INFLUENCES OF AIR TEMPERATURE CHANGE ON LEISURE INDUSTRIES: CASE STUDY ON SKI ACTIVITIES

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Abstract. To evaluate the influences of air temperature change on ski activities, the changes in the numbers of skiers visiting seven ski areas in Japan were predicted in conjunction with climate change. First, having built a model for predicting snow depth based on the budgets of water and heat using the air temperature and precipitation data collected nationwide, we demonstrated good agreement between the predicted and observed snow depths ($p < 0.01$ and the ratios for more than 81% cases ranged from 0.5 to 2). Second, the relationship between the number of skiers and the depth of snow at one of the seven ski areas was analyzed statistically on a daily basis. In addition, we did the same on a monthly basis at six other ski areas and compared the observed and predicted numbers of skiers ($p < 0.01$ and the ratios for more than 94% cases ranged from 0.5 to 2). Using this model and the relationship between daily snow depth and number of skiers, the changes in skier numbers in the seven ski areas were predicted for several scenarios with respect to air temperature changes; e.g. a more than 30% drop in visiting skiers was forecast in almost all ski areas in Japan except northern region (Hokkaido) and/or high altitude regions (center of the Main Island) under the condition of a 3 °C increase in air temperature. The vulnerability of the ski industry and its adaptation to climate change are discussed.

Keywords: climate change, number of skiers, prediction model, ski industry, snow depth

1. Introduction

The sensitivity, adaptive capacity, and vulnerability of natural and human systems to climate change, and the potential consequences of climate change, have been assessed in the report of Working Group II of the Intergovernmental Panel on Climate Change (IPCC) (McCarthy et al. 2001); however, numerous uncertainties still remain. In Japan, a great deal of effort has been made over the last decade to investigate the impact of climate change on natural ecosystems, agriculture/forestry/fisheries, hydrology/water-resources/water-environment, human health, etc. (Nishioka and Harasawa 1997). In particular, the impacts on water resources and environment, water discharge, water temperature and water quality were quantitatively predicted by watershed models and/or by statistical analyses in relation to the past (Moriya and Niwa 1991; Tanakamaru and Kadoya 1992; Takara and Kojiri 1993; Ando 1994; Ozaki et al. 1999; Fukushima et al. 2000; Ozaki et al. 2001).

In contrast to natural systems, the influences on socio-economic systems have been insufficiently focused because they are in general less understood and more sensitive but more adaptive to changes in surrounding conditions. In the present paper, we investigated the influence of global warming on leisure industry, particularly on the ski industry. This was because this activity was not only rather vulnerable to climate change, but one of the major leisure industries as shown below. Moreover, it was pointed out that the ski industry was closely related to socio-economic development in Japan's snowy regions (Kureha 1991; Kureha 1998; Kureha 1999).

Using the data on snow, transported persons, and profits/losses, Abegg and Froesch (1994) concluded that unfavorable snow conditions had direct consequences on demand in ski tourism, i.e., major declines in passenger numbers, bankruptcies of companies etc. They also suggested a complex mix of winners and losers, but not quantitatively. Inoue and Yokoyama (1998) estimated the snowfall, maximum snow depth and snow cover conditions in Japan using the changed climate scenarios derived from numerical experiments of general circulation models as the input data. Because only monthly maximum snow depths were predicted, we could not use them to assess the influence on the ski industry. Hatanaka et al. (2000) developed the model for predicting the skier numbers using the statistical relationship between the air temperature and the days for skiing and predicted the economic loss of about a few hundreds billion yen in Japan caused by a 1 °C air temperature rise. However, it is questionable to predict the number of skiers without forecasting the decline in snow depth.

As the factors affecting the development of ski area regions, Kureha analyzed the skiing facilities (lifts, resting places, etc.), accommodations, accessibility to ski areas, and the competition with other ski areas in the neighborhood (Kureha 1995a; Kureha 1995b). In addition, the numbers of visiting skiers depend not only on the snow conditions but also on the economic state of the country, the size of the young population, fashions in urban society, the day of the week, etc. (Kureha 1998; Kureha 2002).

In this paper, we built a model for predicting snow depth based on the budgets of water and heat using air temperature and precipitation data. Then, the relationship between climate conditions and the number of skiers was analyzed statistically. In conclusion, we discuss the influence of global warming on regional development and the appropriate adaptation strategies for it.

TABLE I

Summary of the seven ski areas under study.

	Latitude	Longitude	Altitude[1] m	Num. of skiers[2] × 1000	H-Distance[3] km	V-Distance[3] m	Data period[4]
Hakkoda	140°50′06″	40°40′41″	991	464	4.5	71	1988–1996
Owani	140°34′04″	40°30′17″	405	2355	8.5	260	1988–1996
Shizukuishi	140°56′02″	39°46′22″	891	2653	6.0	735	1988–1996
Onikoube	140°38′33″	38°47′02″	720	1613	8.0	590	1988–1996
Inawashiro	140°06′08″	37°34′27″	950	3458	1.0	29	1988–1996
Aizukogen	139°37′09″	37°06′14″	1297	3748	14.5	137	1988–1996
Okuibuki	136°23′24″	35°31′07″	980	227	12.0	785	1995–1996

[1] average, [2] annual average for data period, [3] horizontal and vertical distance from the nearest meteorological station, [4] ski season.

2. Methods

2.1. Data on Skiers and Meteorological Conditions

Table I summarizes the locations of the seven ski areas, the annual numbers of skiers, the distances from the nearest meteorological stations, and the analyzed periods. Except for the Okuibuki ski area in central Japan, the other ski areas located in northern Japan (Tohoku Region). The daily numbers of skiers and daily snow depth were obtained for the Okuibuki ski area and monthly data for the other ski areas. The daily snow depths at all ski areas except Okuibuki were predicted based on the assumptions that air temperature decreased with increasing altitude (0.65 °C 100 m^{-1}) and that precipitation and wind velocity had the same values as those at the nearest meteorological stations.

Because the meteorological conditions, e.g., air temperature, precipitation, change to a considerable extent year after year, the snow conditions after global warming will also differ between years. In addition, the obtained relationship between the snow conditions and the numbers of skiers would be also influenced by the snow conditions applied for the analysis. Probabilistic analyses should therefore be made with the data of fairly long term, but they were difficult due to the limited data related to snow and skiers. Thus, we gathered and analyzed nine years data on them and further evaluate the influence of global warming by forecasting in a deterministic manner and comparing the differences over nine years (see 3.5).

2.2. PREDICTION OF SNOW DEPTH

The depth of snow in terms of water and heat in the snow are derived on the basis of budgets of water and heat, respectively (Arai and Nishizawa 1974; Japanese Meteorological Society 1979; Kondo 1994):

$$\mathrm{Wt(n) = Wt(n\text{-}1) + Wp(n) - Wmelt(n)} \quad (1)$$
$$\mathrm{Qt(n) = Qt(n\text{-}1) + Qs(n) + Qm(n) - Qmelt(n)} \quad (2)$$
$$\mathrm{Qm = Rn + SE + LE + Qp} \quad (3)$$

where Wt (m): depth of snow and interstitial water in terms of water (= Wice + Ww; Wice (m): depth of snow, Ww (m): depth of interstitial water), Wp (m): precipitation (= Wr + Ws; Wr (m): rainfall, Ws (m): snowfall), Wmelt (m): percolation through snow melt, n is the day number, Qt (J m^{-2}): total heat in the snow, Qs (J m^{-2}): heat of freshly precipitated snow, Qm (J m^{-2}): heat for snow melting, Qmelt (J m^{-2}): outflow heat through efflux of interstitial water, Rn (J m^{-2}): heat through solar radiation and longwave radiation, SE (J m^{-2}): sensible heat, LE (J m^{-2}): latent heat, and Qp (J m^{-2}): heat through rainfall.

The calculations were conducted day by day and for the total amount of snow as one uniform layer. The transition between snowfall and rainfall depended on air temperature; i.e., all snowfall below 0 °C, all rainfall above 4 °C, and mixed linearly according to air temperature between 0 °C and 4 °C (Kondo 1994). The melted water in snow was retained in the snow layer up to the water retention capacity Wt_{max} (m), and its temperature was assumed to be 0 °C. When it exceeded that capacity, it percolated into the surface soil. Wt_{max} is given by:

$$Wt_{max} = r \cdot Wice \quad (4)$$
$$r = 0.0015\,\varepsilon\ (\varepsilon \geqq 0.4) \quad (5)$$
$$r = 0.001\,\varepsilon\ (\varepsilon < 0.4) \quad (6)$$

where ε (dimensionless) is the ratio of snow depth in terms of water (Wice) divided by the snow depth (H; see below).

The heat required for snow melting Qm induced a change in snow temperature and/or melting/freezing of snow; i.e., Qm is used for rising snow temperature and then its melting when Qm>0 but Qm is also used for freezing of the interstitial water and then decreasing snow temperature when Qm<0. The respective terms of eq. (3) were given in the same way as Ozaki et al. (2001) except for the reflection rate of solar radiation on the snow surface (Yamazaki et al. 1994). Next, the compaction process of snow is expressed as follows and the density of snow ρ_s (kg m^{-3}) was calculated (Maeno and Fukuda 1986):

$$\rho_s(n) = \rho_s(n\text{-}1) \cdot (1 + Wt / \eta) \quad (7)$$
$$\eta = ((0.011 \cdot \exp (0.021\ \rho_s(n\text{-}1))) \quad (8)$$

where η (m) is the parameter reflecting the compaction rate and the ρ_s of freshly precipitated snow is set 100 kg m^{-3}. Since we assumed that the snow was vertically uniform, two problems arose. The first was to overestimate the long-wave

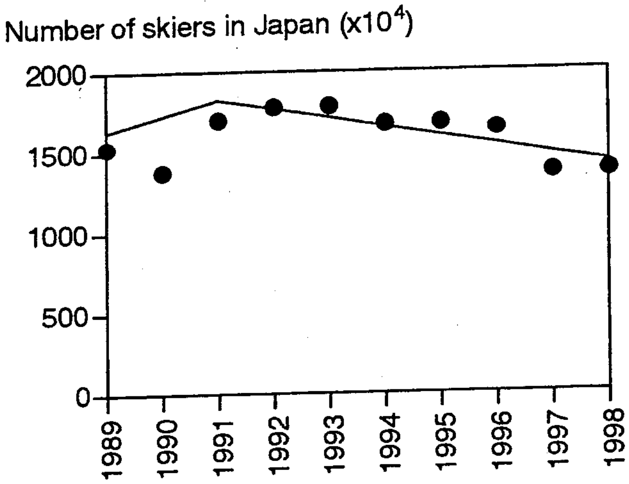

Figure 1. Annual change in the number of skiers in Japan. The lines were used for the analysis (see text).

radiation from the snow surface, leading us to assume that the long-wave radiation from the snow counteracted that to the snow. The second was to overestimate the compaction of freshly precipitated snow, causing a trivial increase in snow depth over 50 cm. Therefore, we assumed that the compaction rate changed vertically from 100 kg m^{-3} at the snow surface (freshly precipitated snow) to the value calculated by eqs. (7) and (8) and that it was proportional to Wt above the depth. The compaction rate averaged for the whole depth ρ_{ave} (kg m^{-3}) was $(\rho_s - 100) / (\ln \rho_s - \ln 100)$, and the snow depth H (m) was calculated:

$$H = \mathrm{Wice} \cdot \rho_{water} / \rho_{ave} \qquad (9)$$

where ρ_{water}(kg mm^{-3}) is the density of water.

Because the season for skiing is winter (for example, the winter between 1993 and 1994 is called the 1993 ski season), the start of the ski season was taken to be Sept. 1.

2.3. METEOROLOGICAL DATA

The daily averaged air temperature, precipitation and wind velocity, and the daily total of solar radiation time were observed at all the meteorological stations for the analytical period of this study. Because the humidity in the air was needed for calculating the heat budget, we changed it at the increment of 10% from 0% to 100%, and then used the humidity which provided the best agreement between the observed and predicted numbers of days showing H = 0.

2.4. Other Factors Influencing Numbers of Skiers

The numbers of skiers were determined mainly by the characteristics of ski area (size, accessibility, facilities, expense, competing ski areas, etc.). However, those changed with socio-economic conditions, fashion, etc., as well as with the annual snowfall. Because the purpose of this study is to analyze the influence of snowfall on the ski industry, any influence due to other factors should be removed. The yearly numbers of all skiers in Japan (Leisure Development Center 1999) showed a declining tendency after 1993 (Figure 1), probably due to the decrease in the population of the younger generation, the arrival of the ski industry to a stage of maturity, and/or the worsening of economic conditions (Kureha 1995b; Kureha 2002). Therefore, we divided the observed numbers of annual skiers in the target ski area by those total numbers in Japan expressed by the lines in Figure 1; the line after 1991 was determined by regressing the observed values and the line before 1991 was connected with the other at 1991 possessing the slope of the regression line. The peak of the lines was set in 1991 since the Japanese economy started to decline from that year.

We investigated the change in other factors either by interviewing the companies in the ski areas and/or looking over the statistical reports; no significant changes were noted such as an increase in ski lifts, or in snow-making machines in the target ski areas.

2.5. Statistical Tests

To evaluate the suitability of the models, we applied the correlation analysis with $p < 0.05$ in assigning significance (p: significance level).

3. Results and Discussion

3.1. Snow Depth Predicted by the Model

The predicted snow depth increased generally with decreasing humidity because higher humidity induced less latent heat, finally leading to decreasing snow depth through a smaller snow-temperature drop. The best agreement (the fewest days when a false snow prediction was made) was usually for humidity between 80% and 90% (Figure 2), coinciding with the observed conditions during snowfall. As mentioned above, we used the humidity that gave the best agreement.

The starting and finishing dates of snow cover on the ground roughly coincided between the observed and predicted time series of snowfalls (Figure 3). There were sometimes rather large discrepancies between these dates, probably due to errors in estimating the compaction rate, but their ratios averaged for one ski season in the respective areas clustered between 0.5 and 2 (more than 81%; Figure 4) and their logarithms correlated significantly ($p < 0.01$). Due to this good agreement, we saw

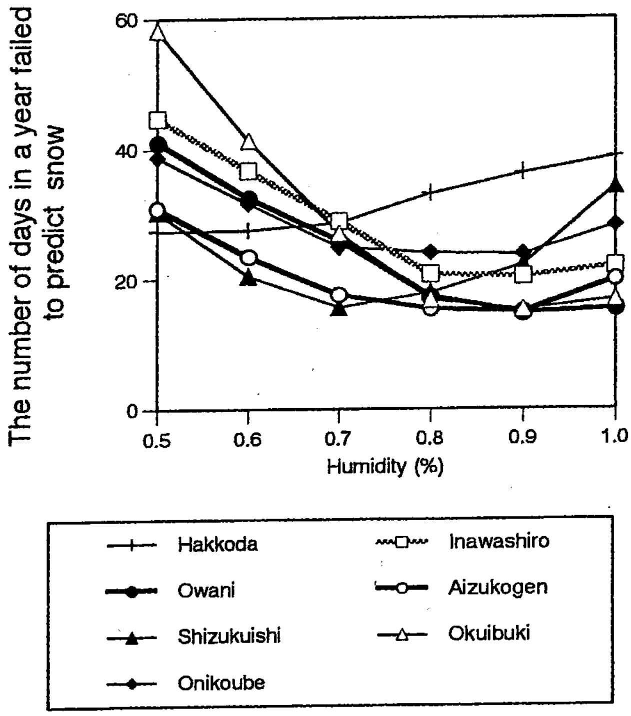

Figure 2. The number of days in a year we failed to predict snow when humidity changed.

no need to modify the rates to correspond to the characteristics of the respective ski areas.

3.2. Yearly Changes in Snow Depths and Visitors Integrated for a Ski Season

The numbers of visitors integrated for a ski season were as a rule logarithmically proportional to those of snow depths (Figure 5; Owani and Inawashiro $p < 0.05$, but other four areas $p > 0.05$), indicating the influence of snowfall on ski industry. The slopes between them were, however, less than unity, which suggested that the numbers of visitors did not vary as much as the snow depth.

3.3. Daily Changes in Snowdepth and Visitors

Because the numbers of skiers on weekends exceeded significantly those on weekdays, we totaled the sums for weekdays and weekends separately. Weeks with holidays were removed from the following analysis. Both numbers seemed to vary generally with the average snow depth, but they showed more consistency during the middle part of the ski season, not corresponding with the snow depth (Figure 6). This is because the impulse to ski does not increase as much as the snow depth, bearing some resemblance to the yearly relationships mentioned above.

In any events, the weekly totals of skiers and average snow depths showed positive relationships on both weekdays and weekends, with saturation numbers

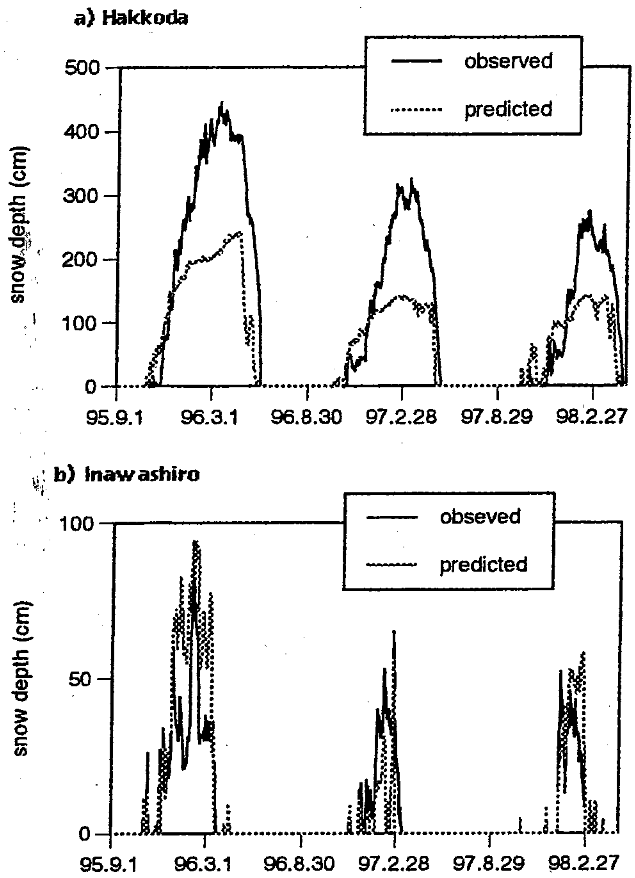

Figure 3. Daily changes in observed and predicted snow depths. 1) Hakkoda, 2) Inawashiro.

ranging around 4000 persons and 8000 persons, respectively (Figure 7). In addition, those relationships changed monthly; i.e., the higher increase rates were observed in earlier months, corresponding to the earlier peaks in skiers rather than to the peaks in snow depths shown in Figure 6.

3.4. MODELING OF SKIER NUMBERS USING SNOWDEPTH

Based on the above relationships, we built a model for predicting the number of skiers, using snow depth (H) as follows. At first, the ceiling snow depth (Hc) (m) was defined as the snow depth below which the number of visitors was proportional to the depth and above which the number peaked. This Hc was introduced in order to express the nonlinear relationship between the two figures as shown above. Next, we calculated the number of days (Ds: days for skiing) in terms of days in the respective months having the maximum visitors:

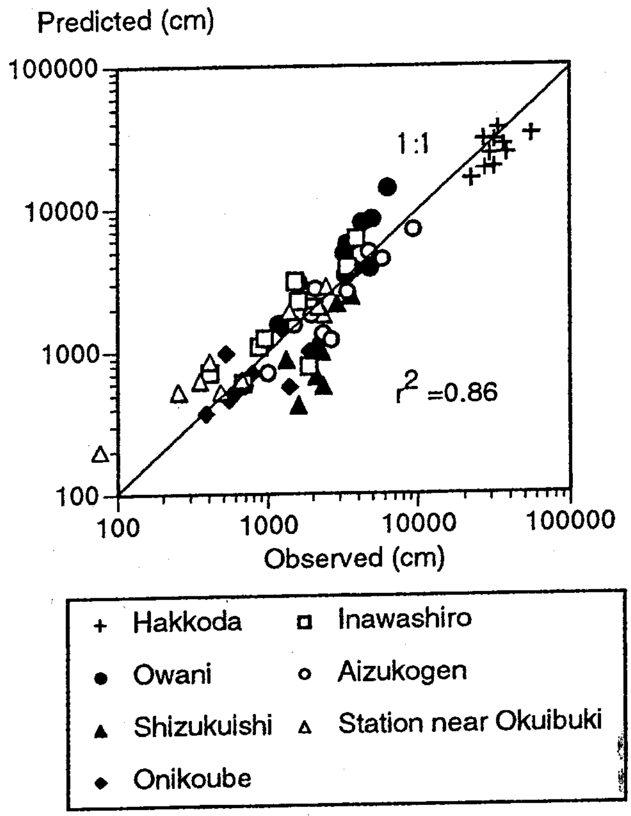

Figure 4. Observed vs. predicted snow depths integrated for each ski season.

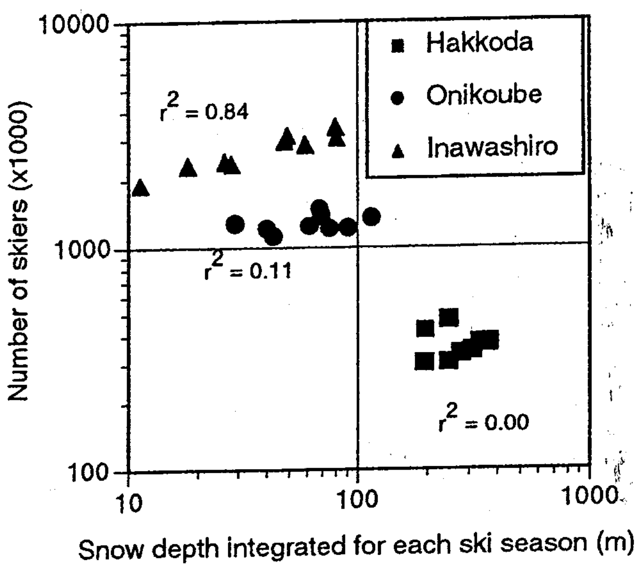

Figure 5. Snow depth integrated for each ski season vs. number of skiers.

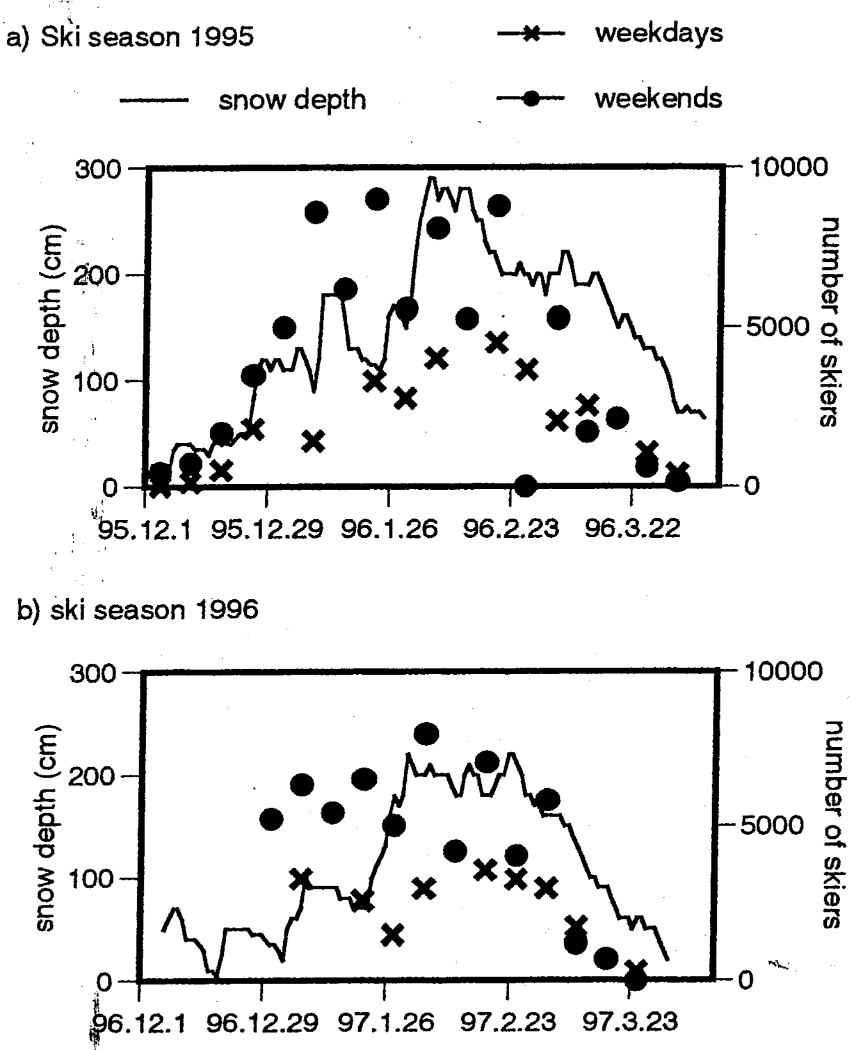

Figure 6. Daily changes in snow depth and number of skiers at Okuibuki. a) 1995 ski season, b) 1996 ski season.

$$\mathrm{Ds} = \sum_{i=1}^{m} \mathrm{X(i)} \qquad (10)$$

$$\mathrm{X(i)} = \mathrm{H(i)} / \mathrm{Hc};\ \mathrm{H(i)} < \mathrm{Hc}$$
$$\mathrm{X(i)} = 1;\ \mathrm{H(i)} \geqq \mathrm{Hc}$$

where, H(i) is the H of the i-th day and m is the number of days in the month.

The correlation coefficients (r) between Ds and numbers of skiers were calculated by changing the value of Hc at increments of 10 cm from 40 cm to 100 cm; then, the value which gave the maximum correlation coefficient was used as Hc for the respective ski areas (p <0.05 when r>0.30). Because we calculated on a monthly basis, the distribution between weekdays and weekends was not made in this prediction procedure. The maximums were observed clearly in several areas

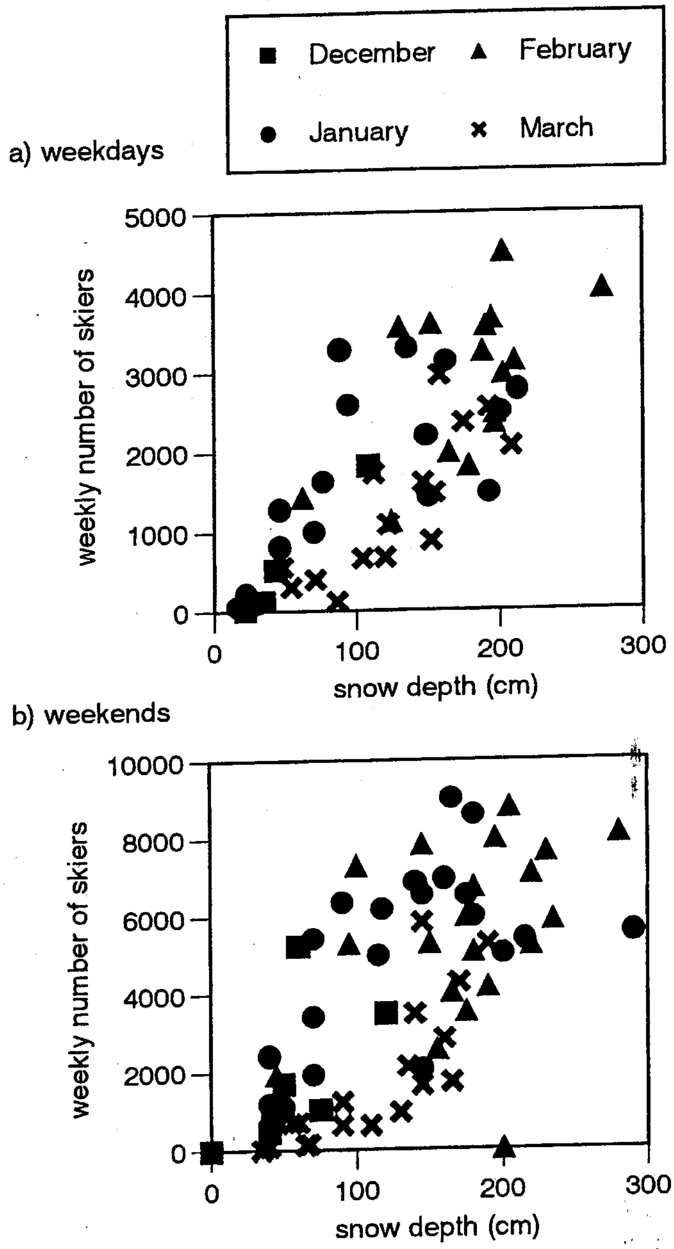

Figure 7. Averaged snow depth vs. weekly number of skiers at Okuibuki. a) weekdays, b) weekends.

(e.g., Shizukuishi, Owani), but not at others, probably depending on such characteristics as accessibility, snow conditions etc. (Figure 8).

Roughly linear relationships between Hs and numbers of skiers were observed at several fields (Figure 9; $p < 0.01$). The slopes indicate the maximum numbers of skiers on the assumption of sufficient snow depth, which we call the ceiling number of skiers (Nc). Using the calculated Hc, Nc and predicted daily snow depth, the numbers of skiers were forecast. Comparing the yearly totals of skiers yielded fairly good agreement in several areas, e.g., Inawashiro, but not so good in other areas, where the numbers changed due mainly to other factors (Figure 10; $p < 0.01$;

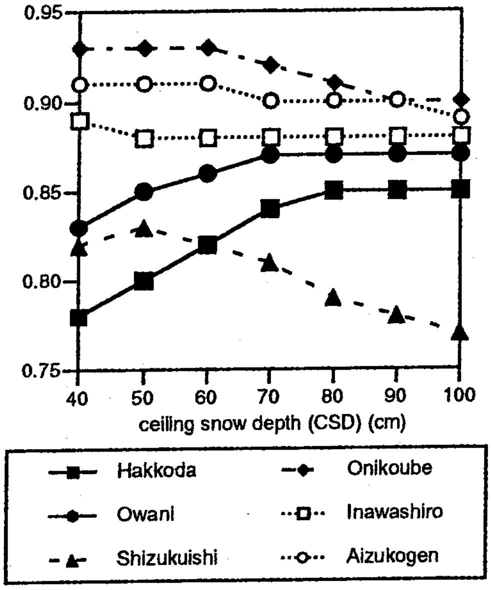

Figure 8. Hc (see text) vs. correlation coefficient between Ds (see text) and number of skiers.

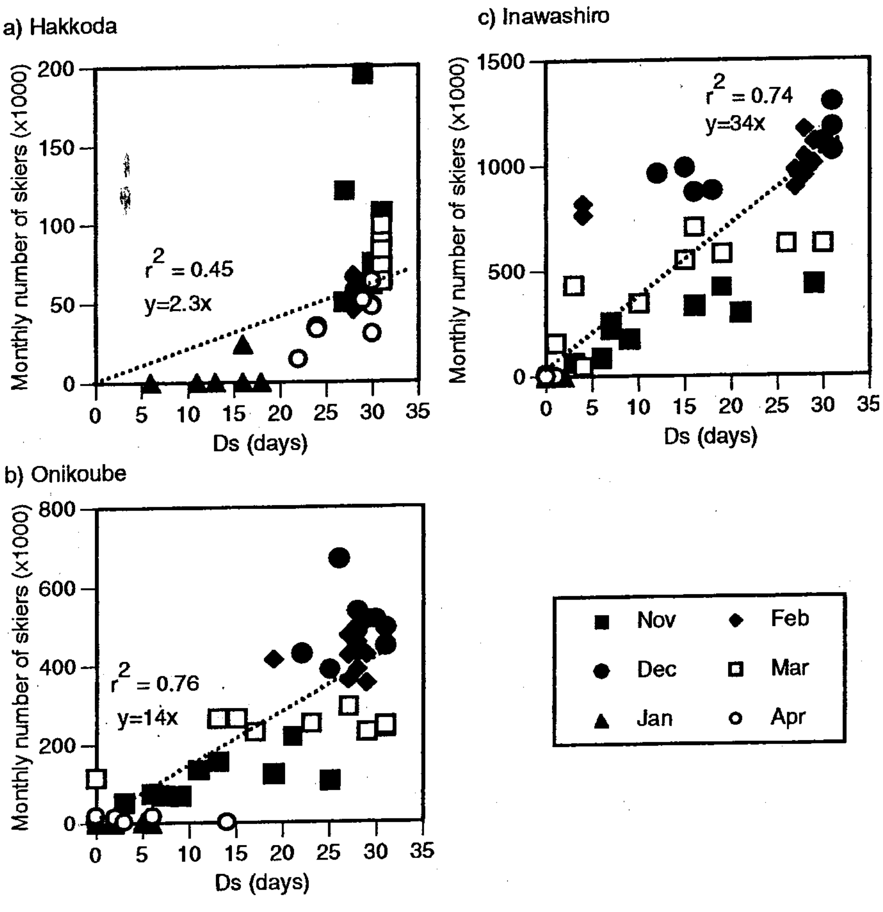

Figure 9. Ds vs. monthly number of skiers. a) Hakkoda, b) Onikoube, c) Inawashiro.

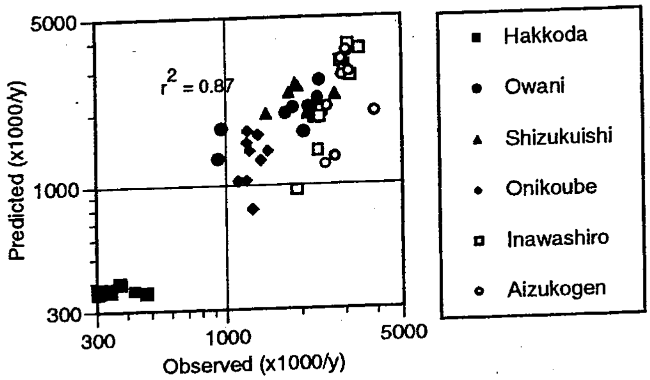

Figure 10. Observed vs. predicted yearly number of skiers.

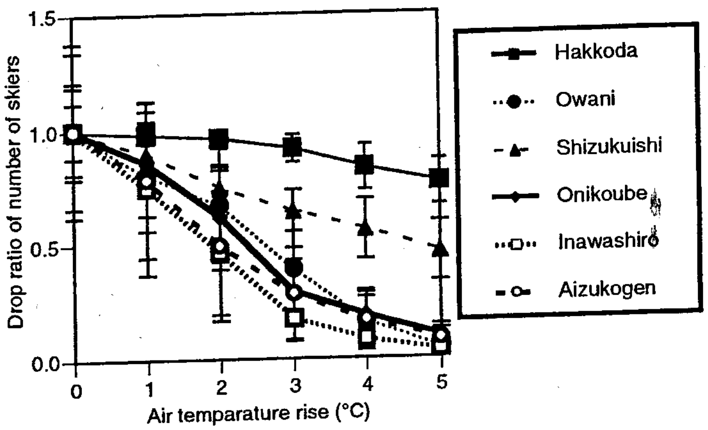

Figure 11. Air temperature rise vs. drop rate in number of skiers compared with those during the period from the 1988 to 1997 ski season. Bars indicate the standard deviations.

more than 94% had the ratios of the observed to the predicted in the range from 0.5 to 2).

3.5. Influence of Global Warming on Numbers of Skiers

Using the model developed as shown above, we predicted the changes in skier numbers according to the air temperature rise. Because the alternation on precipitation due to global warming could not be forecast on a regional basis in Japan, we used the scenario that there would be no change in precipitation. The ratios of skier numbers to those averaged from the ski seasons from 1988 to 1997 were calculated at increments of 1 degree increase up to 5 degrees at the six ski areas located in Tohoku Region. The standard deviations of yearly differences in skier numbers are also shown in Figure 11 in order to show the degree of the scatter year after year.

At Inawashiro and Aizukogen ski areas in the southern Tohoku District, skier numbers were expected to fall more than 50% even for 2 degrees rise air temper-

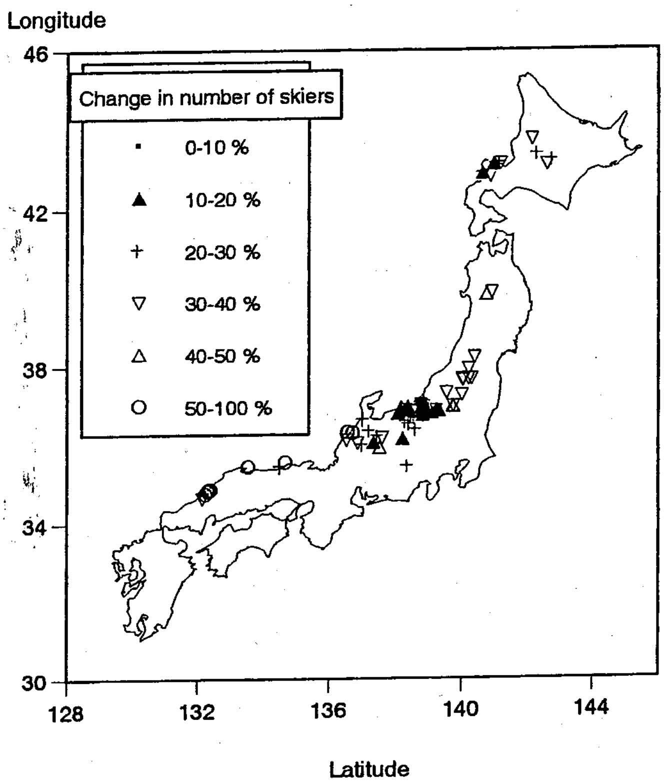

Figure 12. Drop in number of skiers after a 3 °C rise in air temperature without consideration of interaction among ski areas.

ature and coefficients of variations (standard deviation divided by average) were fairly large (up to 40%) (Figure 11). In contrast, the drop at Hakkoda ski area in northern Tohoku as well as at high altitude was predicted to be virtually negligible within any increase up to 3 degrees. Thus, the influences of global warming varied probably area by area. Moreover, the ratios declined non-linearly with the rises, because the change in snow depth is not proportional to the change in air temperature.

Figure 12 shows the influence of global warming upon ski areas on a national scale. We applied the developed model to 61 major ski areas chosen according to the numbers of ski lifts. Any modification due to the interaction among ski areas was not taken into consideration; e.g. increase in number of skiers in less affected areas over these in profoundly affected areas. Following a 3 °C increase in air temperature, a more than 30% drop in visiting skiers was forecast in almost all ski areas in Japan except northern region (Hokkaido) and/or high altitude regions (center of the Main Island). Particularly, the ski areas at low altitude in the southern region would suffer a serious blow (>50% drop).

3.6. Impacts of Global Warming on Ski-Tourism

The annual per-skier expenses for skiing including traveling and equipment costs were 103,000 yen in 1990, 100,000 yen in 1995 and 79,000 yen in 2000. By multiplying the numbers of skiers, the total sales turnovers of the skiing industry were estimated at 1.4, 1.7, and 0.9 trillion yen in 1990, 1995 and 2000, respectively (Leisure Development Center 1990; 1995; Institute for Free Time Design, 2001). The additional sales value from snowboard was comparatively small (around 36 billion yen in 2000). Skiing ranks second in the leisure sports activity domain in Japan, following golf.

Based on two questionnaires on skiing expenses at Geihoku Kokusai (Hiroshima Prefecture; January and March, 2002), 141,000 yen (average of 98 skiers) and 93,000 yen (average of 100 skiers) were obtained, indicating slightly higher expenditures per skier each year than the above-mentioned values. The costs of lift tickets, travel, accommodations, meals, goods, and others, accounted for 22.2%, 18.6%, 8.5%, 11.7%, 32.5% and 6.6% of the total, respectively.

In ski area where snow depth drops considerably, income related to skiing will inevitably diminish. On the contrary, an increase in skiers is can be expected in ski areas with a negligible change in snow conditions (Hokkaido and center of the Main Island). Moreover, the competition with foreign ski areas will become more important than at present. This shift would be affected by factors such as accessibility and socio-economic conditions. Since up to 100 billion yen may be lost or produced in the surrounding areas, the structure of the local community will be seriously impacted. Particularly in regions without other industries, the impact of global warming will be crucial.

4. Conclusions

4.1. Predictions

The prediction procedure was divided into 1) prediction of snow depth, 2) prediction of skier number, 3) prediction of climate change, and 4) prediction of impact on local society. In this paper, we built a sub-model of 2) and applied the previously developed sub-models to 1), 3) and 4). Even as rough estimates, the impacts were predicted quantitatively. For more accurate forecasting, further studies are needed on the compaction rate of snow, changes in precipitation after global warming, influence of accessibility, social-economic conditions, quality of snow, etc. on the ski industry, and spatial variations in snow conditions at ski areas. In addition, interactions among ski areas should be investigated using systems analysis.

4.2. Mitigation and Adaptation

Over the last several years, the Japanese ski industry was involved in a weeding-out process attributable to the decrease in the younger population and the deterioration in natural snow quality. Thus, dozens of ski areas have been driven out of business, and a few hundred had to modify their business structure.

Under such circumstances, a serious impact on the ski industry could be anticipated due to global warming, particularly for ski areas in southwestern Japan or at low altitudes. In the areas where the snow conditions would seriously deteriorate, planning should be begin on the development of new industries more resistant to or suited to global warming, thus avoiding excessive reliance on the ski industry. New leisure industries, e.g., grass-skiing, hiking, residential lodging, could be considered to compensate for the income decrease due to snow deterioration. It would be crucial to develop a new leisure industry (e.g., combination with hot-spring resort, eco-tour) that attracts persons of middle or advanced ages because the graying of Japanese population is making rapid progress. In addition, the economic basis should be gradually shifted to agricultural and forestry.

By the way, the timing for switch to other industries and/or reduction of ski industry should be planned to synchronize with the timing of the facilities renewal. Extension of snow machines should also be carefully considered for the slopes less affected by solar radiation because the investments are effectively made.

In contrast, new investments for the ski industry could be considered in less weather-sensitive fields. However, the construction of ski areas at higher altitudes may be a factor in the deterioration and/or destruction of the natural ecosystem. Careful mitigation measures should be prepared accompanied by its suitable assessment. Planning for the industrial allocation of land use should therefore be studied from a national and international perspective; however, the adaptive planning and management on the allocation should be necessary because the change in meteorological conditions is rather probabilistic.

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