



XIII  
INTERNATIONAL  
WINTER ROAD  
CONGRESS

QUÉBEC, FEBRUARY 8 TO 11, 2010



# SUSTAINABLE WINTER SERVICE FOR ROAD USERS

## *DEVELOPMENT AND CALIBRATION OF FROST DEPTH AND THAW DURATION PREDICTORS BASED ON THE WEATHER INFORMATION*

Jennifer Yang, PhD, Visiting Professor  
Fazal Mabood, MAsc, PEng,  
Former MAsc Candidate  
Susan Tighe, PhD, P.Eng  
Professor and Canada Research Chair

# OUTLINE

- **INTRODUCTION**
- **OBJECTIVES AND APPROACH**
- **USE OF INNOVATIVE SENSORS, DATA COLLECTION, AND INTERPRETATION**
- **FREEZE THAW PHENOMENON AND REAL TIME DATA**
- **COMPREHENSIVE DATA CALCULATION & VALIDATION**
- **CONCLUSIONS AND RECOMMENDATIONS**
- **ACKNOWLEDGEMENTS**



# BACKGROUND

- **Partnering Together to Provide Value CPATT, MTO, MNR, FP Innovations**
- **Better understand Pavement Performance and deterioration during spring thaw (account for environmental/traffic impact)**
- **Performance monitored through collection of strain, vertical pressure, temperature & moisture**



# INTRODUCTION

- **Frost depth varies 1.0 m - 2.0 m in Northern Ontario.**
- **Available moisture in the pavement structure upon freezing pavement structure.**
- **Volumetric expansion impacts frost heaves.**
- **Warmer winters the arrival of spring cause temperatures in the soil to oscillate around the freezing. Pavement reaches a critical state where the upper layers are thawed while the lower layers remain frozen.**
- **Most effective method to prevent the pavement from any damage during this freeze-thaw cycle is to impose loads on the axles and is known as the Seasonal Load Restriction (SLR) regulation.**

# INTRODUCTION

- **SEASONAL LOAD RESTRICTIONS IN ONTARIO**

Seasonal load restrictions are imposed each year on low volume routes designated as “Schedule 2 Highways”, usually throughout March, April and May.

- **SEASONAL LOAD RESTRICTIONS IN CANADA**

- Most typically by using fixed dates across Canada;
- Sometimes frost depth and the number of days with temperatures less than 0 Deg C are used;
- Sometimes use of Tire Pressure Control System (TPCS) to abide by “reduced tire-pressure” periods.

# OBJECTIVES AND APPROACH

- Frost data collected in Northern Ontario showed good correlation with frost thickness in the pavement structure and ambient air temperatures provided by Road Weather Information Systems (RWIS).
- **In Ontario, in order to modify and validate the model, MTO & CPATT built two pilot sites. Highway 601 in Dryden-Ontario, and Highway 651 west of Chapleau-Ontario.**
- Highway 601 and 651 instrumented **to monitor pavement temperature, soil moisture content, relative humidity and air temperature to obtain the comprehensive knowledge of freeze-thaw phenomenon.**



# USE OF INNOVATIVE SENSORS, DATA COLLECTION, AND INTERPRETATION

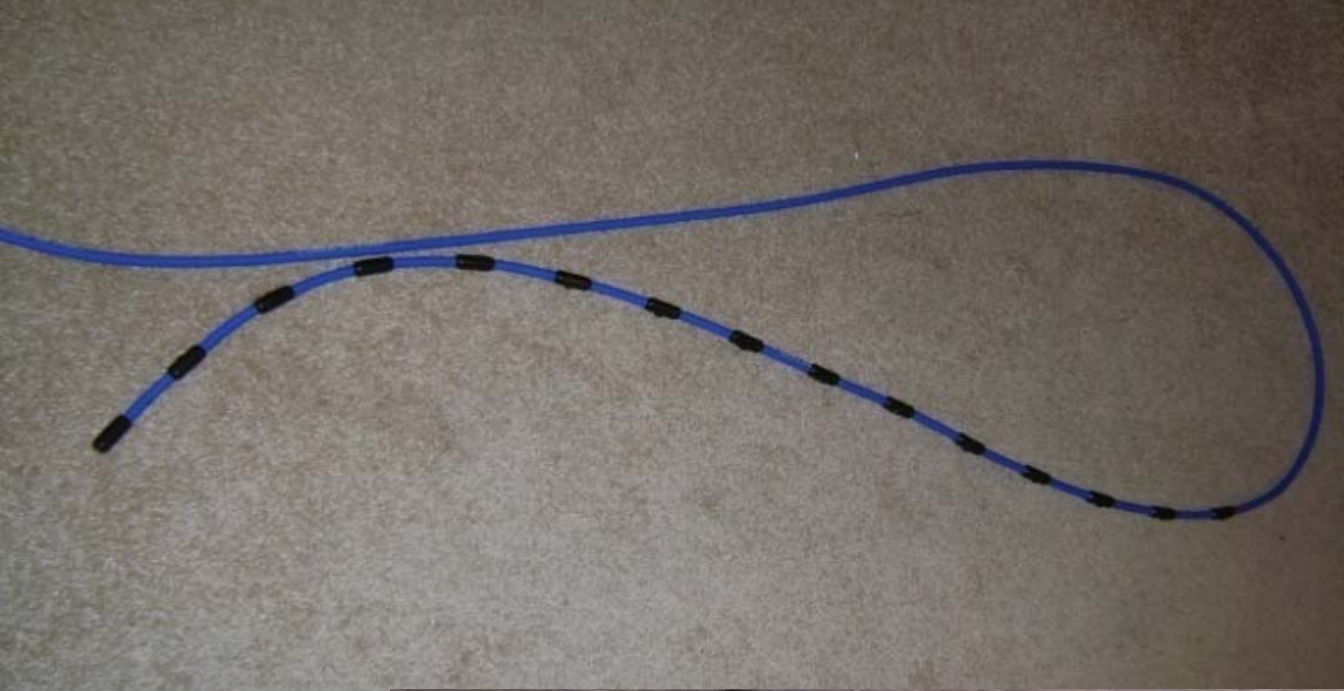
- **Thermistor strings(W0E 404)** , installed within the pavement structure at various depths as follows: 15 cm, 30 cm, 40 cm, 50 cm, 75 cm, 100 cm, and 150 cm;
- **HC-S3 XT Temperature and Relative Humidity Probe**
- **CS616 Water Content Reflectometer**, measuring the volumetric water content of porous media.
- **The CR-1000 data logger**, stores readings after every 5 seconds and the data is stored at five second intervals.













# DATA LOGGER PROGRAM AND DATA ACQUISITION

C:\Campbellsci\PC400\CR1000-1\_Table1.dat

File View Help

All arrays

TIMESTAMP	RECORD	Batt_Vol	Temp_1	Temp_2	Temp_3	Temp_4	Temp_5	Temp_6	Temp_7	AirTC	RH	VW	PA uS
"2008-04-23 05:00:00"	4068	12.63	7.474	7.435	6.511	5.13	4.639	1.191	-0.055	4.797	96.9	0.379	30.12
"2008-04-23 06:00:00"	4069	12.62	7.037	7.144	6.357	5.073	4.698	1.231	-0.053	4.508	97.2	0.379	30.12
"2008-04-23 07:00:00"	4070	12.61	6.659	6.863	6.184	5.007	4.747	1.27	-0.052	3.661	95.5	0.379	30.11
"2008-04-23 08:00:00"	4071	12.72	6.334	6.663	6.092	4.992	4.79	1.303	-0.049	4.457	91.9	0.379	30.11
"2008-04-23 09:00:00"	4072	13.57	6.067	6.503	6.019	4.996	4.823	1.336	-0.063	8.54	70.98	0.379	30.11
"2008-04-23 10:00:00"	4073	13.6	6.263	6.244	5.819	4.884	4.846	1.359	-0.069	10.27	51.08	0.379	30.12
"2008-04-23 11:00:00"	4074	13.51	7.446	6.135	5.662	4.786	4.853	1.396	-0.07	11.85	42.38	0.379	30.11
"2008-04-23 12:00:00"	4075	13.44	9.03	6.241	5.546	4.689	4.853	1.406	-0.079	14.4	32.09	0.378	30.1
"2008-04-23 13:00:00"	4076	13.39	10.84	6.58	5.545	4.612	4.852	1.425	-0.089	15.23	31.6	0.378	30.1
"2008-04-23 14:00:00"	4077	13.36	12.59	7.113	5.651	4.593	4.843	1.453	-0.089	16.78	27.11	0.379	30.11
"2008-04-23 15:00:00"	4078	13.34	14.16	7.783	5.86	4.609	4.83	1.469	-0.092	17.06	24.97	0.379	30.11
"2008-04-23 16:00:00"	4079	13.34	15.39	8.5	6.161	4.706	4.821	1.499	-0.091	16.16	25.38	0.379	30.11
"2008-04-23 17:00:00"	4080	13.38	16.19	9.21	6.531	4.833	4.824	1.52	-0.089	14.57	29.12	0.378	30.1
"2008-04-23 18:00:00"	4081	13.41	16.1	9.81	6.91	5.006	4.833	1.539	-0.089	13.54	25.36	0.379	30.11
"2008-04-23 19:00:00"	4082	13.17	15.14	10.16	7.24	5.169	4.862	1.576	-0.071	12.33	28.55	0.379	30.11
"2008-04-23 20:00:00"	4083	12.89	13.94	10.27	7.527	5.356	4.894	1.598	-0.069	9.91	41.6	0.379	30.11
"2008-04-23 21:00:00"	4084	12.78	12.75	10.19	7.712	5.539	4.932	1.617	-0.059	4.054	65.46	0.378	30.1
"2008-04-23 22:00:00"	4085	12.73	11.55	9.97	7.819	5.712	4.998	1.654	-0.052	0.593	75.07	0.378	30.1
"2008-04-23 23:00:00"	4086	12.68	10.43	9.64	7.824	5.812	5.07	1.667	-0.058	-1.106	80.8	0.379	30.11
"2008-04-24 00:00:00"	4087	12.64	9.38	9.23	7.755	5.88	5.147	1.705	-0.058	-1.77	84.3	0.379	30.11
"2008-04-24 01:00:00"	4088	12.61	8.46	8.8	7.602	5.903	5.208	1.728	-0.055	-1.957	86	0.379	30.11
"2008-04-24 02:00:00"	4089	12.58	7.625	8.36	7.43	5.886	5.288	1.749	-0.043	-2.211	87.6	0.378	30.1
"2008-04-24 03:00:00"	4090	12.56	6.885	7.9	7.206	5.819	5.356	1.788	-0.052	-2.415	89.2	0.378	30.1
"2008-04-24 04:00:00"	4091	12.54	6.208	7.452	6.965	5.744	5.406	1.809	-0.051	-2.838	90.7	0.378	30.1
"2008-04-24 05:00:00"	4092	12.53	5.591	7.025	6.705	5.64	5.466	1.849	-0.049	-2.957	91.5	0.378	30.1
"2008-04-24 06:00:00"	4093	12.52	5.033	6.618	6.453	5.515	5.505	1.868	-0.048	-3.127	92.8	0.378	30.1
"2008-04-24 07:00:00"	4094	12.52	4.534	6.221	6.183	5.391	5.545	1.908	-0.038	-2.754	91.2	0.378	30.1
"2008-04-24 08:00:00"	4095	12.71	4.263	5.939	6.007	5.321	5.553	1.945	-0.049	0.059	84	0.378	30.08
"2008-04-24 09:00:00"	4096	13.74	4.254	5.707	5.852	5.263	5.552	1.955	-0.048	8.31	49.62	0.378	30.08
"2008-04-24 10:00:00"	4097	13.66	4.779	5.414	5.569	5.068	5.53	1.972	-0.058	11.32	39.69	0.378	30.08
"2008-04-24 11:00:00"	4098	13.52	6.13	5.32	5.349	4.896	5.503	1.984	-0.065	14.6	33.04	0.377	30.07
"2008-04-24 12:00:00"	4099	13.42	7.972	5.468	5.208	4.747	5.478	1.998	-0.07	17.28	28	0.377	30.07
"2008-04-24 13:00:00"	4100	13.35	10.01	5.889	5.195	4.627	5.435	2.004	-0.083	20.41	22.94	0.377	30.06
"2008-04-24 14:00:00"	4101	13.3	11.91	6.486	5.298	4.577	5.404	2.021	-0.085	21.4	22.01	0.377	30.06
"2008-04-24 15:00:00"	4102	13.28	13.25	7.204	5.52	4.587	5.347	2.031	-0.094	21.07	20.57	0.376	30.04
"2008-04-24 16:00:00"	4103	13.29	13.87	7.917	5.838	4.654	5.308	2.04	-0.085	20.6	20.79	0.377	30.06
"2008-04-24 17:00:00"	4104	13.29	14.29	8.52	6.196	4.779	5.279	2.05	-0.094	20.28	20.96	0.376	30.04
"2008-04-24 18:00:00"	4105	13.3	14.43	9	6.545	4.943	5.261	2.06	-0.093	19.92	23.62	0.376	30.04
"2008-04-24 19:00:00"	4106	13.3	14.08	9.35	6.856	5.098	5.252	2.07	-0.093	18.21	26.25	0.376	30.04
"2008-04-24 20:00:00"	4107	13.01	13.42	9.52	7.094	5.237	5.247	2.075	-0.079	16.5	28.94	0.376	30.04
"2008-04-24 21:00:00"	4108	12.87	12.69	9.58	7.299	5.401	5.266	2.084	-0.079	15.2	28.26	0.376	30.04
"2008-04-24 22:00:00"	4109	12.83	11.94	9.52	7.436	5.546	5.296	2.085	-0.078	13.98	27.73	0.376	30.04
"2008-04-24 23:00:00"	4110	12.81	11.31	9.39	7.518	5.666	5.338	2.098	-0.076	13.43	28.89	0.376	30.03
"2008-04-25 00:00:00"	4111	12.79	10.75	9.21	7.53	5.764	5.388	2.109	-0.074	12.69	30.82	0.376	30.03

- Figure 1: PC 400 screen demonstrating Highway 601 pavement and air data

# FREEZE THAW PHENOMENON AND REAL TIME DATA

- FREEZING/THAWING INDICES, FROST DEPTH, AND THAW DURATION
- HISTORICAL DATES FOR SLR IN NORTHERN ONTARIO



# FREEZING/THAWING INDICES, FROST DEPTH, AND THAW DURATION

- $D = 0.018(FI) + 25$

Where FI = Freezing Index, Degree-Days

D = Thaw Duration, Days

- The Freezing Index (FI) can also be calculated from Equation given below:

$$FI = \sum (0^{\circ}\text{C} - T_{\text{MEAN}i})$$

Where  $T_{\text{MEAN}i}$  = Mean Air Temperature

# HISTORICAL DATES FOR SLR IN NORTHERN ONTARIO

**Table 1: Implementation and Termination Dates for Reduced Loading  
- Northwestern Region [MTO's Regional Office Record]**

Year	Thunder Bay (Dryden-Hwy 601 location)			Saulte Ste. Marie (Chapleau-Highway 651 location)		
	Start	End	Duration (weeks)	Start	End	Duration (weeks)
1993	Mar 22	May 20	8	Mar 5	May 17	10
1994	Mar 15	May 24	9	Mar 18	May 24	9
1995	Mar 15	May 23	9	Mar 14	May 12	8
1996	Mar 18	May 27	9	April 1	May 21 & 27	8
1997	Mar 14	May 20	9	Mar 21 & 27	May 26 & June 2	9
1998	Mar 2	May 5	9	Mar 2	May 4	8
1999	Mar 15	May 14	9	Mar 17	May 18	8
2000	Mar 1	May 8 & 13	9-10	Mar 1	May 1 & 8	9
2001	Mar 18-20	May 18-22	9	Mar 18	May 18	8
2002	Mar 19-28	May 21-31	10	Mar 18	May 27	9
2003	Mar 18-	May 20-23	9	Mar 20	May 20	8





# COMPREHENSIVE DATA CALCULATION AND VALIDATION

Table 2: Freezing and Thawing Indices on Hwy 651 as worked out from on-site sensor readings  
(2007 November to 2008 October)

Month	Freezing			Thawing		
	Mean Air Temperature $T_{\text{mean, } 0^{\circ}\text{C}}$	Number of Days Temperature Falling Below $0^{\circ}\text{C}$	Freezing Index (FI) [ $T_{\text{mean}} \times \text{No. of Days below } 0^{\circ}\text{C}$ ], <i>Deg C-days</i>	Mean Air Temperature $T_{\text{mean, } 0^{\circ}\text{C}}$	Number of Days Temperature Falling Above $0^{\circ}\text{C}$	Thawing Index (TI) [ $T_{\text{mean}} \times \text{No. of Days Above } 0^{\circ}\text{C}$ ], <i>Deg C-days</i>
Nov	-8	21	166	3	9	26
Dec	-11	30	345	0	1	0
Jan	-15	27	398	1	4	6
Feb	-16	29	455			0
March	-12	31	365			0
April	-4	14	56	4	16	66

# COMPREHENSIVE DATA CALCULATION AND VALIDATION

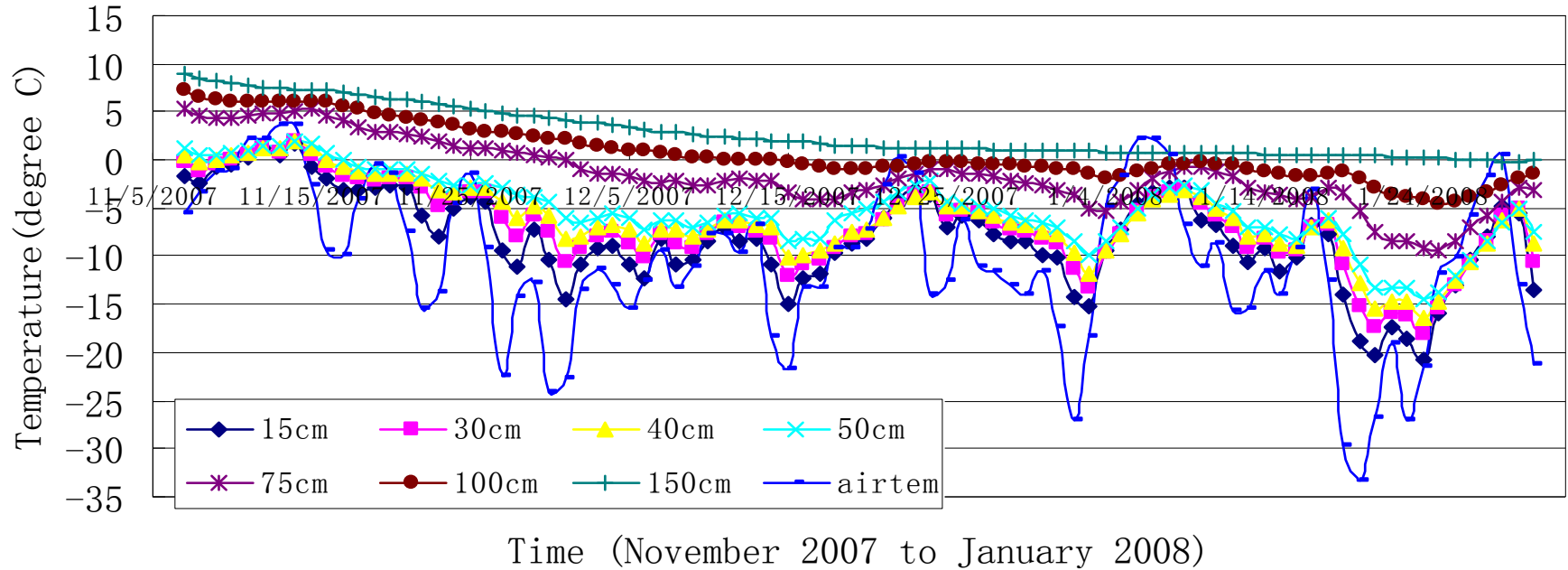
**Table 2: Freezing and Thawing Indices on Hwy 651 as worked out from on-site sensor readings  
(2007 November to 2008 October)**

<b>Month</b>	<b>Freezing</b>			<b>Thawing</b>		
	<b>Mean Air Temp °C</b>	<b>Number of Days Below °C</b>	<b>Freezing Index (FI)</b>	<b>Mean Air Temp °C</b>	<b>Number of Days Above 0°C</b>	<b>Thawing Index (TI)</b>
May	-1	5	6	4	26	116
June			0	12	30	362
July			0	13	31	406
Aug			0	12	31	358
Sept			0	9	30	261
Oct	-3	11	32	5	20	110
<b>Σ FI</b>			<b>1821</b>	<b>Σ TI</b>		<b>1821</b>
Frost Depth FD, $\sqrt{FI}$ – 42.7 inches, 108 cm				Thaw Duration D= 0.018 x FI + 25; 58 Days ~08 weeks		

# COMPREHENSIVE DATA CALCULATION AND VALIDATION

## Pavement Temperature and Air Temperature during November 2007 to January 2008

Temperature at different depth and Air Temperature



**The pavement temperature 15 cm beneath the surface was influenced significantly by the air temperature.**

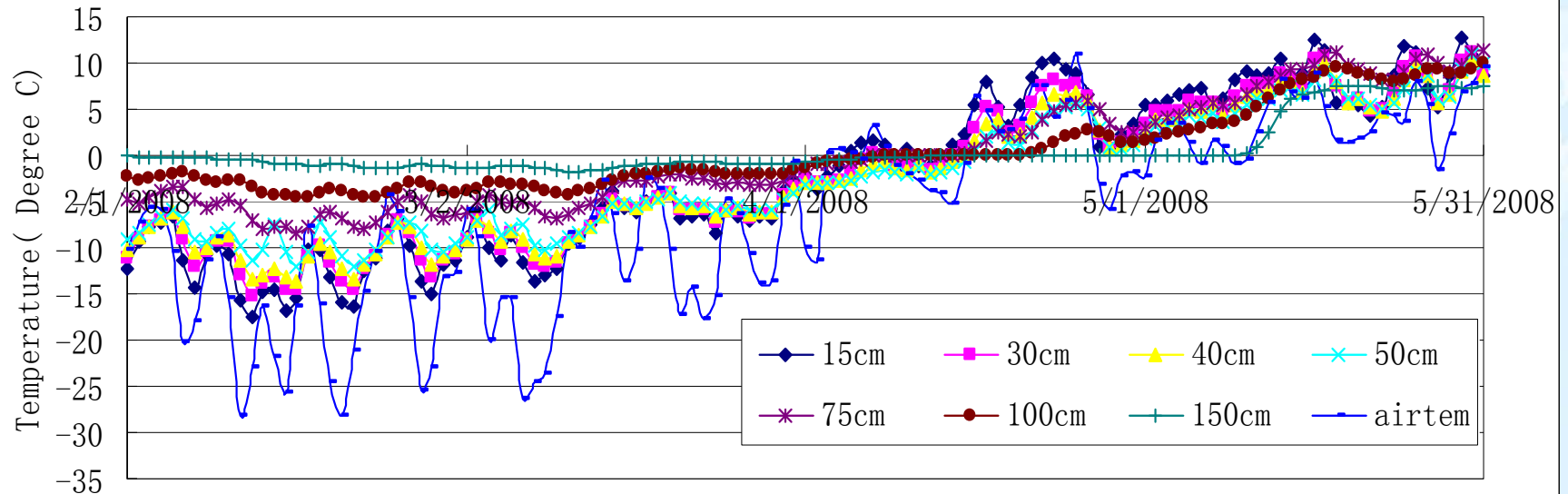
**The actual frost depth in 2008 is deeper than the estimated frost depth.**



# COMPREHENSIVE DATA CALCULATION AND VALIDATION

## Pavement Temperature and Air Temperature during February 2008 to May 2008

Temperature at different depth and Air temperature



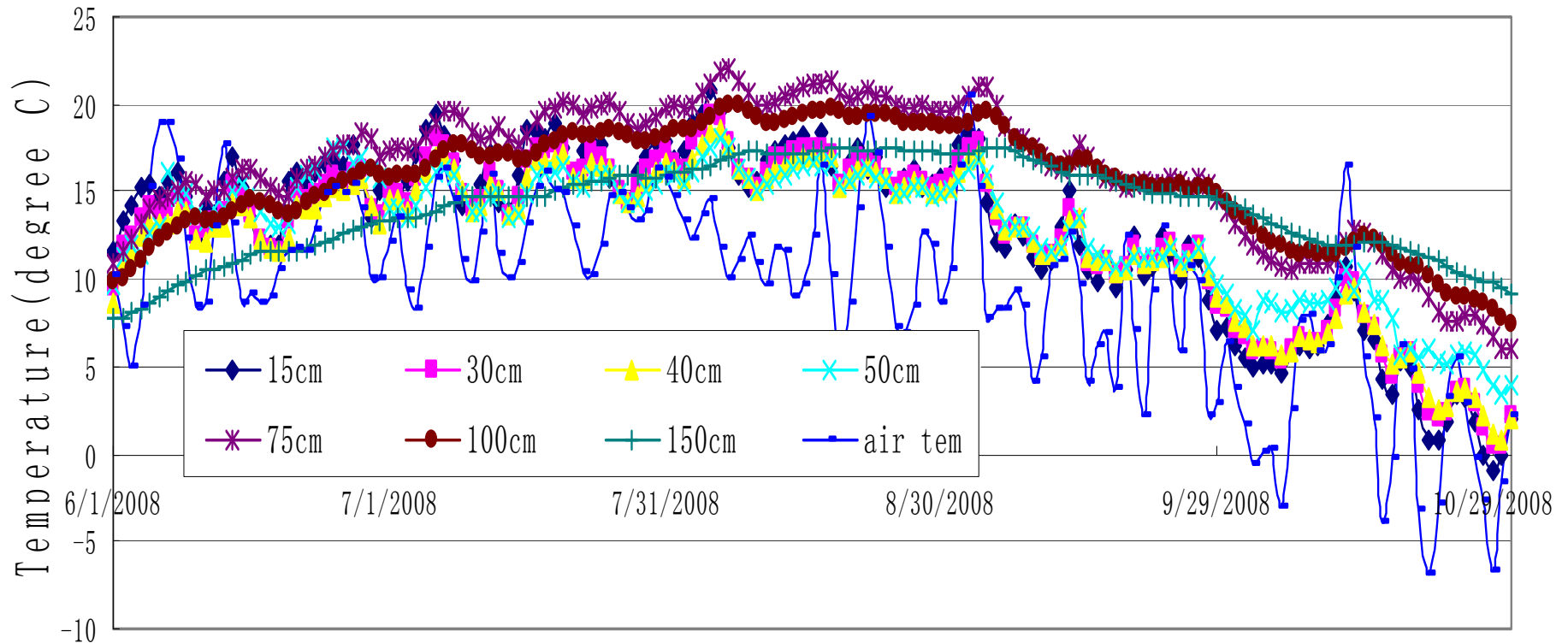
Time (February 2008 to May 2008)

**Pavement started thawing April 5, 2008, and the subgrade below the surface at 150 cm became completely thawed around May 15, 2008, which took 40 days.**

# COMPREHENSIVE DATA CALCULATION AND VALIDATION

## Pavement Temperature and Air Temperature during June 2008 to October 2008

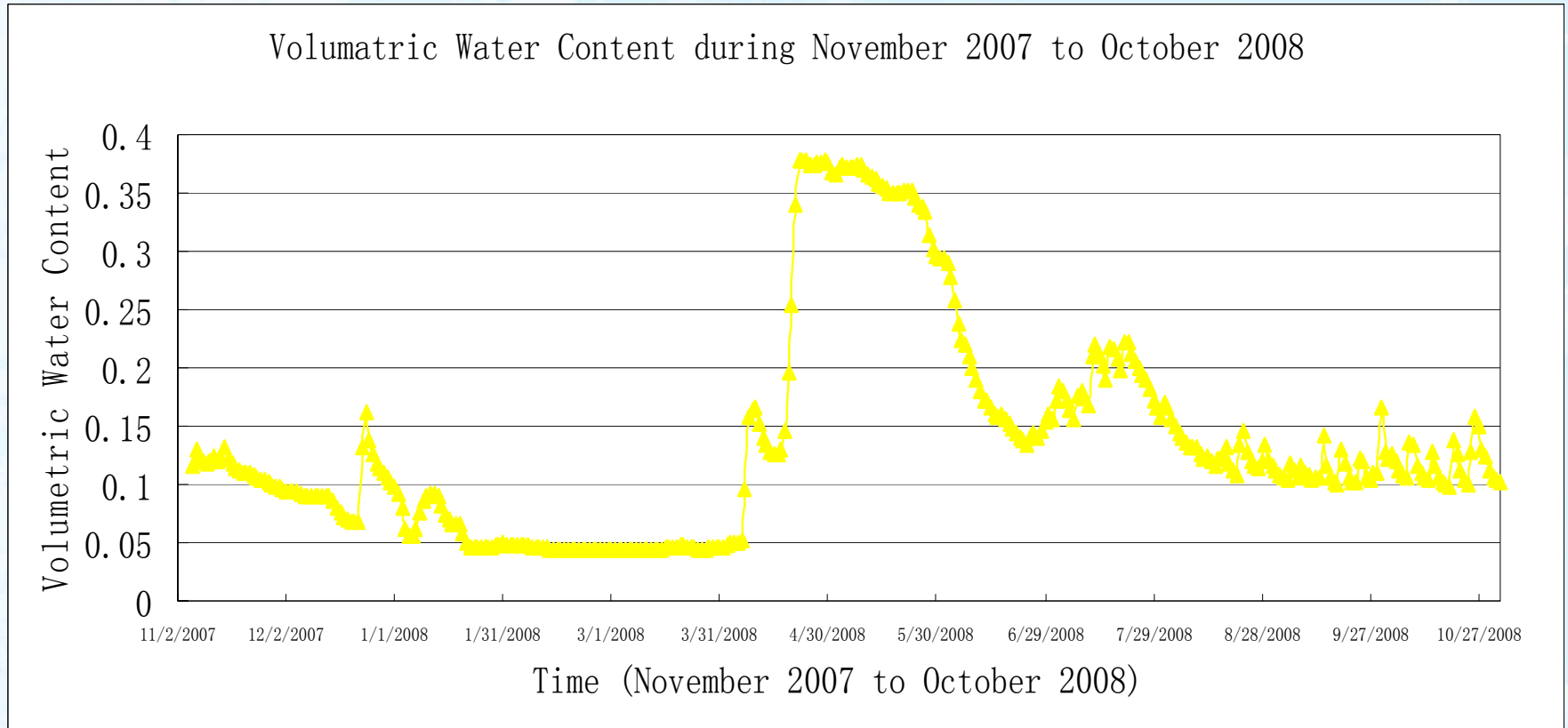
Temperature at different depth and Air Temperature



Time (June 2008 to October 2008)

# COMPREHENSIVE DATA CALCULATION AND VALIDATION

**Figure 3: VWC in Subgrade during November 2007 to October 2008**

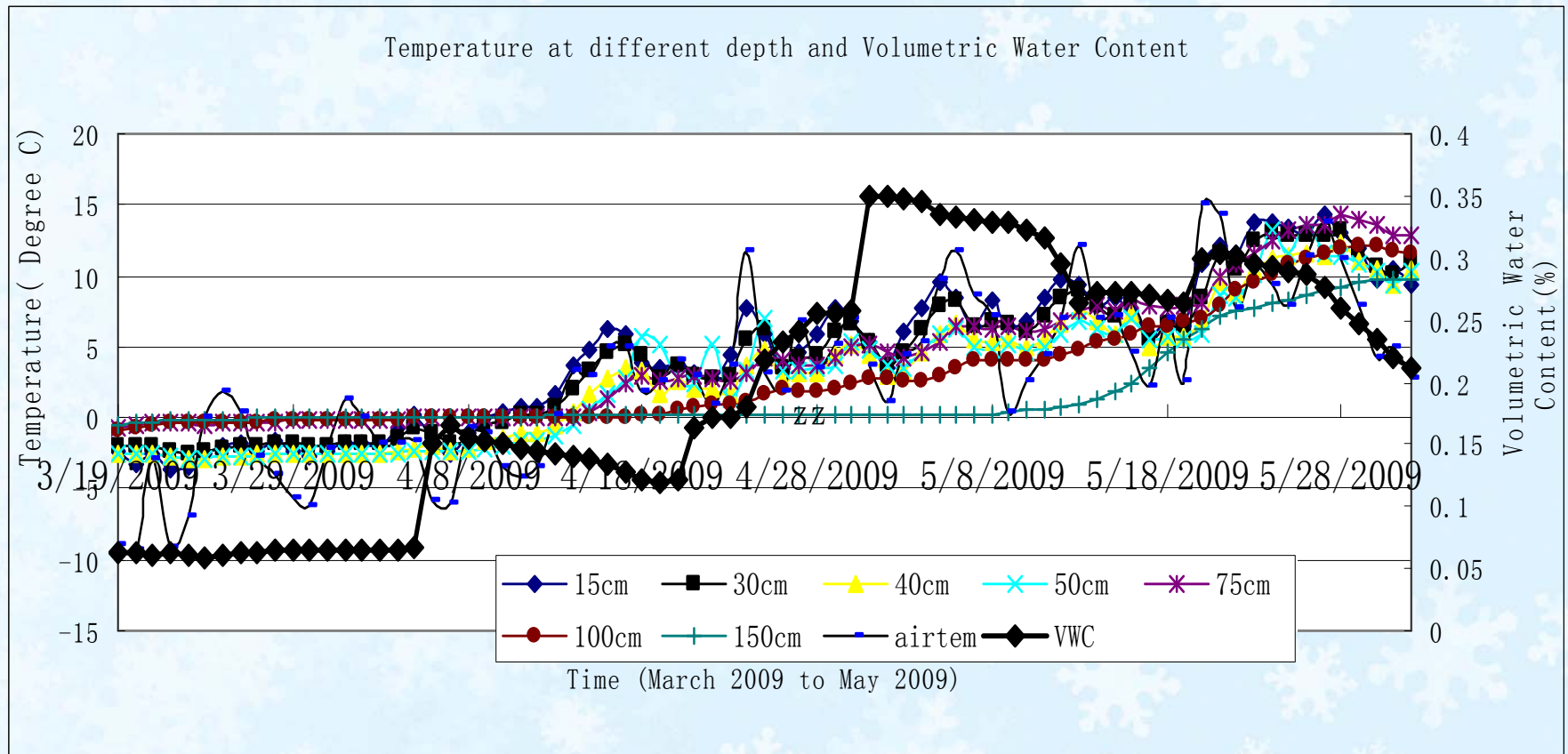


**Volumetric Water Content (VWC) *SLR* should be kept for 8 or 9 weeks from the beginning of April to the end of May.**



# COMPREHENSIVE DATA CALCULATION AND VALIDATION

**Figure 4: Pavement Temperature, Air Temperature and the Volumetric Water Content in Subgrade during March 19 2009 to May 28 2009**



**The VWC's sudden increase in 2009 indicates SLR in 2009 should be lifted end of May.**

# CONCLUSIONS AND RECOMMENDATIONS

- Frost depth of Highway 651 and 601 were 106cm and 103cm based on the mean daily air temperature. Highway 651 structure of frost depth is 150cm in 2008. Actual frost depth is deeper. (Long Term Monitoring)
- Predicted thaw duration of Highway 651 and 601 (55 days and 58 days) in 2008 based on the mean daily air temperature. The temperature sensor data shows **the spring thaw duration was during April 5 to May 26 in 2008, which is consistent with the estimated results.**
- Predicted thaw duration were also compared with the history record of Northwestern Region of Ontario.
- **Overall, the spring thaw duration should start from the end of March or the beginning of the April, which may delay 2 weeks.**

# ACKNOWLEDGEMENTS

- We wish to acknowledge the funding from the Ministry of Transportation of Ontario (MTO)
- FPInnovation (formerly Forestry Engineering Research Institute of Canada, FERIC).
- Tom Klement, Lemieux Maurice and Steve Mercier.



- **Thank you for your attention!**
- **Questions**