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Effects of Global Warming on Climate Conditions in the Japanese Alps Region

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1. Introduction

The region of Japan that lies along the Sea of Japan is known to experience some of the heaviest snowfall in the world. In this region, precipitation brought by snowfall is more important as a water resource than rainfall. During winter, a thermal anticyclone is formed over the Siberian continent by strong radiative cooling. The Tibetan Himalayas towering to the south block the anticyclone southward advance, the advance is enhanced during the winter at low solar elevation angle. When the warm Tsushima Current pours into the Sea of Japan heading north, the cold, dry air mass blowing out of the Siberian anticyclone toward the east becomes unstable, absorbing heat and moisture vapour from the lower layer. This produces cumulus convections in sequence, which land on the northwest coast of the Japanese islands. In cumulus clouds, high moisture rates and cold temperature accelerate the formation of snow particles. In addition, these clouds hit the high mountains that run along the center of the Japanese Archipelago and are forced to climb upward, bringing a much larger amount of snowfall. Therefore, the mountain range experiences exceptionally heavy snowfall that is extreme even by world standard, and in spring, the melting snow becomes a valuable water resource for the region. Snow plays the role of a natural white dam by accumulating in watersheds during winter.

Recent studies have reported that the amount of snowfall in Japan will decrease as a result of global warming (Inoue and Yokoyama, 2003). However, these studies used data observed at low altitudes. The question arises whether the same theory can be applied to high-altitude mountain areas. In a temperate snow-covered area where rainfall is observed in winter or where the temperature is above 0 °C and the snow melts, the temperature often reaches the threshold point, which is the boundary line between snow and rain. At this point, a slight temperature increase or decrease can change snow into rain or, conversely, increase the snow. This means that global warming seems to cause a decrease in snowfall even if the amount of precipitation stays the same, because the snowfall particles melt, transforming into rainfall during precipitation. However, it is possible that even with a temperature rise of several degrees 100 years from now, the amount of snowfall could increase in mountain areas at high altitude where we predict that the temperature will not increase up to the threshold temperature between snow and rain. Inoue and Yokoyama (2003) stated that the amount of snowfall in Hokkaido, at the northern latitude of 41.5^{o} or above, will not change much even after 100 years of global warming. However, in a chart presented in their report, we can see that snowfall is decreasing in coastal areas and increasing on the mountains in Hokkaido. A report published by the Ministry of Education, Culture, Sports, Science and Technology also states that "the amount of snowfall will decrease except for Hokkaido. This is because areas south of Tohoku will get more rain than snow with global warming; on the other hand, in Hokkaido, the cold atmosphere will be maintained even with global warming, and the increase in moisture vapour in the air caused by global warming will increase snowfall." However, it is reasonable to consider that at high altitude regions in Honshu (the main island of Japan), it is "cold enough for snowfall to prevail even with global warming"; therefore, the amount of snowfall will increase as in Hokkaido.

The results of a study on cumulative snowfall variation in recent years using observation data from the Japan Meteorological Agency indicate that the increasing tendency is recognized only at Suttsu, Hokkaido, and that in the decreasing sites, the winter mean temperature is more than 3 ºC. The winter mean temperature in these sites is close to the threshold temperature of snow/rain, which determines whether the precipitating particles will from snow or rain. The rise in temperature in recent years has resulted in a decrease in the accumulated snow depth (Ishii and Suzuki, 2011).

Observations of the amount of snow have not been carried out in high-altitude mountains in Japan where the temperature is colder than the threshold temperature of snow/rain even with the temperature rise observed in recent years. Therefore, we cannot discuss the effect of global warming on the change in the amount of snow in the mountainous region of Japan based on observation data. Therefore, in this study, we discuss the relationship between temperature and the amount of snow using observation data for the Japanese Alps region and present the results of some meteorological observations we carried out at high-altitude sites in the Japanese Alps region.

2. Characteristics of the Japanese Alps region

The Japanese Alps is a collective name for the Hida Mountains, Kiso Mountains, and Akaishi Mountains, spreading approximately 200 km north to south and 100 km east to west. In a wider sense, the Japanese Alps region includes the Ryohaku Mountains in the west and Mt. Fuji, Mt. Yatsugatake, and the Mikuni Mountains in the east, bringing the geographical span of the region to more than 200 km in the east west direction. The altitude of the Japanese Alps summit is around 3,000 m; however, the climate conditions vary widely because it lies in the center of Honshu between the Japan Sea coast and the Pacific coast, with the northern area being known to experience one of the heaviest snowfalls in the world. The vegetation is a mix of circumpolar, northern, and continental elements. It is the habitat of many treasured alpine butterflies and is the southern-most habitat of the Ptarmigan on the planet. Because there are no glaciers in the Japanese Alps, the ecological system constituents such as alpine butterflies or the Ptarmigan are considered to be the remaining survivors from the last glacial period. However, the ecological system is quite sensitive to global-scale environmental changes. Therefore, the mountain ecological system exists under strict and critical environmental conditions (air temperature or hydrological factors). Additionally, global warming has a stronger influence in a smaller space because the temperature decreases more at higher altitudes. Next, we will show that the temperature change is dramatically larger with a change in elevation than with a horizontal change. Figure 1 shows the relationship between the latitude of the meteorological bureau office and the annual mean air temperature. Naturally, the further north the obserbation site is, the bigger the decrease in the annual mean air temperature. We can recognize a good correlation between the latitude and annual mean air temperature, except for the high-altitude Mt. Fuji and the observation sites marked on Fig. 1. According to this relation, for a

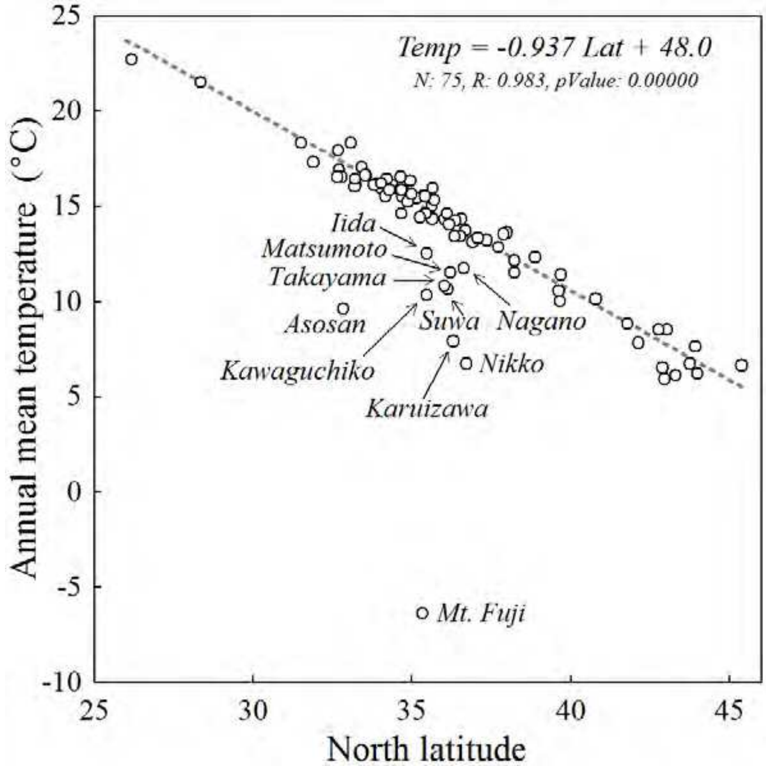

Fig. 1. Relationship between the latitude of the meteorological bureau office and the annual mean air temperature

change of 1 °C in the annual mean air temperature, one must move 118 km north or south. However, if the lapse rate of the air temperature is 0.65 °C/100 m, then a 154 m changes in elevation will bring about a change of 1 °C in air temperature. Thus, the air temperature change due to altitude variation is almost 800 times more drastic than that due to horizontal variation. The distribution of vegetation is perspectively determined by air temperature, so it is difficult to realize the horizontal vegetation change; however, in mountain areas where the air temperature changes rapidly with elevation, the vegetation is very sensitive to global warming. Furthermore, because of the warming, vegetation that has adapted to the high altitude and colder environment could lose its habitat. Changes in vegetation will change the distribution of insects and consequently affect larger animals. Thus, global-scale environmental change will impact the mountain area directly.

In Fig. 1, data that are out of regression line have been named and their locations (circles) and elevations are shown on the map in Fig. 2. The altitude of the observation site on Mt. Fuji is 3,775 m, and it is the highest observation site of the Japan Meteorological Agency. The second highest one, which records temperature, humidity, wind, precipitation, and snow depth, is Nikko, whose altitude is 1,292m. Ten sites, including Nagano with an altitude of 418 m, are located at high altitudes, and the effect of high altitude is coupled with that of temperature change; hence we can see that they are out of the regression line in Fig. 1. All of the sites except for Asosan and Nikko are located in the Japanese Alps region.

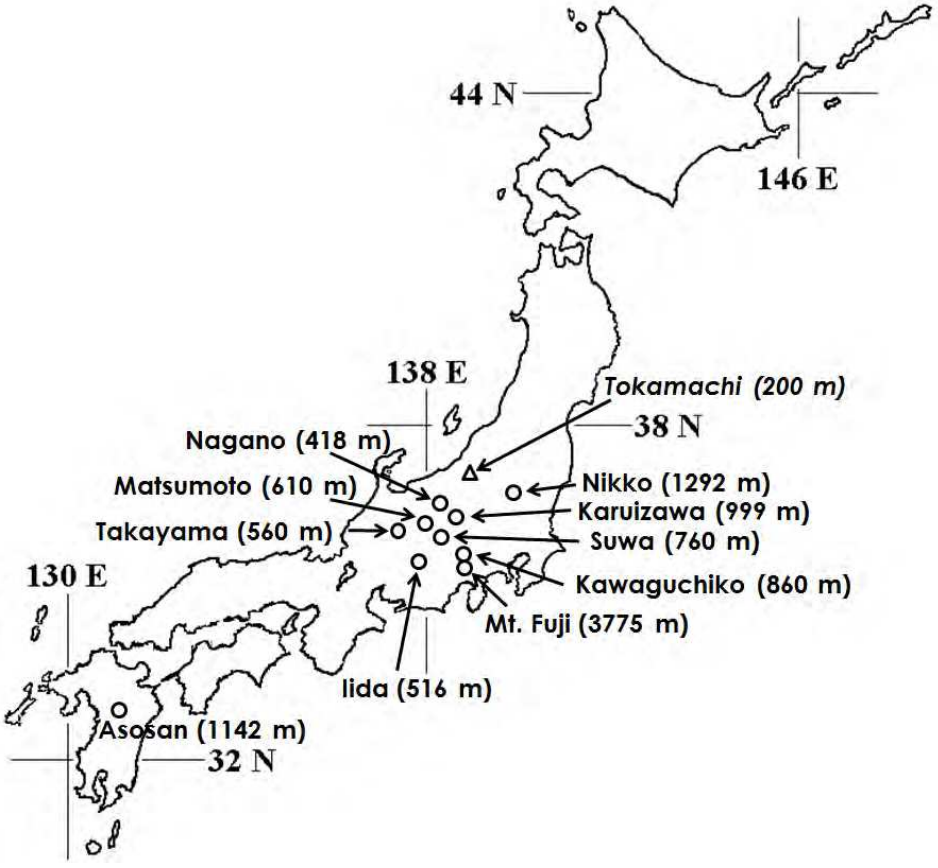

Fig. 2. Location map of the meteorological sites and their elevation

3. Variation in temperature and snow accumulation in the Japanes Alps region

As mentioned above, the high-altitude locations are selected from meteorological observation sites; we will discuss the variation tendencies of temperature and snow accumulation in resent years at these sites. It is well known that global warming trends are notably recognized in minimum temperature rather than mean temperature or maximum temperature, so the annual minimum temperature is discussed for the warming index. Though Nikko and Asosan are not located in the Japanese Alps region, ten sites including these two sites are discussed.

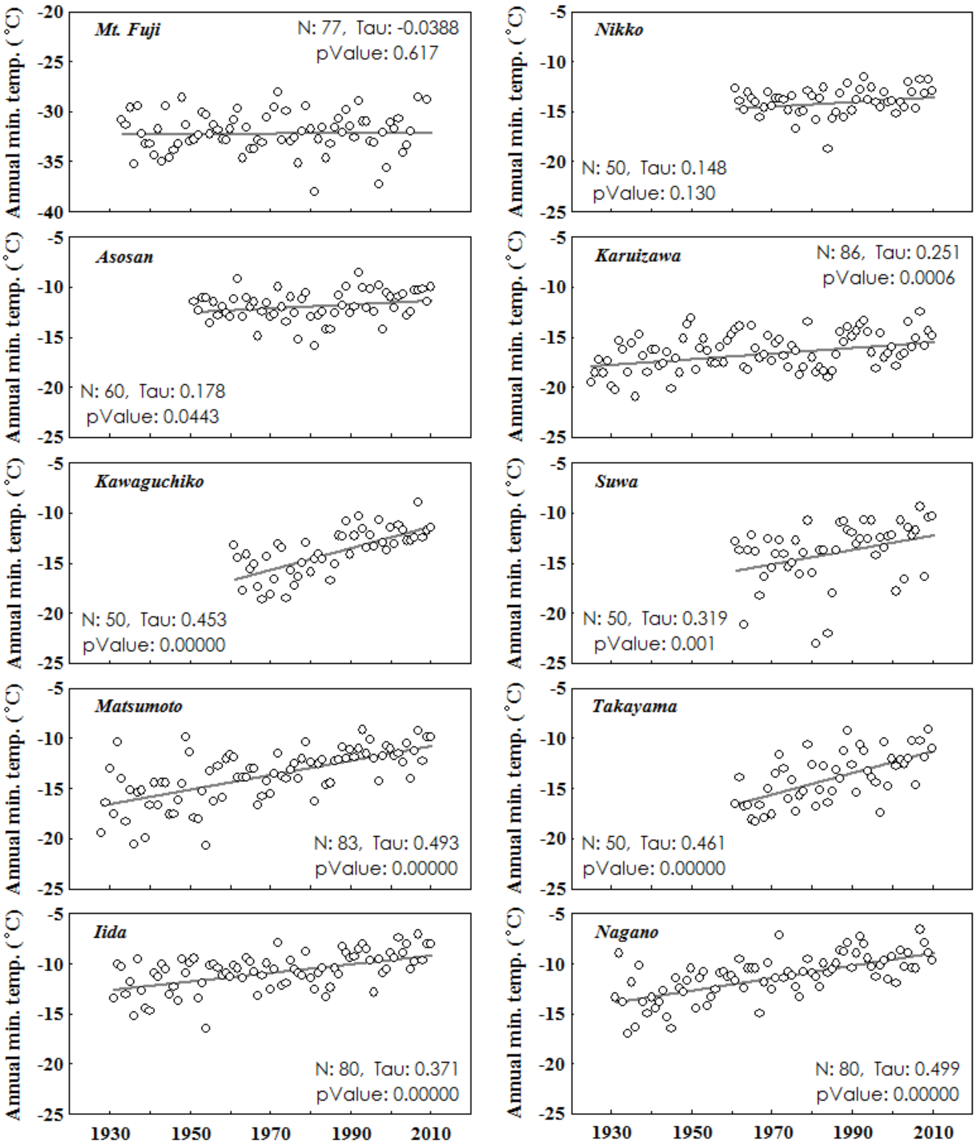

Fig. 3. The varifation in the annual minimum temperature and the results of the Mann-Kendall test at each site

The variation in the annual minimum temperature at each site is shown in Fig. 3, using data from the Japan Meteorological Agency. We used observations up to 2010 for all sites, with the longest dataset going back 86 years to 1925 at Karuizawa. The shortest observation period is 50 years at Nikko, Kawaguchiko, Suwa, and Takayama. In Fig. 3, the results of the

Mann-Kendall test are also shown to demonstrate the statistical significance of the annual minimum temperature variation over long periods. At Mt. Fuji, tau = -0.0388, and shows a slightly decreasing trend; however, P = 0.617 and the change in the annual minimum temperature for 77 years is statistically insignificant. At Nikko, tau = 0.148, which shows a

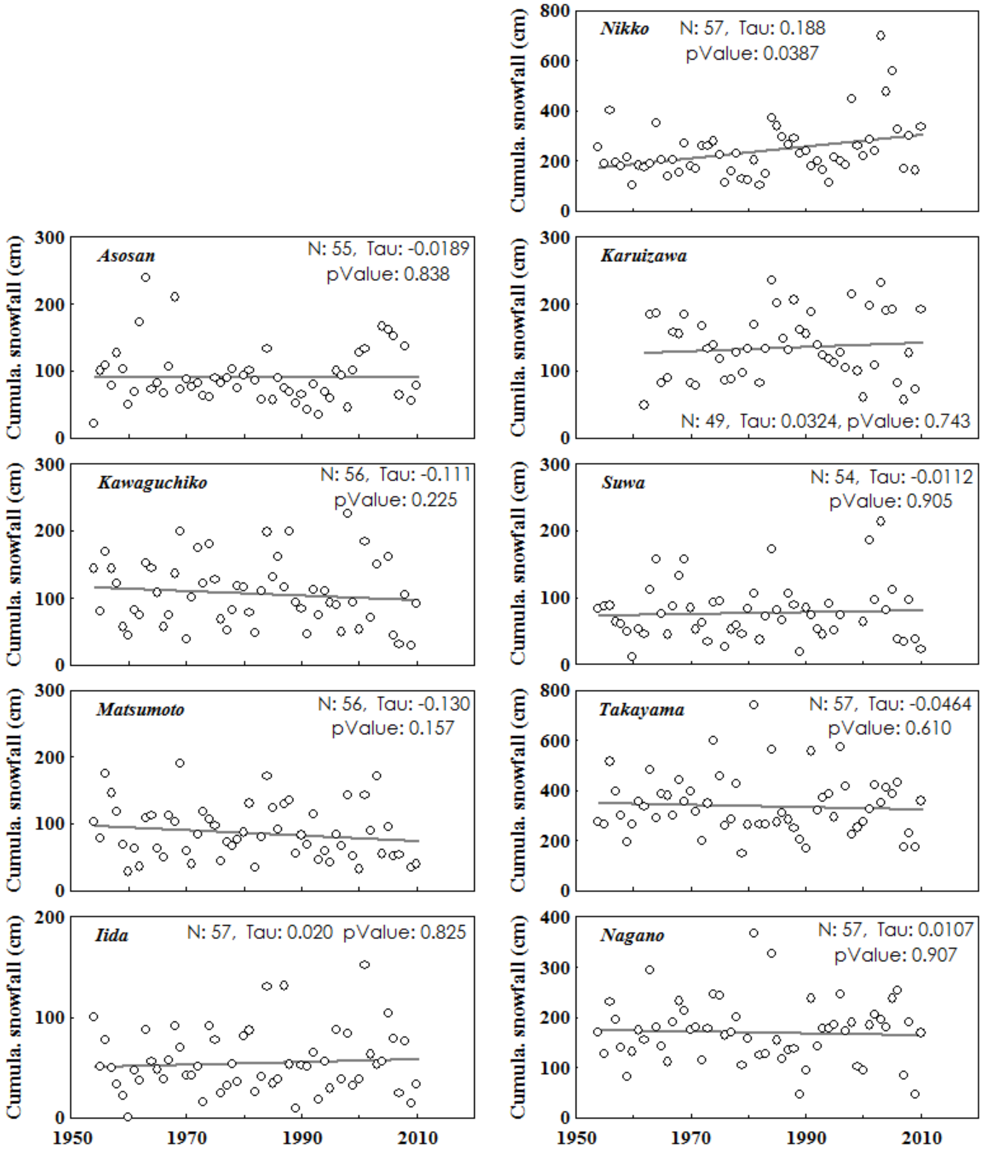

Fig. 4. The variation in the annual cumulative snowfall and the results of the Mann-Kendall test at each site

weak increasing trend of annual minimum temperature; however, P = 0.130 and it does not show a statistically significant trend in 50 years of annual minimum temperature. At Asosan, tau = 0.178 and P = 0.0443, indicating a statistically increasing trend of annual minimum temperature in the 5 % significant level. In seven sites, from Karuizawa to Nagano, an increasing trend of annual minimum temperature is recognized at the 1 % significant level, which is statistically significant. As can be seen, at a location with extreme high altitude such as Mt. Fuji, the annual minimum temperature over the last several decades does not increase or decrease. At the second highest altitude, Nikko, the changing trend is insignificant; however, at altitudes lower than Asosan, the increasing trend of annual minimum temperature during the last several decades is statistically significant. Nonetheless, it should be noted that the observation sites at Mt. Fuji, Nikko, and Asosan are set up in places with either no population or very small population; in contrast, the observation sites from Karuizawa to Nagano are set up in urban environments. Thus, the influence of urban climate is added to the notable increasing trend of annual minimum temperature in Fig. 3.

The variation in the annual cumulative snowfall is shown in Fig. 4 for each observation sites using the data from the Japan Metrological Agency. Winter generally means from November to April, hence, cumulative snowfall here indicates the cumulative value of daily snowfall from November (sometimes October) to next April (sometimes May). The annual cumulative snowfall in 2010 is calculated from the daily value between November 2009 and April 2010. There is no snowfall observation at Mt. Fuji, so it is not shown in Fig. 4. In each site, the aggregation period is almost the same, 54-57 years. The results of the Mann-Kendall test are also shown in Fig. 4 to consider the statistical significance of the variation in the annual cumulative snowfall over a long period. According to these results, at Nikko, tau = 0.188, P = 0.0387, and the increasing trend of annual cumulative snowfall is statistically significant at the 5 % level. At the other eight sites, it is shown that the recent annual cumulative snowfall does not show any increasing or decreasing trend. At Nikko, the annual minimum temperature shows an insignificant, slightly increasing trend; however, the annual cumulative snowfall has a significant increasing trend. At the other eight sites, the annual minimum temperature shows a significant increasing trend; however, the annual cumulative snowfall has no increasing or decreasing trend. Thus, an increase in the annual minimum temperature does not necessarily lead to a decrease in the annual cumulative snowfall.

Figure 5 shows the variation in the annual maximum snow depth in each site using the data from the Japan Metrological Agency. The snow depth and temperature at Karuizawa have been observed for 86 years, since 1925, however, in the other sites the snow depth had been observed only for around 50 years. At Mt. Fuji, observations of snow depth ended in 2004. The results of the Mann-Kendall test are also shown in Fig. 5 for the statistical significance of the long period data of variations in the maximum snow depth. Accordingly, in Mt. Fuji, tau = 0.239, P = 0.032, and the increasing trend of the annual maximum snow depth is statistically significant at the 5 % level. At the other nine sites, the absolute value of tau is small and the P value is large, which means the annual maximum snow depth is not showing a statistically significant change in recent decades. At Nikko, despite the significant increasing trend of annual cumulative snowfall, for the annual maximum snow depth, tau = -0.121 and P = 0.219, which does not show a statistically significant change.

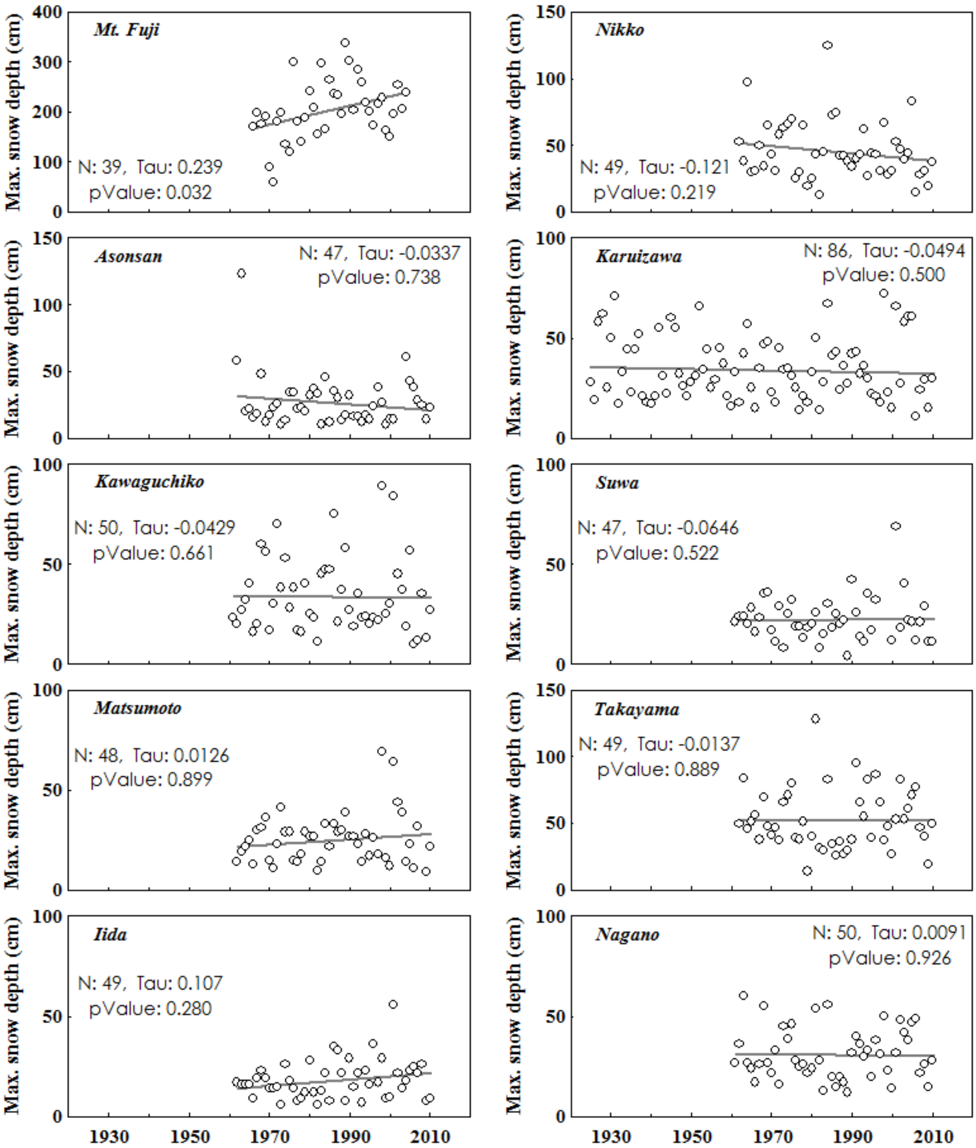

Fig. 5. The variation in the annual maximum snow depth and the results of the Mann-Kendall test at each site

4. Relationship between winter mean air temperature and winter precipitation in the Japanese Alps region

The IPCC 4th report also states that future warming will increase precipitation in mid–high latitudes in winter. To examine this issue with regards to the Japanese Alps region, the

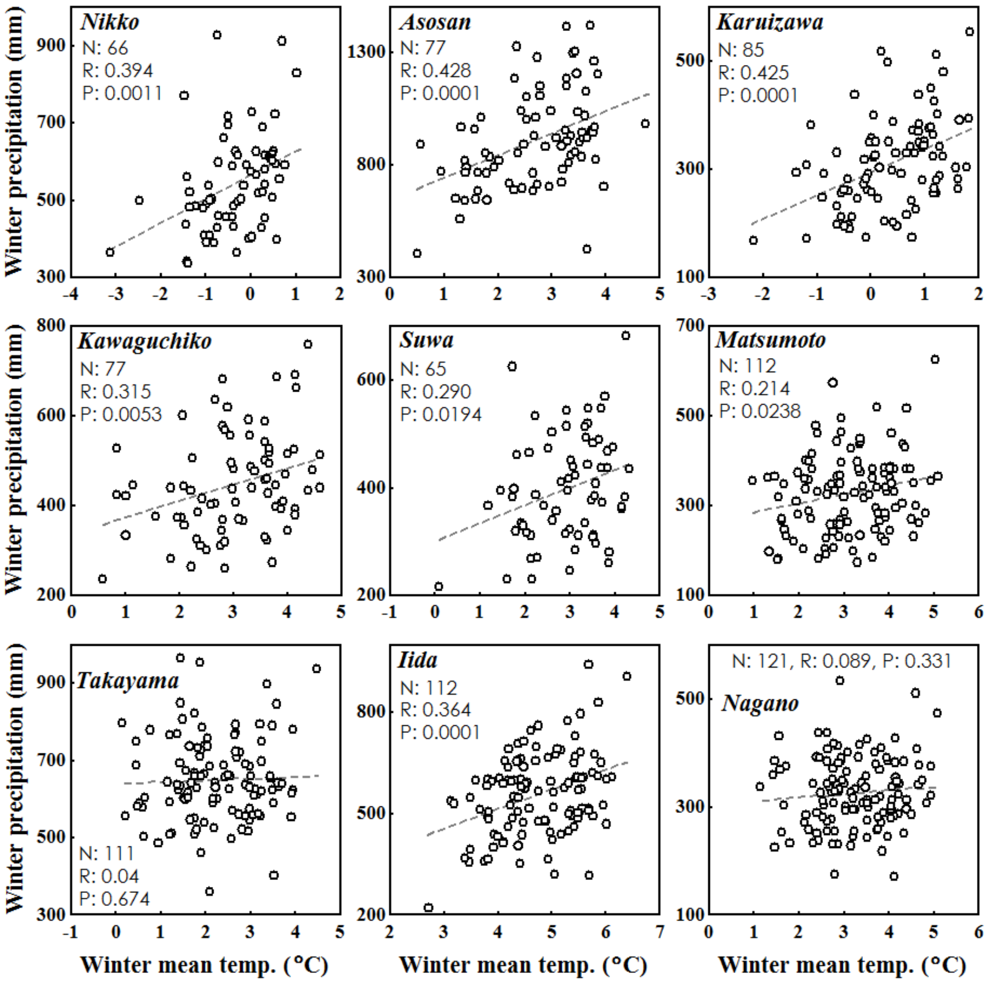

Fig. 6. Relationship between the winter mean air temperature and the winter precipitation at the observation sites

interannual variability of the winter mean air temperature and winter precipitation are discussed. The Japan Meteorological Agency has carried out precipitation observations in all the sites except Mt. Fuji, and these were used to calculate the precipitation in winter (from November to April) which is shown along with the winter mean air temperature in Fig. 6.
The monthly mean air temperature and monthly precipitation have been observed for a long period by the Japan Meteorological Agency. Both data-sets were obtained spanning 121 years from 1890 at Nagano, 112 years (from 1988) at Matsumoto and Iida, and for 111 years (since 1900) at Takayama. Even the shortest record at Suwa goes back 65 years. At all of the nine sites, winter precipitation shows an increasing trend with an increase in the winter mean air temperature. The mutual relations are statistically significant at a 1 % level at

Nikko, Asosan, Karuizawa, Kawaguchiko, and Iida. At Suwa and Matsumoto, the mutual relation is statistically significant at a 5 % level. At Takayama and Nagano, the relation is not statistically significant. Iida is exceptional, in favourable correlation of winter mean air temperature and winter precipitation, we note that the statistical significance of the correlation is reduced as the observations move from high altitude to lower altitudes.

At observational sites except for Mt. Fuji and Nikko, we recognize an increasing trend of winter mean air temperature in recent years along with an increase in winter precipitation. We note, however, that the annual cumulative snowfall or the annual maximum snow depth has not increased. This is because in the area of the Japanese Alps that is below 1,000 m, the changes in air temperature in winter are around 0 ºC, a temperature that is close to the precipitation temperature boundary, which determines whether particles formed in the cloud will fall as snow or rain. That is, if the air temperature increases, winter precipitation would increase; however, this affects rainfall but does not increase snowfall.

However, a relatively large part of the Japanese Alps region is within the altitude range of 1,000–3,000 m and the snowfall there serves as a vital water resource. Therefore, the effect of global warming on snow accumulation in mountain areas is a crucial issue. At places with high altitude in the Japanese Alps, it is rare for the air temperature to rise to around 0 ºC at the current levels of temperature increase. An increase in winter precipitation should lead directly to an increase in snow accumulation in the high altitude area. Unfortunately, currently there are no observational records to base our discussion on. We must note that lack of meteorological observation data from high altitudes is a very unfavorable situation when attempting to evaluate the effect of global warming on the ecological system and water resources in mountainous regions.

5. Variation in snow depth at Tokamachi

As mentioned above, observations of snow depth by the Japan Meteorological Agency have been recorded for over 86 years since 1925, even in Karuizawa. At the Tokamachi Experimental Station of the Forestry and Forest Products Research Institute (represented by a triangle in Fig. 2), snow depth has been continuously observed since 1917 (Takeuchi, *et al.*, 2008).

The record of daily snow depth is shown in Fig. 7. Figure 7 also shows the annual maximum snow depth for each winter, we can see the total amount of snow in each winter from the graphical form. The annual maximum snow depth in the winter of 1944–45 was 425 cm and is the highest recorded at Tokamachi. Snow began falling at the beginning of November 1944 and fell continuously until the middle of May 1945. We can see in the graph that the snow is also extremely deep. The next highest record of annual maximum snow depth was 381 cm in the winter of 1937–38, 380 cm in the winter of 1933–34. In Tokamachi, years with exceptionally heavy snowfall are often observed in the 1930s and 40s. After 1949, there is an increase in lighter snowfall years; however, in the 1980s extraordinarily heavy snow years are more common such as 377 cm in the winter of 1980–81 and 367 cm in the winter of 1983–84. After 1987, the lighter snowfall trend returned. The annual maximum snow depth was only 81 cm in the winter of 1988–89. Then, the trend of heavy snow years resumed, with 305 cm in the winter of 2004–05 and 313 cm in the winter of 2005–06.

As mentioned above, the interannual variation in snowfall at Tokamachi has wide fluctuations; some years have an annual maximum snow depth of 425 cm while on other

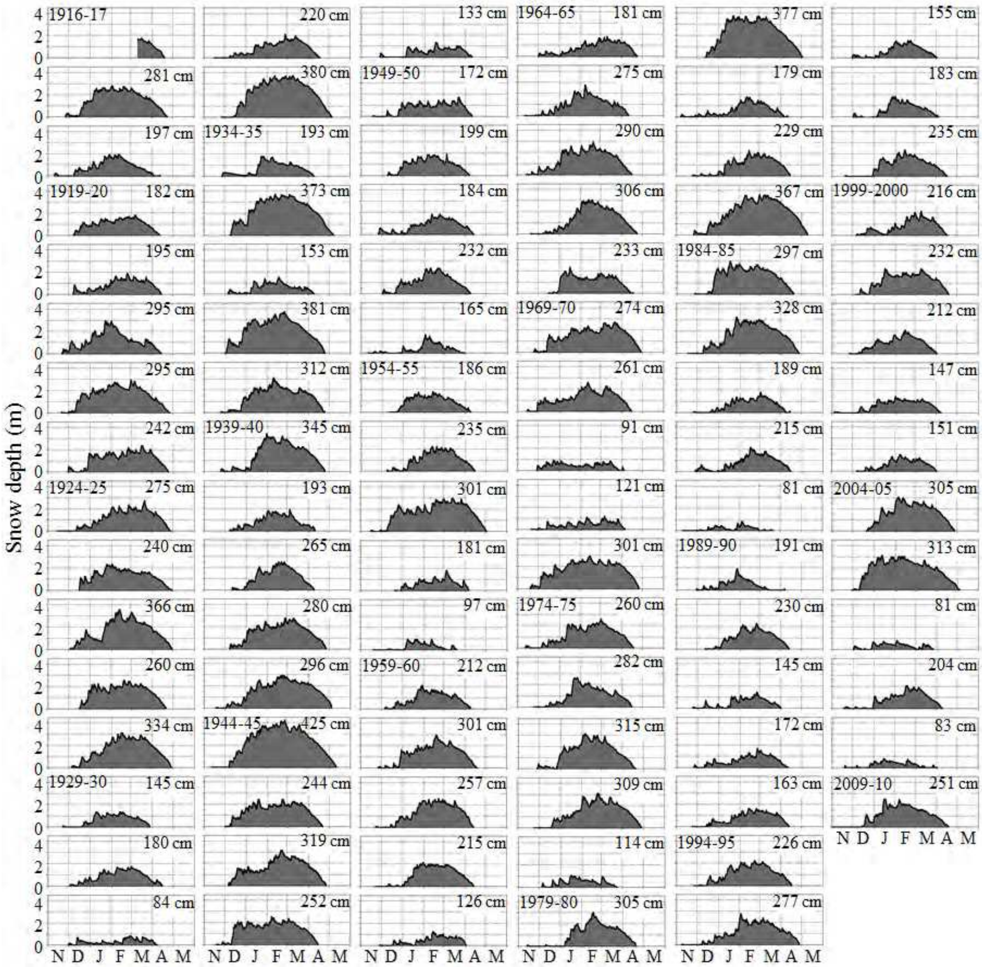

Fig. 7. The record of the daily snow depth in Tokamachi

years it is less than 90 cm. This is because the altitude of the observation site at Tokamachi is 200 m and the winter temperature is relatively high. This area has rainfall even in winter. That is because in a warm winter year, a slight increase in the air temperature creates suitable conditions for precipitation of rather than snow, so the accumulated snow depth does not get deeper.

Because the winter air temperature may affect snow accumulation at Tokamachi; we will discuss the relation between them. Figure 8 shows the relationship between the winter mean air temperature (from November to April) and the annual maximum snow depth from 1918 to 2010 at Tokamachi. As Fig. 8 shows, the statistics for the data spanning 93 years at Tokamachi gives R = 0.749 and P = 0.0000, which statistically shows quite significant.

It is clear that in the winter, when the winter mean air temperature is low, the annual maximum snow depth is greater and when the winter mean air temperature is high, the

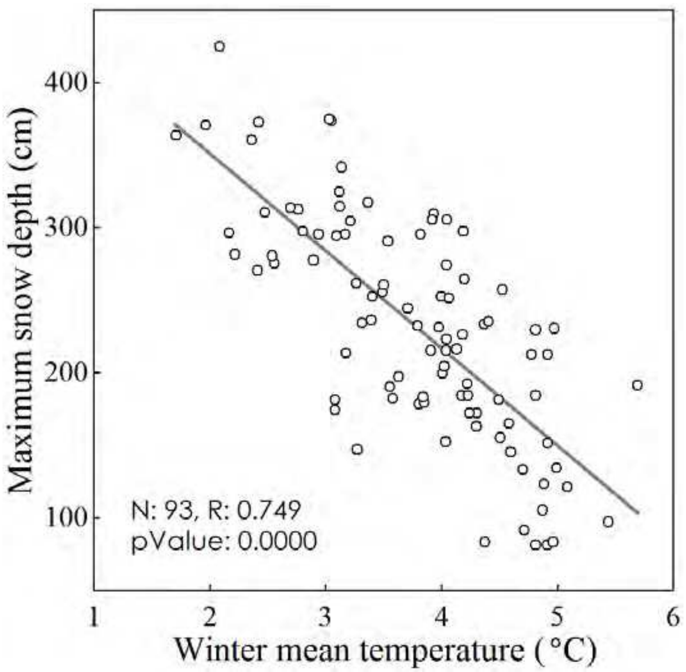

Fig. 8. The variation in the winter mean air temperature (from November to April) and the annual maximum snow depth from 1918 to 2010 in Tokamachi

annual maximum snow depth becomes shallower. We can conclude that snow accumulation is defined by winter air temperature at Tokamachi.

We now consider the interannual variation in the winter mean air temperature and the annual maximum snow depth. Figure 9 shows the variation in the winter mean air temperature and the annual maximum snow depth from 1918 (November 1917–April 1918) to 2010. In Fig. 9, the straight lines that show each variation trend are also displayed, and the result of the Mann-Kendall test which shows the statistics of the long-term variability. Considering the winter mean air temperature for 93 years, tau = 0.262 and P = 0.0002, with a statistically significant increasing trend. The variation in the annual maximum snow depth for 93 years is tau = -0.120 and P = 0.089, with a weak decreasing trend, though statistically significant level was not confirmed. However, there is possibly a gap before and after a certain year in both the winter mean air temperature and the annual maximum snow depth. As mentioned before, years with extraordinary heavy snowfall occurred frequently until 1948, however afterwards, years with lighter snowfall increased. By evaluating the Mann-Kendall test for 1918–1948 and 1949–2010 separately, we find that the annual maximum snow depth in the former period is on a weak increasing trend, tau = 0.166, P = 0.190 while in the latter period no variation in trend can be identified, with tau = 0.0005 and P = 0.995. As for the winter mean air temperature, tau = -0.046 and P = 0.717 in the former period, and tau = -0.009 and P = 0.916 in the latter period with no obvious trend in the variation. Climate is known to change with some gap, but not to shift unilaterally. The winter air temperature and snow accumulation at Tokamachi is characterized by a clear gap.

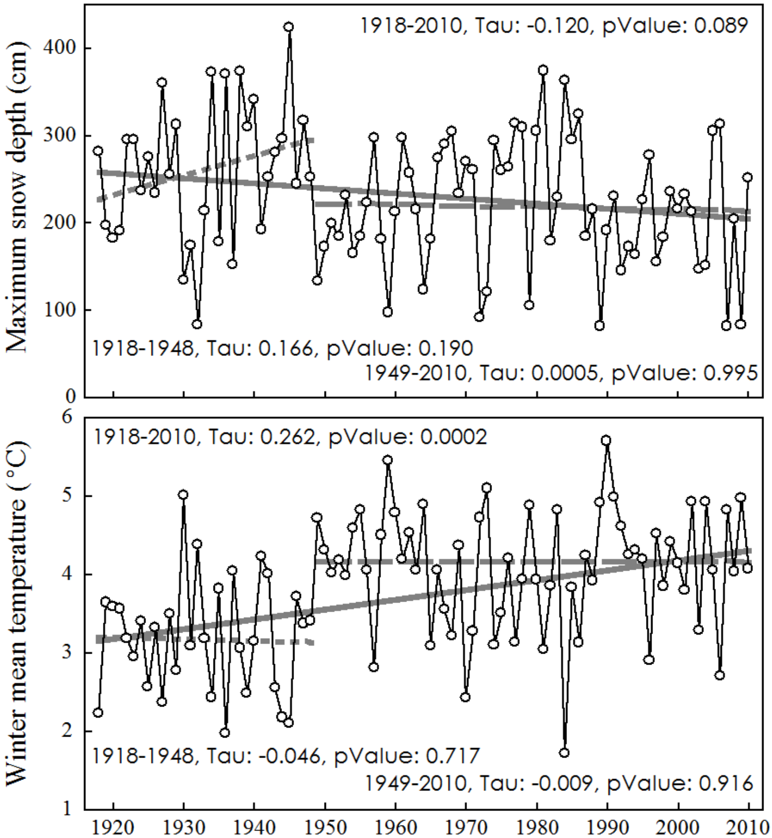

Fig. 9. The variation in the winter mean air temperature and the annual maximum snow depth from 1918 to 2010 in Tokamachi

As mentioned previously, the northwest coast of Honshu is one of the snowiest regions in the world. However, at lower altitudes where the winter temperature is relatively high, the interannual variation in snow accumulation is wide and the variation in snow accumulation is not necessarily a simple upward or downward trend.

6. Development of meteorological observation stations at high altitudes in the Japanese Alps region

It is said that mountainous areas are quite sensitive to global-scale environmental change such as warming. The ecological system in mountainous areas is strongly affected not only by air temperature, wind, or solar radiation, but also by snow cover. Snow accumulation in mountainous areas plays the role of a white dam, which is an essential water resource. Therefore, the effect of global warming on these meteorological elements is a critical issue. However, Mt. Fuji Weather Station, which used to be a symbol of meteorological observation in mountainous areas, has been unmanned since August 2004. Since then, only

temperature, humidity, atmospheric pressure, and hours of daylight (summertime only) are monitored. Of the other observation sites of the Japan Meteorological Agency, Nobeyama, at 1350 m elevation, is the highest. On evaluating the effect of a global-scale warming event on environmental change at a regional scale of the Japanese Alps at a high altitude of 3,000 m, we must note that the lack of meteorological observation data for high altitudes is a very unfavorable situation for any effort to evaluate the effect of warming against the ecological system and water resources in mountainous ranges.
The Institute of Mountain Science, Shinshu University has developed a network of meteorological observations in the Japanese Alps region. The ten stations shown in Fig. 10 have already started recording observations. The highest observation site is Yari at 3125 m.

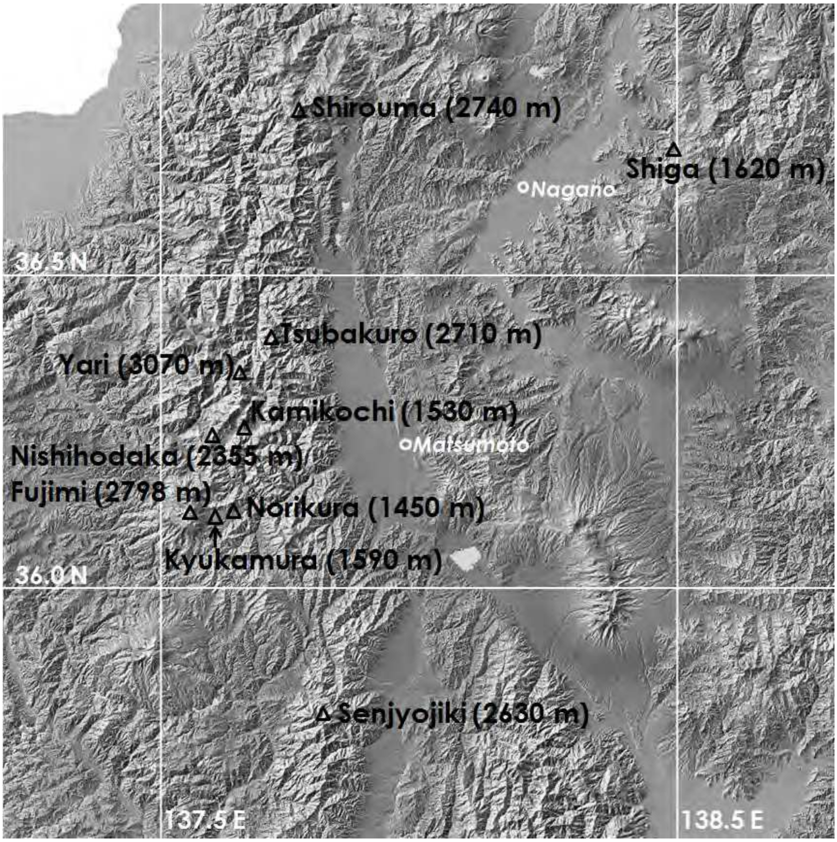

Fig. 10. Location map of the meteorological station developed by the Institute of Mountain Science, Shinshu University

Observation data from these sites are sent to a computer at the Institute via a data communication mobile telephone network or a phone line year around. These meteorological observation data are available on the institute's website in quasi-real time. Table 1 lists the location and observational components at each observation site.

Observation site	Height (m)	North lat. (degree)	East lon. (degree)	Start at (y/m/d)	Obserbation component						
					Temp.	Humid.	Wind	Press.	Solar rad.	Precip.	Snow dep.
Yari	3070	36.340	137.646	2008/10/22	○	○	○	○	○	△	×
Fujimi	2798	36.121	137.558	2003/10/15	○	○	○	○	○	△	×
Shirouma	2740	36.752	137.753	2010/09/26	○	○	○	○	×	△	×
Tsubakuro	2710	36.399	137.715	2008/11/14	○	○	○	○	○	△	×
Senjyojiki	2630	35.778	137.814	2006/11/08	○	○	○	○	○	○	×
Nishihodaka	2355	36.265	137.617	2008/10/15	○	○	○	○	○	△	○
Shiga	1620	36.711	138.495	2007/11/21	○	○	○	○	○	○	○
Kyukamura	1590	36.114	137.613	2002/11/18	○	○	○	○	○	△	○
Kamikochi	1530	36.253	137.669	2008/09/08	○	○	○	○	○	○	○
Norikura	1450	36.122	137.630	2006/03/18	○	○	○	○	○	○	×

Table 1. Location and observational components at each observation site

Figure 11 shows the daily mean air temperature at the Fujimi observation site as an example of an observation result. At the beginning of the observation, some data were missing in winter due to battery condition, *etc.*; however, since spring 2005, continuously observation data have been available. So far, the maximum value of the daily mean air temperature at Fujimi is 15.0 ºC and the minimum value is -24.1 ºC. Considering the air temperature inter-annual variation trend in winter and summer, there is no significant increase or decrease during this period.

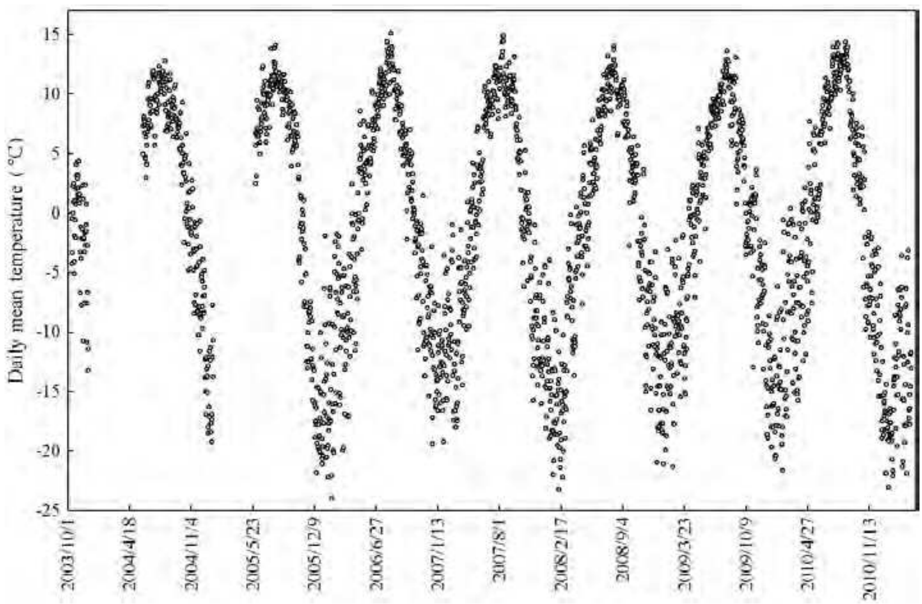

Fig. 11. The variation of the daily mean air temperature at the Fujimi observation site

It is difficult to observe snow depth in a mountain region with extreme heavy snowfall. Moreover, it is almost impossible to observe snowfall as precipitation in a mountain location with no commercial power source. Therefore, a method for estimating winter solid precipitation in mountain regions, using a snow chemical technique is being developed (Suzuki *et al.*, 2011).

7. Conclusion

Under the present circumstances, the role of the mountain regions as a system for purification of water and air that is essential for human beings' existence is not duly recognized and is undervalued. However, there is no doubt that we need to understand the response of mountain regions to global-scale environmental change in the near future. To achieve that, we need to discuss the matter based on proper observation data. We therefore plan to continue our meteorological observations at high–altitude mountain regions, overcoming various issues that arise under the extreme conditions of low temperature and gale-force winds (including powerful blizzards in winter). The steady recording of observations does not get immediate results such as publishing articles, *etc.* so it trends to be overlooked, however, we must not forget that there is no reliable future prospect for understanding this topic without obtaining the above mentioned data on site.

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The failure of the UN climate change summit in Copenhagen in December 2009 to effectively reach a global agreement on emission reduction targets, led many within the developing world to view this as a reversal of the Kyoto Protocol and an attempt by the developed nations to shirk out of their responsibility for climate change. The issue of global warming has been at the top of the political agenda for a number of years and has become even more pressing with the rapid industrialization taking place in China and India. This book looks at the effects of climate change throughout different regions of the world and discusses to what extent cleantech and environmental initiatives such as the destruction of fluorinated greenhouse gases, biofuels, and the role of plant breeding and biotechnology. The book concludes with an insight into the socio-religious impact that global warming has, citing Christianity and Islam.

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