THERMAL MAPPING APPLICATION FOR SNOW AND ICE CONTROL ON EXPRESSWAYS

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1. Summary

About 80% of the expressways that are managed by Tohoku Branch Office, Japan Highway Public Corporation are in a cold snowy area with the maximum snowfall of 30cm or more. Thus, the efforts to keep traffic in the winter season have been concentrated during the snow and ice control period of 6 months from late in October. In the antifreezing work that is one of the important measures for snow and ice control, antifreezing admixture is dusted over the road surfaces before they are frozen. It is important to collect information such as road surface temperatures not to miss the timing of dusting. The information collection work is commonly carried out in patrol of the expressways, but information on all the routes cannot be obtained in real time. It is necessary to accurately acquire the changing information such as road surface temperatures from point to point.

In the thermal mapping study that was made on some sections of the Tohoku Expressway and the Hachinohe Expressway, atmospheric temperatures and road surface temperatures were measured and collected continuously by the use of a measuring vehicle running through those sections. The measured data underwent a statistic analysis. The data analysis was made by obtaining the traverse thermal distribution, extracting the particular low-temperature sections, calculating the correlativity between measured temperatures at local meteorological observatories and the temperatures measured at the measuring points at intervals of 500m. Then, the effective coverage of each meteorological observatory and the positions of new additional observatories to be deployed were discussed. The low-temperature hazardous sections were arranged in a freezing hazard map.

In this study, the freezing hazard sections that had been grasped empirically could be defined in a quantitative way. Further, the effective coverage of each meteorological observatory that can monitor the real-time thermal information and the road sections outside the coverage were made clear, and the scope of data that is readable from the thermal information available from those meteorological observatories could be extracted.

The results of this study will be applicable as the information to predict some measuring points with freezing hazard in road patrol and to presume road surface temperatures and determine the snow and ice control work based on the data from the meteorological observatories installed at intervals of approximately 10km.

2. Introduction

The expressways and general toll roads that are managed by Tohoku Branch Office consist of 12 routes with a total length of 1,100km, of which about 80% is located in the cold snowy area. About 6 months from late in October has been fixed as a snow and ice control period, during which it is one of the most important tasks of this Branch Office to secure traffic in the winter season. For this purpose, the snow-removal and antifreezing work has to be done during day and night and it is also promoted to provide the facilities such as snow break fences to prevent visibility obstacles. Of the snow and ice control works, the antifreezing work is to dust antifreezing admixture over the road surfaces to prevent accidents due to skidding on icy roads. It is most effective and efficient to dust the admixture just before ice formation. Before the dusting work, road patrol is made and the data from the local meteorological observatories is monitored to grasp the road status and determine the work types. A round of road patrol takes 2 to 3 hours, so that it is difficult to grasp the road surface conditions on all the routes in real time. The thermal mapping study was implemented on the Tohoku Expressway and the Hachinohe Expressway in order to continuously measure the atmospheric temperature and road surface temperature in the traverse direction using a measuring vehicle and make a statistic analysis of the measured data. Based on the analysis, the thermal characteristics of the total length of the measured road sections could be presumed to extract a traverse thermal distribution and particular low-temperature sections. Further, the correlation between the data from local meteorological observatories and the measured data at measuring points was calculated to define the effective coverage of each observatory. The data will be used for future snow and ice control works in an efficient way.

3. Thermal Mapping Study

3.1 Study Sites

This study was carried out on a section of approx. 32km, between Nishine Interchange and Ashiro Interchange of the Tohoku Expressway running through the north area of Tohoku Region and on a section of approx. 15km, between Ashiro Junction Terminal and Johoji Interchange of Hachinohe Expressway. The total length of the sections was 46km. (See Figure 1.)

These sections include the maximum elevation (475m) on the Tohoku Expressway of approx. 700km in total length, and their average climate for the past 5 years had about 140 winter

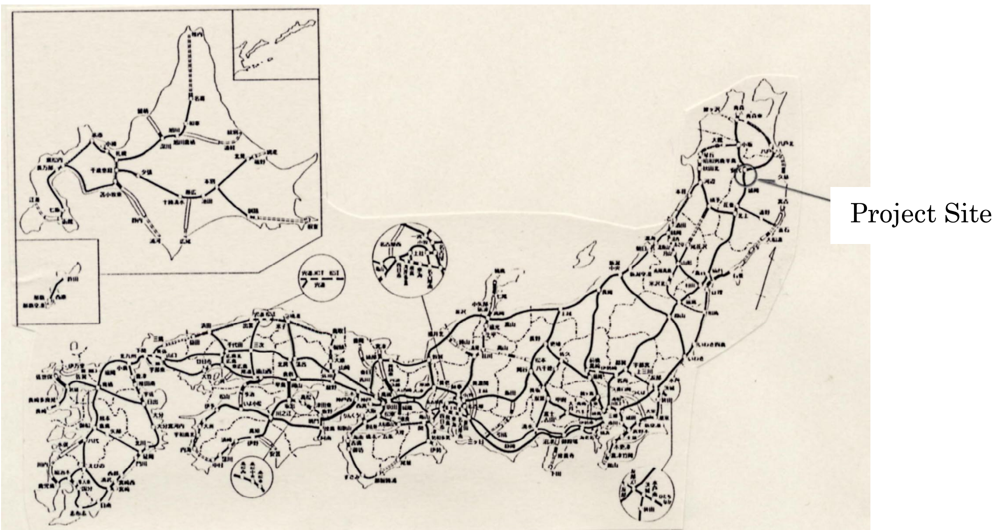

Fig. 1 Location Map

days (where the minimum temperature is less than 0°C) and about 50 midwinter days (where the maximum temperature is less than 0°C), and had about 120 days of snowfall, for a cumulative snowfall of approx. 10m.

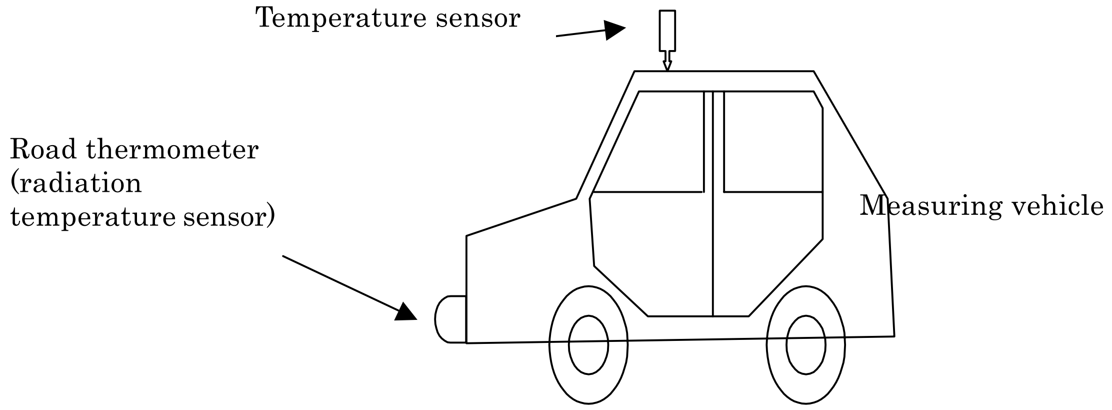

Figure 2 Sketch of measuring vehicle

3.2 Study Method

The thermal mapping study used the method in which a measuring vehicle loaded with a radiation temperature sensor (infrared road thermometer), an atmospheric temperature sensor (thermocouple) and so on was run at a constant speed (60km/h) to sample the data every second and store the sampled data in a personal computer installed inside the vehicle. The information on the positions of meteorological observatories and bridges as well as the road surface conditions was also acquired by the vehicle. This study was carried out for three days when a cold wave was expected to pass over this area during the period of January

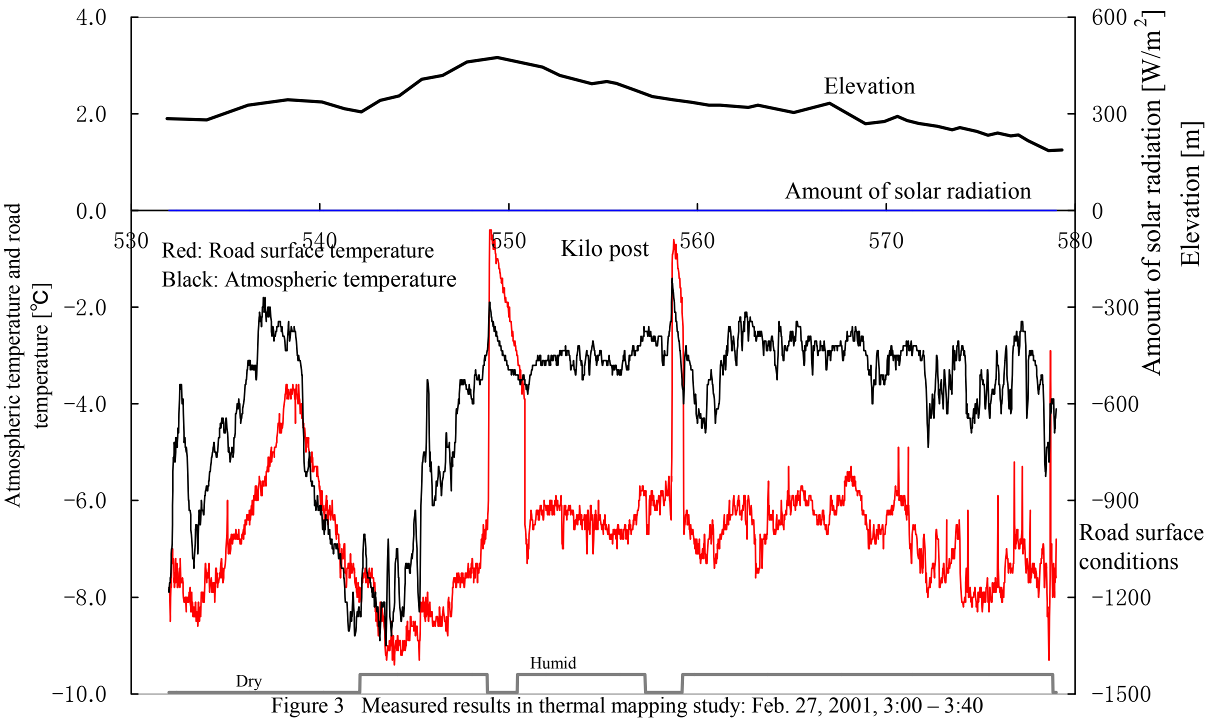

Figure 3 Measured results in thermal mapping study: Feb. 27, 2001, 3:00 – 3:40
(Nishine IC of Tohoku Expressway – Johoji IC of Hachinohe Expressway: Up route)

20 to 22 and February 26 to 27, 2001. The measuring vehicle ran the study sections 18 times in total. Figure 3 shows the results of thermal mapping study.

4. Arrangement of Measured Data

The measured data was arranged as shown in the flow chart in Figure 4. The kilo posts (KP), bridge names data and other remarks were entered into the data measured at intervals of 1-second as listed in Table 1. The measured temperature values obtained every 500m were typically extracted from the values at the closest points. As the measurements were made at intervals of 4-hour, the atmospheric temperatures at specific hours at each measuring point were calculated from the interpolated line between the measured values as shown in Figure 5.

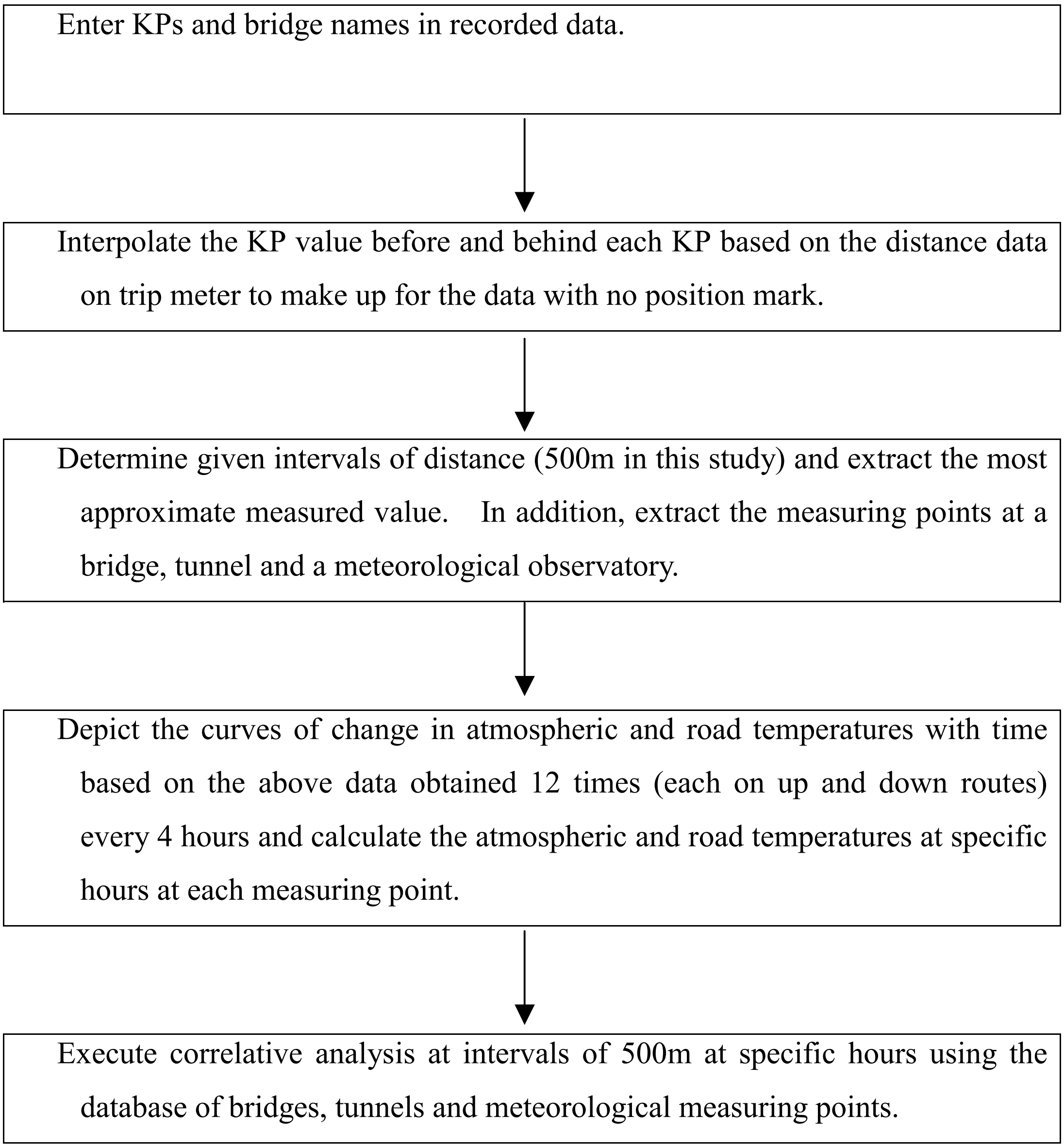

Figure 4 Flowchart of arrangement of measured data

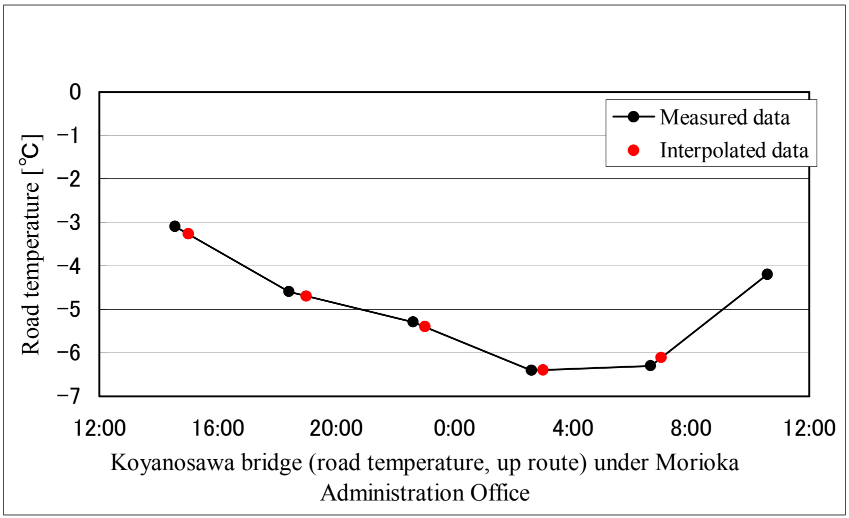

Figure 5 Example of calculation of road temperatures at specific hours based on measured data

5. Extraction of Particular Low-Temperature Sections

On the basis of the general tendency that the temperature falls as the elevation increases, a particular low-temperature section was defined as follows:

(a) A section in which the temperature (atmospheric or road) is 1°C or lower than in the surrounding areas.
(b) A section in which the temperature is low in spite of lying at a low elevation.

In extracting the particular low-temperature sections, the measurements were carried out in three time periods of 22:00 hours, 2:00 hours and 6:00 hours. Figure 6 shows the road temperatures that are the particular low-temperature sections. The extracted sections have the following features:

Section (KP)	Features
Nishine IC – Matsuo IC (KP532 – KP535) in Tohoku Expressway	The section is located in the basin extending at the skirts of the Mount Iwate and easily hit by downdraft from the mountain.
Nishine IC – Ashiro IC (KP536 – KP548) in Tohoku Expressway	The section is apt to be hit by downdraft from the Mount Iwate and Hachimantai mountains.
Ashiro JCT – Ichinohe IC (KP572 – KP579) in Hachinohe Expressway	Located in a narrow valley and running in the northwest direction, the section is apt to be hit by a winter type of cold hovering for a long time because it lies at a low elevation.

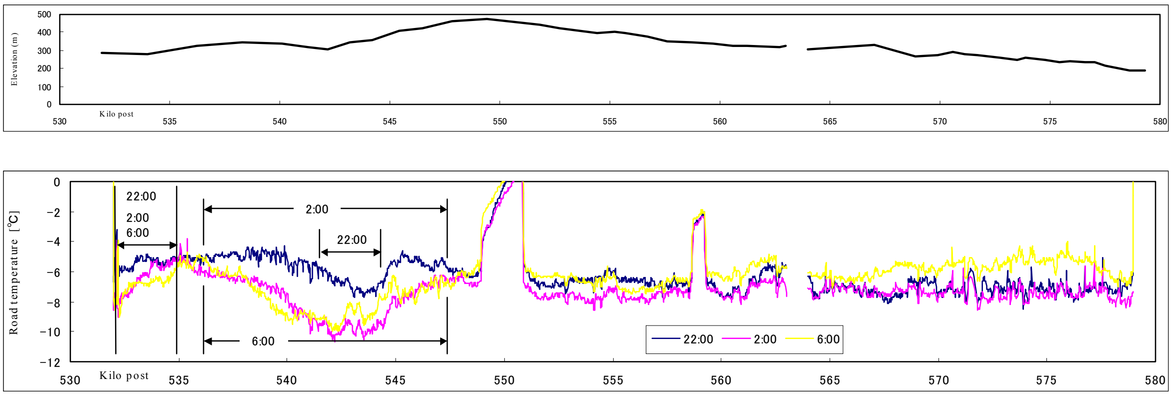

Figure 6 Examples of particular low-temperature points – Road temperatures (Nishine on Tohoku Expressway – Johoji on Hachinohe Expressway: down route)

6. Evaluation of Existing Observatories and Grades of Freezing Hazard Based on Correlative Analysis

6.1 Correlative Analysis of Existing Observatories and Routes

The existing meteorological observatories are used as measuring points and it was not taken into account to measure the data continuously through an entire route. In this study, correlative analysis between the measured values at meteorological observatories and the values at measuring points at intervals of 500m was made in order to verify what section could be covered by the temperature value measured at each observatory and whether each observatory was applicable as the typical point to monitor the changes of atmospheric and road temperatures in the section. Figure 7 shows 4 meteorological measuring points and the correlative coefficients of the measuring points at intervals of 500m that were calculated relative to those 4 points. The correlative coefficients in the dark-shadowed fields are 0.98 or more and those in the light-shadowed fields are 0.95 or more. The correlative coefficients of those measuring points relative to the Hodosaka Tunnel Observatory are shown in Figure 8. As seen from this figure, it is clear that the existing meteorological observatory is not absolutely located at the center of the section and does not cover the section before and behind it. Similarly as seen from Figure 8, the data from the Hodosaka Observatory shows good correlativity on the start point side (KPs of lower numbers), but poor correlativity on the end point side of the section. This means that this meteorological observatory is located at a point under changeable climate, suggesting that the original plan of installing this observatory is right.

The correlative coefficient of 0.98 or more is equivalent to a discrepancy of around 1°C in atmospheric temperature, and 0.95 or more is equivalent to around 2°C, which is deemed to present no problem in practice.

kp	Position	Maemoriyama Observatory	Ryugamori Kita Observatory	Hodosaka Tunnel	Inaniwa Bridge Observatory
532.00	Nishine Toll Plaza	0.91	0.76	0.75	0.82
532.40	Main lane Out	0.87	0.81	0.82	0.86
532.50		0.87	0.80	0.82	0.86
533.00	0	0.88	0.78	0.80	0.84
533.50	0	0.89	0.77	0.79	0.83
534.00	0	0.88	0.81	0.83	0.87
534.50	0	0.87	0.86	0.87	0.91
535.00	0	0.85	0.87	0.89	0.91
535.50	0	0.87	0.92	0.93	0.95
536.00	0	0.82	0.94	0.95	0.96
536.50	0	0.79	0.96	0.97	0.97
537.00	0	0.76	0.94	0.96	0.96
537.50	0	0.81	0.90	0.91	0.93
537.95	Iwate Matsukawa Bridge	0.78	0.87	0.90	0.91
538.00		0.78	0.87	0.89	0.90
538.50		0.77	0.86	0.89	0.90
539.00		0.81	0.86	0.88	0.90
539.50		0.85	0.81	0.83	0.87
540.00		0.87	0.79	0.80	0.85
540.50		0.88	0.78	0.80	0.85
541.00		0.92	0.75	0.76	0.82
541.11	Akagawa Bridge	0.92	0.76	0.77	0.83
541.50		0.96	0.70	0.68	0.77
542.00		0.96	0.74	0.73	0.80
542.50		0.96	0.76	0.74	0.82
543.00		0.99	0.75	0.72	0.80
543.50		0.99	0.74	0.71	0.79
544.00		0.97	0.84	0.80	0.87
544.50	Maemoriyama Observatory	1.00	0.75	0.72	0.78
545.00		0.93	0.91	0.88	0.92
545.50		0.87	0.95	0.91	0.95
546.00		0.87	0.94	0.92	0.95
546.50		0.86	0.94	0.92	0.95
546.74	Koyanosawa Bridge	0.84	0.95	0.93	0.94
547.00		0.86	0.95	0.92	0.94
547.50		0.79	0.96	0.94	0.93
548.00		0.80	0.97	0.94	0.94
548.50		0.79	0.98	0.95	0.94
549.00		0.73	0.96	0.90	0.87
549.50		0.75	0.98	0.92	0.90
549.90	Ryugamori Tunnel	0.75	0.99	0.95	0.91
550.00		0.75	0.99	0.94	0.91
550.50		0.75	0.99	0.96	0.92
551.00		0.76	0.99	0.96	0.92
551.30	Ryugamori Kita Observatory	0.75	1.00	0.96	0.95
551.50		0.74	0.98	0.96	0.90
552.00		0.74	0.99	0.96	0.92
552.50		0.73	0.98	0.97	0.91
552.87	Hoshisawa Bridge	0.73	0.98	0.97	0.91
553.00		0.74	0.97	0.96	0.91
553.50		0.77	0.98	0.96	0.91
554.00		0.77	0.98	0.97	0.93
554.13	Kurosawa Bridge	0.75	0.98	0.97	0.93
554.47	Akasakata Bridge	0.74	0.98	0.98	0.94
554.50		0.75	0.98	0.98	0.94
555.00		0.73	0.97	0.98	0.95
555.50		0.75	0.97	0.98	0.95
556.00		0.74	0.97	0.98	0.95
556.50		0.74	0.96	0.99	0.95
557.00		0.72	0.96	0.99	0.95
557.35		0.71	0.96	0.99	0.95
557.50		0.70	0.96	0.99	0.94
558.00		0.73	0.95	0.98	0.95
558.50	Hodosaka Bridge	0.72	0.96	0.99	0.95
558.55	Hodosaka Tunnel Observatory	0.71	0.96	0.99	0.96
558.60	Hodosaka Tunnel	0.72	0.96	1.00	0.96
558.95		0.71	0.93	0.96	0.93
559.00		0.71	0.93	0.96	0.93
559.50		0.76	0.96	0.97	0.95
560.00		0.82	0.95	0.94	0.94
560.50		0.79	0.95	0.90	0.88
561.00		0.79	0.95	0.90	0.89
561.50	Karuizawa Bridge	0.76	0.96	0.93	0.92
561.65		0.72	0.97	0.95	0.93
562.00		0.77	0.96	0.94	0.95
562.50	Nikaruzawa Bridge	0.75	0.96	0.95	0.96
562.58		0.75	0.95	0.96	0.96
563.00	Hodosawa Bridge	0.75	0.97	0.97	0.96
563.19		0.75	0.96	0.97	0.96
563.50		0.79	0.97	0.96	0.96
564.00		0.78	0.97	0.96	0.96
564.50		0.82	0.96	0.96	0.95
565.00	Tsunagisawa Bridge	0.78	0.97	0.97	0.97
565.15		0.79	0.96	0.96	0.96
565.50		0.79	0.97	0.96	0.96
566.00		0.78	0.97	0.96	0.96
566.50		0.77	0.97	0.94	0.95
567.00		0.79	0.98	0.96	0.96
567.50		0.79	0.97	0.95	0.96
568.00		0.78	0.97	0.97	0.97
568.50		0.78	0.96	0.96	0.97
569.00	Nagamaesawa Bridge	0.80	0.96	0.96	0.98
569.05		0.82	0.95	0.95	0.97
569.50		0.80	0.95	0.95	0.98
570.00		0.81	0.95	0.96	0.97
570.50		0.80	0.95	0.95	0.97
571.00	Urushibata Bridge	0.77	0.94	0.95	0.98
571.28		0.77	0.95	0.96	0.98
571.50	Komagamine Bridge	0.77	0.95	0.96	0.98
571.84		0.78	0.95	0.96	0.98
572.00		0.78	0.94	0.96	0.98
572.50		0.84	0.93	0.94	0.97
573.00	Kaijo Bridge	0.84	0.93	0.95	0.97
573.34		0.82	0.94	0.95	0.98
573.50	Inaniwa Bridge Observatory	0.81	0.95	0.96	0.98
573.80		0.78	0.95	0.96	1.00
574.00	Inaniwa Bridge	0.79	0.95	0.97	0.98
574.07		0.78	0.95	0.97	0.98
574.50		0.86	0.93	0.94	0.97
575.00	Baba Bridge	0.84	0.93	0.95	0.97
575.38		0.83	0.94	0.96	0.98
575.50		0.85	0.93	0.95	0.97
576.00	Yoshida Bridge	0.85	0.93	0.95	0.96
576.38		0.83	0.93	0.95	0.97
576.50		0.86	0.91	0.93	0.96
577.00		0.82	0.92	0.95	0.96
577.50	Ma In route In	0.86	0.88	0.91	0.93
577.90		0.85	0.86	0.90	0.92
578.00		0.86	0.85	0.89	0.91
578.50	Johoji Toll Plaza	0.90	0.85	0.87	0.89
579.00		0.89	0.88	0.89	0.92

Fig.7 Correlative coefficients (atmospheric temperature) of measuring points relative to existing meteorological observatories

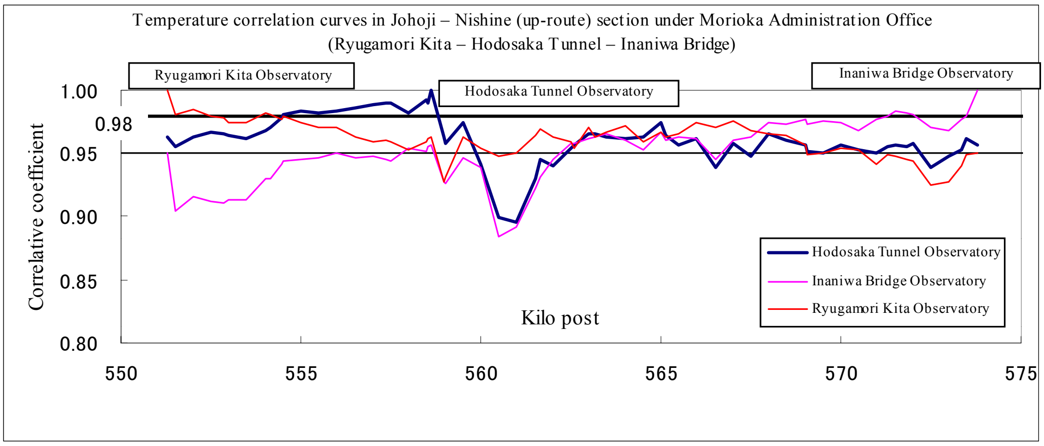

Figure 8 Curves of correlation (atmospheric temperature) with existing meteorological observatory

6.2 Evaluation of Grades of Freezing Hazard

In rounding a section, the work can be conducted efficiently if it is possible to acquire accurate data before road patrol on a section where a high freezing hazard exists or where it is inadequate to rely only on the data from local meteorological observatories because the correlativity between the section and the meteorological observatory is low. Thus, the grade of freezing hazard was evaluated based on the results of correlative analysis.

6.2.1 Category and evaluation of grades of freezing hazard

The grades of freezing hazard in route sections are classified into 4 levels as shown below, on the basis of the particular low-temperature sections extracted in Section 5:

		Minimum temperature relative to the data from meteorological observatory	
		Low	High
Correlativity with meteorological observatory (0.98)	Low	A	C
	High	B	D

Notes:

- A: Low correlativity among particular low-temperature sections and lower temperature compared with a nearby meteorological measuring point
- B: High correlativity among particular low-temperature sections, but lower temperature compared with a nearby meteorological measuring point
- C: Low correlativity among particular low-temperature sections, but higher temperature compared with a nearby meteorological measuring point
- D: High correlativity among particular low-temperature sections and higher temperature compared with a nearby meteorological measuring point

6.2.2 Making up of map of grades of freezing hazard

Figure 9 shows a map of grades of freezing hazard illustrating the road temperatures on the section as categorized above. In this figure, the up and down route sections north of Ryugamori Kita Observatory are categorized to be A or B, having a lower temperature than that at a nearby meteorological observatory. In particular, the section with A has a low correlativity, and it is difficult to presume the temperature value from the data at the

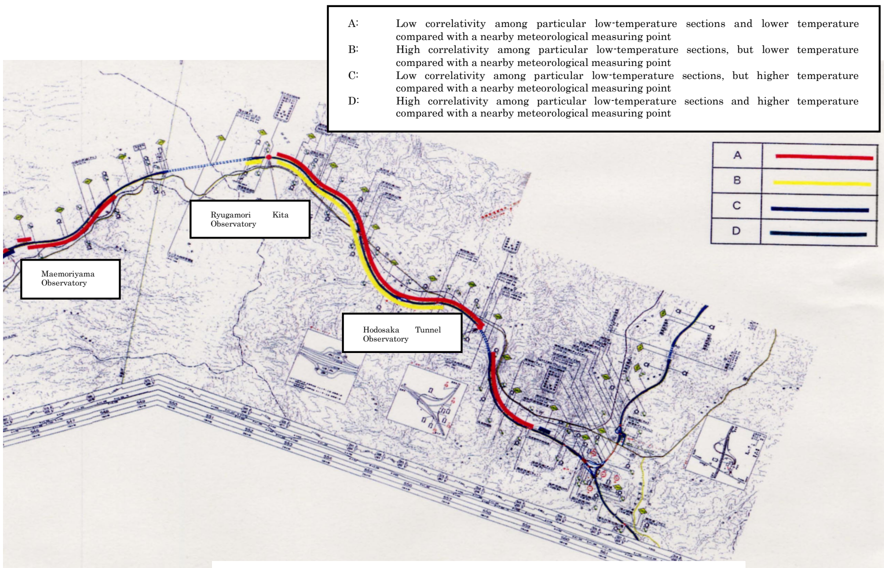

Figure 9 Map of grades of freezing danger

meteorological observatory. In the south of the Ryugamori Tunnel, the up and down routes show the sections of category A alternately. It is deemed that this result was related to the wind direction that affected those sections. As described above, the sections that are liable to be frozen are known from our experience, but the correlative analysis could make clear the relations with the data from nearby meteorological observatories. Therefore, it is possible to effectively use the map of grades of freezing hazard in order to predict the hazardous points in road patrol.

7. Redeployment of Existing Meteorological Observatories

In order to monitor the abrupt change of climate as early as possible, the existing meteorological observatories have been installed mainly before and behind tunnels and bridges where the climate is changeable. From this point of view, the selection of the positions of those existing observatories is surely right, but it is difficult to monitor the road status continuously. Therefore, it was examined how wide the coverage of each existing meteorological observatory could be expanded if it was relocated based on the correlative analysis of the data at intervals of 500m.

Figure 10 shows the correlative coefficients in the case that 4 existing meteorological observatories (yellow fields) are relocated to new positions (green fields) and that a new additional meteorological observatory is installed. In this case, a high correlativity over the entire route can be obtained and the road temperatures on those road sections can be presumed.

Present Status

Road temperature up-route

KP	532.0	532.4	532.5	533.0	533.5	534.0	534.5	535.0	535.5	536.0	536.5	537.0	537.5	537.9	538.0	538.5	539.0	539.5	540.0	540.5	541.0	541.1
Position	Nishine Toll	Main route Out												Iwate Matsukawa Bridge								Akagawa E
Maemoriyama	0.39	0.81	0.84	0.85	0.84	0.85	0.85	0.85	0.87	0.84	0.84	0.83	0.83	0.82	0.82	0.81	0.79	0.78	0.78	0.77	0.80	0.80
Ryugamori Kit	0.41	0.95	0.97	0.97	0.96	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.97	0.97	0.97	0.96	0.97	0.96	0.96	0.96	0.96	0.95
Hodosaka TN																						
Inaniwa Bridge																						

New Installation/ Relocatior

KP	532.0	532.4	532.5	533.0	533.5	534.0	534.5	535.0	535.5	536.0	536.5	537.0	537.5	537.9	538.0	538.5	↓ 539.0	539.5	540.0	540.5	541.0	541.1
Position	Nishine Toll	Main route Out												Iwate Matsukawa Bridge								Akagawa E
539.00	0.49	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.99	0.99	0.98	0.97
545.00	0.48	0.94	0.96	0.96	0.96	0.96	0.96	0.96	0.97	0.95	0.96	0.96	0.96	0.95	0.95	0.95	0.94	0.93	0.92	0.92	0.94	0.94
551.00																						
558.00																						
569.05																						

Figure 10 Correlative coefficients relative to existing meteorological observatories and relative to relocated meteorological observatories

8. Conclusion

In this study, the particular low-temperature sections where attention is to be paid to freezing hazard could be defined. In referring to the map of grades of freezing hazard, the hazardous points in road patrol could also be extracted. On the other hand, the correlative analysis made clear the effective coverage of each existing meteorological observatory, ensuring the target sections to be monitored at the office before road patrol. Furthermore, the potential positions to which any of the existing meteorological observatories should be relocated and in which an additional observatory should be installed can be simulated on the basis of the correlative analysis in advance. Based on this simulation, the meteorological observatories can be redeployed and the temperature distribution over the entire route can be estimated from the data at the meteorological observatories in real time. It is expected that these solutions will contribute to further improvement in the efficiency of the snow and ice control works.