Method for Calculating the Amount of Accumulated Snow Transported during a Single Blizzard

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1. Introduction

In Hokkaido, many vehicles stalled as a result of accumulated snow on National Route 274 in Naganuma on February 23 and 24, 2008 and in the Kushiro/Nemuro district on March 31 and April 1 of the same year. While the maximum amount of accumulated snow and the frequency of blizzards for each winter have been found to serve as indexes indicating blizzard intensity in the past[1), 2)], there are no indexes to represent the intensity of a single blizzard. In this study, a single blizzard was defined with the aim of providing basic data to enable the planning of measures against such events, and the total amount of accumulated snow transported during a single blizzard was calculated to find the probability of the annual maximum value being replicated.

2. Study method

2.1 Relationship between the transport rate of blowing snow and wind velocity

The transport rate of blowing snow Q is the mass of blowing snow particles that passes through a particular unit width orthogonal to the wind direction during a fixed time, and [g/(ms)] is used as the unit. Empirical expressions to express the relationship between the wind velocity V and the transport rate of blowing snow Q have been found in several past studies [3), 4), 5)].

To estimate the transport rate of blowing snow in this study, the equation below presented by Kobayashi [3)] was used.

$$Q = 0.03\ V_1^{3}\ \ [\mathrm{g/(ms)}] \qquad \ldots(1)$$

where V_1 is the wind velocity at a height of 1 meter.

2.2 Conditions required for blowing snow occurrence

Figure 1 shows the conditions required for blowing snow occurrence during snowfall as presented by Takeuchi et al.[6)]. The white circles, black circles and triangles represent conditions with continuous high drift snow, intermittent high drift snow and low drift snow, respectively.

In this study, the conditions required for blowing snow occurrence were defined as follows by referring to Fig. 1, and blizzard occurrence was assumed when either set of criteria were satisfied:

ℵ Condition 1: an air temperature of ≤ -2°C, a wind velocity of ≥ 5.0 m/s and a snow depth of ≥ 1 cm

ℵ Condition 2: an air temperature of ≤ 0.5°C, a wind velocity of ≥ 7.5 m/s and a snow depth of ≥ 1 cm

The three criteria included in 1 and 2 are all AND conditions.

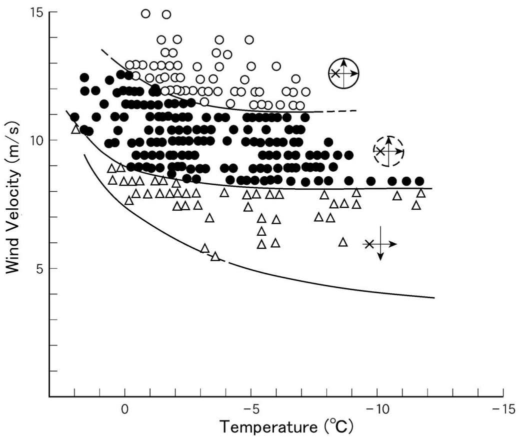


Fig. 1 Conditions required for blowing snow occurrence during snowfall[6)]

2.3 Definition of a single blizzard

There have been no past definitions of a single blizzard. In this study, a blizzard was considered to have ended when the above necessary conditions for blowing snow occurrence were not satisfied for six consecutive hours, and the period between the start and end of a blizzard was defined as a single event.

2.4 Estimation of the transport rate of blowing snow and the probability of replication

Data from AMeDAS (Automated Meteorological Data Acquisition System) observation stations were used to calculate the transport rate of blowing snow. However, wind velocity measurement heights vary by station; since V_1 in Eq. (1) is the wind velocity at a height of 1 m [m/s], correction of the wind value data was necessary. In this study, correction was made on the assumption that the vertical wind velocity distribution is expressed by Eq. (2).

$$U(z) = \frac{U_*}{k} \ln \frac{z}{z_0}$$

…(2)

where U_* is the friction velocity, k is the Karman constant (= 0.4) and z_0 is the surface roughness (= 1.5×10^{-4} m).

In addition, while Eq. (1) uses the transport rate of blowing snow per second, the wind velocity data recorded at AMeDAS stations are hourly values. The transport rate of blowing snow during a single blizzard was therefore calculated on the assumption that wind velocity was uniform for the whole hour. In the sections below, this value is referred to as the total transport rate of blowing snow *Qsum* [kg/m].

The probability of replication was calculated using Iwai's method[7)] on the assumption that the annual maximum values for the total transport rate of blowing snow during a single blizzard follow the logarithmic normal distribution.

3. Results

3.1 Naganuma case

The conditions required for blowing snow occurrence include a certain snow depth. Since depth is not observed at the Naganuma AMeDAS observation station, the values recorded at the adjacent Eniwa-Shimamatsu facility were used. Since measurement at this station began in October 1981, data from the 23 winters between November 1981 and April 2004 were used for analysis. The total transport rate of blowing snow on February 23 and 24, 2008 was also calculated, and was found to have been exceeded twice in the past (Table 1).

In the design of snow fences and other blowing-snow control facilities, it is easier to handle the transport rate of blowing snow as a volume. Accordingly, the total transport rate of blowing snow *Qsum* was converted to a volume value on the assumption that the snowcover density was 350 kg/m^3.

Table 1 Highest total transport rates of blowing snow and the rate in 2008

Period	Rate [m^3/m]
Feb. 12 – 18, 1991	8.6
March 8 – 9, 2003	5.0
Feb. 23 – 24, 2008	4.6

Next, the probability of replication was calculated using the transport rate of blowing snow in the cold seasons of 1982 to 2004. The result indicated that the probability period for replication of this scale of blizzard (February 2008) was approximately 10 years (Fig. 2).

3.2 Attoko case

Similarly, calculation for Attoko was made using data from the 18 winters between November 1986 and April 2004. The total transport rate of blowing snow during blizzards in March and April of 2008 was 4.4 m^3/m, and was found to exceed the total transport rate of blowing snow with a 1000-year probability period (= 4.1 m^3/m) (Fig. 3).

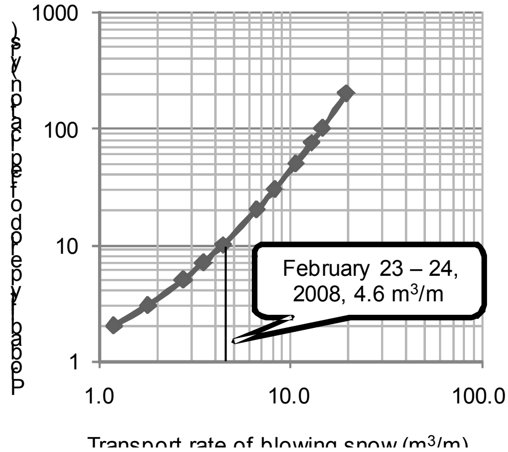


Fig. 2 Total transport rate of blowing snow during a single blizzard and the probability period of replication (Naganuma)

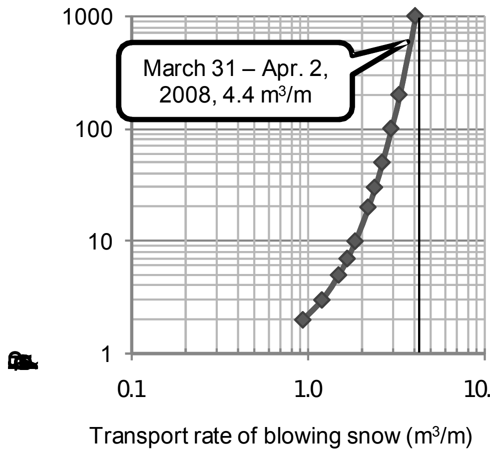


Fig. 3 Total transport rate of blowing snow during a single blizzard and the probability period of replication (Attoko)

3.3 Other regions

The maximum transport rate of blowing snow with a 10-year probability period of replication was found in different parts of Hokkaido (Fig. 4). It can be seen that the values are higher in windy coastal areas. The points marked with triangles in the figure represent AMeDAS observation stations where weather data used in the analysis have been collected for less than 10 years.

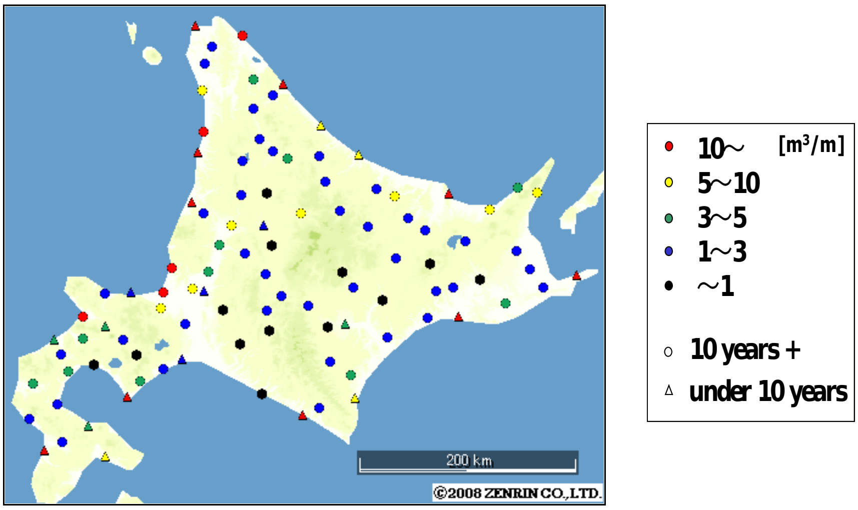


Fig. 4 10-year probability for the transport rate of blowing snow during a single blizzard

4. Improvement of the method for estimating the maximum transport rate of blowing snow

Since the 10-year probability of replication seemed too large for Naganuma, which has experienced severe blizzards in the past, the weather conditions between February 16 and 18, 1991, between March 8 and 9, 2003 and between February 23 and 24, 2008 were presented again (Fig. 5). It can be seen that there was sunshine and almost a total lack of precipitation during the high wind-velocity period on March 8 and 9, 2003. It is well known that blizzards are unlikely to occur when there is no fresh snow on the surface even in conditions of strong wind. While Takeuchi et al.[6] presented the conditions required for blowing snow occurrence during snowfall, the presence of snowcover is not taken into account in the calculation of this study. It is therefore presumed that there may be some overestimation regarding the transport rate of blowing snow.

Accordingly, it was assumed that blowing snow is not seen in the absence of freshly fallen snow on the snowcover surface, and the total snowfall over a distance of 300 m on the windward side from 24 hours before the onset to the end of the blizzard was considered the maximum amount for the total transport rate of blowing snow during a single blizzard.

In other words, if the upper limit of the total transport rate of blowing snow per unit width during a single blizzard is the maximum possible transport rate of blowing snow Qmax [kg/m], the values can be expressed as below.

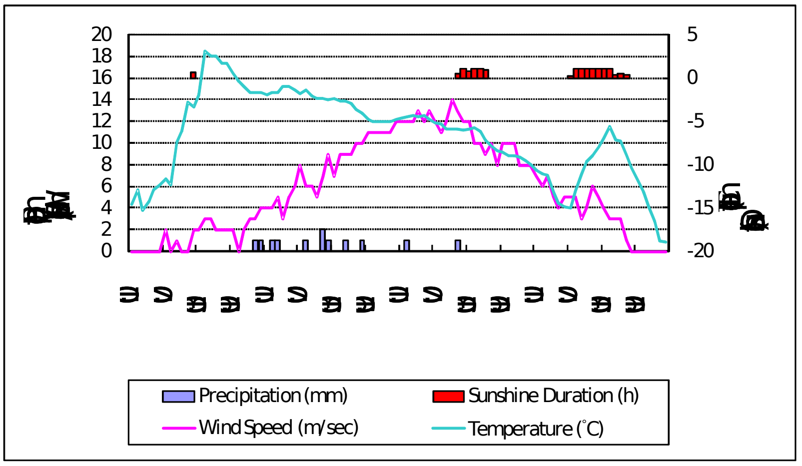
$Qmax$ = total snowfall over a distance of 300 m on the windward side (= 300 * total precipitation [mm])

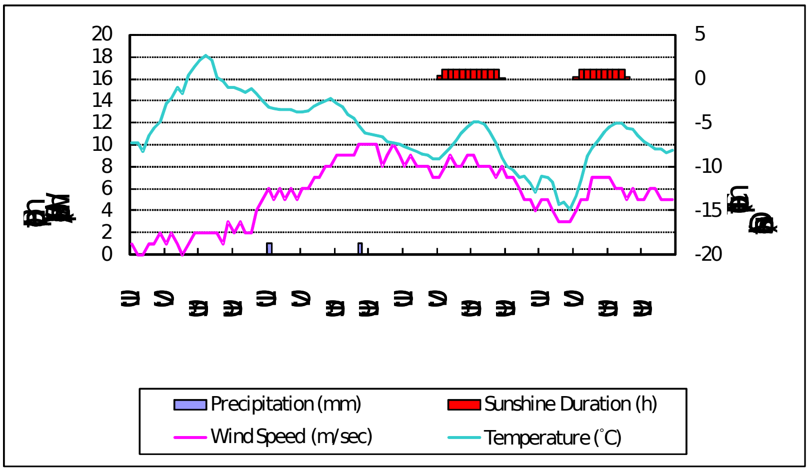
$Qsum \leq Qmax$

Figure 6 shows the annual maximum values for the total transfer rate of blowing snow found by recalculating the total transfer rates of blowing snow in Naganuma. It can be seen from the figure that the value was smaller in 2003. The probability of replication was also found using the total transfer rate of blowing snow obtained by the improved method, and the probability period for replication of the blizzard in 2008 was found to be 30 years.

However, the maximum value for the transfer rate of blowing snow in 1991 was still larger than that of 2008. Figure 5 indicates that the temperature in the high wind-velocity period during the blizzard of 2008 was -10°C, which was lower than that during the blizzard of 1991. It was also presumed that many drivers refrained from going out in their cars during the blizzard of 1991 as the wind velocity exceeded 5 m/s and snow fell from the morning. Conversely, the weather was milder during the blizzard of 2008, with wind velocity values remaining mostly under 5 m/s and temperatures of near 0°C until the early afternoon. Since it was also a holiday, it was presumed that many drivers went out. It can be seen that the blizzard intensified in the afternoon with increased wind velocity and rapidly decreasing temperature accompanied by snowfall. This was probably a reason for the higher level of disruption seen.

In any case, the transfer rate of blowing snow is determined based only on wind velocity in the calculation method of this study. However, since the transfer rate is considered to also depend on temperature and other factors, further studies on this method will be necessary in the future.





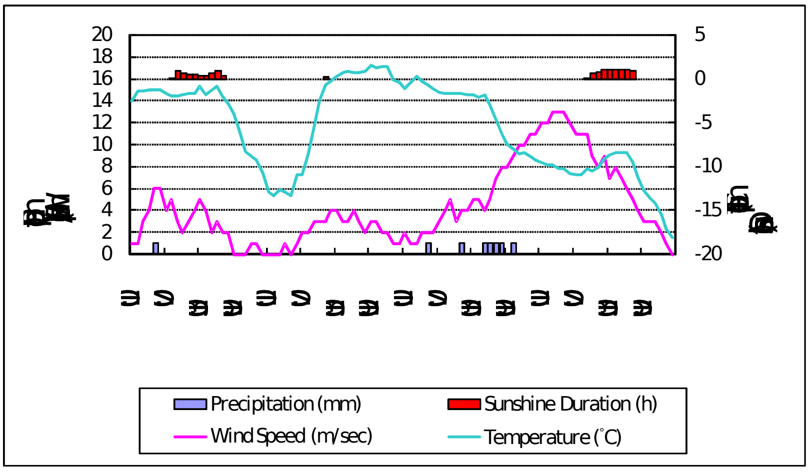


Fig. 5 Weather conditions during blizzards. Top: February 15 – 18, 1991; middle: March 7 – 10, 2003; bottom: February 21 – 24, 2008

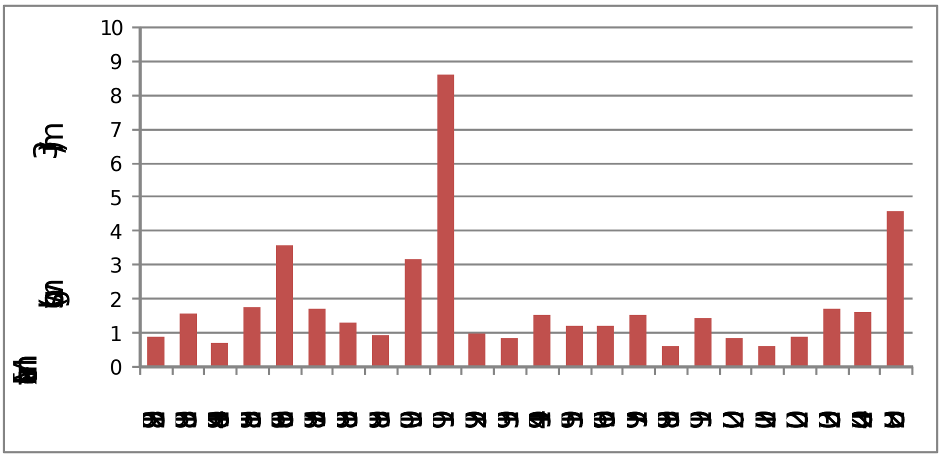


Fig. 6 Changes in annual maximum values for the total amount of blowing snow in Naganuma

5. Conclusion

The total transfer rate of blowing snow during a single blizzard was defined, and a method for finding the probability of its replication was presented. The probability period found using AMeDAS data was approximately 10 years for the blizzard in Naganuma on February 23 and 24, 2008, and more than 500 years for that in Attoko on March 31 and April 1, 2008. The calculation method for the total transfer rate of blowing snow was then corrected with a focus on the precipitation recorded from immediately before a blizzard to its end. The results indicated that the probability period of replication for the blizzard in Naganuma on February 23 and 24, 2008 was approximately 30 years.

While the calculated total transfer rate of blowing snow was higher between February 15 and 18, 1991 than that between February 23 and 23, 2008 in Naganuma, no disruption was caused by blowing snow in the 1991 blizzard. This was considered to be a result of the higher temperature in the 1991 blizzard than that in the 2008 occurrence during the strong-wind period. It is therefore considered that more detailed examination of the conditions required for blowing snow occurrence and the calculation method for the transfer rate of blowing snow will be necessary in the future.

Acknowledgment

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