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THERMOPHYSICAL PROCESSES IN THE CRYOSPHERE

INFLUENCES OF AIR TEMPERATURE AND SNOW COVER ON THE SEASONALLY FROZEN SOIL LAYER CHARACTERISTICS

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The seasonally frozen soil layer dynamics has been studied using the Bakchar meteorological station (Tomsk region) daily records for the period of 1963–2011. Their analysis revealed a co-dependent relationship between the seasonally frozen layer, surface air temperature and snow cover characteristics.

Soil temperature, seasonally frozen layer, snow cover, air temperature, depth of freezing

INTRODUCTION

Soil temperature is a sensitive climate indicator integrating variations of land surface air temperature (SAT), atmospheric precipitation and other climatic parameters which play an important role in all the physical, biological and microbiological processes occurring within the soil. The reaction of soil temperature on the current climate change is largely governed by the landscape conditions of objects of study [*Pavlov, 2008*]. During the period of global warming at the end of the 20th century, temperature variations in the upper and deep soil layers were studied by many researchers based on weather stations records [*Gilichinskii et al., 2000; Sherstyukov, 2008; Vasiliev et al., 2008; Trofimova and Balybina, 2012*] and on reanalyses of archival data, using the dynamically coordinated global fields characterizing current state of the Earth's surface and atmosphere, as raw data for their analyses [*Zolotov et al., 2011*].

Trends in the mean annual soil temperature values recorded at a depth of 320 cm constitute 0.1–0.8 °C/10 years [*Duchkov, 2006; Pavlov, 2008; Sherstyukov, 2008; Zolotov et al., 2011; Balybina and Trofimova, 2013*]. Tendencies in soil temperature variations within the upper soil layers appear quite complex, representing a co-dependent relationship of land surface air temperature, precipitation regime, and snow cover characteristics [*Zang et al., 2005; Popova and Polyakova, 2013; Shmakin et al., 2013*]. Statistically significant negative correlations between the timing of the snow cover degradation and the mean SAT in March have been found for the southern West Siberia [*Popova and Polyakova, 2013*], which signify a great impact of the progressively earlier springtime warming on the onset of ablation processes. The established trends for the Arctic offshore areas north of 70° N are marked by the progressively later formation of snow cover and its earlier destruction [*Radionov et al., 2013*].

Changes in the snow cover characteristics and air temperature oscillations in the cold period directly influence both the development and degradation of the seasonally frozen layer [*Maksyutova and Gustokashina, 2009*]. The study of long-term dynamics of the cold season weather conditions and soil temperature variations allows to identify the factors controlling ground temperature regimes, including processes of the seasonally frozen layer development/degradation.

THE DATA USED

This paper aims at investigating specific features of the seasonally frozen layer dynamics, relying on the observational data from the Bakchar weather station (Tomsk region) for the period of 1963–2011, and analyzing a relationship between the characteristics of seasonal freeze-thaw processes, surface air temperature and the snow cover depth. The data on average daily SAT, sum of precipitation, snow depth and soil temperature in the area of the weather station were provided by VNIGNI World Data Centre (http://www.meteo.ru/climate) [*Sherstyukov, 2012*]. To describe the temperature regime of the cold period, we used such parameters, as mean monthly temperature and average temperature of the cold period (from November through March), the dates of the first and last frost events, and the dates of air temperature stable transition over 0 °C in spring and autumn.

For the snow cover characterization, the following parameters were used: depth of snow; dates of snow cover arrival and disappearance; dates of the onset of operational snow cover and its degradation; year-specific duration of the snow-cover (number of days that the ground is snow covered**)**, and maximum snow depth during the winter [*Drozdov, 1957*]. Given that the snow depth will be increasing during the winter and decreasing in the late winter, monthly averages can not serve as basis for its dynamics monitoring. To this effect, daily averages are preferred.

A rated frost depth was determined by the 0 °C temperature penetration depth into the ground [*Drozdov, 1957*]. The depth of soil freezing was calculated by a linear interpolation of the soil temperatures between two adjacent layers, provided that the temperature in one of the layers was negative. To determine the frost depth, we used data on the diurnal ground temperature variations at depths of 20, 40, 80, 160 and 320 cm in the period spanning from 1963 to 2011. Since temperature measurements were not available for the 0–20 cm surface layer, the estimates for the seasonally frozen layer evolution do not include the topsoil layer.

The Bakchar weather station is positioned on the Bakchar River terrace, where soil is described as sod-gley heavy-textured clay loam. The mean annual SAT for the period of 1963–2011 constituted –0.2 °C, with July ranking warmest (18.3 °C), and January (–19.2 °C) coldest on the records. Total annual precipitation amounted to 471 mm, of which 43 % fell in the summer months and 14 % during the winter. The maximum positive average soil temperature at a depth of 20 cm was observed in July (17 °C), and the lowest (–2.4 °C) in February. Given that the amplitude of annual temperature variations tends to decrease with depth, the onset of maximum and minimum soil temperatures will lag behind the surface temperatures. At a depth of 320 cm, the amplitude equals 4.4 °C, peaking (7.3 °C) in October, and ranking lowest (2.8 °C) in May. The recorded mean annual temperature averaged at 4.9 °C for the soil layer at a depth from 20 to 320 cm.

AIR TEMPERATURES IN THE COLD PERIOD

Over the period of 1963–2011, negative values of the mean monthly air temperatures were observed, typically, from November (averaging at –9.0 °C) through March (–8.9 °C) in the area of the weather station. In some years, negative temperatures were recorded in October (as low as –6.5 °C) and April (–5.6 °C). In the middle of the winter (January) the temperature may drop down to –19.2 °C, on average. Winter of 1968/69 was the coldest, with the mean monthly temperatures in November (–18.4 °C), December (–26.3 °C) and February (–29.7 °C) taking their lowest values during the entire study period.

The temperature during the cold period (from November through March) in 1968/69 averaged at – 23.4 °C, while the long-term average value constituted –14.1 °C. The record low January temperature (–31.8 °C) was in 2006, which is one degree lower, than in 1968. At the end of the study period, positive anomalies of the winter months were recorded for November (–2.8 °C) in 2008; for December (–7.4 °C) in 2006; for January (–9.3 °C) and February (–8.1 °C) in 2002. The mean annual SAT increased at a rate of 0.33 °C/10 years. Significant rising tendencies in the temperature values were revealed for October (0.6 °C/10 years), February (0.93 °C/10 years), March (0.7 °C/10 years) and May (0.55 °C/10 years). The temperature records have shown warming trends in other months, too, being weaker, though. Exceptions are January and July with the temperature trends showing an inconspicuous decrease. Thus, the current global climate warming [*IPCC, 2007*] exert a major impact in the months when the areas receive/become free from their winter snow cover, and during intense development/degradation of the seasonally frozen layer.

The development of the frozen layer is also likely to be affected by the timing of the onset of a freezing cold period, with air temperature resting steadily below 0 °C. The dates of the first and last cold events, usually called spring/fall frosts are associated with the night cooling, and their values are determined by lower readings of the thermometer [*Drozdov, 1957*]. Approximate date of the first frost derived from the long-term observations falls on September, 19, varying over a wide range, from August, 19 (2007) to September, 30 (1987). The last freeze of spring occurs typically between May, 12 (1999) and June, 19 (1992), with May, 29, as its average. Therefore, the period when negative temperatures can be observed during the day will last 260 days (standard deviation, STD = 15.3). From 1963 to 2011, the dates of both the first and last frost were characterized by shifting to earlier dates at a rate of 1.2–1.3 days/10 years, but the trend appears not significant, since the spread of dates from year to year varies greatly (Fig. 1).

The dates of air temperature stable transition over 0 °C were determined by average diurnal SAT [*Kelchevskaya, 1971*]. The period of negative daily temperatures lasts on average 172 days, from October, 21 to April, 11. The date of the onset of belowzero temperatures in autumn tends to shift to later dates at a rate of 2.6 days/10 years, and the date of the positive temperatures onset in spring shifts at a rate of 1.5 days/10 years to earlier dates. The duration of the period with negative temperatures is thus reducing at a rate of 4.1 days/10 years (Fig. 1).

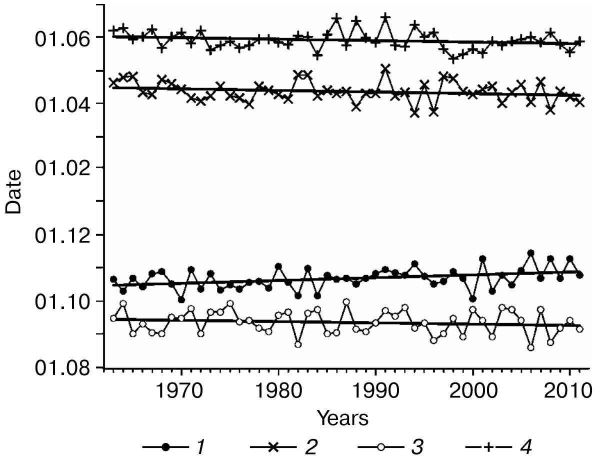

Fig. 1. Dates of air temperature stable transition through 0 °C.

1 – beginning of winter; *2* – end of winter; *3* – first frost; *4* – last frost.

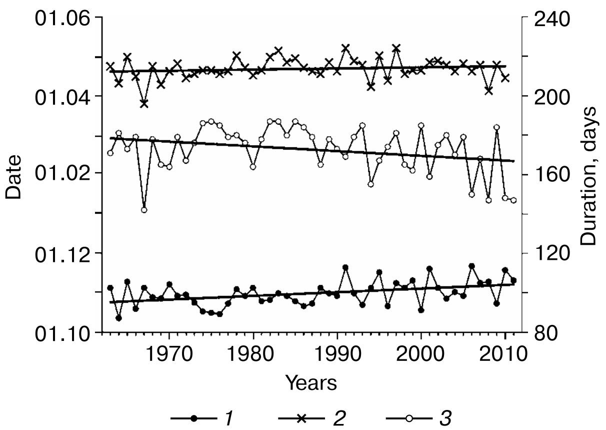

Fig. 2. The dates of onset (*1*) and disappearance (*2*) of steady seasonal snow cover and its duration (*3*).

SNOW COVER

The arrival of first snow cover usually ends by its melting out due to the subsequent thaw days and it's only after stabilization of below-zero temperatures that it sets in for the winter. On average, over the period of 1963–2011 the snow cover would form on October, 10. Typically, 10 days is a standard deviation for that date. The earliest snow cover on set date in was September, 3 in 1968, while its latest date was recorded on November, 10 2010. The formation of seasonal snow cover is succeeded by its stabilization (i.e. operational snow cover) attained on average, in about 21 days. First snow, however, did not melt out in four cases. According to the weather station observations, there has not been any year without seasonal snow cover in this particular area.

The date of the stable snow cover formation falls, on average, on October, 30 (with STD = 10 days). The earliest formation of snow cover occurred on October, 12 (1964), while the latest was November, 21 (2006). Variations of snow cover onset/destruction dates are shown in Fig. 2. It should be noted that during the study period, the timing of the stable snow cover onset tends to shift to later dates. The value of the linear trend attributable to this change is equal to 2.8 days over a 10-year period (the coefficient of determination for a simple linear regression $r^2 = 0.18$).

The degradation of stable snow cover is usually completed by April, 21 (STD = 8 days). The earliest date of snow disappearance was March, 26 (1968), the latest date was May, 8 (1992, 1998). Thus, the duration of the stable snow cover, according to the Bakchar weather station records, is 173 days, which varied from 142 days in 1967 to 187 days in 1975, 1982, 1983 and 1985 (Fig. 2).

The highest snow depth values during the winter season were recorded in mid March, averaging at 64.8 cm in the period of 1963–2011 (STD = 19.5 cm). In the winter of 1967 with little snow, the maximum snow depth did not exceed 23 cm, whereas, for comparison, in 1990 the depth of snow reached 111 cm.

The beginning of the snow cover destruction also tends to later dates. The linear trend for this change constitutes only 0.4 days/10 years, and given that the date when seasonal snow cover sets in is shifted faster, than the date of its destruction, the duration of snow cover will decrease at a rate of 2.4 days/10 years. During the study period, maximum snow depth variations were characterized by divergence in trends over the winter season. In the first half of the period, there was a growth in maximum snow cover depth at a rate of 16.1 cm/10 years, whereas between 1987 and 2011 the depth of snow tended to reduce at a rate of 11.9 cm/10 years.

In East Siberia, the thickness of snow cover showed an increase at rates varying between 0.6 and 6.0 cm in 10 years in the period from 1961 to 2010 [*Maksyutova, 2013*]. Given that increased depth of the snow cover provides additional protection from air temperature variations, thus allowing preservation of heat accumulated during the summer, to be stored in the earth during the winter, the rates of the mean annual soil temperature growth would be higher, versus the rate of the atmosphere warming. The warming of soils will certainly affect the mode of their freezing.

SEASONALLY FROZEN LAYER

Freeze-thaw processes dynamics. The data on the 0 °C temperature penetration depth into the soil is an important characteristic of the soils thermal regime in the cold period, which determines the depth of layer with negative temperatures.

Fig. 3 illustrates the seasonally frozen layer dynamics, showing time dependence of average diurnal snow depth, air temperature and soil temperature isotherm for the period from October, 1 1982 through October, 1 1985. The winter seasons of 1982/83 and 1984/85 have shown various types of modes of freeze/thaw events, with the first period characterized by anomalously weak development of the seasonally frozen layer, and the second – by intense freeze-up and the presence of thawed layer atop the frozen one in spring-time.

The winter of 1982/83 was moderately warm (average temperature for November is –5.2 °C), with snow cover established on October, 26, therefore, the freezing commenced very late. It's only after December, 4 that negative temperature was documented at a depth of 20 cm. The mean January temperature in 1983 (–11.7 °C) was 9 °C higher than the long-term average values, which precluded the formation of the frozen layer. As a result, maximum frost depth in winter 1982/83 reached 51 cm overall by March, 13 and later began to decrease due to the beginning of the seasonally frozen layer thawing from bottom up. This maximum frost depth value over the winter season proved the lowest for the studied period. On April, 30 the ground was totally free from the frozen state.

In the winter of 1984/85, following the snow cover onset on October, 29, the freezing of soil began on November, 6. The November mean monthly temperature constituted –17 °C, and dropped to –30 °C on November, 30, which along with the weakly developed snow cover caused rapid advancement of the frozen layer boundary deep down. By December, 27 1984, the basal part of the frozen layer reached a depth of 90 cm, where the rate of freeze-up slightly slowed down.

By March, 11, 1985 the ground had frozen to a depth of 116 cm, and then the frozen soil began thawing from the bottom upward because of the heat input from deeper layers. By April, 26, 1985 the soil layer had thawed to a depth of 89 cm, and at the same time the thawing began from the upper boundary down, which means that further destruction of the frozen layer occurred simultaneously from the top and bot-

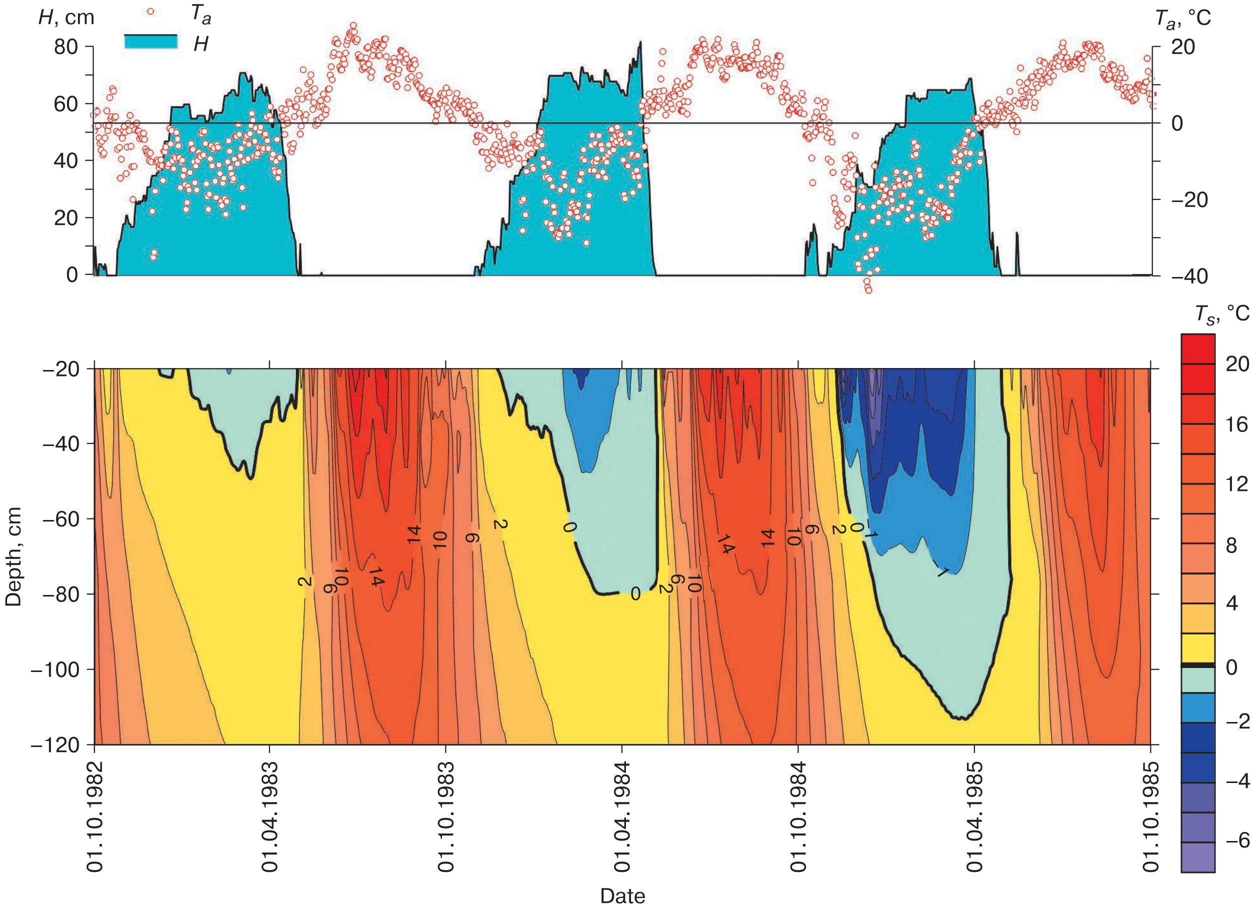

Fig. 3. Time-dependent averages daily for snow cover depth (H), air temperature (T_a) and soil temperature isotherms (T_s) in 1982–1985.

Solid line – rated seasonal freeze depth ($T_s = 0$ °C).

tom, with the downward thawing rate being significantly higher. Negative temperatures were observed at a depth of 80 cm for the longest time (until May, 24 1985). The degradation of the stable snow cover completed on April, 26 1985.

Multi-year average parameters of the frozen layer. As shown above, the behavior of the frozen layer differs greatly even in neighboring years. In terms of multiyear average estimations, according to the weather stations observations, the recorded freezing depth was 20 cm from November, 20 onwards (STD = 16 days), which was preceded by the first frost (September, 11), and first snow arrival (October, 10). Temperature transition to negative values occurred on October, 21, followed by the snow cover stabilization (October, 30). In some years, the freezing events onset date can be observed both earlier (November, 2 1991), and much later (January, 21 1980).The dynamics of formation of the seasonally frozen layer and degradation dates is shown in Fig. 4.

The processes incidental to the frozen layer degradation from its lower boundary revive starting from March, 9. Around that same time, the loss of snow cover thickness becomes observable. From April, 11 onwards positive temperatures set in and 7 days later (April, 18) the frozen zones began to melt intensely from the top down. The rate of the frozen degradation layer from the top is approximately two times higher than from the bottom. On average, by April, 21 the stable snow cover is destroyed and on May, 1 for the most part disappears from the surface, with the latter being completely freed from the snow by May, 5 (STD = = 15 days). April, 4 1981 proved the earliest date of the frozen layer thaw-out. In 1969–1972 the frozen layer remained for abnormally long time, until June, 1–4 (Fig. 4).

The duration of the seasonally-frozen state of ground is 166 days, which is only 7 days less than the time the snow cover lasts. Analysis of the snow cover formation/destruction dates of both frozen layer and snow pack, has shown that the frozen layer freezes up at a depth of 20 cm, on average, 21 days later than the formation of the stable snow cover. In 1965, 1991 and 2006, the formation of the seasonally frozen layer was recorded prior to the onset of the stable snow cover, i.e. 2, 18 and 2 days earlier, respectively.

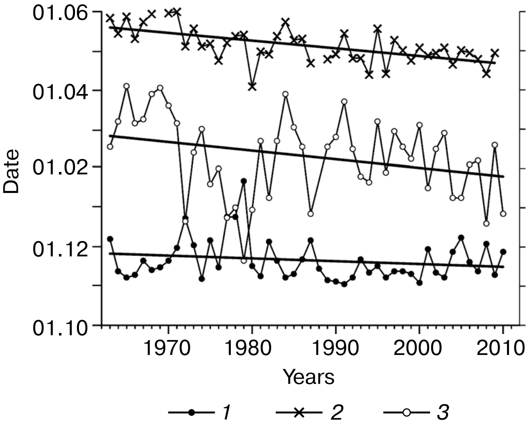

Fig. 4. The date of formation (*1*) and degradation (*2*) of seasonally frozen layer and its duration (*3*).

Maximum freezing depth during the winter season falls on March 9 and was recorded at 93.4 cm on average for the period spanning from 1963 through 2011 (STD = 26.3 cm). Maximum freezing depth (144 cm) was recorded on February, 2 1968 during the abnormally cold winter of 1968/69, whereas the least freeze depth (51 cm) was recorded in 1982.

Another important characteristic of the seasonally frozen layer is the rate of the freezing front advancement. Table 1 provides the data on rates of freezing during the first 30 days after the formation of frozen layer, during the second and third months of its existence, and in the last 30 days, prior to its complete degradation. There are also evidences, that as the freezing proceeds, the rate of the frozen layer development has reduced from 0.84 cm/day at the beginning of the period to 0.49 cm/day in the third month.

In some years (e.g. 1998), the freezing rate increased to 1.82 cm/day during the first 30 days of the freeze-up, when sub-zero temperatures (as low as −10 °C) were observed before the stable seasonal snow cover established. The destruction of the frozen layer begins from its basal part at a rate averaging at 0.86 cm/day (max 2.63 cm/day). The thawing rate from the top downward averages 2.84 cm/day, with a maximum of 7.03 cm/day in the spring of 1992.

The speedy degradation of the frozen ground in the upper layers are likely to have been caused by meltwater at temperature with small positive values, percolating under the snow cover in the shallow subsurface [*Shmakin et al., 2013*]. According to the data for the 49-year observation period provided to us, thawing from the top downward was not recorded in 13 cases, with 10 of them falling within the second half of the studied period. These may have been the years when the two thawing fronts – advancing from

Table 1. **Rate of advancement of the seasonally frozen layer boundary, according to the Bakchar Meteorological Station data**

Observation period	Rate, cm/day		
	ave.	max	STD
First 30 days	0.84	1.82	0.45
30th–60th day	0.58	1.40	0.42
60th–90th day	0.49	1.76	0.59
Last 30 days	−0.86	−2.63	0.57

Note. Ave. – multiyear average value over the period of 1966–2006; max – maximal value; STD – mean-square (standard) deviation.

the top and bottom –are encountered at a depth of over 20 cm.

Multiyear changes in the characteristics of the seasonally frozen layer. The dynamics of the beginning/ending dates (Fig. 2), and the duration of seasonally frozen layer (Fig. 3), and the rates of its formation/ disappearance (as shown in Table 1) allowed to find trends in their values within the analyzed period from 1963 through 2011.

The date of the frozen layer degradation tends to shift to earlier dates at a rate of 6.6 days/10 years (Fig. 4). The date of the ground becoming free from the frozen state is dictated by the timing of the onset of spring, as well as by the nature of the frozen layer development during the winter. The dates of its frozen state decay are largely influenced by the temperatures of the cold period (correlation coefficient $r = -0.37$), maximum snow depth ($r = -0.45$), and the date of steady change of air temperatures to over 0 °C in spring ($r = 0.44$). The observed warming in February–March and May at a rate from 0.55 to 0.93 °C/10 years, as well as a slight shift (–1.5 days/10 years) of the date of air temperature crossing 0 °C will accordingly affect the date the frozen layer has completely decayed.

The time of the formation of the frozen layer is thus slightly shifted to an earlier date at a rate of 2.2 days/10 years. The implications are that the duration of the frozen layer decreases consistently with the shifted date of its degradation.

The rate of shifting the dates of the frozen ground beginning to thaw from the top, and that of the air temperature transition to the positive domain during the examined period are virtually the same and constitute –1.5 days/10 years. The onset date of thawing from the top is also associated with the mean monthly temperature in March ($r = -0.34$), April ($r = -0.52$) and the date of the disappearance of stable snow cover ($r = 0.36$). There exists an essential correlation relationship ($r = 0.38$) between the length of the period of active degradation of the frozen layer from the top (from the date of the thawing onset to the date when the ground becomes totally free from the frozen state) and the rate of the snow cover degradation in spring.

That is, the length of the thawing period proves less in years characterized by rapid melting of the snow cover, accompanied by meltwater percolating into the soil, which does promote the degradation of the frozen ground. The duration of the frozen layer degradation from the top has a negative correlation with the date of the onset of thawing ($r = -0.44$). In the years with a later onset, it would take shorter for the frozen layer to thaw.

Given that the maximum depth of the seasonally frozen layer is decreasing, the value for the depth of frost penetration in the decreasing linear trend is 10.4 cm/10 years. The maximum freezing depth in winter temperature conditions is dictated by the winter months' regime, and is largely affected by a maximum depth of the snow cover during the winter ($r = -0.63$), air temperature in February ($r = -0.35$) and March ($r = -0.40$), and by average temperature of the cold period ($r = -0.41$). The greatest depth of frost penetration are observed during the coldest winters, even with the weakly developed snow cover, which ultimately has a greater effect, as evidenced by the correlation coefficients. Regression analysis has allowed to establish quantitative characteristics of the relationship between the freeze depth and air temperatures in the winter months and the snow cover depth. Linear equation relating maximum frost depth (*FD*, cm) and snow depth (*SD*, cm) takes the form of:

$$FD = 149.0 - 0.85SD,$$

which can be interpreted as a decrease in freeze depth by 8.5 cm at a 10-cm increase in snow depth. The linear regression coefficients characterizing the relationship between the depth of freezing and air temperature in winter months range from –2.1 cm/°C (in February) to –3.4 cm/°C (in March). The rate of the frozen layer boundary advancement in the first month of freezing has slightly decreased (by 4 % in 10 years), while in the second and third months the decrease in its rate constituted 24–25 % over the period of 10 years. The rate of the frozen layer degradation has shown no significant long-term trend.

CONCLUSIONS

The analysis of dynamics of the seasonally frozen layer development and degradation in the context of current global warming has provided a detailed picture of the ongoing changes. With the air temperature increasing during winter months, the duration of snow cover tends to reduce, and the observations have shown that the snow depth has grown less since 1987. The formation and disappearance of the seasonally frozen layer have also shifted to earlier dates.

The period of existence and maximum depth of the frozen layer tends to reduce. The reducing linear trend for the depth of freezing constitutes 10.4 cm/10 years. The observed tendencies in the seasonally frozen layer variability have been shaped by SAT variations over November, and February–April.

In the cold season, the ground freeze depth is greatly affected by maximum snow cover depth and temperatures during the winter months, and, judging from the correlation coefficients, of these, the influences of the snow cover appear commanding. The snow cover characteristics, however, do not have any statistically significant impact on the length of the seasonally-frozen state of the ground.

References

Balybina, A.S., Trofimova, E.I., 2013. Dendro-indication of soil temperature in Baikalian-type basins. Geografya i Prirodnye Resursy, No. 2, 58–65.

Drozdov, O.A. (Ed.), 1957. Methods for Climatological Processing of Meteorological Observations. Gidrometeoizdat, Leningrad, 492 pp. (in Russian)

Duchkov, A.D., 2006. Characteristics of permafrost in Siberia, in: Advances in the Geological Storage of Carbon Dioxide. Springer Publ., Berlin, pp. 81–92.

Gilichinskii, D.A., Bykhovets, S.S., Sorokovikov, V.A., et al., 2000. The use of data from meteorological stations in calculating long-term trends of soil temperature dynamics in the seasonally frozen and permafrost areas of Russia. Kriosfera Zemli IV (3), 59–66.

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change / S. Solomon, D. Qin, M. Manning et al. Cambridge Univ. Press, Cambridge, U.K.; N.Y., 996 pp.

Kelchevskaya, E.S. (Ed.), 1971. Observational Data Analysis Methods in Agroclimatology. Gidrometeoizdat, Leningrad, 215 pp. (in Russian)

Maksyutova, E.V., 2013. Long-term fluctuations of snow cover thickness and maximum snow reserves in the Cis-Baikalia area. Led i Sneg, No. 2 (122), 40–47.

Maksyutova, E.V., Gustokashina, N.N., 2009. Changes in climate characteristics for a cold period in the area of the Irkutsk-Cheremkhovo plain. Geografya i Prirodnye Resursy, No. 4, 87–92.

Pavlov, A.V., 2008. Monitoring of the permafrost zone. Publishers, GeoPublishers, Novosibirsk, 229 pp. (in Russian)

Popova, V.V., Polyakova, I.A., 2013. Changes in the timing of stable snow cover degradation in the north of Eurasia in 1936–2008: The impact of global warming and the role of large-scale atmospheric circulation. Led i Sneg, No. 2 (122), 29–39.

Radionov, V.F., Aleksandrov, E.I., Bryazgin, N.N., Dementiev, A.A., 2013. Changes in temperature, precipitation and snow cover in the Arctic seas areas over the period 1981–2010. Led i Sneg, No. 1 (121), 61–68.

Sherstyukov, A.B., 2008. Correlation between the ground temperature and air temperature and snow cover depth. Kriosfera Zemli XII (1), 79–87.

Sherstyukov, A.B., 2012. Daily soil temperature dataset at depths up to 320 cm from the meteorological stations of the Russian Federation. Tr. FGBU "VNIIGMI-MCD", iss. 176, pp. 233–256. (in Russain)

Shmakin, A.B., Osokin, N.I., Sosnovskii, A.V., Zazovskaya, E.P., Borzenkova, A.V., 2013. Ground freeze and thaw processes affected by snow cover in the West Spitsbergen Influence of snow cover on soil freezingand thawing in the West Spitsbergen. Led i Sneg, No. 4 (124), 52–59.

Trofimova, I.E., Balybina, A.S., 2012. Monitoring of soil temperature and snow cover thickness in Irkutsk region. Led i Sneg, No. 1 (117), 62–68.

Vasiliev, A.A., Drozdov, D.S., Moskalenko, N.G., 2008. Permafrost temperature dynamics in Western Siberia in the context of climate change. Kriosfera Zemli XII (2), 10–18.

Zang, Y., Chen, W., Smith, S.L., Riseborough, D.W., Cihlar, J., 2005. Soil temperature in Canada during the twentieth century: Complex responses to anthropogenic climate change. J. Geophys. Res., Vol. 110, D03112.

Zolotov, S.Yu., Ippolitov, I.I., Loginov, S.V., Luchitskaya, I.O., Belaya, N.I., 2011. Comparison of the soil temperature profiles based on West-Siberian station network measurements and the data of the NCEP/NCAR reanalysis. Kriosfera Zemli XV (2), 14–20.

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