Impact of Surface Air Temperature and Snow Cover Depth on the Upper Soil Temperature Variation in Russia

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Soil temperature data at depths 80, 160 and 320 cm, as well as air temperature and snow depth data were analyzed. The data were obtained from all Russian meteorological stations for 49 years (1965-2004).

The Russian territory, from the western border to 75°E, exhibits significant positive correlation coefficients k = 0.6 between summer soil temperatures at the 160-cm depth and summer air temperatures (mean temperature for June to August). The territories of West Siberia and southern East Siberia, as well as the Far East stations in the vicinity of Sakhalin and Bilbin, east of 75°E, show significant correlation coefficients 0.4 to 0.5. The highest positive correlation coefficients k = 0.6 between summer air temperatures and soil temperatures at all depths considered (with a shift) are primarily observed outside the permafrost zone. In the vast central part of the permafrost zone, the correlation is close to zero (Fig.1).

The analysis of correlations between winter soil temperatures at different depths and snow depth in February shows that significant positive correlation coefficients (k) 0.4 to 0.6 are prevailing at depths 80 and 160 cm over the vast territory of Russia, from Sub-Ural to the eastern borders of the continent, with the exception of North Siberia Plains, Kamchatka and southern East Siberia. At the 320-cm depth, a significant positive correlation is only observed on small areas of southern West Siberia, Vili, Aldan and the southern Far East. As for European Russia, no significant correlation is found between winter soil temperatures at 80-, 160- and 320-cm depths and the snow depth.

The warming influence of snow at each depth is recorded over the vast areas of Asian Russia, but it becomes weaker as the depth increases and is not recorded at all in European Russia.

Mean annual soil temperature in different regions forms in a different way. In European Russia, it is controlled by air temperature changes rather than by snow depth. The warming effect of snow here is nearly absent. In Asian Russia, on the contrary, the changes in mean annual soil temperature are controlled by snow depth changes rather than by air temperature changes.

Fig. 1. Correlation coefficient (k) between air temperatures and soil temperatures at the 160-cm depth in summer

1 – 0.1k<0.2, 2 – 0.2k<0.4, 3 – 0.4k<0.6, 4 – 0.6k<0.8, 5 – southern border of permafrost, 6 – border of Russia.

In winter, the correlation considered proves to be weaker and the values k=0.6 are not noted. Significant correlation coefficients (0.4 to 0.6) between soil temperatures at depths of 80 and 160 cm and air temperatures in winter are primarily recorded over Russian Russia (Fig. 2).

Fig. 2. Correlation coefficient (k) between air temperatures and soil temperatures at the 160-cm depth in winter

1 – 0.1k<0.2, 2 – 0.2k<0.4, 3 – 0.4k<0.6, 4 – 0.6k<0.8, 5 – 0.8k<0.10, 6 – southern border of permafrost, 7 – border of Russia.

It is southern European Russia alone, where the impact of winter air temperature changes is recorded as deep as 320 cm. In winter, the impact of long-term air temperature changes in the permafrost zone is nearly not recorded at depths.

Fig. 3. Long-term trend of mean annual air temperatures (Ta), soil temperatures at depth (Tp) and snow height (Hs) at Onega station

At stations in Asian Russia and the Urals, the values of soil temperature trends are higher than those of air temperature trends. Positive soil temperature trends are recorded even at the stations with negative air temperature trends (Ural, Yenisei, Indigirka, Bolyai). The contribution of snow height to soil temperature changes over Asian Russia is 9.3 to 49.6% of the total variability. And the contribution of the mean annual air temperature to the total variability of soil temperature here is no higher than 7%. Station Bokhara (Fig.4), at the negative air temperature trend (-0.06°C/decade) shows a positive soil temperature trend (0.47°C/decade) that is likely to be related to the growing snow accumulation at this station. The contribution to the total variability is made by the mean annual air temperature, 4.7%, and the snow height, 30%.

The contribution of the mean annual air temperature and the snow depth to the change in mean annual soil temperature was estimated in portions from the total dispersion of the soil temperature (in percent).

The comparison shows that in European Russia, the main contribution to the total dispersion is made by the air temperature (23 to 46%) of the contribution to the total dispersion) and the contribution of snow here is minimal (0.4 to 8.0%). The impact of snow on the soil temperature in this region is so small (Fig.3) that even at negative snow depth trends (stations Sortavala, Vyborg, Onega, Komat), soil temperature trends are positive and significant.

Fig. 4. Long-term trend of mean annual air temperatures, soil temperatures at 160-cm depth and snow height at Bokhara station

A complete picture of the contribution of the two factors to the total variability of mean annual soil temperatures is shown as diagrams on the map (Fig.5) at locations of the stations.

Fig. 5. Contribution (in percent) of mean annual air temperature (Ta) and snow height (Hs) to long-term changes in mean annual soil temperature at 160-cm depth

1 – Contribution (in %) of mean annual air temperature to long-term changes in mean annual soil temperature,
2 – Contribution (in %) of snow height to long-term changes in mean annual soil temperature,
3 – border of Russia,
4 – scale of the 25-per cent contribution of the factor under study.

Nearly on the entire territory of European Russia, the long-term changes in mean annual soil temperature at depths 80 and 160 cm are greatly controlled (20 to 50%) by air temperature changes (light columns in diagrams). The snow changes here determine no more than 10% of the variability of the soil temperature (Fig.6). In Central Volga, the Urals and nearly on the entire territory of European Russia, the long-term changes in mean annual soil temperature are considerably controlled (10 to 50%) by the snow height changes and the air temperature here controls 80 to 10% of the soil temperature variability. At the 320-cm depth, the effect of surface meteorological conditions is very weak and uneven over the Russian territory.

The growing snow accumulation in Siberia results in the additional rise in the mean annual soil temperature and its more rapid increase as compared with the warming trends in the lower atmosphere. This fact is of particular importance in the permafrost zone since it strengthens one of the components of its likely degradation.

The impact of long-term changes in air temperatures on soil temperatures in the central regions of the permafrost zone is weak both in summer and in winter. However, in the regions with broken frozen earth, this impact is substantial. The snow height impact on the soil temperature is observed nearly throughout the permafrost zone of Russia.