# SNOW PRECIPITATION AMOUNT AND ITS SENSITIVITY TO GLOBAL WARMING DURING WINTER SEASON IN JAPAN

Mayumi (OGAWA) HOSODA*

*Abstract* The discriminating temperature, which is applied to determine the precipitation type (snowfall or rainfall), was obtained from climatic data. By the values of the discriminating temperature and digital maps of daily temperature, the precipitation types were judged daily for the whole digital map of daily precipitation. Then snowfall and rainfall were simulated according to seven scenarios to estimate the effect of global warming during winter season (November—April) in Japan. As a result, mass of snowfall in Japan was estimated at about 131.9 billion tons for the current climatic condition (Scenario No. 1), and at about 54.9 billion tons for the minimum case (Scenario No. 7). It may be difficult to use snow as water resources after global warming, especially in the regions which even now have low snowfall. Thus, it is necessary to estimate the effects of global warming on the water balance of watersheds in near future.

**Key words:** climatic data, discriminating temperature, snowfall, global warming, scenarios

## 1. Introduction

In Japan, there are two main precipitation types during winter season. One is snowfall as solid precipitation and another is rainfall as liquid one. Since rainfall easily moves after it reaches the ground but snowfall has the character to tend to stay, the influence on water use is quite a different between snowfall and rainfall. Most of snowfall becomes snowcover, and flows out from the watershed gradually in snowmelt season (spring). Therefore precipitation as snowfall is valuable water resources in Japan, especially for the period until the long spell of rainy weather in early summer because of its characteristics related to runoff.

In recent years global warming has been taken up as one of serious subjects. It is forecasted that global warming have effect on not only air temperature but also precipitation. Takara and Kojiri (1993) said that snowfall may decrease by global warming in Japan. If snowfall decrease in winter, it should result in a decrease of snowcover and snowmelt water during spring. Consequently, there may be increasing water shortages, especially in the regions where even now have low snowfall.

* Free-lance; finished the master's course of Tokyo Metropolitan University in 1992.

Based on the point of view mentioned above, the author has proceeded to study. This paper is a digest of a part of her master's thesis (Ogawa 1992) and two papers, which have already published (Ogawa and Nogami 1994; 1997). The purpose of these papers are to estimate precipitation amount using climatic data during winter season in Japan, and to simulate to estimate the effect of global warming. This paper mainly referred to snow precipitation amount and its sensitivity to global warming.

## 2. Method

The discriminating temperature (DT) was defined by air temperature, which is applied to determine the precipitation type (snowfall or rainfall) corresponding to 50 % occurrence probability. Air temperature at ground level is a good indicator for the judgment of precipitation type (for example Nakazawa and Noto 1971; Ohta 1989). As air temperature is easy to get widely and simultaneously compared with other factors, it is useful for analysis of large area like whole Japan. DT was calculated statistically from climatic data, which was about 155 stations' daily data from 1967 to 1989 (about 641700 samples). DT was obtained for 15 climatic regions (based on Fukui 1928; Fig. 1) and for each month (November—April). The southern part of Shikoku (Region 12) and the Southwest Islands (Region 15) were eliminated from the analysis because the occurrence of snowfall in these regions were once a year on an

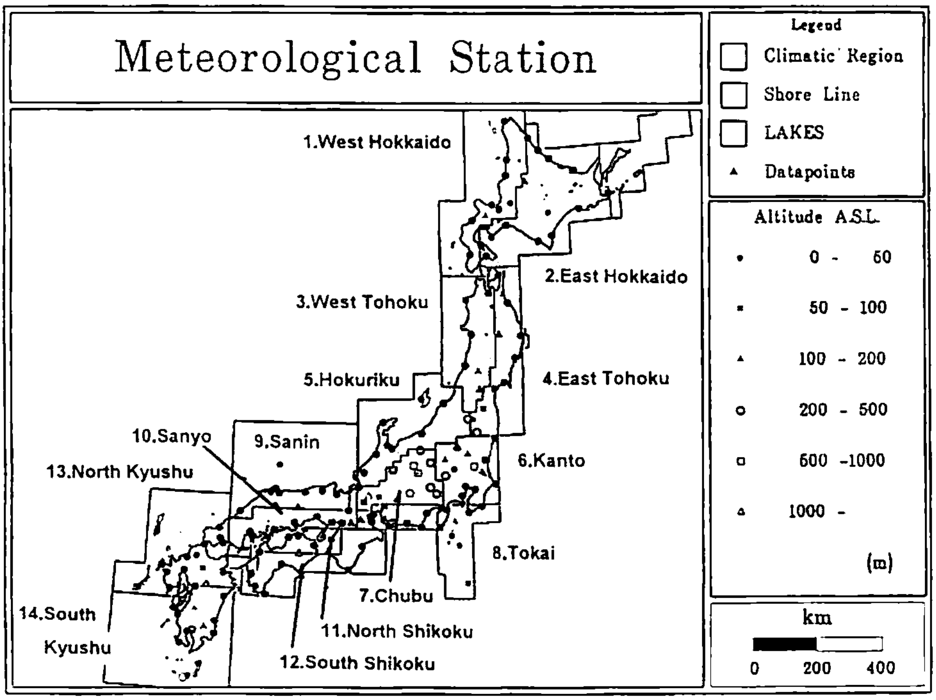



**Fig. 1** Study area; 15 climatic regions in Japan. The Southwest Islands (Region 15) are not drawn in this figure.

average.

By the values of DT and digital maps of daily temperature, the type of precipitation was determined on a daily basis for the entire digital map of daily precipitation. Every digital map has 1600 grid boxes from east to west and 1920 grid boxes from north to south. As the area of each grid box is about one square kilometer, the digital map has the area of about three million square kilometers. Digital maps of daily temperature and daily precipitation were calculated from monthly maps by harmonic functions. Then the digital maps of monthly snowfall and rainfall were obtained by cumulating daily calculations. Ogawa and Nogami (1994) details the above two paragraphs.

Subsequently, seven scenarios of global warming were defined as change in both air temperature and precipitation (Table 1). Matsuoka *et al.* (1992) and Takara and Kojiri (1993) said that the range of upward tendency of air temperature is mostly distributed from +2 °C to +5 °C in general models of global warming. Precipitation change ($\Delta$P) is estimated from ±10 % to ±20 %. In this study, +2 °C temperature change ($\Delta$T) corresponds to gradual global warming and $\Delta$T=+4 °C corresponds to rapid one. $\Delta$P was defined as -10 %, no change and +10 %. The process of changing by $\Delta$T ($\Delta$P) from the current climatic condition is not considered. Using the values of DT, digital maps of daily temperature and precipitation, the digital maps of monthly snowfall and rainfall under each scenario were obtained. Ogawa and Nogami (1997) details this paragraph. In this paper as well as in Ogawa and Nogami (1997), a correction factor to take account of the systematic error of rain gages is applied (see Note). Except this point, the process of calculation was the same as Ogawa and Nogami (1994).

**Table 1** Scenarios of global warming

| No. | Temperature change (Δ T) | Precipitation change (Δ P) |
|---|---|---|
| 1 | No change | No change |
| 2 | +2℃ | No change |
| 3 | +2℃ | +10% |
| 4 | +2℃ | -10% |
| 5 | +4℃ | No change |
| 6 | +4℃ | +10% |
| 7 | +4℃ | -10% |

## 3. Result

DT was obtained for 15 climatic regions of Japan and for each month (from November to April). The values of DT ranged from 1.1 °C to 3.0 °C (Table 2). Hyphen shows no snowfall in that region and in that month. DT was lower in middle winter than in early and late winter. Among DTs in the same month, they were lower in northern part of Japan than in southern. The difference was the largest in February, that is 1.8 °C between the highest (northern part of Shikoku) and the lowest (eastern part of Hokkaido). Hasemi (1991) showed that the differences of DT between regions became large when snow falls by the seasonal wind, which often blows in February. It was supposed that the values of DT reflected climatic

Table 2 Discriminating temperature [°C]

| | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|
| West Hokkaido | 2.3 | 1.7 | 1.3 | 1.2 | 1.6 | 2.2 |
| East Hokkaido | 2.0 | 1.5 | 1.2 | 1.1 | 1.3 | 1.8 |
| West Tohoku | 2.6 | 1.9 | 1.5 | 1.4 | 1.9 | — |
| East Tohoku | 2.6 | 1.7 | 1.4 | 1.5 | 1.9 | — |
| Hokuriku | — | 2.4 | 2.0 | 1.9 | 2.5 | — |
| Kanto | — | — | 2.0 | 2.1 | 2.4 | — |
| Chubu | — | 1.7 | 1.5 | 1.7 | 1.9 | — |
| Tokai | — | — | — | 2.7 | — | — |
| Sanin | — | 2.7 | 2.2 | 2.2 | 2.7 | — |
| Sanyo | — | — | 2.2 | 2.5 | — | — |
| North Shikoku | — | — | 2.6 | 2.9 | — | — |
| South Shikoku | — | — | — | — | — | — |
| North Kyushu | — | 3.0 | 2.6 | 2.5 | — | — |
| South Kyushu | — | — | — | 2.5 | 2.7 | — |

characteristics of each month and each climatic region.

Though one of the climatic characters on the side of Japan Sea is to have heavy snow in winter, the most of precipitation was observed as the type of rainfall along the coast for the average condition (Ogawa and Nogami 1994). While in Hokkaido and in the mountain area of northern part of Japan, precipitation was observed mostly as snowfall in winter (Fig. 2). Mass of snowfall in Japan was estimated at about 131.9 billion tons, in other words $13.19 \times 10^{13}$ kilograms (Scenario No. 1: Table 3). This is almost the same as Nakamura and Abe (1993), who estimated using different process.

By increasing air temperature, the absolute value of snowfall may decrease all over Japan and ratio of snowfall to total precipitation in winter also decrease (Fig. 3). In the mountain area of Honshu and in the southern part of Japan, snowfall may become too low as water resources even if increase of precipitation expected. For one of the severest cases (Scenario No. 7), 54.9 billion tons of snowfall was estimated, which was less than half of the current climatic condition.

## 4. Conclusion

The upper streams of many catchment areas are located in the mountain area, most of which have snowfall in winter at present. The decrease in winter snowfall should result in a serious decrease in snowcover and snowmelt water in such areas. In addition, Yoshino (1990) said that global warming may make distribution of precipitation concentrated to smaller areas or to shorter periods, and may make intervals between precipitation events longer. If snowfall may decrease, it may be more difficult to get water resources stably, especially in the regions which depend on snow as water resources in spring, or in the regions which even now have low snowfall. Consequently, there may be increasing serious water shortages. Thus, it is necessary to estimate the effects of global warming on the water balance of watersheds in near future.

**Table 3** Estimated snowfall amount [$10^{13}$ kg] of 15 climatic regions during winter season (November-April)

| Scenario No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Temperature (Δ T) | No change | +2℃ | +2℃ | +2℃ |
| Precipitation (Δ P) | No change | No change | +10% | -10% |
| West Hokkaido | 2.21 | 1.92 | 2.09 | 1.70 |
| East Hokkaido | 2.46 | 2.11 | 2.28 | 1.85 |
| West Tohoku | 2.83 | 2.07 | 2.26 | 1.85 |
| East Tohoku | 1.04 | 0.68 | 0.74 | 0.60 |
| Hokuriku | 2.72 | 1.83 | 2.01 | 1.64 |
| Kanto | 0.14 | 0.08 | 0.08 | 0.07 |
| Chubu | 0.83 | 0.59 | 0.64 | 0.52 |
| Tokai | 0.03 | 0.01 | 0.01 | 0.01 |
| Sanin | 0.56 | 0.23 | 0.26 | 0.21 |
| Sanyo | 0.20 | 0.07 | 0.08 | 0.06 |
| North Shikoku | 0.05 | 0.02 | 0.02 | 0.02 |
| South Shikoku | 0.00 | 0.00 | 0.00 | 0.00 |
| North Kyushu | 0.10 | 0.02 | 0.02 | 0.02 |
| South Kyushu | 0.02 | 0.01 | 0.01 | 0.01 |
| TOTAL | 13.19 | 9.64 | 10.50 | 8.56 |

| Scenario No. | 1 | 5 | 6 | 7 |
|---|---|---|---|---|
| Temperature (Δ T) | No change | +4℃ | +4℃ | +4℃ |
| Precipitation (Δ P) | No change | No change | +10% | -10% |
| West Hokkaido | 2.21 | 1.58 | 1.72 | 1.40 |
| East Hokkaido | 2.46 | 1.77 | 1.91 | 1.55 |
| West Tohoku | 2.83 | 0.98 | 1.07 | 0.87 |
| East Tohoku | 1.04 | 0.31 | 0.34 | 0.27 |
| Hokuriku | 2.72 | 1.06 | 1.16 | 0.95 |
| Kanto | 0.14 | 0.04 | 0.05 | 0.04 |
| Chubu | 0.83 | 0.38 | 0.41 | 0.33 |
| Tokai | 0.03 | 0.001 | 0.001 | 0.001 |
| Sanin | 0.56 | 0.06 | 0.07 | 0.06 |
| Sanyo | 0.20 | 0.01 | 0.01 | 0.01 |
| North Shikoku | 0.05 | 0.01 | 0.01 | 0.01 |
| South Shikoku | 0.00 | 0.00 | 0.00 | 0.00 |
| North Kyushu | 0.10 | 0.002 | 0.002 | 0.002 |
| South Kyushu | 0.02 | 0.001 | 0.001 | 0.001 |
| TOTAL | 13.19 | 6.20 | 6.75 | 5.49 |

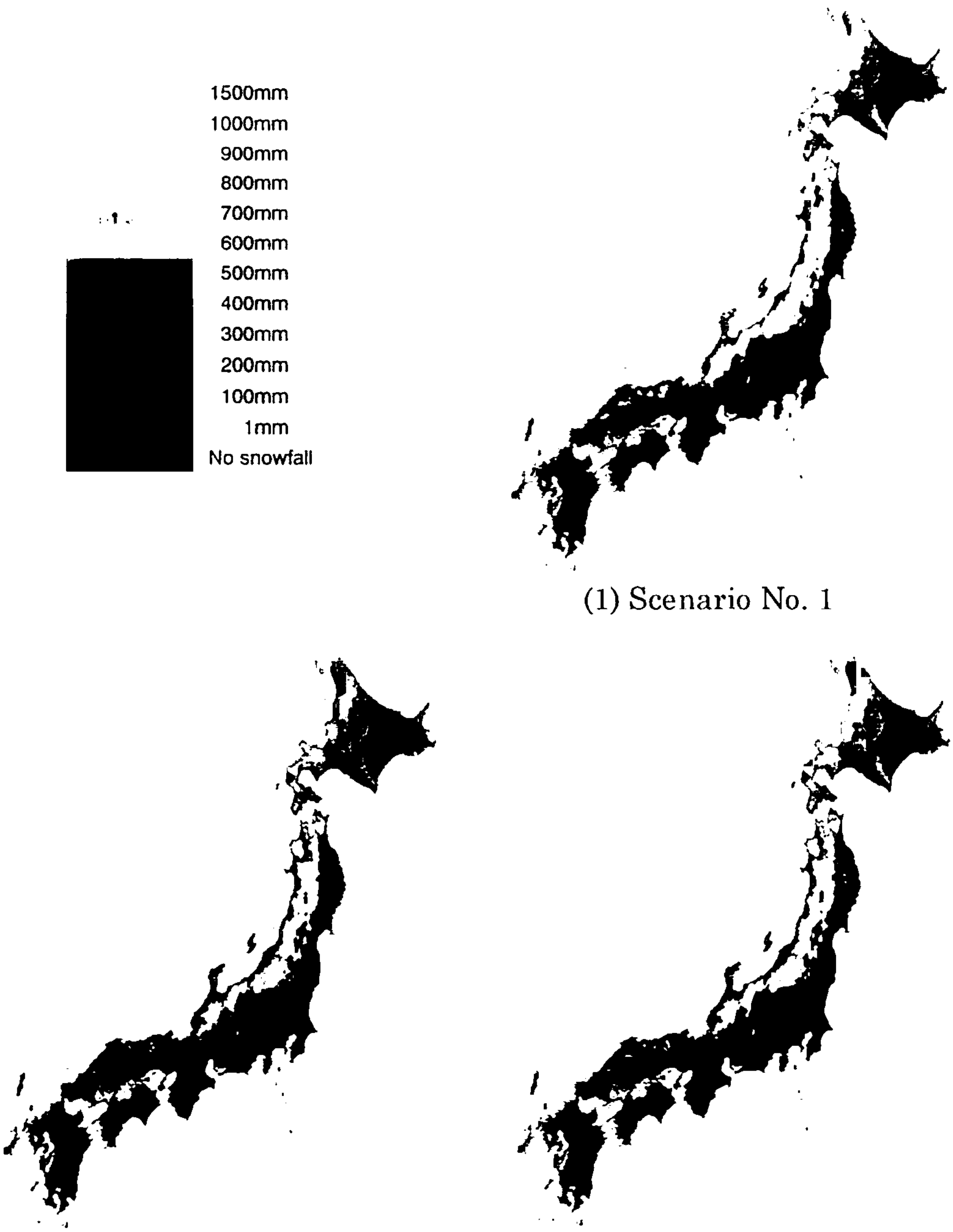



Fig. 2 Distribution of snowfall during winter season in Japan. All figures refer to the same scale upper left.

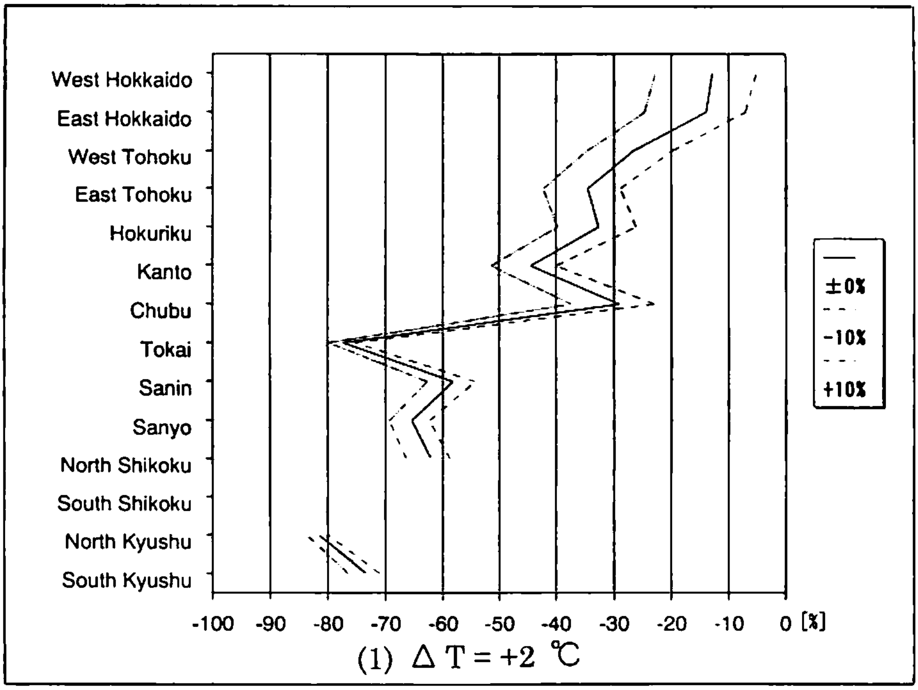
(4) Scenario No. 4

(5) Scenario No. 5

(6) Scenario No. 6

(7) Scenario No. 7

Fig. 2 (Continue)



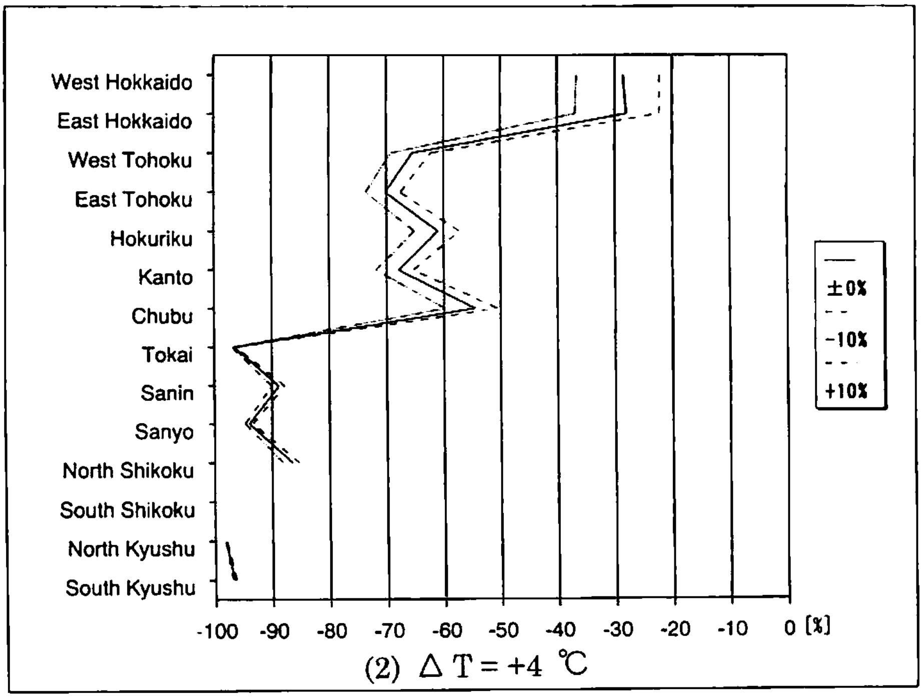




**Fig. 3** Ratio of snowfall to total precipitation in winter.

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This is dedicated to Professor Michio Nogami on the occasion of his retirement from Tokyo Metropolitan University.

## Note

Though precipitation amount is usually measured by rain gages in daily routine of meteorological observation, rain gages tend to fail to catch precipitation sometimes (for example under the strong wind). Such effects on snowfall are really serious subject. The author has studied on this subject using water balance of river basins in her master's thesis. In this paper, the author used "the correction factor" as the result of her thesis (Ogawa 1992).

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