A Method for Predicting Road Surface Temperature Distribution Using Pasquill Stability Classes

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ABSTRACT

It is necessary for road administrators to identify sections on individual routes where freezing is likely to occur and where intensive measures against frozen road surfaces must be taken. The need for such work is especially high at night when temperatures drop and road surface freezing tends to occur. To this end, thermal mapping is used to identify the characteristics of road surface temperature distribution on individual routes.

It is known from the results of such mapping that road surface temperatures vary greatly by section even on the same route, and that the characteristics of this distribution differ widely depending on weather conditions and the time of day or night. Thermal mapping results can be divided into extreme, intermediate and damped depending on weather conditions. Past studies have indicated that these three conditions correspond roughly to G, F, E and D of the Pasquill stability classes used to categorize atmospheric stability.

In this study, a map of road surface temperature distribution at night was created for each of the Pasquill stability classes to enable precise prediction of road surface temperature distribution variations by weather conditions. The level of prediction accuracy was verified by comparing the distribution obtained from these road surface temperature distribution maps and the results of thermal mapping conducted the previous winter.

Keywords: winter road maintenance, thermal mapping, Pasquill stability classes, road surface temperature distribution

1. INTRODUCTION

In cold, snowy regions, road conditions deteriorate due to snowfall, snow cover and temperature reductions in winter. While increased snow removal, de-icing application and other winter road maintenance tasks are conducted to ensure the continued movement of road vehicles, winter traffic performance remains poor, with low travel speeds and a high frequency of slip accidents.

A variety of restrictions also apply (such as limited budget provision for road management and concerns over the environmental burden caused by de-icing application), giving rise to the need for efficient winter road management. As an example, while de-icing application is conducted regularly as a measure against frozen road surfaces, focus is placed on specific sections where freezing is likely to occur rather than treatment along entire routes.

To implement such measures against frozen road surfaces accurately and efficiently, it is necessary to identify sections on individual routes where freezing is likely to occur.

The purpose of this study was to establish a method of predicting road surface temperature distribution on a target route at night in order to enable accurate and efficient winter road management work, including de-icing application, which is often conducted during nighttime and pre-dawn hours.

2. STUDY METHOD

2.1 Literature Review

To improve precision in winter road management, it is necessary to identify changes in winter weather conditions with a higher level of accuracy. To enable a correct understanding of the required timing for snow removal work and changes in freezing and other road surface conditions, the establishment of roadside weather observation devices and the collection of weather information have been promoted (PIARC, 2006).

However, strictly speaking, such devices can only observe weather elements in their target sections, and phenomena occurring in specific areas (such as changes in the road surface conditions of a route) cannot be monitored using only weather sensors at fixed points. To solve this problem, mobile weather measurement has been conducted for many years. Schmidt (1927) and Peppler (1929) first monitored meteorological changes using movable platforms. Since then, vehicles have been used in local meteorology and urban climate studies because of the advantages they offer, including coverage of extensive areas within a relatively short period and the possibility of making different measurements using the same observation devices.

The technique of thermal mapping to monitor surface temperature distribution by running a vehicle equipped with an infrared radiation thermometer was developed in Sweden (Lindqvist, 1976) and Britain (Thornes, 1991). Since then, it has been used to monitor the road surface temperature distribution characteristics of individual routes, identify sections where freezing is likely to occur, and support decision making on de-icing application. In Japan, thermal mapping has been used to assess road surface temperature properties and identify sections of routes prone to freezing since the technique was introduced in the early 1990s (Fig. 1).

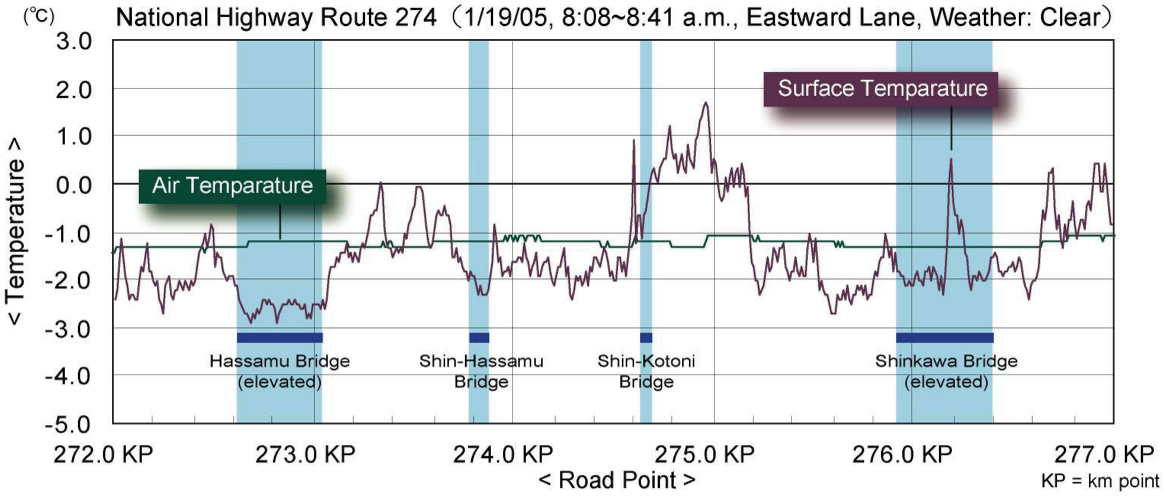

Fig. 1 Sample of Thermal Mapping Result

2.2 Study Method

In thermal mapping, nighttime temperature distribution maps (thermal fingerprints) are created for three weather conditions – extreme, intermediate and damped. These three conditions are known to correspond roughly to G, F, E and D of the Pasquill stability classes used to categorize atmospheric stability (Chapman & Thornes, 2004, SIRWEC).

This study presents a method for predicting road surface temperature distribution at night using Pasquill stability classes, which are used to categorize atmospheric stability based on wind velocity and cloud cover. In Japan, this metric is used for environmental assessment concerning the diffusion of air pollutants. Since the purpose of this study is the development of a method to ascertain surface temperature distribution at night, the classes for nighttime shown in Table 1 are used.

The actual process of identifying surface temperature distribution is as follows:

(1) Thermal mapping
(2) Categorization of thermal mapping results in terms of Pasquill stability classes to assess surface temperature difference distribution
(3) Calculation of road surface temperature distribution by adding the surface temperature differences found in (2) to the temperature difference distribution of the Pasquill stability classes for the target hours

Table 1 Pasquill Stability Classes

Surface wind speed (m/s)	Daytime incoming solar radiation			Daytime / Nighttime cloud cover	Nighttime cloud cover	
	Strong	Moderate	Slight	8 - 10	Upper sky layer 5 – 10, Middle / Lower sky layer 5 - 7	0 - 4
< 2	A	A - B	B	D	G	G
2 – 3	A - B	B	C	D	E	F
3 – 4	B	B - C	C	D	D	E
4 – 6	C	C-D	D	D	D	D
> 6	C	D	D	D	D	D

3. CASE STUDY

3.1 Case Study Route

The target of this study was a 20.23-km-long route spanning National Highways 5 and 274 (Fig. 2). This route is a major national highway that passes through the eastern and northern parts of downtown Sapporo. In the target area, thermal mapping, on-site road surface temperature observation and weather observation have been conducted for a number of years.

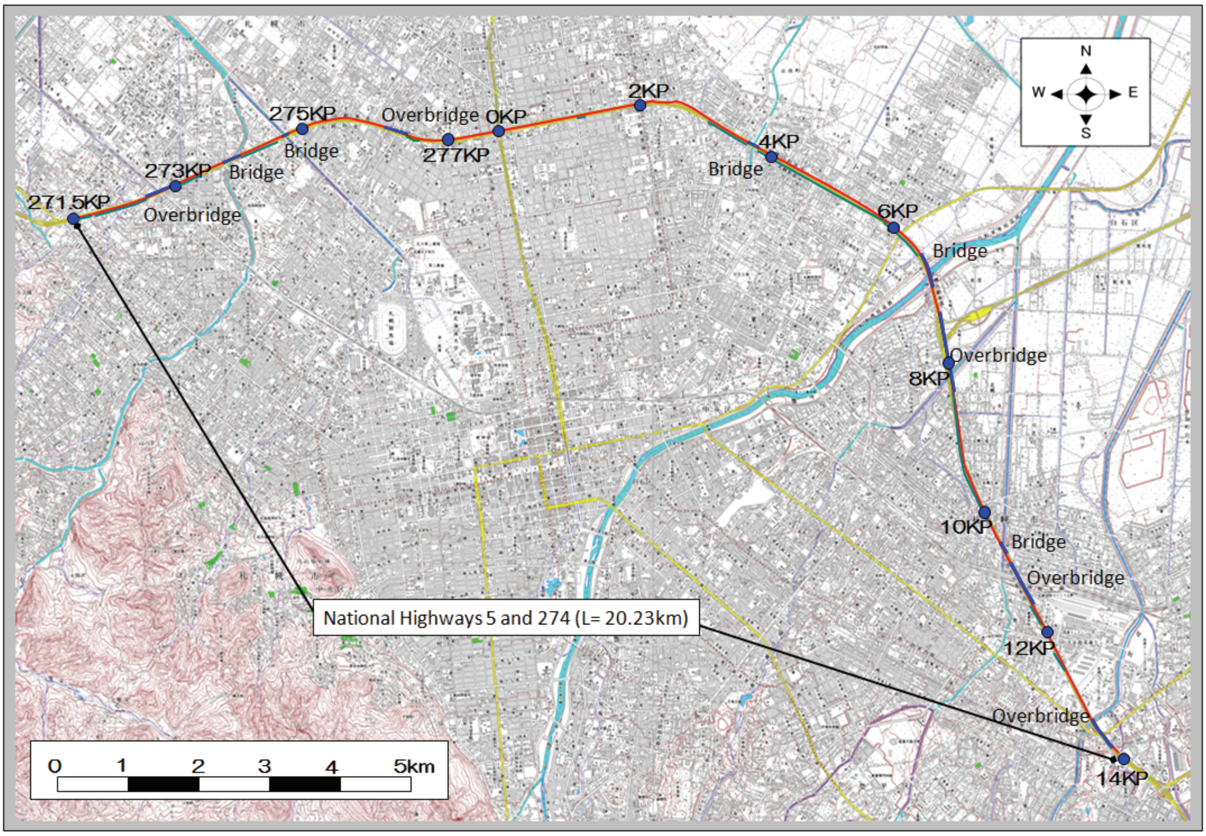

Fig. 2 Case Study Target: National Highway Route 5 and Route 274, Sapporo

3.2 Production of road surface temperature difference distribution charts

Thermal mapping has been conducted every year on the target route. Thermal mapping is conducted in both directions since surface temperature distribution characteristics vary by the direction of travel. The road surface temperature difference distribution charts were produced from the observation results during the winter of 2006 and 2007. From east to west, thermal mapping was conducted nine times in total, and the resulting Pasquill stability classes were D for three and G for six of these occasions. And from west to east, thermal mapping was conducted ten times in total, and the resulting Pasquill stability classes were D for three and G for seven of these occasions. Fig. 3 to Fig. 6 show the road surface temperature difference distribution charts produced from the observation results.

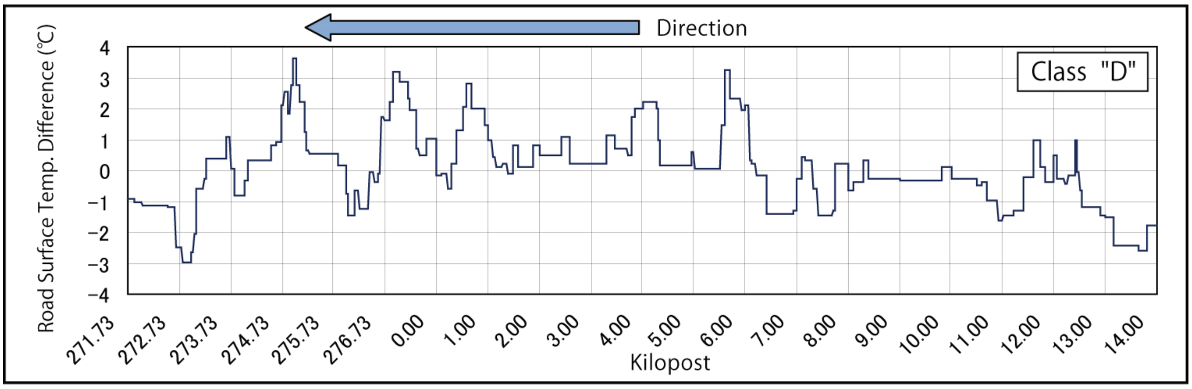

Fig. 3 Road Surface Temperature Difference Distribution
(Direction: East to West, Pasquill stability class: D)

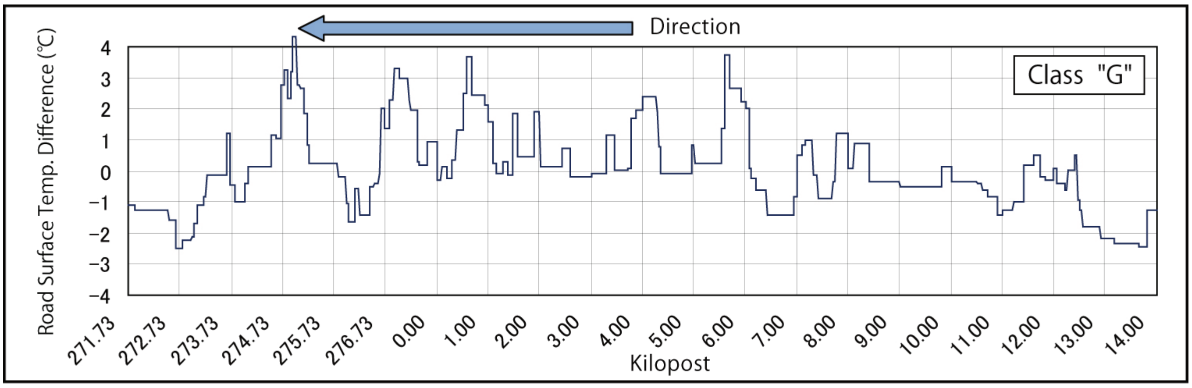

Fig. 4 Road Surface Temperature Difference Distribution
(Direction: East to West, Pasquill stability class: G)

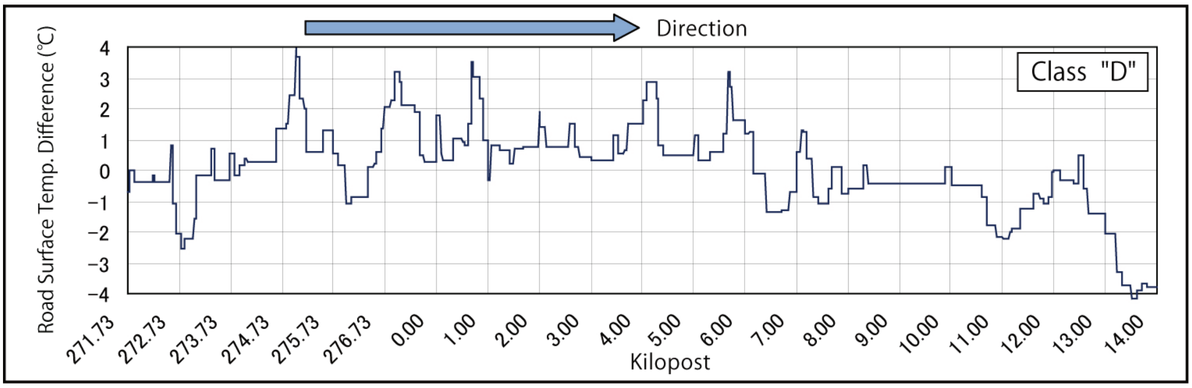

Fig. 5 Road Surface Temperature Difference Distribution
(Direction: West to East, Pasquill stability class: D)

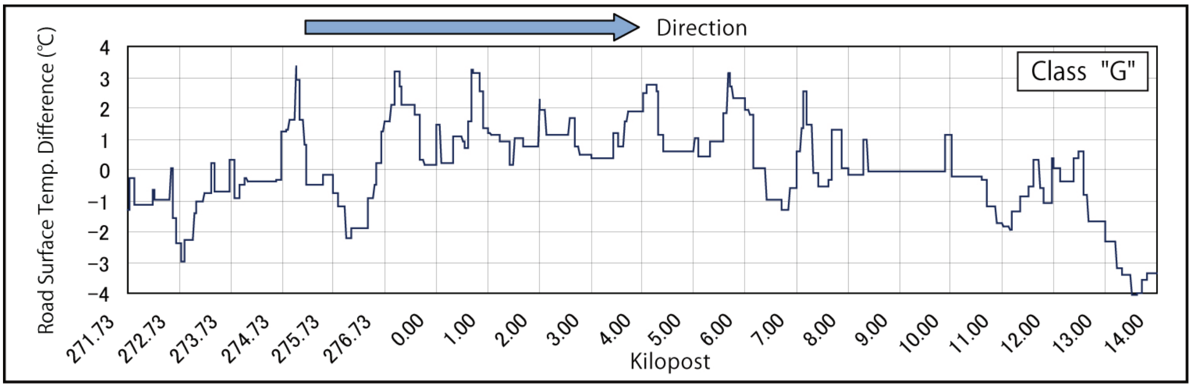

Fig. 6 Road Surface Temperature Difference Distribution
(Direction: West to East, Pasquill stability class: G)

4. TEST RESULTS

The accuracy of road surface temperature prediction using the surface temperature distribution charts produced as outlined in the previous chapter was confirmed. Road surface temperatures on the target route were measured using thermo couples. The calculated road surface temperatures (found by superimposing the above measured values onto the surface temperature difference distribution chart corresponding to the Pasquill stability class at the time of thermal mapping) were compared with the thermal mapping results.

Thermal mapping was conducted twice on February 4, 2009. The first run (Run-1) started at 3:14 from east to west, the second (Run-2) at 4:09 from west to east, and the third (Run-3) at 4:57 from east to west. The Pasquill stability class was G in both cases, as the cloud cover value was 1 and the on-site wind velocity was less than 2 m/s. The measured road surface temperatures were superimposed onto the surface temperature difference distribution chart for Pasquill stability class G. Figures 7, 8 and 9 show a comparison between the calculated values and the results of Run-1, Run-2 and Run-3, respectively.

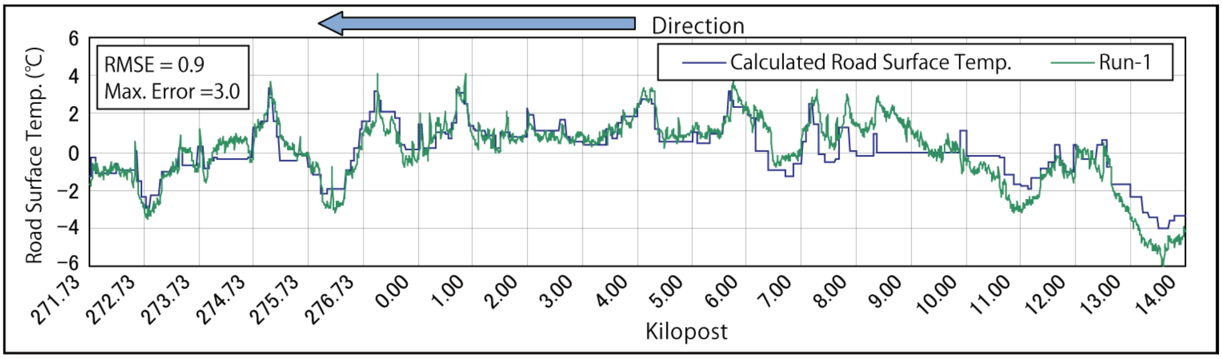

Fig. 7 Comparison of Road Surface Temperatures
(Calculated Values and Thermal Mapping Run-1)

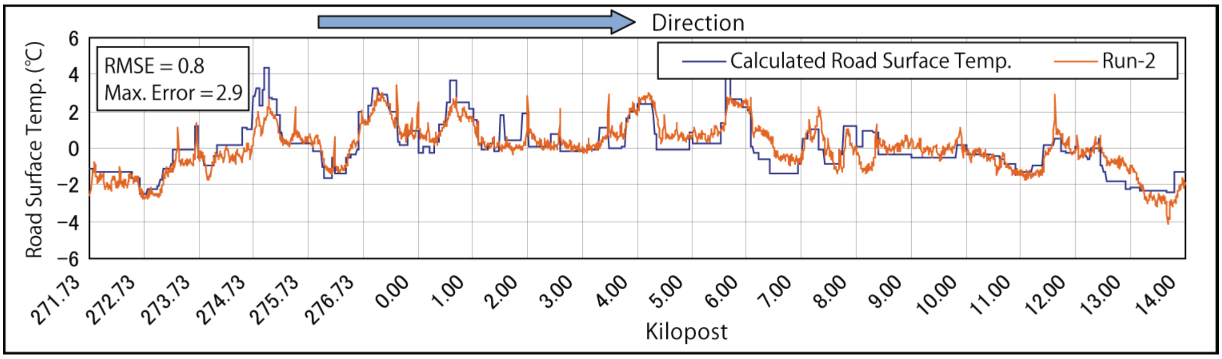

Fig. 8 Comparison of Road Surface Temperatures
(Calculated Values and Thermal Mapping Run-2)

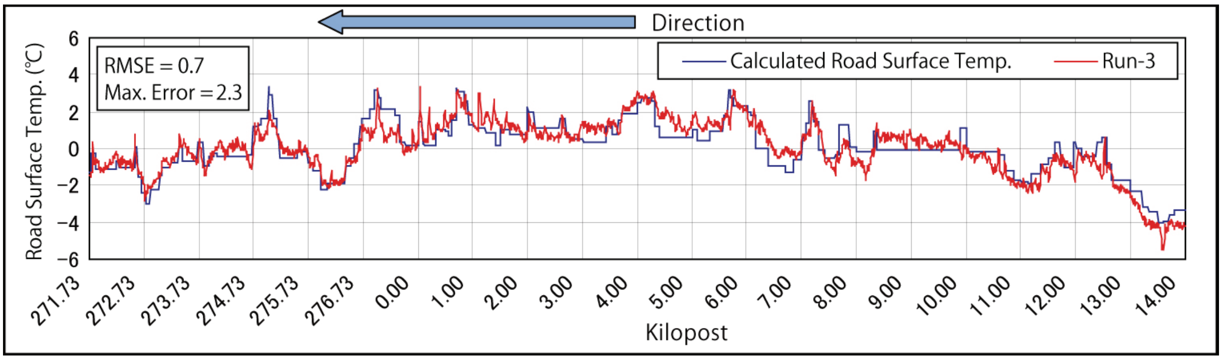

Fig. 9 Comparison of Road Surface Temperatures
(Calculated Values and Thermal Mapping Run-3)

To verify accuracy, the root mean square error (RMSE) and maximum error values were found. The RMSE can be calculated using Eq. (1). In Run-1, the RMSE was 0.9°C and the maximum error was 3.0°C. In Run-2, the RMSE was 0.8°C and the maximum error was 2.9°C. In Run-3, the RMSE was 0.7°C and the maximum error was 2.3°C. While large errors were observed locally, the RMSE remained under 1°C and the degree of accuracy was high. It was also found that the level of error was less than 1°C in 74.2% ad less than 2°C in 97.7% of all the data from Run-1, the level of error was less than 1°C in 84.3% and less than 2°C in 98.1% of all the data from Run-1, and that it was less than 1°C in 86.4% and less than 2°C in 99.5% of all the data from Run-3.

From east to west, errors of 2°C or more occurred between KP 8.0 and 9.0 in Run-1 and at around KP 276.9 km in Run-3. And from west to east, errors of 2°C or more occurred at around KP 5.6, KP 6.4, KP 7.3, KP 7.7, between KP 8.1 and 8.3 in Run-2. Sometimes Large surface temperature divergences occurred at bridge sections, but the cause of these large errors is unclear as of now.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \quad (1)$$

where,

y_i = calculated value

$\hat{y}_i$ = actual measured value.

5. CONCLUSIONS AND FUTURE THEMES

It was confirmed that the method of creating a road surface temperature distribution pattern for each Pasquill stability class was effective in estimating surface temperature distribution on a certain route at night. Since the cause of errors in sections with large surface temperature divergences has not been fully clarified, the authors plan to investigate this matter in the future. Plans are also under way to continue thermal mapping surveys for data accumulation and accuracy improvement, and to produce and verify the accuracy of road temperature distribution charts for Pasquill stability classes E and F, which have not been included in past thermal mapping. A method for predicting daytime road surface temperature distribution will also be considered, since road-surface freezing may occur even during the daytime in the weather conditions of Sapporo’s winter.

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