Impacts of Global Warming on Alpine Plants Growing in the Japanese Alpine Zone and Possibility of Monitoring Global Warming Impacts with Alpine Vegetation

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Abstract

This paper introduces the results of our research projects for the Ministry of the Environment and discusses the possibility of using alpine vegetation to monitor global warming impacts in Japan. We plotted the trend of air temperature in the Japanese alpine zone, and then collected information on possible global warming impacts there, some of which we studied in detail. We elucidated the relationships between these impacts and meteorological factors. From these relationships and common future climate scenarios, we estimated potential global warming impacts in the Japanese alpine zone. We devised a measuring system that could operate properly in the alpine zone, where conditions are very severe. The system operates unmanned, runs on solar power and is small and lightweight. This paper discusses the possibility of monitoring global warming impacts using alpine vegetation in Japan.

Key words: Alpine plants, flowering time, global warming impacts, monitoring, perennial snow patch

1. Introduction

Global warming due to human activity is anticipated to cause serious problems in the future. In response, the Intergovernmental Panel on Climate Change (IPCC) was established in 1988. After the IPCC's first to third reports came out, reports about impacts in Japan began to be published (Global Environment Department, 1994; Nishioka & Harasawa, 1997; Global Environment Department, 2001; Harasawa & Nishioka, 2003). These reports described some remarkable impacts on the Japanese alpine zone. First, global warming during the 20th century was much greater than in any of the previous nine centuries. The best agreement between model simulations and observations over the last 140 years has been obtained when all anthropogenic (greenhouse gases and estimated sulfate aerosols) and natural forcing factors (solar variation and volcanic activity) are combined. Second, regional changes in climate, particularly increases in temperature, have already affected a diverse set of physical and biological systems in many parts of the world. Third, the vulnerability of natural systems to climate change differs across regions. And fourth, alpine ecosystems are among the most vulnerable to global warming. Many publications discuss the impacts of global warming on alpine zones (*e.g.*, Nogami, 1994; Beniston, 1994; Omasa *et al.*, 1996; Masuzawa, 1997; Beniston & Innes, 1998; Köner, 2003; Member of the Diet in charge of environment *et al.*, 2003). On the basis of this information, we began a research project for the Ministry of the Environment. This paper introduces our results and discusses the possibility of monitoring global warming impacts using alpine vegetation in Japan. In this project I collaborated with members of the School of Agriculture and Life Sciences at The University of Tokyo, the Faculty of Science at Shizuoka University, and the Hakusan Nature Conservation Center (Ishikawa Prefecture).

2. Air Temperature Changes in the Japanese Alpine Zone

To study the impacts of global warming on alpine vegetation in Japan, it is necessary to determine trends in air temperature in the Japanese alpine zone. We compared the annual average temperature at the top of Mt. Fuji (Japan Meteorological Agency, 1967, 1979, 1984 and 2000-2003; Shizuoka Meteorological Observatory, 1981-2000) with the global average surface temperature (Oshima *et al.*, 2003) (Fig. 1). The annual average temperature at the top of Mt. Fuji has increased since 1980 at a faster rate than the global average surface temperature. To understand the regional changes in air temperature in the Japanese alpine zone, we compared the annual average temperature at the top of Mt. Fuji with the air temperature at 3,000 m above Wajima (Ishikawa Pref.) and Tateno (Ibaraki Pref.), and at 1,500 m above Nemuro (Hokkaido). These air temperatures were estimated from aerological data published by the Japan Meteorological Agency (Japan Meteorological Agency, January 1980 - December 2000, 1983) The changes in air temperature show similar trends (Fig. 2).

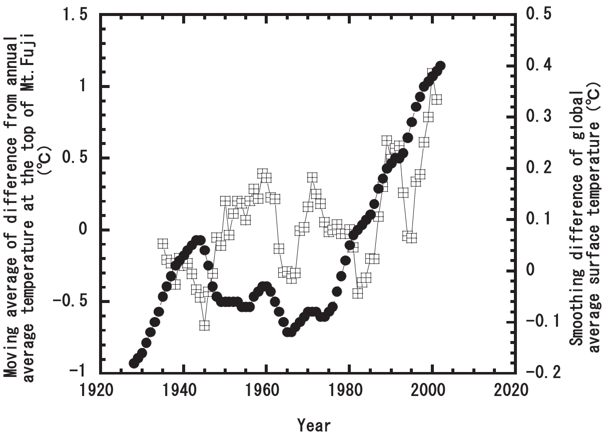

Fig. 1 Annual average temperature at the top of Mt. Fuji (●/squares) and global average surface temperature (⊞/crosses).
Symbols show the moving averages of difference from the annual average temperature from 1961 to 1990. Meteorological data at the top of Mt. Fuji were published by the Japan Meteorological Agency. Closed circles show the smoothing difference of global average surface temperature from the Chronological Scientific Environment.

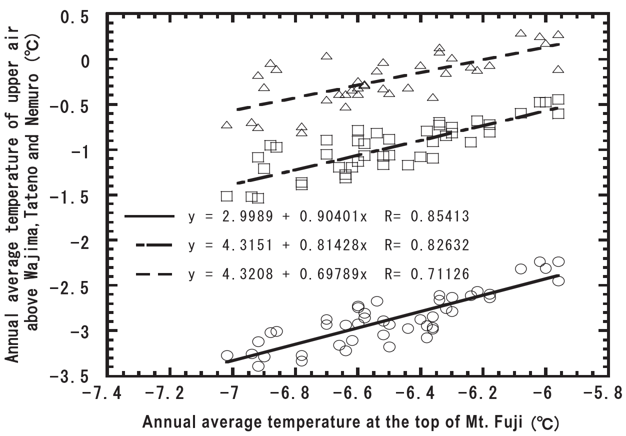

Fig. 2 Comparison of the annual average temperature at the top of Mt. Fuji with upper atmospheric temperatures above Wajima, Tateno and Nemuro.
Moving average data at the top of Mt. Fuji were calculated from data published by the Japan Meteorological Agency. Open circles (○) show the moving average temperature at 3,000 m above Wajima, open squares (□) at 3,000 m above Tateno, and open triangles (△) at 1,500 m above Nemuro. These values were calculated from aerological data published by the Japan Meteorological Agency.

3. Phenomena Possibly Related to the Increase in Temperature in the Japanese Alpine Zone

We collected information on phenomena that might be related to the increase in temperature in the Japanese alpine zone from the literature and personal interviews. Examples from the literature have reference; examples with no reference come from personal interviews. Examples of observed changes include a decrease in the area of alpine fields by expansion of subalpine tree ranges (Mt. Apoi, Hokkaido (Nishikawa *et al.*, 1993; Watanabe, 2005), Mt. Yatsugatake, Nagano Pref.), increase in withered needles of Japanese stone pine in early spring at various sites (Haimatsu-kare Network, 1998a,b), earlier flowering of alpine plants (Mt. Kitadake, Yamanashi Pref (Minamikantochiku National Park and Wildlife Management Office, 1996-2003), Oze, Gunma Pref. (Gunma Prefecture, 1979-2005)), spread of lowland plants such as *Plantago asiatica* and lowland animals up into the alpine zone (Mt. Hakusan, Ishikawa Pref. (Nogami, 2001, 2002, 2003)), earlier emergence of alpine butterflies (Mt. Taisetsu, Hokkaido (Konno & Tanji, 2003)), later molting of Japanese ermine (Shiga-Kogen, Nagano Pref. (Natori, 2005)), reduction in area of perennial snow patches (Mt. Hakusan, Ishikawa Pref. (Ito & Ogawa, 2003)), changes in species composition of alpine vegetation (around Mt. Tekaridake, Shizuoka Pref.), and reduction in area of snow patch vegetation. We selected some of these changes to study by field survey and sought any relationships between changes in the phenomena and environmental factors such as air temperature and time of disappearance of snow cover. As examples of the earlier flowering of alpine plants, this report focuses on changes in the flowering time of *Callianthemum hondense*, which grows only in a narrow area on Mt. Kitadake, and *Lysichiton camtshatcense*, which grows at Oze. As an example of the reduction of perennial snow patches, results of measuring the Senjagaike-Sekkei snow patch are shown.

After we had collected phenological data from the alpine zone, we collected data from reports on the conservation of *C. hondense* (Minamikantochiku National Park and Wildlife Management Office, 1996-2003) and on conservation at Oze. (Gunma Prefecture, 1979-2005). Because the period of observation of the flowering time of *C. hondense* in the report was too short, we added data from a field survey that I conducted, from flowering specimens preserved at Tsukuba Botanical Garden, and from Mizuno (1984). Annual changes in the date of full flowering of *C. hondense* and *L. camtshatcense* are shown respectively in Figs. 3 and 4. Data since 1995 shown in Fig. 3 (*C. hondense*) were collected at roughly the same sites, but data before 1994 contained no detailed site information. Therefore, strictly speaking, comparisons between data since 1995 and before 1994 are

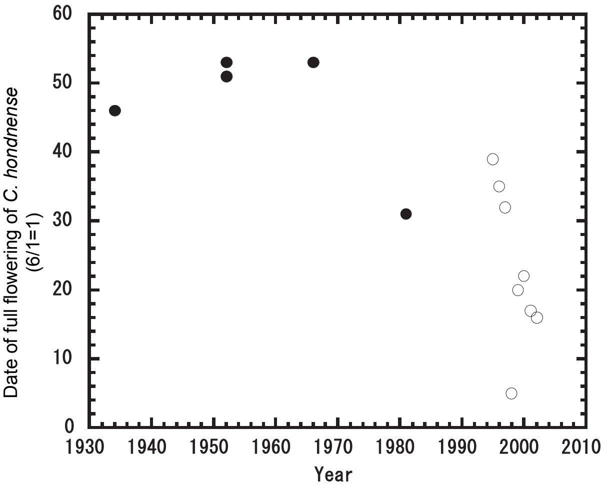

Fig. 3 Annual changes in date of full flowering of *Callianthemum hondense.*
Open circles (○) show dates of full flowering from management reports for the *C. hondense* conservation area and my field surveys, and closed circles (●) show data of flowering specimens preserved at Tsukuba Botanical Garden and flowering periods described by Mizuno (1984).

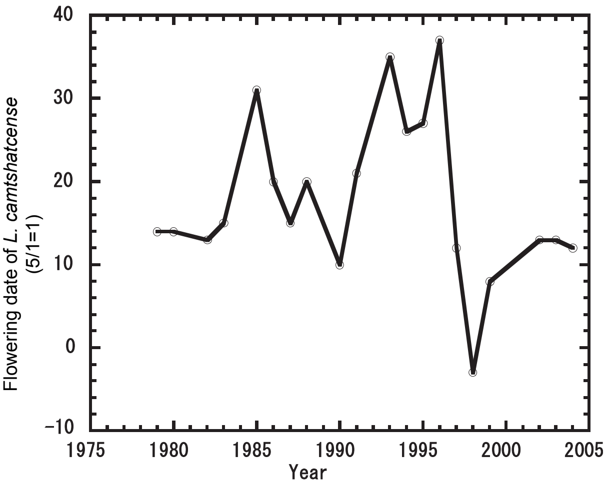

Fig. 4 Annual changes in dates of flowering of *Lysichiton camtshatcense* at Oze.
Open circles (○) show dates from a conservation area report (Gunma Prefecture, 1979-2005).

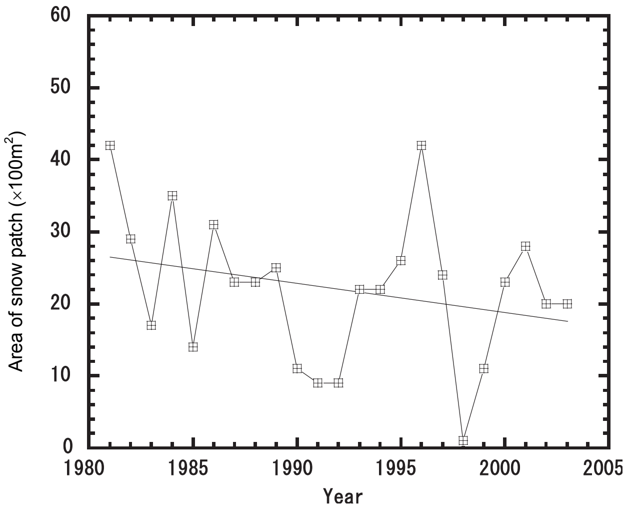

Fig. 5 Annual changes in size of the Senjagaike-Sekkei snow patch at Mt. Hakusan.
Symbols (⊞) indicate the area early in October before snowfall. These data came from Mr. Ogawa of the Hakusan Nature Conservation Center.

not valid, because the date of full flowering of *C. hondense* varies among growing sites. Nevertheless, the data suggest that the date of full flowering of *C. hondense* has advanced. Data shown in Fig. 4 were collected at the same site, and suggest that the date of flowering of *L. camtshatcense* has also advanced. The relationship between the flowering time of each plant and meteorological factors show that the date of full flowering of *C. hondense* was roughly similar to the date of snow disappearance at the top of Mt. Fuji, and the date of flowering of *L. camtshatcense* was related linearly to the monthly average temperature in April at Oze (data not shown).

The Senjagaike-Sekkei snow patch, situated at about 2,750 m on a western slope of Mt. Hakusan, is one of the few perennial snow patches in Japan. To determine the annual change in size of this patch, we measured the surface area early in October before snowfall, when the surface area is minimum. Annual changes since 1981 in the minimum area are shown in Fig. 5 with extra data from Dr. F. Ito of Fukui University. During the data period, the maximum area was 4,200 m^2 in 1981, and the minimum was 500 m^2 in 1998. From 1981 to 1992, the area change tended to decrease, but after 1992 the area showed large variations, though it still showed a tendency to decrease.

4. Evaluation of Risk of Global Warming Impacts on the Japanese Alpine Zone Based on Common Future Climate Scenarios

We estimated changes in the alpine area in Japan, flowering time of *C. hondense* on Mt. Kitadake and *L. camtshatcense* in Oze, snow patch vegetation, size of a perennial snow patch (Senjagaike-Sekkei), and the growing altitude of *P. asiatica* at Mt. Hakusan at 10-year intervals from 2000 to 2100 under common future climate scenarios (mesh size, 10 km × 10 km) scaled down from General Circulation Models (CCCM, CSIR, CCSR, MPKI) (Yokozawa *et al*., 2003) and the relationships estimated in Section 3. We regarded these changes as indicative of risks of global warming. Figure 6 shows the impact on flowering time of *C. hondense*. The calculation procedure had five steps: (1) A multiple regression equation (dependent variable, day of snow disappearance at the top of Mt. Fuji; independent variables, maximum snow depth and monthly average temperature in May at the top of Mt. Fuji) was calculated from past meteorological data. (2) The monthly average temperature in the common future climate scenarios was corrected to values at the top of Mt. Fuji. (3) From these corrected values, the future maximum snow depth at the top of Mt. Fuji was calculated according to Inoue and Yokoyama (1998). (4) Future dates of snow disappearance at the top of Mt. Fuji were calculated from the multiple regression equation and from the future maximum snow depth and future monthly average temperature in May.

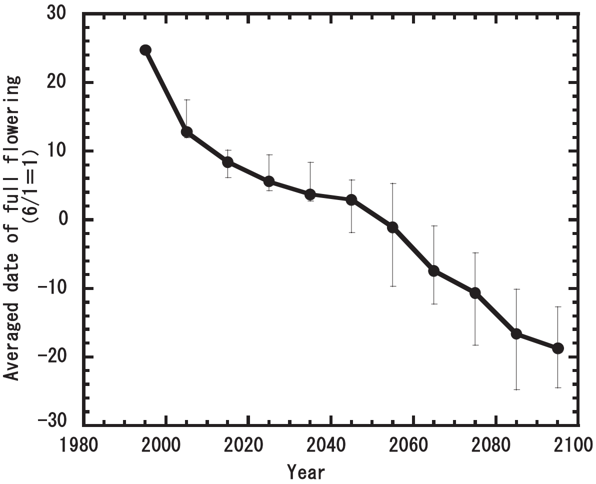

Fig. 6 Projection of dates of full flowering of *Callianthemum hondense.*
Dates of full flowering were calculated for intervals of 10 years from 2000 to 2100 under common future climate change scenarios and from the relationship between meteorological factors and dates of full flowering of *C. hondense*.

(5) From the relationship described in Section 3, the future date of snow disappearance at the top of Mt. Fuji was regarded as the future date of full flowering of *C. hondense*. This date was shown to gradually become earlier, falling to the beginning of June by the 2040s in the average of four common future climate scenarios. This date was also the earliest date of full flowering during our research period, in 1998.

5. Establishing a System for Measuring Snow Factors in the Japanese Alpine Zone

To evaluate the impacts of global warming in alpine zones, it is necessary to determine the relationships between changes in the alpine zones and meteorological factors. The main meteorological characteristics of the Japanese alpine zone are strong wind and heavy snowfall in winter in spite of the low altitude. Many phenomena in the Japanese alpine zone are influenced strongly not only by low temperatures, but also by snow factors such as the time of snow disappearance and snow depth. The limited meteorological data published allow air temperature at various sites in the Japanese alpine zone to be estimated, but the time of snow disappearance and snow depth are difficult to estimate, because they are influenced strongly by micro-topography. Therefore, to measure snow factors in the Japanese alpine zone, where conditions are severe, requires a small, lightweight, automatic measuring system that can withstand the conditions. We tested three such systems.

The first was a commercial field thermometer with two sensors set at different heights, powered by a lithium battery. The sensors recorded the temperature every hour from the beginning of November to the following June or July. The records allowed us to estimate the date of snow disappearance more clearly than the records of thermometers with one sensor. The second was a commercial half-film camera that took one picture every day from the beginning of the snow-melt season. From the 72 half-photographs, we could calculate the day of snow disappearance. We made the third from a digital camera that operated automatically, because of the inaccessibility in winter of observation sites that we could reach at beginning of the snow melt season. With a 1-gigabyte memory card and two solar panels, this camera operated every day for a year. It recorded not only the date of snow disappearance, but also the date of flowering of alpine plants.

We also tested a small, lightweight snow pressure gauge to estimate snow depth and an anemometer. In addition, using the Normalized Difference Vegetation Index (NDVI) calculated from NOAA data, we have been developing the method to estimate the disappearance of snow in the Japanese alpine zone in past years.

6. Discussion

To determine the vulnerability of the Japanese alpine ecosystem to global warming, we focused on the small number of meteorological factors that are recorded widely throughout the Japanese alpine zone and monthly meteorological data from common future climate scenarios. To project the date of full flowering of *C. hondense* we used the maximum snow depth, calculated from the monthly average temperature and monthly precipitation, and the monthly average temperature in May. To project the distribution of alpine vegetation warmth indices, we used the monthly average temperature, although there is criticism that the relationship between the warmth index and distribution range of alpine vegetation in Japan is too static (Uchijima, 1993). From these results and the results obtained in Sections 3 and 4, we concluded that the Japanese alpine ecosystem is vulnerable to global warming. Therefore, the impacts on the ecosystem are not unique, because the relationships between the phenomena and meteorological factors are not unique. Thus, it is necessary to investigate these relationships in detail and clarify the impacts of rising temperature on the Japanese alpine ecosystem. Furthermore, the relationships between rising temperature and other meteorological factors must be considered together, because increasing temperature is linked with drought and changes in rainfall; for example, the potential evapotranspiration as a simple index of climate (Iwasaki, 1974) is calculated from the monthly average temperature and rainfall. It will also be necessary to establish methods of measuring other meteorological factors in the Japanese alpine zone.

Given the above results, is it possible to monitor global warming impacts from the alpine vegetation in Japan? The Japanese alpine zone has four distinct seasons with characteristic temperatures. Therefore, an increase in temperature caused by global warming will have effects on almost all natural phenomena in the zone. Relating particular phenomena to global warming, however, is not straightforward. Nevertheless, the third report from the IPCC concluded that regional changes in climate, particularly increases in temperature, have already affected a diverse set of physical and biological systems in many parts of the world. Many people support this conclusion, which is based on the following evidence: the degree of warming during the 20th century was much greater than during the previous nine centuries; the best agreement between model simulations and observations over the last 140 years has been found when all anthropogenic and natural forcing factors are combined; long-term changes, typically of 20 years or more, in biological and physical systems are correlated with regional changes in temperature; the relationships between changes in biological and physical systems and increases in temperature are scientifically clear, and the direction of changes is explained by known mechanisms; and changes in these systems are consistent and coherent across diverse regions. Thus, it can be concluded that recent regional changes in temperature have had discernible impacts on many physical and biological systems (Global Environment Departmnet, 2001).

In Japan, the change in annual average temperature at the top of Mt. Fuji has increased since 1980 in step with the global average surface temperature (Fig. 1), and these increases are similar to those in the Japanese alpine zone (Fig. 2). Several observed long-term changes in biological phenomena and the relationships between them and temperature change are relatively clear. The size of Senjagaike-Sekkei, a perennial snow patch at Mt. Hakusan, has tended to decrease since 1981. And the flowering times of *C. hondense* and *L. camtshatcense* appear to have advanced recently. It will be necessary to study changes over the long term, including those clearly related to change in temperature, throughout the Japanese alpine zone. Data should be collected at fixed sites because phenomena are locally affected by snow factors.

Decreases in the size of alpine fields on Mt. Apoi due to expansion of the distribution range of subalpine trees have recently been recognized. Similar projected changes in the distribution of vegetation caused by global warming are well described in the literature. However, the relationship between the range of vegetation distrubution and temperature is complex. For example, the range of the Japanese stone pine was related to warmth index in one study (Ohmori & Yanagimachi, 1989) and not related in another (Okitsu & Ito, 1984). In an analysis of the relationship between change in vegetation distribution and climate change, the time scale and reaction time (or time constant) are very important, and the response time tends to increase with an increase in complexity from the individual to the ecosystem level (Uchijima, 1993). As Uchijima (1993) pointed out, we must clarify the dynamic relationships between the distribution of vegetation selected as a biological index of global warming and climate change. In this way, changes in the distribution of vegetation can be used as an index of global warming.

In the Japanese alpine zone, other biological changes could be developed as biological indices, including the molting time of the Japanese ermine, withering of needles of the Japanese stone pine in early spring, and changes in species compositions of alpine vegetation. If the relationships between these changes and the increase in temperature can be clarified, these changes could be useful indices of global warming.

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