Provision of Snowstorm Visibility Information

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ABSTRACT

Traffic hindrance that is frequently caused by snowstorm-induced poor visibility or snowdrifts due to snowstorms at winter roads in snowy cold regions has a significant social impact. The Civil Engineering Research Institute of Cold Region (CERI) developed techniques for estimating visibility distances on the basis of meteorological data. In February 2013, CERI started to use its website Snowstorm Visibility Information System for informing road users of visibility forecasts. In December 2013, the Snowstorm Visibility Information System was made accessible from smartphones, and a mail delivery service was started for providing visibility forecasts. With an aim of understanding the usefulness of the visibility information, the authors asked users of the Snowstorm Visibility Information System to answer a questionnaire. The questionnaire result indicated that 80% of respondents used the system for determining whether or not to change their travel plans.

Keywords: Snowstrom, Visibility Forecast, Traveler Information System

INTRODUCTION

The traffic hindrances that frequently occur due to snowstorm-induced poor visibility or snowdrifts caused by snowstorms on winter roads in snowy cold regions have significant social impacts (*1*). In recent years, Hokkaido, the northernmost of Japan's four major islands, has experienced snowstorm disasters caused by unusually strong snowstorms as a result of rapidly developing low-pressure systems. When a severe snowstorm swept across Hokkaido in March 2013, many national highways were closed to traffic for an extended period. The snowstorm caused considerable damage, including the loss of nine lives. In light of this, it is necessary to take non-structural measures to prevent drivers from getting caught in heavy snowstorms. Specifically, information on the current conditions and forecasts of snowstorms needs to be provided to drivers in order to support their decision-making on what they should do during snowstorms.

In February 2013, the authors began providing forecasts of highway visibility in Hokkaido by using the *Snowstorm Visibility Information Services* website, operated by the Civil Engineering Research Institute of Hokkaido (CERI). In December 2013, the authors started to develop a visibility information site for smartphones, as visibility information had been accessible only from PCs, and we also began testing an e-mail delivery service that makes notifications of poor highway visibility.

The authors conducted questionnaire surveys to understand the usefulness of these visibility information services for the FY2014 winter. This paper reports the series of surveys and their results.

REVIEW OF CONVENTIONAL WINTER ROAD INFORMATION WEATHER INFORMATION SERVICES

There are many examples of projects that provide weather radar observation data or information on tornadoes and thunderstorms(*2*) to road users and road administrators.
Less commonly, winter road information is also provided to road users as follows.

The Federal Highway Administration (FHWA) of the U.S.A. has made experimental field tests in which road weather information is provided to road users to make them aware of road weather conditions using Clarus(*3*). One of the experiments is the provision of advisory on the 511 *NY* road information website of New York State.The Western Transportation Institute (WTI) of Montana State University College of Engineering has developed a website that provides integrated, seamless road weather information for the states of California, Oregon, Washington and Nevada(*3*). Similar undertakings have been made by other states (*4*).
The University of Maryland Center for Advanced Transportation Technology Laboratory (CATT Lab) has developed the RITIS system(*5*). RITIS issues alerts on reduced visibility by providing current visibility derived from Clarus data.
In Canada, the provinces of Ontario(*6*) and Quebec(*7*) have developed a system for the provision of road weather information (rain, snow, ice, and wind speed and wind velocity), closed circuit television camera road images, road closure information and current snowstorm visibility information. However, there are no systems that provide snowstorm visibility forecasts to drivers.

OUTLINE OF THE SNOWSTORM INFORMATION SERVICE FOR FY2014

Method of Estimating Visibility during Snowstorms

Visibility during snowstorms has a strong correlation with the mass flux of snow ($g/m^2/s$), defined as the mass of snow particles passing through a unit space per unit time. Previous studies clarified Visibility during snowstorms correlates closely with the mass flux of snow ($g/m^2/s$), defined as the mass of snow particles passing through a unit space per unit time. The relationship is shown by Equation (1) (*8*).

$$Vis = 10^{-0.886 \times \log(Mf) + 2.648} \qquad (1)$$

Where, *Vis*: Visibility (m) and *Mf*: Mass flux of snow ($g/m^2/s$).
Mf is the product of suspended-snow concentration (g/m^3) and wind speed (m/s). To calculate the visibility under snowstorm, estimation of the suspended-snow concentration is necessary.

However, the suspended-snow concentration tends not to be measured, so the data are unavailable. Matsuzawa et al. (*9*) proposed Equation (2) for estimating the suspended-snow concentration using snowfall intensity, wind velocity and air temperature.

$$N(z) = \frac{P}{w_f} + \left(N_t - \frac{P}{w_f}\right)\left(\frac{z}{z_t}\right)^{-\frac{w_b}{kU_*}} \qquad (2)$$

Where, *P*: Snowfall intensity ($g/(m^2s)$), *wf*: Falling velocity of snowfall particles (m/s), *wb*: Falling velocity of suspended snow particles (m/s), *z*: Height for forecasting the visibility (m), z_t: Reference height (m), N_t: Suspended-snow concentration at reference height z_t (g/m^3), U^*: Friction velocity and *k*: Karman's constant (=0.4).

First, Equation (2) is used for calculating N_t at the height of *z*. Then, the value of N_t is multiplied by the value of the wind velocity at the height of z_t to obtain *Mf*. Next, the value of *Mf* is substituted into Equation (1) to estimate snowstorm visibility. To calculate the visibility, appropriate parameters must be given to Equation (2). In this study, we set parameter values with reference to previous studies(*10*) (*11*) (*12*) (*13*). The parameters are as follows:

wf = 1.2 (m/s)
wb = 0.21 (m/s)
z = 1.2 (m) (Height of the viewpoint of a driver in a car)
$U^* = 0.036 \times V_{10}$ (m/s) (V_{10} is the wind speed at 10 m from the ground surface in m/s.)
$z_t = 0.15$ (m)

To obtain N_t (g/m^3) at a height of zt, different formulas were used, depending on the snowfall intensity(*14*).

$N_t = 0.166 \cdot e0.309 \cdot V_{10}$ (g/m^3) When snowfall intensity is high.
$N_t = 0.274 \cdot e0.401 \cdot V_{10}$ (g/m^3) When snowfall intensity is low or zero (i.e., there is no snowfall)

The *Road Structure Ordinance* of Japan(*15*) specifies 1.2 m as the eye height of drivers of compact

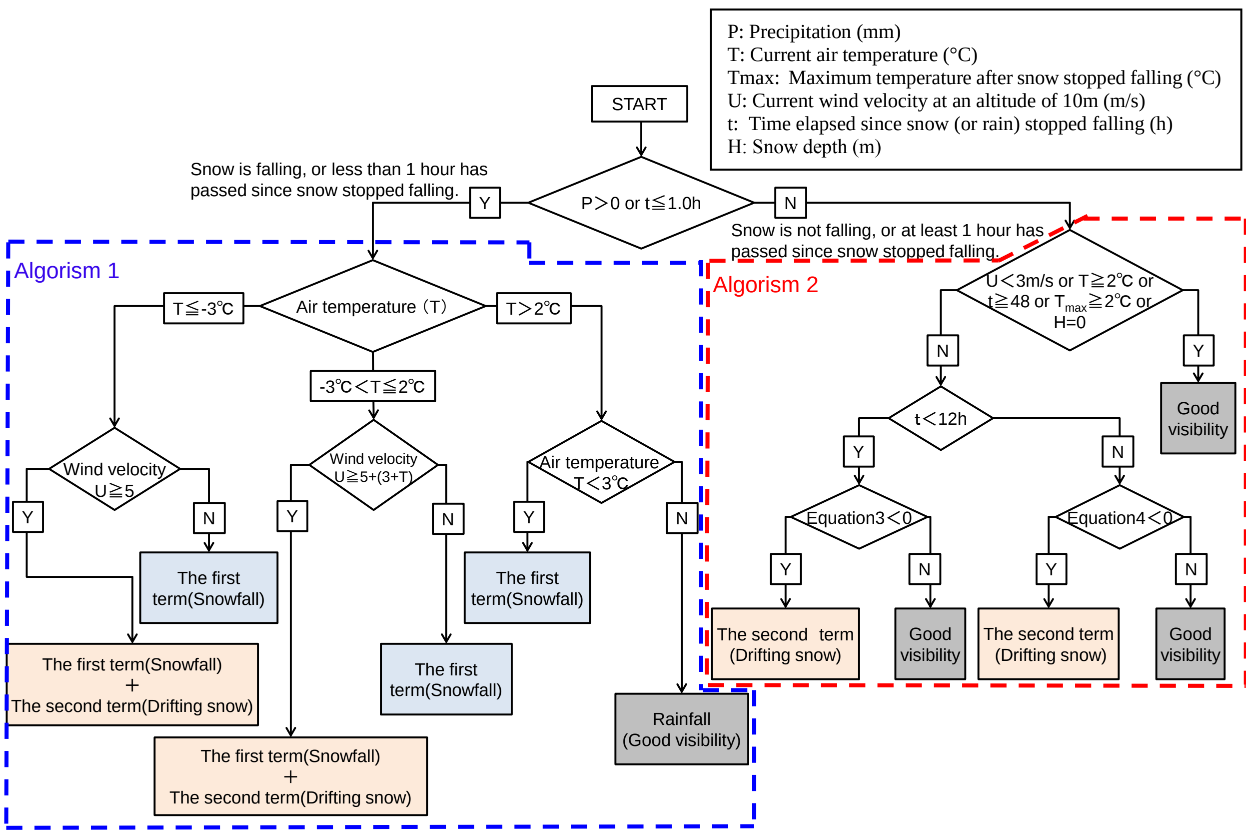
cars. In line with this, the visibility was calculated for the height of 1.2 m.
Snowfall intensity, P, was calculated using hourly snowfall Pn (mm/h) as follows:

$$P = 0.28 \cdot Pn \text{ (mm/h)}$$

In this study, the first term of Equation (2) is called "the snowfall term", and it represents the suspended-snow concentration derived from falling snow particles. The second term of Equation (2) is called "the drifting snow term", and it represents the suspended-snow concentration derived from drifting snow particles saltating from the snow surface.

Algorisms to Estimate Visibility during Snowstorms

First, using the algorisms(*16*) in Figure 1 and the meteorological data, two determinations are made at the site where visibility is estimated: whether the precipitation is rain or snow, and whether drifting snow occurs or does not occur in the absence of snowfall. Algorism 1 is used when there is snowfall, and Algorism 2 is used when there is no snowfall.



Twelve or more hours have passed since precipitation stopped.

$D = -0.59U + 0.20T - 0.08SF + 4.77$ ·····················(3)

Twelve or more hours have passed since precipitation stopped.

$D = -1.18U + 0.16T - 0.09t + 0.03Usum + 4.93$ ··········(4)

Where, U: Current wind velocity (m/s), T: Current air temperature (℃), SF: Snowfall amount from the start to the end of the snowfall event (cm), U_{sum}: Cumulative value of the fourth power of hourly wind velocity since snowfall stopped, divided by 1000, and t: Time elapsed after the end of snowfall (h).

FIGURE 1 Algorisms to determine whether drifting snow occurs

Algorisms to Estimate the Visibility under Snowstorms

Algorism 1 estimates the visibility during snowfall. When the air temperature is 2°C or lower, we use the formula proposed by Takeuchi et al. that is based on the drifting snow occurrence conditions(*17*). When the air temperature is higher than 2°C, it is assumed that drifting snow does not occur. Whether the precipitation is snow or rain is determined based on the snowfall event classifications for Sapporo(*18*) (central Hokkaido).

Algorism 1 has been used for our Internet service, Snowstorm Visibility Information System, since it started. However, because the algorism tends to overestimate the visibility when snow is not falling, we developed a new algorism to estimate the visibility when it is not snowing.

Algorisms to Estimate the Visibility when Snow is not Falling

Algorism 2 estimates the visibility when it is not snowing. Under the following conditions, drifting snow almost never occurs: 1) Current wind velocity < 3 m/s; 2) t ≥ 48 hours ; 3) T_{max} (the max. air temperature after snowfall stopped) ≥ 2°C; 4) current T ≥ 2°C; or 5) the snow depth is zero. In using Algorism 2, the events with these conditions are classified(*19*) into "Yes" ("Y" in Figure 1). Events whose conditions do not fall under any of these five conditions are sorted as "No" ("N" in Figure 1). Then, we determined whether drifting snow occurs by using equations (3) and (4), when it is not snowing(*19*). When equations (3) or (4) give a negative value, drifting snow occurs. The value of U_{sum} in Equation (4) is given as follows: The hourly wind speed after snow has stopped falling is raised to the fourth power, and the values calculated for each hour after snow has stopped falling are summed up. The sum is divided by 1,000.

$$Usum = \sum_{t=1}^{t} U_t^{\,4} \Big/ 1000 \qquad (5)$$

In Equation (5), *t* is a positive integer representing the number of hours (h) after snow has stopped falling.

Accuracy Verification

The accuracy of the visibility estimation method adopted for FY2014 was verified using observation data taken in Teshikaga Town in Eastern Hokkaido, Japan, by comparing the readings of a visibility meter with the current visibilities estimated using the FY 2014 method giving the observed data of precipitation, air temperature and wind velocity.

To verify accuracy, visibility is classified into the five ranks of visibility < 100 m; 100 m ≤ visibility < 200 m; 200 m ≤ visibility < 500 m; 500 m ≤ visibility < 1,000 m; visibility ≤ 1,000 m. These ranges were set based on research on the drivers' behavior during snowstorm(*20*).

Table 1 shows relationships between observed visibility and estimated visibility using the five classifications: Estimated visibility higher than actual visibility by at least two ranks (2-up); Estimated visibility is higher than actual visibility by one rank (1-up); estimated visibility is the same as observed visibility (hit); estimated visibility is lower than actual visibility by at least two ranks (2-down) and estimated visibility is lower than actual visibility by one rank (1-down). Their occurrence rates were calculated as follows:

The rate of 2-up = (C 31＋C 41＋C 42＋C 51＋C 52＋C 53) / *r*

The rate of 1-up = (C 21＋C 32＋C 43＋C 54) / *r*
Hit rate = (C 11＋C 22＋C 33＋C 44＋C 55) / *r*
The rate of 1-down = (C 12＋C 23＋C 34＋C 45) / *r*
The rate of 2-down: (C 13＋C 14＋C 15＋C 24＋C 25＋C 35) / *r*
Where, *r* represents the total number of observations.

TABLE 1 Hit Rates of Estimated Snowstorm Visibility

			Method of estimating visibility during snowstorm					Total
			1	2	3	4	5	
			< 100 m	100 - 200 m	200 - 500 m	500 - 1000 m	1000 m ≦	
Observed visibility	1	< 100 m	C11	C12	C13	C14	C15	
	2	100 - 200 m	C21	C22	C23	C24	C25	
	3	200 - 500 m	C31	C32	C33	C34	C35	
	4	500 - 1000 m	C41	C42	C43	C44	C45	
	5	1000 m ≦	C51	C52	C53	C54	C55	*r*

The results show that the hit rate (i.e., the share of "accurate") is 88.6%, which is reasonably accurate.

Arithmetic Processing of Snowstorm Visibility

The visibility calculation server outputs the current and forecast visibilities using the FY 2014 method of estimating visibility during snowstorms from input weather data obtained from the Japan Meteorological Agency. These weather data are precipitation intensity, air temperature and wind velocity of 5-km mesh data for every 3 hours until 33 hours after the current time, and the precipitation intensity of 1-km mesh data for the current time and for every 30 minutes until 6 hours after the current time(Figure 2).

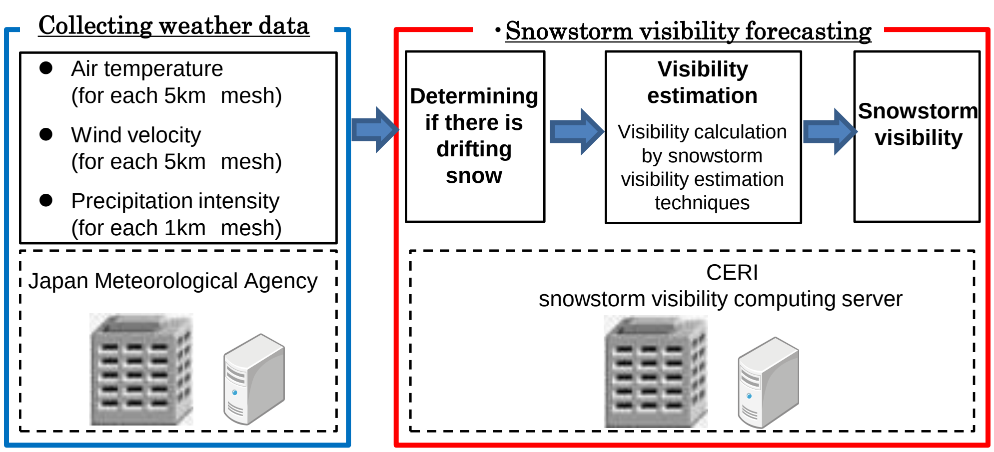


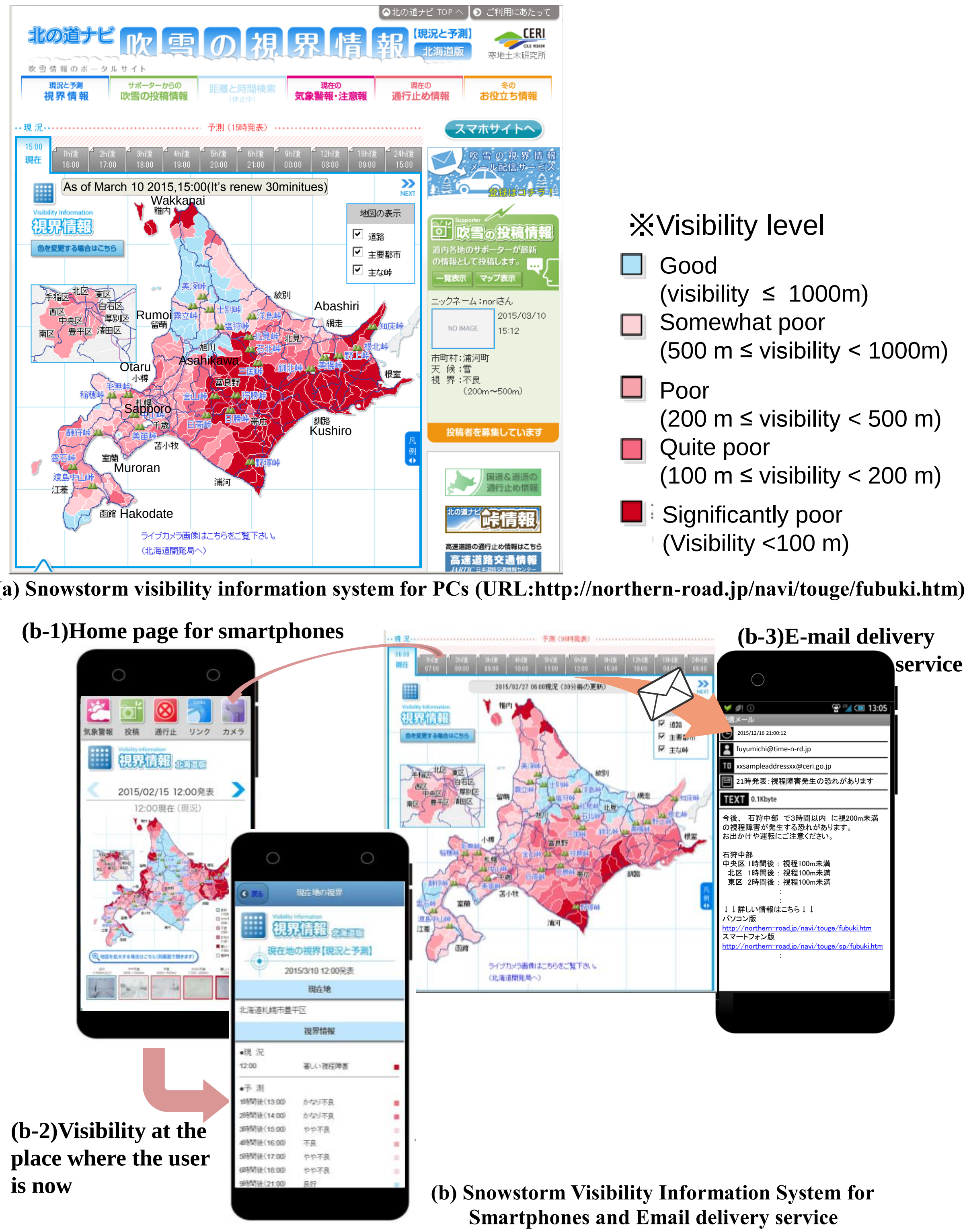
FIGURE 2 Algorism of calculation for determining current and forecast snowstorm visibility

FY2014 Outline of the Testing of a Snowstorm Information Service

From November 28, 2014 through May 7, 2015, the authors tested a snowstorm information service online. The test is outlined below.

Snowstorm Visibility Information System for PCs and Smartphones

On the website of the Snowstorm Visibility Information System for PCs, information has been provided since February 1, 2013, regarding 1) snowstorm visibility, 2) weather warnings and advisories, and 1) road closures (Figure 3 (a)).



(a) Snowstorm visibility information system for PCs (URL:http://northern-road.jp/navi/touge/fubuki.htm)

(b) Snowstorm Visibility Information System for Smartphones and Email delivery service

FIGURE 3 Overview of Snowstorm Visibility Information System

Information on current and forecast snowstorm visibility is provided. Snowstorm visibility is forecast with lead times of 1, 2, 3, 4, 5, 6, 9, 12, 18, and 24 hours, and the forecast values are updated every 3 hours. Current visibility is updated every 30 minutes. Hokkaido is divided into 221 areas, and information is provided for each of these areas. Visibility distances along arterial roads in each of the 221 areas are extracted from the mesh in which each area is located. The visibility in an area is defined as the 90th percentile of the visibility distances in order from longest to shortest. Degree of visibility is classified and color-coded in accordance with the aforementioned 5 levels (Figure 3(a)).

For the greater convenience of users, the Snowstorm Visibility Information System was made accessible from smartphones as of December 1, 2013 (Figure 3(b-1)), so that users can access the site when traveling or caught in a snowstorm. For the greater convenience of users who use the site during travel, the home page includes buttons for accessing information on weather warnings and advisories as well as on road closures. A new feature was added to the site for smartphones. By sending geolocation information to the Snowstorm Visibility Information System, users can check the visibility at their current location (Figure 3(b-2)).

E-mail Delivery Service

On December 20, 2013, an e-mail delivery service was started in order to warning users of poor visibility in advance. This is a push-type (i.e., automatic) delivery service (Figure 3(b-3)). Users who have registered their e-mail addresses and conditions for automatic e-mail delivery (Table 2) receive e-mails informing them of poor visibility forecasts when the registered conditions are met.

TABLE 2 Conditions for Automatic E-mail Delivery

Item	Outline
Area	The user selects areas for poor visibility forecasts. (Multiple selections are possible.) Hokkaido is divided into 46 areas.
Delivery time of day	The user chooses the delivery times from two options: 6 times a day (at 6:00, 9:00, 12:00, 15:00, 18:00, and 21:00) or 4 times a day (at 9:00, 12:00, 15:00, and 18:00).
Poor visibility conditions	The user selects the poor visibility conditions for e-mail delivery from three options: visibility less than 500m, less than 200m, or less than 100m.
Hours for poor visibility forecasting	Users select either 3 hours or 6 hours from the present for poor visibility forecasts.

User Traffic for the Snowstorm Visibility Information System

Figure 4 shows the number of visits to the Snowstorm Visibility Information Service website between November 2014 and March 2015. The daily mean of page views was more than 4,000. On December 17, 2014 when the Meteorological Agency announced that a severe snowstorm of a scale experienced only once in several years was headed to Hokkaido, the number of page views exceeded 30,000. It is likely that users visited the Snowstorm Visibility Information System in order to determine what actions to take.

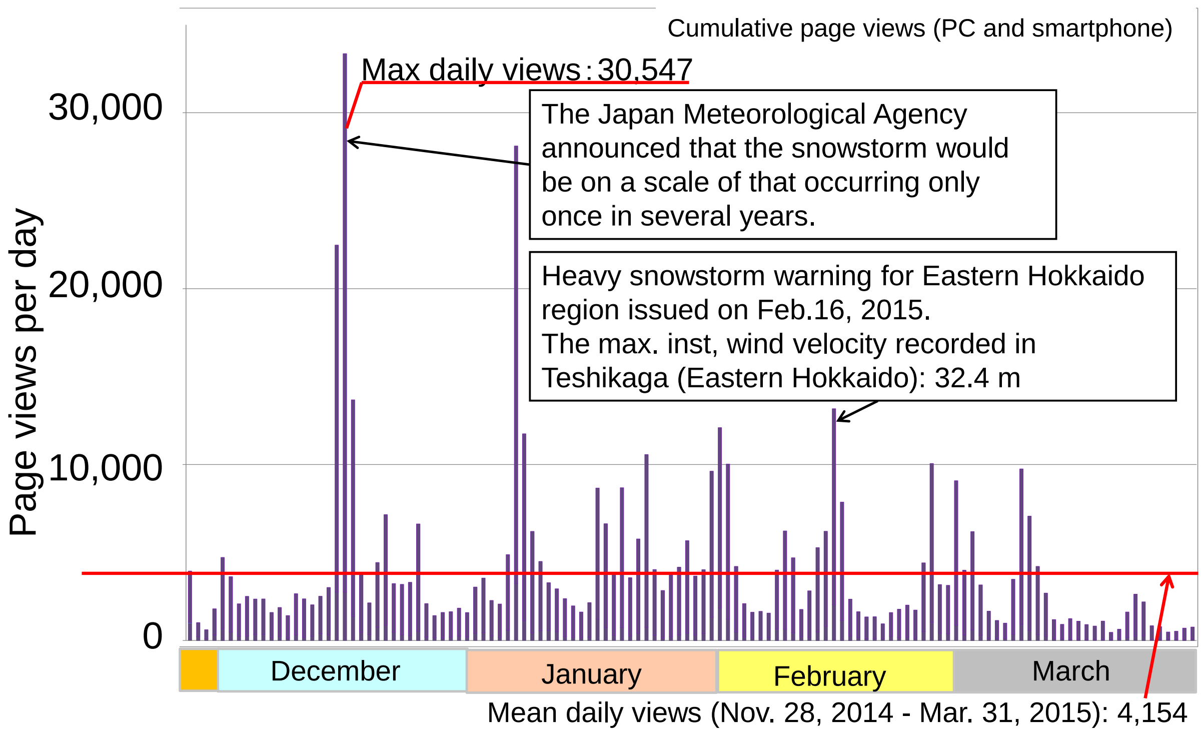


FIGURE 4 Page views of the Snowstorm Visibility Information System

QUESTIONNAIRE SURVEY

Questionnaire surveys were conducted to determine the effectiveness of the snowstorm visibility information service and the e-mail delivery service.

Questionnaire Survey on Visibility Information Provision When a Snowstorm Warning is Issued

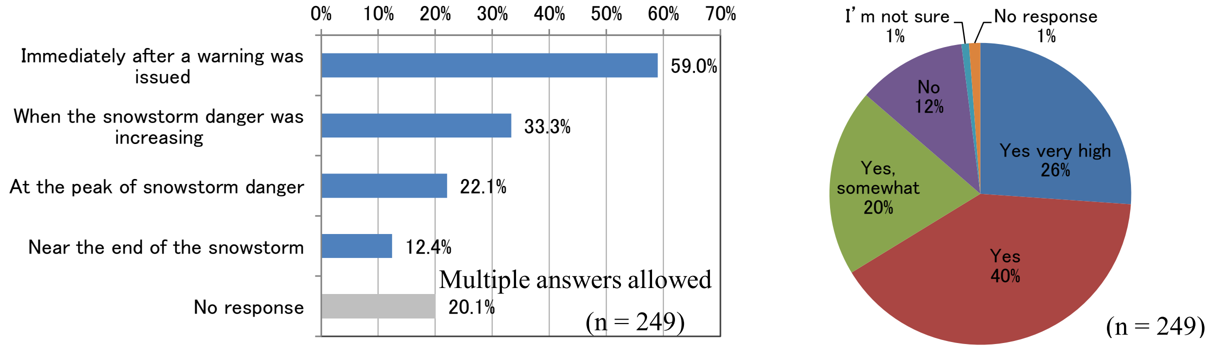
Outline

From February 14 through 16, 2015, the Japan Meteorological Agency issued heavy snowstorm warnings for Eastern Hokkaido. A questionnaire survey was conducted online among the users of both the PC system and the smartphone system of the Snowstorm Visibility Information System about how they used the system. There were 349 responses. The snowstorm had a maximum wind speed of 22 m and a maximum instantaneous wind speed of 32.4 m in Teshikaga Town in eastern Hokkaido, and a 24-hour snowfall of 32 cm in Nakashibetsu Town in eastern Hokkaido. From the respondents, we chose the 249 respondents who mainly use the roads in the warning-issued area.

Results

Figure 5(a) shows the responses to the question "When did you use the Snowstorm Visibility Information System between the issuance of the snowstorm warning and the end of the snowstorm?" 59% responded "Immediately after the warning was issued". The Japan Meteorological Agency usually issues such warnings a few hours ahead of the event(*21*); therefore, the system may have been actively used a few hours ahead of the event.

To the question "Did the information provided by the Snowstorm Visibility Information System increase your awareness of danger?", 86% responded "Yes, very much", "Yes " or "Yes, somewhat"(Figure 5(b)).



(a) When respondents use Snowstorm Visibility Information System

(b) Increases in danger awareness as a result of using the Snowstorm Visibility Information System

FIGURE 5 Questionnaire survey on information provision when a heavy snowstorm warning is issued

Questionnaire Survey on the Snowstorm Visibility Information Services During the FY2014 Winter

Outline

From April 20 through May 20, 2015, a questionnaire survey was conducted online among PC and smartphone users of the Snowstorm Visibility Information System. A total of 483 people responded.

Results

Figure 6(a) shows satisfaction of people who accessed the Snowstorm Visibility Information System from PCs or smartphones. To the question "How satisfied are you with the services provided by the Snowstorm Visibility Information System?", 86% responded "very satisfied", "satisfied" or "fairly satisfied". Of those responded either "very unsatisfied," "unsatisfied" or "fairly unsatisfied", some respondents answered the open-end question on reasons for dissatisfaction as follows: "The accuracy of the visibility forecast provided by the PC site is too low" and "The view on the smartphone site cannot be enlarged by swiping and the site is difficult to read".

Figure 6(b) shows responses concerning users' perceptions of differences between forecast visibility and encountered visibility. Of 409 respondents, 257 (63%) reported not noticing differences between forecast visibility and encountered visibility. 24% of the respondents reported that the encountered visibility was higher than the forecast visibility by at least two visibility levels, and 13% of the respondents reported that the encountered visibility was lower than the forecast visibility by at least two visibility levels.

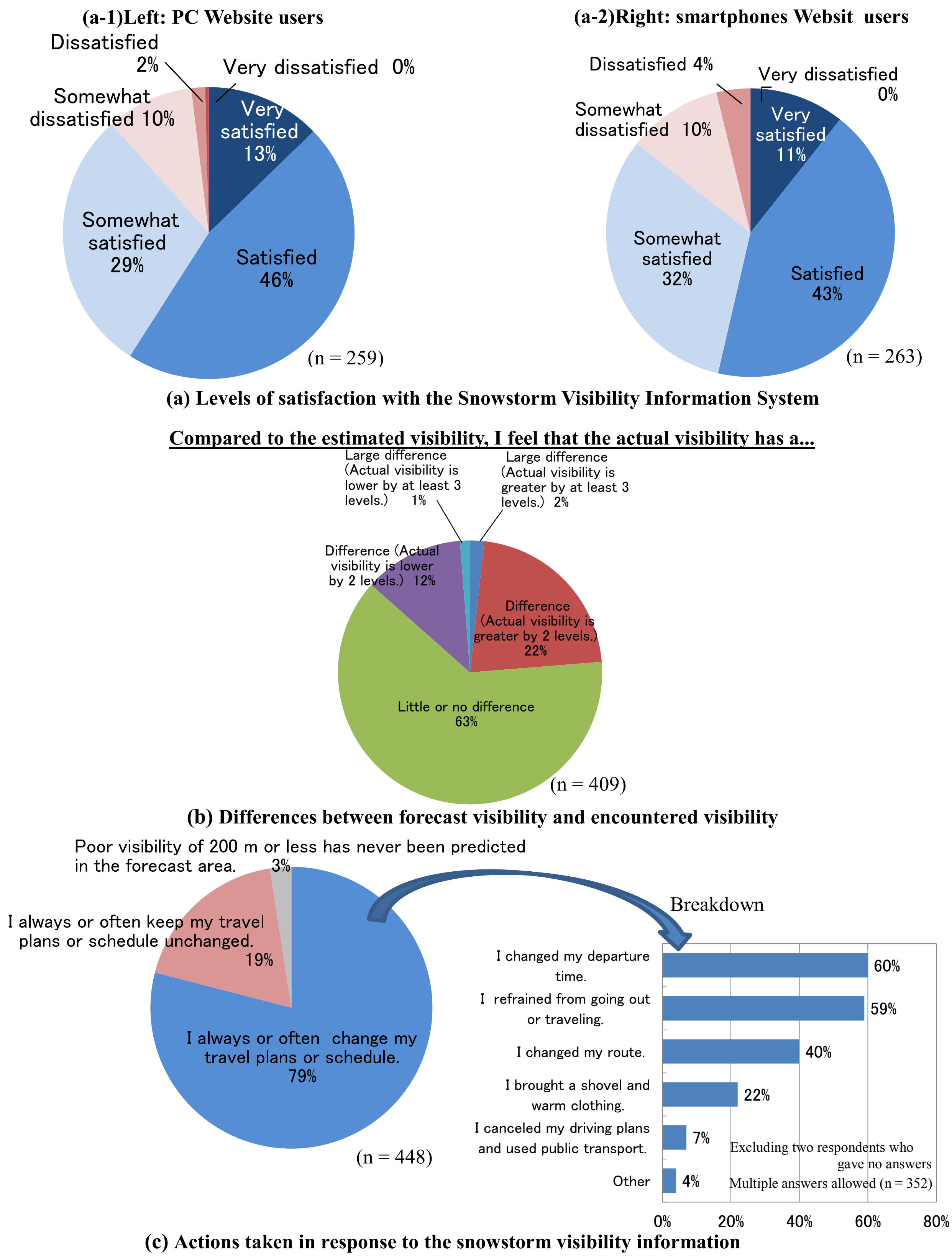


FIGURE 6 Questionnaire survey on the snowstorm visibility information services during the FY 2014 winter

Figure 6(c) shows responses to the question, “How likely is it for you to change your schedule or travel plans when poor visibility of less than 200 m is predicted by the Snowstorm Visibility Information System?" Of the 448 respondents, 354 (79%) answered that “It is very likely for me to change my schedule or travel plans". Of these respondents, 211 people (60%) reported changing their departure time, and 209 people (59%) reported refraining from going out or traveling. This indicates that users change their plans based on the snowstorm information.

Questionnaire Survey on the E-mail Delivery Service during the FY 2014 Winter

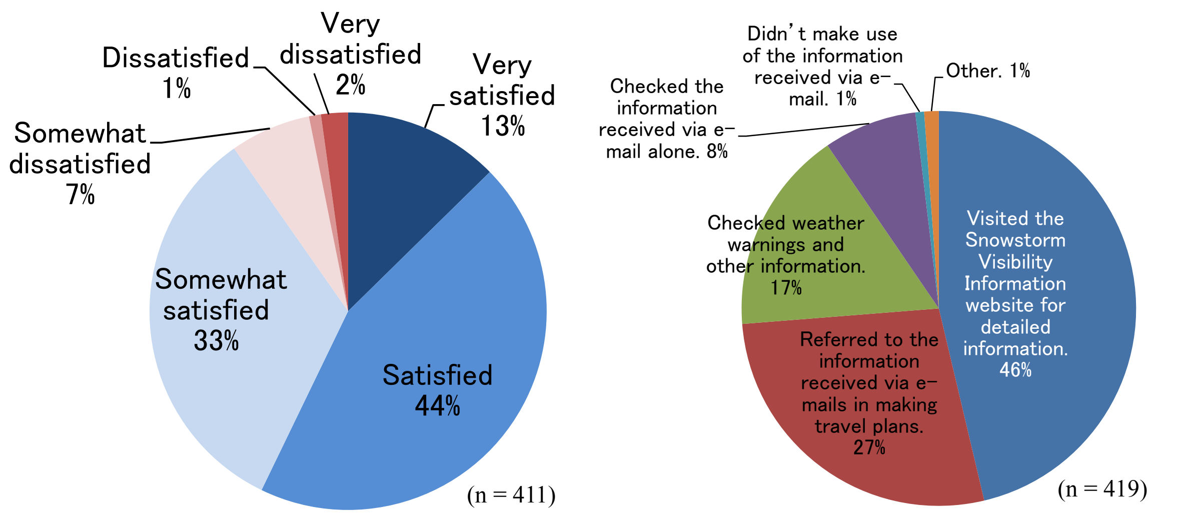
Outline

From April 7 through May 20, 2015, a questionnaire survey on the e-mail delivery service was conducted online among PC system and smartphone system users of the Snowstorm Visibility Information System. A total of 425 users responded.

Results

Figure 7(a) shows the satisfaction levels of users. For the question "How satisfied are you with the e-mail delivery services?" most respondents (90%) reported being “very satisfied”, “satisfied” or “somewhat satisfied”. Thus, users valued the e-mail delivery service. Among those responded "very unsatisfied", "unsatisfied" or "fairly unsatisfied", some respondents answered the open-end question on reasons for dissatisfaction as follows: "The visibility forecast accuracy is too low".

Figure 7(b) shows responses to the question, "How did you make use of the e-mail information?" The answers suggest that users actively seek information after receiving e-mails. For example, 194 people (46% of the respondents) visited the Snowstorm Visibility Information System, and 70 people (17%) checked weather information.



(a) Satisfaction with the e-mail delivery service **(b) Actions taken after receiving e-mails**

FIGURE 7 Questionnaire on the e-mail delivery service

SUMMARY

With the aim of supporting drivers' decision-making during snowstorms, the authors conducted tests on road users who were provided with snowstorm visibility information. The information provision was confirmed to be useful, as summarized below.

(1) The questionnaire survey on the use of system revealed that many users start using the Snowstorm Visibility Information System immediately after the meteorological agency issues a snowstorm warning.

(2) The questionnaire survey on the services during FY 2014 winter showed that users of the Snowstorm Visibility Information System change their travel plans based on the website's information.
Most of the respondents reported changing their departure times, refraining from departing or using alternative routes.

(3) The results of another questionnaire survey showed that users of the e-mail delivery service actively seek related information after receiving e-mails about poor visibility.

However, the accuracy of snowstorm visibility forecast is not high enough. The authors will work on enhancing the forecast prediction accuracy.

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