NIGHT ICING POTENTIAL – DEMONSTRATION PROJECT

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ABSTRACT

Thermal imaging of roadways is an effective approach to deal with frost for regions which experience mild and very moist winters where the formation of frost on roadways is a dominant winter road maintenance problem. The cost-benefit ratio of this technique, done in the traditional manner, for cold snowy winter climates is poor and operational applications lacking. However, it is important to develop new tools using these techniques to deal with ever milder winters that a warming climate will bring where frost will become more common.

This project used a very cost-effective approach for the preparation of infra-red (IR) thermal fingerprints. A Nova Scotia Transportation and Infrastructure Renewal (NS TIR) patrol vehicle equipment with an IR sensor and an Automatic Vehicle Location (AVL) service was used to perform IR data runs along a section of Highway 104 in Pictou County, Nova Scotia. The signal from the IR sensor was fed directly into an AVL unit. The AVL unit used a GPS antenna to determine vehicle location and relayed that along with the temperature information directly to the AVL provider, Grey Island.

AMEC meteorologists coordinated the IR runs with NS TIR staff. IR run data was extracted from the Grey Island web site daily and analysed against the weather from the previous night along the route. Events were classified as Extreme, Intermediate, Damped, or Unusable and thermal fingerprints for each weather type for the route were produced in a modern GIS format.

The thermal fingerprints for highway 104 were then associated with the two (2) Road Weather Information Systems (RWIS) along the route and the route divided into equal, one-kilometre long, segments. Operationally, the appropriated (Extreme, Intermediate, or Damped) segmented thermal fingerprint corresponding to the coming nights prevailing forecast weather was used together with the associated RWIS forecast pavement temperature and dew points, to produce hourly forecast pavement temperatures for each segment of the route. The earliest time at which frost could form in each kilometre-long segment is then determined and plotted on a GIS map of the route. Thus a single simple graphical guidance product to deal with frost formation is delivered daily to the maintenance supervisor. It indicates whether any frost is possible for any segment of the route, and if so, the earliest time at which frost could form in those segments where frost is possible.

The NIP product was developed in early 2007 and tested in the spring and fall of 2007. A modern GIS-based format for thermal fingerprints will be presented. The logic and steps in the preparation of a Night Icing Potential (NIP) chart will be covered and the NIP product will be described. NIP product assumptions and limitations will be reviewed. Finally, verification results from the NIP operational demonstration phase will be provided.

INTRODUCTION

Thermal imaging of roadways using infra-red (IR) sensors was first developed almost two decades ago. IR sensing has been used to quantitatively describe the thermal behaviour of a roadway at night under various weather conditions along its entire length ([i]). The diagrams produced are generally referred to as thermal fingerprints. As more roads in an area are 'fingerprinted', a two-dimensional thermal map for an entire road network, or part of it, can be produced. However, acquiring the IR data for the roadway is a labour intensive, time consuming, expensive process.

In the last several decades, road agencies around the world have been deploying Road Weather Information Systems (RWIS) which monitor atmospheric and pavement conditions at a single point. Meteorological services are then retained for the preparation of forecasts of future road surface temperature and condition for the RWIS locations. These services perform very well today but only for the instrumented location. Thermal fingerprints provide a means of determining which road segments are colder or warmer than its associated RWIS site and can be used to forecast pavement temperature changes along the entire length of the roadway at night. These products are particularly effective winter maintenance tools in mild and very moist winter climates such as are found in the southern United Kingdom where the formation of frost on roadways is a dominant winter road maintenance problem. Using RWIS data and forecasts together with thermal fingerprints provides a means of determining where along a roadway surface temperatures may drop to below 0º Celsius over the coming night. With early morning relative humidity values in excess of 97% on virtually all nights, one can then make a very safe assumption that frost will form on those sections of roadway where road surface temperatures dip below freezing.

For cold, snowy winter climates such as are found through most of southern Canada, the formation of frost on roadways presents a greater challenge. Road surface temperatures can be well below freezing the entire night all along the full length of the roadway but frost may not be present at all or form only along some sections. This is because all of the necessary conditions for frost to form on the roadway have not been met. Specifically, road surface temperature must drop to below freezing and the road surface temperature must be below the air dew point. To forecast where and when frost will form, if at all, one must determine where and when road surface temperatures will simultaneously meet these two necessary conditions.

While snow fighting or snow clearing continues to be the dominant winter road maintenance concern across most of southern Canada, our recently warming climates may cause fundamental changes to the amounts and types of precipitation in winter and the shoulder seasons. With milder and moister conditions becoming more common, the occurrence of frost on roads will increase. It will therefore become very important to have tools to deal effectively with this phenomenon.

Producing thermal fingerprints and thermal maps in the traditional manner, by contracting out the entire data acquisition activity, was generally prohibitively expensive in cold climates where the formation of frost on roadways is less prevalent and the benefits to be gained smaller. Further, the ultimate end use of these products had never been advanced to the point of providing a simple, operationally useful product to guide the maintenance decisions of road supervisors. Still the formation of black ice on roadways is a particularly insidious road hazard that is especially difficult to deal with. With the occurrence of frost becoming more common under warming climates, this treacherous phenomenon needs to be addressed. Modern informatics tools can be effectively applied to determine precisely when and where there is a Night Icing Potential (NIP). This paper describes some new approaches.

COST-EFFECTIVE THERMAL FINGERPRINTS

This demonstration project used a very cost-effective approach for the preparation of thermal fingerprints. Officials of the Nova Scotia Department of Transportation and Infrastructure Renewal (NS TIR) proposed to acquire all of the IR data themselves. A patrol vehicle, suitably equipped with a Sprague RoadWatch IR sensor and an Automatic Vehicle Location (AVL) unit, was already available as well as contracted operator time. The AVL service provided by Grey Island Systems Inc. collects vehicle location, speed, heading, and time information using the Global Position System (GPS) and provides this information back to NS TIR through the Internet. The IR sensor was connected directly into the AVL unit so that road surface and air temperatures from the RoadWatch unit were also relayed to Grey Island along with the location and time information. In this way, NS TIR carried out very cost-effectively, as part of their regular road patrolling, the full data acquisition portion of the thermal fingerprint production process.

A section of Trans-Canada Highway (TCH) 104 in Pictou County, Nova Scotia, was selected for this demonstration project (Figure 1). The test length commenced just east of New Glasgow and ran 42 kilometres along TCH 104 to the Pictou County line halfway to Truro. There are two RWIS sites along the route: Upper Mount Thom and Mount William Road. The terrain varies significantly along the route from near sea level around New Glasgow to elevations approaching 250 metres above sea level in the Mount Thom area. Mount Thom is known to be particularly prone to dangerous driving conditions due to local weather and elevation effects.

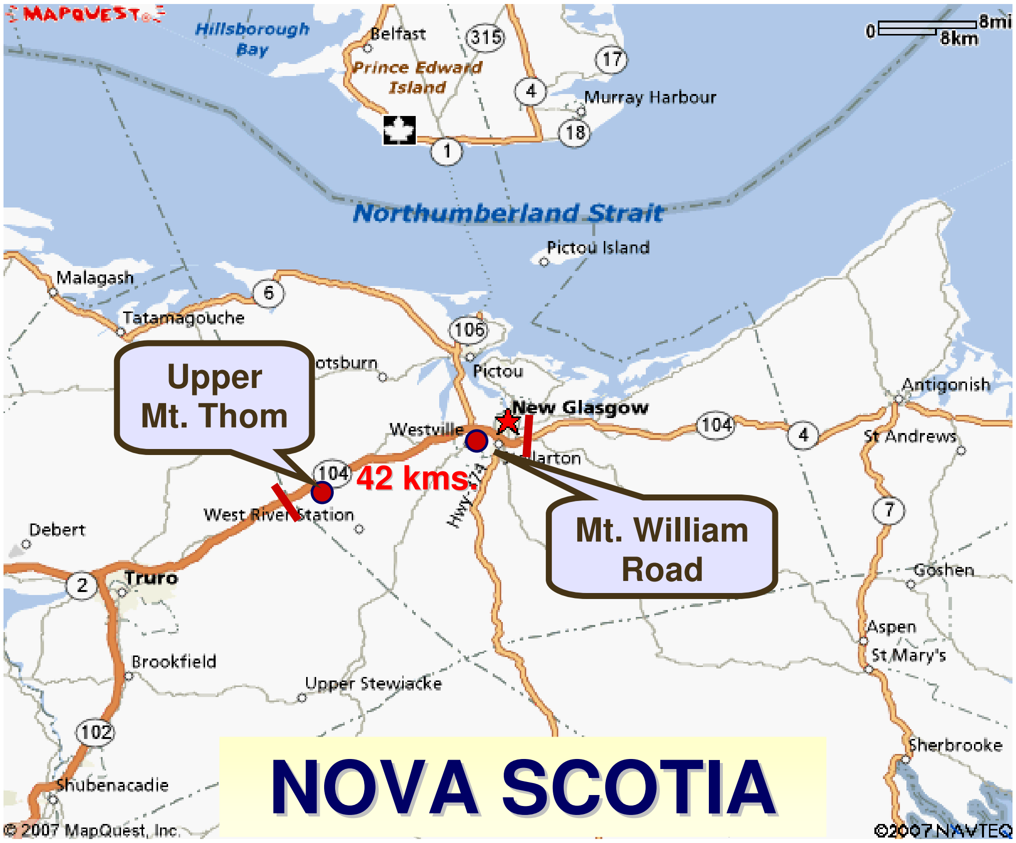

Figure 1. Demonstration area.

All of the runs were performed starting from the west end of the route and while driving in the East-Bound (EB) lane. The Sprague RoadWatch IR sensor claims to be able to sense a 1º C surface temperature change in 1/10 of a second (accuracy of ± 1 º C and a response time of 0.1 seconds). The Grey Island AVL unit was able to provide regular position, and therefore temperature and time fixes, at 2 second intervals. Shao and Lister ([ii]) recommend a sampling interval of 4 to 5 meters. For this reason, the speed of the patrol vehicle was slowed to 35 kilometers per hour (9.7 meters/second). This provides a set of temperature and locations readings at intervals of 20 meters or about 2100 data points per run along the test route. For highway applications, this was considered sufficient.

Thermal fingerprints are generally produced for three set weather types: Extreme, Intermediate, and Damped ([iii]). Extreme in this case means clear and calm conditions which yield the most *extreme* temperature variations along the road surface. Intermediate is defined as partly cloudy conditions with light to moderate winds. Damped refers to the weather conditions that will yield the least temperature variation along the roadway: overcast and windy conditions.

MODERN THERMAL FINGERPRINTS

AMEC meteorologists coordinated the IR runs with NS TIR staff. IR run data was extracted daily and analysed against the weather from the previous night along the route. A total of 23 runs were performed over the period 6 February to 13 March 2007. The analysis consisted of the following steps:

1. Confirmation of suitability and classification according to weather type;
2. Fixing the run start and end points;
3. Scanning the run data to remove any erroneous readings;
4. Calculation of the mean road surface temperature for the entire run and then the deviations from the mean at each data point;
5. Data filtering of the road surface temperature deviations from the mean;
6. Precise positional alignment of run data points; and
7. Averaging multiple runs performed under each of the set weather types.

Runs were classified as Extreme, Intermediate, Damped, or Unusable. Whenever there had been any precipitation of any type, the roads had been treated, or there were weather fronts moving through the area, the run was deemed unusable and discarded.

Occasionally, the IR sensor was not able to acquire a reading and errors, coded as 999, appeared in the road surface temperature data. These needed to be removed. On a few occasions, the vehicle stopped for some minutes, likely to deal with some road hazard, and then continued the run. Resulting data gaps also needed to be removed and precise positioning of the vehicle along the route determined. Since runs were not all started at exactly the same point and the speed varied during each run, careful alignment of the data sets from successive runs was required. The eastern-most start point from the west end of the route over all of the runs was chosen as the common start point and all data west of this point were discarded. Similarly, the western-most end point at the east end of the route was established as the common end point for all runs.

The average road surface temperature for the entire run was then calculated. Then, at each data point, the mean road surface temperature for the run was subtracted from the actual road surface temperature. This gives deviations from the mean along the run and identifies those road segments that were warmer and colder than the mean. The road environment is quite dirty, with many surface irregularities and slight variations in vehicle speed causing the IR data to be quite noisy. Cleaning the data consists of removing spurious outlying data points by a technique known as data filtering. The non-recursive low-pass adjustable filter described in Shao and Lister ([ii]) was used for this purpose.

Latitudes and longitudes provided with the AVL service were used to calculate the actual position along the route from the start point. In this way, the curves generated from successive runs could be lined up correctly for comparison and averaging. Finally, filtered curves from the collection of runs according to each weather type were averaged to arrive at a single IR fingerprint for each weather type: Extreme, Intermediate, and Damped.

The next exercise was to confirm that the classic thermal fingerprint reported in the literature ([iv]) could be produced. Figure 2 shows the thermal fingerprint for the Extreme case for TCH 104. Two graphics are aligned vertically in the figure: the x-axis of the top graph is distance in kilometres along the roadway while that of the bottom graph is longtitude along the roadway. The y-axis of the bottom section of the diagram provides the elevation of the roadway, in metres, above mean sea level, while the y-axis of the upper section provides the deviation of the road surface temperature from the mean in degrees Celsius. The shapes that appear in the lower part of the diagram along the road elevation curve, are rudimentary indicators of land cover along TCH 104. Rectangles represent built-up areas while green triangles represent vegetation and, when stacked vertically, treed areas. Parallel lines denote overpasses or bridges.

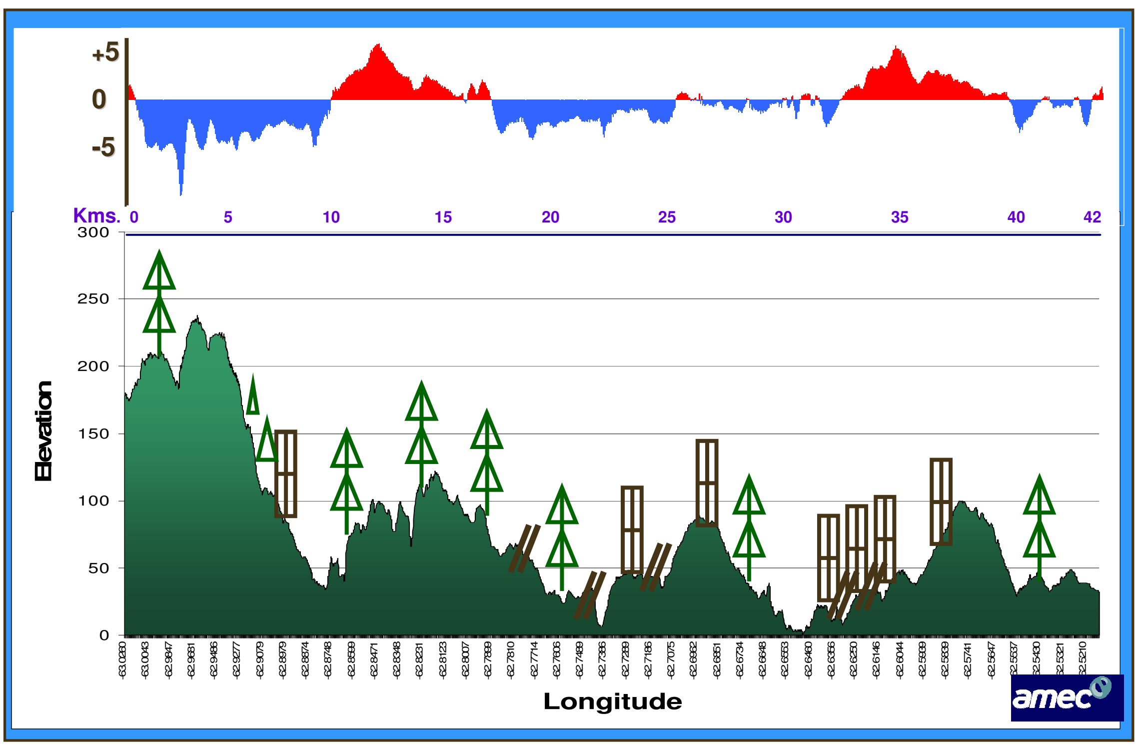

Figure 2. Classic Extreme Thermal Fingerprint for TCH 104 in Nova Scotia.

The classic representation of thermal fingerprints predates the development of Geographic Information Systems (GIS) applications which offer significant advantages for the representation of thermal fingerprints. Figure 3 is a modern representation of the same Extreme thermal fingerprint for TCH 104 in Nova Scotia in a GIS map format. The diagram is composed of three parts. The upper panel presents land cover and road temperature variations along the western half of the route and a lower panel provides those for the eastern half of the route. The legend in the upper left corner provides the color codes for the land-cover and the temperature ranges for the colours along the road itself. A much broader two-dimensional aerial view surrounding the road and adjacent areas is provided. The GIS database provided by NS TIR allowed selections from nearly 100 different land use categories for analysis, allowing the richer representation to be user definable in GIS software applications.

The insert, middle right panel, provides an aerial two-dimensional view of the topography along the route. The terrain mapping colors range from aqua for near sea level to dark brown for 442 meters above sea level. This is important since the road's thermal behaviour is more a function of the lay of the land spatially in two dimensions than just the elevation along the road itself.

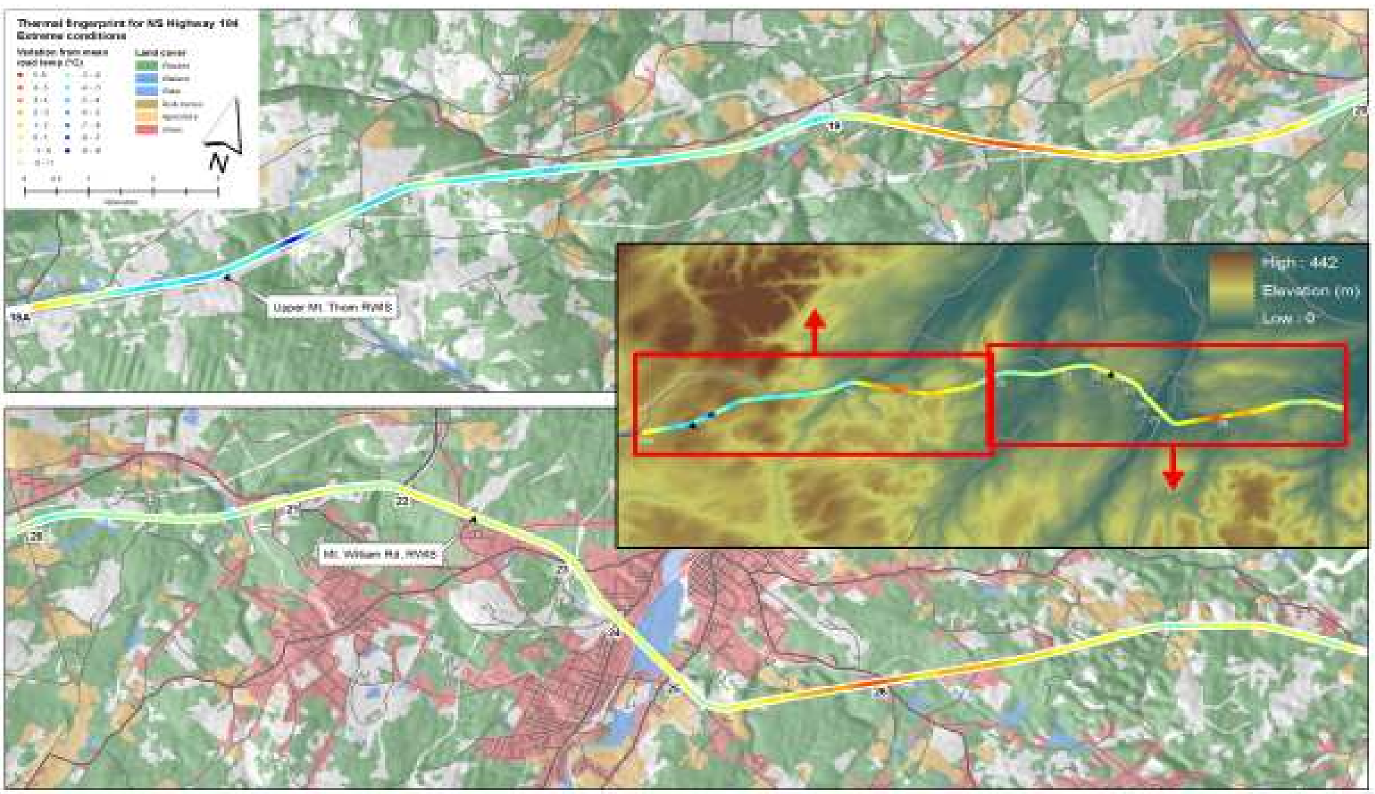

Figure 3. Modern Thermal Fingerprint (Extreme) for TCH 104 in Nova Scotia in GIS format.

The temperature variations from the mean along the roadway are also provided in the topographic insert in the middle right panel. Finally, the precise location of the two RWIS along TCH 104, Upper Mt. Thom and Mt. William Road, are provided in all three panels.

This GIS representation for a thermal fingerprint provides much more information than the classic representation. Users can import and display other land cover data for analysis and can very easily modify the whole representation at will. The thermal fingerprint data itself can be imported into other GIS applications for other purposes. Thermal fingerprints for the three weather types were produced in this format and made available as a digital layer for NS TIR's use.

OPERATIONAL NIGHT ICING POTENTIAL SERVICE

The modern thermal fingerprint presented in Figure 3 is a powerful tool that imparts an enormous amount of information about the road's thermal behaviour. As such it possesses intrinsic value for winter road maintainers newly assigned to that section of TCH 104. It allows individuals to acquire, through some tens of minutes of study, the intimate knowledge of the roadway's thermal behaviour that would otherwise have taken years of working the road to acquire. Despite this, the modern thermal fingerprint in this form remains a challenge to use operationally in cold snowy climates.

More work was required to develop a simple tool to determine which road segments might be subject to the formation of frost on any given night and, if there was a night icing potential, when would frost form and on which specific segments along the road. The following steps were required:

1. Associate roadway portions with one of the two RWIS sites;
2. Segment the roadway – break it up into discrete segments; and
3. Determine the temperature differential from the associated RWIS site for each roadway segment.

Figure 4 illustrates the first step--association. A relationship needs to be established between different road segments and a neighbouring RWIS station, since forecasts prepared for the RWIS sites provide the starting point in assessment of Night Icing Potential (NIP). Since there are two RWIS stations along this 42 kilometre stretch of TCH 104, a coarse first guess association could have been done simply by dividing the route in half and assigning the west half to the Mt. Thom site and the eastern half to the Mt. William site.

Figure 4 provides all three thermal fingerprints: Extreme in red, Intermediate in purple, and Damped in blue, together with the elevation curve in green. All three curves converge at a point approximately one third of the way from the western end of the route. This also corresponds roughly to the base of

Mt. Thom and provides a more suitable break point in the association exercise. The western third of the route was therefore associated with the Mt. Thom RWIS site. The eastern two thirds of the route were associated with the Mt. William RWIS site which happens to be approximately half-way along the eastern two-thirds of the route.

Next, each portion of the route needed to be divided into a number of smaller segments. Several attempts were made to devise segments of differing lengths according to the variability of temperature along the roadway or other land cover and elevation features. To continue with such an approach would have been extremely difficult and time consuming. In the interest of efficiency and to facilitate automation, it was decided to proceed with segments of equal length. Equal segment lengths of 2 kilometres, 1 kilometre, and 250 metres were tried. Segments of 1 kilometre length provided an optimal resolution for a highway application such as this. Although it was felt that 250 meter segments were too fine, they may work well in an urban setting.

The final step was to determine the temperature differential from the associated RWIS site for each of the kilometre long segments, and for each of the three weather types. In order to err on the side of caution, the coldest departure from the route mean temperature was selected for each segment.

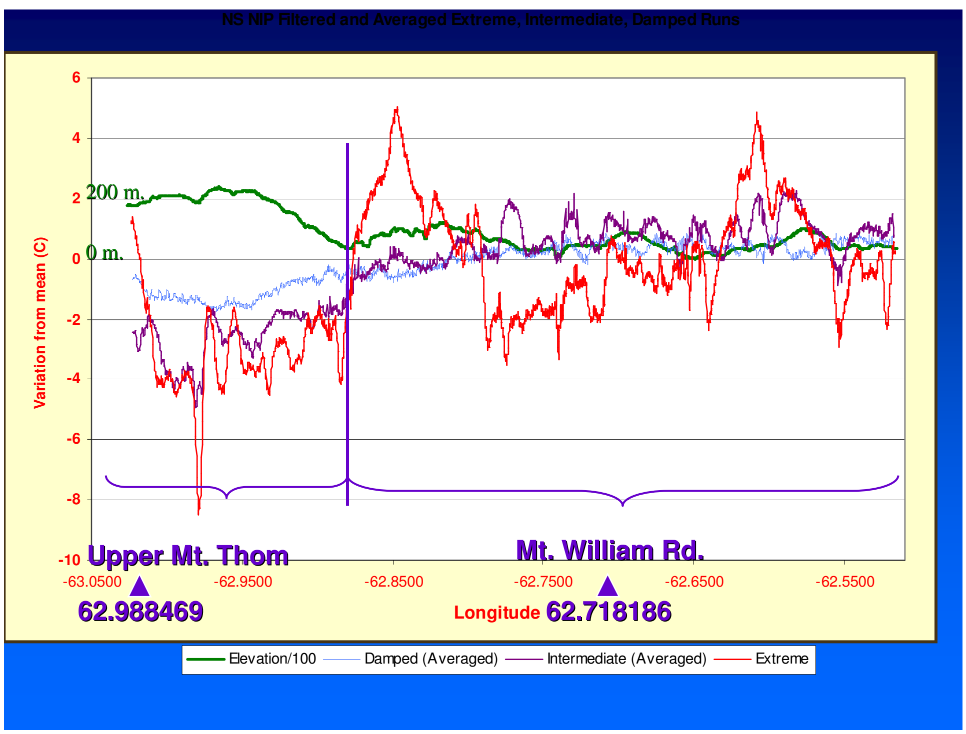

Figure 4. Association of road portions with RWIS sites.

With the thermal fingerprint portions now associated with the appropriate RWIS site and the temperature differentials calculated for each road segment for each weather type (Extreme, Intermediate, and Damped), an operational NIP service that works in a cold climate is possible. The requirements for the formation of frost along any segment are:

$$\mathbf{T_r \leq 0\,^{\circ}C} \quad \text{and}$$

$$\mathbf{T_r \leq T_d}$$

Where T_r is the temperature of the road surface and T_d is the air dew point temperature. The steps in the determination of Night Icing Potential (NIP) are as follows:

1. Prepare atmospheric forecasts including wind, cloud cover and dew point for each RWIS site;
2. Run a thermodynamic heat-balance model to produce a pavement temperature forecast for each RWIS site;
3. Type class the weather over the route for the coming night as Extreme, Intermediate, Damped, or Unsuitable;
4. Select the corresponding segmented thermal fingerprint for the route; abandon if Unsuitable;
5. Using the RWIS forecast and the appropriate fingerprint for the coming night, calculate the forecast road surface temperature for each segment for each hour through the night;
6. Determine if the forecast road surface temperature for any segment will meet the above two conditions simultaneously (dip below zero and below the forecast air dew point for that time of the night) and note the earliest time at which this would occur; and
7. Prepare a GIS map with these times for each segment.

NIP CASE STUDY

The process described above is best illustrated by reviewing an actual case. Figure 5 provides the RWIS forecast for Mt. Thom for the night of 12-13 March 2007. The clear weather of the afternoon which had yielded near 15 Celsius degree pavement temperatures was forecast to remain clear overnight with very light winds over central Nova Scotia, giving it a NIP classification of ‘Extreme’. Note that the dew point temperatures were forecast to rise over 10 degrees Celsius during the night. With clear skies and near-calm winds, the very high afternoon pavement surface temperatures, near 15 degrees Celsius, were forecast to plummet, falling to below zero by 20:00, then to below the air temperature well before midnight (around 22:30). At Mt. Thom itself, pavement temperatures were forecast to fall below the air dew point by 03:00. on the morning of 13 March. This is the earliest time at which frost would form at the Mt. Thom RWIS site.

The NIP product is designed to determine if there is a potential for frost, a Night Icing Potential, for any segments of the stretch of TCH 104 around an associated RWIS site, and if so, where and at what time? The left-most 4 columns of Table 1 provide the same forecast temperature information (with all temperatures rounded to the nearest 0.5 degrees Celsius for simplicity) for the night of 12-13 March for Mt. Thom as are represented in Figure 5 (air temperature values were left off of Table 1). The difference between the forecast road surface temperature and the dew point values, the 'Diff' column in Table 1, becomes negative at 03:00 on 13 March. With forecast pavement temperatures at that time below 0º C and below the air dew point, there was a Night Icing Potential at the RWIS site just before that time. Conditions remained conducive for frost up to 09:30 on 13 March.

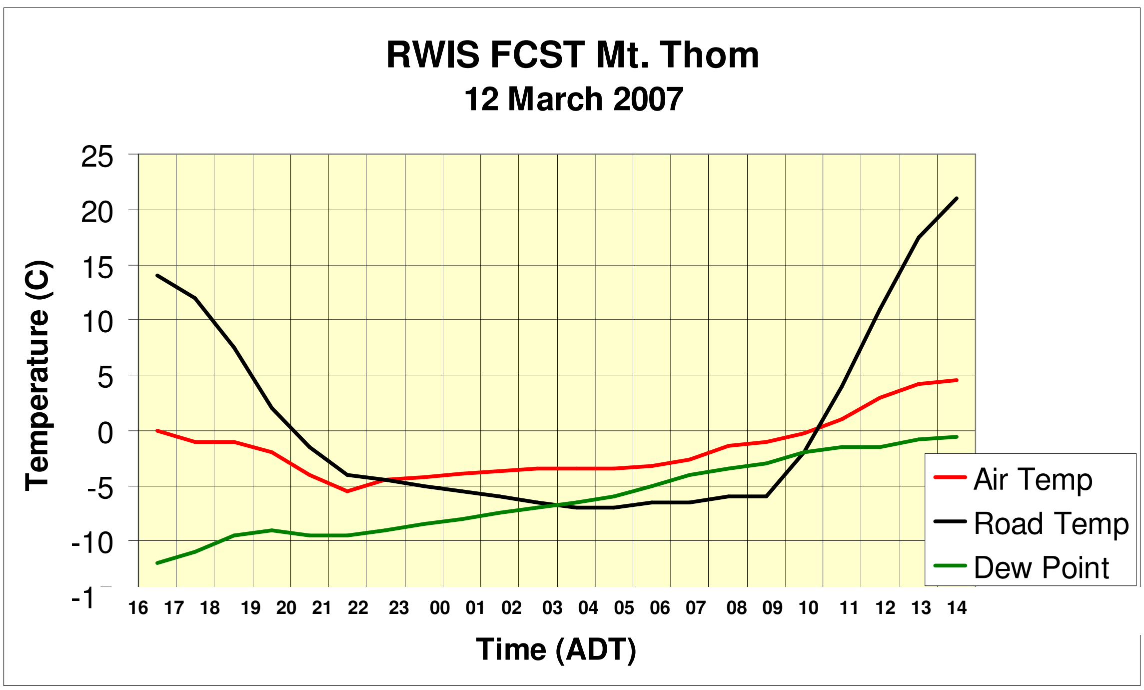

Figure 5. RWIS forecast for Mt. Thom for the night of 12-13 March.

	ADT	FORECAST			FCST	Road Segment Temp Diff					
DATE	TIME	Troad	Tdew	Diff		+3	+2	+1	-1	-2	-3
12	21	-4	-9.5	5.5		8.5	7.5	6.5	4.5	3.5	2.5
12	22	-4.5	-9	4.5		7.5	6.5	5.5	3.5	2.5	1.5
12	23	-5	-8.5	3.5		6.5	5.5	4.5	2.5	1.5	0.5
12	00	-5.5	-8	2.5		5.5	4.5	3.5	1.5	0.5	-0.5
13	01	-6	-7.5	1.5		4.5	3.5	2.5	0.5	-0.5	-1.5
13	02	-6.5	-7	0.5		3.5	2.5	1.5	-0.5	-1.5	-2.5
13	03	-7	-6.5	-0.5	NIP	2.5	1.5	0.5	-1.5	-2.5	-3.5
13	04	-7	-6	-1	NIP	2	1	0	-2	-3	-4
13	05	-6.5	-5	-1.5	NIP	1.5	0.5	-0.5	-2.5	-3.5	-4.5
13	06	-6.5	-4	-2.5	NIP	0.5	-0.5	-1.5	-3.5	-4.5	-5.5
13	07	-6	-3.5	-2.5	NIP	0.5	-0.5	-1.5	-3.5	-4.5	-5.5
13	08	-6	-3	-3	NIP	0	-1	-2	-4	-5	-6
13	09	-2	-2	0	NIP	3	2	1	-1	-2	-3
13	10	4	-1.5	5.5		8.5	7.5	6.5	4.5	3.5	2.5

Table 1. NIP forecast for Mt. Thom and adjacent road segments, 12-13 March.

Other road segments along the western end of TCH 104 can be several degrees warmer or colder than the forecast pavement temperatures at the Mt. Thom site itself; see the rightmost six columns in Table 1. For road segments that are 3º C warmer than Mt. Thom, provided for illustrative purposes only, we can simply add +3 to the T_r - T_d values in the Diff column. Conditions for NIP are just barely met then at 08:00, 13 March. The same process can be repeated for road segments that are +2, +1, -1, -2, -3 , etc. º C different from the Mt. Thom site. Note that the calculation is performed using the forecast dew point temperature for the air mass for each successive hour in the night. Note also that the table provides local times.

We see that for road segments that are much colder than Mt. Thom, the onset of frost will be correspondingly much earlier than at Mt. Thom because those road segments become colder than the forecast air dew point much earlier in the night. For warmer road segments, the onset of frost will be later than at Mt. Thom. Thus temperature differentials along the route can be converted into correspondingly earlier or later frost onset times for those segments. Proceeding in this way, the earliest possible time for the onset of frost, the time of interest to road maintainers, can be determined for each kilometre long road segment. Once these times are determined, they can be plotted for each road segment in a GIS application. The resulting NIP chart for the west end of TCH 04 in Pictou County for the ‘Extreme’ night of 12-13 March 2007 is provided in Figure 6.

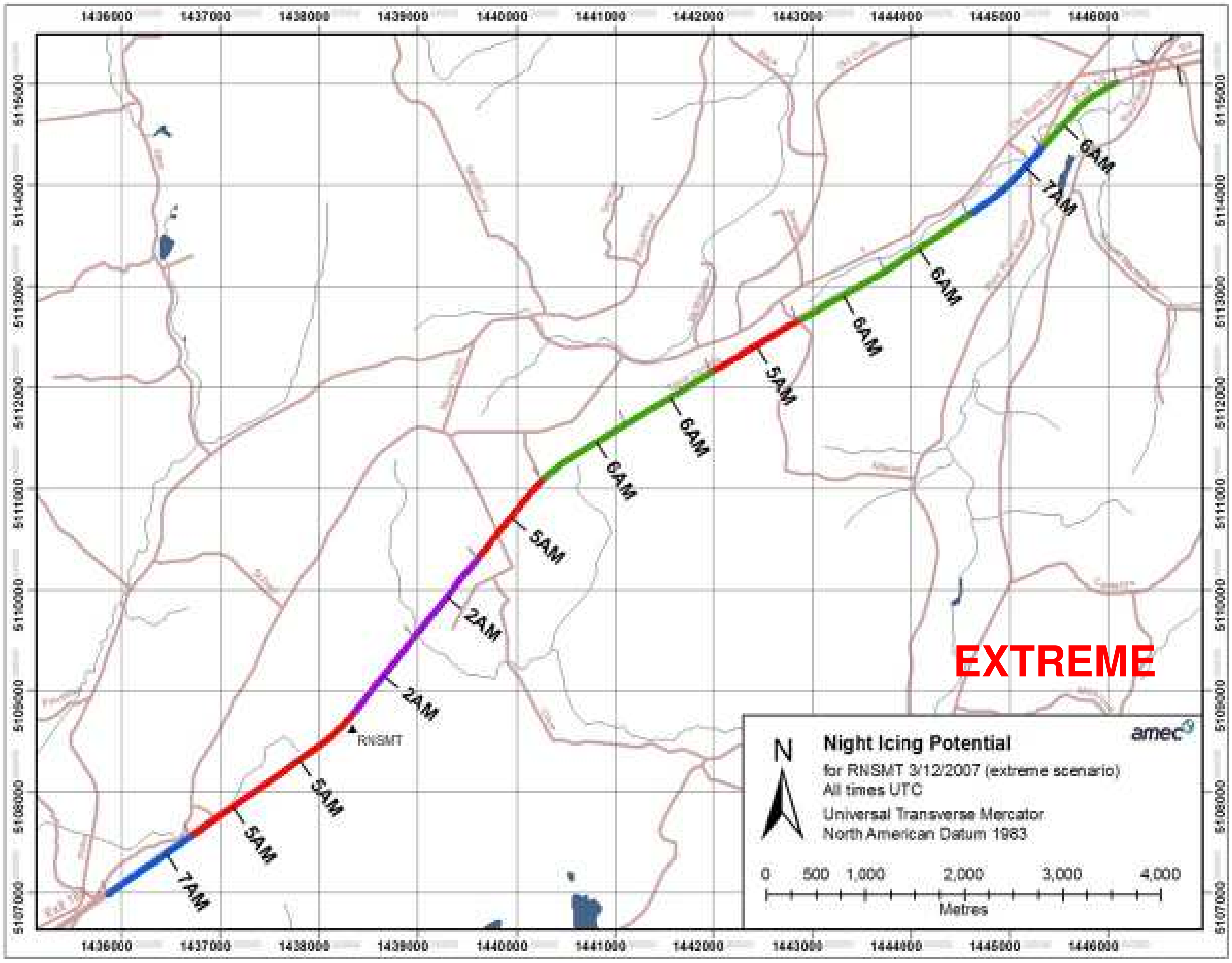

Figure 6. Night Icing Potential (NIP) chart for west end of TCH 104 for the night of 12-13 March 2007.

STRENGTHS AND LIMITATIONS

The new NIP product has been well received by the target user community – winter road maintainers. It is a valuable aid for winter road maintenance supervisors dealing with potential frost events which are particularly difficult to deal with. Based on the forecast for the RWIS site, the atmospheric forecast, and the appropriate thermal fingerprint for the prevailing forecast weather type, NIP provides an easy to use guide as to where frost may form, if any, and the earliest time for the onset of frost for each road segment. Prepared in the middle of the afternoon for the coming night, it provides an excellent planning tool for the winter maintainer, who can then schedule road patrols for the various segments at about, or shortly after, the earliest frost onset time. The alternative would be to plan patrols for many more hours on many more nights or, worse, needlessly pre-treat roads on many more nights.

It has been shown, Shao et al ([v]), that once the thermal maps have been prepared, they can be used with confidence for many years. So the IR data collection only needs to be done once along with the classification into the three weather types. This is because the physical features surrounding the roadway typically do not change drastically from year to year so the road's thermal characteristics do not change. Once major new construction on the roadway or immediately adjacent to the roadway is completed however, or some seismic event occurs that disrupts the road's thermal properties, then the thermal maps would have to be redone over the affected road segments.

In some jurisdictions, there may be little or no labour savings depending on contractual arrangements with the road patrol drivers. However there would likely still be savings in fuel and wear and tear on the patrol vehicle as well as, ultimately, savings in salt expenditures. There would also be reduced exposure to liabilities. Indirect benefits would include enhanced safety for the motoring public as well as reduced greenhouse gas emissions (fewer patrols) and reduced salt loading in the environment.

It can be shown that using the cost-effective IR data collection and thermal map preparation approach described earlier, the NIP service can pay for itself quite easily within a few years based on salt savings alone. Clearly though, the savings are substantially more than just that especially if some accidents with serious injuries can be avoided. The completion of detailed cost-benefit analyses is best left to individual maintenance organizations who are better able to define and quantify their specific categories and amounts of savings since these will vary markedly from jurisdiction to jurisdiction.

NIP does have limitations and it is important to understand these. The thermal response of the roadway along its entire length is mapped and is used as a thermal fingerprint. However, there has been no attempt to resolve the moisture variations along the roadway that may arise with certain wind directions or at different points in the winter season when adjacent water bodies may still be open. On clear calm nights, the moisture fluxes along a roadway can be quite large and more complex than even the thermal response.

The NIP product simply uses the forecast dew point temperatures for each hour in the night prepared for the RWIS sites and applies those evenly for the entire route. The fact that the forecast dew points for each hour in the night are used does help. As the RWIS density increases, the NIP product will become better and better as it adds greater moisture flux resolution.

This shortcoming, not resolving the moisture fluxes, is what motivated the selection of the name for the product and service: Night Icing Potential. NIP does not profess to be an absolute categorical forecast of frost formation. What it tries to determine is, first, if frost could form anywhere along the route at night and, if so, where and specifically when along the route the potential for frost formation exists. It has several features built in, selecting the coldest temperature for each kilometre-long segment of the road and applying it over the whole segment for example, to ensure that NIP will provide the earliest time at which the potential for frost formation arises.

OPERATIONAL EVALUATION

The NIP service was tested operationally in the late spring of 2007 for several weeks and again for nearly 2 months in the fall of 2007. The tests consisted of the preparation of RWIS forecasts for the two RWIS sites, Mt. Thom and Mt. William, and the preparation of the NIP output charts for those nights with a potential for icing along one or more road segments. NS TIR arranged road patrols, sometimes multiple patrols, to determine if signs of frost could be detected in any segments along TCH 104 in Pictou County. This is necessary since NIP involves forecasting frost anywhere along the entire length of the roadway and not just at the RWIS site. NS TIR and AMEC both freely contributed resources to complete this evaluation. Because of operational constraints, the tests were only run weekdays. A total of 22 NIP forecasts in all were generated and evaluated.

One of the simplest and best ways to test a system's ability to forecast a discrete event is a two-by-two contingency table[vi]. This tests the first part of the NIP generalized output; that icing is or is not expected to occur somewhere along the route. With an operationally significant event or outcome chosen, that of frost formation, this scheme is also one of the better approaches to assess the utility of a forecast.

Two possible forecasts for the full length of the route from NIP are defined: icing in one or more segments or no icing at all anywhere. The two possible outcomes are: ice observed somewhere along the route or ice not observed anywhere along the route. The two-by-two contingency table is presented in Table 2.

		FORECAST	
		Icing	**No Icing**
OBSERVED	**Icing**	✔ - A	✗ - B
	No Icing	✗ - C	✔ - D

Table 2. Two-by-two Contingency Table.

The forecast is correct if icing is expected and it does occur (A) or no ice is expected and none occurs (D). The other two outcomes, B and C, are incorrect forecasts. The consequences of these incorrect forecasts differ greatly. For errors of type C, with ice forecast, extra patrols would have likely been scheduled, so some labour and fuel may have been wasted in trying to detect the ice that did not form. For errors of type B, with no ice forecast, it is possible that no patrols or treatment of the road would have taken place. Yet with ice actually forming somewhere along the route and roads left untreated, road friction could have been adversely affected and accidents could have resulted. Clearly, errors of type B are the worst sort of error.

For the two verification periods, using very strict definitions of frost formation, the following results were recorded:

A = 5	B = 0
C = 6	D = 11

Total events for verification = 22

From the simple two-by-two contingency table some useful statistics can be calculated. The Percent Correct (PC) metric gives the ratio of the total number of events that were correctly forecast[vi]. The higher PC is, the better the forecast score.

PC = (A + D) / total # of forecasts = (5 + 11) / 22 = 72.7 %

The PC score is encouraging, given this testing is evaluating a detailed end product generated with some assumptions against the observation of icing along an entire route. A PC score in this range is quite good.

Two other, perhaps more useful, statistics in judging the quality of a forecast are the Yes events and the No events[vii]. The relationships and results are as follows:

YES Forecasts = A / (A + C) = 5 / (5 + 6) = 5 / 11 = 45.4 %

NO Forecasts = D / (B + D) = 11 / (0 + 11) = 11 / 11 = 100%

The Yes Forecast score is quite low but, as discussed previously, these errors are less serious. In addition, the verification scheme applied was demanding with several events forecasting icing over just a single road segment over the whole route and several more with icing in only a few road segments towards dawn. All of these were included as icing forecasts. Eliminating these marginal icing forecasts would improve the YES score. Plus, NIP is designed to err on the side of safety so it should, and it does, over-forecast icing events. The No Forecast score is 100% which shows that NIP did not commit any of the more serious errors: forecasting no icing when icing actually occurred. This is a particularly good outcome.

A full ‘paired value comparison’ test was not possible. As the name implies, this requires a comparison of the forecast onset time for frost against the actual onset time for frost for each road segment for each night where some icing was expected. This would have required road patrols of the entire roadway, at least hourly, commencing several hours before the earliest onset of frost in any segment and continuing through to dawn each day. This would have been very expensive to achieve. In addition, this approach would only test the A events when frost was forecast and it did occur.

CONCLUSIONS

This project demonstrated an efficient cost-effective approach for the preparation of road thermal fingerprints. It also advanced the state-of-the-art in the presentation of road thermal fingerprints through the use of modern GIS mapping techniques. This should also facilitate the use of road thermal profiles in other areas.

This project devised a new operational service, the Night Icing Potential (NIP) service, for use in cold snowy climates to determine, through the use of RWIS forecasts together with the thermal fingerprint for the prevailing weather type, which specific road segments, if any, may be susceptible to frost formation overnight and when. NIP is the end result of numerous calculations made possible through the power of computers together with some simplifying assumptions about moisture distribution along a route. Thermal Fingerprints and RWIS forecasts are necessary in order to generate NIP outputs. Thermal Fingerprints, once developed, are useable for many years. NIP provides a simple early warning and planning tool for road maintenance supervisors to use on ‘non-weather’ nights which make up the majority of nights through the fall, winter and spring seasons.

The project went on to test NIP products for an admittedly short two-month period spread between the spring and fall of 2007. This preliminary testing shows that NIP was correct nearly three quarters of the time. NIP showed particular strength in not missing any icing events and so avoiding the most serious and potentially dangerous kinds of errors. NIP has performed well at what it claims to be: a guide to whether icing is expected anywhere along an entire route and, if so, then providing the earliest time for the onset of the ice formation process for each kilometre-long segment of the roadway.

It is suggested that NIP can be a useful guide for road maintenance organizations in planning their overnight operations on non-weather nights. As a consequence of global warming, winters across most of southern Canada will change in the coming decades. The number of frost potential nights may increase, thus heightening the need for maintenance planning tools, such as NIP, to deal with this phenomenon.

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