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Seasonal Variations in Soil Temperature on the Alpine Tundra Community in Mt. Changbai in Northeast China: Comparison with Mt. Tateyama in Central Japan

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Abstract

We examined the synchronization of soil temperatures on an alpine tundra community between Mt. Changbai in northeastern China, and Mt. Tateyama in central Japan. The soil temperatures were measured at one-hour intervals for a total of 7526 recordings at both study sites, where a glacial relict plant *Dryas octopetala* var. *asiatica* was predominant. The hourly mean soil temperatures had high synchronization between the two mountains (r^2 = 0.87). After comparing soil temperatures by dividing the climate into two seasons, we found that synchronization of temperatures between the two mountains was higher in winter (r^2 = 0.75) than in summer (r^2 = 0.44). The Arctic Oscillation index, which is related to atmospheric circulation in the Northern Hemisphere, was significantly correlated with air temperature near each study site in the coldest month. Despite the difference in geographical location, a high similarity of seasonal variations in soil temperature in winter suggests that the thermal condition on the two mountains is controlled by the same air masses from higher latitudes.

Keywords: *Alpine tundra, Arctic Oscillation, Circumpolar plants, Glacial relict, Temperature*

Introduction

The arctic tundra forms a circumpolar band between the Arctic Ocean and the polar ice caps to the north and the coniferous forests to the south. Smaller, but ecologically similar regions found above the tree line on high mountains are called alpine tundra (Mackenzie *et al*., 1998). Alpine tundra occurs across a very great range of latitudes and geological settings, and their environments are correspondingly diverse (Wookey, 2002).

Middle-latitude alpine ecosystems contain the southern margins of ranges of many circumpolar arctic species such as *Dryas octopetala* L. (Hultén, 1968). The Asian endemic variety *D. octopetala* L. var. *asiatica* (Nakai) Nakai is a glacial relict plant species, and it is found on wind-blown ridges (i.e., fellfields) in alpine life zones both on Mt. Changbai in northeast China, and on Mt. Tateyama in central Japan. A cold air mass from high latitudes likely controls thermal conditions on alpine tundra communities in the middle-latitude mountains, providing extremely cold environments in winter to alpine plants. In this study, we report seasonal variations in soil

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temperature on alpine tundra communities predominated by *D. octopetala* var. *asiatica* on Mt. Changbai in northeast China and on Mt. Tateyama in central Japan. Circumpolar arctic plants inhabit the southernmost margins of their geographical ranges as glacial relicts. We herein clarify whether the thermal environment on the two mountains is affected by a cold air mass from the high latitude regions such as Siberia and/or the Arctic.

Study sites

On Mt. Changbai in northeast China (Fig. 1), alpine tundra communities are greatly developed, and they were found above the timberline at ca. 2000 m above sea level (Zhu *et al*., 1999). The study site was selected on a fellfield community dominated by *Vaccinium uliginosum* var. *alpinum, Rhododendron confertissimum, R. redowskianum,* and *Dryas octopetala* var. *asiatica* (42°02.4'N, 128°04.0'E, and 2268 m a.s.l.; see Fig. 2A, B). However, on Mt. Tateyama in central Japan (Fig. 1), the alpine life zone is distributed above the timberline at ca. 2400 m a.s.l., and the alpine tundra communities occupy very little space. They are only found on the ridges of northward slopes at ca. 2700 m a.s.l. (Wada *et al*., 2003; Wada and Nakai, 2004). The study site was chosen for an investigation of this fellfield community, which is dominated by *Arcteria nana* (Maxim.) Makino, *Diapensia lapponica* L. var. *obovata* Fr. Schm., and *D. octopetala* var. *asiatica* (36°33.8'N, 137°36.5'E, and 2710 m a.s.l.; see Fig. 2C, D).

Materials and Methods

The species cover was surveyed in the summer of 2004 at both study sites based on one 10-m line transect, and species at every 100 mm were recorded to give a total of 100 observations. The method was used by Cooper and Wookey (2003).

We measured soil temperatures 5 cm below the ground surface on Mt. Changbai and 1 cm below the surface on Mt. Tateyama during the period from 19 July 2003 to 27 May 2004. Soil temperatures were measured automatically at one-hour intervals during this period at both study sites. A thermometer was used with a data logger for the measurements (StowAway TidbiT, Onset Computer Corporation, MA, USA). We could not insert the thermometer at 5 cm below the ground surface on Mt. Tateyama because of the gravel there. However, the thermometer was completely buried and deposited in the soil between stones.

A previous study revealed that seasonal variations in soil temperature showed little influence with snow cover at this study site (i.e., fellfield habitat) on Mt. Tateyama (Wada and Nakai, 2004). We previously determined that soil temperatures were correlated with ambient temperatures at the study sites on Mt. Tateyama (Wada, unpublished data) and on Mt. Changbai (Liu and Wada, unpublished data). Therefore, in this study, we assumed that variations in soil temperature would be

Figure 1. Location map of study sites: Mt. Changbai in northeast China (42°02.4'N and 128°04.0'E) and Mt. Tateyama in central Japan (36°33.8'N and 137°36.5'E).

caused by variations in air temperature at both sites. We analyzed the relationship between air temperature and Arctic Oscillation (AO) to evaluate the influence of a cold air mass from high latitude regions on the thermal regime at both study sites. The AO was introduced as an annular mode of atmospheric circulation by Thompson and Wallace (1998). Fluctuations in the AO create a seesaw pattern in which atmospheric pressure and mass in northern polar and mid-latitudes alternate between positive and negative phases (Wallece, 2000). The AO has been reported to influence mid- to high latitude climates significantly in the Northern Hemisphere (Thompson *et al.*, 2000; Gong *et al.*, 2001). AO indices are determined by the time series of the leading principal component of monthly mean sea level pressure in the Northern Hemisphere (poleward of 20° N)(Thompson and Wallace, 1998). The data was obtained from a web site (http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/monthly.ao.index.b50.current.ascii.table). Data on air temperatures recorded by the Changbai meteorological observatory in northeast China (41.4°N, 128.3°E, and 1017 m a.s.l., 80 km south of the study site) was also obtained from a web site (http://data.giss.nasa.gov/gistemp/station_data/), and data recorded by the Kurobe Dam meteorological observatory in central Japan (36.6°N, 137.7°E, and 1459 m a.s.l., 5 km east of the study site) was obtained from the Kansai Electric Power Co. (Wada *et al.*, 2004). The data available from 1965 to 1990 was used for the analysis.

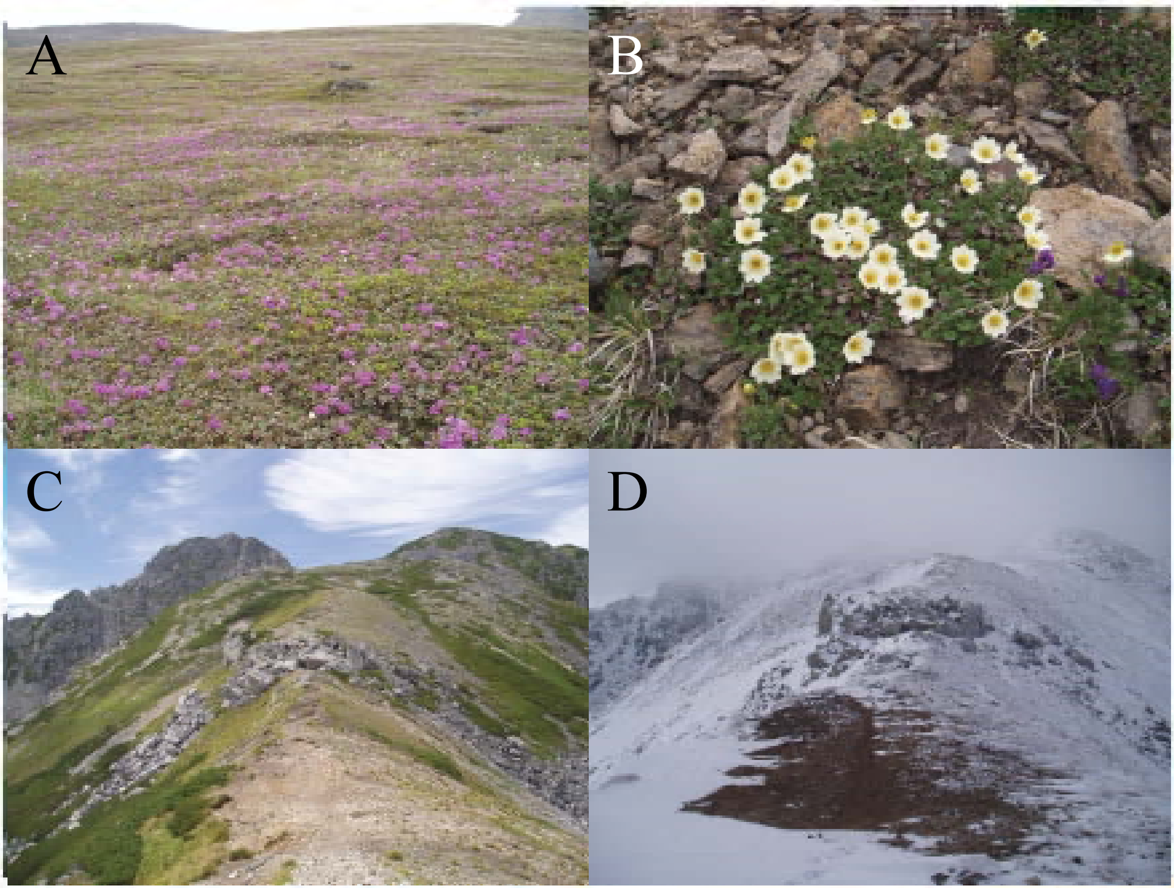

Figure 2. Landscapes of study sites. **A**, alpine tundra vegetation predominated by *Rhododendron confertissimum* Nakai (pink flowers) and *Dryas octopetala* L. var. *asiatica* (Nakai) Nakai on Mt. Changbai in northeast China (17 June 2004). **B**, *D. octopetala* var. *asiatica* on Mt. Changbai (17 June 2004). **C**, alpine fellfield vegetation on Mt. Tateyama in central Japan (1 September 2004). **D**, the fellfield habitat in early winter (25 October 2005).

Results and discussion

Fourteen vascular plant species were recorded in the alpine community on Mt. Changbai, while 17 species were recorded on Mt. Tateyama (Table 1). The study site on Mt. Changbai was mostly occupied by vascular plants, while the site on Mt. Tateyama was largely covered with stones and gravels. The common species of the two sites were glacial relicts; *Dryas octopetala* var. *asiatica*, *Bistorta vivipara* (L.) S. F. Gray, and *Lloydia serotina* (L.) Rchb. (Table 1). Deciduous shrubs such as *Vaccinium uliginosum* L. var. *alpinum* Nakai, *Rhododendron confertissimum* Nakai, and *R. redowskianum* Maxim. were the dominant species at the study site on Mt. Changbai, while evergreen shrubs, such as *Diapensia lapponica* var. *obovata* and *Arcterica nana*, and herbaceous plants were predominant in the study site on Mt. Tateyama. Although the species composition and coverage of alpine plants differed considerably between the two mountains, three species of glacial relicts were commonly found.

Table 1. Species composition and coverage (%) at the two study sites. On a 10-m transect in each site, species encountered at every 100 mm were recorded, with a total of 100 observations made.

Species	Changbai	Tateyama
Vaccinium uliginosum var. *alpinum*	34	
Dryas octopetala var. *asiatica*	13	6
Rhododendron confertissimum	12	
Rhododendron redowskianum	11	
Tofieldia coccinea	6	
Bupleurum euphorbioides	5	
Carex siroumensis	4	
Hierochloe alpina	3	
Cladonia sp.	3	
Lloydia serotina	2	2
Saussurea tomentosa	2	
Anthoxanthum nipponicum	1	
Oxytropis anertii	1	
Bistorta vivipara	1	4
Diapensia lapponica var. *obovata*		8
Arcterica nana		7
Potentilla matsumurae		7
Arenaria arctica var. *hondoensis*		6
Carex stenantha		4
Loiseleuria procumbens		3
Arctous alpinus		2
Deschampsia flexuosa		2
Gentiana algida		2
Tilingia tachiroei		2
Calamagrostis deschampsioides		1
Calamagrostis sachalinensis		1
Campanula chamissonis		1
Geum calthifolium var. *nipponicum*		1
Moss	2	2
Types of stones and gravel		39

We measured the soil temperatures at one-hour intervals at both sites during the period from 19 July 2003 to 27 May 2004, and we obtained a total of 7526 records at each site (Fig. 3). The hourly mean soil temperature was 1.1°C higher on Mt. Tateyama than on Mt. Changbai, showing a high synchronization (r^2 = 0.87, n = 7526 hrs, P < 0.0001; Fig. 4A). The maximum and minimum temperatures were 20.8°C and - 24.6°C on Mt. Changbai, and 22.7°C and - 21.6°C on Mt. Tateyama. After comparing soil temperatures by dividing two seasons (summer from 19 July 2003 to 30 September 2003 and winter from 1 October 2003 to 30 April 2004), we found that the synchronization of temperatures between the two mountains was higher in winter (r^2 = 0.75, n = 5113 hrs, P < 0.0001; Fig. 4C) than in summer (r^2 = 0.44, n = 1776 hrs, P < 0.0001; Fig. 4B); the slope of the regression between the two mountains was 1.00 in winter (Fig. 4C), while it was 0.75 in summer (Fig. 4B). The hourly mean soil temperatures were 0.8°C and 0.9°C higher in summer and in winter, respectively, on Mt. Tateyama than on Mt. Changbai.

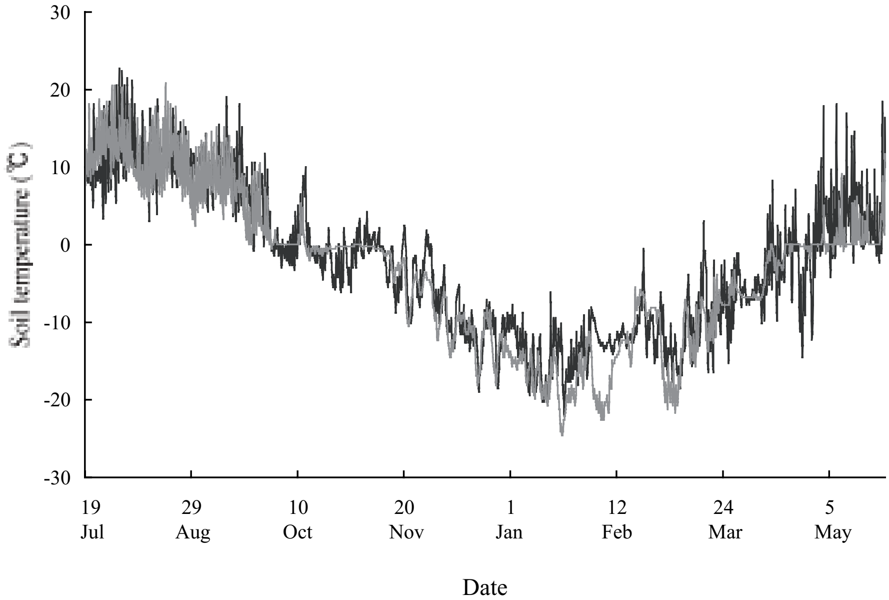

Figure 3. Seasonal changes in soil temperatures measured at one-hour intervals, from 19 July 2003 to 27 May 2004, on Mt. Changbai (gray line) in northeast China and on Mt. Tateyama (black line) in central Japan.

On Mt. Changbai, soil temperatures were almost zero degrees from early October to mid November in 2003 and from mid April to mid May in 2004 (Fig. 3). This suggests a snow cover effect in early winter and a snow melting effect in early spring. At the study site, we observed a well-developed litter layer, ca. 5 cm deep, on Mt. Changbai but found no litter layer on Mt. Tateyama. The well-developed litter layer (Wu et al., 2006) and high vegetation cover (Table 1) might serve in part as a thermal insulator on Mt. Changbai. Although a considerable amount of snow falls on Mt. Tateyama (Toyama et al., 2005), there was little snow cover based on our direct observations there in late October (Fig. 2D) and early November. This was mostly because steep topography and strong wind from the northwestern monsoon would not allow snow to accumulate. Some differences were found between the two mountains. However, the high similarity of seasonal variations in soil temperature, especially in winter (Fig. 4C), suggests that the thermal condition for the growing habitat of glacial relict plant species on the two mountains should be controlled by the same air masses despite the difference in geographical location.

After comparing air temperatures recorded by a meteorological station located near each study site, we found that the interannual variations had high synchronization, especially in winter (Table 2), when significant correlations between the two stations were found in the five months from November to March. However, only two months, May and July, in the summer season had this high synchronization (Table 2). Among them, the highest correlation was found in February. The Arctic Oscillation index, which is related to atmospheric circulation in the Northern Hemisphere, was significantly correlated with air temperature only in the winter (Table 2); the highest correlation was found in February both for Changbai and Tateyama. These analytical results in the meteorological data suggest that cold air masses from the high latitudes strongly influence the alpine

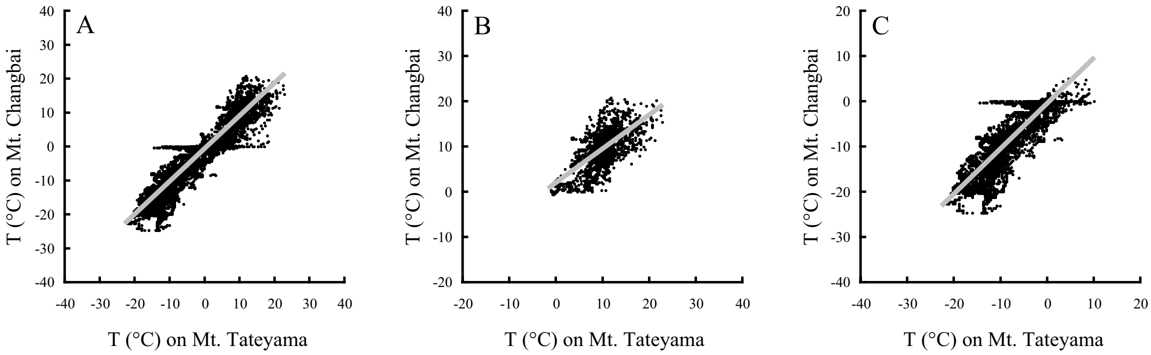

Figure 4. Relationships of soil temperatures between Mt. Changbai (northeast China) and Mt. Tateyama (central Japan). One-hour intervals. **A**, $Y = 0.97\,X - 1.10$, $r^2 = 0.87$, $n = 7526$ hrs, during the period from 19 July 2003 to 27 May 2004; **B**, $Y = 0.75\,X - 1.69$, $r^2 = 0.44$, $n = 1776$ hrs, during the summer from 19 July 2003 to 30 September 2003; **C**, $Y = 1.00\,X - 0.81$, $r^2 = 0.75$, $n = 5113$ hrs, during the winter from 1 October 2003 to 30 April 2004.

Table 2. Correlations (r) between monthly means of the daily mean air temperature in Changbai (at the Changbai meteorological observatory), northeast China, and monthly means of the daily maximum temperature in Tateyama (at the Kurobe Dam meteorological observatory), central Japan, from 1965 to 1990, and correlations (r) of Arctic Oscillation index (AO) and air temperature between sites.

Month	Changbai-Tateyama	AO-Changbai	AO-Tateyama
Jan.	0.75**	0.55**	0.28
Feb.	0.83**	0.75**	0.54**
Mar.	0.66**	0.66**	0.52**
Apr.	0.32	0.25	0.01
May	0.42**	0.10	-0.29
Jun.	0.12	0.08	0.06
Jul.	0.52**	-0.14	-0.13
Aug.	0.25	0.23	0.04
Sep.	0.25	0.08	0.30
Oct.	0.38	-0.06	-0.20
Nov.	0.46*	0.14	0.09
Dec.	0.71**	0.23	0.27

*, $P < 0.05$; **, $P < 0.01$.

tundra communities in the coldest month, February, leading to soil freezing. The frozen soils melt in spring, so periglacial debris should move seasonally, resulting in disturbance tolerant plants establishing and growing in these habitats (Chujo, 1983). Thus, the environment would allow cold tolerant and disturbance tolerant species to survive, and intolerant species would be eliminated. This might be one of the reasons that circumpolar plants have been surviving as glacial relicts in the middle-latitude mountains of Northeast Asia.

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