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

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INTRODUCTION:

- Road conditions worsen due to snowfall, snow cover and decline of temp. in winter.
- Winter road maintenance is indispensable.
- Winter traffic performance remains low, with low travel speeds and a high frequency of slip accidents.

Restraining factors

- Limited budget for road management
- Environmental burden caused by anti-icing agent

Need to enhance the efficiency of winter road maintenance

e.g.) anti-icing agent application (often conducted at night)
→conduct where freezing is likely to occur

Need to identify sections on routes where icing potential exists.

Objective:

Establish a method of predicting road surface temp. distribution at night in order to enable accurate and efficient winter road maintenance operations.

STUDY MEHOD:

Literature Review

To improve precision in winter road maintenance
- identify changes in winter weather conditions and road surface conditions circumstantially.

Mobile weather observation

–Cover extensive areas within a relatively short period
–Use same observation devices.

Thermal Mapping

–Monitor the road surface temp. by a vehicle equipped an infrared sensor
–Identify road surface temp. distribution characteristics & sections where icing potential exists.
–Support decision making on anti-icing agent application.

…In Japan, thermal mapping was introduced in the early 1990s

– Nighttime temp. distribution maps (**Thermal Fingerprints**) are developed.
extreme, **intermediate** and **damped**.

– Known to correspond roughly to G, F, E and D of the Pasquill stability classes. (Chapman & Thornes, SIRWEC)

Surface wind-speed (m/s)	**Thinly overcast or ≥ 4/8 octas of low cloud**		**<4/8 octas cloud**	
<2	**G**	*extreme*	**G**	*extreme*
2-3	**E**	*intermediate*	**F**	*intermediate*
3-5	**D**	*damped*	**E**	*intermediate*
5>	**D**	*damped*	**D**	*damped*

Source: RWIS Web Guide, http://www.sirwec.org/documents/rwis_web_guide.pdf

Pasquill stability classes

- Categorize atmospheric stability based on wind velocity and cloud cover.
- In Japan, this index is used for environmental assessment concerning the diffusion of air pollutants.

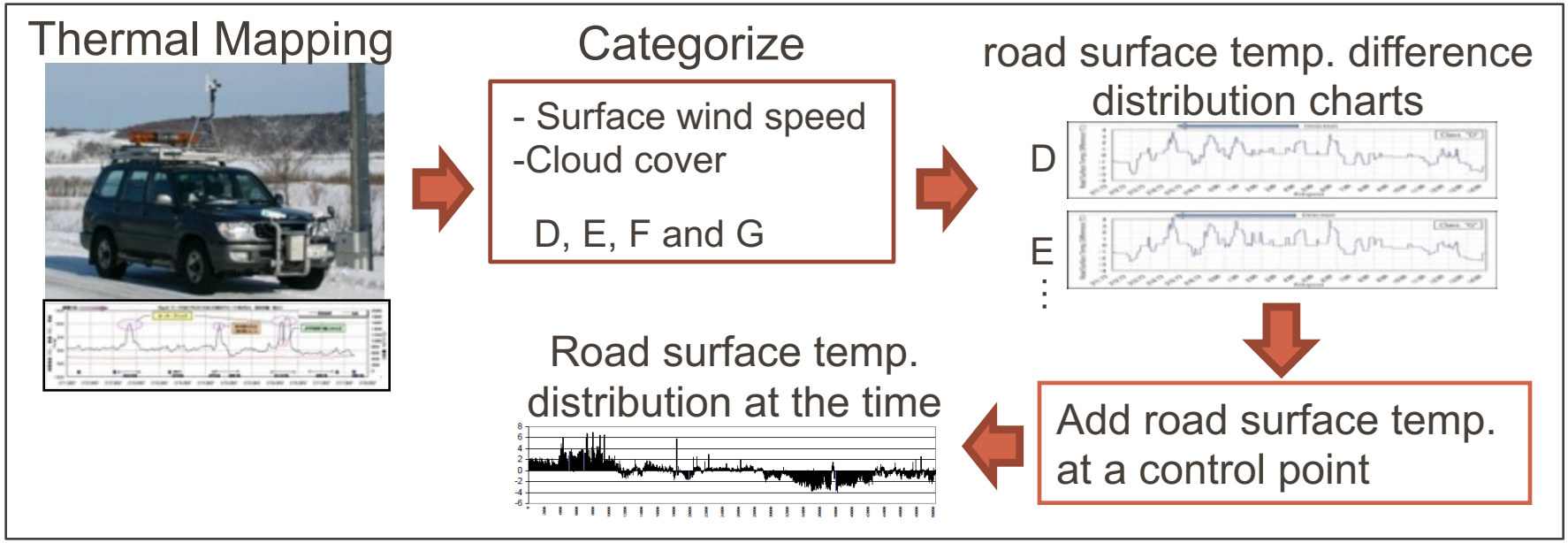
Pasquill stability classes applied in Japan

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

This study tests to predict road surface temp. distribution at night using Pasquill stability classes.

The process of identifying surface temp. distribution

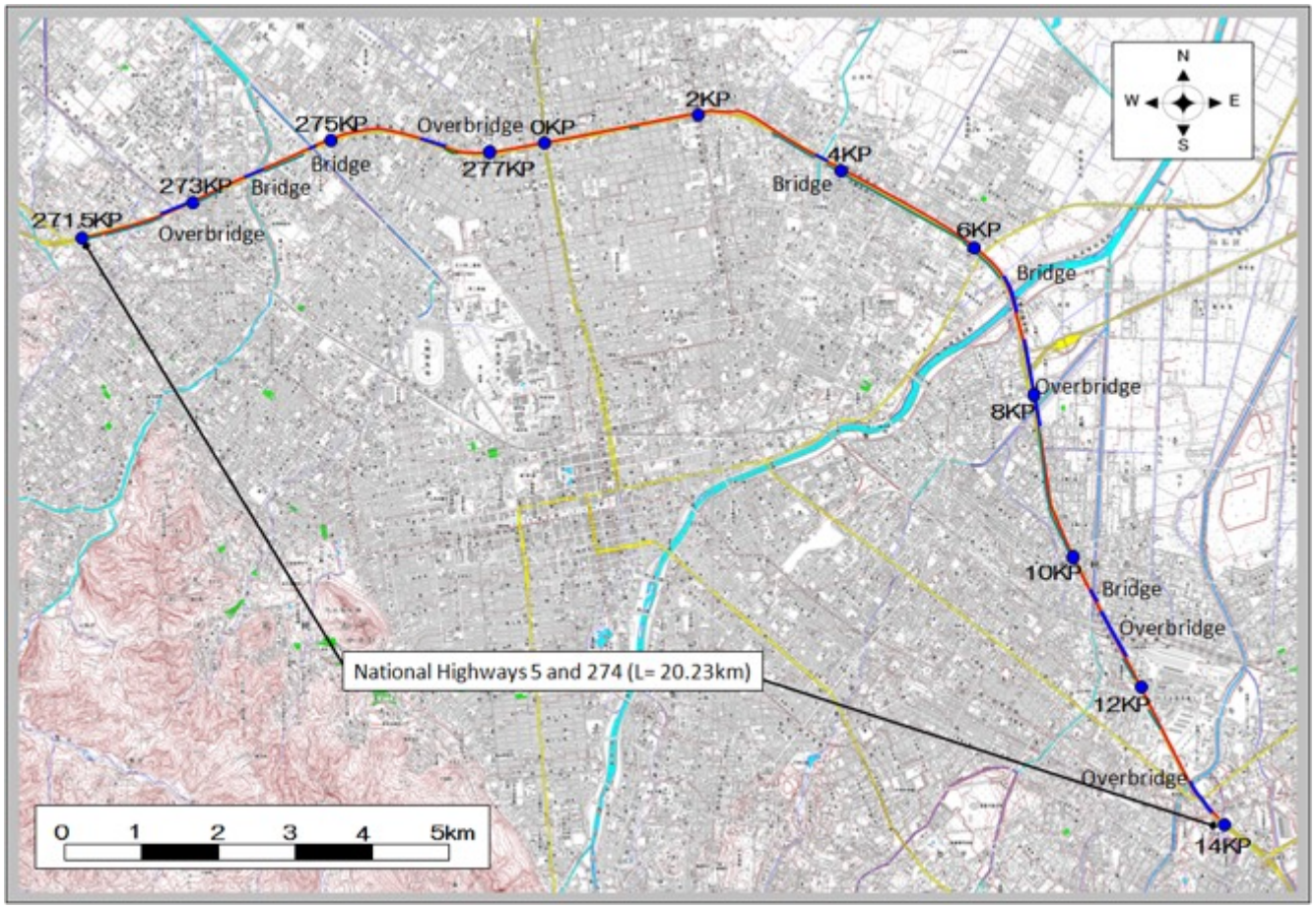
1. Thermal mapping
2. Categorize thermal mapping results in terms of Pasquill stability classes
3. Produce surface temp. difference distribution chart for each Pasuquill stability class
4. Calculate road surface temp. distribution by adding road surface temp. at a control point to the chart found in (3).



CASE STUDY:

Case Study Route:

- National Highways 5 and 274 (L= 20.23km).
- Major national highway that passes through the eastern and northern parts of downtown Sapporo.



Production of road surface temp. difference distribution charts

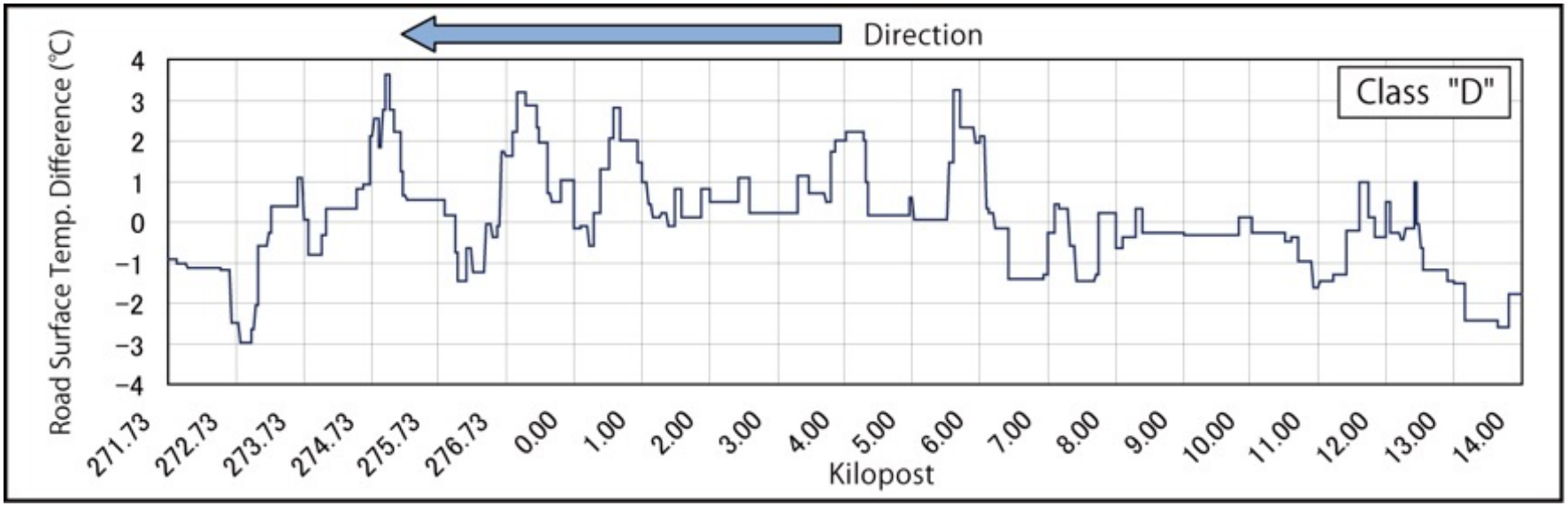
- Thermal mapping was conducted in both directions *surface temp. distribution characteristics vary by the direction of travel.
- The road surface temp. difference distribution charts were produced from the observation results during the winter of 2006 and 2007.

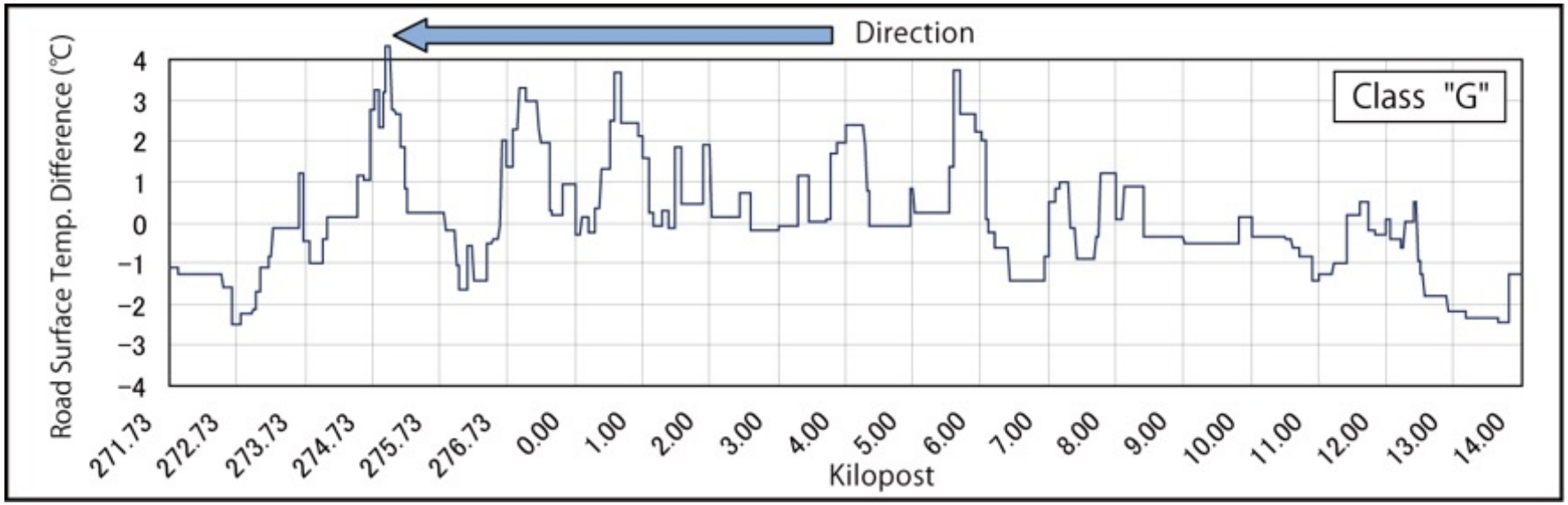
From east to west:
- Thermal mapping: 9 times in total
- Pasquill stability classes: D for 3, G for 6.

From west to east:
- Thermal mapping: 10 times in total
- Pasquill stability classes: D for 3, G for 7.

Road surface temp. difference distribution charts

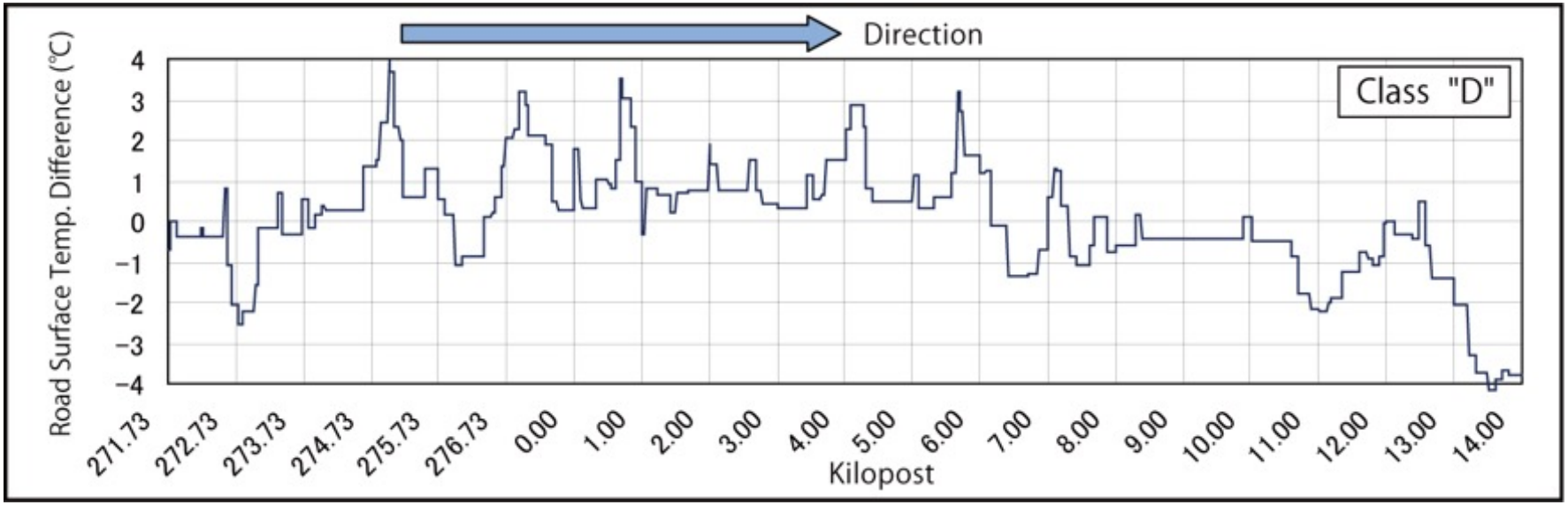
Direction: East to West

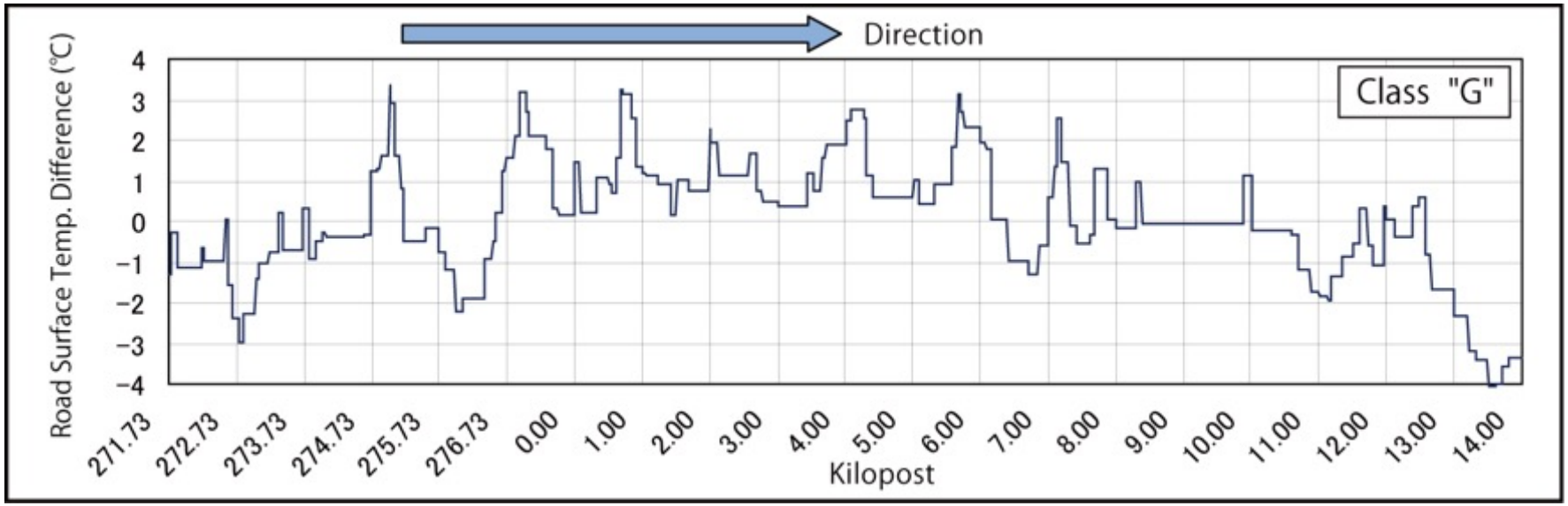




Road surface temp. difference distribution charts

Direction: West to East





TEST RESULT:

- The accuracy of calculated road surface temp. distribution using the surface temp. distribution charts produced was confirmed.
- Road surface temp. observation point on the target route was used as a control point.
- The calculated road surface temp. distribution* was compared with the thermal mapping results.

*found by adding the measured values at the control point to the surface temp. difference distribution chart corresponding to the Pasquill stability class at the time

- Thermal mapping was conducted 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 temp. were added to the surface temp. difference distribution chart for Pasquill stability class G.

Verification:

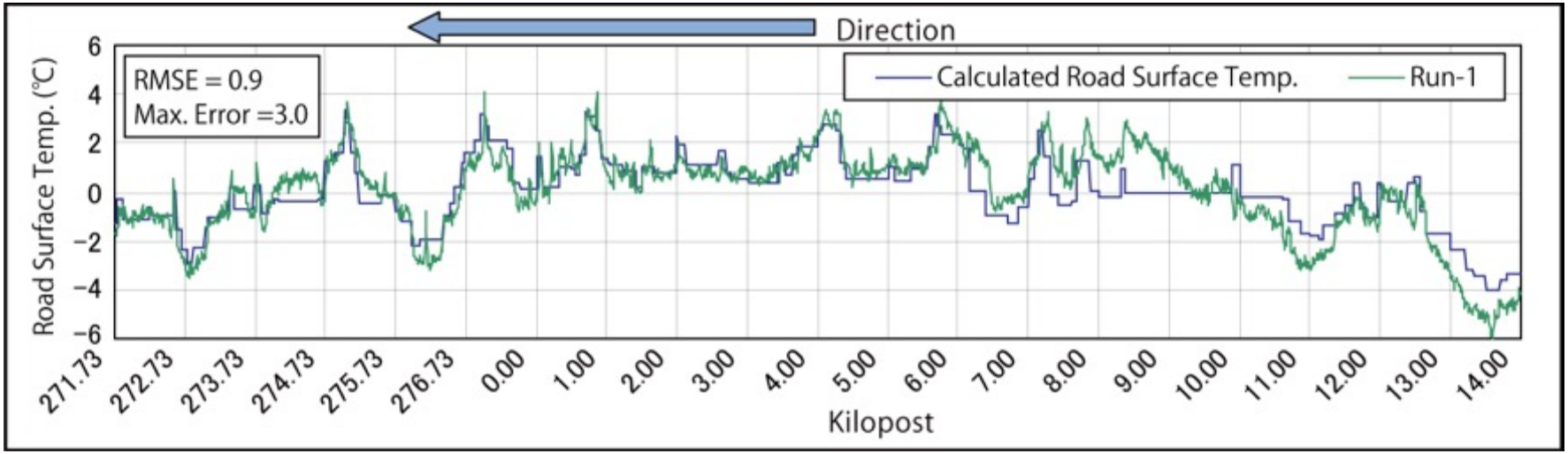
- To verify accuracy, the root mean square error (RMSE) and maximum error values were found.

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

y_i = Predicted Value
$\hat{y}_i$ = Measured Value

Run-1:

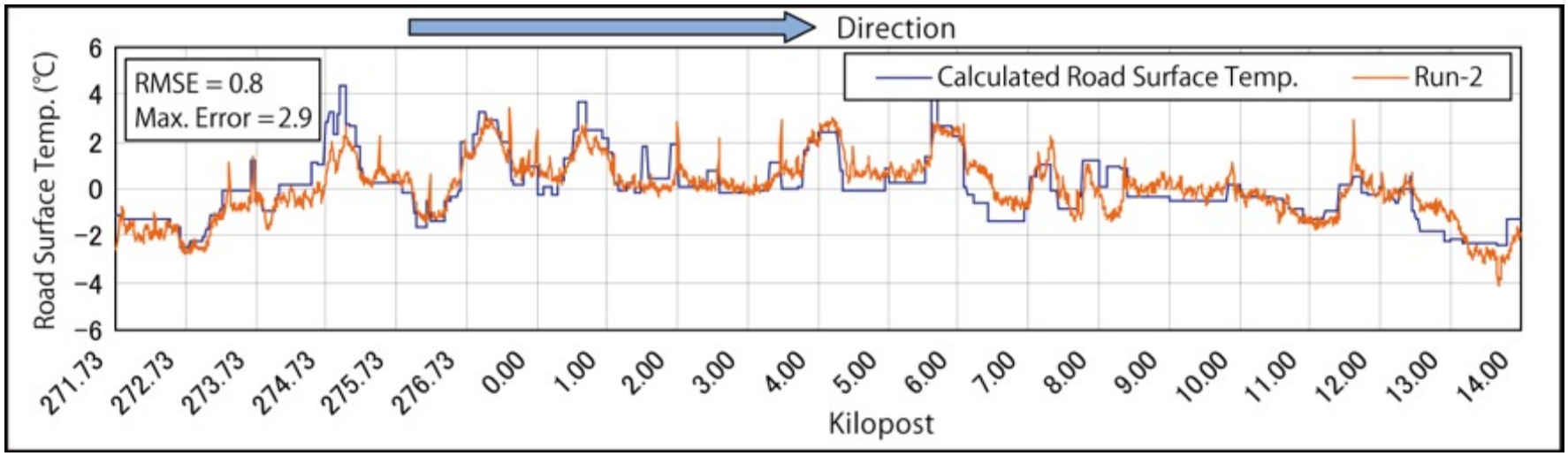
- Pasquill stability class G
- RMSE was 0.9 degree Celsius & maximum error was 3.0 degree Celsius
- Level of error: less than 1 degree Celsius in 74.2%, less than 2 degree Celsius in 97.7%
- Errors of 2 degree Celsius or more occurred between KP 8.0 and 9.0



Comparison between the calculated values & the thermal mapping results of Run-1

Run-2:

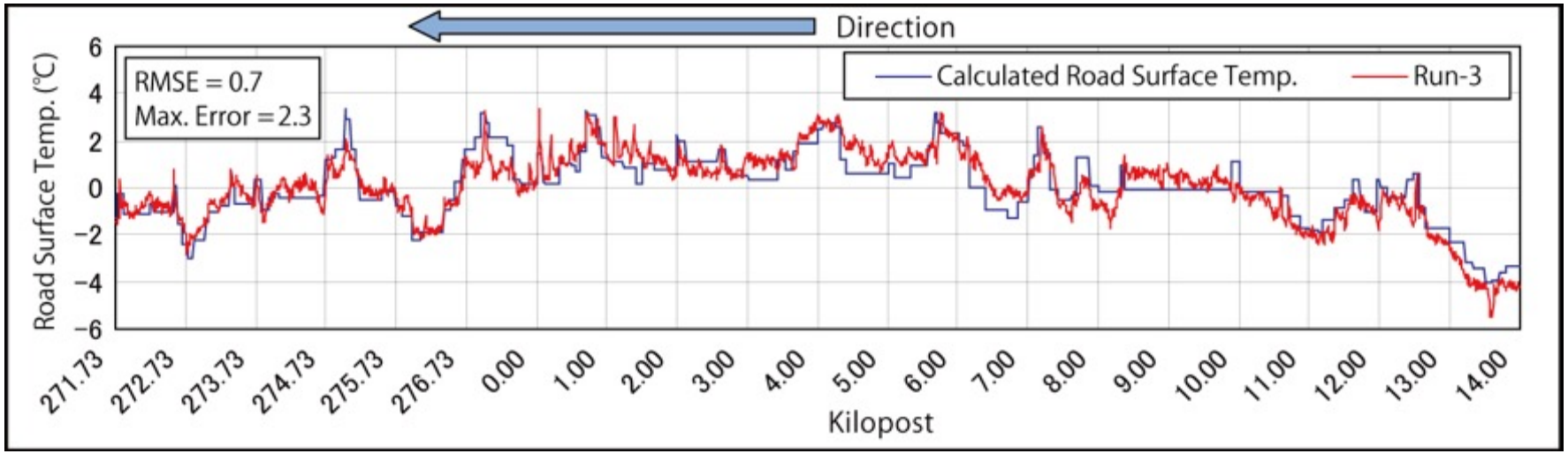
- Pasquill stability class G
- RMSE was 0.8 degree Celsius & maximum error was 2.9 degree Celsius
- Level of error: less than 1 degree Celsius in 84.3%, less than 2 degree Celsius in 98.1%
- Errors of 2 degree Celsius or more occurred at around KP 274.8, KP 5.6, between KP 8.1 and KP8.3 & KP11.6



Comparison between the calculated values & the thermal mapping results of Run-2

Run-3:

- Pasquill stability class G
- RMSE was 0.7 degree Celsius & maximum error was 2.3 degree Celsius
- Level of error was less than 1 degree Celsius in 86.4% and less than 2 degree Celsius in 99.5%
- Errors of 2 degree Celsius or more occurred at around KP 276.9



Comparison between the calculated values & the thermal mapping results of Run-3

- Large surface temperature divergences occurred at bridge sections, but the cause is unclear as of now.

CONCLUSIONS & FUTURE STUDIES:

- The method of creating a road surface temp. distribution pattern for each Pasquill stability class is effective in estimating surface temp. distribution at night.
- The cause of errors in sections with large surface temp. divergences has not been clarified.
- Continue thermal mapping surveys for data accumulation and accuracy improvement, and to produce and verify the accuracy of road temp. distribution charts for Pasquill stability classes E and F.
- A method for predicting daytime road surface temp. distribution will also be considered, since road-surface freezing may occur even during the daytime in the weather conditions.

Thank you for your attention!

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