**A CENTURY OF TEMPERATURE OBSERVATIONS OF SOIL CLIMATE: METHODS OF ANALYSIS AND LONG-TERM TRENDS**

D. A. Gilichinsky¹, Roger G. Barry², S. S. Bykhovets¹, V. A. Sorokovikov¹, T. Zhang², S. L. Zudin¹, D. G. Fedorov-Davydov¹

1. Institute of Soil Science & Photosynthesis, Russian Academy of Sciences, Pushchino, Russia

2. National Snow and Ice Data Center, University of Colorado, Boulder, USA

**Abstract**

We have considered the spatial and temporal characteristics of the temperature distribution in the active layer in Russia, where an annual cycle of long and deep seasonal freezing/thawing is a leading process. The results collected are unique in terms of period covered, the extent of territory, natural zones, type of soils, and wide spectrum of geographical conditions from polar lowlands to arid deserts and Central Asian mountains. The primary contribution of this collection from about 1000 stations is to studies of global change, because regular measurements at some of them were started in 1890, and the data cover almost 100 years. The present paper discusses the long-term soil temperature trends at depths 0.4, 0.8, 1.6 and 3.2 m from seven stations (mean annual and monthly data for January, April, July and October).

**Introduction**

The global trend of warming at the Earth’s surface should be recorded in trends of soil temperature regime (as an integrator of all natural processes) rather than by those of air temperatures. The goal of this work is to show the preliminary results and perspectives to be gained by using soil temperature data collected at meteorological stations in Russia (Figure 1).

**Methods of analysis**

Observations made by the Hydrometeorological Service include the following parameters: temperature at the ground surface, specifically the temperature of the underlying surface: a bare soil surface in summer, the snow surface in winter; soil temperatures at 0.05-0.2 m depth in the warm season measured by bent-stem thermometers; soil temperatures at 0.2-3.2 m depth measured by extraction thermometers; the depths of ground freezing/thawing. Observations at the soil surface and to 0.6 m depth were made at 0700, 1300, 2100 hours before 1936; at 0100, 0700, 1300 and 1900 hours during 1936-1965; and 0000 and every three hours Moscow standard time (UTM+3 hours) since 1966. Observations with the extraction thermometers at 0.8 m or deeper were made once daily near midday.

The observation site is a level, unshaded part of the meteorological enclosure. The soil surface and bent-stem thermometers are installed within a bare surface area, free of vegetation but with a natural snow cover which is dug-over to a depth of 25 cm, aerated and leveled in early spring. The extraction thermometers are within a plot with natural cover which is grass covered and representative of the station surroundings (regularly maintained) or with a natural snow-covered state. The temperature of the soil or snow surface is routinely measured with an alcohol and mercury soil thermometer for current, minimum and maximum values. The soil thermometers on the bare plots are installed so that the half of their reservoirs are buried in the soil. In the case of snow cover the thermometers are installed in an analogous manner with respect to the snow surface. The initial temperatures were determined to 0.1°C but the procedure did not give high accuracy and since 1959, observations have been rounded to whole degrees.

The temperatures in the upper layers of the soil (0.05, 0.1, 0.15, 0.2 m) are measured routinely in the warm season by bent-stem thermometers. They are installed in spring after the disappearance of the snow cover and are removed in autumn. Deep soil temperatures are measured using extraction thermometers, enclosed in an ebonite pipe, and installed under a natural surface cover: grass in summer; snow in winter. The standard depths are: 0.2, 0.4, 0.8, 1.6 and 3.2 m, with additional ones at 0.6, 1.2 and 2.4 m. At a small number of stations, observations were (or are) made under both natural and bare soil surfaces. The depth of soil freezing/thaw-
ing is primarily determined by drilling a hole or by marking a soil pit. The frozen condition is established by the presence of ice crystals and cemented soil forms in samples extracted at different depths. Since the 1950s, most stations have used a freezing tube to obtain the depth of soil freezing.

Data collected at the meteorological station network are processed in summarized form and published in reports: Climatological Handbook of the USSR; Annual and Monthly Meteorological data; Soil temperature, The History; and physical-geographical description of the meteorological stations.

Results

Below we describe the seasonal trends for 4 stations of the Enisei meridian profile (see Figure 1) in central Siberia from 65° to 52°N.

#33, Turukhansk
There is a 35 year increasing trend for the mean January and April temperatures at 0.4 and 0.8 m; stable temperatures at 1.6 m; and a small decrease at 3.2 m. In the summer, there is an opposite trend: the mean July temperatures at 0.4, 0.8 and 3.2 m depths decreased and were stable at 1.6 m. In October in the upper layers (0.4 and 0.8 m) the temperature changes are the same as in winter – an increasing trend, and in the lower part (1.6 and 3.2 m), a small decrease.

#35, Eniseisk
The 70-year monthly January and April temperature levels at depths of 0.4 m (-2°C) and 0.8 m (0°C) are stable with an increasing trend in deeper layers. July temperatures increase in the three upper horizons and decrease at 3.2 m. Practically no changes occur at 0.8 and 1.6 m depths in October, but at 0.4 and 3.2 m depths, the data show decreasing trends.

#37, Krasnoyarsk
There is an increasing trend of January and April temperatures at all depths from 1916 (in spring this trend is pronounced in the lower horizons). July temperatures are characterized by a slight decrease from 0.4 to 1.6 m and by a sharply opposite trend at 3.2 m. The autumn trend is the same as at Eniseisk station.

Station #90, Tashtyp
The southern point of the profile has big differences in temperature trends in time and depths. From 1931, January temperatures increased 1.5°C at depths of 0.4 and 0.8 m and decreased 0.5°C at 1.6 and 3.2 m. In April, a slight decrease of soil temperatures at all depths was observed. Summer temperatures increased at the two upper levels and decreased sharply at the two lower ones.

The seasonal trends for another 3 stations in Baikal Region (Irkutsk), Yakutia (Zyryanka) and Northern European Russia (Kargopol) are shown on Figures 2-4.
Discussion

The present findings are considered illustrative rather than representative of the likely variety of trends in the surface and soil climate across Russia. This paper discusses actual values of temperature change rather than freezing/thawing indexes. Considerable differences in seasonal trends of soil temperature are observed at different depths. Moreover, the seasonal trends of soil temperature do not necessarily correspond with the trends observed for air temperature. There is good evidence of soil climate inertia and this shows the necessity to correlate soil temperatures with conditions of the previous season, for example, April soil temperatures are partly a function of winter conditions, July temperatures of spring conditions, and so on. Nevertheless, the history trend of annual soil temperature at most depths and stations shows increasing trends (Figure 5).

The results indicate that the increase in the mean annual soil temperature was mainly (but not in all cases) due to an increase in winter soil temperatures, even though summer soil temperatures had a small opposite effect. The cold period is much longer than the warm season. The main regulators of soil temperature are the water-ice phase changes due to soil physical properties (primarily soil moisture), and the cryogenic processes of freezing/thawing which are dependent on the autumn rainfall, time of establishment of snow cover and its depth. Because the cryogenic factor compensates for the influence of possible additional heat inputs, soil temperature trends are different in different regions, at different depths and for different periods of observations.

Acknowledgments

This work was supported in part by funding for the Global Geocryological Database (NSF-ATM 95-28007), NSF-ARCSS support for the NSIDC Data Coordination Center (NSF-OPP 96-14557), and by the U.S. Soil Survey; the support and encouragement of the GAD development by J. Brown and the IPA is appreciated. We also thank, for financial support, the Arctic program of Russian Ministry of Science and Russian Fund of Fundamental Research, and the Russian Federal Hydrometeorological Service for making the data available.
Figure 3. Monthly (January, April, July, October) trend history of air and soil temperatures at Zyryanka station (See the legend on Figure 2).

Figure 4. Monthly (January, April, July, October) trend history of air and soil temperatures at Kargopol station (See the legend on Figure 2).
Figure 5. The annual trend history of air temperatures at Zyryanka, Irkutsk and Kargopol stations and soil temperatures at all depths discussed: (0.4, 0.8, 1.6, 3.2 m) for all 7 stations (See the legend on Figure 2).