Chin. Geogra. Sci. 2016 Vol. 26 No. 4 pp. 527–538
doi: 10.1007/s11769-016-0825-y

Springer Science Press
www.springerlink.com/content/1002-0063

Effects of Snow Cover on Ground Thermal Regime: A Case Study in Heilongjiang Province of China

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Abstract: The important effects of snow cover to ground thermal regime has received much attention of scholars during the past few decades. In the most of previous research, the effects were usually evaluated through the numerical models and many important results are found. However, less examples and insufficient data based on field measurements are available to show natural cases. In the present work, a typical case study in Mohe and Beijicun meteorological stations, which both are located in the most northern tip of China, is given to show the effects of snow cover on the ground thermal regime. The spatial (the ground profile) and time series analysis in the extremely snowy winter of 2012–2013 in Heilongjiang Province are also performed by contrast with those in the winter of 2011–2012 based on the measured data collected by 63 meteorological stations. Our results illustrate the positive (warmer) effect of snow cover on the ground temperature (GT) on the daily basis, the highest difference between GT and daily mean air temperature (DGAT) is as high as 32.35℃. Moreover, by the lag time analysis method it is found that the response time of GT from 0 cm to 20 cm ground depth to the alternate change of snow depth has 10 days lag, while at 40 cm depth the response of DGAT is not significant. This result is different from the previous research by modeling, in which the response depth of ground to the alteration of snow depth is far more than 40 cm.
Keywords: snow cover; ground temperature; lag time analysis; spline mean; difference between ground temperature and air temperature (DGAT)

Citation: Li Xiaofeng, Zheng Xingming,Wu Lili, Zhao Kai, Jiang Tao, Gu Lingjia, 2016. Effects of snow cover on ground thermal regime: a case study in Heilongjiang Province of China. *Chinese Geographical Science*, 26(4): 527–538. doi: 10.1007/s11769-016-0825-y

1 Introduction

The analysis of ground thermal regimes is of importance in many problems of scientific interest, e.g., climate modelling, agriculture and ecosystem studies and engineering design in cold regions. In the northeastern China, especially in the most northern Heilongjiang Province, the ground temperature is a crucial factor in determining the spring-sowing time, and it is also the most important environmental factors controlling seed germination rates and timing (Alvarado and Bradford, 2002). Since snow cover has low thermal conductivity and high albedo and emissivity, it has large impacts on the ground thermal regime, which has been widely recognized recent years (Cohen and Rind, 1991; Robinson *et al.*, 1993; Groisman *et al.*, 1994; Barry, 1996; Zhang *et al.*, 1997; Ling and Zhang, 2003). The high surface albedo and emissivity of snow cause a reduction in the absorbed solar energy and an increase in the out-going long-wave radiation that result in the cooler snow surface. The low thermal conductivity of snow insulates the ground, reducing the amount of cooling which occurs

Received date: 2016-01-08; accepted date: 2016-04-01
Foundation item: Under the auspices of National Natural Science Foundation of China (No. 41471289, 41301368), Natural Science Foundation of Jilin Province (No. 20140101158JC), Foundation of State Key Laboratory of Remote Sensing Science (No. OFSLRSS201517)
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during the cold season (Zhang *et al*., 1997; Sturm *et al.*, 1997; Liston *et al.*, 2002; Taras *et al*., 2002; Bartlett *et al.*, 2004). At the same time, snow has high latent heat of fusion which makes snowmelt being a heat sink. The overall impact of snow cover on the ground thermal regime depends on the complex factors, which include timing, duration, accumulation, and melting processes of snow cover, density, structure, and thickness of snow cover and interactions of snow cover with micrometeorological conditions, *etc*. (Zhang, 2005; Li *et al.*, 2014). If the other environment conditions are almost similar, snow properties themselves (e.g., depth, density and timing) will have a significant impact on the ground temperature (Ling and Zhang, 2003; 2006; 2007).

Many studies have evaluated the influence of snow cover on ground thermal regime through the numerical models, e.g., Goodrich (1982) presented the results of a numerical study of the effects of snow cover on long-term, periodic, steady-state equilibrium ground temperatures. Ling and Zhang (2003) used a one-dimensional heat transfer model with phase change to analyze the impact of changes in the timing and duration of snow cover on the thermal regime of the active layer and permafrost in the Alaskan Arctic. In another paper, Ling and Zhang (2006) also reported that variations in tundra snow density can strongly affect the near-surface ground temperature and conductive heat flux in the northern Alaska. The effects of the different factors on ground thermal regime can be studied and discussed by adjusting the input parameters of models. However, less cases and insufficient data based on field measurements are available to verify the results of models and to show nature cases, particularly for agricultural regions. In addition, we also concern whether these findings apply to other sites, especially to the cold and agricultural regions in China.

In this study, a typical case in Mohe County, located in the most northern tip of China, is given firstly to show the effects of snow cover on the ground thermal regime. Mohe (abbreviated to MH) and Beijicun (abbreviated to BJC) are two comparable and close meteorological stations, which both are in Mohe County, their nature geography environment are almost the same, only the snow depth and timing are different. This gives us a chance to analyze ground temperature variations at different depth with different snow depth and timing in a nature state, not in control or by modeling. Based on the analysis in the above two stations, another typical case is discussed to indicate the effect of snow cover on the ground temperature. As we all know, the past 2012–2013 winter is an especially snowy winter in Northeast China, it is also the snowiest winter in Heilongjiang Province since the year 1961. At the same time, in the spring of 2013 due to the low ground temperature and too wet soil, the spring-sowing time has to be postponed again and again, which has brought big threat for the crop growth and the food production. To illustrate the effect of snow cover, the ground thermal regime in this extreme snowy winter is compared with that in 2011–2012 winter in Heilongjiang Province based on the measured data collected by more than 60 meteorological stations. The analysis results in this typical case study provide an additional insight to the hazard prediction and develop the more effective model.

2 Materials and Methods

2.1 Study area

Heilongjiang Province (43°26′–53°34′N, 121°13′–135°06′E) has an area of 469 000 km^2, and it is the northernmost province of China (Fig. 1). It borders the provinces of Inner Mongolia to the west, Jilin to the south and Russia on the Northeast. Heilongjiang Province is located between the temperate and the frigid zones with continental monsoon climate, the yearly average temperature of which is fluctuating from minus 4 to 4 degrees centigrade, and it is also the province with the longest winters in China. Snow covers the ground as long as half a year from October to April.

Mohe County (52°10′−53°33′N, 121°07′−124°20′E) is a county of Heilongjiang Province, China, and is the northernmost Chinese county (Fig. 1). Mohe County is one of the few locations in China with a subarctic climate, with long, severe winters, and short, warm summers. Winter begins in early to mid-October and lasts until late April, and temperatures then are normally the coldest nationwide. Average temperatures stay below freezing for a total of nearly seven months of the year, and the frost-free period is just short of 90 days; in addition, the diurnal temperature variation is large, averaging 15.9℃ annually. The monthly 24-hour average temperature ranges from −29.8℃ in January to 18.4℃ in July, with an annual mean of −4.29℃, so that the county is only a little south of the line of continuous permafrost. Extreme temperatures have ranged from −52.3℃ to 39.3℃ (Gui *et al.*, 2009).

Beijicun, the northernmost Chinese settlement, at the latitude of 53°29'N known as the 'Arctic Village' lies in Mohe County, on the Heilongjiang River, which forms the border with Russia's Amur Oblast and Zabaykalsky Krai.

2.2 Data

The basic meteorological data used in this study are collected from 63 national meteorological stations in Heilongjiang Province, including snow depth, mean daily air temperature, ground temperature from 0 cm to 40 cm during the winter of 2011−2012 and 2012−2013. The meteorological stations distribution is shown as black and grey points in Fig. 1.

As mentioned above, firstly we will focus on the time series analysis of the snow depth and ground temperature at MH and BJC during the winter of 2011−2012. Therefore, these data are firstly shown in Fig. 2. The data show that the lowest air temperature are −37.42℃ and −37.63℃, respectively, at MH and BJC stations; the lowest ground temperature are MH: −17.36℃ and BJC: −15.93℃ both at 0 cm, they are much higher comparing with the lowest air temperature. The thickest snow depth is 16 cm appearing at MH meteorological station from 8th to 11st, March 2012. Since two meteorological stations are close, the daily air temperature is the same basically, as shown in Fig. 2(a), but it is easy to see from Fig. 2(b) that snow depth in MH and BJC is very different, before 21st January, 2012 the snow depth in BJC is thicker and after that time it is deeper in MH. The same environment conditions and different snow depth give us a typical case to study the effect of the snow depth on the ground regime. The ground temperatures with different depth (0 cm, 5 cm, 10 cm, 15 cm, 20 cm, and 40 cm underground) in MH and BJC are also shown in Figs. 2(c)−2(d).

2.3 Methodology

2.3.1 Spline Mean

To compare the different effect of the snow depth on the ground temperature, daily data will be used in this study. Daily air and ground temperature has more significant fluctuations at the neighboring days, which is not suitable for trends analysis and comparison. Enlightened by Intrinsic Mode Function (IMF, Huang *et al.*, 1998), a spline mean method is used to smooth the daily temperature data, and the processing procedure is as follows: firstly, to find the maximum and minimum points of the temperature series $T(t)$ and three-order spline function to fit the maximum and minimum envelope of $T(t)$, respectively; secondly, to obtain the average value, $M(t)$, for every day from the maximum and minimum envelope curve. Here, $M(t)$ is called as the spline mean of the original temperature series $T(t)$. A simple example of spline mean is shown in Fig. 3. Unlike the method of multi-day mean which is usually used to smooth the data, the spline mean will not change the temporal resolution.

2.3.2 Lag time correlation analysis

The previous research shows that there is an observable lag in the thermal response of a soil relative to changing air temperature due to the insulating of snow cover (Zhang, 2005; Mackiewicz, 2012). Here, the lag time is referred to the number of days from the first snowfall date to the occurrence of the maximum correlation coefficient between DGAT and the difference between snow depth in MH and BJC. A lag correlation analysis is proposed here as follows:

$$t^* = \underset{0 \le t \le d}{\arg\max} \left\{ C(DS(t_0 : t_s), DT(t_0 + t, t_s + t)) \right\} \quad (1)$$

where t^* is the lag time, and $C(x, y)$ represents correlation coefficient of vectors x and y. $DS(t_0 : t_s)$ denotes the difference of snow depth from the first snowfall time t_0 to the date t_s when snow melts away. Similarly, $DT\ (t_0 +$

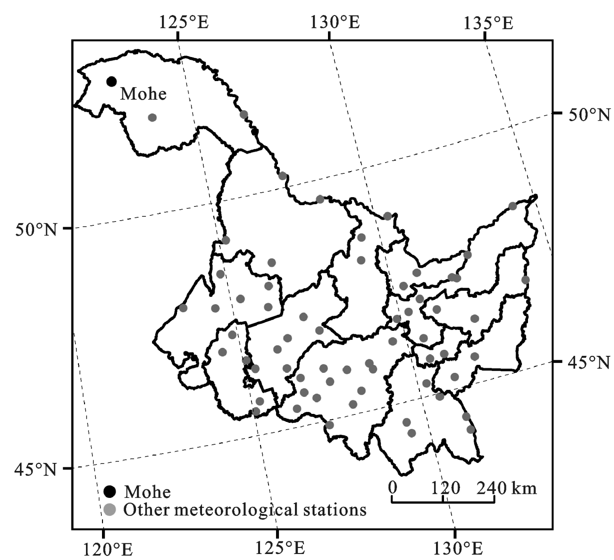

Fig. 1 Geographic locations of Mohe County in Heilongjiang Province

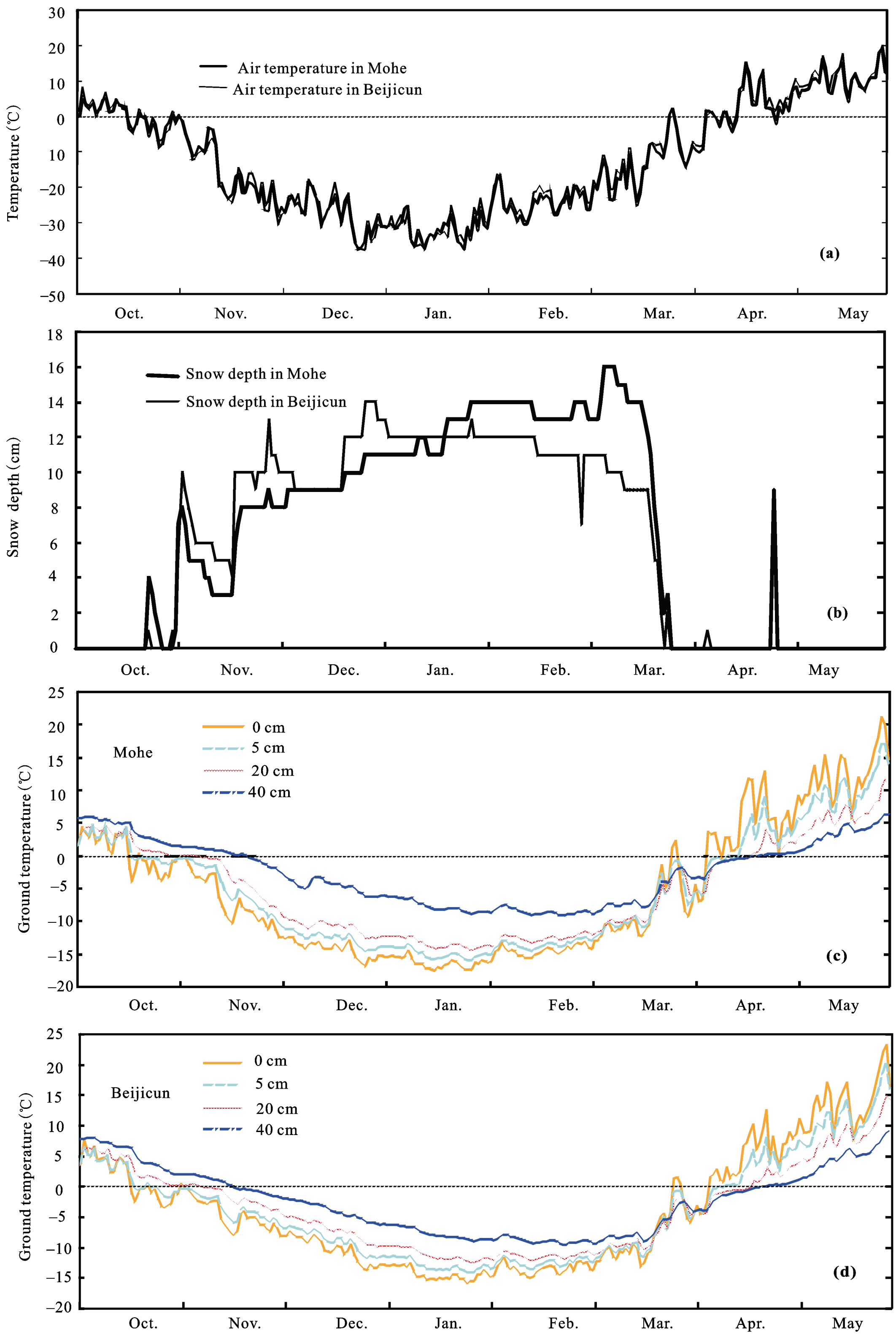

Fig. 2 Meteorological conditions (a) daily air temperature; (b) snow depth; (c) and (d) 0 cm–40 cm ground temperature in Mohe and Beijicun during October, 2011–May, 2012. The horizontal coordinate is abbreviation of each month from October 2011 to May 2012

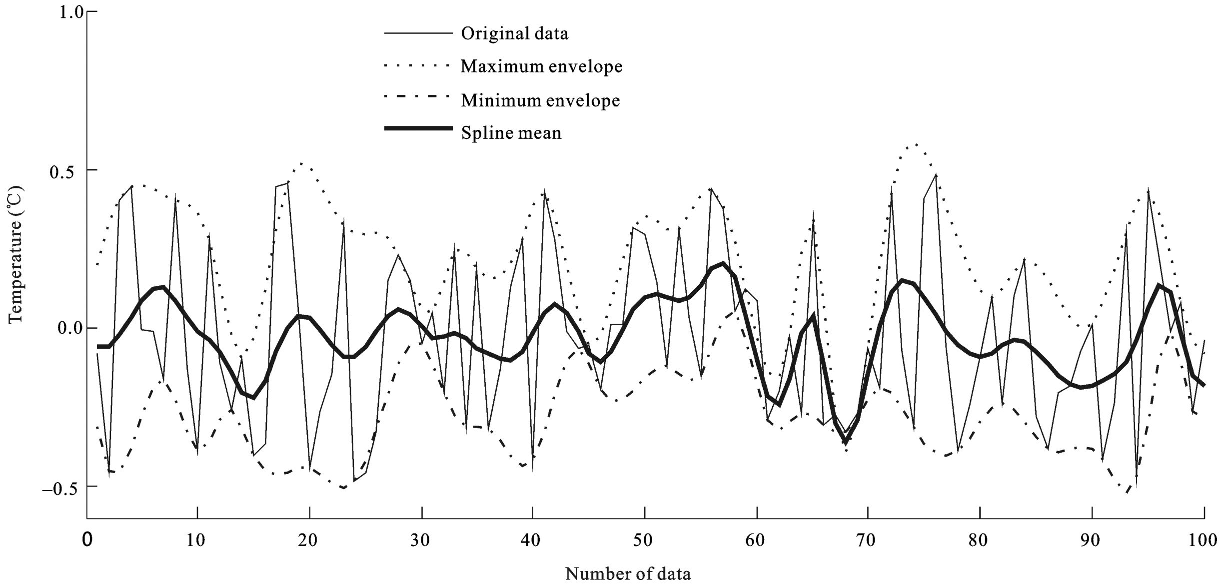

Fig. 3 An example for spline mean of a set of temperature data

t, $t_s + t$) represents the difference of ground temperature from the time $t_0 + t$ to $t_s + t$, and t denotes the lag time. arg max $C(t)$ is the set of values of $t \in [0, d]$ for which $C(t)$ attains its largest value, and d is the upper limit of the number of days, which is usually less than 30 days. The value of t^* indicates the response time of ground temperature at different depth to the snow thickness and its variation at the different stations. The larger value of t^* implies the longer response time, and vice versa.

2.3.3 Difference between ground temperature and air temperature (DGAT)

DGAT is usually used as an indicator to study the effect of snow cover on the ground temperature (Zhang *et al.*, 1997). It can remove the other influence factors and highlight the effect of snow cover on the underlying ground. The positive or negative DGAT means the warmer or cooler effect of snow cover. The spatio-temporal comparison analysis of DGAT at MH, BJC meteorological stations and the whole Heilongjiang Province will be performed to reveal the effect of the alternation of snow depth on DGAT at the different depth. The correlation between DGAT and snow depth will be also demonstrated further.

3 Results and Discussion

3.1 Profile analysis results of DGAT

From the snow data of October 2011 to May 2012 (Fig. 2(b)), we note that before 21st January, 2012 the snow depth is larger in BJC than MH, and it is converse after that time. To analyze the effect of the snow depth at two different phases, DGAT with the different depth at two stations are compared in Fig. 4. The mid-time of every phase, i.e., 3rd December, 2011 and 24th February, 2012, are chosen to show in these two figures. From them, it is easy to see that the case is different completely at two phases, when snow cover of BJC is thicker than that of MH at the first phase, DGAT with the depth from 0 cm to 40 cm at BJC are all larger than ones at MH, while at the second phase when snow cover is thicker in MH, DGAT with the different depth in MH are clearly higher than those in BJC. At the same time, all DGAT are larger than zero. These results mean that snow cover results in the warmer ground evidently at two stations at the time, and the thicker the snow cover, the higher the ground temperature.

Mean and standard deviation of DGAT is calculated at the different underground depth (0 cm, 5 cm, 10 cm, 15 cm, 20 cm, 40 cm) before and after 21st January, 2012 when the snow depth start to change alternately at MH and BJC meteorological stations. The statistical results are listed in Table 1, and Fig. 5 shows the mean and half standard deviation for two cases. From the Table and Figure, the average DGATs at all the depth at BJC are larger than that at MH before 21st January, 2012 when snow is thicker at BJC, the case is just the reverse when snow is thicker at MH (after 21st January, 2012). It should be noted that all the standard deviations are very large and they increase with the underground depth. They even excess the difference of DGAT of two stations, which will result in DGAT fluctuating wildly and having no comparable trend on the daily scale. This is the reason that spline mean method will be used in the next temporal analysis of DGAT. At the same time, the difference of the average DGAT between MH and BJC is smaller after 21st January, 2012, as shown in Fig. 5(b), which is mainly resulted from air temperature rising and snow reducing and disappearing (Fig. 2).

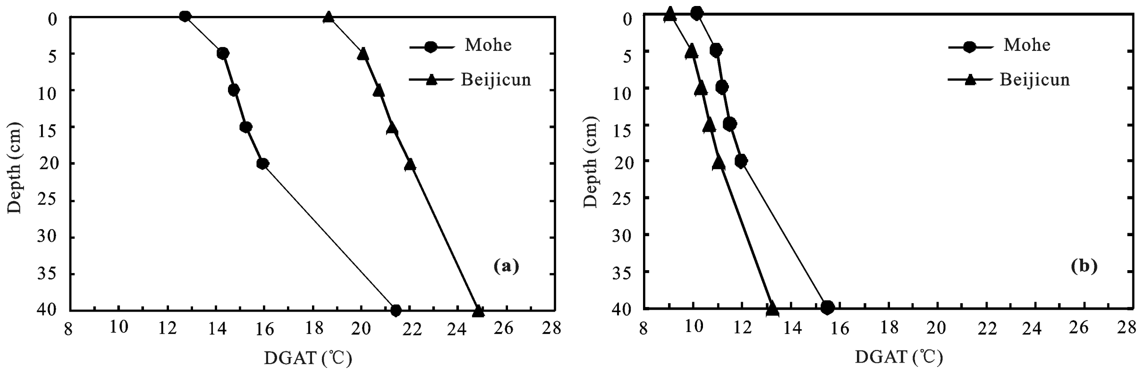

Fig. 4 Difference of ground temperature and air temperature (DGAT) with different ground depth at Mohe (MH) and Beijicun (BJC) meteorological stations at (a) 3rd December, 2011 (b) 24th February, 2012

Table 1 Multi-day Mean ± standard deviation of DGAT (℃) at the different underground depth before and after 21st January, 2012 at MH and BJC meteorological stations

Time	Station	0 cm	5 cm	10 cm	15 cm	20 cm	40 cm
Before 2012.1.21	MH	9.15±6.71	10.61±7.22	10.93±7.47	11.52±7.47	12.18±7.63	16.24±9.43
	BJC	11.60±7.91	12.70±8.44	13.28±8.59	13.87±8.61	14.51±8.74	16.99±9.33
After 2012.1.21	MH	7.05±5.23	6.86±6.77	6.65±7.43	6.87±7.63	7.05±8.03	9.28±9.90
	BJC	6.62±5.21	6.54±6.62	6.51±7.21	6.56±7.61	6.71±8.01	7.80±9.49

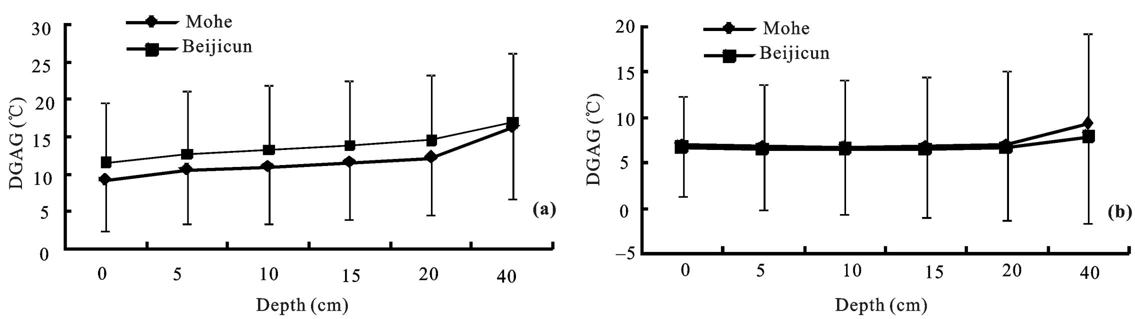

Fig. 5 Multi-day mean and standard deviation of DGAT from 0 cm to 40 cm underground (for brevity, only half standard deviations are shown) when snow is thicker (a) at Beijicun than Mohe (b) at Mohe than Beijicun before and after 21st, January 2012

3.2 Temporal variations of DGAT

The alternate change of the snow depth at MH and BJC could result in the increase or decrease of DGAT with time. Figure 6 shows the temporal variations of DGAT at 0 cm and 40 cm depth underground at two stations from 1st, October 2011 to 31st, May 2012. The highest DGAT is 32.35℃, which presented on 24th December, 2012 at BJC station at 40 cm underground depth. The other DGATs with depth of 5 cm, 10 cm, 15 cm and 20 cm are not shown in Fig. 6 due to their same changing trends as that with the depth of 0 cm. Note that DGAT data in Fig. 6 is processed using spline mean method mentioned above in order to obtain more obvious trends to compare the difference.

For contrast, the snow depth of two stations is also shown in Fig. 6 using the minor vertical axis. Moreover, according to the alternate change of the snow depth in MH and BJC, the whole snow season is divided to four time ranges, R1 to R4, as shown in Fig. 6. At the beginning of R1, there is no snow on the ground, then the first snowfall came in both stations at 23rd, Oct. 2011, and the snow depth in MH is larger than that in BJC. At first, DGAT is higher in BJC than in MH with both depths of 0 cm and 40 cm, and then DGAT in MH increases quickly to catch up or exceed slightly DGAT in BJC due to the first snow. In the range of R2, the snow depth in BJC is always thicker than that in MH. DGAT has the obvious response to snow cover at the depth of 0 cm, DGAT is also always higher in BJC than in MH. DGAT at the depth of 40 cm has no very clear response trends to the snow depth, DGAT of two stations increase alternately, which is mostly due to the more underground depth. On the contrary, in the range of R3 DGAT at 40 cm depth is more sensitive to the snow depth than that at 0 cm depth, where snow is thicker in MH than that in BJC. This could have a lot to do with the higher DGAT history in BJC in R2, its response to the variations of snow depth has a lag time, which is also the study content of the next section. In the region of R4, as the weather turns warmer, snow begins to melt. Now, the air temperature has become the major factor that affect the ground thermal regime. Although there is a snow at 8th and 28th, April 2012, in BJC and MH, respectively, the effect of snow on DGAT is not very obvious.

On the whole, DGAT of two stations varies accordingly with alternate changes of the snow depth from the range of R1 to R4. Snow cover has the positive effect (warmer) on the ground temperature with the different depth from 0 cm to 40 cm during the snow season of 2011–2012 winter in MH and BJC.

3.3 Lag time response of ground temperature

The snow depth on the ground may influence the rate of change in soil temperature. Due to the insulation of snow and the relatively heat capacity of the ground, a time lag exists necessarily between the alternation of snow depth and variations of DGAT. Here, the lag time will be extracted using lag correlation analysis method

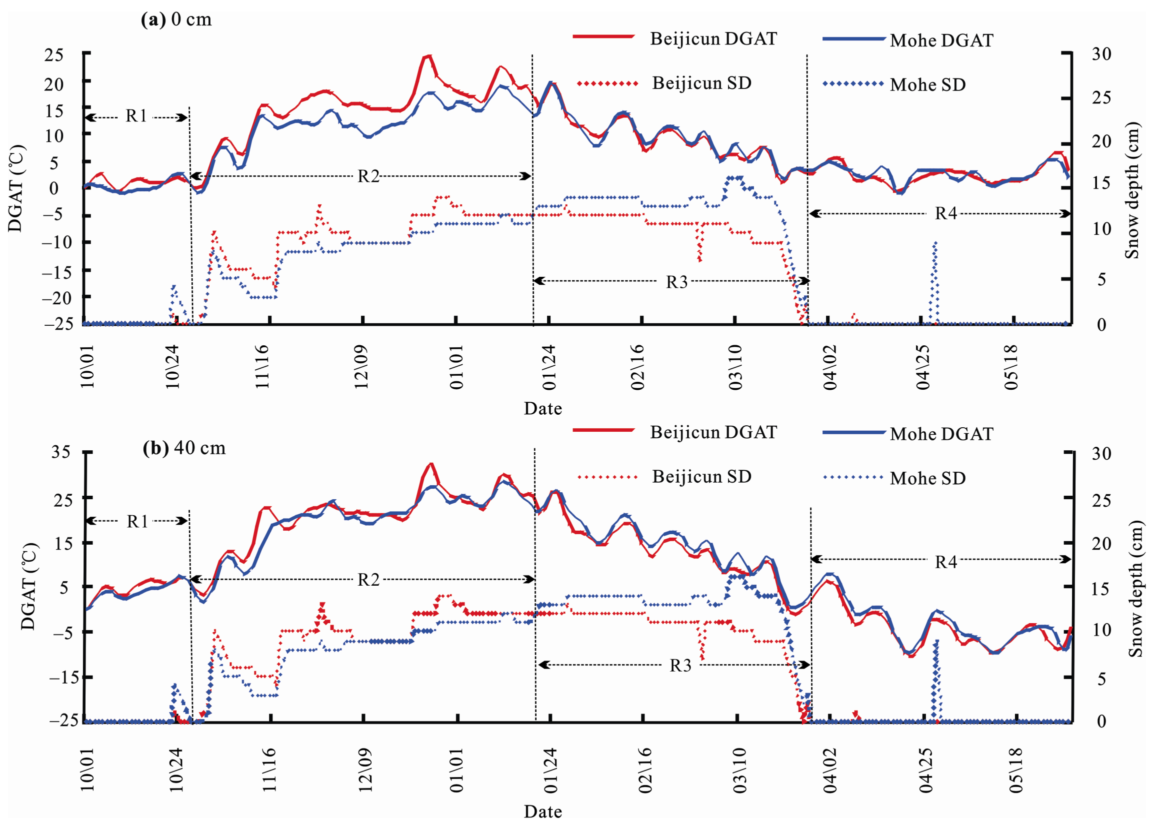

Fig. 6 Temporal series of difference between ground temperature and daily mean air temperature (DGAT) at the depth of (a) 0 cm, (b) 40 cm from 1st, Oct. 2011 to 31st, May 2012. The snow depth in Mohe and Beijicun (Mohe SD and Beijicun SD) are also shown using the minor vertical axis. R1, R2, R3 and R4 represent different time ranges during which the snow is thicker or thinner uniformly in Mohe than that in Beijicun

proposed in this study. According to the Equation (1), a correlation analysis is performed for the difference of the snow depth and DGAT, and d is set to 30 days, which means the time lag is limited within about one month. Figure 7 shows the result of correlation coefficient as a function of lag time at six different underground depth. From the figure, it is easy to see that the correlation coefficients at the depth from 0 cm to 20 cm are different obviously from those of 40 cm, most of them are larger than 0.55, but the correlation coefficients at 40 cm depth are all less than 0.50. We can conclude that on the daily basis the alternation of snow depth at MH and BJC has no significant effect on the alternate changes of the ground temperature at 40 cm depth. Table 2 shows the maximum correlation coefficients between the difference of snow depth and DGAT at the different underground depth and the corresponding lag time. Evidently, the maximum correlation coefficients from 0 cm to 20 cm appear simultaneously when the lag time is 10 days, and they are all above 0.60. The whole correlation coefficients are all smaller at 40 cm depth, which means that the response of DGAT is not significant. This result is different from the previous research by modeling, in which the response depth of ground to the alteration of snow depth is far more than 40 cm (Ling and Zhang, 2007). This may be mainly due to the different ground properties and snow parameters in our study region from their model input.

3.4 An example analysis during 2012−2013 winter

2012−2013 winter is an especially snowy winter in Northeast China, both the average and the thickest snow depth of Heilongjiang Province hit a record high of 27.1 cm and 50 cm, respectively, since the year 1961. At the same time, in the spring of 2013 the air temperature′s fluctuations and large amounts of snow melting resulted in the low ground temperature and too wet soil and the spring-sowing time has to be postponed seriously. Based on the above analysis method in Mohe and Beijicun meteorological stations, to illustrate the effect of snow cover on the ground thermal regime further, this extreme snowy winter is compared with a benchmark (the relative normal 2011−2012 winter) in Heilongjiang Province based on the measured data collected by 63 meteorological stations.

Generally, the seed is sown at a depth about 5 cm, therefore the ground temperature at the depth of 5 cm plays a significant role in deciding whether it is suitable for spring sowing. 5 cm ground temperature (GT) from 1st, Oct. 2012 to 31st, May 2013 is chosen to compare with that during the same time period of 2012−2013, as shown in Fig. 8(a). In the meantime, the air temperature (AT) and DGAT are also given in Figs. 8(b)−8(c). The temporal (the whole time period) and spatial (all 63 stations) average AT and 5 cm GT are calculated and shown in Table 3.

From Figs. 8(a)−8(b), it is easy to see that the air temperature in two years is similarly same, but 5 cm ground temperature is very different, especially during the wintertime (see the region R1, 12th November to 15th March) when GT in 2012−2013 is always larger than that in 2011−2012. Similarly, during R1 region DGAT in 2012−2013 is almost all larger than that in 2011−2012. This is clearly caused by the warmer effects of more snow on ground. From Table 3, during the whole time period the all-station average AT of 2012−2013 is lower (−6.62℃ < −4.97℃), but 5 cm average GT is reverse (0.33℃ > −1.83℃), which also fully demonstrates the positive (warmer) effects of snow cover on the ground thermal regime during the whole snow season.

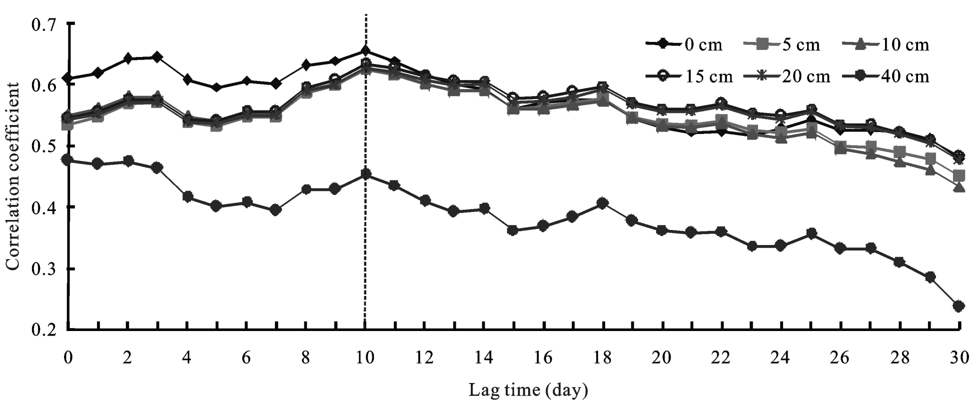

Fig. 7 Correlation coefficient between difference of snow depth and DGAT varies with lag time at the different ground depth

Table 2 Maximum correlation coefficient between difference of snow depth and DGAT and corresponding lag time at different ground depth

	0 cm	5 cm	10 cm	15 cm	20 cm	40 cm
Lag time (day)	10	10	10	10	10	0
Correlation coefficient	0.65	0.62	0.63	0.63	0.63	0.48

On the other hand, the time region R2 (8th to 26th April) is worthy of notice. In Figs. 8(a)− 8(b), GT and AT have the same trends, they both are lower in 2012−2013 than 2011−2012.The lower GT in 2013 than the same period of the normal year is one of the influence factor which results in the spring sowing is postponed. However, DGAT is higher in 2013 than that in 2012 in the region R2 of Fig. 8(c). To review the spatial distribution of GT and AT during this period, the multi-day average (from 8th to 26th April) 5 cm GT and AT anomalies of 2012−2013, which is calculated by the average of GT and AT during the same period in 2011−2012 and 2012−013, are shown in Fig. 9. In space, the lower GT anomaly values (bigger solid points) mostly present in the south farmland regions without vegetation covering. The statistical result show that the average GT and AT are 3.59℃ and 5.36℃ lower during 8th to 26th April, 2013 than the same period of 2012. However, the multi-day average DGAT is 0.68℃, which indicates that GT keeps basically identical with AT. Therefore, the lower GT during this period resulted mainly from the lower AT, and it has little to do with the lag effect of snow according to the lag time (10 days) in the section 3.3 and the snow-free time on the ground (about 28th, March). At the same time, amounts of snow in winter melted into water in spring, which made the soil too wet (Zheng *et al.*, 2015). In addition, further research is needed to answer whether the abnormal low AT in the spring of 2013 is connection with the extremely much snow in winter of 2012−2013.

4 Conclusions

The importance of snow cover to ground thermal regime has received much attention during the past few decades. Many important research results are obtained by the previous studies based on modeling, but specific examples and validation data are lacking. In this study, two northeast meteorological stations in China, MH and BJC, are firstly chosen to perform a comparison study about the effect of snow cover on the GT. Because there is almost the same regional climate and geographic environment except for the alternate change of snow depth around two stations, the data can provide a very typical case study. On the other hand, 2012−2013 winter is extremely snowy in Northeast China, as a typical example, GT in this winter in Heilongjiang Province is compared with one in the normal winter of 2011−2012. Based on the analysis result, the higher GT in winter and the lower GT in spring of 2013 can be explained and understood very well.

To study the effect of snow depth on GT at the different depth, the DGAT is used as an indicator, which can eliminate the effect of the different air temperature. In the process of the two-station and all-station (63 meteorological stations) comparison, the ground profile and time series analysis is performed together. The obtained conclusions are as follows: 1) from the ground profile analysis, the alternate change of snow depth has important effects on GT. DGAT of the different depth at two meteorological stations change accordingly with the alternation of snow depth. The date (21st January, 2012) when snow begin to change alternatively is used as a time node, before that (there is thicker snow at BJC station), the average DGAT at the different depth are all higher at BJC than at MH. The case is just reverse after that node (thicker snow at MH), only the difference of DGAT at two stations becomes smaller, which is mainly resulted from the rising air temperature with it graduating into spring. On the whole, results of the profile analysis illustrate the positive (warmer) effect of snow depth on GT; 2) from the time series, the variation of DGAT at the depth of 0 cm and 40 cm with snow depth is analyzed. DGAT at 0 cm depth responses significantly to the snow depth: the larger difference of snow depth between MH and BJC, the more significant positive (warmer) effect. On the other hand, DGAT at 40 cm depth does not response significantly, but its change trends agree well with the snow depth after its alternation (when snow is thicker at MH), which has a lot to do with DGAT history at BJC, because of its small variation before DGAT is easy to transfer and response to the alternation of the snow depth. In all-station (63 meteorological stations) analysis, during the whole time period the all-station average AT of 2012−2013 is lower than that of 2011−2012, but

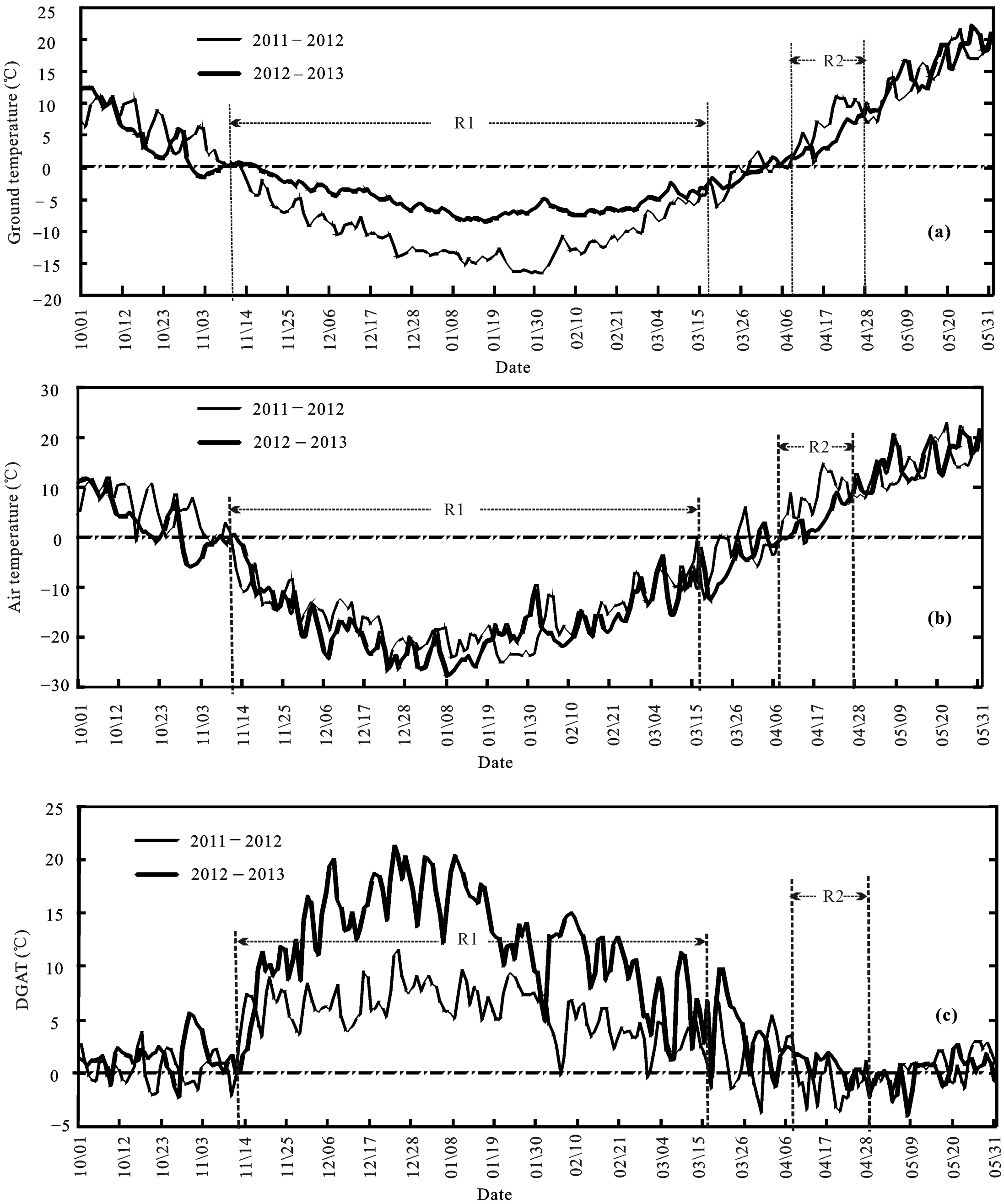

Fig. 8 Average of (a) 5 cm underground temperature, (b) air temperature, and (c) DGAT at 63 meteorological stations everyday from 1st Oct., 2012 to 31st May, 2013 in Heilongjiang province. R1 and R2 represent two time phases, 12th November to 15th March and 8th to 26th April

Table 3 All-station average air temperature (AT) and 5 cm average ground temperature (GT) from 1st, October to 31st, May of 2011–2012 and 2012–2013

Time	Average AT (℃)	5 cm Average GT (℃)
2011–2012	−4.97	−1.83
2012–2013	−6.62	0.33

5 cm average GT of 2012–2013 is higher, which also fully demonstrates the positive (warmer) effects of snow cover on the ground thermal regime during the whole snow season. In addition, the low GT in the spring of 2013 is considered to result mainly from the lower AT, while too much snow in winter melted into water in spring, which made the soil too wet. The two unfavorable factors result that the spring-sowing time is delayed.

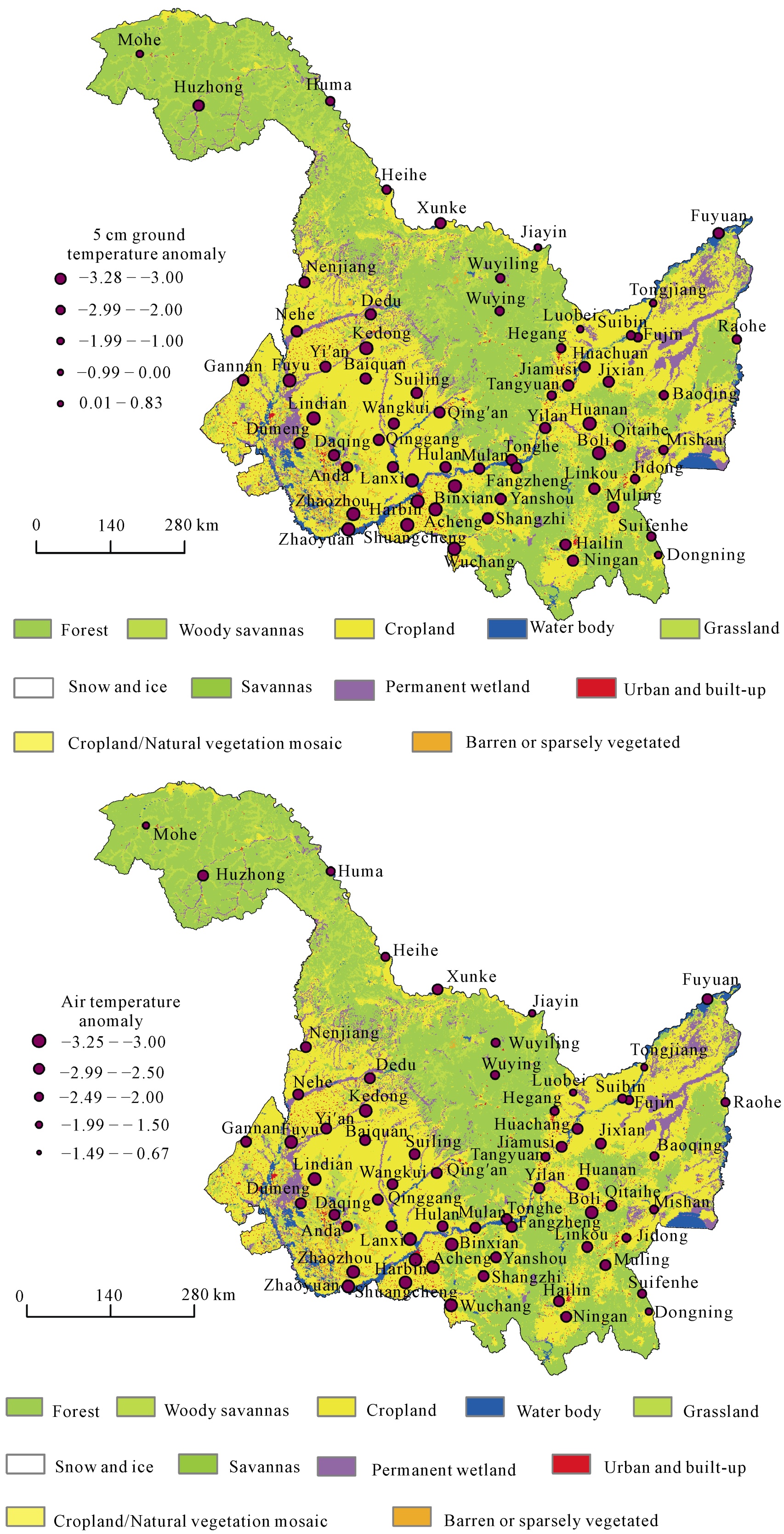

Fig. 9 Multi-day average (a) 5 cm ground temperature anomaly and (b) air temperature anomaly for 63 meteorological stations during 8th−26th, April 2013

In this study, two methods of data processing are proposed, which play a large role in the trend analysis and data mining. Firstly, on the daily basis, AT and GT fluctuate wildly and have no comparable trends, spline mean method can smooth the data and highlight the trend without loss of temporal resolution. Moreover, using the lag time analysis method we find that the response time of DGAT to the alternate change of snow depth from 0 cm to 20 cm ground depth has 10 days lag, while at 40 cm depth the response of DGAT is not significant, which agree with the conclusion obtained by temporal analysis. However, this result is different from the previous research by modeling, in which the response depth of ground to the alteration of snow depth is far more than 40 cm .This can be attributed to the reason that ground properties and snow parameters in our study region are different from model input before. The next work involves designing the control experiment to obtain more observation data at MH and BJC station and validating and developing models which adapt for the local environment.

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