Investigation of Road Visibility Conditions using Precipitation Intensity measured by Weather Radar during Winter Seasons

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Abstract: In Hokkaido, Japan, in winter, poor road visibility occurs due to snowstorm and snowfall, the risk of traffic restriction and crash increases. Snowfall information along the road is necessary to contribute to road safety. Aim of the present study is to explore applicability of precipitation intensity measured by XRAIN as snowfall information on the road. We investigated relationship between precipitation intensity and value of the WIPS measured by the CCTV Camera which shows road visibility conditions using cross-correlation analysis. As a result, under snowfall and snowstorm conditions, it was revealed that road visibility could be estimated by precipitation intensity. Whereas, time series of values of the WIPS and precipitation intensity was different under strong wind and slightly snowfall condition. In this case, it was also revealed that we should consider advection of snow particles in the air.

Keywords: Poor road visibility, Precipitation intensity, XRAIN, Value of the WIPS, Cross-correlation

1. INTRODUCTION

1.1 Background

In Hokkaido, Japan, poor road visibility frequently occurs due to snowstorm during winter season, and the risk of traffic restriction and crash increases (2001, 2006). Poor road visibility suddenly occurs and changes rapidly, quantitative evaluation is difficult. In the actual situation of winter road maintenance is supported by road administrator’s experience and hunch, who is familiar with regional weather condition. Evaluating poor road visibility in real-time would be minimize the risk and aid to judgement of driver’s behavior (2005, 2018, and 2022).

Prior researches about weather and traffic, in the United States of America, Maze, T. H. et al. introduced research results and literatures about the effects of traffic demand and safety due to weather conditions (2006). Ting et al. developed framework to analyze effects of driver’s behavior on highway under severe winter weather condition, and indicated usefulness evaluation using framework (2015). In Canada, K. C. Dey et al. considered possibility of ITS innovation takes in various data sources to minimize effects of road weather condition (2015). In Hokkaido, Japan, Nagata and Hagiwara et al. (2006) evaluated winter road visibility conditions used by value of the Weighted Intensity of Power Spectra (hereinafter WIPS) measured by the Closed-circuit Television (hereinafter CCTV) Camera, and developed visibility inspection system for road administrator. Nagata and Hagiwara et al. (2006) revealed a high correlation between 15-level visibility evaluation indexes obtained from value of the WIPS and visibility evaluation by human eyes. Nakamura et al. (2018) detected poor road visibility due to snowstorm using value of the WIPS measured by the CCTV camera installed along National Route (hereinafter NR) 244 and NR 272 in Hokkaido. When snowfall wasn't observed, value of the WIPS and weather data could evaluate poor road visibility occurred by strong wind. Next, Nakamura et al. evaluated road visibility condition using values of the WIPS measured by the CCTV camera and on-board camera installed on the road patrol vehicle to generate road visibility information as a route (2020, 2022). The result showed positive correlation between value of the WIPS measured by on-board camera and driver's subjective visibility. In addition, value of the WIPS by on-board camera indicated the section where poor road visibility condition may occur due to snowstorm. However, driving frequency of road patrol vehicle is limited. Evaluating and estimating poor road visibility condition in real-time are necessary. At this time, observation points by Automated Meteorological Data Acquisition System (hereinafter AMeDAS) are limited, using snowfall information with high spatio-temporal resolution is desirable.

Precipitation intensity observed by weather radar might be available as snowfall information with high spatio-temporal resolution. Weather radar could observe precipitation intensity with high spatio-temporal resolution. In Finland, precision for the amount value of snowfall estimated by weather radar was verified by comparing observed snowfall value from Europe gauge (2015). In Japan, since 2016, the X-band multi-parameter radar network (hereinafter XRAIN) for river maintenance and prevention activities such as landslide has developed by the Ministry of Land, Infrastructure, Transport and Tourism (hereinafter MLIT) (2017). XRAIN could observe precipitation per 250-meter square grid mesh every 1-minutes, road visibility evaluation in detail might be possible. In Hokkaido, Japan, Omiya et al. (2022) considered the possibility to evaluate snowstorm in real-time on the ground using XRAIN. It is noted that real-time precipitation intensity by XRAIN is based on observation of particles in the air, this research didn't deal in drifting snow on the ground.

1.2 Objective

Aim of the present study is to explore applicability of precipitation intensity by XRAIN as snowfall information along the road to evaluate poor road visibility condition due to snowfall and snowstorm. Using cross-correlation analysis, we investigated relationship between precipitation intensity measured by XRAIN and value of the WIPS measured by the CCTV Camera which shows road visibility conditions. In winter, road visibility can be changed by blowing snow due to strong wind even when snowfall is light. Therefore, wind velocity and wind direction data from AMeDAS are also used to consider the road visibility change effected by wind.

2. A METHOD FOR IVVESTIGATION OF THE TIME VARIATION BETWEEN WEATHER CONDITIONS AND VISIBILITY CONDITIONS ON THE ROAD

2.1 Investigate Road Section and Time Period

In Haboro area, a 22-km/section of NR 232 from 56.0 kilometer post (hereinafter K.P.) to K.P. 78.0 was selected for investigation. Fig. 1 shows a map of the 22-km/section on NR 232, the locations of K.P., CCTV cameras, and AMeDAS. In Haboro area, when the winter pressure pattern weakens, a small low-pressure system or convergence zone develops around the west coast of Hokkaido. When winter atmospheric pressure pattern, poor road visibility due to the winds from various directions and developed snow clouds may be occurred. The west side of the road is the ocean. When the wind from west is strong, snowstorm might be occurred. Table 1. shows average air temperature, average wind velocity, and major wind direction of each of 11 time periods during two winter seasons. These 11 time periods have a greater chance of occurring poor visibility caused by snowstorm (wind velocity was over 6.0 (m/s), and major wind direction was west). There was a high possibility that wind velocity would increase and that snowstorms would cause poor visibility.

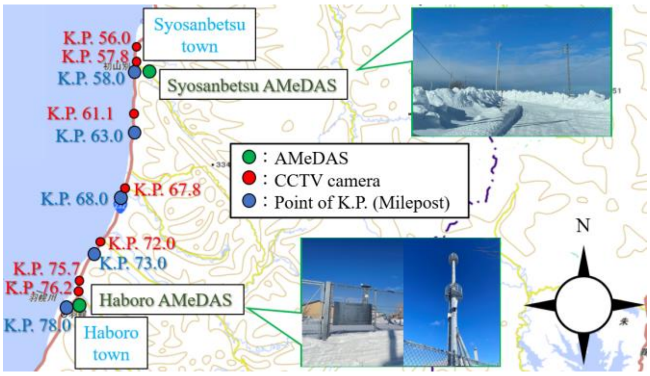


Fig. 1 Map of the 22-km/section in Haboro area included the 22 km/section of NR 232

Table 1. Time Periods under Poor visibility was Likely to Occur due to Snowstorm

MM/DD/YY	No.	Time Period	Average Temperature (°C)	Average wind velocity (m/s)	Major wind direction
Dec. 26, 2020.	1	12:00-16:00	-5.7	10.5	West-Northwest
Dec. 27, 2020.	2	11:00-15:00	-4.5	8.0	West or West-Northwest
Dec. 29, 2020.	3	10:00-14:00	-5.4	9.7	West
Dec. 31, 2020.	4	12:00-13:30	-7.2	3.3	South-Southeast
	5	13:40-16:00	-6.6	11.9	West-Northwest
Dec. 28, 2021.	6	10:00-11:00	-9.4	1.8	East-Southeast
	7	11:10-14:00	-4.7	7.6	West-Northwest
Dec. 30, 2021.	8	8:00-12:00	-2.5	6.0	West-Northwest
Jan. 29, 2022.	9	11:00-15:00	-4.8	7.6	West or West-Southwest
Feb. 3, 2022.	10	12:00-13:20	-4.1	3.0	Nort or North-Northeast
	11	13:30-16:00	-3.6	6.8	Northwest

2.2 Collecting Weather and Visibility Data for Investigation

2.2.1 Precipitation intensity of XRAIN (mm/h)

The present study, we applied precipitation intensity measured by XRAIN as snowfall information on the road. XRAIN was developed by MLIT as precipitation observation system. We downloaded precipitation intensity data from “MLIT XRAIN CXMP composite dataset” in Data Integration and Analysis System (hereinafter DIAS) (2017). This dataset consists of “MLIT X-band multi-parameter radar” and “C-band multi-parameter radar” and provides precipitation intensity per 250-meter square grid mesh every 1-minutes. The present study, we used precipitation intensity per 1-kilometer square grid mesh instead of 250-meter one. Fig. 2 shows the location of the Hakodake radar station close to the 22-km/section on NR 232 and 10-kilometer square grid mesh in Haboro area included the 22-km/section. The 10-kilimeter square grid meshes (Fig. 3) consist of 100 1-kilometer square ones to provide precipitation intensity.

The observation of precipitation intensity by XRAIN is based on rain particle in the air. In winter, most particles in the air are snow. The size of snow particle is smaller than that of rain one, reflection intensity by weather radar under snowfall might be different from under rainfall. In addition, considering advection of snow particles and falling velocity from the air is necessary. Table 2. shows elevation angles in winter season at Hakodake radar station. Altitude of winter snow clouds are lower than summer clouds, elevation angles in winter season has been changed from November, 2021. The brackets degree in Table 2 represents winter elevation angles. The relationship between size and shape of snow particles is unclear, and falling velocity of snow particles ranges from 1.0 to 4.0 (m/s). When snowfall was observed by the mesh just above the road, considering advection and falling velocity, time lag from 5 to 15 minutes might be occur until snowfall reflected on the ground (2019). Non-vertical fall of snow particle in winter tends to make time lag large (2022). When a time lag increases, observed data by XRAIN might be different from actual snowstorm condition on the ground. The present study, to minimize effects of the difference due to time lag as much as possible, average value from before 10-minutes to the current time is used as represented precipitation intensity at the current time. When using precipitation intensity by XRAIN as snowfall information for winter snow evaluation, reflection intensity of radar and advection of snow particles are issues.

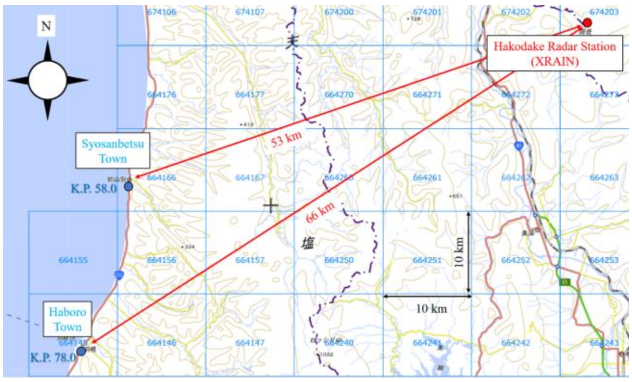


Fig. 2 Map of the radar station and 10-km/square grid mesh in Haboro area

Table 2. Angle of Elevation in Winter Season

Angle of Elevation		Altitude	Height from Ground
θ0	θ1	Hakodake：1,129(m)	1,251(m)：0.1°
0.1°	0.4°	Weather Radar：1,149(m)	1,569(m)：0.4°
(-0.4°)	(0.1°)		729(m)：-0.4°

2.2.2 Still images captured by the CCTV camera

MLIT installs CCTV cameras about 8 to 10 meters above the road for monitoring road and weather conditions. In the 22-km/section of NR 232, there are seven CCTV cameras. Table 3. shows the main specifications of CCTV cameras. Currently, HD quality (1280×720) is standard for CCTV cameras in Japan. CCTV cameras in Haboro area are SD quality (720×480). CCTV camera records the video images continuously and transmitted via the fiber-optic network independently maintained by MLIT to the road maintenance office. Road administrators could confirm video images directly (2006). Still images by the CCTV camera used in the present study were captured at 5-minute intervals from video images. Therefore, if road visibility condition changed in 5-minute rapidly, it might be difficult to evaluate visibility condition in a few minutes from still image. Poor road visibility may occur suddenly and rapidly, we recognize as an issue that time resolution of still image is 5-minute. The glass side in front of CCTV camera case is equipped with wipers and defrosters to prevent from adhesion of snow/ice. The present study, still images captured by CCTV cameras at K.P. 67.8 and K.P. 72.0 were used for road visibility evaluation. These two cameras hardly occurred adhesion of snow/ice and almost hasn't been changed the shooting direction in winter season. Other five cameras sometimes occurred heavy adhesion of snow/ice and changed the shooting direction in winter season.

Table 3. Main Specifications of CCTV Cameras

Image Sensor	Veneer CCD (Color)
Valid Pixels	About 380,000 pixels or more
Definition	Horizontal: 480 or more
S/N	47dB or more
Minimum Illuminance Level	Electronic Sensitivity OFF: 0.4 lux or less Electronic Sensitivity ON: 0.007 lux or less
Camera Case	Installed Wiper and Defroster

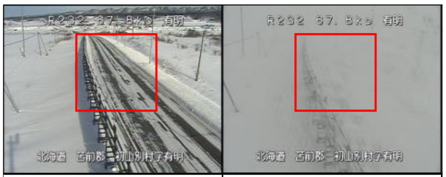
2.2.3 Temperature, wind velocity, and wind direction measured by Haboro AMeDAS

Haboro AMeDAS locates near Haboro town. It has been observed air temperature, wind velocity and wind direction every 10-minutes. Observation points of AMeDAS are limited, evaluating weather condition along the road accurately is difficult. However, there is no observed weather data about temperature, wind velocity and direction with high spatio-temporal resolution rather than AMeDAS in the target area. The present study, weather data observed by Haboro AMeDAS was used. Table 1. shows average value of air temperature, wind velocity, and major wind direction during each of 11 time period.

2.2.4 Value of the Weighted Intensity of the Power Spectrum (WIPS)

The present study, we adopted value of the WIPS as road visibility assessment index developed by Hagiwara et al. (2006). Value of the WIPS represents the difference in spatial frequencies within the still image based on the human contrast sensitivity function. Positive correlation between driver's subjective visibility and value of the WIPS was revealed (2020). We considered value of the WIPS could evaluate road visibility condition. Snowstorm and fog are major factors of poor road visibility. Value of the WIPS focused on subjective visibility evaluation by human eyes, so it doesn't classify the factors of poor road visibility.

The followings are image processing method for calculation value of the WIPS (2006). First, still image was captured from CCTV camera every 5-minutes. Second, a two-dimensional image of 256×256 pixels was cropped from still image. Third, the grayscale intensity of each pixel was calculated from the intensities of the red-green-blue (RGB) components recorded in the two-dimensional image. The grayscale intensity ranges from 0 to 255. Fourth, the image was broken into sinusoidal gratings of different spatial frequencies using the two-dimensional fast Fourier transform (hereinafter FFT). The power spectrum value computed by FFT corresponds to the amplitude of the spatial frequency for each cycle per degree. At the final step, the power spectrum intensities in the range of 1.5 to 18 cycles per degree were summarized. In Fig. 3, under clear road visibility conditions, the power spectra for each spatial frequency component of the still image are great and value of the WIPS is large. Under poor road visibility conditions, such as those in fog or snow, the power spectra are small. As a result, value of the WIPS is small.



WIPS: 11.3	WIPS: 6.9

Fig. 3 Values of the WIPS and visibility conditions

2.3 Cross-Correlation between Precipitation Intensity and Value of the WIPS

Cross-correlation is used to know the closeness of the relationship between two variables in the form of time series data (2021). In the relationship between two time series (y_i and x_i), the series x_i may be related to past time lag (τ) of the x-series. We calculated the cross-correlation between two time series variables, precipitation intensity and value of the WIPS, where $\tau = -\tau_{max}, \ldots, \tau_{max}$ represents the time lag. Cross-correlation is ranged from -1.0 to +1.0, where zero indicates no relationship between the two variables. In the present study, we adopted value of the WIPS as y_i and precipitation intensity as x_i. Cross-correlation was calculated by equation (1). When one or more $x_{i+\tau}$, with τ negative, are predictors of y_i, it is that x leads y. When one or more $x_{i+\tau}$, with τ positive, are predictors of y_i, it is that x lags y.

$$C(\tau) = \frac{\sum_{i=1}^{N-\tau} (x_i - \bar{x})(y_{i+\tau} - \bar{y})}{\sqrt{\left\{\sum_{i=1}^{N} (x_i - \bar{x})^2\right\}\left\{\sum_{i=1}^{N} (y_i - \bar{y})^2\right\}}} \tag{1}$$

$C(\tau)$: Cross-correlation
τ : Time lag (min.)
N : i=1 to N, Number of data
x_i : Precipitation intensity (mm/h)
y_i : Value of the WIPS
$\bar{x}$: Average value of the precipitation intensity
$\bar{y}$: Average value of the WIPS

The present study, we supposed a linear relationship between two variables, and adopted cross-correlation for analysis. The time period for calculating the cross-correlation was set to 1 hour. Number of data: N in Equation 1 was 12. We explored time zone of each of 11 time periods when the precipitation intensity became strong, and determined time when the precipitation intensity became peak within the time zone. One hour period for calculating cross-correlation was set from 30 minutes before the peak time to 30 minutes after the peak time. Then, $-\tau_{max}$ is -60 (min.) and τ_{max} is 60 (min.). If there were multiple time zones of the precipitation intensity, the cross-correlation was calculated per each of multiple time zones.

In calculating cross-correlation, unit of the time lag between two variables was set to 5-minutes due to data limitation. Precipitation intensity by XRAIN is observed every 1-minute. While, still image by the CCTV camera captured every 5-minute from video image. Therefore, still image couldn't be captured from CCTV camera continuously. Time interval alignment in two variables is necessary to calculate cross-correlation. To align observation condition between two variables as much as possible, time interval was 5-minute. For example, value of the WIPS calculated from still image captured by the CCTV camera from 8:25 to 8:30 as representative value at 8:30. Likewise, average precipitation intensity from 8:21 to 8:30 as representative value at 8:30. Next, value of the WIPS calculated from still image captured by the CCTV camera from 8:30 to 8:35 as representative value at 8:35. Likewise, average precipitation intensity from 8:26 to 8:35 as representative value at 8:35. In this way, time interval was 5-minute, the present study calculated cross-correlation.

In addition, we conducted visual confirmation for still images by the CCTV camera to prevent from difference between value of the WIPS and actual road visibility condition. By conducting visual confirmation, we considered that still image and value of the WIPS show actual road visibility condition. When we evaluate actual road visibility condition, how to deal with both observation data should be considered as an issue. To further improve the observation accuracy and fully understand the relationship between precipitation intensity and value of the WIPS, we also recognize that additional analysis is needed.

3. RELATIONSHIP BETWEEN WEATHER CONDITIONS AND VISIBILITY CONDITIONS

We tried to investigate applicability of precipitation intensity by XRAIN as snowfall information on the road. Cross-correlation was applied to investigate relationship between precipitation intensity by XRAIN and value of the WIPS by the CCTV camera. This section shows detailed results for the four time periods which are as follows:

・No. 2 time period on December 27, 2020
・No. 4 and No. 5 time periods on December 31, 2020
・No. 9 time period on January 29, 2022

From Fig. 4 to Fig. 9, for each of the four time periods contain the following three graphs and weather maps.
1) Two Line charts: Above line chart in Fig. 4 (a) to Fig. 9 (a) shows the time series of wind velocity, and major wind direction. Below line chart in Fig. 4 (a) to Fig. 9 (a) shows the time series of precipitation intensity and value of the WIPS. The large value of the vertical axis shows strong wind velocity and large precipitation intensity. It should be noted that large value of the WIPS means poor road visibility condition. Red points on line of value of the WIPS show still images in Fig. 4 (b) to Fig. 9 (b).
2) Still images: To understand actual road visibility condition, Fig. 4 (b) to Fig. 9 (b) show still images captured by the CCTV camera corresponded to red points on line chart of value of the

WIPS. Red boxed frame on the still image shows a two-dimensional image of 256×256 pixels cropped from still image.
3) Bar charts: Bar charts shown in Fig. 5 (c) to Fig. 9 (c) are results of cross-correlation between precipitation intensity and value of the WIPS. The vertical axis shows the cross-correlation, the horizontal axis shows time lag. The white bar shown in Fig. 5 (c) to Fig. 9 (c) was the highest cross-correlation.
4) Weather maps around Hokkaido: Fig. 4 (d) to Fig. 9 (d) show weather maps in each day around Hokkaido, Japan. Left weather map shows at 9:00 (JST). Right one does at 21:00 (JST).

3.1 No. 2 Time period on December 27, 2020.

In this time period, precipitation intensity was slight although strong wind. At K.P. 67.8, precipitation intensity continued almost 0.0 (mm/h). We could confirm clear road visibility conditions at four still images in Fig. 4 (b). Time series of value of the WIPS was flat and continuously showed clear visibility conditions.

At K.P. 72.0, from 11:00 to 12:30, precipitation intensity was under 0.5 (mm/h). We could confirm slightly poor road visibility condition from No. 2 still image in Fig. 5 (b). In Fig. 5 (c), from 11:35 to 12:35 (CC-1), the sign of the highest cross-correlation was negative and time lag was 5.0 (min). Value of the WIPS moved in synchronization with precipitation intensity.

According to weather map shown in Fig. 4 (d) and Fig. 5 (d), a low pressure moved away from Hokkaido through the night. In the day time, there was a low pressure around Hokkaido, poor road visibility might be occurred due to snowstorm. However, from these results, snowstorm didn't occur and road visibility condition was clear on December 27, 2020.

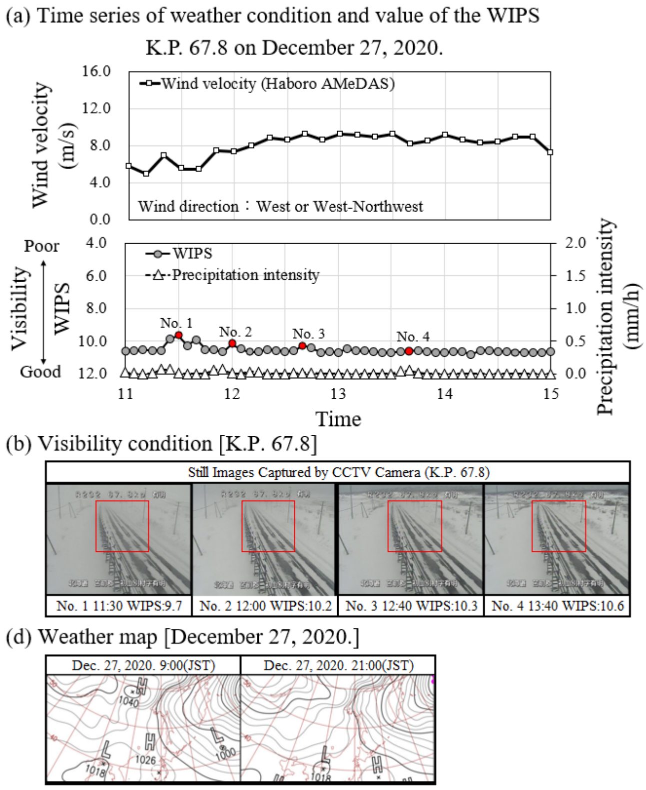


Fig. 4 Time series of weather and visibility conditions at K.P. 67.8 on December 27, 2020.

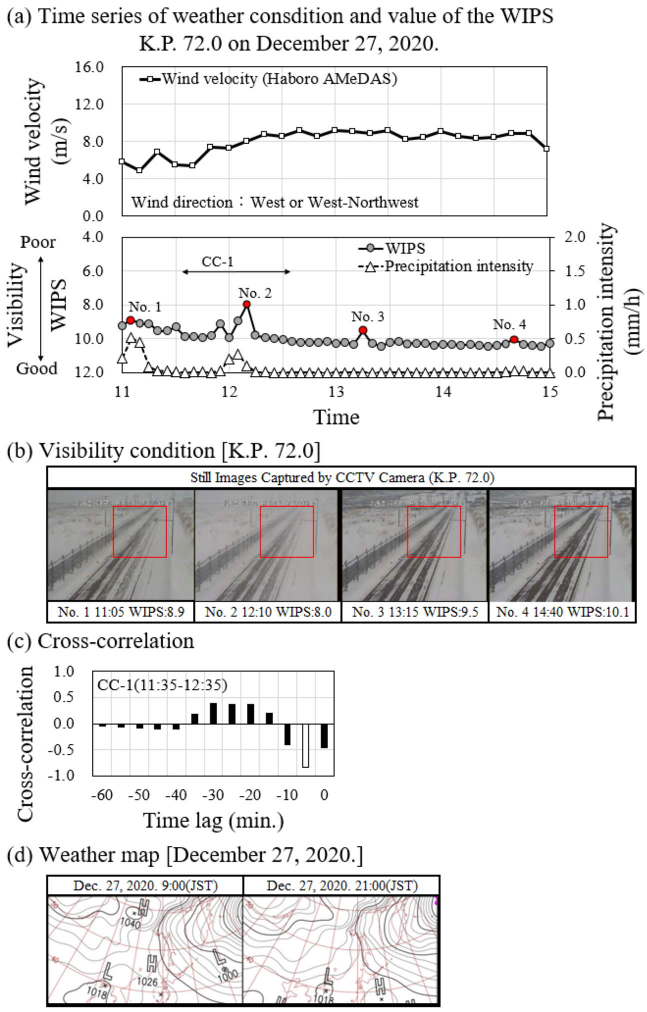


Fig. 5 Time series of weather and visibility conditions at K.P. 72.0 on December 27, 2020.

3.2 No.4 and No. 5 time periods on December 31, 2020 at K.P.67.8.

In No. 4 time period, wind velocity wasn't strong and wind direction was South. At K.P. 67.8, from 12:00 to 13:15, precipitation intensity was almost 0.0 (mm/h). The time series of value of the WIPS was flat and road visibility conditions were clear.

After, in No. 5 time period, wind velocity increased in two times. Wind direction changed from West. From 13:20 to 14:00, precipitation intensity was about 1.5 (mm/h). We could confirm very poor road visibility condition from No. 2 still image in Fig. 6 (b). From 14:00 to 15:00, time series of precipitation intensity and value of the WIPS didn't move in synchronization. At 14:30, precipitation intensity was almost 0.0 (mm/h), value of the WIPS was 6.0. We could confirm very poor road visibility condition from No. 3 still image in Fig. 6 (b). At this time, wind velocity was over 12.0 (m/s). There were much fresh snow particles on the ground due to snowfall observed by XRAIN. After the snowfall, by the change in wind velocity and direction, poor road visibility occurred due to snowstorm. In Fig. 6 (c), from 13:10 to 14:10 (CC-1), the sign of the highest cross-correlation was negative, and time lag was 10.0 (min.). Value of the WIPS moved in synchronization with precipitation intensity.

From 14:40 to 15:30, precipitation intensity increased again (1.5 (mm/h)). We could confirm poor road visibility condition from No. 4 still image in Fig. 6 (b). Poor road visibility occurred due to snowstorm. In Fig. 6 (c), from 14:40 to 15:40 (CC-2), the sign of cross-correlation value was positive. Value of the WIPS didn't move in synchronization with precipitation intensity. At this time, advection of snow particles may be occurred in the air.

According to Fig. 6 (d), a low pressure was approaching the northeastern Hokkaido. When interval of isobars was narrow, wind velocity was likely to strong and snowstorm may occur. However, in No. 4 time period, wind wasn't strong and wind direction was South, road visibility didn't change. After the change in wind velocity and direction, poor road visibility occurred due to snowstorm.

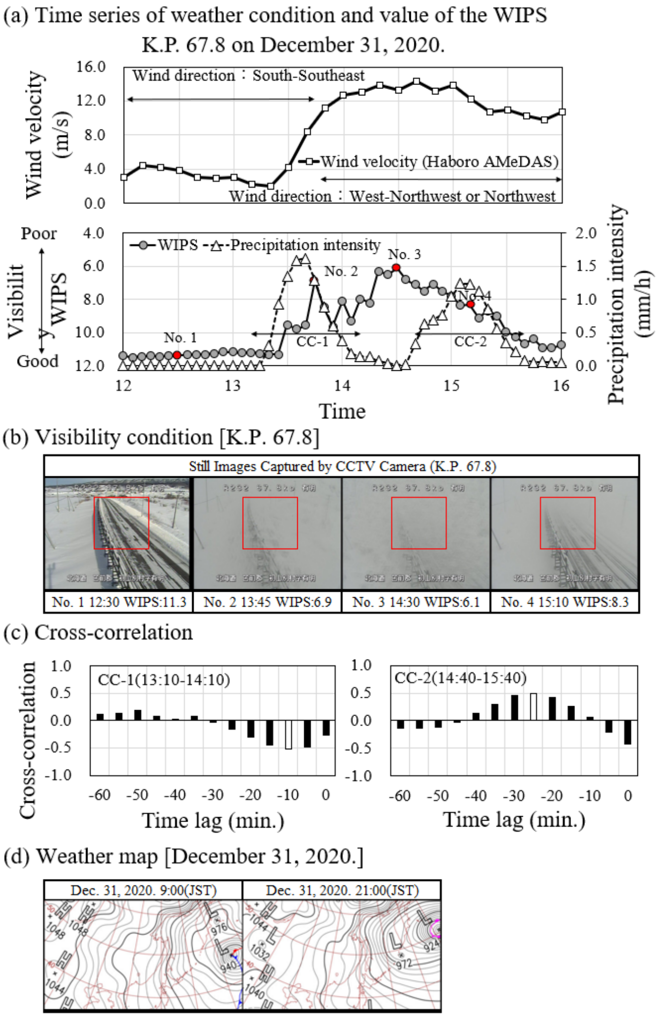


Fig. 6 Time series of weather and visibility conditions at K.P. 67.8 on December 31, 2020.

3.3 No.4 and No. 5 time periods on December 31, 2020 at K.P.72.0.

In No. 4 time period, wind velocity wasn't strong and wind direction was South. At K.P. 72.0, from 13:10 to 13:30, precipitation intensity increased (about 1.5 (mm/h)). However, the time series of value of the WIPS was flat and showed clear road visibility conditions. We could confirm clear road visibility condition from No.1 still image in Fig. 7 (b). In Fig. 7 (c), from 12:45 to 13:45 (CC-1), the sign of the highest cross-correlation was negative, and time lag was 15.0 (min.). Time series of precipitation intensity and value of the WIPS was different.

After, in No. 5 time period, wind velocity increased around 14.0 (m/s) and wind direction changed from West. While, from 13:30 to 14:30, precipitation intensity decreased under 0.5 (mm/h). At 13:45, precipitation intensity was almost 0.8 (mm/h), value of the WIPS was 6.6. At 14:30, although precipitation intensity was almost 0.2 (mm/h), value of the WIPS was 4.3. We could confirm very poor road visibility conditions from No. 2 and No. 3 still images in Fig.

7 (b). At this time, wind velocity was over 12.0 (m/s). There were much fresh snow particles on the ground due to snowfall in No. 4 time period. After the snowfall, by the change in wind velocity and direction, poor road visibility occurred due to snowstorm. From 14:30 to 15:30, precipitation intensity increased again (1.0 (mm/h)). We could confirm poor road visibility condition from No. 4 still image in Fig. 7 (b). Poor road visibility occurred due to snowstorm. After 15:30, precipitation intensity decreased (almost 0.0 (mm/h)). In Fig. 7 (c), from 14:20 to 15:20 (CC-2), the sign of the highest cross-correlation was positive. Value of the WIPS didn't move in synchronization with precipitation intensity. At this time, advection of snow particles may be occurred in the air.

According to Fig. 7 (d), a low pressure was approaching the northeastern Hokkaido. Interval of isobars was narrow and wind velocity was likely to strong, snowstorm might be occur. However, in No. 4 time period, wind velocity wasn't strong and wind direction was South, road visibility didn't change. After the change in wind velocity and direction, poor road visibility occurred due to snowstorm.

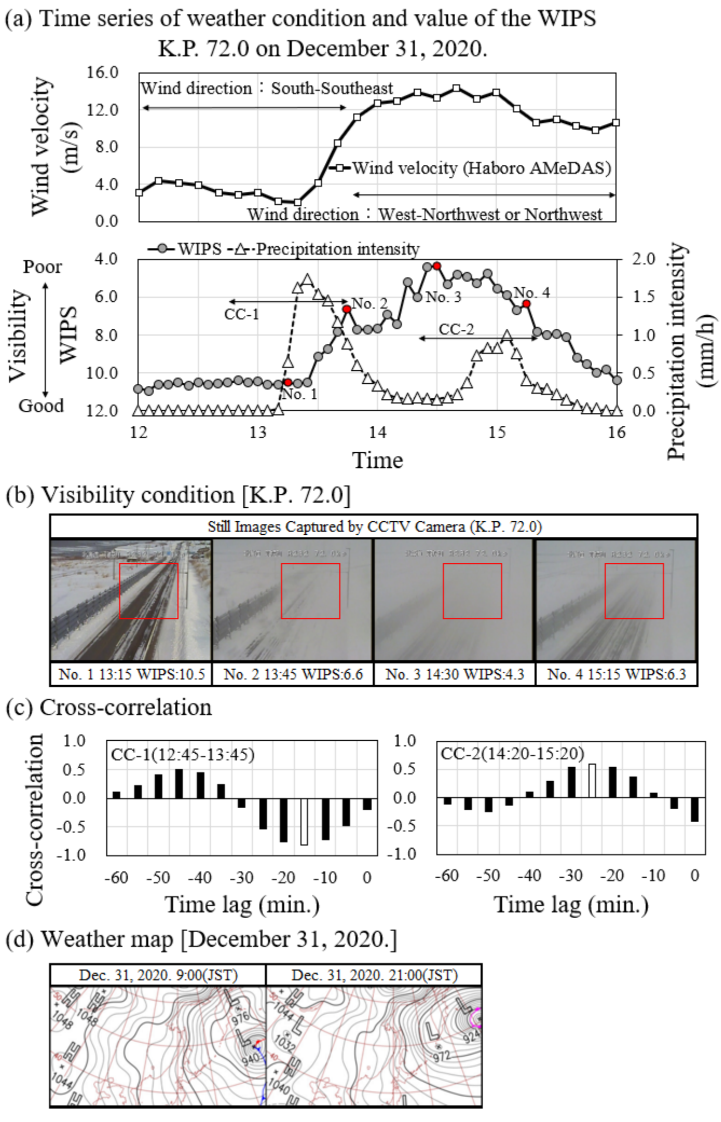


Fig. 7 Time series of weather and visibility conditions at K.P. 72.0 on December 31, 2020.

3.4 No.9 time period on January 29, 2022.

In No. 9 time period, wind velocity was slightly strong and wind direction was West. At K.P. 67.8, from 12:30 to 14:30, precipitation intensity increased (2.0 (mm/h)). We could confirm poor road visibility conditions from No. 2 and No. 4 still images in Fig. 8 (b). In Fig. 8 (c), from 12:25 to 13:25 (CC-1), and from 13:35 to 14:35 (CC-2), the sign of the highest cross-correlation was negative. Time lag was 0.0 and 5.0 (min.). Value of the WIPS moved in synchronization with precipitation intensity. Poor road visibility occurred due to snowfall.

At K.P. 72.0, from 12:30 to 13:00, precipitation intensity increased (about 1.0 (mm/h)). We could confirm poor road visibility condition from No.2 still image in Fig. 9 (b). In Fig. 9 (c), from 12:10 to 13:10 (CC-1), the highest cross-correlation was 0.8, time lag was 10.0 (min.). After, precipitation intensity decreased and wind velocity increased. In this case, poor road visibility occurred due to snowstorm. From 13:00 to 14:00, precipitation intensity increased again (about 1.0 (mm/h)). We could confirm very poor road visibility conditions from No. 3 and No. 4 still images in Fig. 9 (b). In Fig. 9 (c), from 13:00 to 14:00 (CC-2), the sign of the highest cross-correlation was negative. Time lag was 0.0 (min). From 13:30 to 14:00, precipitation intensity was around 0.5 (mm/h), wind velocity was slightly strong. In this case, poor road visibility occurred due to snowfall.

According to Fig. 8 (d) and Fig. 9 (d), there was a low pressure around Hokkaido. However, interval of isobars was wide, wind velocity was not so strong. Under these weather condition, poor road visibility mainly occurred due to snowfall.

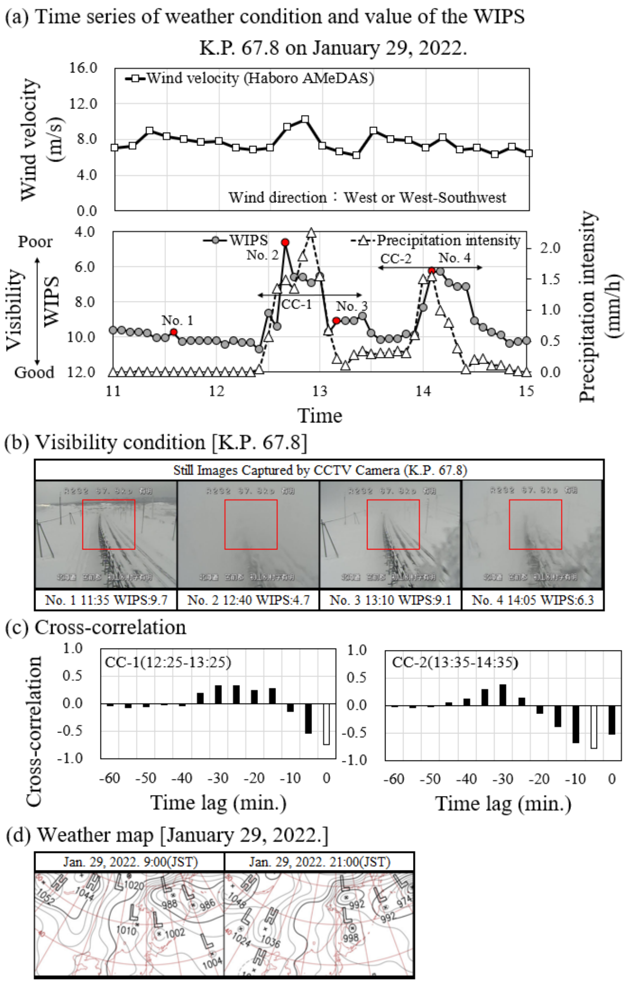


Fig. 8 Time series of weather and visibility conditions at K.P. 67.8 on January 29, 2022.

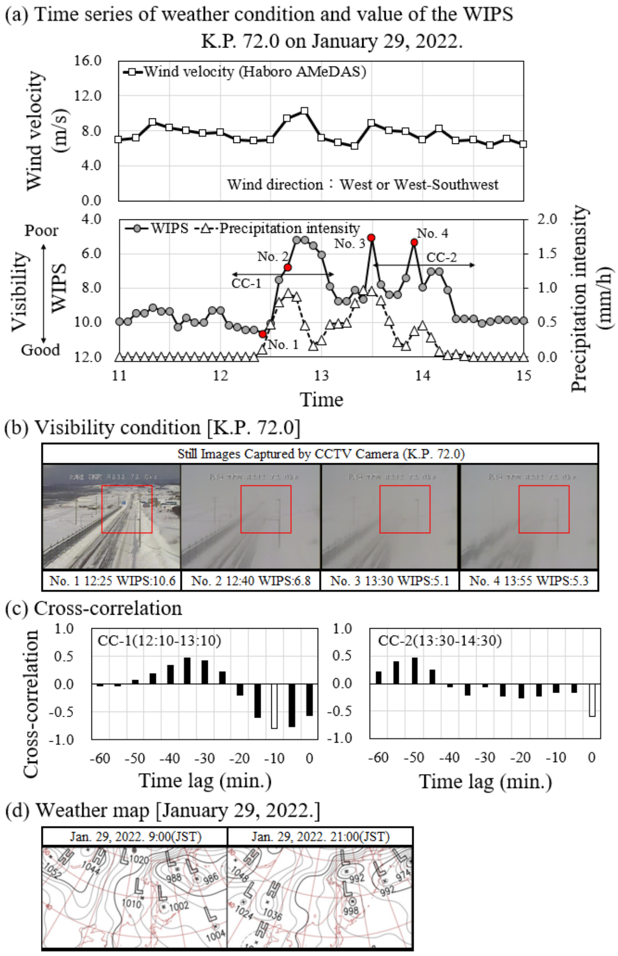


Fig. 9 Time series of weather and visibility conditions at K.P. 72.0 on January 29, 2022.

3.5 Results of Cross-Correlation

We calculated the cross-correlation and time lag between two time series variables, precipitation intensity and value of the WIPS. Results of 11 time periods could be classified into three categories depending on the cross-correlation value and time lag. Table 4. and Table 5. show the number of time period in Table 1., time period of calculating cross-correlation, the highest cross-correlation, time lag, and Category in K.P. 67.8 and K.P. 72.0 respectively.

In Category-1, precipitation intensity was almost 0.0 (mm/h) and road visibility condition was clear. In Category-2, value of the WIPS moved in synchronization with precipitation intensity. Cross-correlation was larger than 0.4, and time lag between two time series variables was relatively small. In Category-3, the relationship between precipitation intensity and value of the WIPS were complex. The sign of cross-correlation was positive, cross-correlation was weak less than 0.4, and time lag between two time series variables was large (over 15.0 (min.)).

Category-1 shows a time period that value of the WIPS shows clear visibility condition under none precipitation intensity. It should be noted that snowstorm on the road might occur under none precipitation if there are fine and fresh snow particles on the ground around the CCTV location. No. 2 time period is classified into Category-1. Wind velocity was over 8.0 (m/s) and there was little precipitation intensity during No. 2 time period. The time series of value of the WIPS shown clear visibility conditions during No. 2 time period. In this case, snow particles didn't pile on the ground due to strong wind from the previous day. As a result, on December 27, 2020, snowstorm didn't occur despite strong wind.

Category-2 shows a time period that value of the WIPS shows poor road visibility under precipitation intensity. Major wind direction was West. Time lag between precipitation intensity and value of the WIPS was relatively small. The sign of the highest cross-correlation was negative. Value of the WIPS moved in synchronization with precipitation intensity. In Category-2, there are two causes of poor road visibility under the similar cross-correlation. One is poor road visibility due to snowstorm. Under poor road visibility due to snowstorm, time lags were ranged from 0.0 to 10.0 (min.). Poor road visibility affected by not only precipitation but strong wind from West. Falling velocity of snow particles ranges from 1.0 to 4.0 (m/s). It was considered there will be some time lag until snowfall observed by XRAIN is reflected on the ground. The other is one due to snowfall. Under poor road visibility due to snowfall, time lags were ranged from 0.0 to 5.0 (min.). Wind velocity was weak, and major wind direction wasn't West. It was considered snowfall made road visibility worse directly.

Category-3 shows a time period that value of the WIPS didn't move in synchronization with precipitation intensity. One of the reasons is that snowstorm due to strong wind didn’t occur when wind direction wasn’t West. Geographical features of the road affected occurrence of poor road visibility (2022). East side of NR 232 is high cliff. Then, wind from east side becomes weak. Another reason is that wind velocity and direction were not stable, road visibility has been affected by them and become unstable. In these cases, as a result, cross-correlation was positive and weak, time lags between two time series variables tend to large.

Road visibility condition changes complicatedly due to various factors, we need to conduct inspection the applicability of precipitation intensity by XRAIN as snowfall information on the road in other area. Matsushita et al. reported that there isn’t the high occurrence area of freezing rain or sleet in Hokkaido, Japan (2004). Therefore, the present study, we dealt with poor road visibility due to snowfall and snowstorm as evaluation targets.

Table 4. Results of Cross-correlation and Time Lag [K.P. 67.8]

K.P. 67.8					
Date	Time Period in TABLE 1	Time Period	The Highest Cross-correlation	Time lag (min.)	Category
Dec. 26, 2020.	No.1	12:00-13:00	-0.79	5	2
		12:15-13:15	-0.74	5	2
		12:55-13:55	-0.64	0	2
		14:55-15:55	-0.74	0	2
Dec. 27, 2020.	No.2	No precipitation			1
Dec. 29, 2020.	No.3	10:00-11:00	-0.57	5	2
Dec. 31, 2020.	No.4 and No.5	13:10-14:10	-0.52	10	2
	No.5	14:40-15:40	0.50	25	3
Dec. 28, 2021.	No.6	10:25-11:25	0.47	10	3
	No.6 and No.7	10:45-11:45	-0.60	0	2
Dec. 30, 2021.	No.8	8:00-9:00	-0.35	35	3
		8:25-9:25	0.34	35	3
		11:00-12:00	-0.68	10	2
Jan. 29, 2022.	No.9	12:25-13:25	-0.75	0	2
		13:35-14:35	-0.78	5	2
Feb. 3, 2022.	No.10	12:20-13:20	-0.70	5	2
	No.11	14:35-15:35	0.53	0	3

Table 5. Results of Cross-correlation and Time Lag [K.P. 72.0]

K.P. 72.0					
Date	Time Period in Table 1.	Time Period	The Highest Cross-correlation	Time lag (min.)	Category
Dec. 26, 2020.	No.1	12:15-13:15	-0.80	5	2
		12:55-13:55	-0.59	0	2
		14:55-15:55	-0.72	5	2
Dec. 27, 2020.	No.2	11:35-12:35	-0.84	5	2
Dec. 29, 2020.	No.3	10:00-11:00	-0.71	0	2
		11:05-12:05	-0.72	0	2
Dec. 31, 2020.	No.4	12:55-13:55	-0.81	15	3
	No.5	14:35-15:35	0.59	25	3
Dec. 28, 2021.	No.6	10:15-11:15	0.60	10	3
Dec. 30, 2021.	No.8	8:50-9:50	-0.70	0	2
		11:00-12:00	-0.84	10	2
Jan. 29, 2022.	No.9	12:10-13:10	-0.79	10	2
		13:30-14:30	-0.59	0	2
Feb. 3, 2022.	No.10	12:05-13:05	-0.71	0	2
	No.11	14:50-15:50	0.47	15	3

4. SUMMARY

The present study, we investigated applicability of precipitation intensity by XRAIN as snowfall information to estimate road visibility in winter season in Haboro area of Hokkaido. Using cross-correlation, we explored the degree of influence between precipitation intensity and value of the WIPS. As a result of investigation, in Category-1 and Category-2, time series of precipitation intensity and value of the WIPS were related. In Category-3, time series of them were different. Therefore, in Category-1 and Category-2, applicability of road visibility estimation using precipitation intensity was indicated. Whereas, in Category-3, when wind velocity was so strong, it was also revealed that we should consider the advection of snow particles in the air. Using precipitation intensity by XRAIN as snowfall information on the road to evaluate snowfall and snowstorm in winter season, accuracy of observation, falling velocity and advection of snow particles should be considered.

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