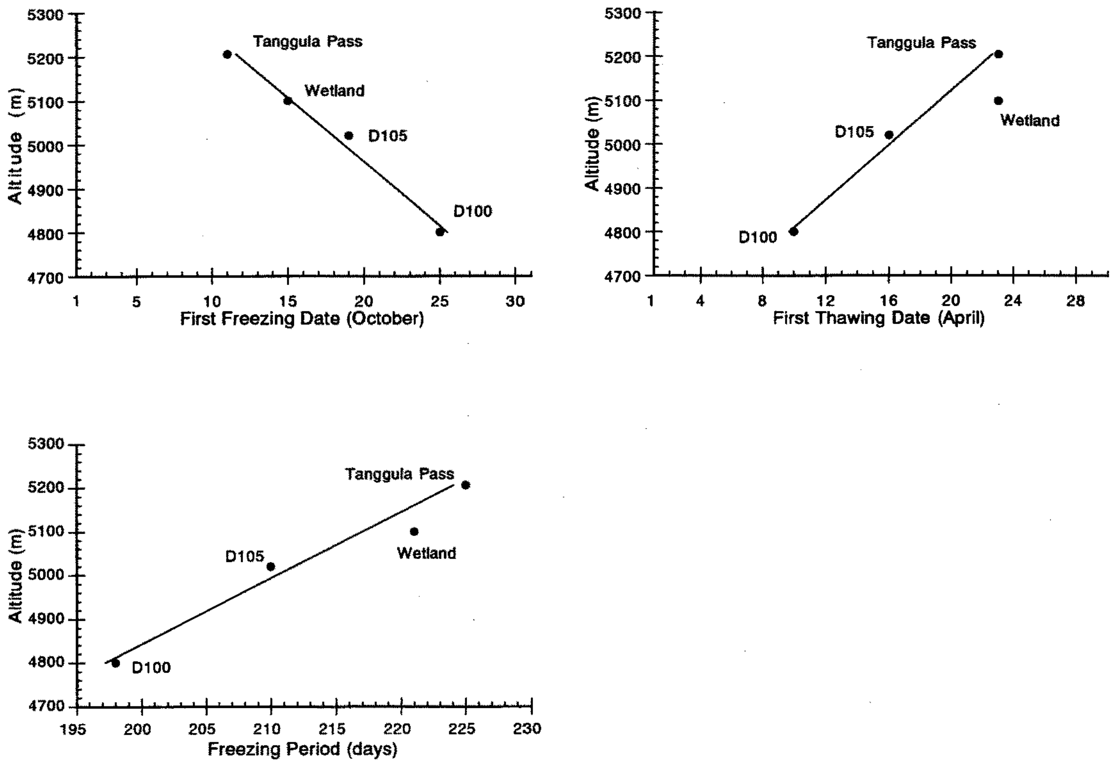

Fig. 2. Altitudinal differences of first freezing dates, first thawing dates and freezing period.

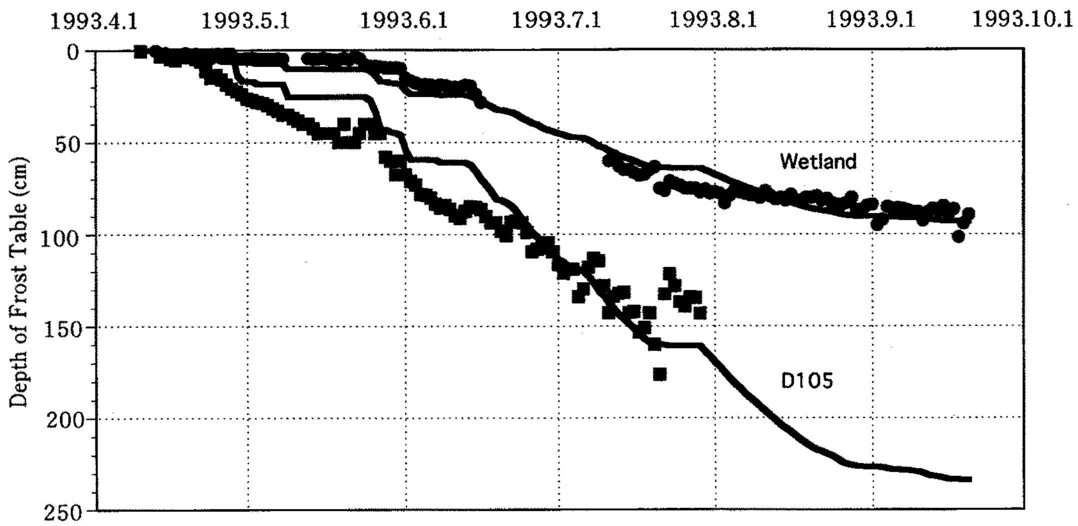

Fig. 3. Change of depth of frost table at D105 and Wetland. Solid lines show the depth of frost table.

Coefficient a depends on surface condition, soil moisture, heat conductivity, heat capacitance, and soil type. Figure 4 shows the relations between thawing depth (Z) and accumulated daily mean air temperature (Ω_T) at D105 and Wetland. The values of a are 13.2 for D105 and 5.3 for Wetland, obtained by the least square method. Using these values, thawing depths are calculated and are shown as solid lines in Fig. 3.

Air temperature decreases to 0 °C around September 20. The 0 °C depth at this time can be considered to be the thickness of the active layer 234 cm at D105 and 93 cm at Wetland. In spite of the similar air temperatures at both sites, the large difference in thickness of the active layer seems to be due to the difference in soil moisture content, which will be explained later. The thicknesses of the active layer at these sites were smaller than those previously obtained in this region (Tong and Li, 1983).

4.2. Soil moisture content

Soil moisture content was measured by two methods. One was the direct method described in section 3, and the other was an indirect method, transforming the value of heat conductivity to soil moisture.

4.2.1. Direct method

The soil moisture contents on October 2, 1992 and May 31, 1993 at each site are shown in Fig. 5. The averages in the surface 40 cm at D100, D105, Wetland and Tanggula Pass were 18, 19, 53 and 16 % respectively on October 2, 1992, and were 20, 18, 48 and 27 % respectively on May 31, 1993. Soil moisture content never exceeded 35 % at all depths at D100, D105 and Tanggula Pass, and soil moisture never fell below 35 % at all depths at Wetland. Soil moisture content was not so different from place to place in autumn and spring except at the surface. As all layers freeze and soil moisture does not change much in winter, these soil moisture content in autumn were thought to be unchanged through winter. Soil moisture content below 40 cm depth at D100 was different in autumn and spring ; the difference was more than the measurement error but the cause obtain is not clear.

Figure 6 shows the variations of soil moisture content, frost table and water table at D105 and Wetland from the end of May to July. This figure shows that the depth of the frost table on July 10 was 125 cm at D105 and 58 cm at Wetland. The water table was observed at 55 cm on July 10 and increased to 25 cm on July 29 at D105 ; it was at the depth of 28 cm on July 10 and reached the surface on July 19 at Wetland. At D105, soil moisture content was 45 % at the depth of 50 cm on July 20, and the frost table depth was 58 cm. This increase of soil moisture content corresponds to the rising water table.

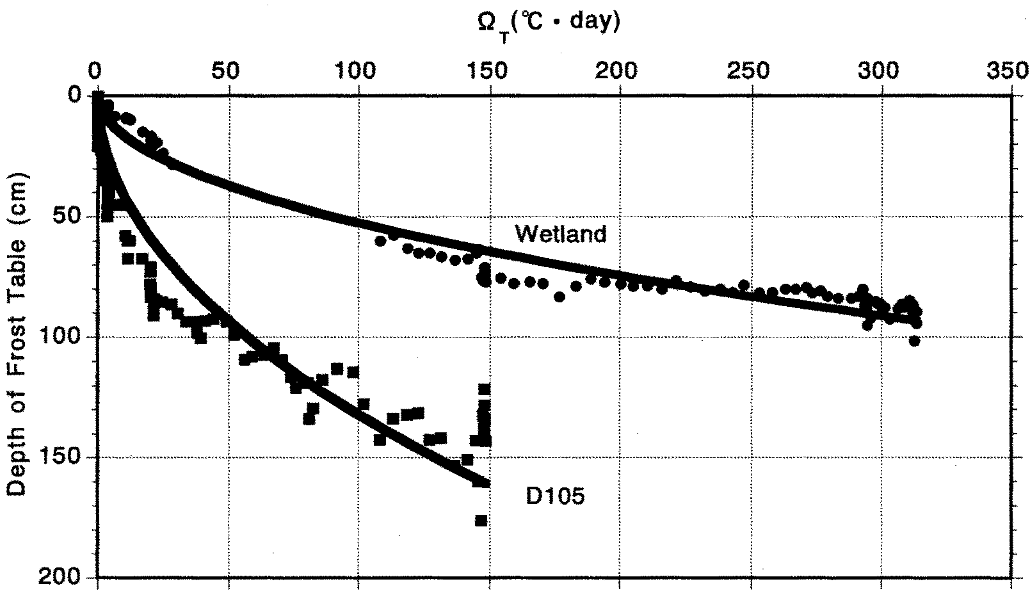

Fig. 4. Relation between depth of frost table (Z) and thawing index (Ω_T) at D105 and Wetland. Solid lines are obtained by equation (1).

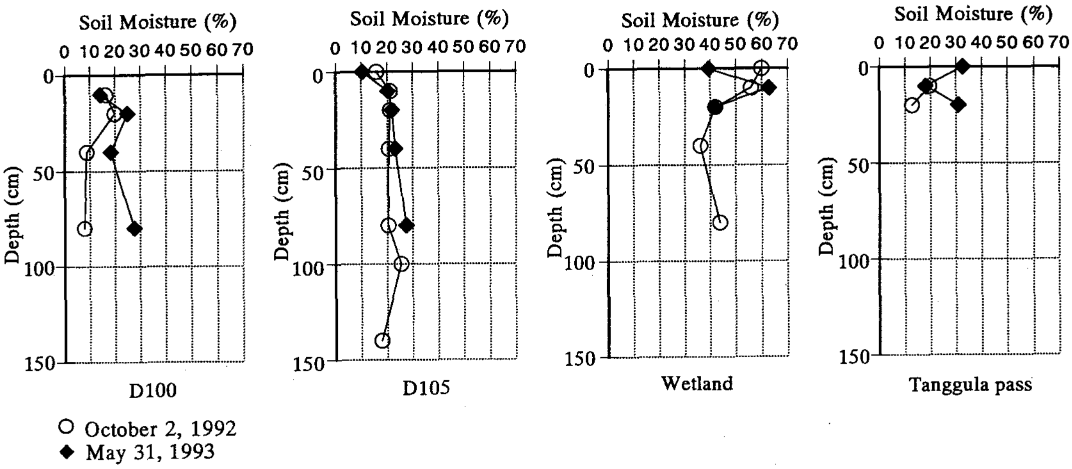

Fig. 5. Soil moisture contents on October 2, 1992 and May 31, 1993 at D100, D105, Wetland and Tanggula Pass. Open circles indicate values on October 1992, and solid squares values on May 31 1993.

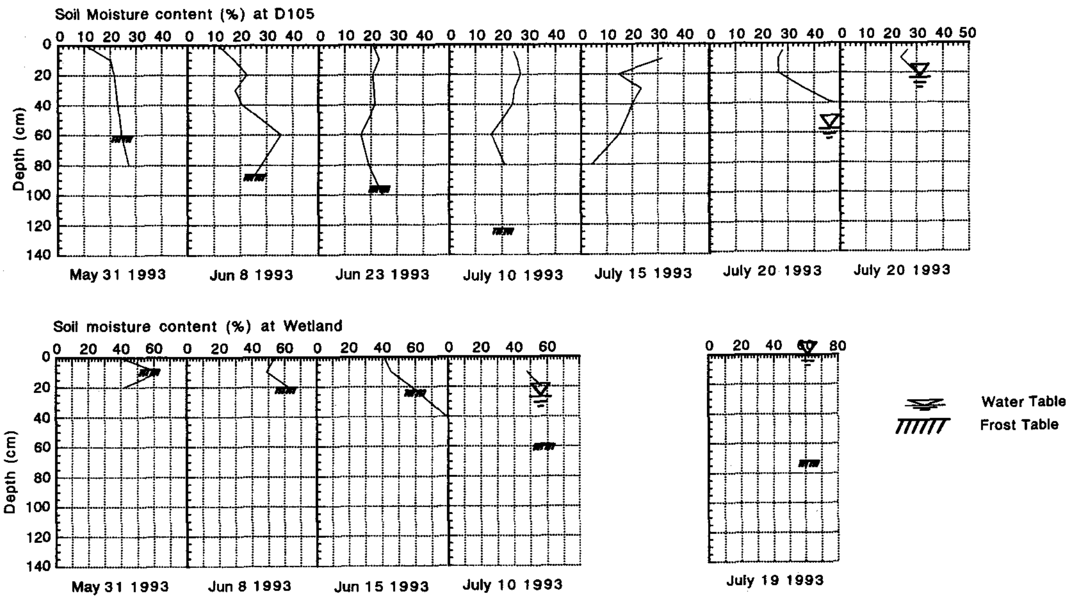

Fig. 6. Variation of soil moisture content (% volume), frost table and water table by at D105 and Wetland.

4.2.2. *Indirect method*

Only limited soil moisture contents were obtained by the direct method. In order to obtai n longer data and the daily variation, heat conductivity was measured and was transformed to soil moisture content. The result obtained at D105 is explained below.

The relationship between heat conductivity and soil moisture content was investigated in detail by Farouki (1981) and the following linear relation was obtained.

$$\Theta = b + c\lambda \qquad (2)$$

Θ : volumetric soil moisture (%)

b, c : coefficient

λ : heat conductivity (W/m·K)

The coefficients b and c in equation (2) were obtained by comparing with the values of soil moisture contents obtained by both direct and indirect methods. Table 1 shows the values of b and c for each depth at D105. The coefficients depend on the method of sensor installation and soil texture. Therefore, they cannot be used at other sites.

Table 1. The values of coefficients b and c in equation (2).

Depth	b	c
5 cm	−27.3	36.9
10 cm	− 5.6	24.9
20 cm	10.4	12.6
30 cm	−27.5	27.6

The daily mean soil moisture contents obtained by equation (2) at 5, 10, 20 and 30 cm in depth at D105 are shown in Fig. 7. Solid lines indicate the values obtained by the indirect method and solid circles indicate values measured by the direct method. This figure shows the good correlation between soil moisture contents obtained by both direct and indirect methods.

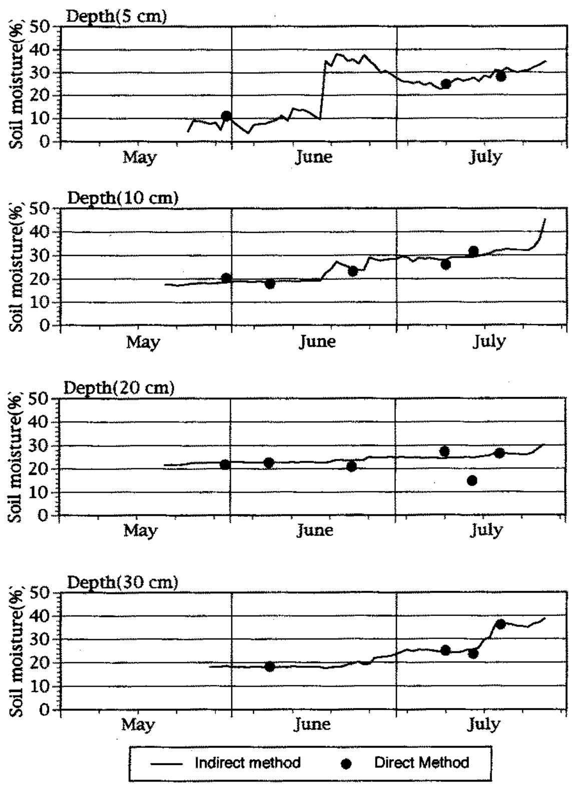

Fig. 7. Daily mean soil moisture content (% volume) obtained by equation (2) at 5, 10, 20, 30 cm in depth at D105. Solid circles indicate values obtained by the direct method.

5. Concluding remarks

The following results were obtained from the measurement of ground temperature and soil moisture content in the Tanggula Mountains, Tibetan Plateau in 1992–1993.

(1) The thawing dates and the freezing period at sparse by vegetated sites lay on a linear line, but these values at the densely vegetated site did not fall on this regression line.

(2) The thicknesses of the active layer at D105 and Wetland in 1993 were 234 and 93 cm respectively.

(3) The average values of soil moisture content at 40 cm depth at D100, D105 and Tanggula Pass (sparsely vegetated sites) at May 31, 1993 were 20, 18 and 27 %. The value at Wetland (densely vegetated site) was 48 %. Soil moisture content at the densely vegetated site was larger than that at sparsely vegetated sites.

(4) The detailed variation of soil moisture from May to July in 1993 can be obtained by soil moisture content-heat conductivity respectively.

The relation between active layer depth soil moisture, soil texture and surface condition such as vegetation will be analyzed in near future.

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