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Spatial heterogeneity of snow covers in Sugadaira, central Japan

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Abstract

This is a field report about snow covers in Sugadaira, central Japan, observed in typical cold and warm winters of 2005/06 and 2006/07, respectively. Evident decrearing of snow depth was found due to passing of warm sector of extratropical cyclone. Spatial heterogeneity of the snow cover was examined by means of snow depth, snow cover structure, and surface skin temperature. Zonal pattern in the snow depth distribution indicated occurrence of redistribution by the winter monsoon. Differences of more than 3 °C was observed in the surface skin temperature between the snow and snow-free areas by an Infrared Thermography.

Key words: snow cover, Sugadaira, heterogeneity

1. Introduction

Sugadaira Montane Research Center (SMRC) locates at 1320 m of the highlands in the Nagano prefecture. The center was established in 1934 in order to study ecology of the chilly climate, and have been an important research function for biology and geosciences representing in the central highland of Japan. Winter climate is dry and cold, and the snow depth is usually less than 1 m. Snow falls in cases of not only the winter monsoon but also the passing of extra-tropical cyclones, and dept-hoar type snow crystal is sometimes observed in the snow cover indicating the occurrence of strong temperature gradient (Yasunari and Ueno,1987). Miyashita and Tase (1993) identified that the isotopic ratio of a snowfall is well preserved in the dry snow covers. Those characteristics are distinctively different from the thick and wet snow covers in the lower elevations along the Japan Sea sides. SMRC has manually observed the occurrence of rain/snow and accumulation amount/depth of new snow layer every day, which allow us to examine the long term trends of phase changes of winter precipitation at high elevations. For instance, Shimizu (2005) reported the increase of winter precipitation amount through the 35 years, and raised the possibility that snow covers were recently becoming wet.

Landform of the Sugadaira is composed of a basin at 1200 m level sandwiched with Mt. O-matsu and Mt. Taro, and a large hill slope facing north-west extends from Mt. Nekodake (2128 m). Many of the hill slopes are used for ski run, covered with artificial snows frequently. According to the snow survey (Yasunari and Ueno, 1987; Nishimori, 2000), snow depth increases as going up along the slope of Mt. Nekodake, but it is also quite variable depending on the land usage and topography. Regarding to the land usage, snow covers in the forest are strongly affected by intermittence. Since a snowfall is very dry, deposition and re-distribution of snow are affected by the surface wind speed distribution controlled by small topography, and causing heterogeneity in the snow covers. But, quantitative identification of the snow cover heterogeneity around the SMRC has not conducted yet, although it is important to evaluate the characteristics of point measured records.

Re-distribution of snow cover is a common phenomenon in the northern continents, in which the precipitation amount is small but surface wind speed affected by the small topography and forests cause large spatial heterogeneity of snow depth. Recently, atmosphere-land interaction processes are diagnosed by combining snow re-distribution model with the regional climate model, such as in Canada or Siberia (Déry et al., 2004; Hirashima et al., 2004). Especially, snow drifts enhance patchy snow cover in spring and the snow cover pattern changes the area mean surface heat budgets (Liston, 2004). On the other hand, snow covers in Japan are generally characterized as wet and deep. Many studies have been focused on the simulation about multiple layers structure (Yamazaki,2001), altitudinal dependency (Matsuyama, 1998), or effects of forests (Ohta et al., 1990; Hashimoto et al., 1997) of snow covers. Re-distribution process is especially paid attention to prevent the blowing of snow by the engineering scientists, but the snow cover heterogeneity in the highland of the central Japan are not fully paid attention.

Snow cover observation was conducted in winter 2005/06 as an extreme heavy snow case and 2006/07 as a warm winter case at SMRC. This report described the observational evidences relating with the snow cover

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heterogeneity. At first, differences of intra-seasonal changes in snow depth and small-scale snow depth distribution between the two winters were clarified. Secondly, surface temperature heterogeneity observed by a thermal imager was introduced.

2. Observation and data

The SMRC locates at the foot of Mt. Nekodake consisted with four different land use (Fig. 1a). A dry field farming lands distributs in the north-west (marked V) facing to the winter monsoon. To examine the effect of undergrowth in the forests for the snow depth measurement by stick works, field survey was done just after the snow expiring season. In the early April, we found that grounds in the forest were surprisingly flat (Fig. 1b) due to pressing of snow covers. Errors of snow depth measured by stick works must be small after the thick snow covers, but it must be serious in the beginning of snow deposition, such as in December.

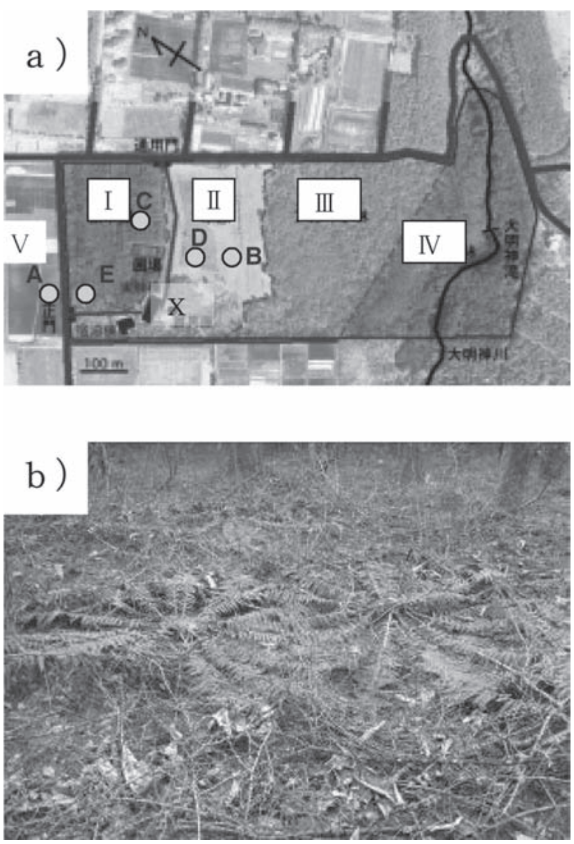

Fig. 1 a) Land use of SMRC; I: Botanical forest garden with broadleaf and needle-leaf trees, II: Grass lands which is the flat snowfields in winter, III: Pine forest with shrubs in summer, IV: Deciduous broad-leaved forest, and V: Dry field farming lands. Snow pit works are done at A-E points. Temperature and precipitation are observed at X. (Base map was copied from http://www.sugadaira.tsukuba.ac.jp/outline/manag/aeroview.html), b) Land surface condition after the snow melting near the point C, on April 12, 2007.

SMRC observes air temperature and humidity at 1.5 m above the snow surface with artificial ventilation in the east of a laboratory building (X in Fig. 1a) and precipitation at the same place by a tipping bucket gauge with heating system. Every morning, around 9:00AM, total snow depth and new snow depth are measured manually. In the winter of 2005/06 and 2006/07, snow depth was automatically observed with 10 minuets interval by an ultra-sonic snow depth sensor in the center of grass land (Fig. 1a, B). During the Feb. 8-10 in 2006 and Feb. 10-12 in 2007, snow depth distribution was intensively measured by stick works in the SMRC. Snow cover structure, such as identification of snow layers, snow types, density, temperature and grain size, was observed by a pit works at five representative points (Fig. 1a, A-E). On Feb. 10, 2007, skin surface temperature distribution was observed at several locations in the Sugadaira basin by an Infrared Thermography (Nippon Avionix Co. Ltd., TVS-600).

3. Results

3.1 Comparisons of cold and warm winter in Sugadaira

It was the very contrastive winter between 2005/06 and 2006/07. The cold wave intermittently came from Siberia in December and January in the 2005/06 winter, and the snow covers exceeded 4 m in February at Tsunan town which located only 70 km northeast of the Sugadaira. The heavy snow winter was named “Heisei-18nen go-setsu” in Japanese. Kawamura and Ogasawara (2007) explained the reason of such intermitted cold waves by a strong anti-cyclonic anomaly over China enforced by the strong convections over the western Pacific. On the other hand, in the first half of winter 2006/07, cold surge was temporal with nationwide warm winter prevailed, and sporadic strong cold waves in March caused late heavy snows in the mountains. Figure 2 shows intra-seasonal variations of snow depth, precipitation and temperature at SMRC for the two winters. In 2005/06, snow cover started in the beginning of December, and it lasted till April 15. Continuous increase of snow depth was due to lower temperature in December and early January. During December through January, average temperature was -7 °C and accumulated precipitation was 162 mm in 05/06, and it was -3.5 °C and 141 mm in 06/07. Difference of the precipitation was 20 mm, but it caused 50 cm difference in the snow depth. The reason was that precipitation in 05/06 was provided with frequent snowfall (1.5 times more precipitation days than in 06/07) by the winter monsoon, instead, the precipitation in 06/07 included many rainy days with passing extratropical cyclones (indicated by cross marks in Fig. 2d). Usually, winter precipitation amount along the coastal areas of Japan Sea shows negative correlation with the temperature, because the cold surge is the main cause of precipitation. But the relation becomes obscure in the Sugadaira due to the effect of synoptic disturbances passing in the Pacific side. Even the winter 05/06 was categorized as nationwide extreme heavy snow fall year, the snow depth did not exceed more than 1 m in the Sugadaira. This is because that most of the precipitation cells were dissolved by the mountains in the north-northwest of Nagano prefecture.

Two characteristics were obvious in the snow depth changes in Fig. 2a and 2b. One is the evident concave decreases of snow depth as marked by ⇩. The sudden decrease occurred in one day when the warm sector of the extra-tropical cyclone passed with prevailing of positive temperatures through the day. Melting of snow cover, not only by the sensible heating but also by the latent heating by intruding of moist air mass, and re-freezing at the snow surface after the successive fair nights are supposed to induce such a unique change of snow depth (Daimon and Ueno, 2007). Flush flooding may occur if such sudden decrease accompanies the melting of snow cover at once in large areas, and further analysis is anticipated. The other is the sudden extinction of snow covers when the snow depth became lower than 10 cm. The extinction occurred around April 13 in 05/06 winter and March 25 on 06/07. Ultra-sonic sensor could detect a snow depth directly at a footprint without effects of installation equipments. According to the albedo data, relativelly high albedo still continued for several days after those extinction dates. We speculated that sudden decrease of the snow depth in spring indicated the occurrence of discontinuous snow covers. Dating of expiring snow covers is very important to verify the snow cover models. Actual feature of the last stage of snow covers is planed to be observed in detail by the digital images together with snow depth and albedo measurements.

3.2 Snow depth distribution in the SMRC

Intensive snow depth surveys were done on Feb. 9, 2006 and Feb. 11, 2007 in the SMRC (Fig. 3). Firstly, we were expecting to detect distinctive differences in snow depth according to the land usage as shown in the Fig. 1a. But, the results were different. Zonal distribution running north-south direction was appeared in the Fig. 3 as a primarily pattern. The running direction corresponded with the surface wind flow in case of winter monsoon, so it was apparent that local scale snow deposition was primarily determined by the prevailing of surface winds even in the forested areas. Width of the zone was around 100 m, and location of maximum/minimum center appeared in the similar location in both winters. For instance, there was a maximum in the center of area (I) which corresponded with an open space in the forest, and shallow snow depth

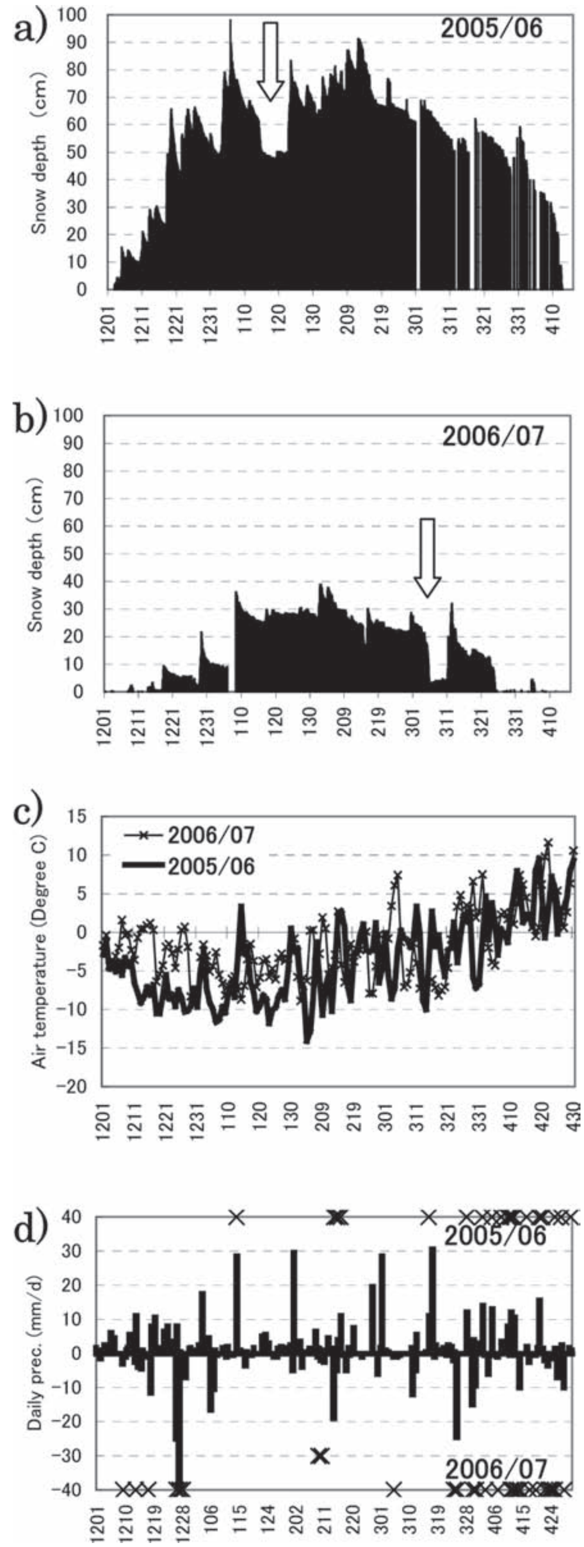

Fig. 2 Snow depth changes in 2005/06 (a) and 2006/07 (b) winter, air temperature changes at 1.5 m (c), and daily precipitation changes (d). Spikes in the figure (a) and (b) indicate missing of the data. Crosses in the figure (d) indicate occurrence of rain or sleet.

zone existed along the northwest of deep depth zone extending to laboratory buildings. As the northwest of SMRC (V) was a flat open field, obstacles along a road running northeast-southwest along the northwestern side of SMRC would initiated the zones. In 2007, difference of snow depth between the area I and II was recognized as a secondary pattern. Snow depth in the grass area was almost 15 cm less than that in the forest which was opposite to the theory that snow covers in the forest is generally reduced by the interceptions. We speculate that shading of daytime radiation and increase of roughness in the area (I) could capture more snow cover, and further investigation is expected.

Intensive measurement of snow depth with 5 m interval was conducted along a transect (X-X', Fig. 3a) on February 11, 2007 (Fig. 4) to examine the effect of small-scale topography and undergrowth. Large gaps at the boundary of V-I and I-II were caused by asphalt roads. Snow surface was very flat in the grass land (area II), but the depth tended to increase in the forest (area I) as going leeward. There were no 50-100 m scale variabilities, indicating that the trend in the forest was not influenced by the heterogeneity of individual undergrowth but the nature of snow accumulation itself. We are planning to survey the small-scale distribution of trees and topography during snow free season to identify obstacles initiated the snow cover heterogeneity in Fig. 3 and 4.

Structure of snow cover on February 9, 2006, at 3 points (A-C) was compared in Fig. 5. Air temperature at 1.5 m was -6 °C to -7 °C and the snow cover was dry. Snow

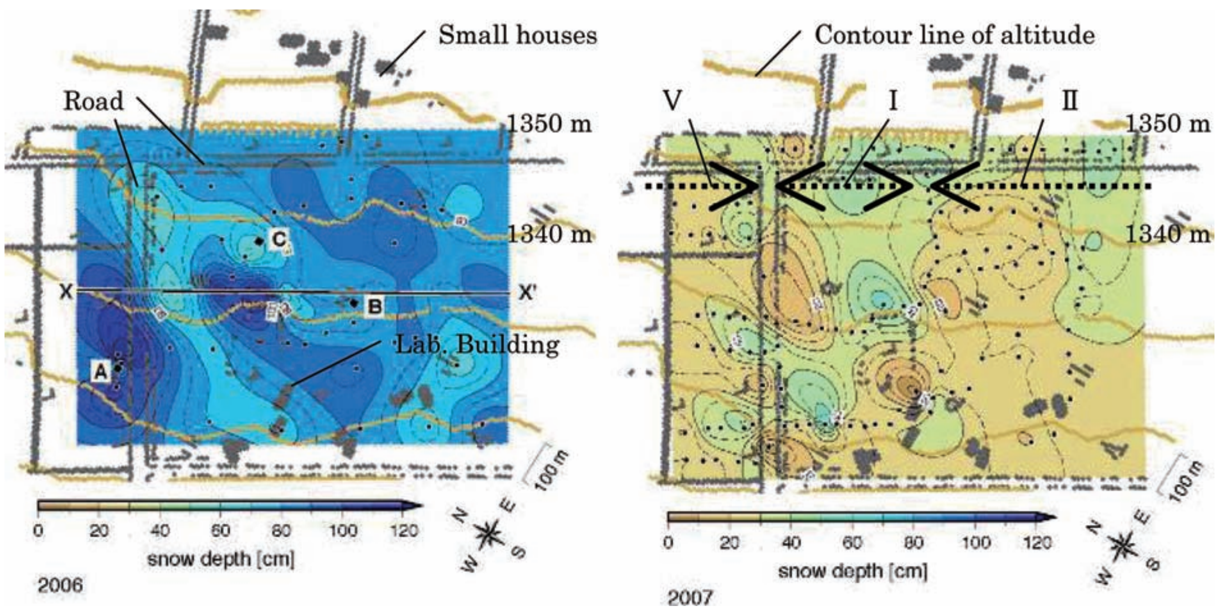

Fig. 3 Snow depth distribution around the north-western parts of SMRC, measured on Feb. 9, 2006 (left) and Feb.11, 2007 (right). Alphabet and X-X' in the left map correspond to the location of pit work and a transect in the Fig. 4, and dash lines in the right map correspond to land use I, II, and V as shown in Fig. 1a.

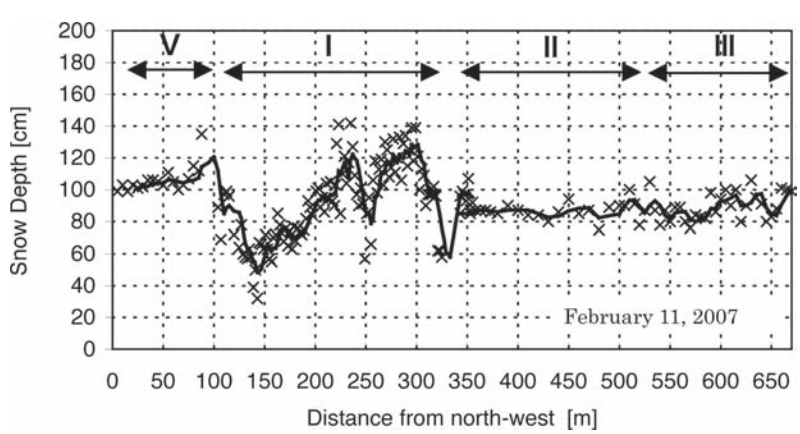

Fig. 4 A transect of snow depth along X-X' on Fig. 3 (left) with 5 m interval (×) with 50 m running mean (solid line). Zoning by arrows corresponds to land-use shown in Fig.1a.

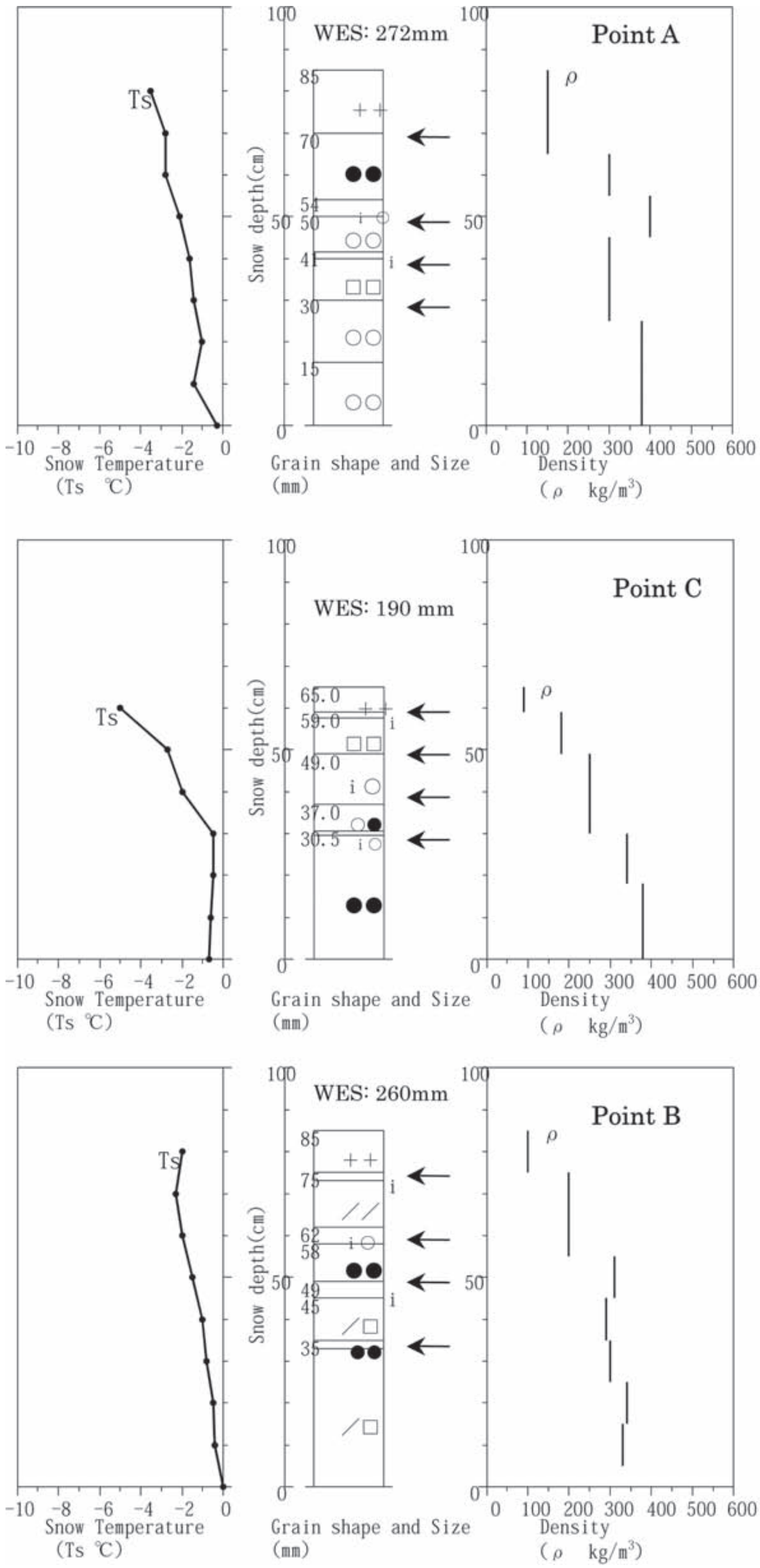

Fig. 5 Vertical profile of snow cover structure with WES (center), temperature (left) and density (right) observed at three different locations on Feb. 9, 2006. Marks of the snow types are based on international classification, such as + for new snow, / for lightly compacted snow, ● for compacted snow, □ for soild-type depth hpar, ○ for granular snow, and i for ice layer.

cover density increased from 0.1 to 0.35 as going from top to the bottom. Four common layers were identified even in the forests, as indicated by horizontal arrows divided by ice layers. It was quite difficult exactly to date each layer, but we presumed that a lower most part of the layers would formed in December 2005 when the snow depth continuously increased (Figure 2a). Precipitation amount from December 1 to February 9 at SMRC was 206 mm. Total water equivalent of snow (WES) at point A and B (described in the Figure 5) was more than the precipitation amount. This mismatch of the water budget will be explained by serious under catch of precipitation over the gauge or snow cover drifts around the pit work points. Formation of depht-hoar was observed below the ice layer, indicating that large temperature gradient with diurnal cycle below the exposed snow surface occurred during successive fair weather days and could develop the depth-hoar layer. The results of snow survey are going to utilize for the verification of multi layer snow model results.

3.3. Surface temperature distribution

Surface temperature is an important parameter in deciding upward long wave radiation and surface heat flux. Metamorphism of snow surface adjacent tree or bare field is frequently observed, indicating the strong thermal radiation with considerable high skin temperature from the non-snow materials even the air temperature is below 0 °C. Snow surface always moves, and only the remote sensing could measure the skin temperature quantitatively. On February 10, 2007, skin temperature distribution was observed by a handy infrared radiation camera at several spots with heterogenic land forms. Weather was fine and there was no snow caps on the trees. Figure 6a and b show visible and infrared images of slopes at Mt. O-matsuyama (1649m) facing east. The altitude difference between a summit and bottom is almost 350 m, and white belts in the Fig. 6a are ski slopes. In the infrared image (Fig. 6b), orange color at the foot of forests changed to green color at the summit. This change correspanded to almost 3 °C differences or 0.85 °C/100 m by means of lapse rate. Therefore, lapse rate in the free atmosphere was enhanced in the surface temperature distribution along the slope. In the meantime, snow covered area at the middle of mountain (blue color) was 3 °C below the temperature of surrounding forest areas (yellow color). Hot spots at the foot of mountain (pink color) indicated a roof of the house.

Another scene was focused on more narrow areas facing south, composed of snow covers, bare grounds, and white birch trees (Fig. 6c). In the thermal image (Fig. 6d), surface temperature on the bare ground exceeded 4 °C, and also the tree trunk receiving the direct radiation showed

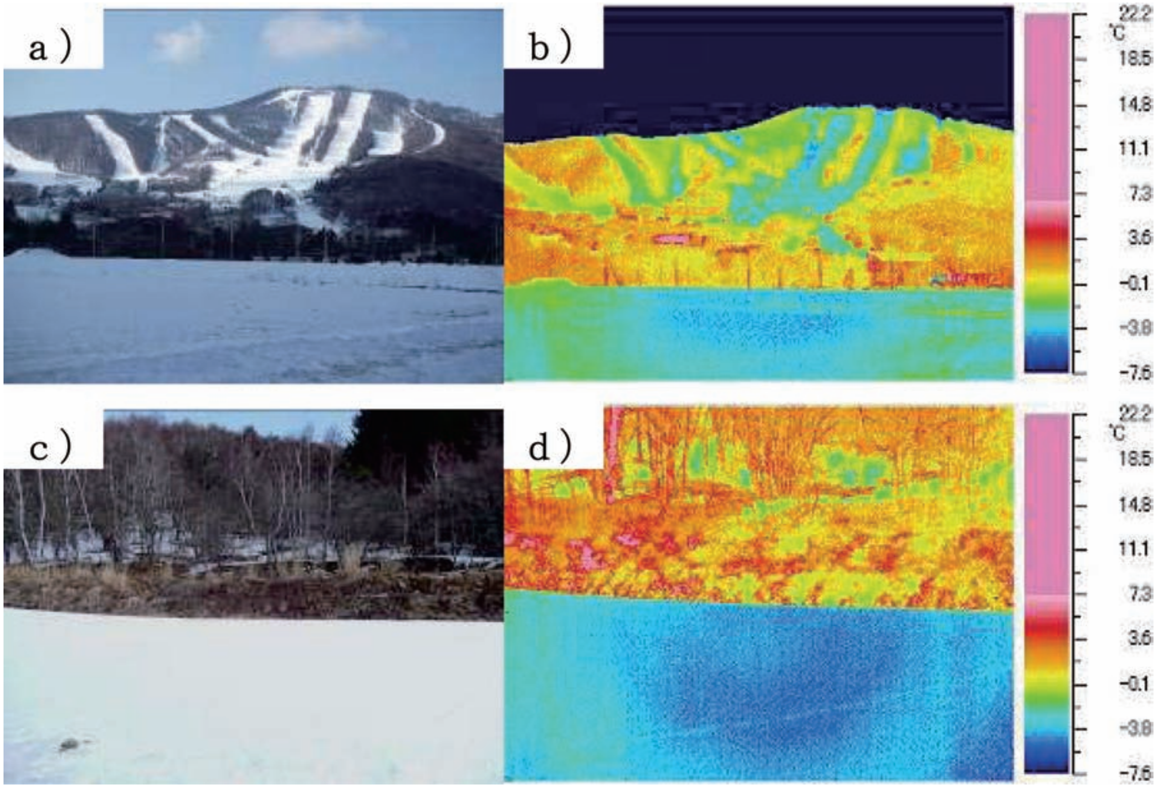

Fig. 6 Comparisons between the visible (left) and infra-red (right) images in cases of forested areas with sky slope (up) and patchy snow covers with white birch trees (down) in Sugadaira, observed on February 10 morning, 2007.

the similar temperature. Snow surface temperature in the forest was -2 °C. Therefore, there existed 6 °C of skin temperature difference between the snow cover and tree trunk which corresponded to 30 W/m^2 by means of thermal radiation. This amount seems to be small in compare with instantaneous daytime insolation. However, seasonal mean surface heat budget is in the order of several 10 W/m^2 to 100 W/m^2 in the cold season of the mid-latitude, and the contrasts of long-wave radiation exist through season by the land cover heterogeneity. Accordingly, coexisting of snow cover and non-snow cover areas is expected to affect the surface heat balance in several 10 % order, and it would not be negligible for area mean heat balance especially in patch snow covers or forest areas.

4. Summary

Characteristics of the snow depth variations were compared between the cold (2005/06) and warm (2006/07) winters in the Sugadaira highlands, Nagano Prefecture. Cold winter was characterized as continuous snow fall in December due to intermitted winter monsoon, and warm winter was characterized as rain events by passing extra tropical cyclones. Effects of passing extratropical cyclones to the snow covers in the mountain of central Japan will be an important topic related to the issue of global climate changes. Intensive snow depth measurements in the SMRC revealed a primary zonal pattern affected by winter monsoon, and observed water equivalent of snow cover was imbalanced with precipitation records. Quantitative evaluation of drifting snow covers around the observation points in SMRC is expected near future. Heterogeneity of more than 3 °C in the surface temperature was captured by a handy type infrared thermography. Geographical distribution of the surface temperature and its rate to the surface heat budget were discussed.

We hope this report will help for understanding sub-grid scale behavior of snow covers in conjunction with large scale environmental changes at one of the representative highland observatory in the central Japan.

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