Height-Dependent Difference in Visibility on Roads

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1. Introduction

Vehicles running in the harsh winters of cold, snowy regions encounter severe road conditions, including icy road surfaces and blowing-snow-induced poor visibility. When visibility is reduced, particularly by drifting and blowing snow, the recognition of a traffic accident or stopped vehicle ahead tends to be delayed, and this sometimes results in multi-vehicular collision. Kajiya et al. (1998) noted that multi-vehicular collisions of dozens of vehicles typically involve a heavy vehicle, and that many such collisions occur when a large trailing vehicle collides with a small leading vehicle that has stopped in blowing snow.

Several studies have been conducted in recent years on height-dependent variation in visibility. Sato et al. (2002) obtained visibilities at different heights by mathematical calculation, and demonstrated that when the wind velocity at a height of 10 m is 12 to 14 m/s, the visibility at a height of 2.4 m is greater than 300 m but at a height of 1.2 it is less than 300 m. This, however, was visibility at a snowfield, not on a road. Tozuka et al. (2001) measured visibility on the road while driving a vehicle equipped with the Snow Particle Counters at different heights. They confirmed that visibility depended on height, with visibility improving with increase in height. However, no quantitative examination was made as to how the height-dependent difference in visibility varied with weather and road conditions, or which factor made the greatest contribution to such variation.

This paper uses observation of mass flux of snow to investigate the effects of weather conditions and snowbank height on the height-dependent variation in visibility above the road.

2. Observation method

2.1 Observation equipment

The mass flux of snow was observed using a blowing-snow trap of net type with mouth diameter of approximately 10 cm. Plankton net of 105-μm mesh pore was used. The snow trap was mounted on a specially designed bracket. A bearing between the upper and lower parts allows the neck of the top part (where the trap is mounted) to swivel freely. When a snow trap is placed on the upper part of the anchor, the opening automatically faces windward because of the streamer principle (Figure 1).

Each snow trap was weighed before the observation. The lower part of the bracket was fixed on an appropriate pole, so that when the trap was mounted, its center came to the target height. First, the snow trap was mounted on the upper part of the bracket. Then the lid of the trap was opened and clocking started. The lid was closed before the net became clogged. Closing of the lid marked the end of clocking. Next, after snow accreted on the outside was brushed off, the trap was weighed immediately to avoid sublimation of the snow particles in the net. This weight minus the weight of the counter measured in advance is the weight of the captured snow particles. Dividing the weight of the captured blowing snow by the length of time the lid was open and the cross-sectional area of the trap meter opening yields mass flux of snow in g/m^{2}s.

The obtained mass flux of snow can be used “as is,” but it is easier to understand when converted into visibility in blowing snow. To do this, we used the following equation of Matsuzawa and Takeuchi (2002).

$$log(Vis)=-0.77*log(Mf)+2.85 \quad \cdots(1)$$

Where Vis: visibility (m), Mf: Mass flux of snow (g/m^{2}s)

Furthermore, when a blowing-snow trap of net type is used, it is necessary to take the capture rate into consideration. Based on the study by Takeuchi and Fukuzawa (1976), only the aerodynamic capture rate was taken into account herein, and it was corrected to 85% at a wind velocity of 5.0 m/s or greater and 75% at velocities from 3.0 to 5.0 m/s.

Figure 1. Blowing-snow trap of net type (A), and mount (B). Part (C) contains the bearing. The trap mouth faces windward.

2.2 Observation conditions

The observation site is a road at the Ishikari Blowing Snow Test Field of the Civil Engineering Research Institute of Hokkaido. The test field is on the dry riverbed of the Ishikari River, on the right bank at the lower reaches, about 17 km north of central Sapporo. The prevailing winter winds in this area come from between west-northwest and northwest. The observation was made on the straight section running north-south. Windward of the observation spot is grassland with a fetch of at least 300 m.

Mass flux of snow was measured windward of the snowfield (at a height of 1.2 m above the snow surface) and on the roadway (at heights of 1.2 m and 2.4 m) (Figure 2). The heights of 1.2 m and 2.4 m correspond to the respective eye levels of a small-vehicle driver and a large-vehicle driver. Wind velocity was measured using three-cup type anemometers. The air temperature was measured at the Ishikari Blowing Snow Test Field every ten minutes with a platinum resistance thermometer installed at a height of 2.5 m. Likewise, a velocity meter of windmill type (aerovane) was installed at a height of 10 m and a value was obtained every ten minutes. Snowfall intensity was not measured at the site. Instead, we used mean values of snowfall intensity obtained every ten minutes at Oyafune Observation Station (4 km northwest of the site) and Futomi Observation Station (4 km southwest of the site) of Sapporo City's weather telemeter system. Snow cover distribution on the cross section of the road at the observation site was also measured (Figure 3).

Figure 2 Observation of mass flux of snow

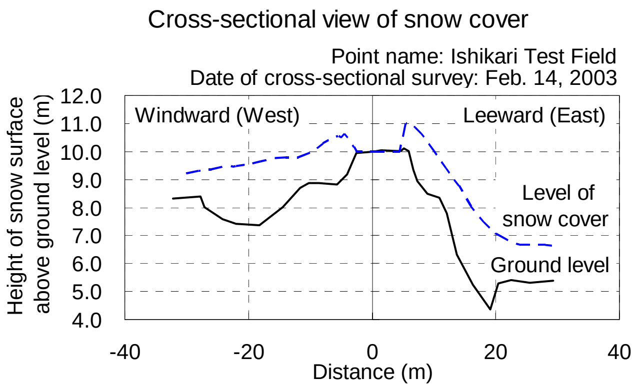

Figure 3 Snow cover distribution on the cross section of the road

3. Factors that affect visibility on the road

Before examining height-dependent differences in visibility, we present the findings on two relationships: visibility vs. weather conditions, and visibility vs. snowbank height.

3.1 Relationship between visibility and weather factors

Figure 4 shows the relationship between visibility at a height of 1.2 m above the road in blowing snow and weather factors. From the top to the bottom, the figure shows visibility's relationship with wind velocity, air temperature and snowfall intensity. The figures demonstrate that visibility correlates negatively with wind velocity and snowfall intensity, and positively with air temperature.

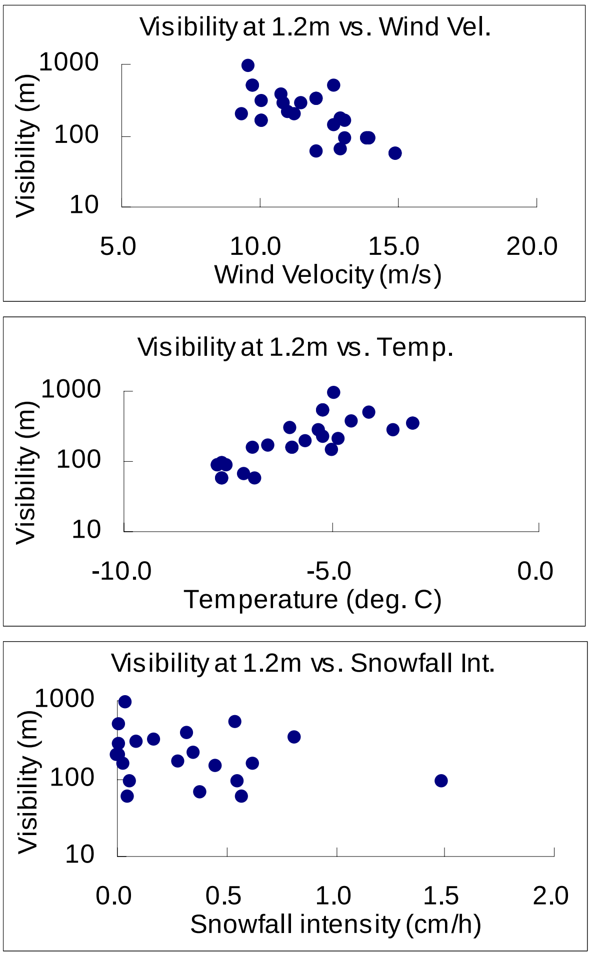

Figure 4 Relationship between visibility at a height of 1.2 m above the road and weather conditions. Top: visibility vs. wind velocity. Middle: visibility vs. temperature. Bottom: visibility vs. snowfall intensity

3.2 Visibility above the road and snowbanks

Factors other than weather conditions also affect visibility above the road. The effect can be particularly adverse if there is a high snowbank at the roadside, in which case snow blowing from the top of the snowbank passes at the driver's eye level.

Figure 5 shows the relationship between snowbank height and visibility. It indicates that visibility tends to decrease as the snowbank height increases.

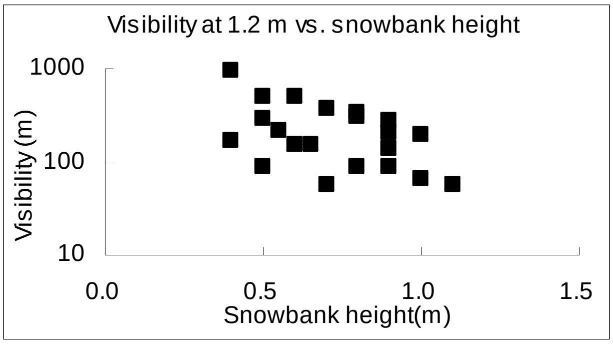

Figure 5 Visibility at a height of 1.2 m vs. snowbank height

4. Factor analysis

A relationship has been confirmed between visibility and each weather factor, and visibility and snowbank height. Next, to examine the contribution of these factors to visibility, we performed multiple linear regression analysis. Air temperature, wind velocity at a height of 10 m, snowfall intensity and snowbank height were chosen as explanatory variables. Values were standardized to examine their contribution to visibility.

The findings are shown in Table 1. Visibility at a height of 1.2 m above the road depends most strongly on air temperature, correlating positively. It depends the next most strongly on snowbank height and then wind velocity, correlating negatively with both. It also correlates negatively, but weakly, with snowfall intensity.

The values measured in this study, however, include only one datum of snowfall intensity exceeding 1 cm/h. To properly evaluate the impact of snowfall intensity on visibility, it is presumed necessary to add data measured under heavy snowfall.

Table 1 Multiple linear regression analysis of factors affecting visibility

	Coefficient
Air temperature	0.53
Snowbank height	-0.47
Wind velocity at 10 m	-0.34
Snowfall intensity	-0.10

5. Height-dependent differences in visibility

Next, we will discuss the difference in visibility between that at a height of 2.4 m and that at a height of 1.2 m, by focusing on the difference in driver visibility between a large and small vehicle.

5.1 Height-dependent differences in visibility

Figure 6 compares visibility at a height of 1.2 m and 2.4 m above the road. It shows that the values of visibility at 2.4 m exceed those at 1.2 m. This is consistent with the findings of Tozuka et al. (2001).

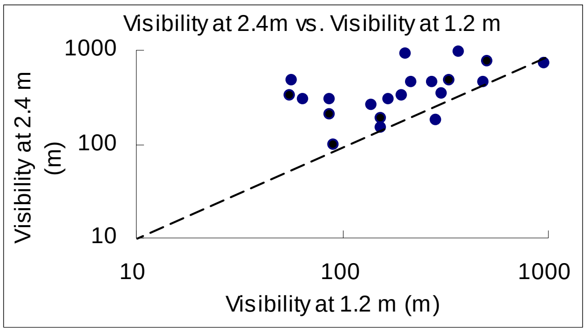

Figure 6 Comparison of visibility at 2.4 m and 1.2 m above the road. The dotted line indicates a visibility ratio of 1, i.e., where visibility at 2.4 m and 1.2 m are equal.

5.2 Difference in visibility depending on height and weather conditions

Figure 7 plots the relationship between visibility ratio and weather conditions. ("Visibility ratio" is defined hereinafter as "ratio of visibility at a height of 2.4 m to visibility at a height of 1.2 m.") From the top to the bottom, the plot shows the relationship of the visibility ratio with wind velocity, air temperature and snowfall intensity, respectively. Figure 7 indicates that the visibility ratio is independent of wind velocity. A relatively weak correlation is found between the visibility ratio and temperature and between visibility ratio and snowfall intensity.

However, the visibility ratio varies widely from 1 to 10, even when snowfall intensity remains around zero. To determine the cause of this variation, we examine the relationship between snowbank height and visibility ratio.

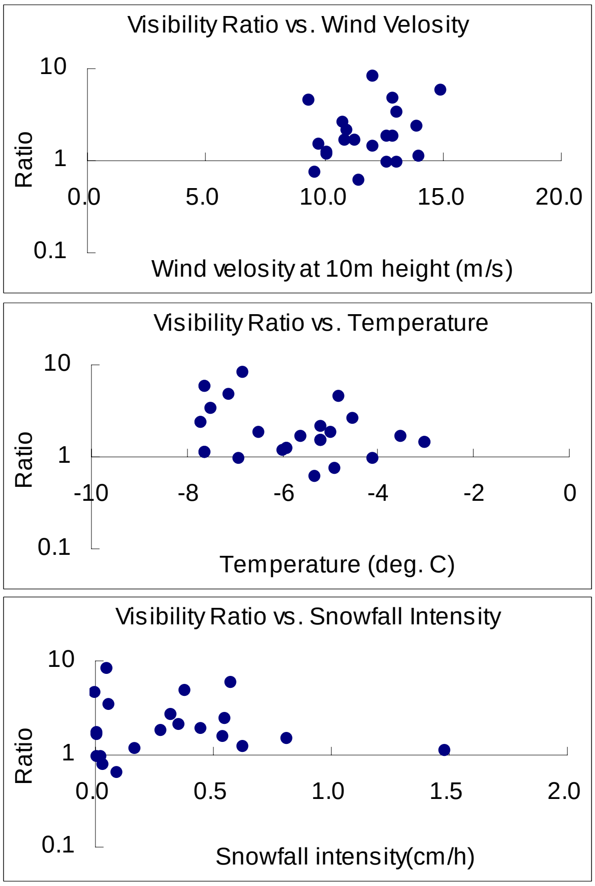

Figure 7 Visibility ratio (visibility at a height of 2.4 m : visibility at a height of 1.2 m) vs. weather factors. Top: wind velocity. Middle: air temperature. Bottom: snowfall intensity.

5.3 Differences in visibility depending on height and snowbank height

Figure 8 shows the relationship between snowbank height and visibility ratio. It indicates that the visibility ratio becomes greater as the snowbank height increases, approaching 10 when the height exceeds 1 m.

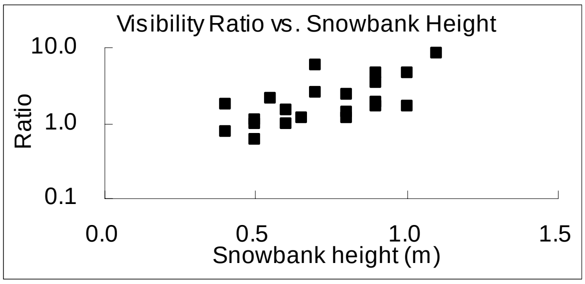

Figure 8 Visibility ratio (visibility at a height of 2.4 m : visibility at a height of 1.2 m) vs. snowbank height.

6. Analysis of factors that affect the visibility ratio

We then performed multiple linear regression analysis to examine the contributions of factors that affect the visibility ratio. Air temperature, snowfall intensity and snowbank height were chosen as explanatory variables. Table 2 shows the result of analysis. It indicates that the snowbank height gives the greatest contribution to the visibility ratio. Temperature makes the second-greatest contributor. Snowfall intensity makes a negligible contributor.

Table 2 Multiple linear regression analysis of factors affecting the visibility ratio

	Coefficient
Snowbank height	0.67
Air temperature	-0.31
Snowfall intensity	0.08

7. Conclusion

The following results were obtained from the observations in this study.

(1) The factors making the greatest contribution to visibility variation on the road are air temperature, snowbank height and wind velocity.

(2) The factor most greatly affecting the height-dependent visibility difference is snowbank height.

(3) The visibility ratio becomes greater as the snowbank height increases. When the height exceeds 0.9m, visibility ratio was 3 to 10.

This study had few cases of measurement under the condition of snowfall intensity exceeding 1 cm/h. There were no cases where measurement was conducted under snowfall intensity exceeding 2 cm/h. These results show that snowfall intensity contributes slightly to visibility variation on the road and to difference in visibility depending on the height. However, experience shows that when snowfall is heavy, visibility on the road deteriorates. The results of this study, therefore, are considered to hold true only for low-intensity snowfall (< 1 cm/h).

In our future study it is necessary to clarify relationship between visibility and weather conditions by doing more observations during heavy snowfall.

Acknowledgments

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References

Kajiya Y., Fukuzawa Y., Kaneko M., Takeuchi M., Tanji K. and Kaneda Y., 1998: Study on Causes and Countermeasures against Multiple Collisions under Snow Storm Conditions (The 3rd report): To Develop Safe Driving Support System (in Japanese). Proceeding of Cold Region Technology Conference, 14, 57 – 62.

Matsuzawa M. and Takeuchi M., 2002: Study on Methods to Calculate Visibility on Blowing Snow. Proceedings of 11th SIRWEC International Road Weather Conference (CD-ROM), 2002, Sapporo.

Sato T., Kosugi K., and Sato A., 2002: Estimation of Blowing Snow and Related Visibility Distributions above Snow covers with Different Hardness. Proceedings of 11th SIRWEC International Road Weather Conference (CD-ROM), 2002, Sapporo.

Takeuchi M. and Fukuzawa Y., 1976: On the Light Attenuation and Visibility in Snow Drift (in Japanese). Seppyo, 38, 9 - 14.

Tozuka S., Sato S. Sato M., Arakawa H., Iinuma K., Ishimaru T., Sato T. and Kera K., 2001: Development of a Method of Measurement on Moving Visibility by Vehicle-mounted Saltating Snow Particle Counter (in Japanese). Proceeding of Cold Region Technology Conference, 17, 115 - 119.