TRB Annual Meeting

Investigation of Relationship between Weather Conditions and Visibility Conditions on the Road in Winter

--Manuscript Draft--

Full Title:	Investigation of Relationship between Weather Conditions and Visibility Conditions on the Road in Winter
Abstract:	In Hokkaido, Japan, in winter, poor visibility frequently occurs due to snowstorm and the risk of traffic restriction and crash increases. Estimation of poor visibility on the road due to snowstorm is necessary to contribute to traffic safety. Aim of the present study is to explore possibility of precipitation intensity measured by the X-band multi-parameter radar network (XRAIN) for estimating visibility conditions along the road in winter. XRAIN could observe precipitation per 250-meter square grid mesh every 1-minutes, visibility evaluation along the road in detail would be possible. We investigated relationship between precipitation intensity and value of the Weighted Intensity of Power Spectra (hereinafter WIPS) measured by the Closed-circuit Television (hereinafter CCTV) Camera which shows visibility conditions on the road. Cross-correlation analysis was used to see relationship between precipitation intensity and value of the WIPS. Results of this study revealed the possibility to evaluate visibility conditions on the road using precipitation intensity measured by XRAIN. Meanwhile, there were several causes of poor visibility conditions, then it is difficult for us to estimate visibility conditions using precipitation intensity only. It is supposed that integration of weather conditions including precipitation intensity by XRAIN and ground conditions on the road are required to estimate the visibility conditions on the road.
Manuscript Classifications:	Infrastructure; Highway Maintenance; Winter Maintenance AKR40; Automated vehicle location systems; Management tools and practices; Snow and ice
Manuscript Number:	
Article Type:	Presentation and Publication
Order of Authors:	Yuki Nakamura, M.S.
	Toru Hagiwara, Ph.D.
	Yasuhiro Nagata, Ph.D.
	Sho Takahashi, Ph.D.
	Ryoichi Tsurumaki, Ph.D.
	Naoki Matsuoka, B.E.
Additional Information:	
Question	**Response**
The total word count limit is 7500 words including tables. Each table equals 250 words and must be included in your count. Papers exceeding the word limit may be rejected. My word count is:	5528
Is your submission in response to a Call for Papers? (This is not required and will not affect your likelihood of publication.)	No

Investigation of Relationship between Weather Conditions and Visibility Conditions on the Road in Winter

Yuki Nakamura, M/S.
Student
Hokkaido University
Sapporo, Japan, 060-8628
Email: yuki-nakamura@frontier.hokudai.ac.jp

Toru Hagiwara, Ph.D.
Professor
Hokkaido University
Sapporo, Japan, 060-8628
Email: hagiwara@eng.hokudai.ac.jp

Yasuhiro Nagata, Ph.D.
Principal Researcher
Hokkaido Development Engineering Center
Sapporo, Japan, 001-0011
Email: nagata@decnet.or.jp

Sho Takahashi, Ph.D.
Associate Professor
Hokkaido University
Sapporo, Japan, 060-8628
Email: stakahashi@eng.hokudai.ac.jp

Ryoichi Tsurumaki, Ph.D.
Chief Engineer
Hokkaido Weather Technology Center
Sapporo, Japan, 064-8555
Email: ryoichi.tsurumaki@howtecc.jp

Naoki Matsuoka, B.E.
Managing Director
Hokkaido Weather Technology Center
Sapporo, Japan, 064-8555
Email: naoki.matsuoka@howtecc.jp

Word Count: 4,778 words + 3 table (250 words per table) = 5,528 words

Submission date: August 1, 2022.

ABSTRACT

In Hokkaido, Japan, in winter, poor visibility frequently occurs due to snowstorm and the risk of traffic restriction and crash increases. Estimation of poor visibility on the road due to snowstorm is necessary to contribute to traffic safety. Aim of the present study is to explore possibility of precipitation intensity measured by the X-band multi-parameter radar network (XRAIN) for estimating visibility conditions along the road in winter. XRAIN could observe precipitation per 250-meter square grid mesh every 1-minutes, visibility evaluation along the road in detail would be possible. We investigated relationship between precipitation intensity and value of the Weighted Intensity of Power Spectra (hereinafter WIPS) measured by the Closed-circuit Television (hereinafter CCTV) Camera which shows visibility conditions on the road. Cross-correlation analysis was used to see relationship between precipitation intensity and value of the WIPS. Results of this study revealed the possibility to evaluate visibility conditions on the road using precipitation intensity measured by XRAIN. Meanwhile, there were several causes of poor visibility conditions, then it is difficult for us to estimate visibility conditions using precipitation intensity only. It is supposed that integration of weather conditions including precipitation intensity by XRAIN and ground conditions on the road are required to estimate the visibility conditions on the road.

Keywords: Poor visibility, Snowstorm, Precipitation intensity, XRAIN, WIPS, Cross-correlation

INTRODUCTION

In Hokkaido, Japan, every winter, poor visibility frequently occurs due to snowstorm and the risk of traffic restriction and crash increases (*1*). Estimation of poor visibility due to snowstorm is necessary to contribute to traffic safety (*2*). Nagata and Hagiwara et al. evaluated visibility conditions in winter 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 (*3*).

Hagiwara et al. suggested that value of the WIPS may be appropriate for identifying poor visibility using digital images (*4*). Nakamura et al. detected poor visibility on the road using value of the WIPS measured by the CCTV camera installed along National Route (hereinafter NR) 244 and NR 272 in Hokkaido, Japan. Still images recorded by CCTV camera evaluated poor visibility conditions occurred by strong wind despite no snowfall (*5*). Visibility conditions on the road could be evaluated by the CCTV camera. Nakamura et al. developed visibility estimation model using value of the WIPS using images taken by on-board camera. Under severe poor visibility conditions, the model could not estimate visibility conditions precisely due to missing snowfall information along the road (*6*). Then, snowfall information is required to estimate occurrence of poor visibility conditions on the road.

Precipitation intensity observed by weather radar might be available to observe snowfall on the road in winter. Weather radar could observe precipitation intensity frequently in high spatial density. In the United States of America and Japan, precipitation measured by weather radar has been used. In the United States of America, in 1988, NEXt-Generation RADar network (hereinafter NEXRAD) was developed to observe precipitation and wind velocity all over the United States of America (*7*). In the state of Alaska, NEXRAD is used to observe scattered material by tornado and precipitation quantitively (*8*). In Japan, since 2016, the X-band multi-parameter radar network (hereinafter XRAIN) for river maintenance and prevention activities such as landslide developed by the Ministry of Land, Infrastructure, Transport and Tourism (hereinafter MLIT) (*9*). XRAIN could observe precipitation per 250-meter square grid mesh every 1-minutes, visibility evaluation along the road in detail would be possible. In Hokkaido, Japan, Omiya et al. discussed whether it is possible to spatially obtain real-time information on surface snowstorm based on data observed in the air by XRAIN (*10*).

Aim of the present study is to explore possibility of precipitation intensity measured by the X-band multi-parameter radar network (XRAIN) for estimating visibility conditions along the road in winter. Relationship precipitation intensity measured by XRAIN and value of the WIPS using images recorded by the CCTV cameras along the road was examined. Using these two time series variables, we tried to evaluate the situation of occurrence poor visibility.

METHODS

Investigate Road Section and time period

A 22-km/section of National Route 232 (hereinafter NR 232) from 56.0 kilometer post (hereinafter K.P.) to K.P. 78.0 was selected for investigation. K.P. in Japan represents milepost in the United States of America. **Figure 1** shows a map of the 22-km/section on NR 232 and shows the locations of K.P., CCTV cameras, and Automated Meteorological Data Acquisition System (AMeDAS). The 22-km/section potentially tends to occur poor visibility due to snowstorm in winter. **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/s.

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

MM/DD/YY	No.	Time Period	Average Temperature (℃)	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

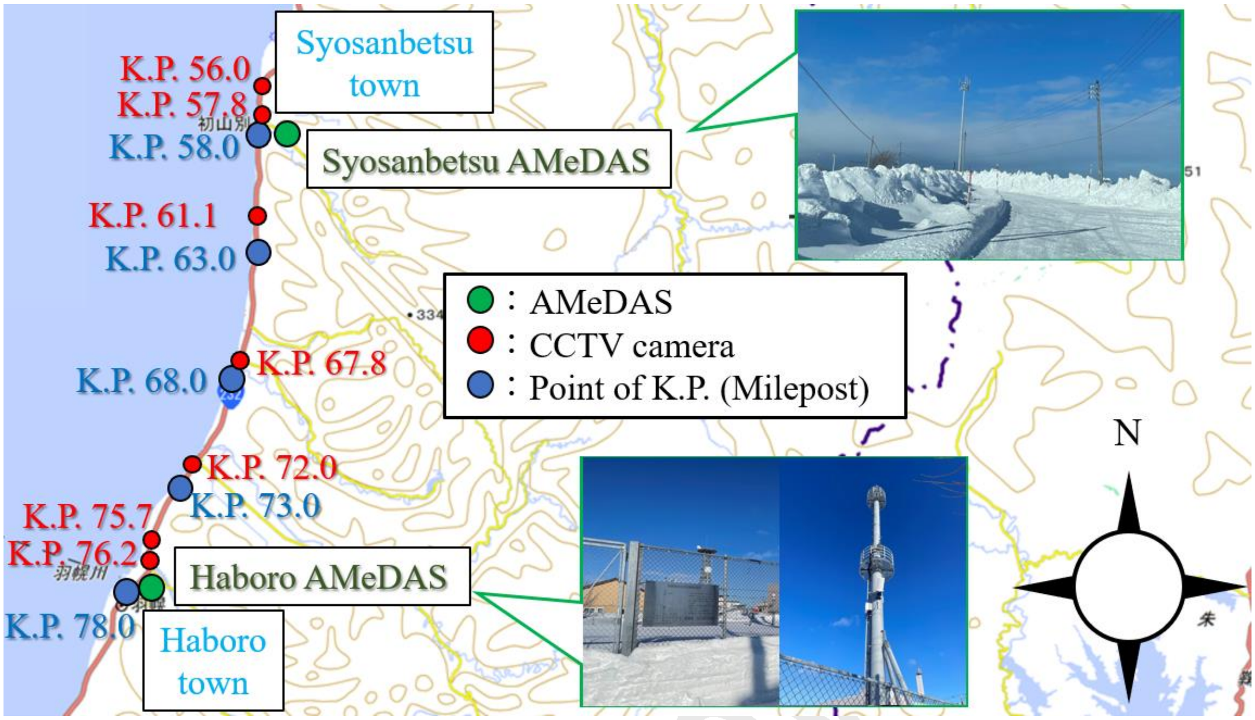

Figure 1 Map of the 22-km/section in Haboro area included the 22 km/section of NR 232

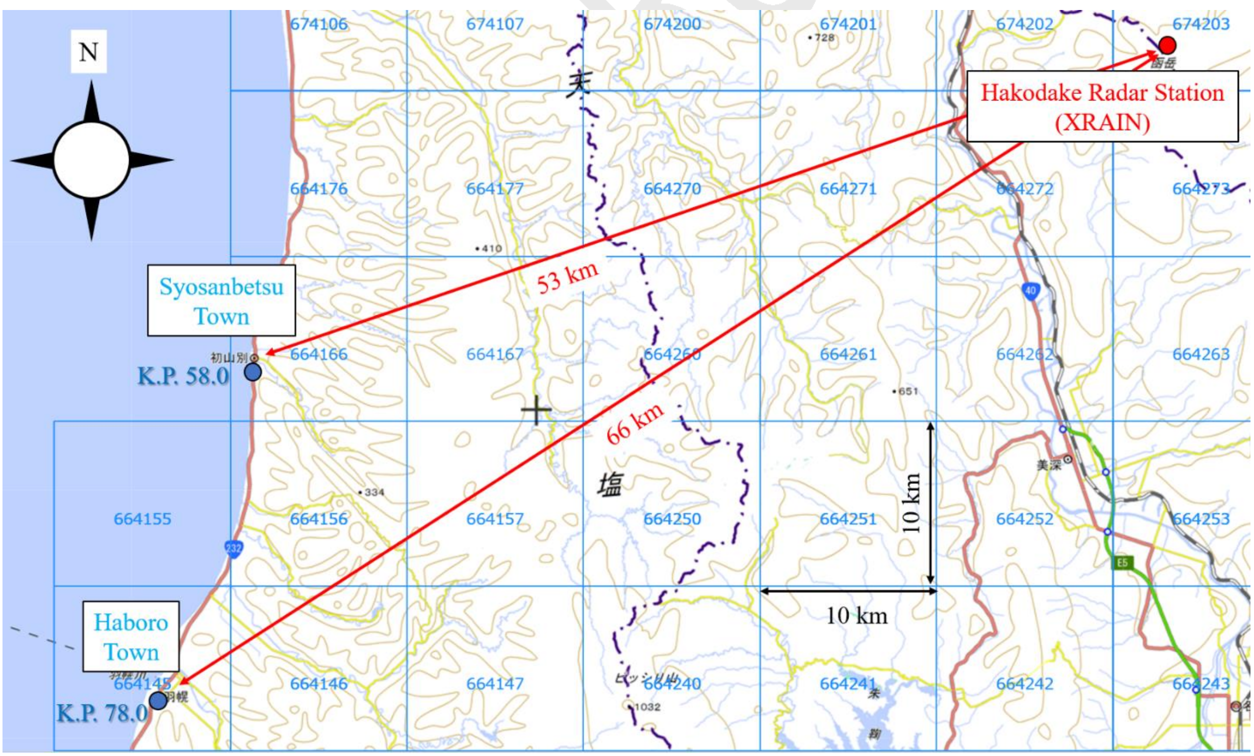

Figure 2 Map of the radar station and 10-km/square grid mesh in Haboro area including the 22 km/section of NR 232

Data Collection

Precipitation intensity of XRAIN (mm/h)

MLIT developed XRAIN as precipitation observation system. The present study, we downloaded "MLIT XRAIN CXMP composite dataset" from Data Integration and Analysis System (hereinafter DIAS) (*9*). "MLIT XRAIN CXMP composite dataset" consists of "MLIT X-band multi-parameter radar" and "C-band multi-parameter radar". "MLIT XRAIN CXMP composite dataset" 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 squire grid mesh. **Figure 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 of NR 232. The 10-kilimeter square grid mesh (shown in **Figure 2**) consists of 100 1-kilometer square grid meshes to provide precipitation intensity.

Precipitation intensity measured by XRAIN is based on observations of rain particle in the air. Time lag may occur between precipitation intensity and amount of precipitation on the ground (*11*). In winter, most rain particles in the air are snow particles. Then, value of time lag increases caused by the non-vertical fall of snow particle in winter (*10*)(*12*). Then, average value from precipitation intensity before 10-minutes to the current time is used as represented precipitation intensity at the current time.

Still images captured by the CCTV camera

In the 22-km/section of NR 232, seven CCTV cameras are installed. The video images recorded by CCTV cameras are continuously transmitted by means of a fiber-optic network to the road maintenance office, and still images are provided to drivers via the Internet (*3*)(*4*). CCTV camera captures still image every 5-minutes. We used still images captured by CCTV cameras at K.P. 67.8 and K.P. 72.0 for visibility evaluation on the road. These two CCTV cameras almost never changed the shooting direction. Also, there were few cases for ice and snow on the camera lens due to the relationship between major wind direction and their shooting direction.

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

Haboro AMeDAS is located near Haboro town. Haboro AMeDAS has been observed air temperature, wind velocity and wind direction every 10-minutes. **Table 1** shows average value of air temperature and wind velocity during each of 11 time period, and shows major wind direction during each of 11 time period.

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

Hagiwara et al. developed value of the WIPS measured by the CCTV camera to evaluate visibility (*4*). The present study, value of the WIPS has been adopted as an assessment value of visibility conditions on the winter road. The value of the WIPS represents the difference in spatial frequencies within the still image based on the human contrast sensitivity function, and it can assess visibility level road ahead (*13*). The followings are image processing method for calculation value of the WIPS (*3*)(*4*). 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 of 256×256 pixels. 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. Under clear conditions, the power spectra for each spatial frequency component of the still image on the road are great and value of the WIPS is large. Under poor visibility conditions, such as those in fog or snow, the power spectra are small. As a result, value of the WIPS is small.

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 (*14*). 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 $\tau = -\tau_{max}, \dots, \tau_{max}$ 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.

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

$C(\tau)$: 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

In the present study, 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 $\tau_{max}$is 60 (min.). If there were multiple time zones of the precipitation intensity, the cross-correlation was calculated per each of multiple time zones.

For calculating the cross-correlation, unit of the time lag between precipitation intensity and value of WIPS was set to 5-minutes. Value of the WIPS was calculated every 5-minutes corresponded to the still image collect by the CCTV cameras. Precipitation intensity every 5-minutes was set to an average of 10-minutes precipitation intensity before the current time period. There is the time lag caused by the non-vertical fall of rain particle from the cloud shot by radar to the ground (*10*). Then, average value from precipitation intensity before 10-minutes to the current time is used as represented precipitation intensity at the current time.

RELATIONSHIP BETWEEN WEATHER CONDITIONS AND VISIBILITY CONDITIONS

Cross-correlation was applied to investigate relationship between precipitation intensity measured by XRAIN and value of the WIPS measured by the CCTV camera. We tried to reveal the effect of precipitation intensity for snowstorm/s on the road. This section shows detailed results for the four time periods which are No.2 time period on December 27, 2020, No.4 and No.5 time periods on December 31, 2020, and No.9 time period on January 29, 2022. Results shown from **Figure 3** to **Figure 8** for each of the four time periods contain the following three graphs.

1) Two Line charts: Above line chart in **Figure 3 (a)** to **Figure 8 (a)** shows the time series of wind velocity, and major wind direction. Below line chart in **Figure 3 (a)** to **Figure 8 (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 visibility condition. Red points on line of value of the WIPS show the worse visibility conditions.

2) Still images: To understand actual visibility condition on the road, **Figure 3 (b)** to **Figure 8 (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 **Figure 4 (c)** to **Figure 8 (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 **Figure 4 (c)** to **Figure 8 (c)** was the highest cross-correlation.

No 2. Time period on December 27, 2020

In this time period, there were slight precipitation intensity and strong wind. At K.P. 67.8, time series of precipitation intensity was almost 0.0 (mm/h). Visibility conditions from four still images at No.1 point to No.4 point in **Figure 3 (a)** were good shown in **Figure 3 (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). Visibility condition of still image at No.2 point in **Figure 4 (a)** was slightly poor in **Figure 4 (b)**. The white bar shown in **Figure 4 (c)** was the highest cross-correlation. The sign of the highest cross-correlation was negative. The value of the WIPS moved in synchronization with precipitation intensity.

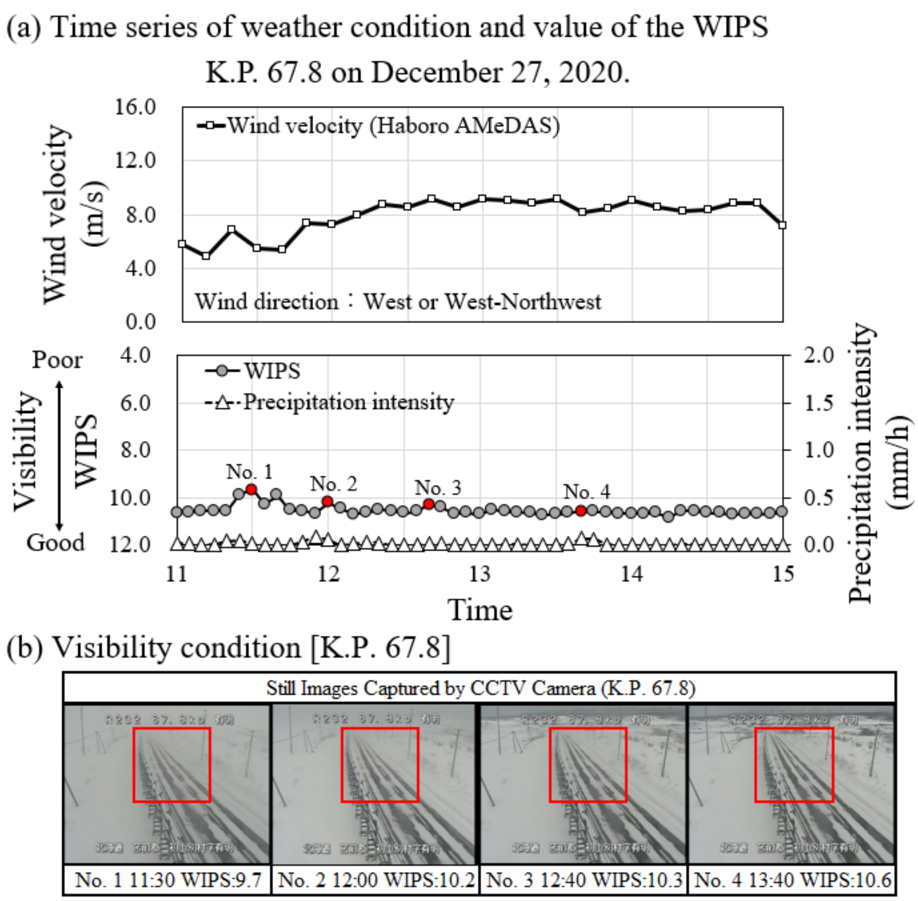

Figure 3 Time series of weather and visibility conditions at K.P. 67.8 on December 27, 2020.

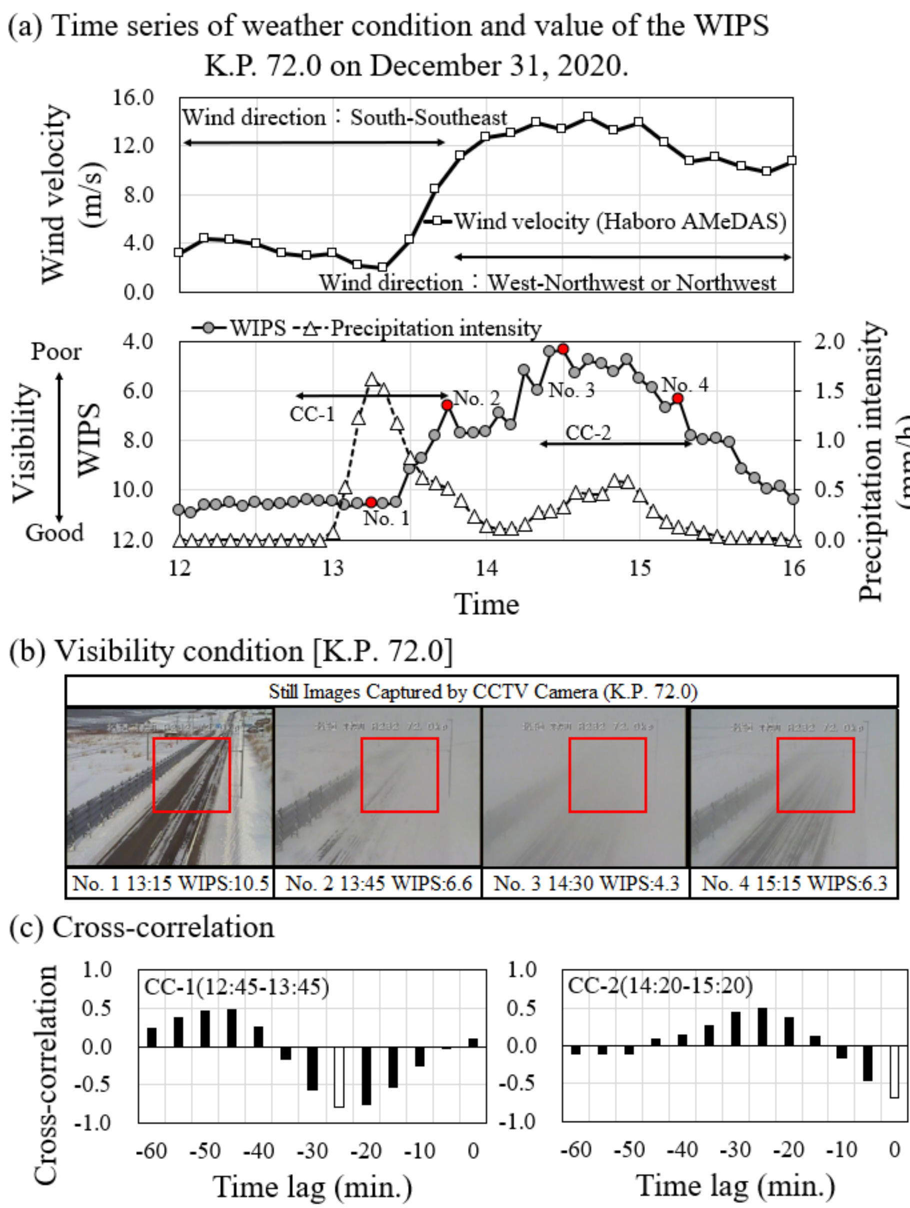

Figure 4 Time series of weather and visibility conditions at K.P. 72.0 on December 27, 2020.

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 13:20, precipitation intensity was almost 0.0 (mm/h). The time series of value of the WIPS was flat and showed clear visibility conditions. In No.5 time period, wind velocity increased in two times and wind direction changed from West.

From 13:30 to 14:00, precipitation intensity was about 1.5 (mm/h). Visibility condition of still image at No.2 point in **Figure 5 (a)** was very poor in **Figure 5 (b)**. From 14:00 to 15:00, the 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), the value of the WIPS was 6.0. Visibility condition of the still image at No.3 point was very poor in **Figure 5 (b)**. Wind velocity was over 12.0 (m/s). There were much fresh snow particles on the ground. Poor visibility occurred due to snowstorm. From 13:10 to 14:10, the sign of the highest cross-correlation was negative, and time lag was 5.0 (min.). The value of the WIPS moved in synchronization with precipitation intensity.

From 15:00 to 15:30, precipitation intensity increased again, and its value was 1.5 (mm/h). Visibility condition of the still image at No.4 point in **Figure 5 (a)** was poor in **Figure 5 (b)**. Poor visibility occurred due to snowstorm. The cross-correlation was shown in **Figure 5 (c)**. White bar shown in **Figure 5 (c)** was the highest cross-correlation. From 14:40 to 15:40, the sign of cross-correlation value was positive. The value of the WIPS did not move in synchronization with precipitation intensity.

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 13:00 to 13:30, precipitation intensity increased and its value was about 1.5 (mm/h). The time series of value of the WIPS was flat and showed clear visibility conditions. Visibility condition of the still image at No.1 point in **Figure 6 (a)** was good in **Figure 6 (b)**. From 12:45 to 13:45, the sign of the highest cross-correlation was negative, and time lag was 25.0 (min.).

In No.5 time period, wind velocity increased until around 14.0 (m/s) and wind direction changed from West. From 13:30 to 14:30, precipitation intensity decreased, and its value was under 0.5 (mm/h). At 13:45, precipitation intensity was almost 0.5 (mm/h), the value of the WIPS was 6.6. At 14:30, precipitation intensity was almost 0.3 (mm/h), the value of the WIPS was 4.3. Visibility conditions of still images at No.2 point and No.3 point in **Figure 6 (a)** were very poor in **Figure 6 (b)**. Wind velocity was over 12.0 (m/s). There were much fresh snow particles on the ground. Poor visibility occurred due to snowstorm.

From 14:30 to 15:30, precipitation intensity increased again, and its value was almost 0.5 (mm/h). Visibility condition of the still image at No.4 point in **Figure 6 (a)** was poor in **Figure 6 (b)**. Poor visibility occurred due to snowstorm. After 15:30, precipitation intensity decreased and its value was almost 0.0 (mm/h). The value of the WIPS moved in synchronization with precipitation intensity. From 14:20 to 15:20, the sign of the highest cross-correlation was negative, and time lag was 0.0 (min.).

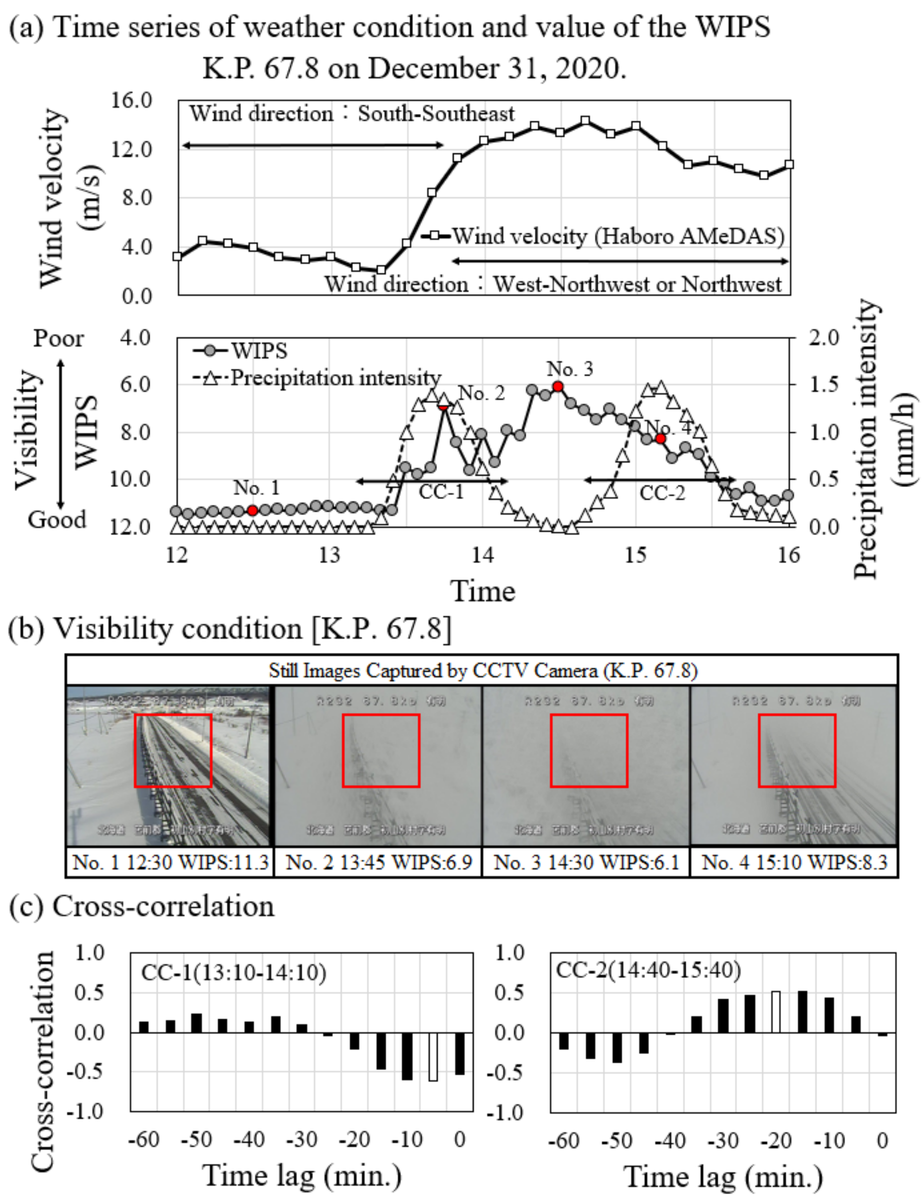

Figure 5 time series of weather and visibility conditions at K.P. 67.8 on December 31, 2020.

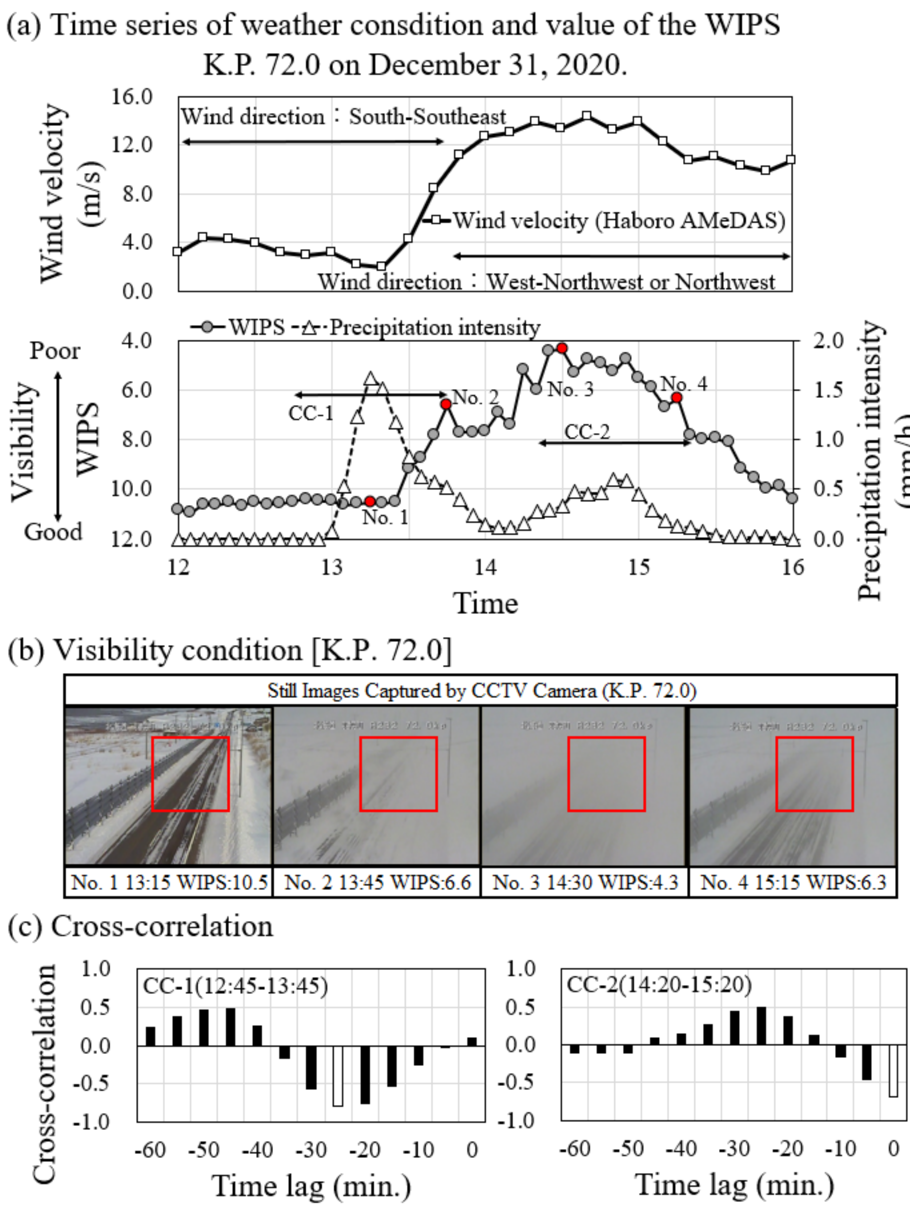

Figure 6 Time series of weather and visibility conditions at K.P. 72.0 on December 31, 2020.

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 and its value was 2.0 (mm/h). Wind velocity was slightly strong, and wind direction was West. Visibility conditions of still images at No.2 point and No.4 point in **Figure 7 (a)** were poor in **Figure 7 (b)**. Poor visibility occurred due to snowfall. The highest cross-correlation was 0.7, and time lag was 0.0 (min.) in **Figure 7 (c)**. From 12:30 to 13:30, and from 13:35 to 14:35, the sign of the highest cross-correlation was negative and large. Time lag was 5.0 (min.). Value of the WIPS moved in synchronization with precipitation intensity.

At K.P. 72.0, from 12:00 to 13:00, precipitation intensity increased and its value was about1.0 (mm/h). From 12:00 to 13:00, wind velocity was slightly strong, and wind direction was West. Visibility condition of the still image at No.2 point in **Figure 8 (a)** was poor in **Figure 8 (b)**. From 12:00 to 13:00, the highest cross-correlation was 0.8. However, time lag was 15.0 (min.) in **Figure 8 (c)**. From 12:30 to 13:00, precipitation intensity decreased and wind velocity increased. Poor visibility occurred due to snowstorm. From 13:00 to 14:00, precipitation intensity increased again and its value was about 1.0 (mm/h). From 13:00 to 14:00, wind velocity was slightly strong, and wind direction was West. Visibility conditions of still images at No.3 point and No.4 point in **Figure 8 (a)** were very poor in **Figure 8 (b)**. From 13:00 to 14:00, the highest cross-correlation was 0.4 and small. From 13:30 to 14:00, precipitation intensity decreased and its value was 0.5 (mm/h). Wind velocity was strong. Poor visibility occurred due to snowstorm.

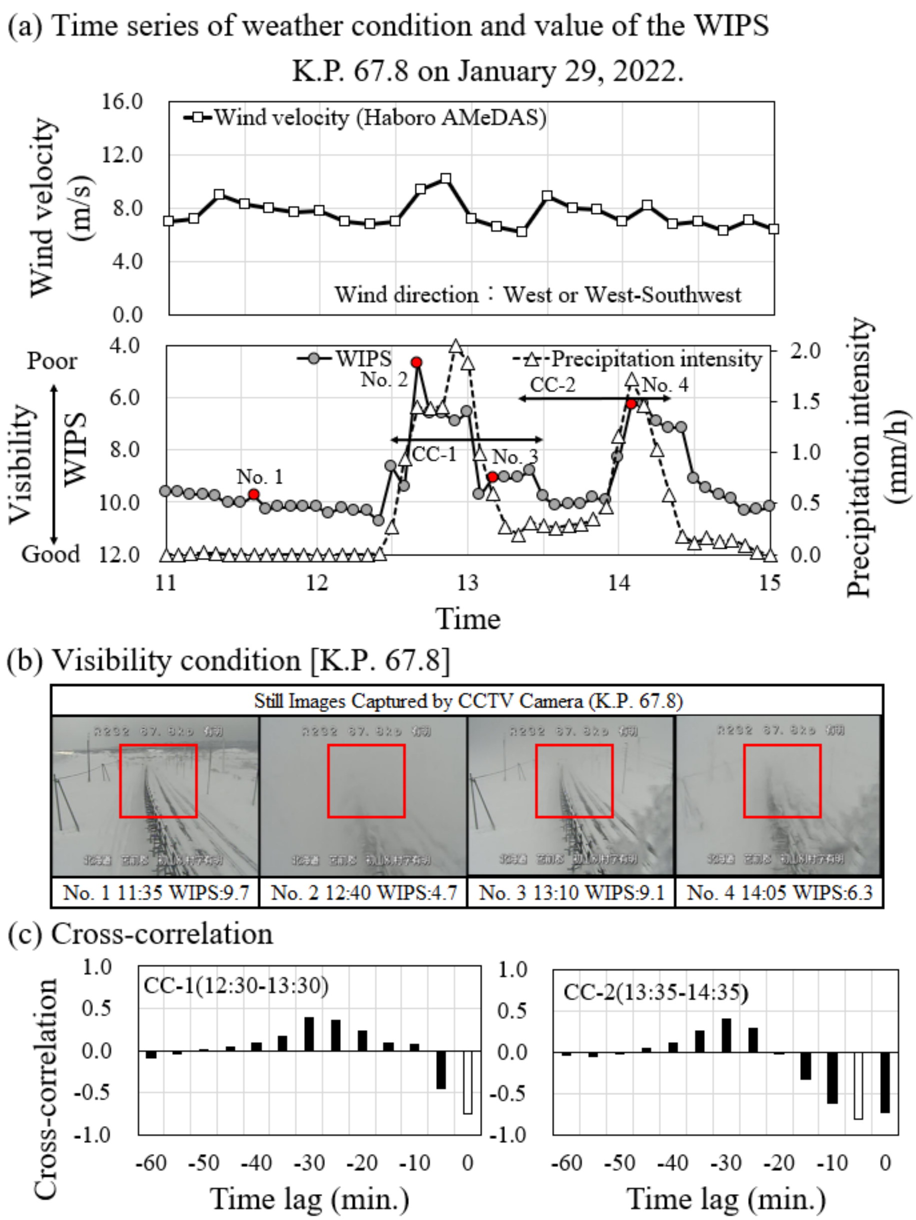

Figure 7 Time series of weather and visibility conditions at K.P. 67.8 on January 29, 2022.

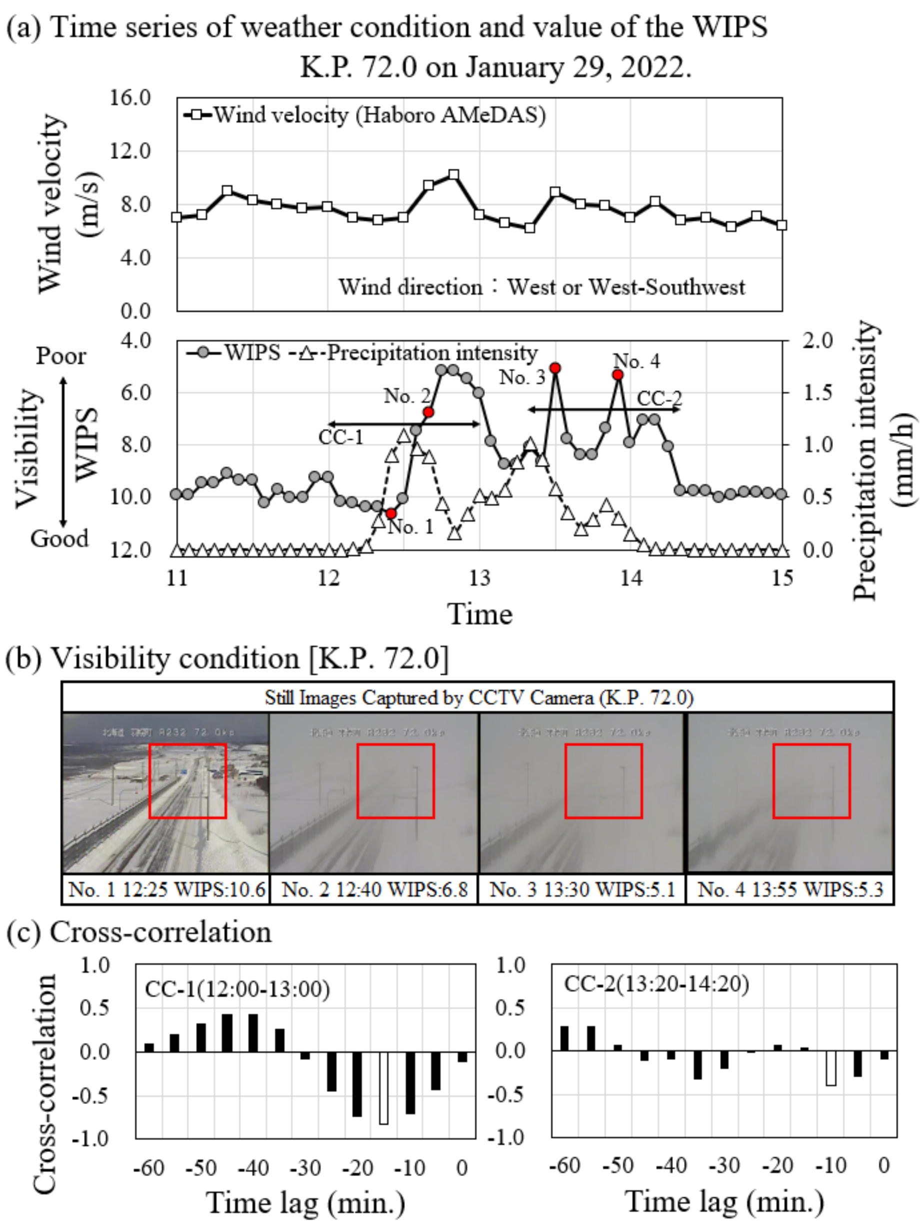

Figure 8 Time series of weather and visibility conditions at K.P. 72.0 on January 29, 2022.

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 2** shows the number of time period in **Table 1**, time period of calculating cross-correlation, the highest cross-correlation, time lag, and Category at K.P. 67.8. **Table 3** shows the number of time period in **Table 1**, time period of calculating cross-correlation, the highest cross-correlation, time lag, and Category at K.P. 72.0.

In Category-1, precipitation intensity was almost 0.0 (mm/h) and visibility condition on the road was good. 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 20.0 (min.)).

Category-1 shows a time period that value of the WIPS shows good visibility under none precipitation intensity. It should be noted that snowstorm on the road might occur poor 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 good visibility conditions during No.2 time period. In this case, snow particles did not pile on the ground due to strong wind from the previous day. As a result, on December 27, snowstorm didn't occur despite strong wind.

Cetegory-2 shows a time period that value of the WIPS shows poor 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 visibility under the similar cross-correlation. One is poor visibility due to snowstorm. Under poor visibility due to snowstorm, time lag was ranged from 5.0 to 15.0 (min.). Poor visibility affected by not only precipitation but strong wind from West. The other is poor visibility due to snowfall. Under poor 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 visibility worse directly.

Category-3 shows a time period that value of the WIPS did not 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 visibility along the road (*15*). East side of NR232 is high cliff. Then, wind from east side becomes weak. Another reason is that wind velocity and wind direction were not stable, visibility on the road has been affected by them and become unstable. In these cases, as a result, cross-correlation was positive and weak. Also, time lag between two time series variables tends to large.

TABLE 2 Results of Cross-correlation and Time Lag. [K.P. 67.8]

K.P. 67.8					
DD/MM/YY	**Time Period in TABLE 1**	**Time Period**	**The Highest Cross-correlation**	**Time lag (min.)**	**Category**
Dec. 26, 2020.	No.1	12:00-13:00	-0.85	5	2
		12:15-13:15	-0.77	5	2
		12:50-13:50	-0.67	5	2
		15:00-16:00	-0.73	0	2
Dec. 27, 2020.	No.2	No precipitation			
Dec. 29, 2020.	No.3	10:00-11:00	-0.55	5	2
		10:30-11:30	-0.79	5	2
Dec. 31, 2020.	No.4	13:10-14:10	-0.62	5	2
	No.5	14:40-15:40	0.50	20	3
Dec. 28, 2021.	No.6	10:20-11:20	0.46	20	3
	No.7	10:45-11:45	0.54	20	3
Dec. 30, 2021.	No.8	8:00-9:00	-0.38	30	3
		8:30-9:30	-0.32	5	3
		11:00-12:00	-0.71	5	2
Jan. 29, 2022.	No.9	12:30-13:30	-0.71	0	2
		13:35-14:35	-0.81	5	2
Feb. 3, 2022.	No.10	12:20-13:20	-0.80	0	2
	No.11	14:40-15:40	0.20	0	3

TABLE 3 Results of Cross-correlation and Time Lag. [K.P. 72.0]

K.P. 72.0					
DD/MM/YY	**Time Period in TABLE 1**	**Time Period**	**The Highest Cross-correlation**	**Time lag (min.)**	**Category**
Dec. 26, 2020.	No.1	12:10-13:10	-0.80	10	2
		12:50-13:50	-0.49	5	2
		14:50-15:50	-0.61	10	2
Dec. 27, 2020.	No.2	11:30-12:30	-0.76	10	2
Dec. 29, 2020.	No.3	10:00-11:00	-0.67	5	2
		11:00-12:00	-0.79	5	2
Dec. 31, 2020.	No.4	12:45-13:45	-0.78	25	3
	No.5	14:20-15:20	-0.68	0	2
Dec. 28, 2021.	No.6	10:10-11:10	-0.68	10	2
Dec. 30, 2021.	No.8	8:30-9:30	-0.71	0	2
Jan. 29, 2022.	No.9	12:00-13:00	-0.83	15	2
		13:20-14:20	-0.40	10	2
Feb. 3, 2022.	No.10	12:00-13:00	-0.57	10	2
	No.11	14:40-15:40	-0.77	0	2

DISCUSSION

In Category-3, at K.P. 72.0 on December 31, 2020, time lag was negative and large. At 13:00, precipitation intensity was almost 0.0 (mm/h), wind velocity was 4.0 (m/s), and wind direction was South-Southeast. From 13:00 to 13:15, precipitation intensity increased rapidly. However, at 13:15, visibility condition from the still image was clear despite precipitation intensity was large. After that, wind direction changed to West-Northwest, and wind became strong, its velocity increased 6.0 to 14.0 (m/s). The strong wind from West-Northwest occurred and visibility became poor on the road shown in **Figure 6 (a)** and **Figure 6 (b)**.

At 13:30, snowstorm occurred on the ground. From 13:30 to 14:00, visibility became poor despite precipitation intensity decreased. It is required to know the reasons why the time lag was large in case of No.4 time period on December 31, 2020. We considered effects of wind-drift on snow particles in the air. Steven A. Lack. et al. mentioned to the effect of wind-drift on radar-derived surface rainfall estimations (*16*). Six 1-kilometer square grid meshes shown in **Figure 8** located in North-West from the square grid mesh including K.P. 72.0 on NR 232. These 1-kirometer square grid mesh are painted by green. **Figure 9 (a)** shows the time series of precipitation intensity on six 1-kilometer square grid meshes and value of the WIPS. **Figure 9 (b)** shows the time series of precipitation intensity on two 1-kilometer square grid meshes, which are 66414588 square grid mesh above K.P. 72.0 and 66415514 square grid mesh. Time lag between precipitation intensity at 66415514 and value of the WIPS was 10.0 (min.). Under strong wind, snow particles did not fall into the road directly below.

It is supposed that snow particles are falling on the road around K.P.72 might be coming from 5-kilometer approximately in the afternoon on December 31, 2020 according to **Figure 9 (b)**. It might be considered that time series of precipitation intensity should be measured on upstream 1-kirometer square grid mesh reflected by wind velocity and wind direction. When we catch visibility conditions on the road by precipitation intensity by XRAIN in winter, it is required to adjust location of the 1-kirometer square grid mesh according to wind velocity and wind direction.

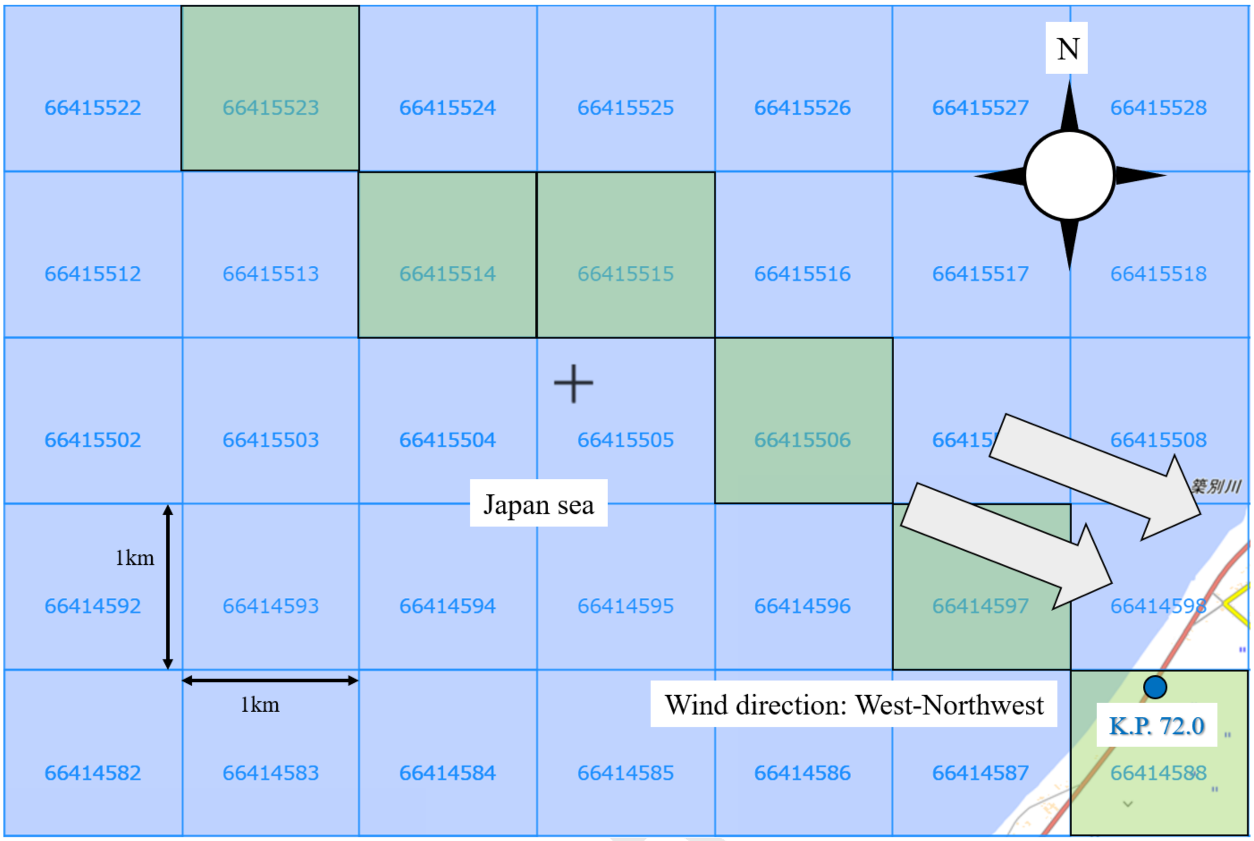

Figure 8 Map of the 1-kilometer square grid mesh West-Northwest side from K.P. 72.0.

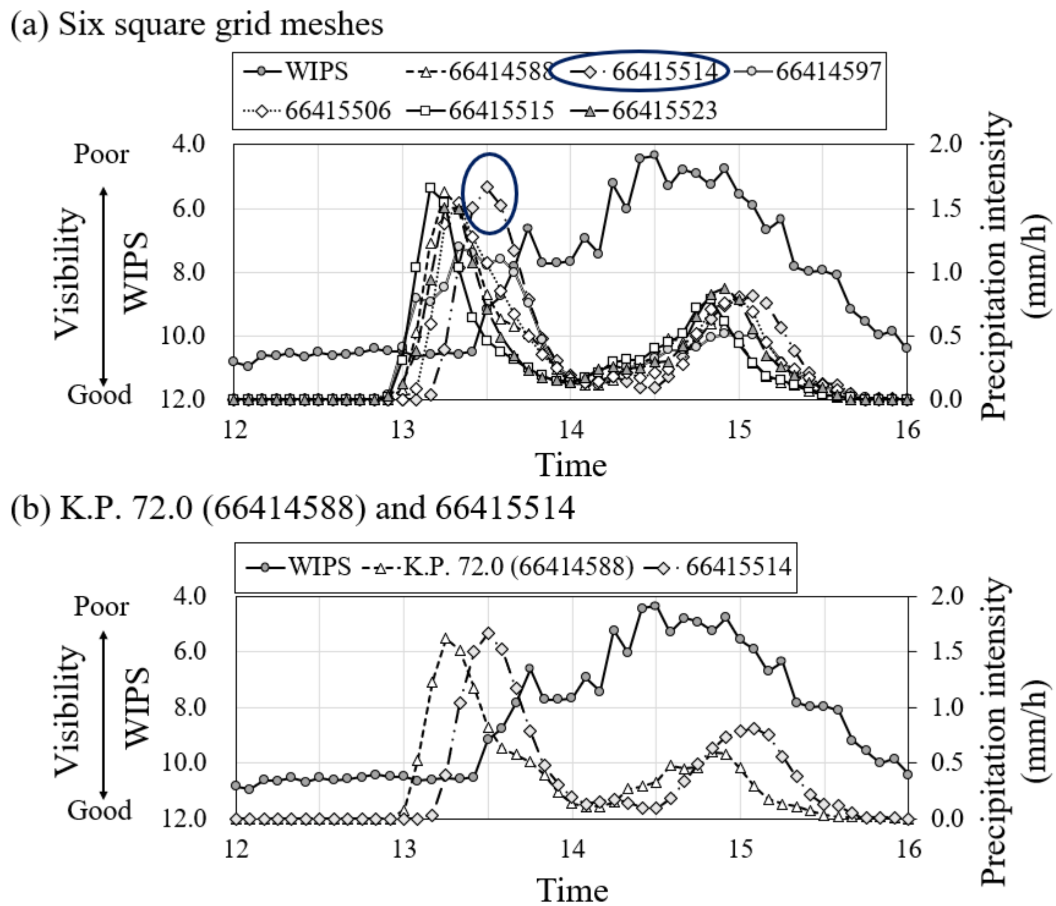

Figure 9 Time series of precipitation intensity at six 1-kirometer grid meshes on December 31, 2020.

CONCLUSIONS

The present study examined relationship between precipitation intensity measured by XRAIN and value of the WIPS using images recorded by the CCTV cameras along the road. As a result, we found cases that value of the WIPS moved in synchronization with precipitation intensity. Value of the WIPS changed with time lag (from 5 to 10 minutes) in response to precipitation intensity. The situations that result in these outcomes are limited to when the maximum precipitation intensity was between 0.5 and 2.0 (mm/h), wind velocity was not so strong, and wind direction was West. In these cases, visibility conditions on the road in winter could be estimated by precipitation intensity by XRAIN. Meanwhile, in several other cases, value of the WIPS did not move in synchronization with precipitation intensity. One case was discussed, when wind velocity was too strong, it is required to adjust location of the 1-kirometer square grid mesh according to wind velocity and wind direction. Then, for estimating visibility conditions on the road in winter, as future research, we will propose a model that should integrate precipitation intensity by XRAIN, wind velocity, wind direction, volume of snow particles on the ground, and so on.

ACKNOWLEDGMENTS

The present study, we used "the XRAIN CXMP composite dataset" provided by the Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT). This dataset was provided by Data Integration and Analysis System (DIAS). DIAS was developed and operated under the auspices of the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Y. Nakamura, T. Hagiwara; collection still images captured by CCTV cameras: Y. Nagata, S. Takahashi; interpretation of weather conditions: R. Tsurumaki, N. Matsuoka. All authors reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Kajiya, Y., Kaneda, Y., and Tanji, K. Factors Inducing Multi-vehicular Collisions During Visibility Reduced by Blowing snow. *Transportation Research Record: Journal of the Transportation Research Board*, 2001. Vol.1745, pp. 61-66.

2. Matsuzawa, M., Kajiya, Y., and Takeuchi, M. The development and validation of a method to estimate visibility during snowfall and blowing snow. *Cold Regions Science and Technology*, 2005. Vol.41, Issue 2, pp. 91-109.

3. Nagata, Y., Hagiwara, T., Kaneda, Y., Araki, K. and Murakami, K. Simple way to use closed-circuit television road images for poor-visibility information. *Transportation Research Record: Journal of the Transportation Research Board*, 2006. Vol.1980, pp. 105-116.

4. Hagiwara, T., Ota, Y., Kaneda, Y. and Araki, K. Method of processing closed-circuit television digital images for poor visibility identification. *Transportation Research Record: Journal of the Transportation Research Board*, 2006. Vol.1973, pp. 95-104.

5. Nakamura, Y., Hagiwara, T. and Nagata, Y. P A study on the detection of deterred driver's visibility caused by snowdrifts by the use of image processing, *Journal of Japan Society of Civil Engineers, Ser. D3 (Infrastructure Planning and Management)*, 2018. Vol.74(5) pp. I_165-I_172. [In Japanese]

6. Nakamura, Y., Hagiwara, T. and Nagata, Y., and Takahashi, T. Development of visibility estimation model on winter road conditions using image-based driver's visibility index by on-board video camera. *Proceedings (Spring) of Society of Automotive Engineers of Japan*, 2022. No.53-22.

7. Klazura, G.E., and Imy, D.A. A Description of the Initial Set of Analysis Products Available from the NEXRAD WSR-88D System. *Bulletin of the American Meteorological Society*, 1993. Vol.74, Issue 7, pp. 1293-1311.

8. Brian R. Nelson., Olivier P. Prat., and Ronald D. Leeper. An Investigation of NEXRAD-Based Quantitative Precipitation Estimates in Alaska. *Remote Sensing*, 2021. Vol.13(16), pp. 3202.

9. Kawasaki, A., Yamamoto, A., Koudelova, P., Acierto, R. A., Nemoto, T., Kitsuregawa, M., and Koike, T. Data Integration and Analysis System (DIAS) Contributing to Climate Change Analysis and Disaster Risk Reduction. *Data Science Journal*, 2017. 16: 41, pp. 1-17.

10. Omiya, S., Kokubu, T., Matsushita, H., Takahashi, J. and Matsuzawa, M. Possibility of quantitative blowing snow estimation using the X-band multi-parameter radar. *Journal of the Japanese Society of Snow and Ice*, 2022. Vol.82(3), pp. 145-156. [In Japanese]

11. Yagmur, Derin., Emmanouil, Anagnostou., Marios, Anagnostou., and John, Kalogiros. Evaluation of X-Band Dual-Polarization Radar-Rainfall Estimates from OLYMPEX. *Journal of Hydrometeorology*, 2019. Vol.20(9), pp. 1941-1959.

12. Nakai, S., Yamashita, K., Motoyoshi, H., Kumakura, T., Murakami, S., and Katsushima, T. Relationships between Radar Reflectivity Factor and Liquid-Equivalent Snowfall Rate Derived by Direct Comparison of X-band Radar and Disdrometer Observations in Niigata Prefecture, Japan. *Journal of the Meteorological Society of Japan*, 2022. Vol.100(1), pp. 45-56.

13. Nagata, Y., Hagiwara, T., Nakamura, Y., Kaneda, Y., Matsuoka, N., Takahashi, S., and Hoshino, H. Vision for Road Visibility Inspection Using Driving Video Images Recorded by On-board camera. *Transportation Research Board*, 2020. no. 20-04308.

14. Oktaviani, F., Miftahuddin, and Setiawan. Cross-correlation Analysis Between Sea Surface Temperature Anomalies and Several Climate Elements in The Indian Ocean. *Parameter: Journal of Statistics*, 2021. Vol.1(1), pp. 13-20.

15. Nakamura, Y., Hagiwara, T., Nagata, Y., and Takahashi, S. Development of poor visibility assessment method in winter using images taken by on-board video camera. *Journal of the Eastern Asia Society for Transportation Studies*, 2022. Vol.14, pp. 1824-1841.

16. Steven A. Lack., and Neil I. Fox. An examination of the effect of wind-drift on radar-derived surface rainfall estimations, *Atmospheric Research*, 2007. Vol.85(2), pp. 217-229.