Measuring and predicting soil temperature and moisture content beneath Nova Scotia's highways: A report and preliminary results from a recently installed network

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Abstract

The passage of heavy vehicles (high per axle weight) during the spring thaw causes faster degradation of the pavement and leads to increased maintenance costs. To reduce the damage, most provinces in Canada implement spring load restrictions for heavy vehicles. Given that conditions often veer from climatology and that regional climatology is changing, imposing load restrictions at fixed dates every year is not optimal: it can lead to increased road damage and/or increased costs to the transportation industry.

The main goal of this project was to develop an objective guidance to help departments of transportation determine the beginning and end of the seasonal load adjustment periods, long enough in advance for the road transportation industry to adjust their plans. A soil energy and mass balance model driven by atmospheric conditions from numerical weather prediction models to predict soil temperature and moisture content was selected since it offers a complete physical deterministic approach.

With funding from the Nova Scotia Department of Transportation and Infrastructure Renewal, six probes capable of measuring both soil temperature and moisture to a depth of 150 cm were installed at various locations around Nova Scotia in 2010. Using data from these sensors, AMEC then initialized a point subsurface model to produce a five day prediction of subsurface temperatures. Results to date are promising and indicate that it is possible to provide advance warning of the spring thaw in roads. Research is ongoing to better incorporate moisture data, review other existing subsurface models, and investigate driving the models with different sources of forecast data.

Text

Introduction

The civil engineering community estimates that during the period of spring thaw, roads may lose in excess of 70% of their load bearing capacity [3] exposing them to greatly increased structural damage from heavy traffic during this critical period. In an effort to preserve the investment of billions of dollars in roadway infrastructure, many jurisdictions impose weight restrictions during periods of the year when the roads are most susceptible to damage due to soft-subsurface layers.

Through the Maritimes, thaws can occur at different points in the winter. With global climate change, mid-winter thaws are becoming more frequent and more pronounced so that the thaw penetrates sufficiently below the roadway to cause some loss of load-bearing capacity. The final thaw of the season naturally occurs in the spring. However, in many recent years, final thaws have been occurring much earlier than the long term climatology would indicate. Those final early spring thaws often occur before the traditional dates for the imposition of spring load restrictions with the result that more road damage is being reported in recent years.

Road engineers use deflectometers to measure a road's load bearing capacity. Such road testing is often performed by contractors including AMEC. However, with the more frequent and lengthier mid-season thaws and the earlier spring thaw, significantly increased testing is required and this, in turn, is placing a strain on operating budgets. Clearly, a forecast of load bearing capacity is required.

Spring Thaw—How it Affects Roads

Each year in Canada, the onset of cold winter temperatures causes roadbeds across the country to freeze. With successive incursions of cold air masses and shorter days, the roads gradually freeze from the top downwards to ever greater depths. At what time, where, and to what depth the roadbeds freeze depends on geography, climate, and road construction. A frozen roadbed generally means more weight can be carried on the road without structural damage and some jurisdictions take advantage of this in the form of a Winter Weight Premium. During the WWP, heavy haulers are allowed to increase their weight per axle, effectively reducing transportation costs.

Serious problems arise in the spring as the roads thaw. This is a gradual process driven by successive incursions of warm air masses combined with longer days. Thawing is also a top-down process which, for a period of time ranging from days to weeks, creates a thawed layer consisting of the roadway and part of the substrate while still leaving a hard still frozen layer beneath. This traps spring rains and winter snow-melt water in between the hard road surface and the ice layers at depth and seriously impacts the integrity and weight-bearing capacity of the road structure during this particularly vulnerable period. Heavy vehicles during the spring thaw cause faster degradation of the pavement and leads to very costly maintenance and repair. To reduce the damage, most provinces in Canada implement spring weight restrictions on certain roads. Secondary roads are particularly susceptible, especially in areas where there is heavy logging, industrial activity, etc. The restrictions generally begin sometime before the

end of winter and carry over into early spring. These restrictions are a source of frustration to loggers, haulers and other stakeholders who use the roads, as they create a variety of logistical difficulties such as the need for alternate routing, reduced revenue per load, etc. with attendant lobbying of the transportation agencies.

How Spring Thaw Restrictions are currently being addressed

Literature review

The particular vulnerability of road infrastructure during the spring thaw period has been recognized for quite some time [2][3]. The phenomena giving rise to the weakening, the entrapment of a thawed moist layer between the hard road surface material and a hard frozen sub-surface layer, is well understood [3][5]. The traditional approach of imposing fixed climate-derived calendar-based load restrictions every spring to minimize the damages has drawbacks (variable dates from one jurisdiction to another and dates no longer valid with a warming climate) and detractors (haulers dissatisfied with their increased costs during this period and long after it is no longer required). The sound understanding of the problem, including the great impact of meteorological influences on road weight-bearing capacity developed by the engineering community, led them to devise approaches to predict when the meteorological conditions might give rise to weakened infrastructure [3][4][5]. The original approaches developed were fairly simplistic approaches consisting of running totals of a Frost or Freezing Index and a Thaw Index.

The science of meteorology offers more rigorous physical approaches. The heat-balance approach, summing all of the heat gains and losses over a surface (the road) and propagating it downward, has also been well understood for many decades. Point, or one-dimensional (1D), models have been developed to precisely calculate the resultant temperature changes at the surface and at depth [1] [2]. These require as inputs a complete description of atmospheric influences (air temperature and humidity, wind speeds, sky cover etc.) over the road for specific time steps in the future, calculating for each time step the change in surface and sub-surface temperatures.   In this way, these 1D models can be applied to generate a forecast profile of sub-surface temperature for as many days into the future as numerical weather prediction model outputs are available (with good confidence out to 5 days) [6][7]. This heat-balance approach is being pursued by engineers working in tandem with meteorologists in both Iceland and Canada, specifically Nova Scotia and the Northwest Territories. This paper will focus primarily on the results for Nova Scotia.

The Nova Scotia Frost Probe Project

Nova Scotia is a province with a very active forestry industry. All of the 100 series and some of the Trunk, Route and local type roads are Schedule C roads, which do not have spring weight restrictions. The majority of the local or secondary roads are subject to restrictions. There is

also a category called Spring Exempt which applies to a road, or portion of a road, that has been tested and confirmed that it will carry heavy loads. Spring Exempt roads can be trunks, routes and local roads.

Traditionally, restrictions were implemented primarily on an understanding of local climatology using air temperature as a proxy for when road beds would begin thawing. In addition, the restrictions would sometimes be lifted at night when the forecast was predicting air temperatures of -5C or colder (sufficiently cold long enough to refreeze the upper road layers to a sufficient depth).

Regionally, there is considerable variation in climate and its associated effects on the spring thaw across Nova Scotia. The southwestern part of the province is much warmer, with reduced winter snow cover and daytime high temperatures that frequently are above freezing even in January. However, even in this region there are important differences. While primary roads tend to follow the coast where it is warmer, there is higher terrain inland where much of the forestry activity takes place. Inland and at higher elevation, temperatures are colder and road beds can still freeze during the winter where coastal roads in the same region may not. In Northern Nova Scotia, it is climatologically colder and ocean effects are less pronounced. Frost tends to penetrate the ground in most areas no later than January, and will thaw during March. In Cape Breton, terrain rises to elevations over 400 metres in the Highlands, and deep snow cover in this area can persist into April. Spring thaws of the road bed tend to come later in the Cape Breton Highlands than anywhere else in the province.

All of these geographical features and climatological influences underscore the broad spatial and seasonal variation in road weight-bearing across the province. An evidence based approach to preserve the infrastructure without imposing undue restrictions on its use is highly desirable. Even in much colder climates, for example the Northwest Territories, where climate change influences are being felt more acutely, similar monitoring and forecasting approaches are required to make good use of, and to protect, expensive infrastructure.

Overview of project

Equipment Used

The Seasonal Load Adjustment (SLA) sites installed in Nova Scotia consist of temperature (thermistor) and moisture (conductivity) sensors mounted on a column manufactured by the Icelandic company SAMRAS ltd and available through Road Monitor Systems ltd. The sensors installed in Nova Scotia are distributed every 5 cm along the probe from 10 cm below the surface down to 60 cm then they are distributed every 10 cm down to 110 cm. In the Northwest Territories, the sensors are every 20 cm along the probe from 10 cm to 150 cm under the surface. The accuracy of the thermistor temperature readings is 0.06 C. The SLA sites are polled every hour but have the capacity for more frequent polling if desired.

The network of Road Weather Information System (RWIS) sites in Nova Scotia is Vaisala equipment with a meteorological tower and pavement sensors at each site. Pavement sensors

are located at the surface, in the pavement, 40 cm under the surface and 150 cm below the surface. Most RWIS sites in the province are polled every 20 minutes.

Location of Equipment

Nova Scotia has an extensive network of 45 RWIS stations located throughout the province (Figure 1), and two of the stations are operated by Parks Canada. The RWIS sites are mainly located along the 100 series highway and major trunk roads, the backbone of the provincial transportation network. The SLA sites measuring subsurface temperatures and moistures were installed in 2010 on secondary roads except for East Bay on Trunk 4. The East Bay and Trafalgar SLA sites are collocated with RWIS sites.
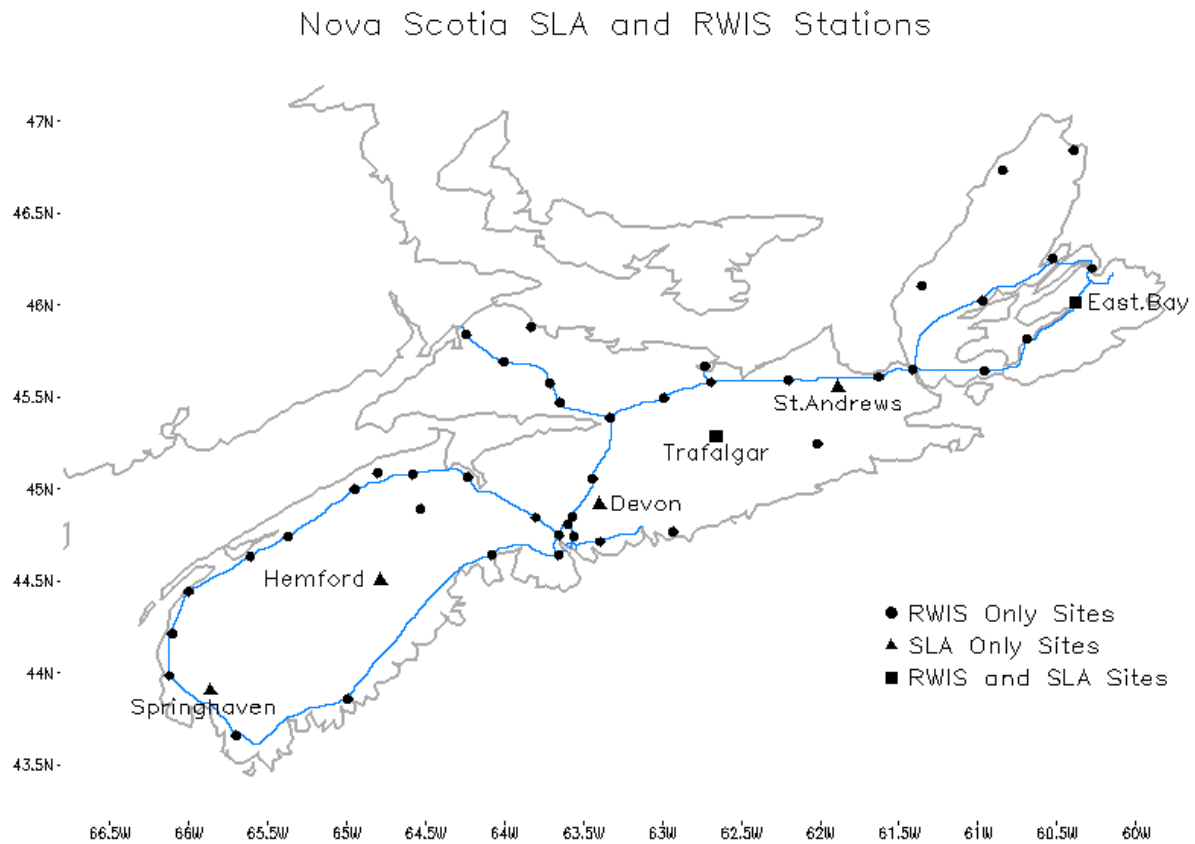
Figure 1: Nova Scotia SLA, RWIS Network and Main Highways

Polling and Website Display

SLA sites are polled once an hour. Temperature variations under the surface are slower as depth increase and more frequent polling would not give significantly more information except potentially for the shallowest levels. On AMEC's Nova Scotia RWIS website, data is updated every hour in a summary table (Figure 2). Data observed at 18 UTC is displayed for the past several days at all measured depths for individual sites, displayed in both table and graph

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format (Figure 3 and Figure 4). These products also display the sub-surface temperature forecast. Archived data is also available through the portal.

Subsurface Network   View Map

2011-05-02
15:37:37 NDT

SLA Site	time	Subsurface Data							
		depth 10cm		depth 30cm		depth 50cm		depth 110cm	
		temperature(°C)	moisture(%)	temperature(°C)	moisture(%)	temperature(°C)	moisture(%)	temperature(°C)	moisture(%)
Devon	08:20	7.8	33	8.4	89	9	97	8.2	97
East Bay	15:20	7.2	68	6.9	68	7.3	68	-0.1	68
Hemford	13:20	11.7	93	11	53	11.3	97	9.8	97
Springhaven	13:20	15.5	0	12.4	6	11.9	22	9.8	87
St. Andrews	13:20	7.1	97	7.9	97	8.4	97	7.4	97
Trafalgar	15:20	8.6	44	9.1	94	9.1	97	7.8	97

Figure 2: Nova Scotia Subsurface Network Conditions Summary

*data based on 18:00 UTC observations and forecasts

DISPLAY: ⦿ Tabular   ○ Graphs

Temperature (°C)

| < -10 ▪ | -10 – < -4 ▪ | -4 – < -1 ▪ | -1 – < 1 ▪ | >= 1 ▪ |

Sensor Depth (cm)	r	Apr 25	Apr 26	Apr 27	Apr 28	Apr 29	Apr 30	May 01	May 02	May 03	May 04	May 05	May 06
10	2	-3.2	0.8	2.0	1.9	0.6	2.9	0.2	3.0	4.0	1.5	1.9	4.4
30	0	-3.0	-2.3	-1.2	-0.7	-0.4	-0.3	-0.1	-0.3	2.4	1.9	0.9	1.5
50	3	-2.5	-2.3	-1.8	-1.4	-1.1	-0.8	-0.5	-0.5	-0.3	-0.3	-0.3	-0.3
70	9	-3.0	-2.9	-2.7	-2.4	-2.1	-2.0	-1.8	-1.7	-1.6	-1.5	-1.5	-1.4
90	0	-3.0	-3.0	-2.8	-2.6	-2.4	-2.2	-2.1	-2.0	-2.0	-2.0	-1.9	-1.9
110	2	-3.2	-3.2	-3.1	-3.0	-2.8	-2.7	-2.5	-2.5	-2.3	-2.3	-2.2	-2.2
130	1	-3.0	-3.0	-2.8	-2.8	-2.7	-2.6	-2.5	-2.4	-2.4	-2.4	-2.4	-2.4
150	0	-3.0	-2.9	-2.9	-2.8	-2.7	-2.7	-2.6	-2.5	-2.5	-2.5	-2.5	-2.5

Sensor Depth (cm)	r	Apr 25	Apr 26	Apr 27	Apr 28	Apr 29	Apr 30	May 01	May 02	May 03	May 04	May 05	May 06
10		0	0	8	8	4	5	7	8				
30		0	0	0	1	3	4	5	5				
50		0	0	0	0	0	0	0	0				
70		7	7	7	7	8	8	8	8				
90		12	12	12	12	13	13	13	13				
110		0	0	0	0	0	0	0	0				
130		0	0	0	0	0	0	0	0				
150		11	11	11	11	11	11	12	12				

Moisture (%)

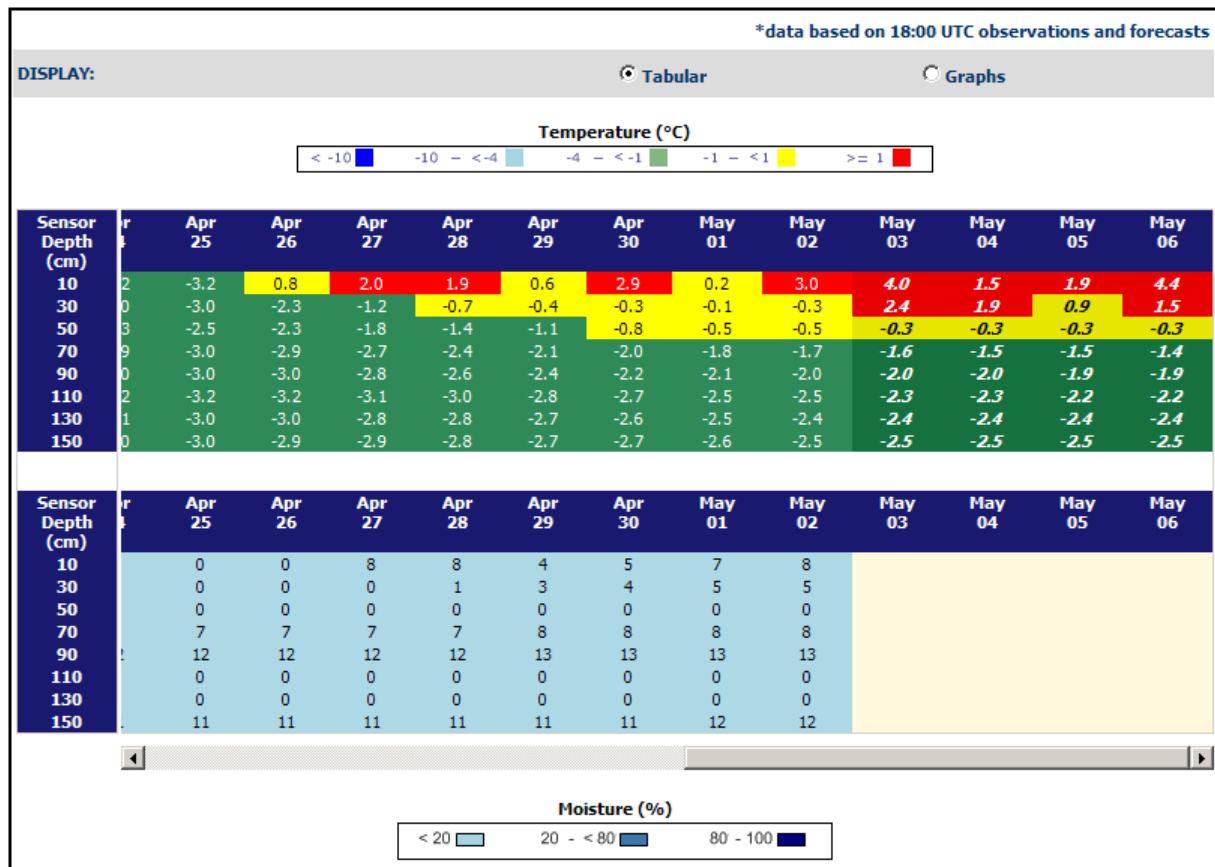| < 20 ▫ | 20 - < 80 ▪ | 80 - 100 ▪ |

Figure 3: Subsurface conditions and forecast (italic) for Chan Lake, Northwest Territories
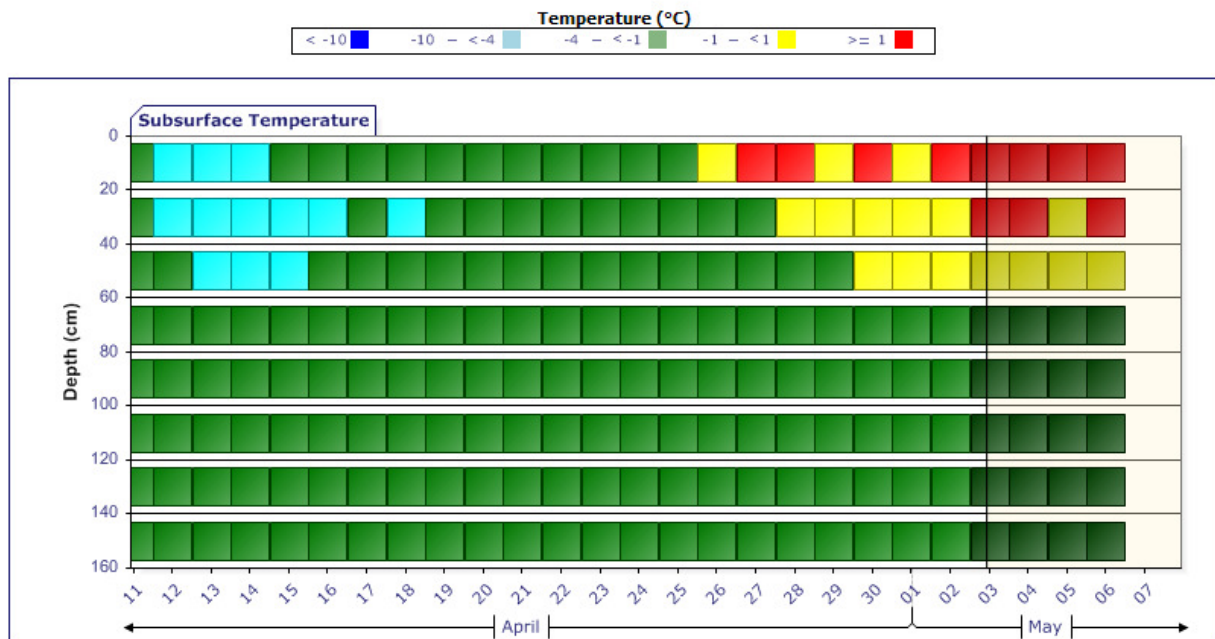
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Figure 4: Subsurface conditions and forecast (darker colour) in Chan Lake, Northwest Territories

Forecasting Approach

A sub-surface temperature forecasting system was developed in 2008 and implemented in 2009-2010 to offer operational daily forecasts for the six Nova Scotia sites and for one site in the Northwest Territories.

AMEC used a complete physical deterministic approach to forecasting. The basis is a thermal balance model, driven by initial conditions provided by the SLA observation sites and surface boundary conditions provided by a numerical weather prediction model. The system is run on a server and the results are presented to the clients through the AMEC RWIS website.

The subsurface model used is SNTHERM developed by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). SNTHERM is a research grade one-dimensional mass and energy balance model. It is flexible, allowing for arbitrary subsurface composition and takes as inputs the significant meteorological conditions. SNTHERM was initially developed for snowpack modelling, in particular to forecast the temperature at the surface of the layer of snow, but it has been used successfully for bare soil. The availability of this tested model and its flexibility in representing various soil types and in handling varied weather conditions are some of the main advantages of SNTHERM [1].

SNTHERM requires surface boundary conditions in the form of meteorological data: temperature, relative humidity, wind speed, rain amount, snowfall amount, and radiation fluxes or cloud cover. The U.S. Global Forecast System (GFS), one of the world's leading global numerical weather prediction models, was used to provide these forecast weather conditions. GFS data is available at full resolution out to 8 days with coarser resolution output available out to 16 days. To date, forecasts have been run out to 5 days as a compromise between the

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requirements for a useful product for decision making and the diminishing accuracy of numerical weather prediction models as lead time increases. AMEC intends to consider longer lead times but rigorous verification will be necessary to evaluate the usefulness of the longer range forecasts.

Temperature and bulk water density at each layer are needed as initial conditions for SNTHERM. The SLA observation sites provide direct measurement of temperatures at many depth levels while the bulk water density has to be derived from the measured relative humidity. In addition to observations at depths from 10 cm to 110 cm, the two Nova Scotia SLA sites collocated with RWIS stations additionally avail of temperatures observations at the surface and at 150 cm.

Results

Unseasonably warm season

The 2010-2011 winter season was particularly warm, with ice much sparser than usual in the Gulf of St. Lawrence.
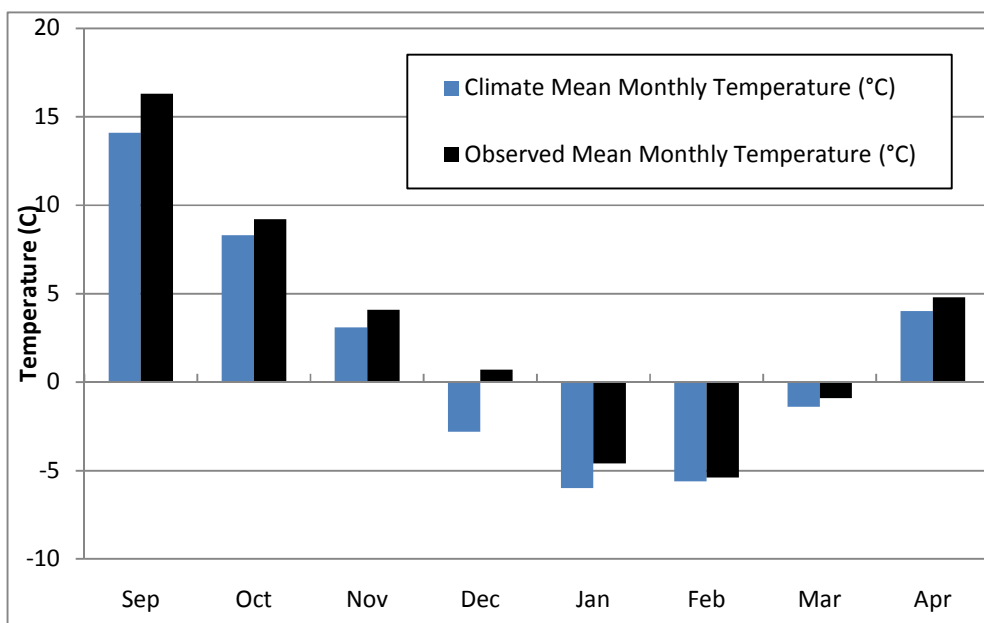

Figure 5: Observed and climatic mean monthly temperature at Halifax International Airport for the 2010-2011 winter

The winter proceeded in two fairly distinct phases as illustrated in Figure 5. Early winter featured temperatures well above normal, with frost greatly delayed in penetrating beneath the surface. The warmth was primarily driven by an unusually large atmospheric block over the North Atlantic which brought long periods of mild weather due to sustained easterly flow off the Atlantic. In late January the pattern returned to more typical winter conditions as illustrated in

the chart below, and temperatures were near climatic normals through the end of the winter season. Although sub-surface temperature data from prior winter seasons was not available, it is suspected that the depth to which frost penetrated in winter 2010-2011 was more shallow than in winters with more climatically normal conditions.
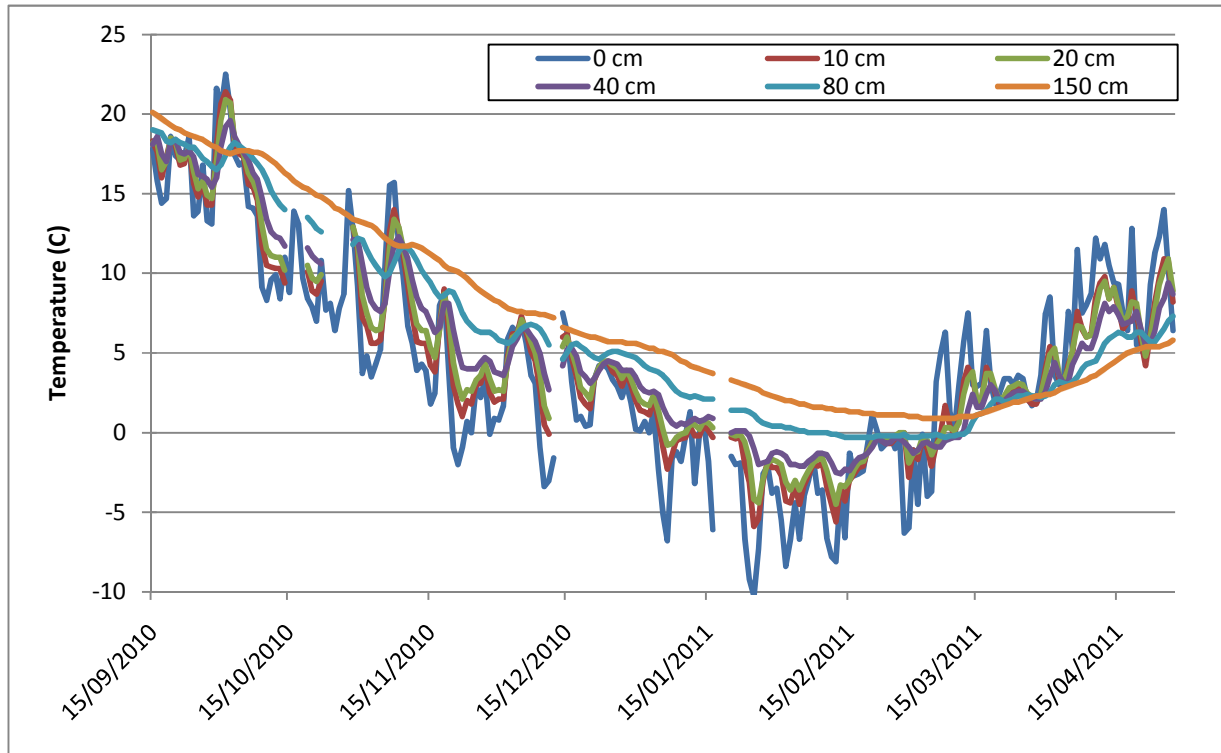

Figure 6: Daily averaged sub-surface temperature evolution at East Bay at selected depths.

Results on frost penetration at various sites

The buildup of the frost in the early winter is generally gradual while the frost layer breaks down in only a few days in the spring. For comparisonthe evolution of the frost depths at 3 different sites is presented: Chan Lake in the Northwest Territories at a latitude of 61.8 N, Trafalgar is located significantly inland in central Nova Scotia at 45.3 N and Springhaven in Southwest Nova Scotia relatively near the ocean at latitude 43.9 N.

As can be expected, the Northwest Territories, with a very continental and cold climate, sees frost building early and steadily from mid-October, reaching deeper than the 1.5 metre sensor in early December (Figure 7). With longer days in late March, the surface frozen layer erodes with diurnal cycles, then a more systematic erosion starts in late April. The frost period at Chan Lake was over 200 days long in 2010-2011.
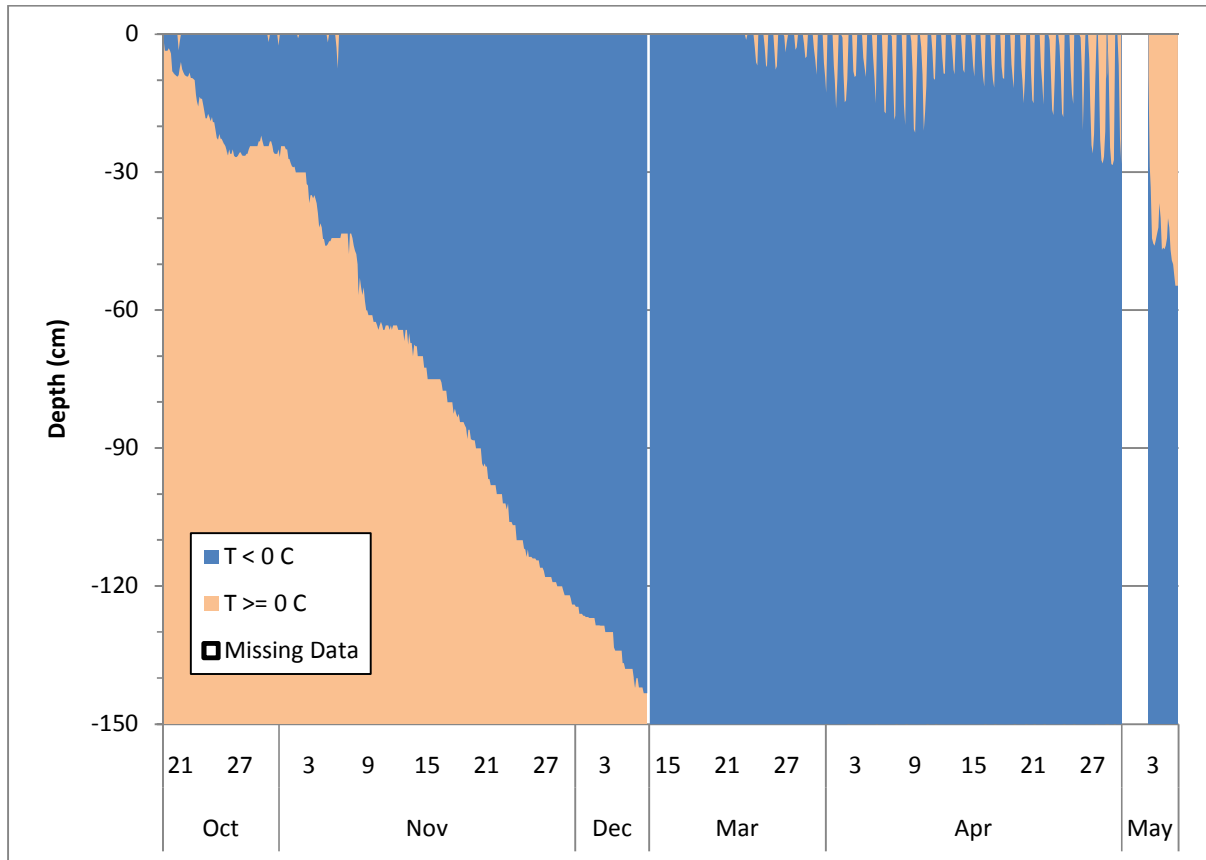
Figure 7: Frost by depth at Chan Lake, NWT from October 19 to December 7 and from March 13 to May 5 2011. Data for mid-December to mid-March is omitted; the whole depth sampled by the sensors remained frozen.

At Trafalgar (Figure 8), occasional nighttime freezing of the pavement began in November (not shown) and increased in frequency during a warm December. The longest frost period lasted nearly 60 days from January 18 to March 24 with a maximum depth slightly less than 90 cm. In March, the frozen layer began to erode, and collapsed over the March 16 to March 24 period.
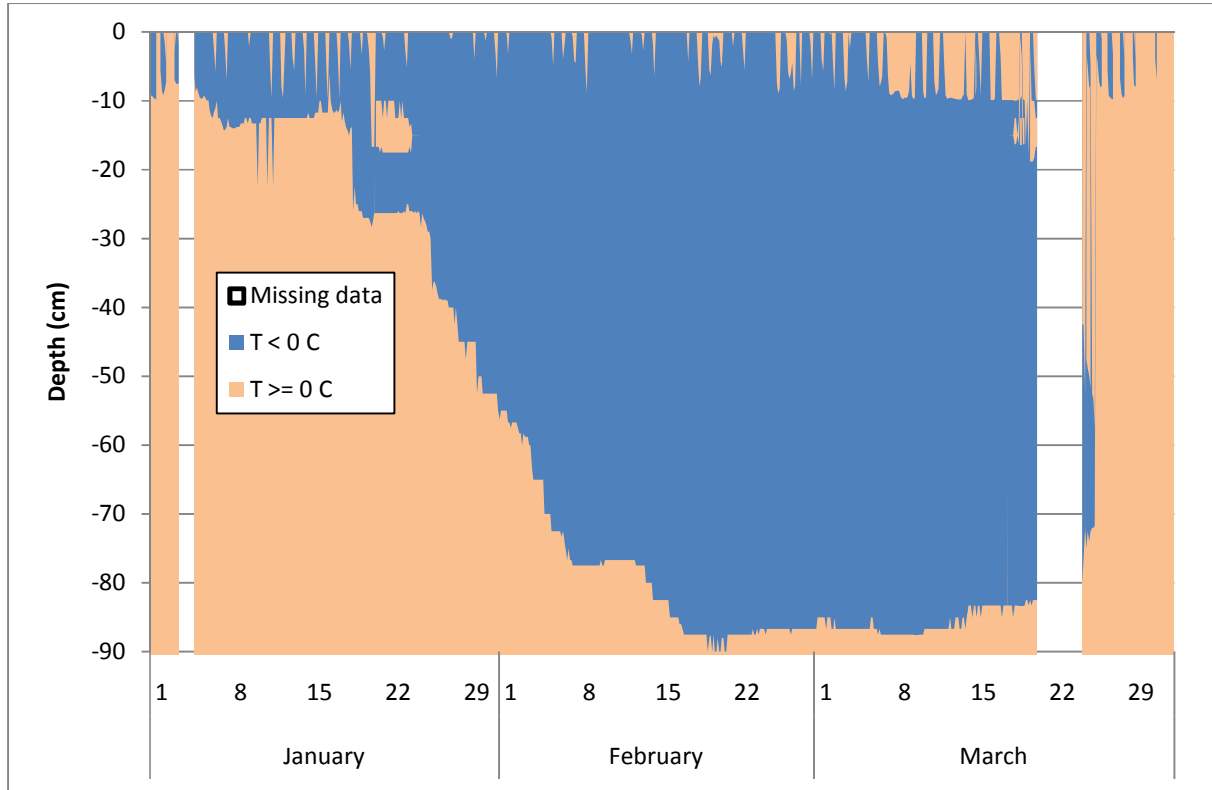
Figure 8: Frost by depth at Trafalgar, NS from January 1 to March 31 2011. The frost breakpoint was set at 0C.

Of note, the collapse of the frost layer is relatively rapid, from March 16 to March 24 at Trafalgar, and occurs both from below and from above. The warmer and deeper subsurface temperatures can have a significant impact on the nearby ground that is only slightly below 0C at that time. This is illustrated by Figure 9 and Figure 10 highlighting the thaw period at the Devon site southwest of Trafalgar.

Figure 9: Devon Frost Penetration for March 5 to March 13 2011

Temperature (°C)

< -10	-10 – <-4	-4 – <-1	-1 – <1	>= 1

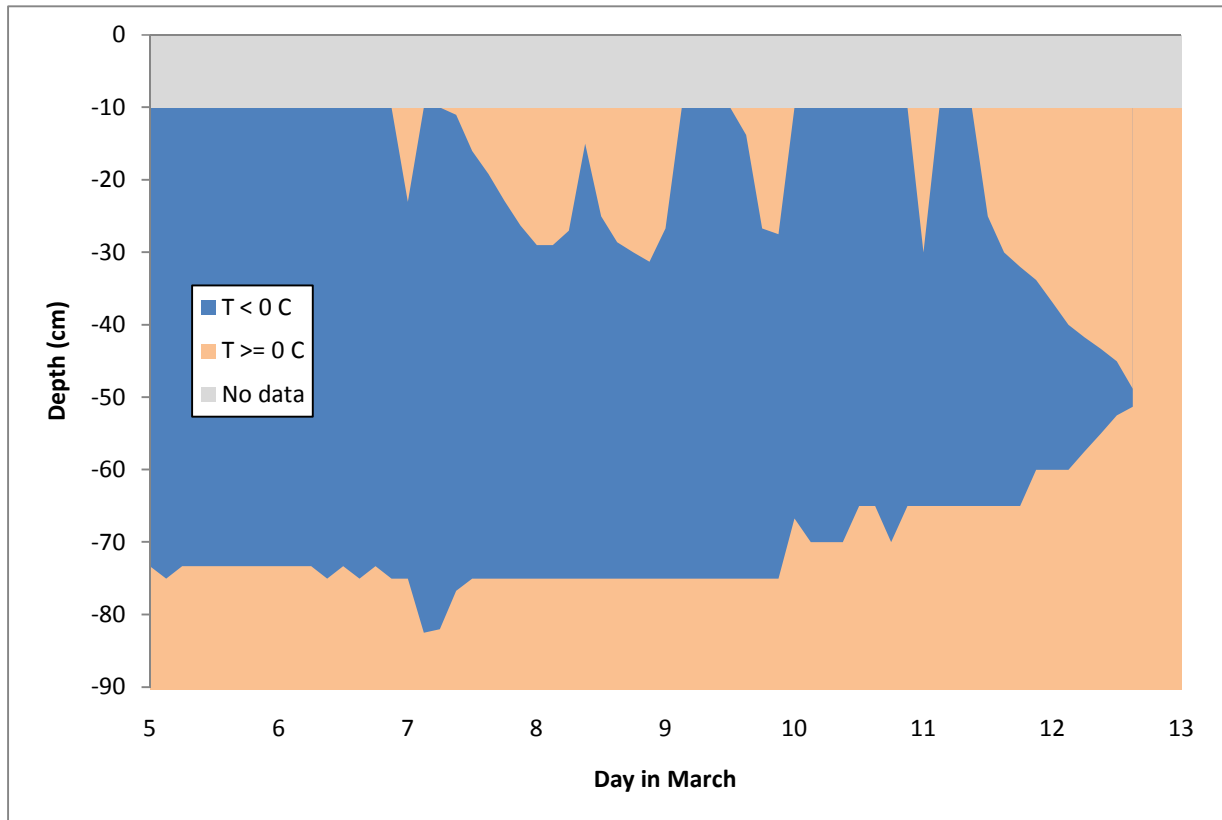| Sensor Depth (cm)	Mar 01	Mar 02	Mar 03	Mar 04	Mar 05	Mar 06	Mar 07	Mar 08	Mar 09	Mar 10	Mar 11	Mar 12
10	-1.3	-1.5	-1.2	-2.2	-1.8	-0.8	2.3	3.3	1.4	-0.5	1.9	5.8
15	-1.4	-1.6	-1.2	-2.4	-2.0	-1.0	1.2	2.6	0.9	-0.4	1.5	5.3
20	-1.4	-1.6	-1.2	-2.3	-2.1	-1.1	0.1	1.7	0.3	-0.4	0.9	4.5
25	-1.4	-1.5	-1.1	-2.1	-1.9	-1.1	-0.3	0.9	0.0	-0.3	0.5	3.8
30	-1.4	-1.4	-1.2	-1.9	-1.9	-1.3	-0.5	-0.1	-0.2	-0.3	0.1	2.9
35	-1.2	-1.2	-1.1	-1.5	-1.6	-1.2	-0.5	-0.3	-0.1	-0.1	-0.3	2.1
40	-1.0	-1.0	-1.0	-1.1	-1.3	-1.1	-0.4	-0.2	-0.3	-0.1	-0.3	1.4
45	-0.9	-0.9	-0.9	-1.0	-1.1	-1.1	-0.6	-0.3	-0.4	-0.3	-0.4	0.6
50	-0.9	-0.9	-0.9	-0.9	-1.0	-1.0	-0.7	-0.4	-0.5	-0.4	-0.4	0.2
55	-0.5	-0.5	-0.5	-0.5	-0.6	-0.6	-0.4	-0.3	-0.3	-0.2	-0.2	0.4
60	-0.3	-0.4	-0.4	-0.4	-0.4	-0.4	-0.3	-0.3	-0.2	-0.1	-0.1	0.4
70	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.1	0.4
80	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.4
90	0.6	0.6	0.6	0.6	0.6	0.5	0.4	0.4	0.5	0.6	0.6	0.8
100	0.8	0.8	0.8	0.8	0.8	0.8	0.6	0.6	0.7	0.8	0.8	0.9
110	1.2	1.2	1.2	1.3	1.2	1.2	1.1	1.1	1.1	1.1	1.2	1.3

Sensor Depth (cm)	Mar 01	Mar 02	Mar 03	Mar 04	Mar 05	Mar 06	Mar 07	Mar 08	Mar 09	Mar 10	Mar 11	Mar 12
10	97	83	97	81	89	97	97	52	18	54	97	31
15	97	91	97	85	83	97	97	97	43	49	97	83
20	97	86	97	81	78	97	97	97	74	44	97	97
25	97	90	97	87	84	97	97	97	97	53	97	97
30	86	94	97	95	92	97	97	97	97	66	97	97
35	83	90	97	97	92	97	97	97	97	55	97	97
40	81	81	97	97	90	97	97	97	97	76	97	97
45	74	73	97	93	82	97	97	97	97	97	97	97
50	69	66	72	86	75	93	97	97	97	97	97	97
55	62	59	57	73	63	58	97	97	97	97	97	97
60	77	71	69	73	69	65	97	97	97	97	97	97
70	97	91	87	82	79	76	97	97	97	97	97	97
80	97	97	97	97	97	93	97	97	97	97	97	97
90	97	97	97	90	84	81	97	97	97	97	97	97
100	97	97	97	97	97	97	97	97	97	97	97	97
110	97	97	97	97	97	97	97	97	97	97	97	97

Moisture (%)
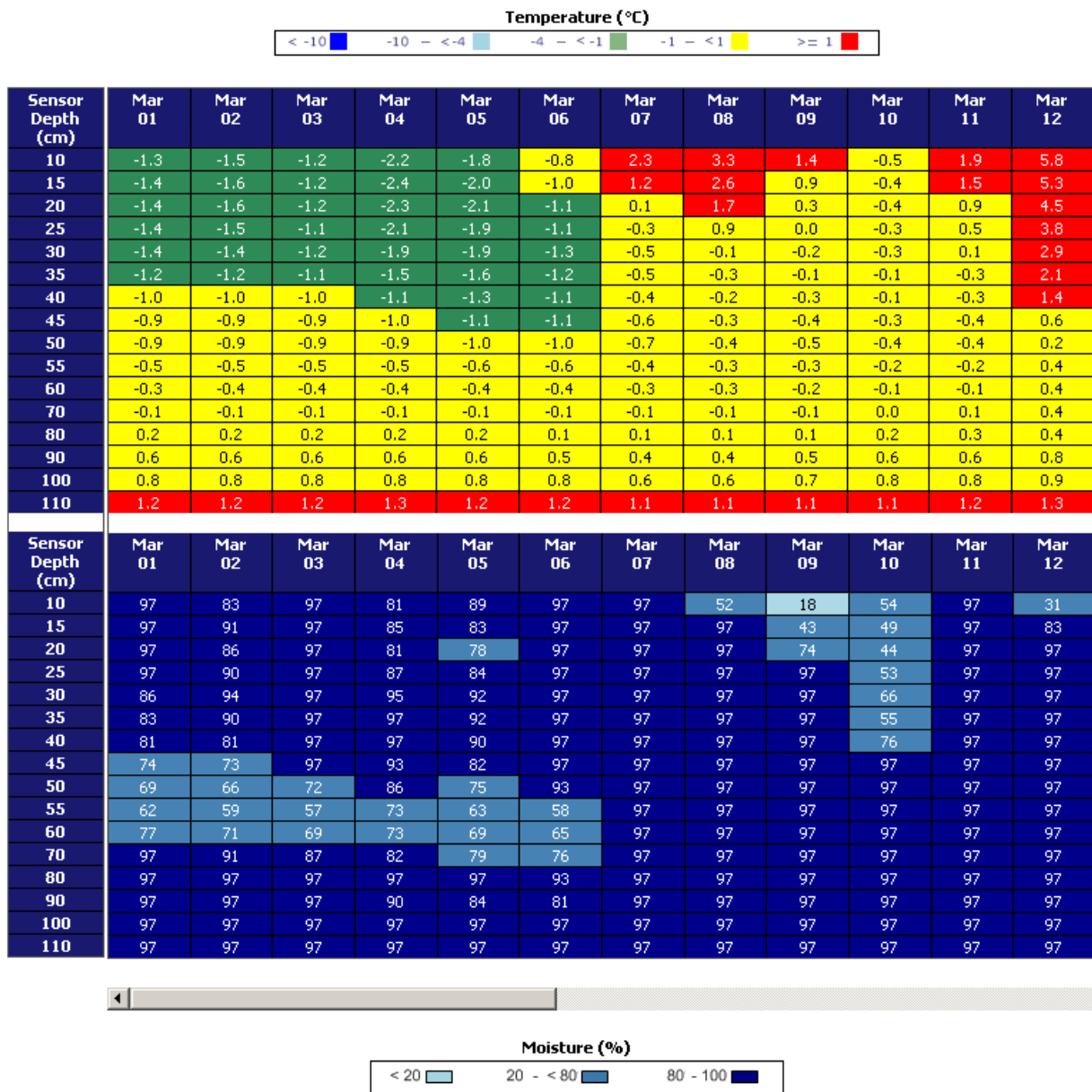
< 20	20 - < 80	80 - 100

Figure 10: Website display of sub-surface temperature and moisture evolution for Devon

In Southwest Nova Scotia, at Springhaven, the influence of a milder and more moderate oceanic climate kept deep frost penetration relatively short and shallow as illustrated in Figure 11. The longest frost period lasted 17 days from January 21 to February 6 with a maximum depth slightly less than 50 cm.
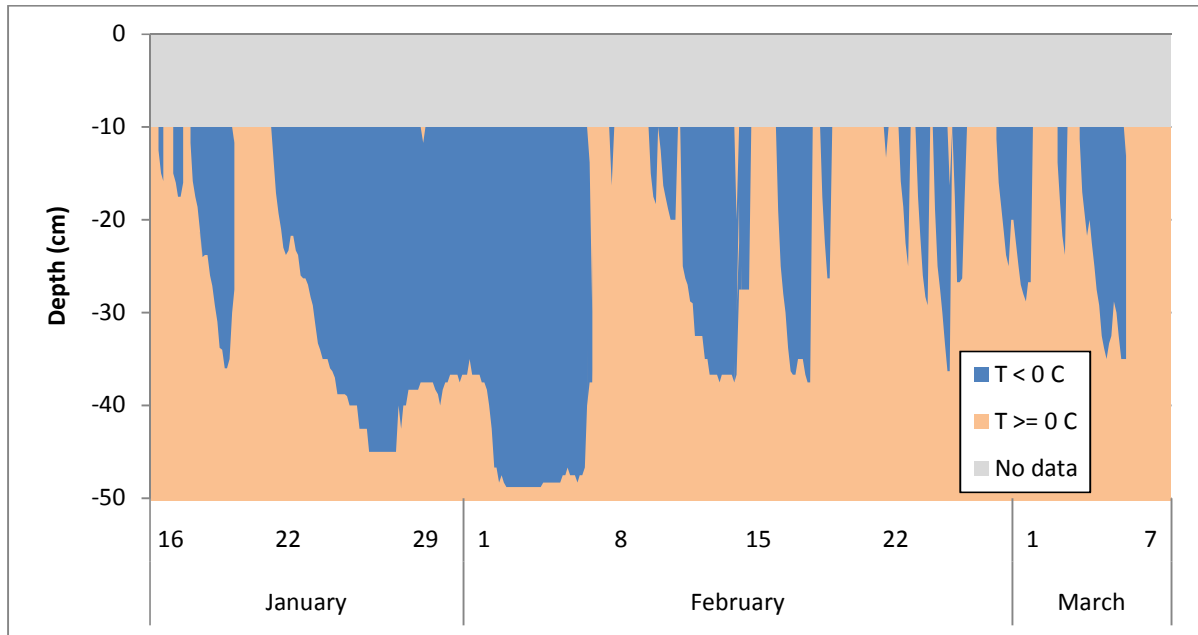
Figure 11: Frost by depth at Springhaven, NS from January 15 to March 7

Accuracy of forecasts

The forecast system has shown significant skill. As can be seen in Table 1, large errors are relatively rare except in the top layers where rapid temperature swings are common. Slower temperature variation for deeper layers means more stringent error criteria are appropriate. However, for errors smaller or equal than the 0.2 C thresholds, instrument reading errors estimated near 0.06C become significant.

Table 1: Percentage of (3-hourly) forecast periods with error less than specified threshold at Trafalgar, NS from November 2010 through March 2011 (all lead times up to day 5).

Depth (cm)	Error ≤ 2 C	Error ≤ 1 C	Error ≤ 0.5 C	Error ≤ 0.2 C
10	*68*	44	26	13
20	*92*	*74*	51	24
30	**97**	***83***	**60**	**32**
40	100	*92*	73	39
50	100	99	*91*	60
60	100	100	95	65
70	100	100	99	*80*
80	100	100	99	*87*
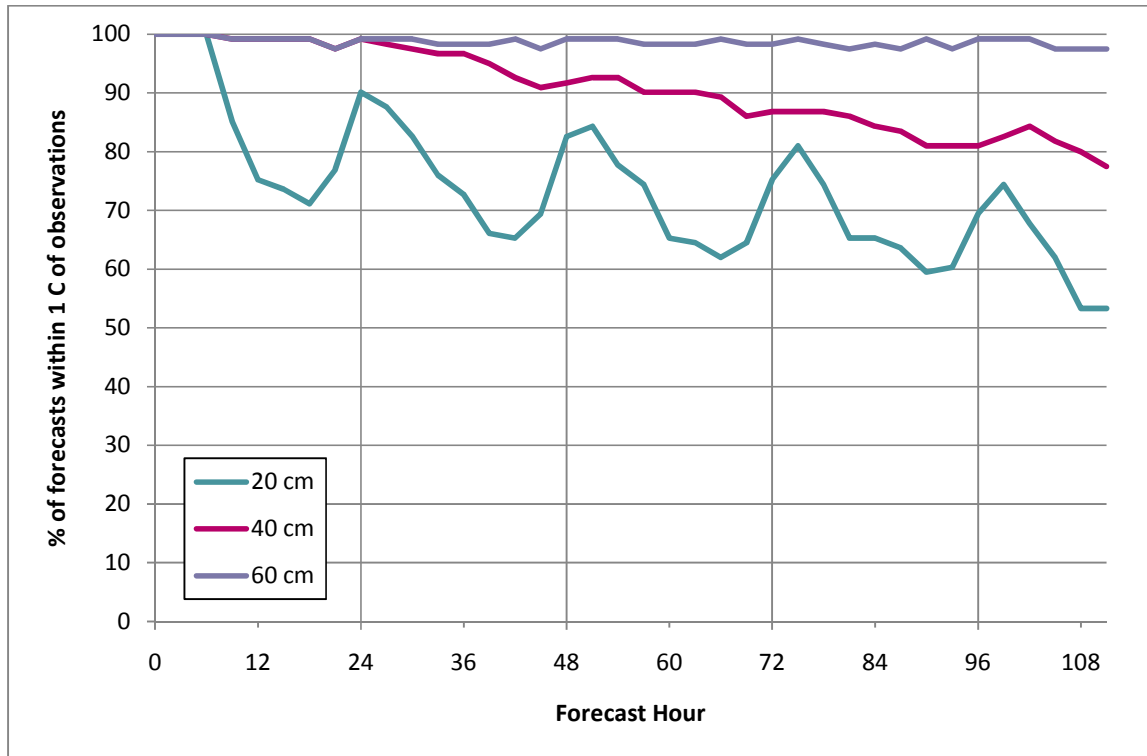
Figure 12: Percentage of forecasts within 1 C of observations for all lead times at Trafalgar from November 2010 through March 2011

The model exhibits expected behaviour with performance deteriorating with longer lead times as can be seen in Figure 12. This is natural for any forecast model, even more so for one that uses as input a model for which accuracy also decreases with time. The impact of the numerical weather prediction model errors is significant at the surface, and then as depth increases SNTHERM's errors become dominant. However, another obvious issue is a strong diurnal variation in error levels. SNTHERM has a marked cold bias at the surface in the morning where actual temperatures rise much faster than forecast. This error dampens with depth but is still noticeable down to 40 cm.

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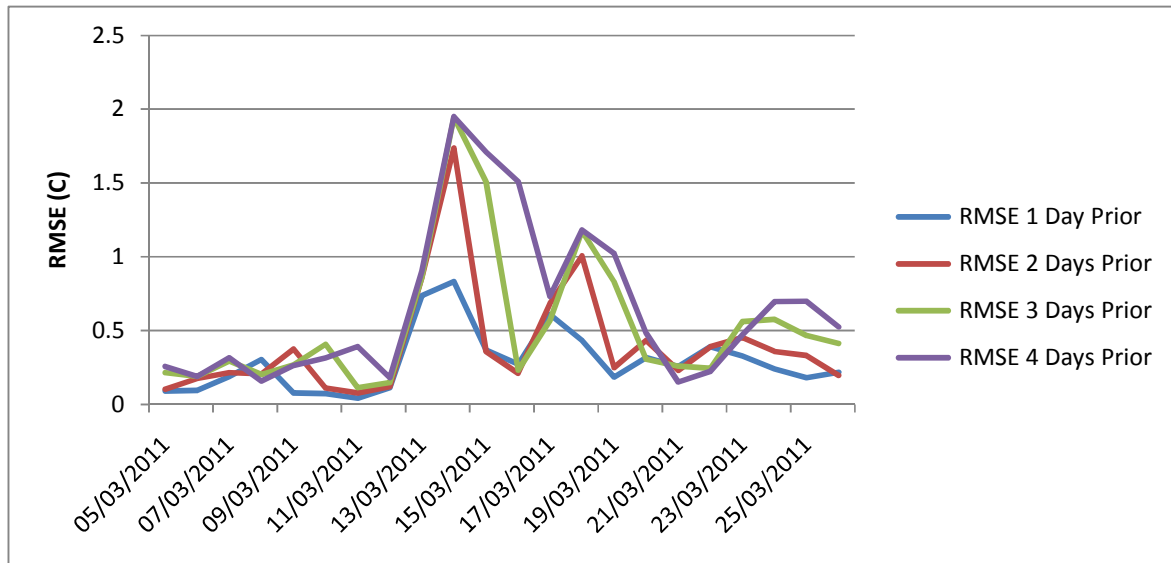
Figure 13: RMSE Forecast error at East Bay for depths 60-80 cm. Notice the sharp increase on March 14 around the time when the frozen layer breaks down.

Another effect worth nothing is that some days are disproportionately responsible for the forecast error at all lead times. The effect of heavy rain seems to be poorly handled by SNTHERM. But other not yet determined factors are at play on some days. One factor that has been particularly concerning is difficulties around the critical time of the spring thaw where the model has been showing some of its worst performance as can be seen in Figure 13. It is surmised this is related to the limited ability of SNTHERM to handle water flow in the ground.

Outside of the intrinsic bias and limitations of SNTHERM and the accuracy of the driving weather model, additional errors are due to uncertainty in the nature and distribution of materials under the road surface. The thickness of the asphalt layer, the nature and thickness of the base and sub-base as well as the nature of the sub-grade are major inputs of any sub-surface model; more detailed samples taken at the time of installation would have been of great use. To remedy this, the model is getting tuned through the use of statistical tools. While this is a useful exercise, it should deal mainly with numerical model parameters and not fundamental physical parameters.

Future Work

In many respects, this project is still a work in progress. Research is ongoing to better incorporate moisture data and investigate driving the models with different sources of forecast data, perhaps from the Meteorological Service of Canada (MSC).

For all its strengths, the thermodynamic model used, SNTHERM, is not without weaknesses as noted in the previous section. AMEC is considering improving it or investigating the use of other point heat-balance models. While temperature and moisture are the parameters currently forecast, it would be interesting to investigate the use of a model to translate this information

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into some measure of road strength. For this to be possible it would be necessary to consult with engineers, to collect precise data on the road composition and to obtain a good time series of deflectometer, or other strength testing device, results for an SLA site.

For any future installation where there is an intention to do physical modelling, the installation crew should proceed with systematic coring and/or augering, take measurements of the thickness of each layers of different materials, and retain samples.

It is also thought that there may be an opportunity to extend the reach of the information provided by leveraging the denser RWIS network that offers temperature observations at pavement level, 40 cm and 150 cm. Using these limited observation levels from the RWIS network, more complete data sets from SLA stations, some knowledge of road and substrate construction and composition, and the pavement model, synthetic observations could be created for each RWIS site. And from there forecasts could be generated. The uncertainty would be greater but it would give one more tool for more refined Seasonal Load Adjustment decisions using existing data sets.

Nova Scotia's perspective about the benefits of system

In 2010, Nova Scotia Transportation and Infrastructure Renewal (NS TIR) commissioned the installation of six frost probes across the province measuring soil temperature and soil moisture at depths up to 110 cm. The frost probes were polled hourly through the 2010-2011 winter.

This data has immediately proven useful to NS TIR in the spring of 2011 in two ways. The measurements were used, in conjunction with the long range weather forecast and input from the local Area Managers, to reach a decision on the date of the beginning of spring weight restriction season. In prior years, weight restrictions were lifted on nights when specific air temperatures were forecast. This season, the data from the frost probes was used to determine if the weight restrictions would be lifted at night. The data had to demonstrate frost at a depth of 10 to 15cm for overnight openings; however this season no overnight openings occurred. This first season showed there is the potential for making more or regional (County by County) decisions in the future.

Conclusion

The Seasonal Load Adjustment program of Nova Scotia Transportation and Infrastructure Renewal now has at its disposal a new tool to determine road weight-bearing capacity: a forecasting system that utilizes data from six sub-surface observations stations. In the Nova Scotia context, load restrictions can be imposed in the day but removed on nights when favourable conditions are expected. This offers heavy haulers a means to maintain nearly constant hauling costs while limiting road damage. This dynamic application of load restrictions illustrates the direct benefit of these observations in critical periods. The sub-surface observations were also helpful tools for the implementation of spring load restriction in this

unusually warm winter. Future work needs to determine how moisture data can be used most effectively to support the removal of spring load restrictions.

Multiple forecasting approaches can and ideally should be considered to provide a full toolbox to support variable seasonal load restrictions. AMEC believes that of the forecasting approaches, deterministic physical modelling has an edge by being the most likely to assess all meteorological factors, which makes it more likely to correctly predict subsurface conditions when abnormal weather conditions prevail.

Early results using only six sites in Nova Scotia have shown very promising results for the single and first spring thaw where physical modeling approaches were attempted. Further work as outlined in the previous sections will have to continue to make this forecast solution as accurate as possible. Further verification will be needed to ascertain that this tool can be used confidently as a guidance to determine when load restrictions have to be implemented.

The observations and forecast can help identify the appropriate narrow window of time when deflectometer testing would be most appropriate. The sensor installations and predictive service are both good approaches to ensure maximum throughput at lowest cost on the road infrastructure while ensuring its preservation.

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