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# Airport Engineering

**ATR-038**

**PG Binder Test Section**
**Calgary International Airport**
**Pavement Temperature Analysis**
**1998/1999 and 1999/2000**

R&D PROJECT

PG Binders for Canadian Airport Pavements
Calgary Field Trial

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Airport Engineering Division
National Capital Area

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Canada

# PG BINDER TEST SECTION
# CALGARY INTERNATIONAL AIRPORT
# ANALYSIS OF TEMPERATURE
# INSTRUMENTATION DATA
# 1998/1999 AND 1999/2000

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# 1.0 INTRODUCTION

Public Works and Government Services Canada (PWGSC) has initiated a review of the applicability of Superpave Performance Graded (PG) Binders for the construction of Canadian airport pavements. This work has been coordinated by PWGSC as a joint research effort involving Transport Canada, the U.S. Federal Aviation Administration and the Calgary Airport Authority.

Initial work was conducted in 1997/1998 examining the original basis of the Superpave PG Binder specification and its applicability to Canadian Airport pavements. Subsequent work undertaken in 1998/1999 developed guidelines for selecting PG binders for Canadian Airport pavements with consideration for the type of aircraft using the facility.

Test sections have since been constructed to provide performance information relative to the performance of hot mix asphalt concrete (HMAC) constructed using Superpave PG binder grades compared to conventional CGSB asphalt grades. In 1998, the extension of Taxiway 'J' at the Calgary International Airport was constructed with a PG Binder Test Section utilizing PG 58-34 binder; the Control Section utilized CGSB 150-200A binder. Within the PG Binder Test Section, thermocouples were installed in the pavement structure and subgrade to allow for the analysis of pavement temperatures.

This report provides an analysis of the measured pavement temperatures after one and two years of data collection for the periods of November 1998 to February 1999 and November 1999 to February 2000. Specifically, the analysis examines the measured temperatures and compares the results to work reported by other Canadian researchers. The scope of work reported herein includes the following:

- Evaluation of the variation in the collected temperature data,
- Manipulation and extrapolation of the Calgary International Airport pavement temperature data to predict pavement surface temperature, and
- Regression analysis of the extrapolated surface temperatures to measured air temperatures.

## 2.0 BACKGROUND

The Superpave methodology utilizes design pavement temperatures as the means of grading asphalt binders. In the original Superpave methods, the design low temperature was originally proposed to be equal to the ambient temperature. Canadian research had previously identified that this was overly conservative and low temperature algorithms from Canada were proposed as the method of establishing a low design temperature. Currently, there are several Canadian and American algorithms available for predicting low design temperatures which have been developed since the initial implementation of Superpave. These models have been developed based on instrumented highway test sites.

PWGSC studies undertaken in 1998 and 1999 identified that the Canadian algorithm, as published by the Transportation Association of Canada (TAC), was the most reasonable model for use for Canadian airport pavements. However, that study also recognized that Canadian airport pavements are often constructed with thick granular layers to mitigate potential frost action, and that the thermal characteristics of such pavements may differ from typical highway pavements.

Therefore, in conjunction with other PWGSC initiatives to obtain performance information with Superpave PG binders, temperature instrumentation was installed in the Calgary International Airport PG Binder Test Section. Temperature information collected at this site will help to confirm the applicability of the existing algorithms to Canadian airport pavements with thick granular layers.

## 3.0 SITE LAYOUT

The Superpave PG 58-34 Binder Test Section at the Calgary International Airport is located on Taxiway J from Station 2+000 to the intersection with Taxiway Alpha. Figure 1 shows the site layout. The pavement structure consists of 200 mm of HMAC, 300 mm of crushed granular base and 1050 mm of granular sub-base. Within the test section, thermocouple strings were installed through the entire pavement structure. Thermocouples were installed at depths of 20 mm and 100 mm from the surface within the HMAC layer, and at a nominal 200 mm depth coinciding with the bottom of the HMAC layer. As the HMAC layer thickness varied somewhat, this thermocouple is at different depths in the three installation locations. Thermocouples were also placed at 500 mm depth coinciding with the bottom of the granular base layer, at 1000 mm and 1550 mm depth within the sub-base and within the subgrade at a depth of 2000 mm from the surface. Three sets of instrumentation were installed; one at centreline and at 5 m and 10 m offsets from centreline. This installation set-up provides redundancy in the event that any instrumentation fails, as well as providing a means of comparing the effect of the varying distances from the pavement edge.

Two separate thermocouples are mounted in their individual radiation shields on the instrumentation tower to measure ambient air temperature. Figure 2 shows the layout of the instrumentation as well as the taxiway dimensions and pavement cross-section.

## 4.0 PAVEMENT TEMPERATURE DATA

The temperatures at the Calgary site have been recorded by the datalogger every half-hour since November 1998. From November 1998 to February 2000, almost 26,000 temperature readings were recorded for each thermocouple. The temperature data is collected by PWGSC and posted to a ftp server for public access at the following address:

ftp://ftp.pwgsc.gc.ca/rps/aes/civil/airports/calgary/tempdata/. EBA downloaded the temperature data from this ftp site and developed a database for further manipulation and analysis of the measured temperatures.

## 5.0 ANALYSIS APPROACH

The main focus of EBA's analysis was to use the temperature data recorded at the Calgary International Airport over the previous two winters to develop pavement surface temperature prediction equations.

The following represents the analysis steps followed for this study. Each step is further discussed in the Sections following for both the 1998/1999 and 1999/2000 analyses.

- Screening of Temperature Data
- Selection of minimum daily temperatures
- Extrapolation to estimate pavement surface temperatures (using linear and polynomial regression analysis)

- Regression analysis to determine Pavement Surface Temperatures-Air Temperature relationships.

### 5.1 Screening of Temperature Data

There were two steps employed to select the temperature data appropriate for the analysis. Only months during which freezing temperatures are most typical (i.e., November through February) were selected as the first screening of the data.

The data were further screened to include only temperatures measured during cooling cycles. Because the minimum pavement temperature will occur during cooling cycles these periods are considered the most significant. A cooling cycle is defined as the days when each subsequent day's minimum temperature is lower than the preceding day. Examples of the monthly temperature data for the 1998/1999 and 1999/2000 analysis periods are presented graphically in the Appendices A and B.

This screening process is consistent with the approach undertaken by TAC[1].

### 5.2 Selection of Minimum Daily Temperatures

The minimum daily temperature was selected for the air temperature and for each thermocouple in the HMAC layers. This selection process recognizes that there is a time lag between the minimum air temperature and the minimum temperatures that occur in the underlying pavement layer. The minimum pavement layer temperatures in a cooling cycle generally occurs at some time interval after the minimum air temperature is reached.

### 5.3 Pavement Surface Temperatures

The pavement surface temperature has been selected by the Superpave protocols as the critical pavement temperature input for design purposes. Because of the difficulties associated with measuring pavement surface temperatures, it is often necessary to estimate surface temperatures by extrapolating from other temperature measurements within the pavement structure.

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[1] *Determining the Winter Design Temperature for Asphalt Pavements*, Transportation Association of Canada, Research Report, 1330, W.D. Robertson, 1997.

The pavement surface temperatures were, therefore, extrapolated from the top three temperature measurements from the three thermocouples installed in the HMAC layer.

Two methods of extrapolation were undertaken, the first used a second-degree polynomial, as was done during the development of the TAC algorithms, while the second used simple linear extrapolation.

## 5.4 Thermocouple Correlation Analysis

As previously noted, three sets of thermocouples were installed in the taxiway. To simplify the analysis, a correlation analysis examined the consistency of the temperatures measured at each of the three installations. Tables 1 and 3 presents correlation matrices for all thermocouples for the 1998/1999 analysis periods and for the 1999/2000 analysis periods. The analysis presented in Tables 1 and 3 were limited to temperature readings when air temperatures were at or below 0°C.

Figures 3 to 9 and 13 to 19 graphically present the relationship between the temperatures measured by the thermocouples for the air temperatures and the first three thermocouples in the pavement structure for the 1998/1999 and 1999/2000 analysis periods respectively. The data in these figures include all temperature measurements (i.e. +/- 0°C) and also includes the linear regression equation and the regression coefficient for the data.

The correlation between the various thermocouple installations indicates that there is a high degree of correlation between each of the installations. Based on the significance of these correlations, it was concluded that the thermocouples were measuring the same temperatures in all three installations.

Because the pavement temperatures measured correlate so well to each other, it was considered reasonable to utilize a single installation for the analysis. The temperature readings from the first thermocouple installation (i.e. T1, located near centreline) were therefore selected for the subsequent analysis for both the 1998/1999 and 1999/2000 analysis periods.

## 6.0 1998/1999 ANALYSIS

### 6.1 Selection of Minimum Daily Temperatures

For the 1998/1999 data, the final selection process resulted in 75 sets of temperature measurements representing 75 days of temperature recordings during cooling periods from November 1998 to February 1999. Table 2 presents the temperature data used in the analysis

### 6.2 Pavement Surface Temperatures

For the 1998/1999 data, an extrapolation was conducted for each of the 75 sets of temperature data to provide two pavement surface temperatures. The first pavement surface temperature was obtained using a linear regression analysis while the second was obtained using a polynomial regression analysis. The data are presented in Table 2.

### 6.3 Pavement Surface Temperatures vs. Air Temperatures

The correlation between pavement surface temperatures and air temperatures represents the final step in the analysis. The air temperature was treated as the independent variable, and the pavement surface temperature as the dependent variable. The results of the regression are presented in Figure 10 and Figure 11, which also show the correlation coefficients obtained. The resulting linear equations are as follows:

$$T_{Surface} = 0.7547 * T_{air} + 0.8399 \qquad r^2 = 0.92 \text{ (based on polynomial extrapolation of } T_{surface}) \qquad (1)$$

$$T_{Surface} = 0.7668 * T_{air} + 0.8514 \qquad r^2 = 0.93 \text{ (based on linear extrapolation of } T_{surface}) \qquad (2)$$

Figures 10A and 11A show the results if the respective regressions are forced through the origin, which allows for comparison to the published TAC relationship. The resulting equations, when forced through the origin are as follows:

$$T_{Surface} = 0.7032\ T_{air} \qquad r^2=0.92 \text{ (based on polynomial extrapolation of } T_{surface}) \qquad (3)$$

$$T_{Surface} = 0.7146\ T_{air} \qquad r^2=0.92 \text{ (based on linear extrapolation of } T_{surface}) \qquad (4)$$

The relationship reported by TAC is as follows:

$$T_{Surface} = 0.749 * T_{air} \qquad r^2 = 0.95 \text{ (based on polynomial extrapolation of } T_{surface}\text{)} \qquad (5)$$

## 6.4 Discussion

The analysis undertaken using the low temperature data collected during the first year of the temperature monitoring at the Calgary International airport site supports the applicability of the TAC low temperature to Canadian airport pavements.

Figure 12 plots all equations developed in the 1998/1999 Calgary analysis along with the TAC equation. There is little difference between the pavement surface temperature predicted by the TAC equation and the Calgary site-specific relationships (Equations (1) and (2)) determined on the basis of the 1998/1999 data. For the range of air temperatures generally of interest for Canadian sites (i.e. -25°C to -50°C) the difference between the pavement temperature calculated using the TAC equation compared to the site specific equation(s) was less than about 1°C.

# 7.0 1999/2000 ANALYSIS

## 7.1 Selection of Minimum Temperatures

For the 1999/2000 data, the final selection process resulted in 74 sets of temperature measurements representing 74 days of temperature recordings during cooling periods from November 1999 to February 2000. Table 4 presents the temperature data used in the analysis.

## 7.2 Pavement Surface Temperatures

For the 1999/2000 data, an extrapolation was conducted for each of the 74 sets of temperature data to provide two pavement surface temperatures. The first pavement surface temperature was obtained using a linear regression analysis while the second was obtained using a polynomial regression analysis. The data are presented in Table 4.

## 7.3 Pavement Surface Temperatures vs. Air Temperatures

The correlation between pavement surface temperatures and air temperatures represents the final step in the analysis. The air temperature was treated as the independent variable, and the pavement surface temperature as the dependant variable. The results of the regression are presented in Figure 10 and Figure 11, which also show the correlation coefficients obtained. The resulting linear equations are as follows:

, $T_{Surface} = 0.6352 * T_{air} - 0.3699$ *$r^2 = 0.90$ (based on polynomial extrapolation of $T_{surface}$)* (6)

, $T_{Surface} = 0.6479 * T_{air} - 0.372$ *$r^2 = 0.90$ (based on linear extrapolation of $T_{surface}$)* (7)

Figures 20A and 21A show the results if the respective regressions are forced through the origin, which allows for comparison to the published TAC relationship. The resulting equations, when forced through the origin are as follows:

$T_{Surface} = 0.6567\ T_{air}$ *$r^2 = 0.90$ (based polynomial extrapolation of $T_{surface}$)* (8)

$T_{Surface} = 0.6694\ T_{air}$ *$r^2 = 0.90$ (based linear extrapolation of $T_{surface}$)* (9)

The relationship reported by TAC is as follows:

$T_{Surface} = 0.749 * T_{air}$ *$r^2 = 0.95$* (5)

## 7.4 Discussion

Figure 22 plots all equations developed in 1999/2000 Calgary analysis along with the TAC equation. There appears to be some difference between the pavement surface temperature predicted by the TAC equation and the Calgary site-specific relationships determined on the basis of 1999/2000 data. For the range of air temperatures generally of interest for Canadian sites (i.e. -25°C to -50°C) the difference between the pavement temperature calculated using the TAC equation compared to the site specific equations was significant. The apparent differences between predicted pavement surface temperatures obtained from the TAC and Calgary based equations are discussed in Section 8 of this report.

The confidence level related to the data generated from equations developed in this analysis is directly related to the temperature range used to develop the equations. Using an equation to generate pavement surface temperature data for temperatures outside of the maximum and minimum temperatures used in their development may be outside the scope of the statistical analysis.

## 8.0 COMPARISON OF 1998/1999, 1999/2000 AND MULTI-YEAR ANALYSIS

The final section of this report analyzed combined temperature data from both the 1998/1999 and 1999/2000 analysis periods at the Calgary site to generate pavement surface temperature prediction equations. It has been assumed that all correlations and data selection criteria presented in Sections 6 and 7 of this report were correct and thus will not be reviewed in the multi-year analysis section. The equations based on this combined data were compared to those generated in the 1998/1999 and 1999/2000 analysis periods.

### 8.1 Selection of Minimum Temperature Data

For the 1998/1999 and 1999/2000 combined data, the final selection process resulted in 75 and 74 sets of temperature measurements respectively, which resulted in 149 days of temperature recordings during cooling periods of the selected months. Tables 2 and 4 previously presented the temperature data used in the analysis for 1998/1999 and 1999/2000 analysis periods.

### 8.2 Pavement Surface Temperatures vs. Air Temperatures

The method of analysis was identical to that used for the 1998/1999 and 1999/2000 analysis periods. The air temperature was treated as the independent variable, and the pavement surface temperature as the dependant variable. The results of the regression are presented in Figures 23 and Figure 24, which also show the correlation coefficients obtained. The resulting linear equations are as follows:

$$T_{Surface} = 0.6815 * T_{air} - 0.0344 \qquad r^2 = 0.91 \text{ (based on polynomial extrapolation of } T_{surface}) \qquad (10)$$

$$T_{Surface} = 0.7032 * T_{air} - 0.1379 \qquad r^2 = 0.91 \text{ (based on linear extrapolation of } T_{surface}) \qquad (11)$$

Figures 23A and 24A show the results if the respective regressions are forced through the origin, which allows for comparison to the published TAC relationship. The resulting equations, when forced through the origin are as follows:

$T_{Surface} = 0.6835\ T_{air}$ *$r^2$ = 0.91 (based on polynomial extrapolation of $T_{surface}$)* *(12)*

$T_{Surface} = 0.7112\ T_{air}$ *$r^2$ = 0.91 (based on linear extrapolation of $T_{surface}$)* *(13)*

## 8.3 Discussion

To enable direct comparison between the 1998/1999, 1999/2000, and the multi-year analysis periods, and the TAC equations, Calgary site equations based on a polynomial extrapolation of $T_{Surface}$ and that were forced through the origin were selected. These were the same conditions used to develop the TAC equation.

$T_{Surface}$ was calculated over a range of air temperatures from 5°C to -50°C using the following equations. The results are presented in Table 5.

$T_{Surface} = 0.749 * T_{air}$ *with a reported $r^2$ of 0.95 (TAC Equation)* *(5)*

$T_{Surface} = 0.7032\ T_{air}$ *$r^2$ = 0.92 (based on 98/99 polynomial extrapolation of $T_{surface}$)* *(3)*

$T_{Surface} = 0.6567\ T_{air}$ *$r^2$ = 0.90 (based on 99/00 polynomial extrapolation of $T_{surface}$)* *(8)*

$T_{Surface} = 0.6835\ T_{air}$ *$r^2$ = 0.91 (based on multi-year polynomial extrapolation of $T_{surface}$)* *(12)*

Figure 25 plots these equations developed from the 1998/1999, 1999/2000 and the multi-year Calgary analysis along with the TAC equation.

As would be expected, differences between pavement surface temperature predicted by the TAC algorithm compared to the multi-year Calgary equations were in between those in the 1998/1999 and 1999/2000 analysis periods.

Similar results were obtained when comparing predicted surface temperatures generated by the TAC and Calgary equations over the temperature range of which the Calgary equations were developed (i.e. +3°C to -28°C). The difference between the pavement surface temperature predicted by the TAC equation and the multi-year equation was -2°C at an air temperature of -30°C.

When a comparison was carried out using air temperatures outside the ranges used to develop the Calgary equations (i.e. above +3°C and below -28°C), differences in predicted pavement surface temperatures become more evident. The difference between the pavement surface temperature predicted by the TAC equation and the multi-year equation was -3.3°C at an air temperature of -50°C.

This analysis indicates that pavement surface temperatures predicted by the multi-year analysis equation are similar to those predicted by the TAC equation over the temperature range experienced at the Calgary International Airport (e.g. +3°C to -28°C). However at temperatures below -28°C, these differences increase and suggest that comparisons between equations outside the temperature range used in their development should be carried out with caution.

## 9.0 CLOSURE

EBA Engineering Consultants Ltd. appreciates the opportunity to work with PWGSC on this very meaningful evaluation of air and pavement temperature relationships.

It can further be noted that the extensive pavement temperature data collected at the Calgary site provides significant opportunity for evaluating frost penetration, the effect of cooling periods on pavement temperatures, and other thermal conditions within the pavement structure. It is expected that these data will provide an opportunity to expand the current state-of-the-knowledge as more data representing a broader range of air temperatures and cooling rates and conditions is collected and analyzed.

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# Tables

**Table 1 Correlation Matrix Comparing Relationship Between Redundant Instrumentation**
**Taxiway Juliet**

| | Tair1 | Tair2 | T1-20 | T1-100 | T1-200 | T1-500 | T1-1000 | T1-1550 | T1-2000 | T2-20 | T2-100 | T2-200 | T2-500 | T2-1000 | T2-1550 | T2-2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tair1** | 1 | | | | | | | | | | | | | | | |
| **Tair2** | **0.99923** | 1 | | | | | | | | | | | | | | |
| **T1-20** | 0.84489 | 0.84440 | 1 | | | | | | | | | | | | | |
| **T1-100** | 0.77931 | 0.77658 | 0.95876 | 1 | | | | | | | | | | | | |
| **T1-200** | 0.66931 | 0.66687 | 0.87821 | 0.96306 | 1 | | | | | | | | | | | |
| **T1-500** | 0.57342 | 0.57199 | 0.80666 | 0.88913 | 0.96767 | 1 | | | | | | | | | | |
| **T1-1000** | 0.43274 | 0.43189 | 0.64653 | 0.72045 | 0.81812 | 0.91922 | 1 | | | | | | | | | |
| **T1-1550** | 0.33562 | 0.33504 | 0.49771 | 0.56001 | 0.65550 | 0.78226 | 0.95766 | 1 | | | | | | | | |
| **T1-2000** | 0.26521 | 0.26491 | 0.37910 | 0.43083 | 0.51975 | 0.65676 | 0.88266 | 0.97888 | 1 | | | | | | | |
| **T2-20** | 0.83406 | 0.83224 | **0.99320** | 0.97723 | 0.89729 | 0.81934 | 0.66113 | 0.51311 | 0.39403 | 1 | | | | | | |
| **T2-100** | 0.76819 | 0.76535 | 0.95133 | **0.99932** | 0.96974 | 0.89989 | 0.73628 | 0.57652 | 0.44641 | 0.97144 | 1 | | | | | |
| **T2-200** | 0.67782 | 0.67521 | 0.88466 | 0.96869 | **0.99938** | 0.96250 | 0.81358 | 0.65135 | 0.51549 | 0.90520 | 0.97533 | 1 | | | | |
| **T2-500** | -0.05293 | -0.05238 | -0.12287 | -0.13990 | -0.16096 | **0.99903** | -0.18952 | -0.18397 | -0.16514 | -0.12699 | -0.14340 | -0.15975 | 1 | | | |
| **T2-1000** | 0.44763 | 0.44673 | 0.66808 | 0.74384 | 0.84032 | 0.93530 | **0.99847** | 0.94166 | 0.85840 | 0.68280 | 0.75944 | 0.83597 | -0.18687 | 1 | | |
| **T2-1550** | 0.34686 | 0.34627 | 0.51431 | 0.57823 | 0.67410 | 0.79874 | 0.96592 | **0.99891** | 0.97185 | 0.52990 | 0.59489 | 0.67018 | -0.18308 | 0.95199 | 1 | |
| **T2-2000** | 0.27641 | 0.27609 | 0.39704 | 0.45050 | 0.54027 | 0.67605 | 0.89576 | 0.98409 | **0.99909** | 0.41221 | 0.46635 | 0.53624 | -0.16638 | 0.87318 | 0.97892 | 1 |
| **T3-20** | 0.83245 | 0.83066 | **0.99201** | 0.97923 | 0.90389 | 0.82616 | 0.66358 | 0.51283 | 0.39221 | **0.99819** | 0.97361 | 0.91116 | -0.12760 | 0.68556 | 0.52967 | 0.41042 |
| **T3-100** | 0.76767 | 0.76489 | 0.95066 | **0.99841** | 0.97117 | 0.90261 | 0.73795 | 0.57821 | 0.44822 | 0.96987 | **0.99900** | 0.97615 | -0.14425 | 0.76087 | 0.59623 | 0.46784 |
| **T3-200** | 0.67995 | 0.67743 | 0.88660 | 0.96840 | **0.99910** | 0.96353 | 0.81578 | 0.65557 | 0.52112 | 0.90619 | 0.97472 | **0.99921** | -0.16130 | 0.83753 | 0.67373 | 0.54128 |
| **T3-500** | 0.55885 | 0.55750 | 0.79310 | 0.87483 | 0.95626 | **0.99817** | 0.93892 | 0.81341 | 0.69320 | 0.80619 | 0.88636 | 0.95117 | **0.99903** | 0.95262 | 0.82866 | 0.71160 |
| **T3-1000** | 0.43303 | 0.43222 | 0.64797 | 0.72134 | 0.81868 | 0.91960 | **0.99970** | 0.95723 | 0.88217 | 0.66236 | 0.73703 | 0.81403 | -0.19253 | **0.99794** | 0.96497 | 0.89479 |
| **T3-1550** | 0.34042 | 0.33985 | 0.50845 | 0.57117 | 0.66694 | 0.79248 | 0.96247 | **0.99939** | 0.97424 | 0.52369 | 0.58764 | 0.66269 | -0.18819 | 0.94702 | **0.99837** | 0.97951 |
| **T3-2000** | 0.26857 | 0.26827 | 0.38615 | 0.43793 | 0.52695 | 0.66366 | 0.88726 | 0.98083 | **0.99972** | 0.40102 | 0.45353 | 0.52266 | -0.16968 | 0.86315 | 0.97382 | **0.99882** |

Data includes temperature readings from November 1998 to November 1999 when air temperature was at or below freezing

T1, T2, T3 indicate instrumentation location where T1 is at centerline, T2 = 5 m offset, and T3 - 10 m offset.
-20, -100, -200 etc is the nominal depth of thermocouple in the pavement structure

| Table 2 Temperature Data and Extrapolated Surface Temperature | | | | | | |
|---|---|---|---|---|---|---|
| | | Minimum Temperature at Depth (mm) | | | Extrapolated Surface Temperature | |
| Date | Minimum Air Temperature | 20 | 100 | 200 | Linear | Polynomial |
| 01-11-1998 | 0 | 1 | 2.8 | 5.11 | 0 | 0.6 |
| 02-11-1998 | 0 | 2 | 2.52 | 4.08 | 1.3 | 2 |
| 03-11-1998 | 0 | 2 | 2.88 | 4.1 | 1.5 | 1.8 |
| 04-11-1998 | -3 | 0 | 1.74 | 3.73 | -0.9 | -0.5 |
| 05-11-1998 | -3 | 0 | 0.93 | 2.63 | -0.7 | -0.2 |
| 06-11-1998 | -5 | -2 | -0.38 | 1.72 | -2.9 | -2.4 |
| 07-11-1998 | -6 | -3 | -1.39 | 0.67 | -3.9 | -3.4 |
| 08-11-1998 | -6 | -2 | -0.9 | 0.62 | -2.7 | -2.3 |
| 09-11-1998 | -8 | -3 | -1.63 | 0.26 | -3.8 | -3.3 |
| 10-11-1998 | -14 | -7 | -3.53 | -0.23 | -8.4 | -8 |
| 11-11-1998 | -15 | -8 | -5.2 | -1.31 | -9.7 | -8.7 |
| 12-11-1998 | -9 | -6 | -4.43 | -1.8 | -7.1 | -6.3 |
| 14-11-1998 | -11 | -6 | -4.22 | -0.86 | -7.4 | -6.3 |
| 15-11-1998 | -9 | -5 | -3.15 | -0.75 | -6 | -5.5 |
| 16-11-1998 | -10 | -6 | -4 | -1.69 | -7 | -6.5 |
| 17-11-1998 | -9 | -6 | -4.52 | -2.31 | -7 | -6.3 |
| 22-11-1998 | -3 | -4 | -2.13 | -0.64 | -4.7 | -4.6 |
| 23-11-1998 | -9 | -7 | -4.99 | -1.98 | -8.3 | -7.4 |
| 24-11-1998 | -9 | -6 | -4.36 | -2.07 | -7 | -6.4 |
| 25-11-1998 | -3 | -3 | -2.24 | -1.01 | -3.5 | -3.2 |
| 27-11-1998 | -8 | -4 | -2.74 | -0.32 | -5 | -4.2 |
| 29-11-1998 | -14 | -9 | -6.66 | -3.13 | -10.5 | -9.5 |
| 01-12-1998 | -6.88 | -5.2 | -3.48 | -1.68 | -6 | -5.7 |
| 02-12-1998 | -13.31 | -6.98 | -5.42 | -3.07 | -8 | -7.3 |
| 03-12-1998 | -16.48 | -9.6 | -7.65 | -4.39 | -11 | -10 |
| 04-12-1998 | -17.45 | -10.44 | -8.41 | -5.2 | -11.8 | -10.9 |
| 17-12-1998 | -11.85 | -8.53 | -5.78 | -1.94 | -10.2 | -9.2 |
| 18-12-1998 | -24.9 | -15.82 | -12.94 | -8.26 | -17.8 | -16.4 |
| 19-12-1998 | -29.15 | -20.93 | -17.27 | -11.76 | -23.3 | -21.7 |
| 20-12-1998 | -30.29 | -22.44 | -19.63 | -14.55 | -24.6 | -23 |
| 21-12-1998 | -30.42 | -22.67 | -20.09 | -15.42 | -24.7 | -23.2 |
| 22-12-1998 | -21.38 | -16.54 | -14.39 | -11.42 | -17.8 | -17 |
| 27-12-1998 | -16.32 | -10.5 | -9.51 | -8.25 | -11 | -10.7 |
| 28-12-1998 | -20.74 | -14.65 | -12.64 | -9.66 | -15.9 | -15.1 |
| 29-12-1998 | -20.48 | -16.08 | -14.34 | -11.61 | -17.3 | -16.5 |
| 04-01-1999 | -3.53 | -7.01 | -7.4 | -7.32 | -7 | -6.8 |
| 05-01-1999 | -16.58 | -10.85 | -9.04 | -6.52 | -11.9 | -11.3 |
| 06-01-1999 | -19.72 | -14.51 | -12.55 | -9.32 | -15.9 | -14.9 |
| 07-01-1999 | -22.77 | -15.71 | -14.01 | -11.15 | -16.9 | -16.1 |
| 08-01-1999 | -19.36 | -13.38 | -11.98 | -10.4 | -14.1 | -13.7 |
| 15-01-1999 | -5.71 | -6.15 | -4.18 | -2.73 | -6.8 | -6.8 |
| 16-01-1999 | -9.44 | -7.97 | -6.76 | -4.96 | -8.7 | -8.2 |
| 17-01-1999 | -15.65 | -10.37 | -8.56 | -6.14 | -11.4 | -10.8 |
| 18-01-1999 | -11.73 | -8.75 | -7.15 | -5.55 | -9.5 | -9.2 |
| 19-01-1999 | -11.63 | -8.92 | -7.89 | -6.31 | -9.6 | -9.1 |
| 20-01-1999 | -11.75 | -8.05 | -6.97 | -5.53 | -8.7 | -8.3 |
| 21-01-1999 | -14.08 | -9.49 | -8.26 | -6.65 | -10.2 | -9.8 |
| 22-01-1999 | -17.75 | -12.94 | -10.91 | -8.15 | -14.1 | -13.4 |
| 23-01-1999 | -26.19 | -17.56 | -14.96 | -11.11 | -19.2 | -18.1 |
| 24-01-1999 | -24.98 | -19.23 | -17.23 | -13.63 | -20.8 | -19.6 |
| 26-01-1999 | -11.85 | -10 | -8.16 | -7 | -10.5 | -10.6 |

**Table 2 Temperature Data and Extrapolated Surface Temperature (cont'd)**

| | | Minimum Temperature at Depth (mm) | | | Extrapolated Surface Temperature | |
|---|---|---|---|---|---|---|
| Date | Minimum Air Temperature | 20 | 100 | 200 | Linear | Polynomial |
| 27-01-1999 | -18.78 | -13.31 | -11.57 | -8.88 | -14.5 | -13.7 |
| 28-01-1999 | -5.29 | -7.68 | -6.96 | -6.17 | -8 | -7.9 |
| 08-02-1999 | -8.91 | -5.57 | -4.12 | -2.41 | -6.3 | -5.9 |
| 09-02-1999 | -10.75 | -6.32 | -4.93 | -2.93 | -7.2 | -6.6 |
| 10-02-1999 | -11.94 | -7.99 | -6.22 | -4.2 | -8.9 | -8.5 |
| 11-02-1999 | -13.72 | -10.37 | -8.38 | -5.46 | -11.6 | -10.8 |
| 03-11-1999 | -2.85 | 0.86 | 2.09 | 3.92 | 0.1 | 0.6 |
| 04-11-1999 | -12.34 | -4.13 | -1.26 | 2.57 | -5.8 | -4.8 |
| 05-11-1999 | -14.72 | -6.21 | -4.01 | -0.18 | -7.9 | -6.6 |
| 15-11-1999 | -0.29 | 3.61 | 4.49 | 5.31 | 3.2 | 3.4 |
| 16-11-1999 | -2.27 | 0.87 | 2.32 | 4.23 | 0 | 0.5 |
| 17-11-1999 | -2.06 | 0.16 | 1.12 | 2.95 | -0.6 | 0 |
| 18-11-1999 | -5.56 | -2.29 | -0.21 | 2.21 | -3.3 | -2.8 |
| 19-11-1999 | -6.88 | -3.24 | -1.65 | 0.84 | -4.3 | -3.6 |
| 20-11-1999 | 1.2 | 0.01 | 0.85 | 2.21 | -0.6 | -0.2 |
| 21-11-1999 | -8.98 | -3.86 | -1.72 | 1.15 | -5.1 | -4.4 |
| 22-11-1999 | -9.7 | -6.05 | -4.18 | -0.67 | -7.5 | -6.4 |
| 23-11-1999 | -6.44 | -4.57 | -3.05 | -0.44 | -5.7 | -4.9 |
| 24-11-1999 | -11.43 | -6.62 | -4.76 | -1.46 | -8 | -7 |
| 25-11-1999 | -12.77 | -6.91 | -4.31 | -1.34 | -8.2 | -7.6 |
| 26-11-1999 | -14.27 | -8.19 | -6.3 | -2.95 | -9.6 | -8.6 |
| 27-11-1999 | -15.57 | -10.46 | -8.47 | -4.84 | -12 | -10.8 |
| 28-11-1999 | -12.86 | -9.25 | -7.69 | -4.91 | -10.4 | -9.5 |

**Table 3 Correlation Matrix Comparing Relationship Between Redundant Instrumentation Taxiway Juliet**

| | Tair1 | Tair2 | T1-20 | T1-100 | T1-200 | T2-20 | T2-100 | T2-200 | T3-20 | T3-100 | T3-200 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tair1** | 1 | | | | | | | | | | |
| **Tair2** | **0.99886** | 1 | | | | | | | | | |
| **T1-20** | 0.89339 | 0.89100 | 1 | | | | | | | | |
| **T1-100** | 0.82759 | 0.82139 | 0.95603 | 1 | | | | | | | |
| **T1-200** | 0.70518 | 0.69821 | 0.85400 | 0.95211 | 1 | | | | | | |
| **T2-20** | 0.87719 | 0.87271 | **0.99014** | 0.97455 | 0.87497 | 1 | | | | | |
| **T2-100** | 0.81710 | 0.81047 | 0.94691 | **0.99794** | 0.95862 | 0.97058 | 1 | | | | |
| **T2-200** | 0.71871 | 0.71145 | 0.86466 | 0.96045 | **0.99834** | 0.88926 | 0.96852 | 1 | | | |
| **T3-20** | 0.85433 | 0.84962 | **0.97765** | 0.97000 | 0.88595 | **0.98466** | 0.96487 | 0.89650 | 1 | | |
| **T3-100** | 0.79373 | 0.78675 | 0.93082 | **0.98966** | 0.96495 | 0.95359 | **0.99157** | 0.97199 | 0.96951 | 1 | |
| **T3-200** | 0.70111 | 0.69387 | 0.85087 | 0.94881 | **0.99613** | 0.87423 | 0.95699 | **0.99591** | 0.89380 | 0.97110 | 1 |

Data includes temperature readings from November 1999 to February 2000 when temperatures were at or below freezing
T1, T2, T3 indicate instrumentation location where T1 is at centerline , T2 = 5 m offset, and T3 = 10m offset.

| Table 4 Temperature Data and Extrapolated Surface Temperature | | | | | | |
|---|---|---|---|---|---|---|
| Date | Minimum Air Temperature | Minimum Temperature at Depth (mm) | | | Extrapolated Surface Temperature | |
| | | 20 | 100 | 200 | Linear | Polynomial |
| 03-11-1999 | -2.85 | 0.86 | 2.09 | 3.92 | 0.5 | 0.6 |
| 04-11-1999 | -12.34 | -4.13 | -1.26 | 2.57 | -4.9 | -4.8 |
| 05-11-1999 | -14.72 | -6.21 | -4.01 | -0.18 | -7.1 | -6.6 |
| 15-11-1999 | -0.29 | 3.61 | 4.49 | 5.31 | 3.5 | 3.4 |
| 16-11-1999 | -2.27 | 0.87 | 2.32 | 4.23 | 0.5 | 0.5 |
| 17-11-1999 | -2.06 | 0.16 | 1.12 | 2.95 | -0.3 | 0 |
| 18-11-1999 | -5.56 | -2.29 | -0.21 | 2.21 | -2.8 | -2.8 |
| 19-11-1999 | -6.88 | -3.24 | -1.65 | 0.84 | -3.8 | -3.6 |
| 20-11-1999 | 1.2 | 0.01 | 0.85 | 2.21 | -0.3 | -0.2 |
| 21-11-1999 | -8.98 | -3.86 | -1.72 | 1.15 | -4.4 | -4.4 |
| 22-11-1999 | -9.7 | -6.05 | -4.18 | -0.67 | -6.8 | -6.4 |
| 23-11-1999 | -6.44 | -4.57 | -3.05 | -0.44 | -5.1 | -4.9 |
| 24-11-1999 | -11.43 | -6.62 | -4.76 | -1.46 | -7.4 | -7 |
| 25-11-1999 | -12.77 | -6.91 | -4.31 | -1.34 | -7.5 | -7.6 |
| 26-11-1999 | -14.27 | -8.19 | -6.3 | -2.95 | -8.9 | -8.6 |
| 27-11-1999 | -15.57 | -10.46 | -8.47 | -4.84 | -11.3 | -10.8 |
| 28-11-1999 | -12.86 | -9.25 | -7.69 | -4.91 | -9.9 | -9.5 |
| 02-12-1999 | -5.88 | -4.96 | -3.66 | -1.87 | -5.3 | -5.3 |
| 03-12-1999 | -8.59 | -6.04 | -3.95 | -1 | -6.7 | -6.5 |
| 04-12-1999 | -9.68 | -6.5 | -4.89 | -2.49 | -7 | -6.9 |
| 05-12-1999 | -3.22 | -3.74 | -2.78 | -1.42 | -4 | -4 |
| 06-12-1999 | -10.11 | -5.98 | -4.43 | -2.1 | -6.5 | -6.3 |
| 07-12-1999 | -15.79 | -7.68 | -5.36 | -1.91 | -8.4 | -8.2 |
| 12-12-1999 | -9.53 | -6.42 | -5.31 | -3.45 | -6.8 | -6.6 |
| 13-12-1999 | -9.8 | -7.24 | -5.57 | -3.12 | -7.8 | -7.6 |
| 14-12-1999 | -18.2 | -11.09 | -9.07 | -5.8 | -11.8 | -11.5 |
| 17-12-1999 | -7.71 | -4.41 | -3.5 | -2.13 | -4.7 | -4.6 |
| 18-12-1999 | -10.35 | -8.34 | -6.14 | -3.21 | -8.9 | -8.9 |
| 19-12-1999 | -18.35 | -12.01 | -9.89 | -6.53 | -12.7 | -12.5 |
| 28-12-1999 | 3.24 | -0.65 | -0.24 | 0.14 | -0.7 | -0.8 |
| 29-12-1999 | -9.24 | -3.14 | -0.73 | 1.6 | -3.6 | -3.8 |
| 30-12-1999 | -13.14 | -6.57 | -4.56 | -1.13 | -7.3 | -7 |
| 31-12-1999 | -11.9 | -6.58 | -4.8 | -1.92 | -7.2 | -7 |
| 01-01-2000 | -15.16 | -8.08 | -6.28 | -3.3 | -8.7 | -8.4 |
| 02-01-2000 | -27.65 | -14.93 | -11.73 | -6.66 | -16 | -15.6 |
| 03-01-2000 | -27.22 | -17.03 | -14.47 | -9.84 | -18.1 | -17.5 |
| 04-01-2000 | -8.52 | -9.22 | -8.76 | -7.11 | -9.6 | -9.2 |
| 05-01-2000 | -9.75 | -6.97 | -5.48 | -3.76 | -7.3 | -7.4 |
| 06-01-2000 | -12.15 | -8.63 | -7.23 | -5.16 | -9.1 | -8.9 |
| 07-01-2000 | -5 | -4.52 | -3.47 | -2.56 | -4.7 | -4.8 |
| 08-01-2000 | -6.24 | -5.41 | -4.53 | -3.08 | -5.7 | -5.6 |
| 09-01-2000 | -11.36 | -7.83 | -6.13 | -3.79 | -8.3 | -8.2 |
| 10-01-2000 | -19.16 | -12.35 | -9.67 | -5.96 | -13.1 | -13 |
| 11-01-2000 | -22.53 | -14.11 | -11.75 | -8.19 | -14.9 | -14.6 |
| 12-01-2000 | -20.48 | -11.15 | -10.1 | -7.8 | -11.7 | -11.3 |
| 13-01-2000 | -20.36 | -13.57 | -12.22 | -9.56 | -14.2 | -13.8 |
| 14-01-2000 | -25.86 | -15.31 | -13.93 | -11.27 | -15.9 | -15.6 |
| 15-01-2000 | -27.08 | -17.8 | -15.82 | -12.49 | -18.5 | -18.2 |
| 17-01-2000 | -20.66 | -14.82 | -13.6 | -11.39 | -15.3 | -15 |
| 18-01-2000 | -23.66 | -17.02 | -15.34 | -12.41 | -17.7 | -17.3 |
| 19-01-2000 | -24.84 | -16.63 | -14.98 | -12.11 | -17.3 | -17 |
| 21-01-2000 | -9.39 | -9.72 | -9.01 | -8.25 | -9.9 | -9.9 |
| 22-01-2000 | -16.19 | -11.19 | -9.14 | -7.44 | -11.5 | -11.8 |

| Table 4 Temperature Data and Extrapolated Surface Temperature | | | | | | |
|---|---|---|---|---|---|---|
| Date | Minimum Air Temperature | Minimum Temperature at Depth (mm) | | | Extrapolated Surface Temperature | |
| | | 20 | 100 | 200 | Linear | Polynomial |
| 23-01-2000 | -16.47 | -12.04 | -10.65 | -8.56 | -12.5 | -12.9 |
| 28-01-2000 | -11.77 | -9.88 | -8.74 | -6.84 | -10.3 | -10.1 |
| 29-01-2000 | -12.17 | -10.57 | -9.26 | 0 | -11.1 | -10.8 |
| 30-01-2000 | -12.36 | -9.37 | -8.24 | -6.39 | -9.8 | -9.6 |
| 02-02-2000 | -6.45 | -5.69 | -4.57 | -3.24 | -6 | -6 |
| 03-02-2000 | -15.99 | -9.39 | -7.46 | -4.72 | -10 | -9.8 |
| 04-02-2000 | -17.63 | -12.06 | -10.21 | -7.24 | -12.7 | -12.4 |
| 05-02-2000 | -17.48 | -12.57 | -10.82 | -7.94 | -13.2 | -12.9 |
| 10-02-2000 | -19.02 | -10.83 | -7.54 | -4.13 | -11.5 | -11.7 |
| 11-02-2000 | -23.83 | -14.61 | -12.18 | -8.32 | -15.4 | -15.1 |
| 12-02-2000 | -18.68 | -12.97 | -11.54 | -8.65 | -13.6 | -13.2 |
| 13-02-2000 | -23.92 | -15.23 | -13.36 | -10.1 | -16 | -15.6 |
| 14-02-2000 | -25.68 | -16.28 | -14.25 | -10.84 | -17 | -16.7 |
| 15-02-2000 | -14.31 | -9.53 | -8.47 | -7.7 | -9.6 | -9.9 |
| 16-02-2000 | -22.95 | -14.72 | -12.94 | -10.1 | -15.3 | -15.1 |
| 17-02-2000 | -24.84 | -15.79 | -14.02 | -10.95 | -16.5 | -16.1 |
| 23-02-2000 | -3.42 | -3.15 | -1.99 | -0.8 | -3.4 | -3.5 |
| 24-02-2000 | -4.91 | -2.77 | -1.85 | -0.51 | -3.1 | -3 |
| 25-02-2000 | -10.72 | -5.59 | -3.84 | -1.12 | -6.2 | -6 |
| 26-02-2000 | -10.8 | -6.02 | -4.28 | -1.7 | -6.6 | -6.4 |
| 27-02-2000 | -13.37 | -6.74 | -4.83 | -1.82 | -7.4 | -7.1 |

**Table 5 Comparison of Calgary 1998/1999, 1999/2000, Multi-Year and TAC Equations**

| Air Temp | 1998/1999 Calgary Equation | 1999/2000 Calgary Equation | Multi- Year Analysis Equation | TAC Equation |
|---|---|---|---|---|
| | TSurface=0.7032*Tair | TSurface=0.6567*Tair | TSurface=0.6835*Tair | TSurface = 0.749*Tair |
| 5 | 3.5 | 3.3 | 3.4 | 3.7 |
| 0 | 0 | 0 | 0 | 0 |
| -10 | -7 | -6.6 | -6.8 | -7.5 |
| -20 | -14.1 | -13.1 | -13.7 | -15 |
| -30 | -21.1 | -19.7 | -20.5 | -22.5 |
| -40 | -28.1 | -26.3 | -27.3 | -30 |
| -50 | -35.2 | -32.8 | -34.2 | -37.5 |

(All Temperatures in °C)

# Figures

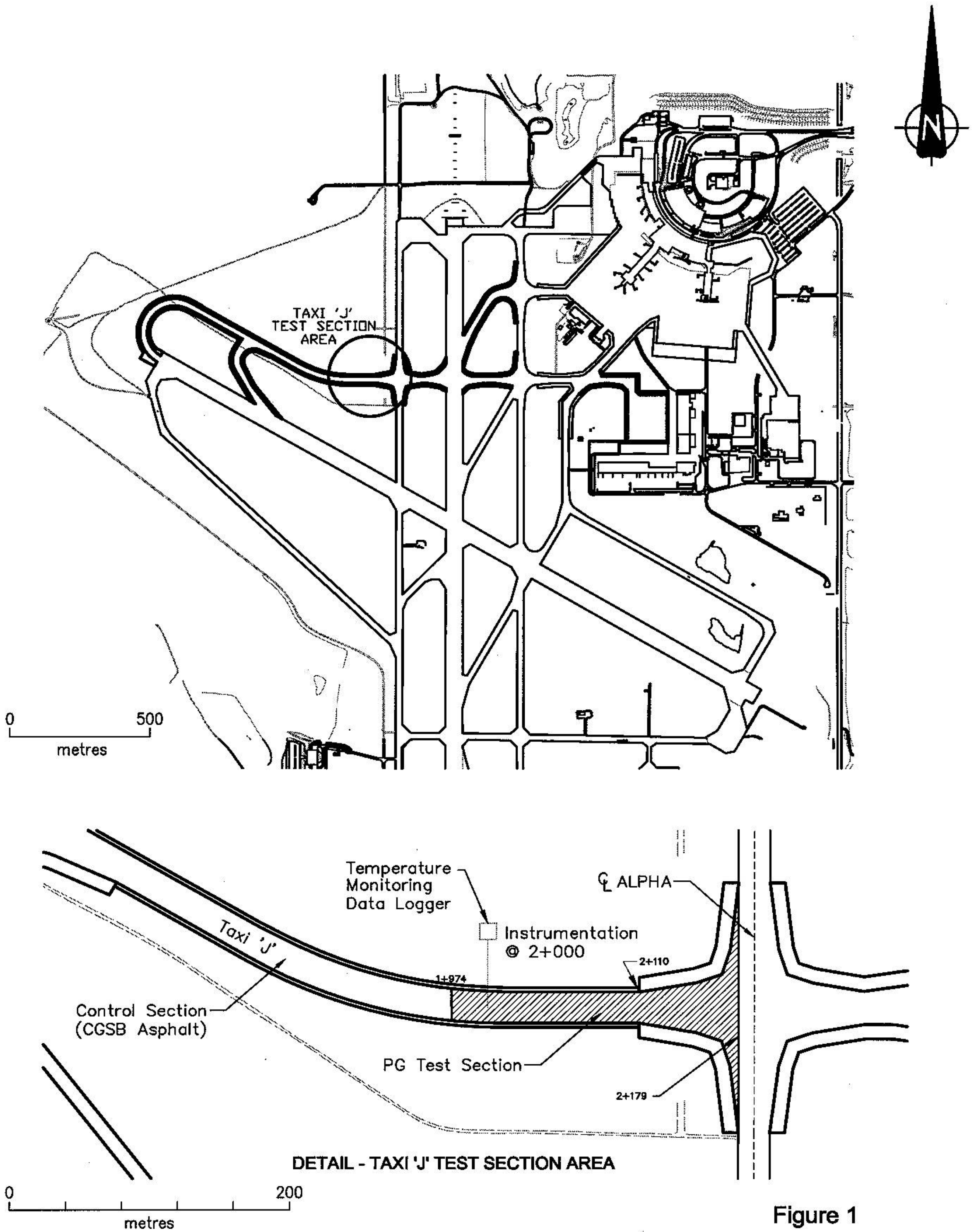
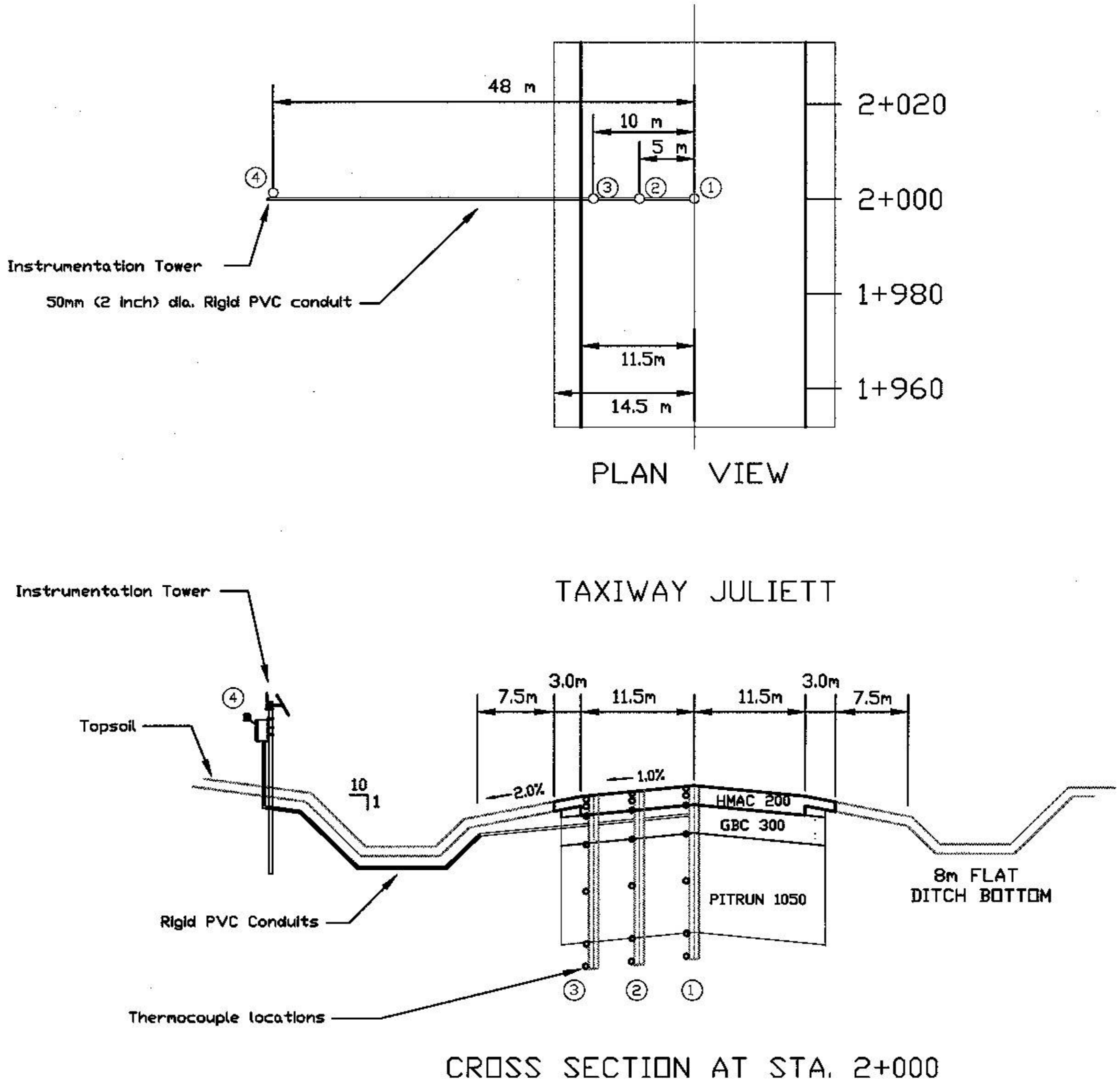



**Figure 1**
**Calgary International Airport**
**Location of Taxi 'J'**




Thermocouples placed at 4 locations as follows:
1) Taxiway Centerline - 7 Thermocouples
2) Taxiway Wheelpath - 7 Thermocouples
3) Taxiway Edge - 7 Thermocouples
4) Instrumentation Tower - 2 Thermocouples

Thermocouples at locations 1, 2 & 3 placed at 20, 100, *200, 500, 1000, 1550 and 2000 mm depth.

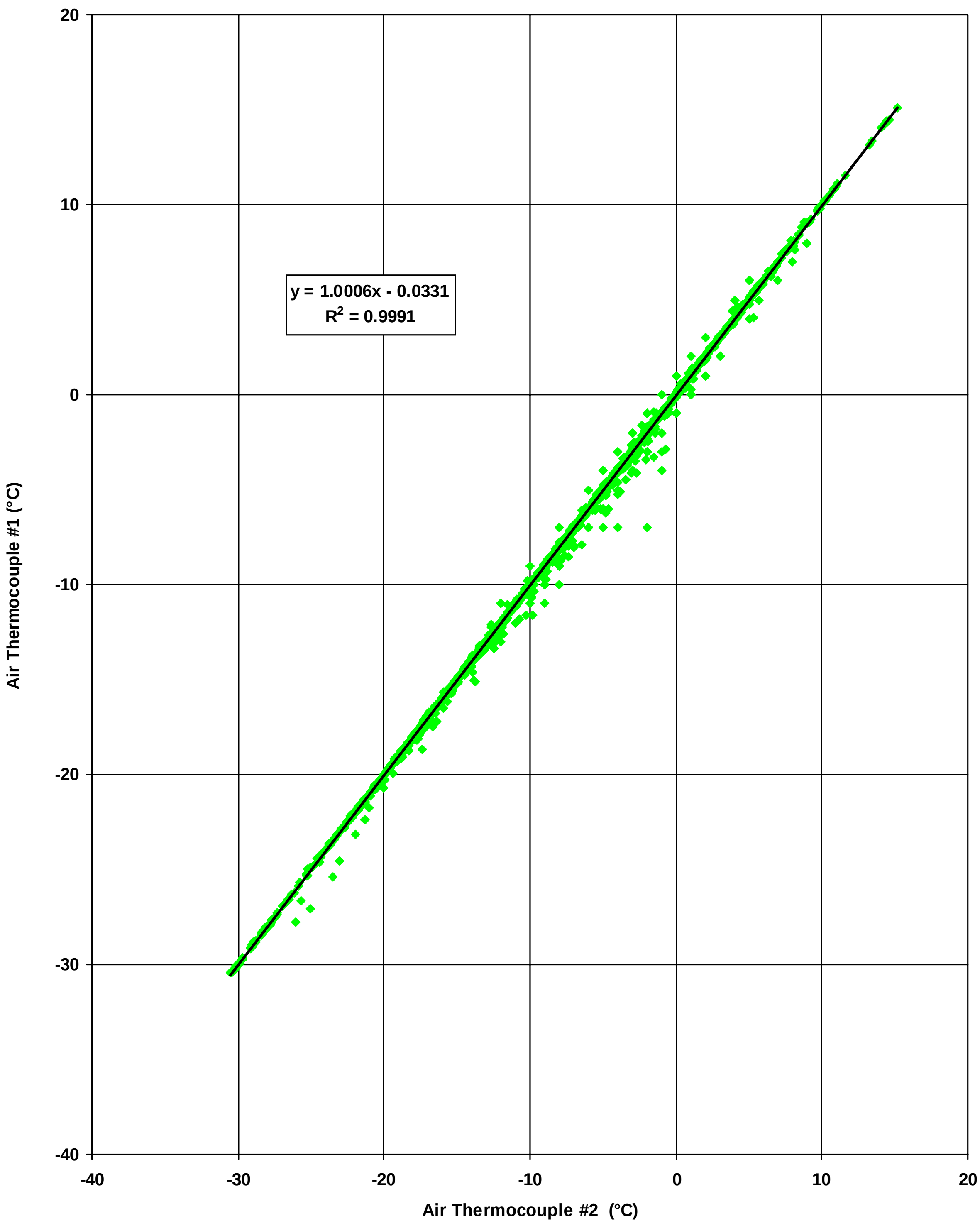
* Location 2 thermocouple @ 225mm
* Location 3 thermocouple @ 220mm

Original drawing provided by James Scarlet PWGSC

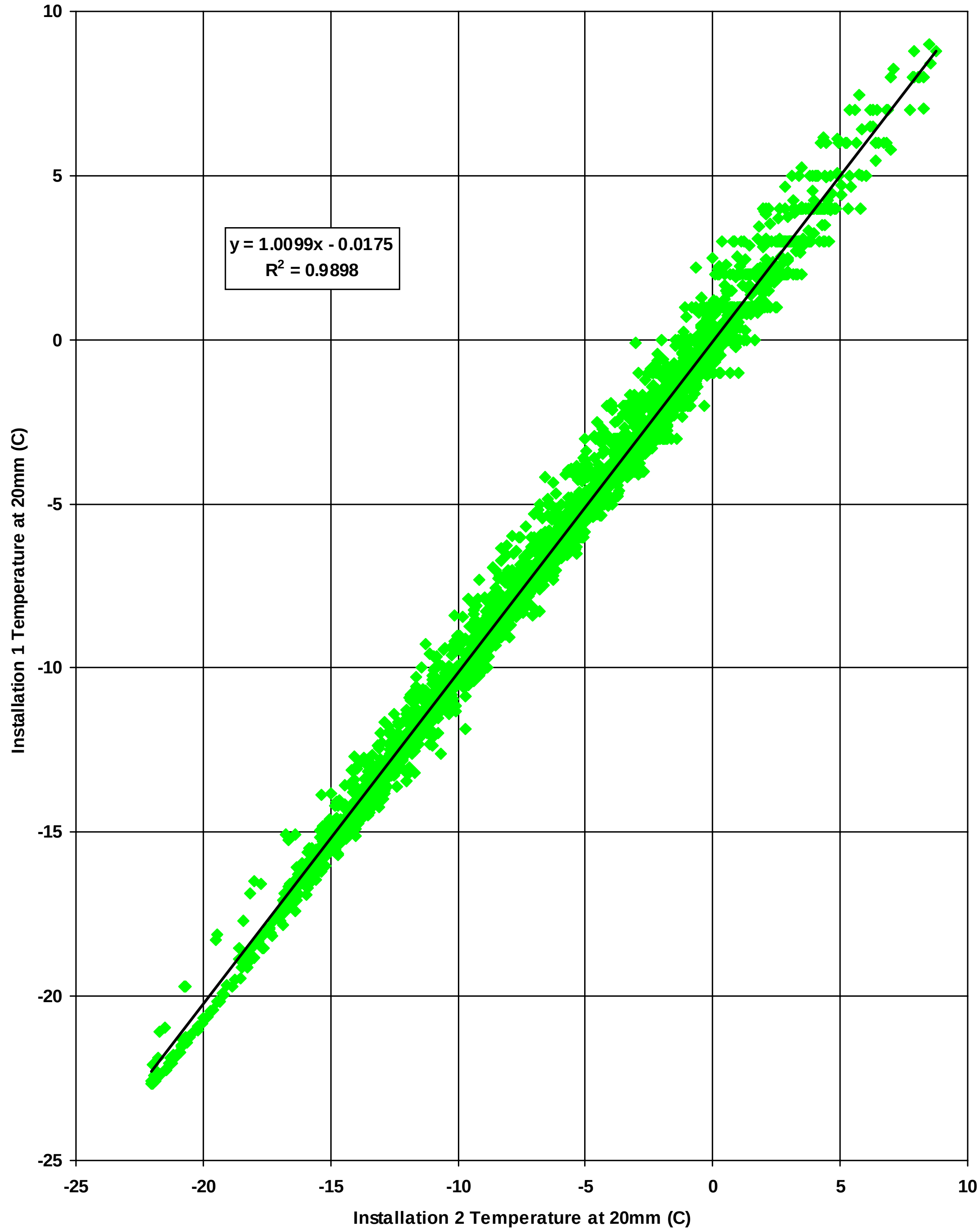
N.T.S.

**Figure 2**
**Taxiway Juliett**
**Instrumentation Layout**

## Figure 3 1998/1999 Correlation Between Air Temperature Thermocouples



## Figure 4 1998/1999 Correlation Between Installation 1 and 2 Thermocouples at 20 mm Depth



## Figure 5 1998/1999 Correlation Between Installation 2 and 3 Thermocouples at 20mm Depth

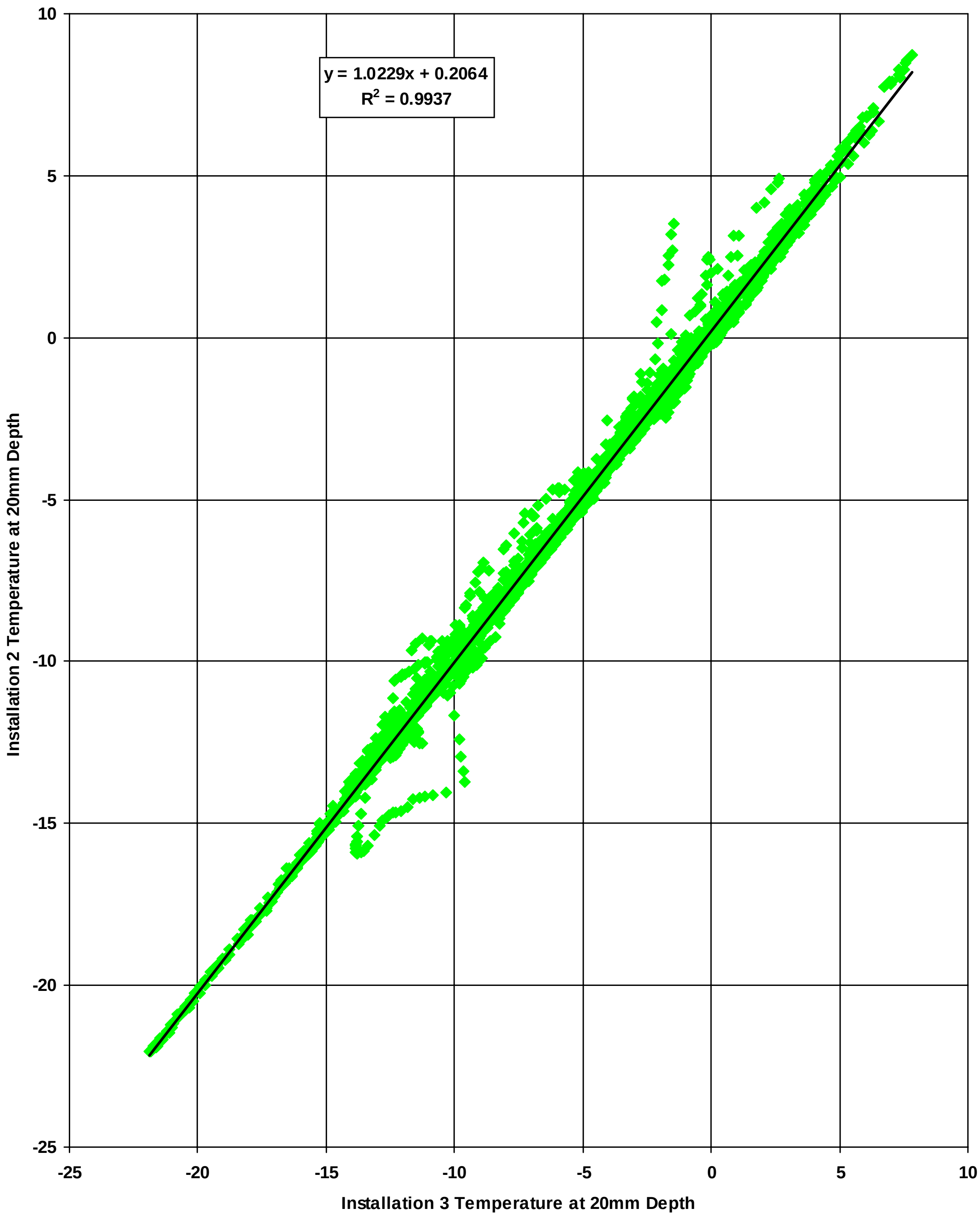


**Figure 6 1998/1999 Correlation Between Installation 1 and 2 Thermocouples at 100mm Depth**

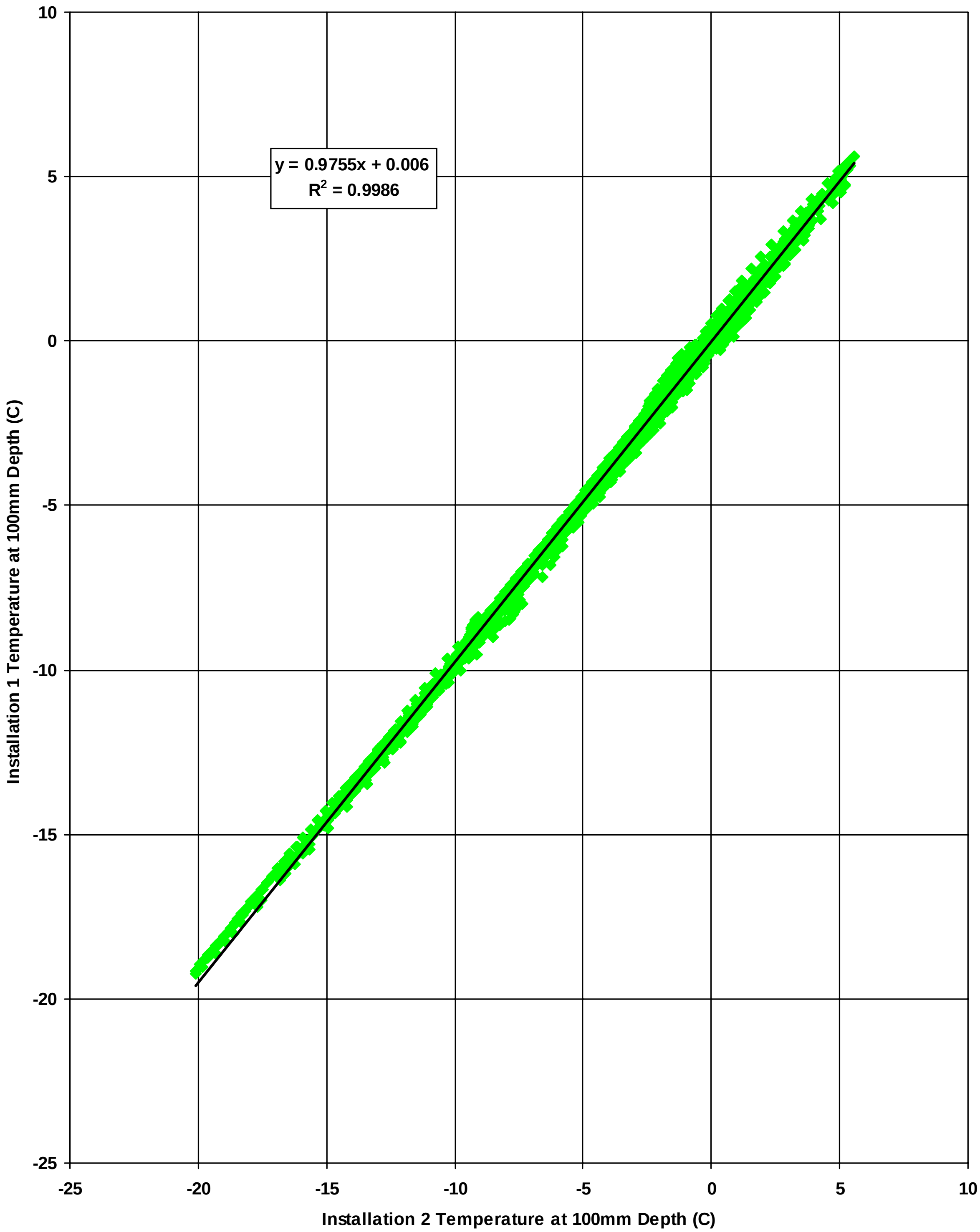
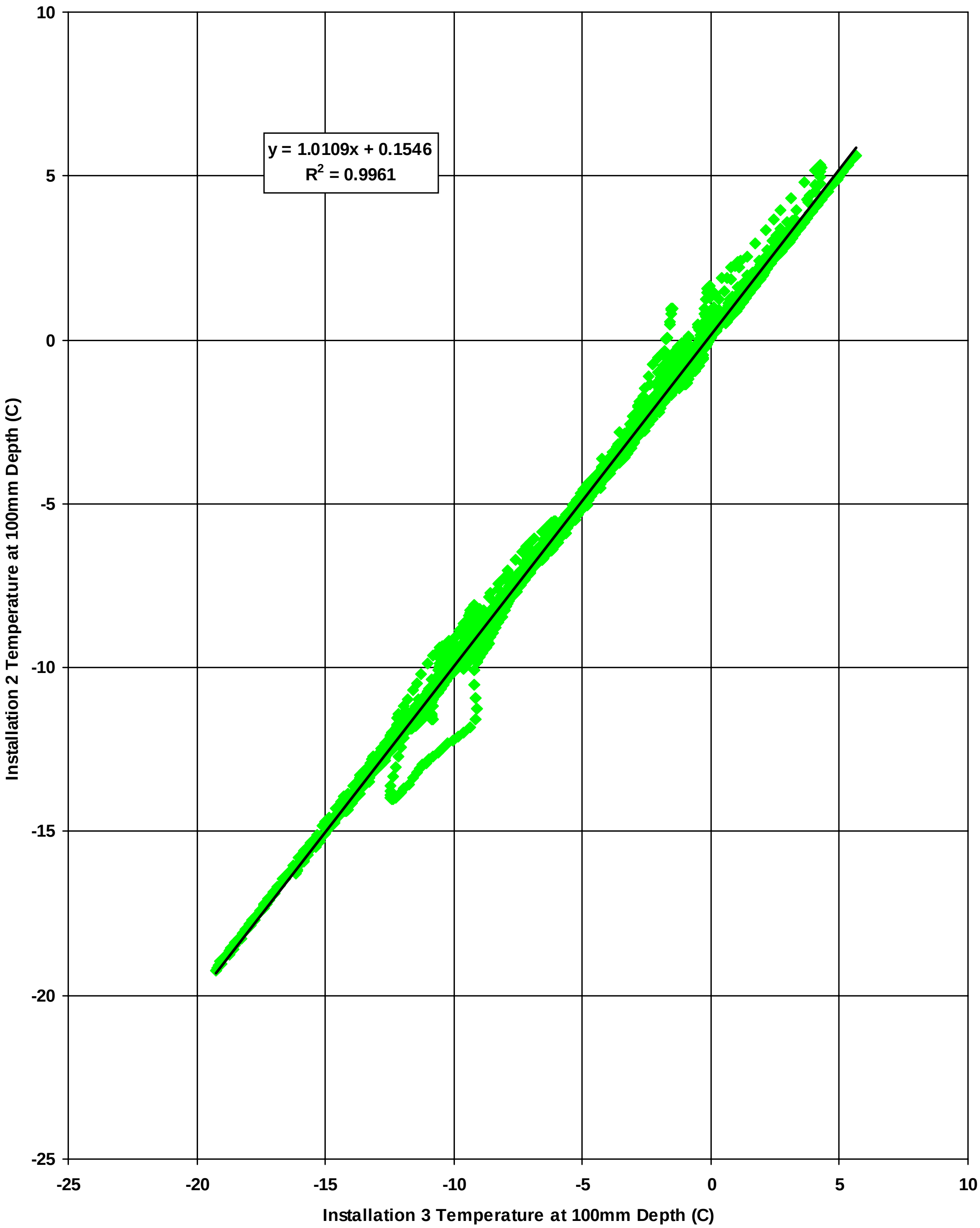
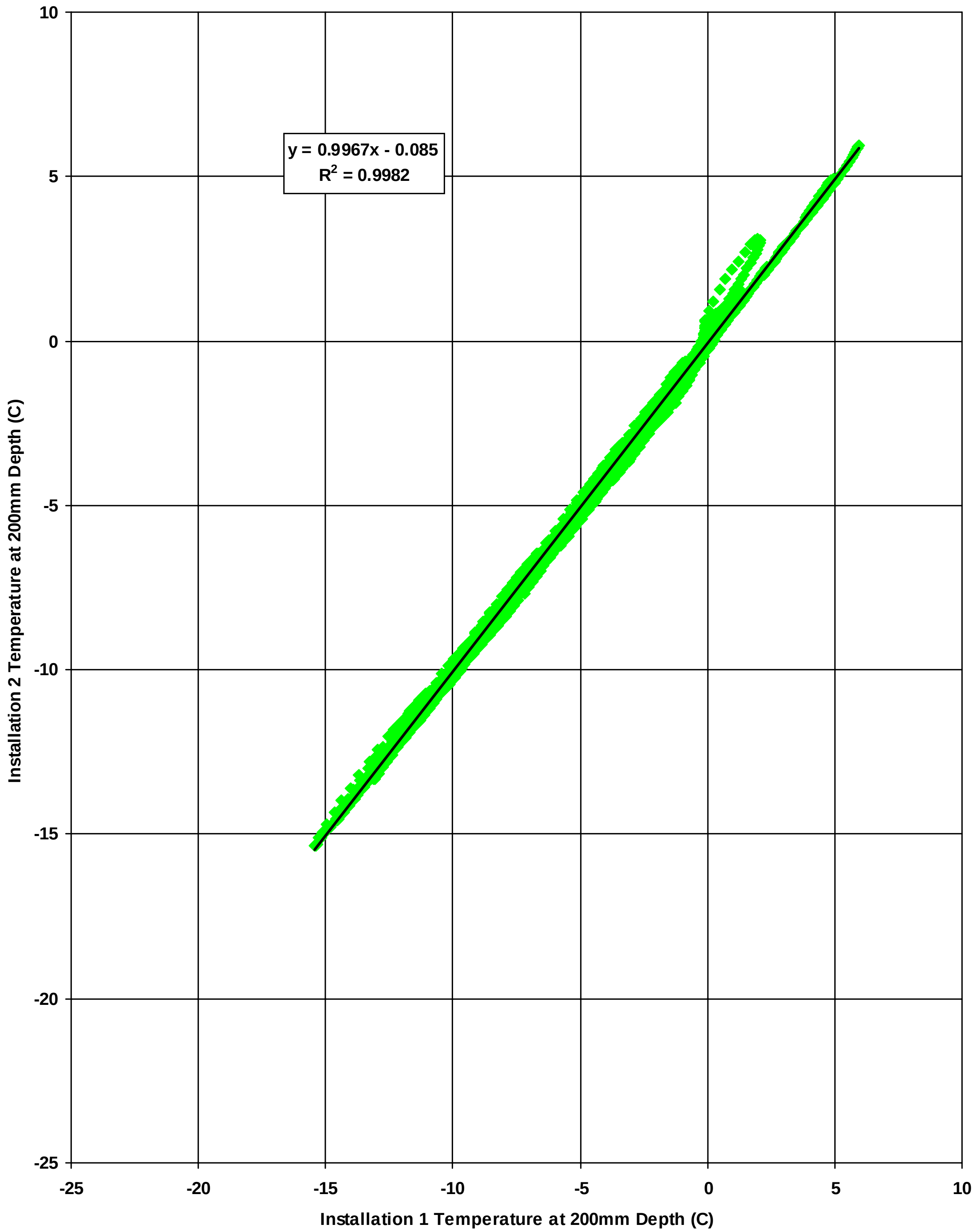


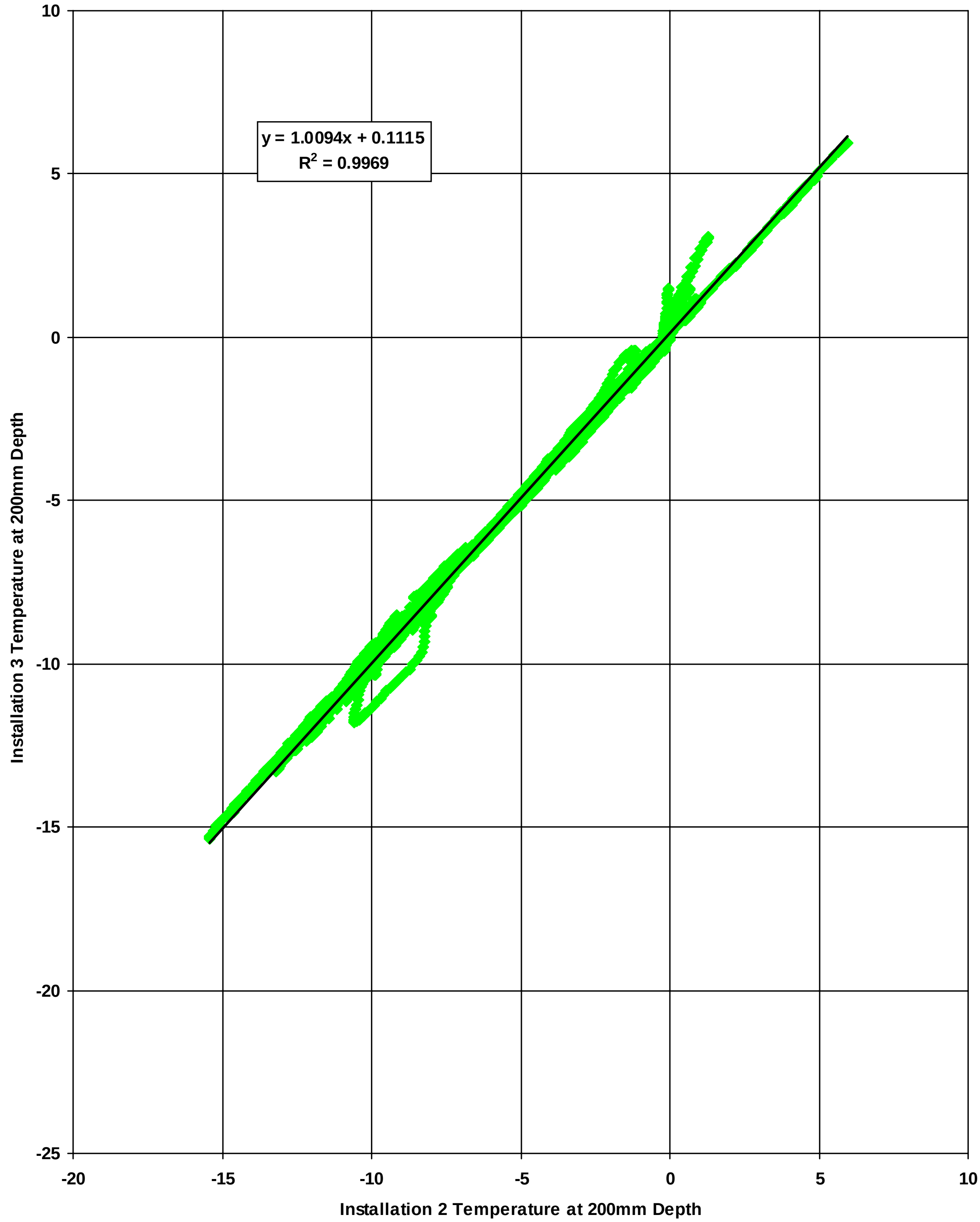
**Figure 7 1998/1999 Correlation Between Installation 2 and 3 Thermocouples at 100mm Depth**



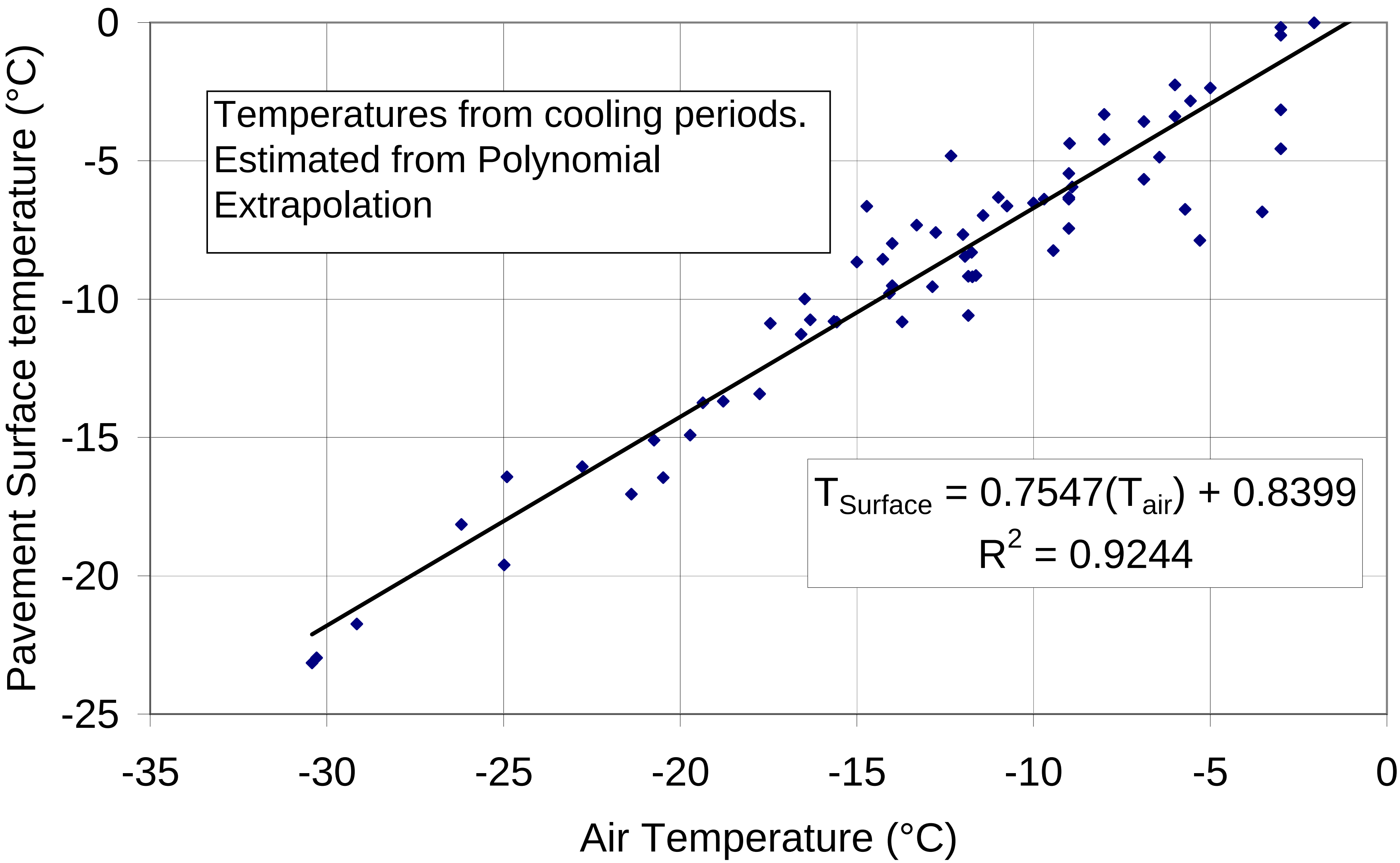
## Figure 8 1998/1999 Correlation Between Installation 1 and 2 Thermocouples at 200mm Depth



## Figure 9 1998/1999 Correlation Between Installation 2 and 3 Thermocouples at 200mm Depth



## Figure 10 1998/1999 Pavement Surface Temperature Versus Air Temperature Taxi 'J'



## Figure 10A 1998/1999 Pavement Surface Temperature vs. Air Temperature Taxi 'J'

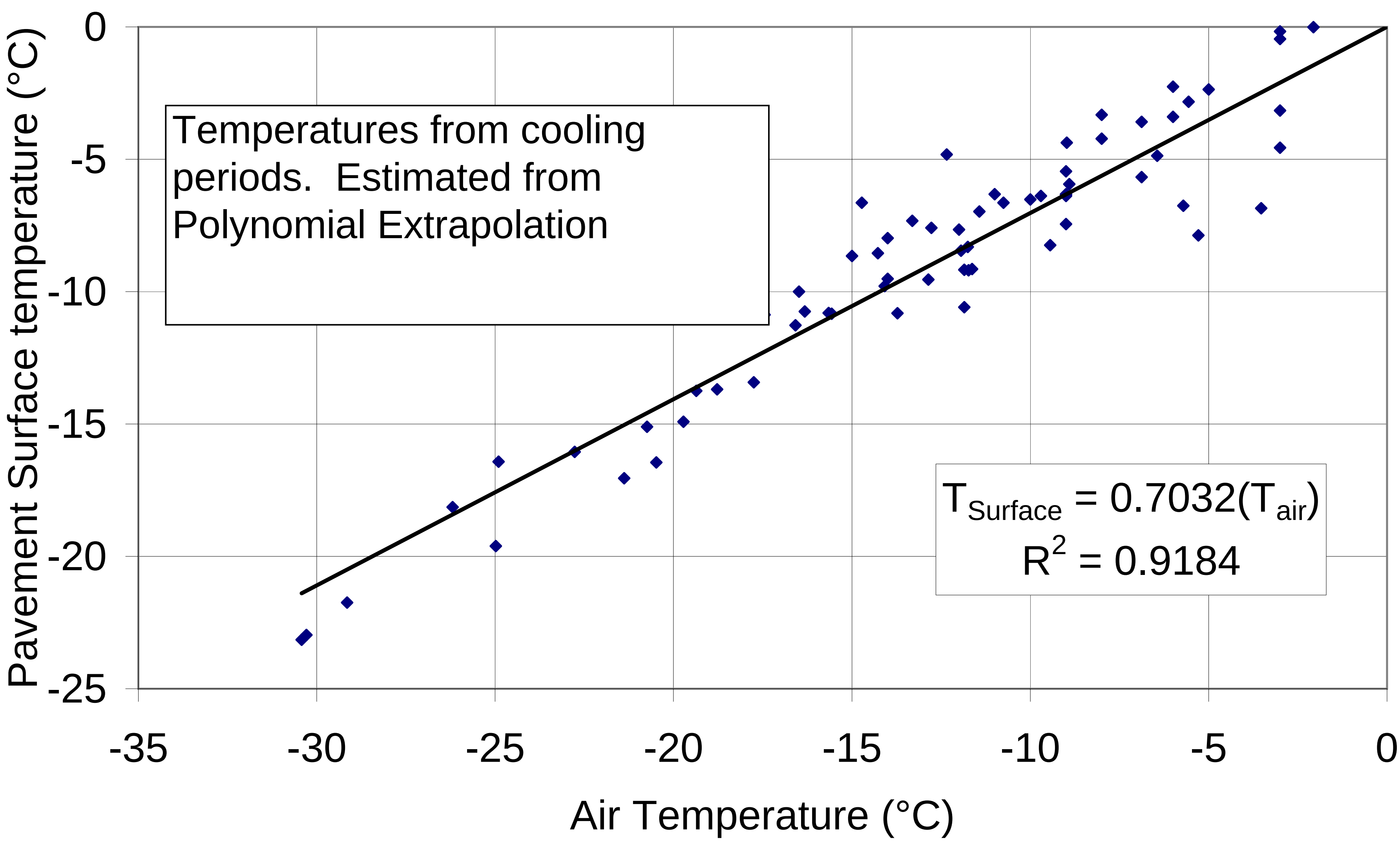
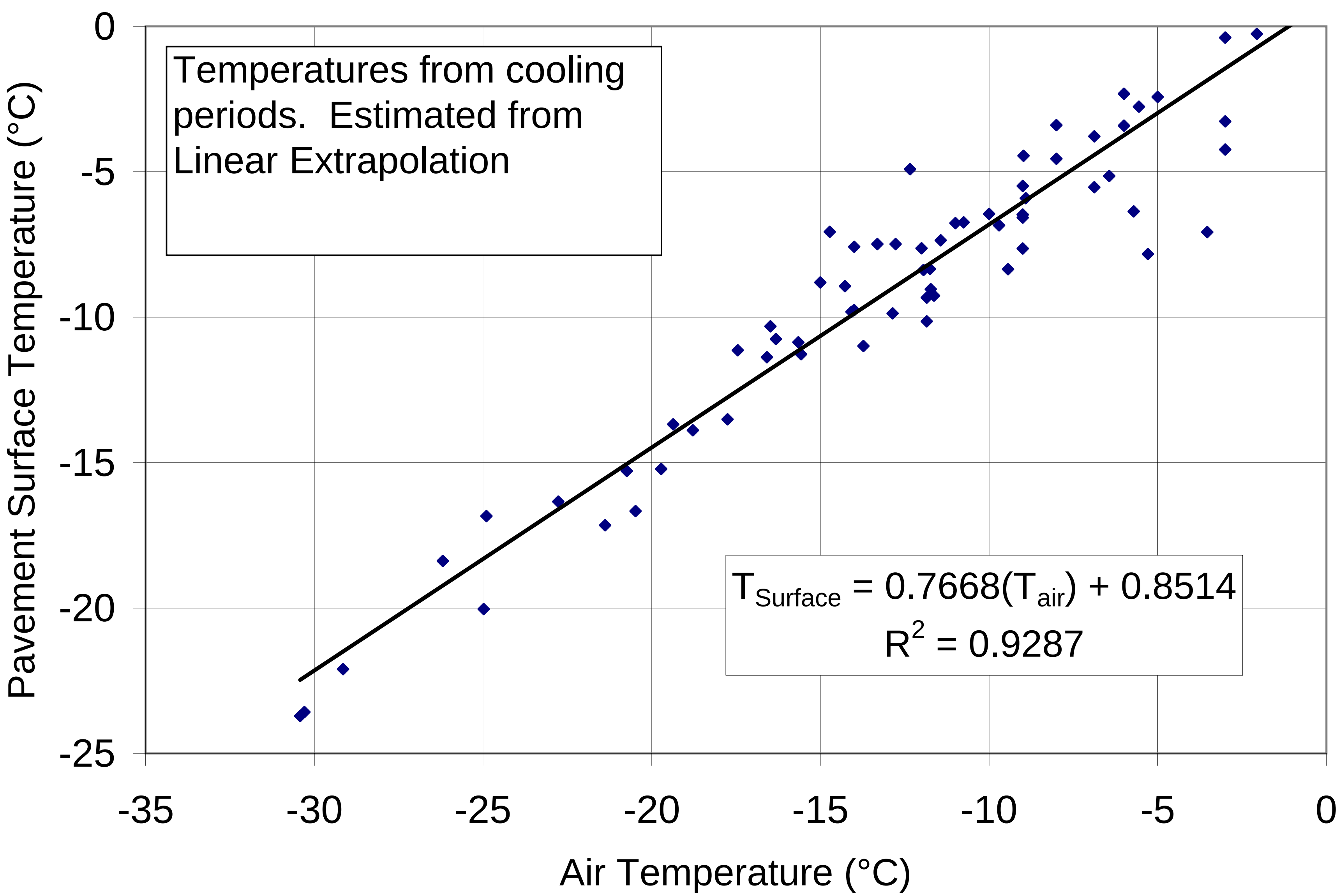
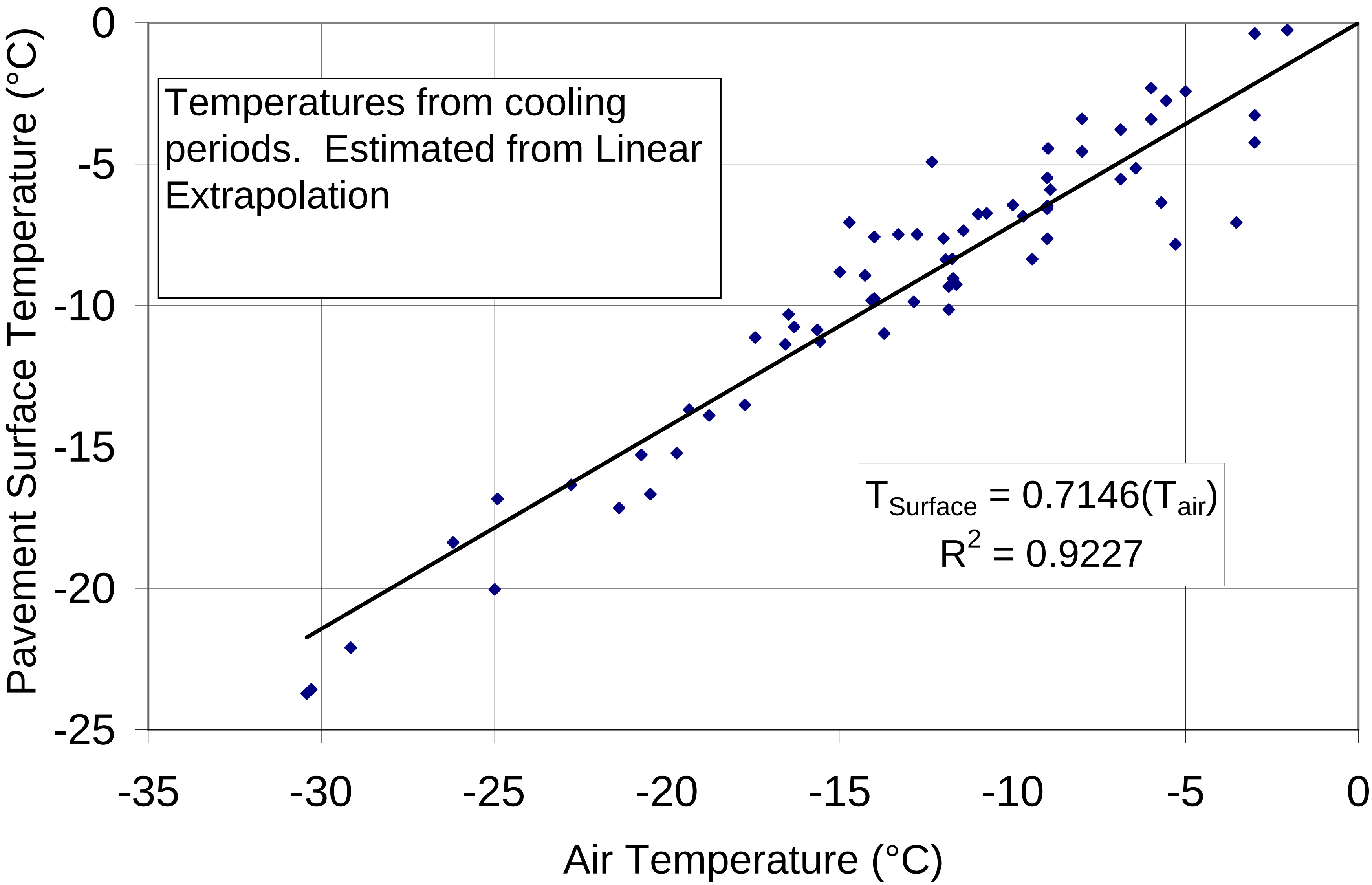


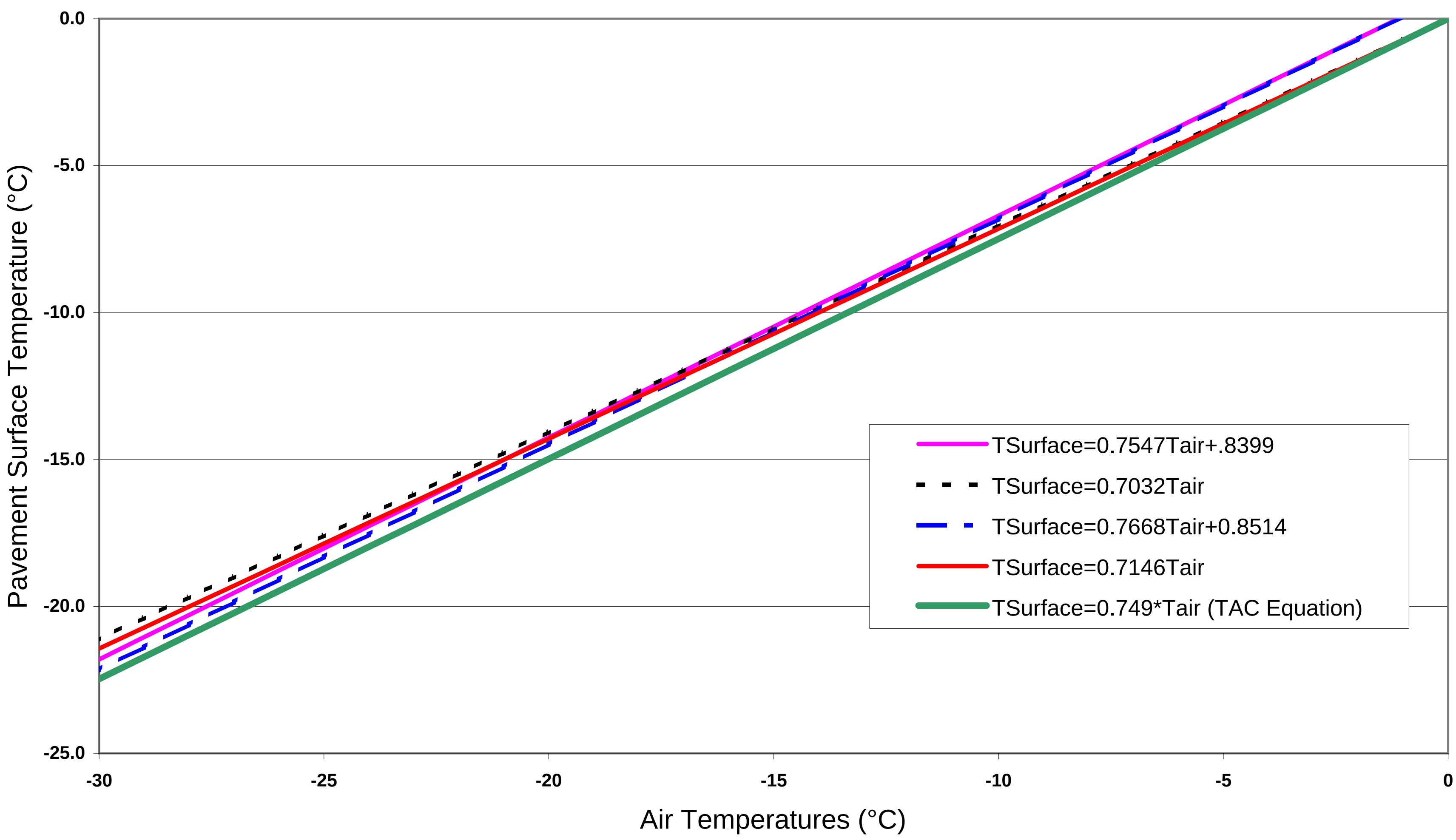
**Figure 11 1998/1999 Pavement Surface Temperature Versus Air Temperature**
**Taxi 'J'**



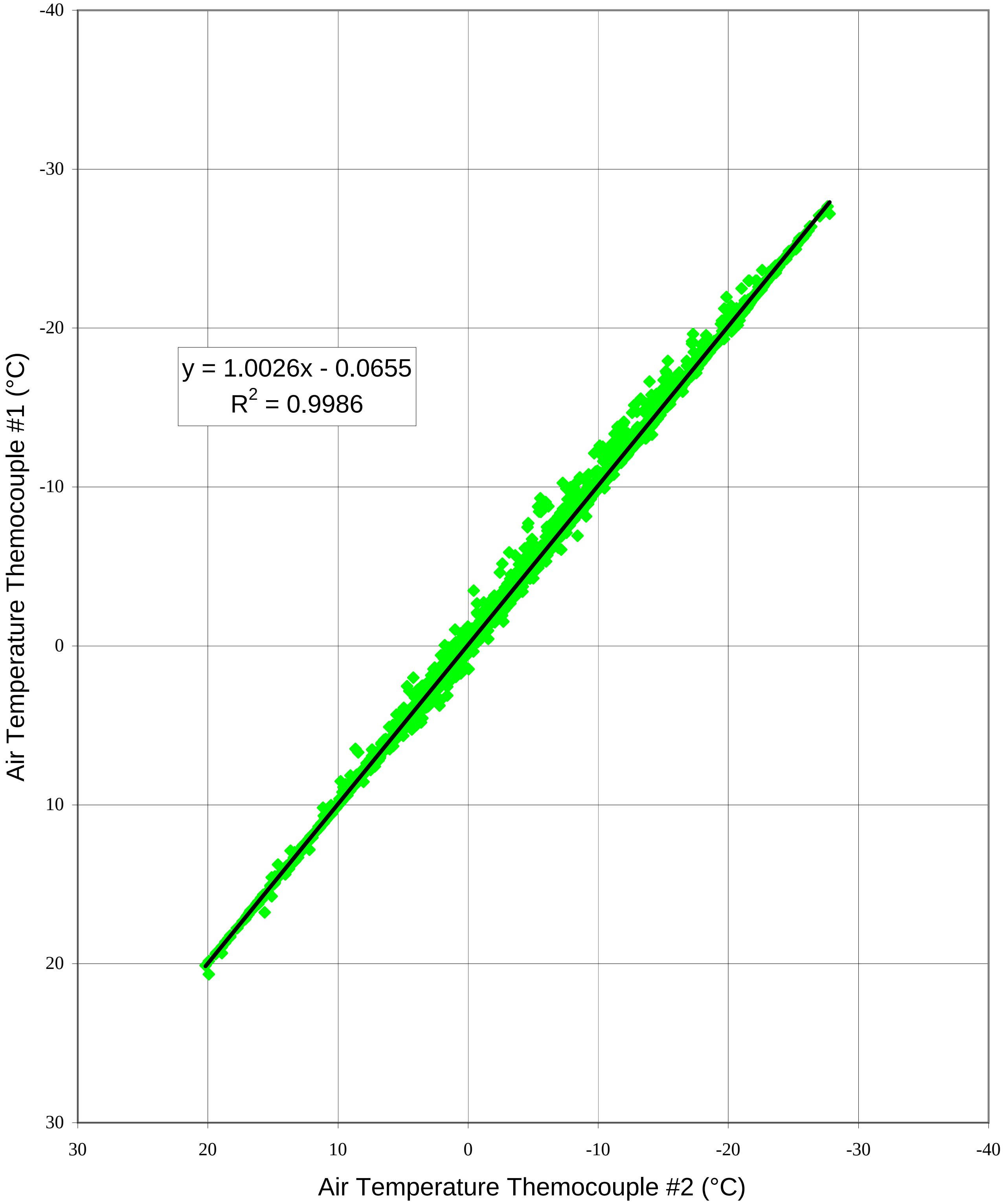
## Figure 11A 1998/1999 Pavement Surface Temperature Vs Air Temperature Taxi 'J'



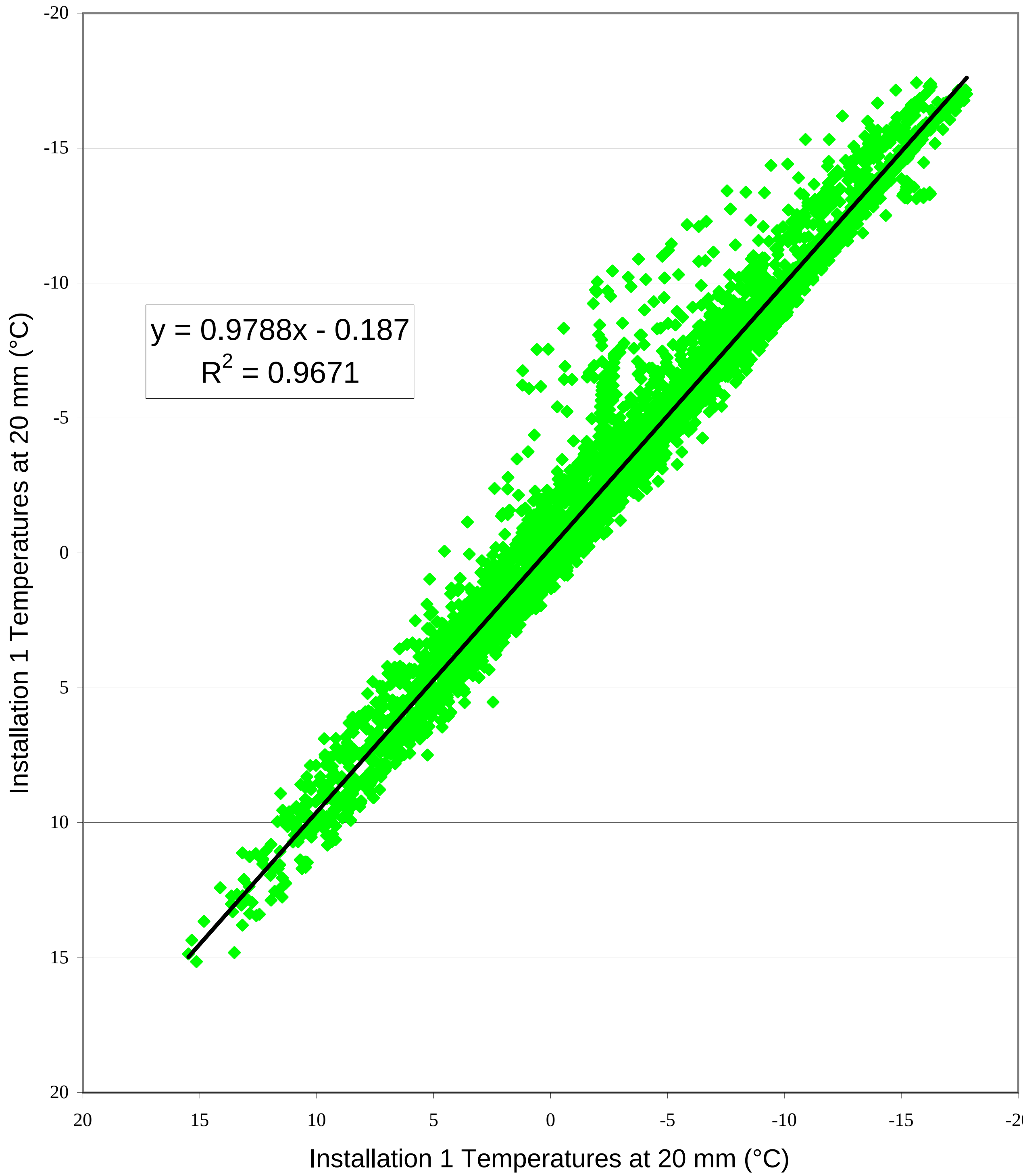
# Figure 12 1998/1999 Calgary Based Equations and TAC Equation



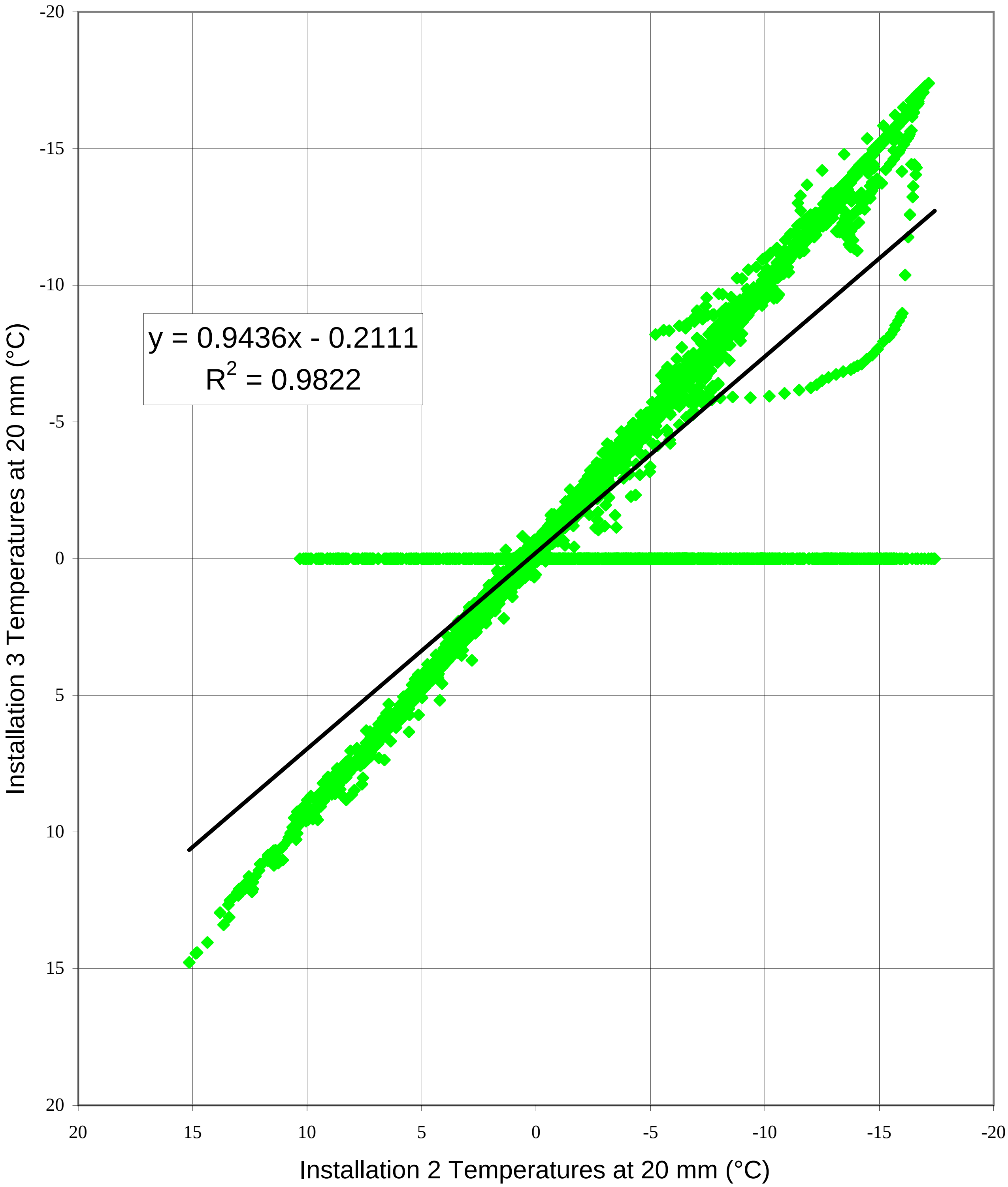
# Figure 13 1999/2000 Correlation Between Air Temperature Thermocouples



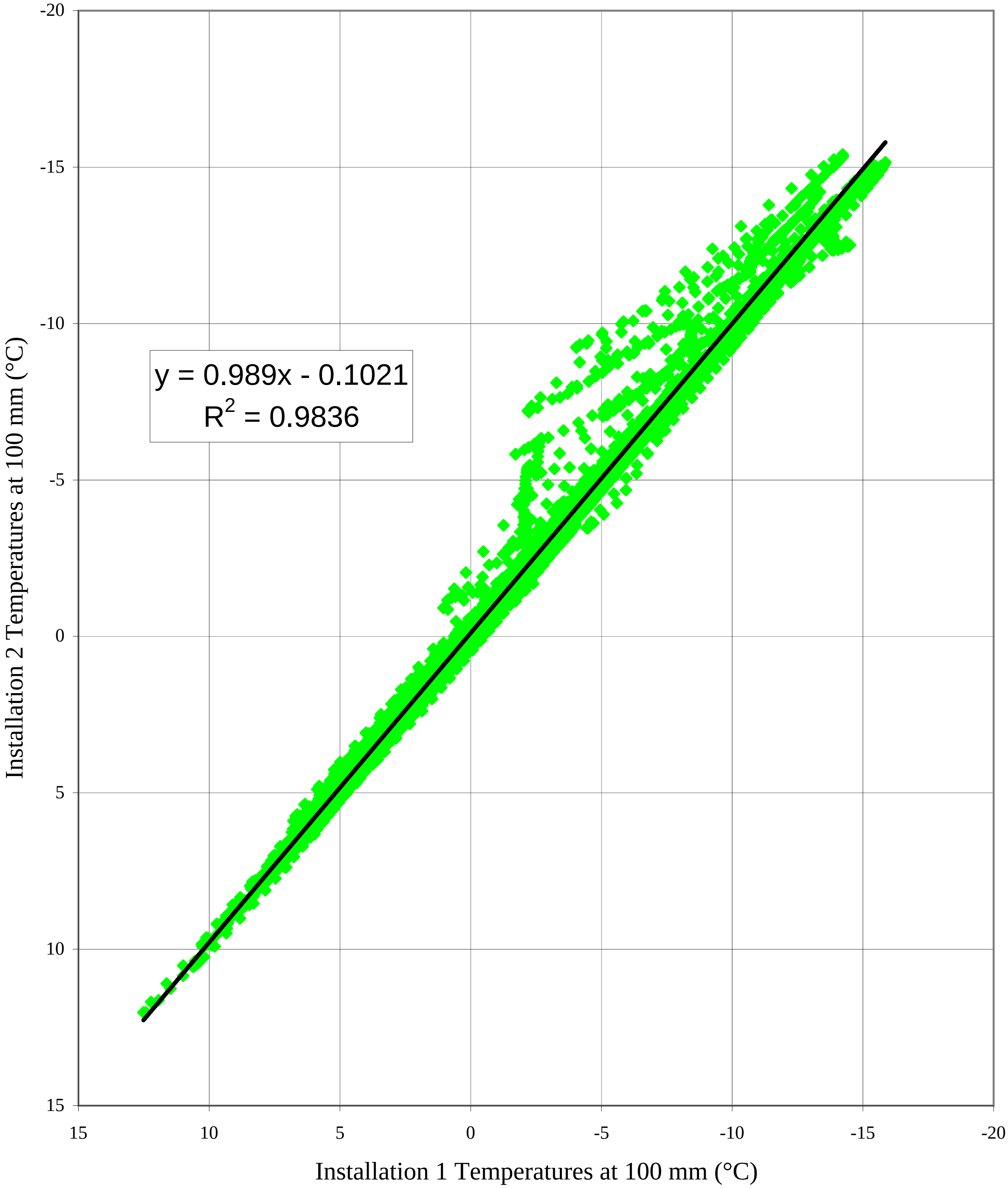
## Figure 14 1999/2000 Correlation Between Installation 1 and 2 Thermocouples at 20 mm Depth



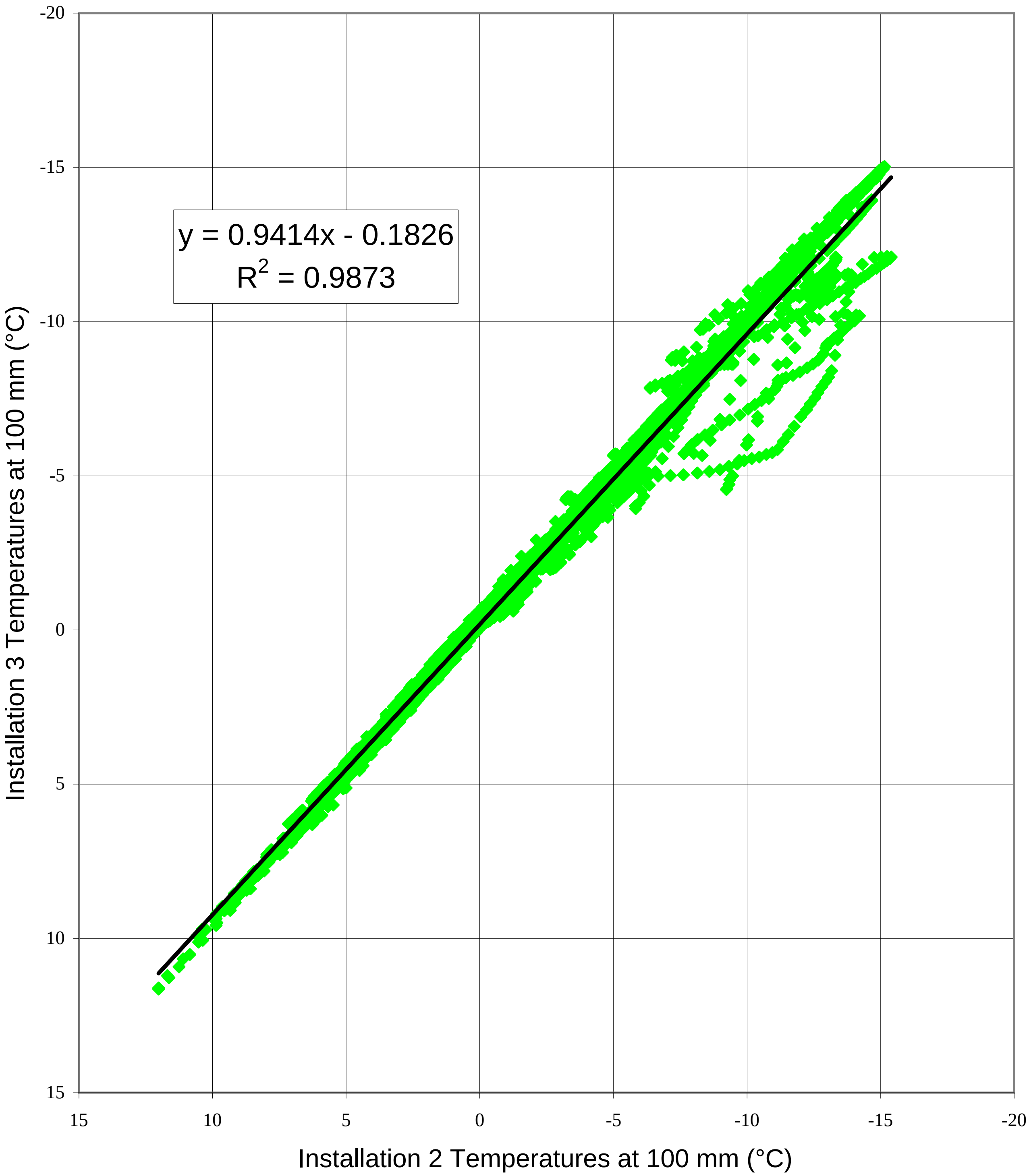
# Figure 15 1999/2000 Correlation Between Installation 2 and 3 Thermocouples at 20 mm Depth



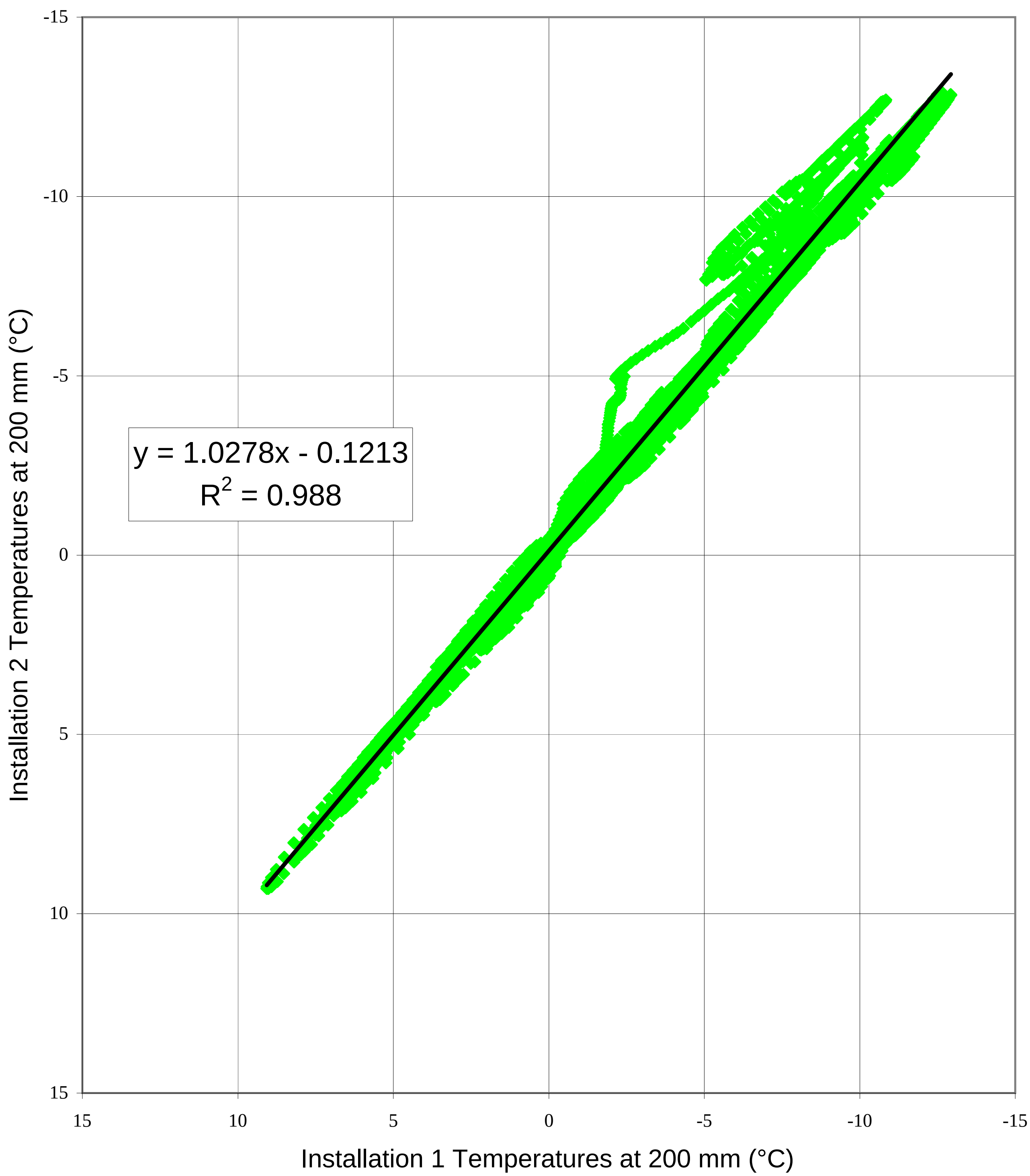
# Figure 16 1999/2000 Correlation Between Installation 1 and 2 thermocouples at 100 mm Depth



# Figure 17 1999/2000 Correlation Between Installation 2 and 3 Thermocouples at 100 mm Depth



# Figure 18 1999/2000 Correlation Between Installation 1 and 2 Thermocouples at 200 mm Depth



## Figure 19 1999/2000 Correlation Between Installation 2 and 3 Thermocouples at 200 mm Depth

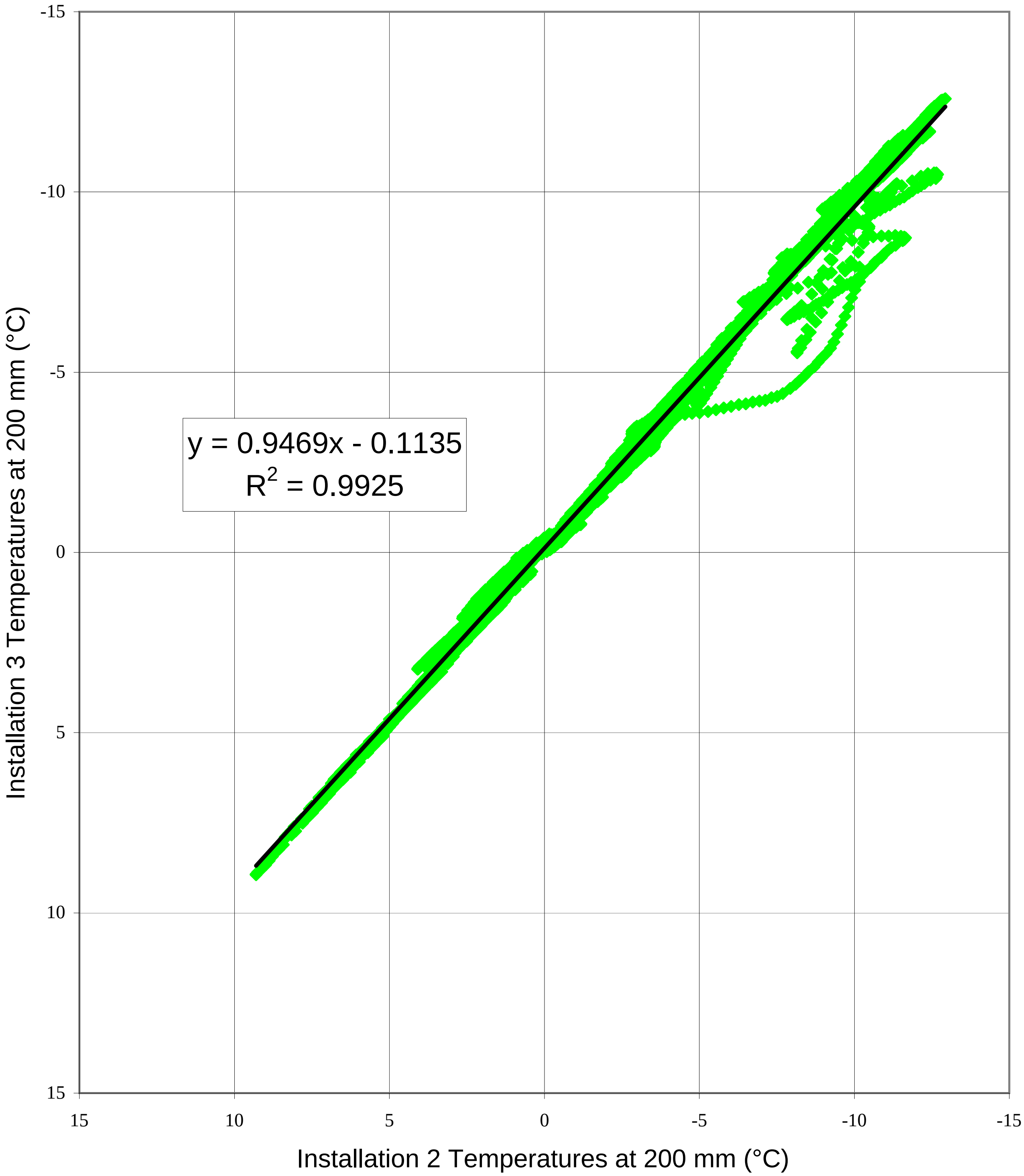


**Figure 20 1999/2000 Pavement Surface Temperature Versus Air Temperature Taxi "J"**

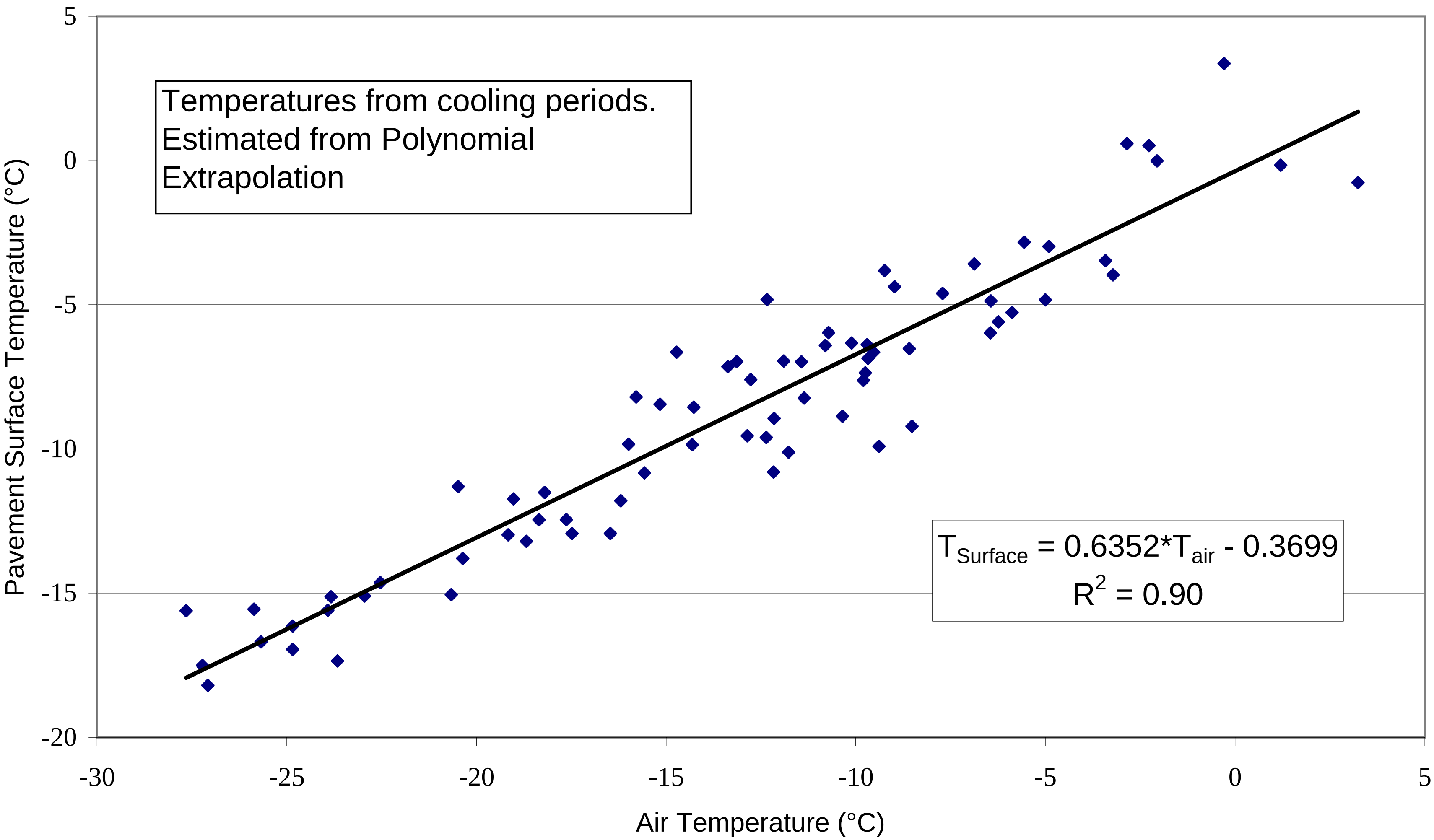


**Figure 20A 1999/200 Pavement Surface Temperature Versus Air Temperature Taxi "J"**

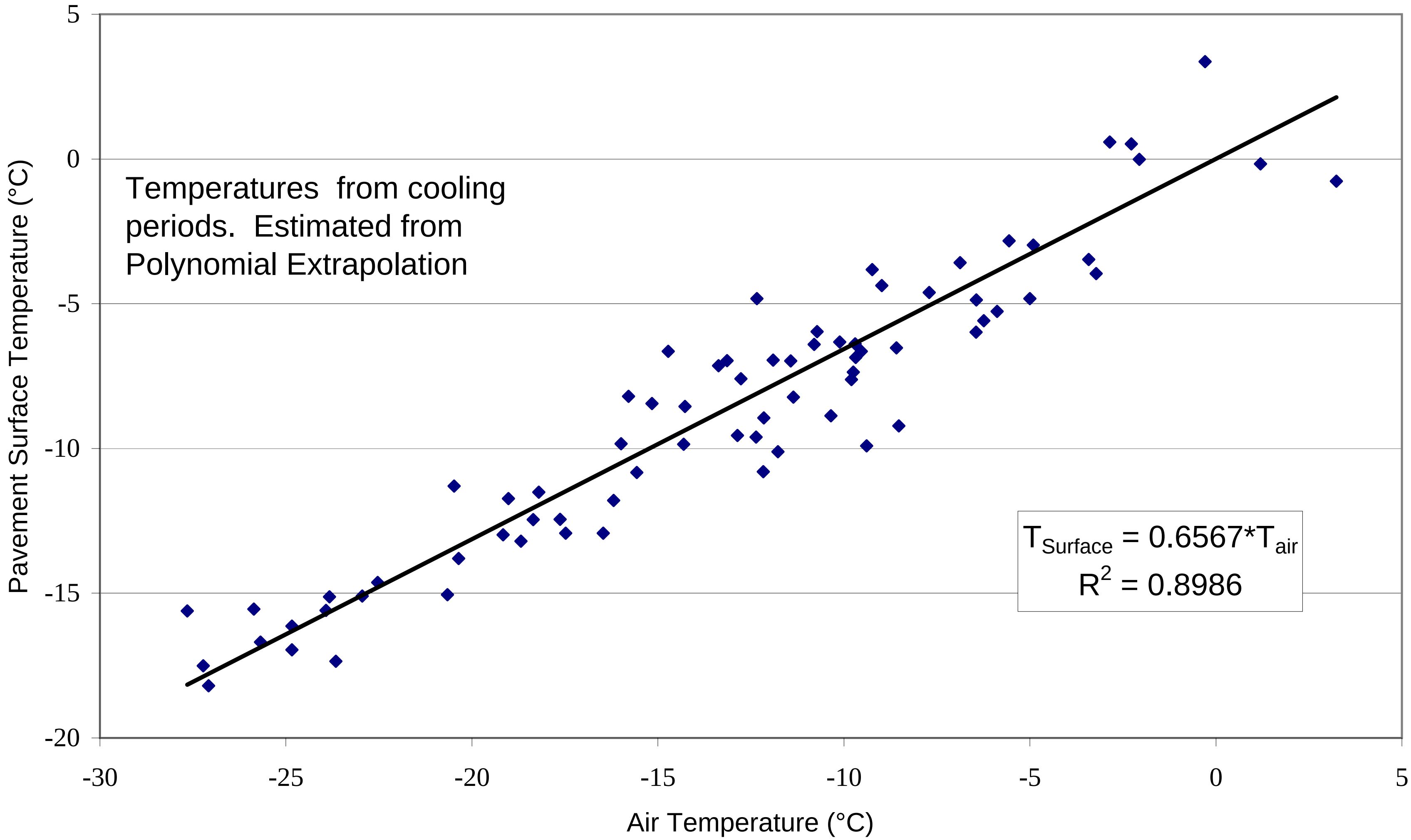
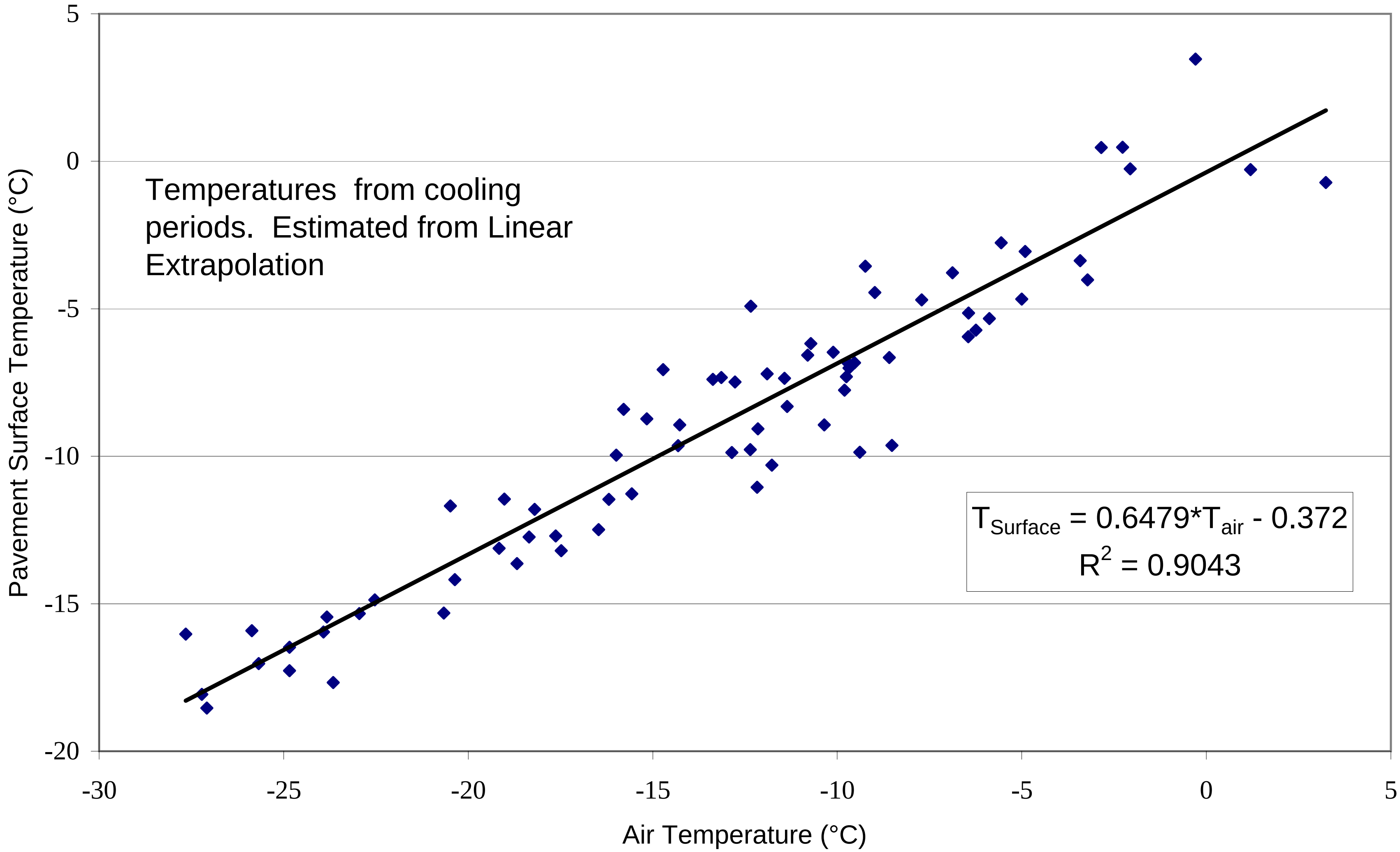
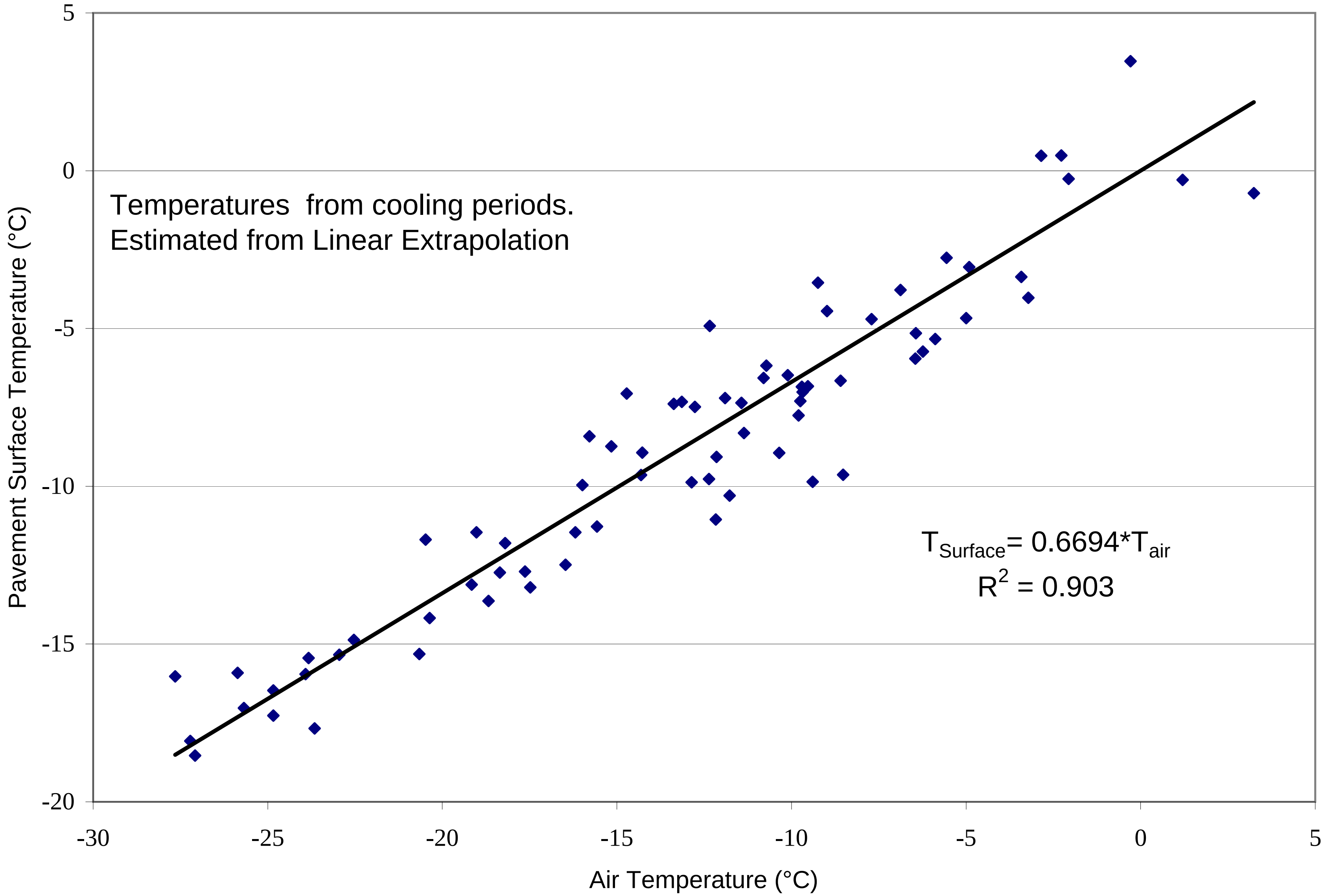


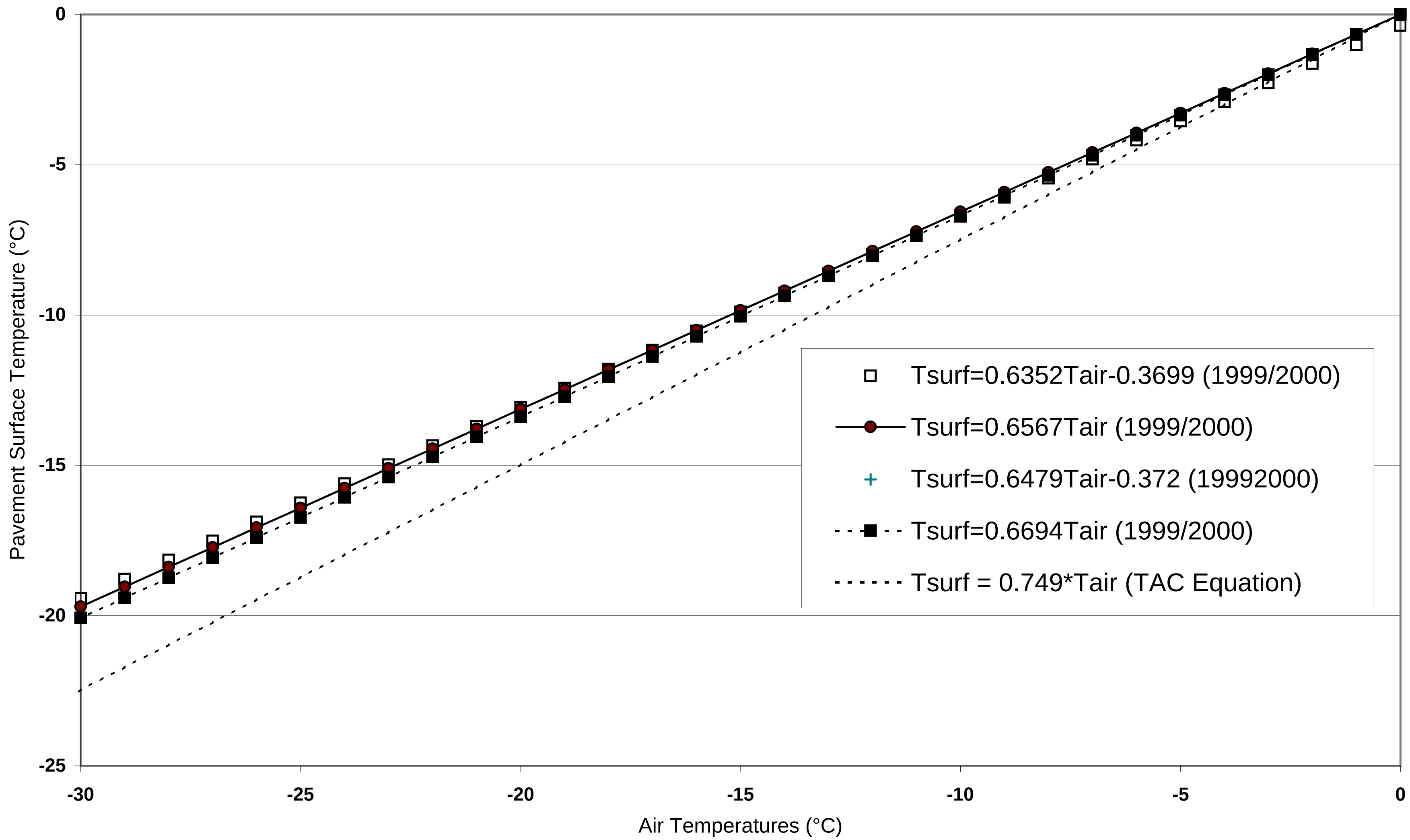
**Figure 21 1999/2000 Pavement Surface Temperature Versus Air Temperature Taxi "J"**



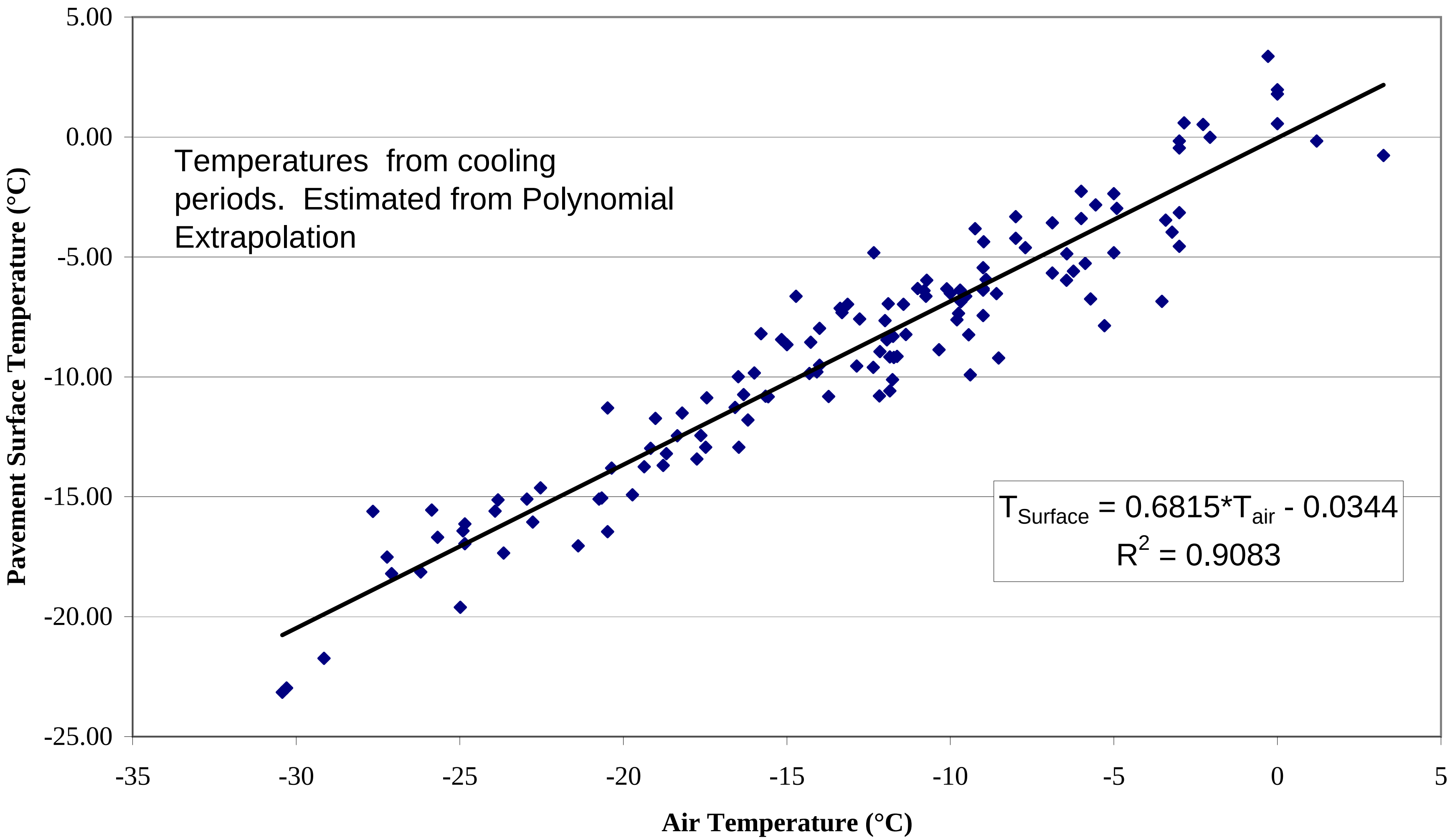
## Figure 21A 1999/2000 Pavement Surface Temperature Versus Air Temperature Taxi "J"



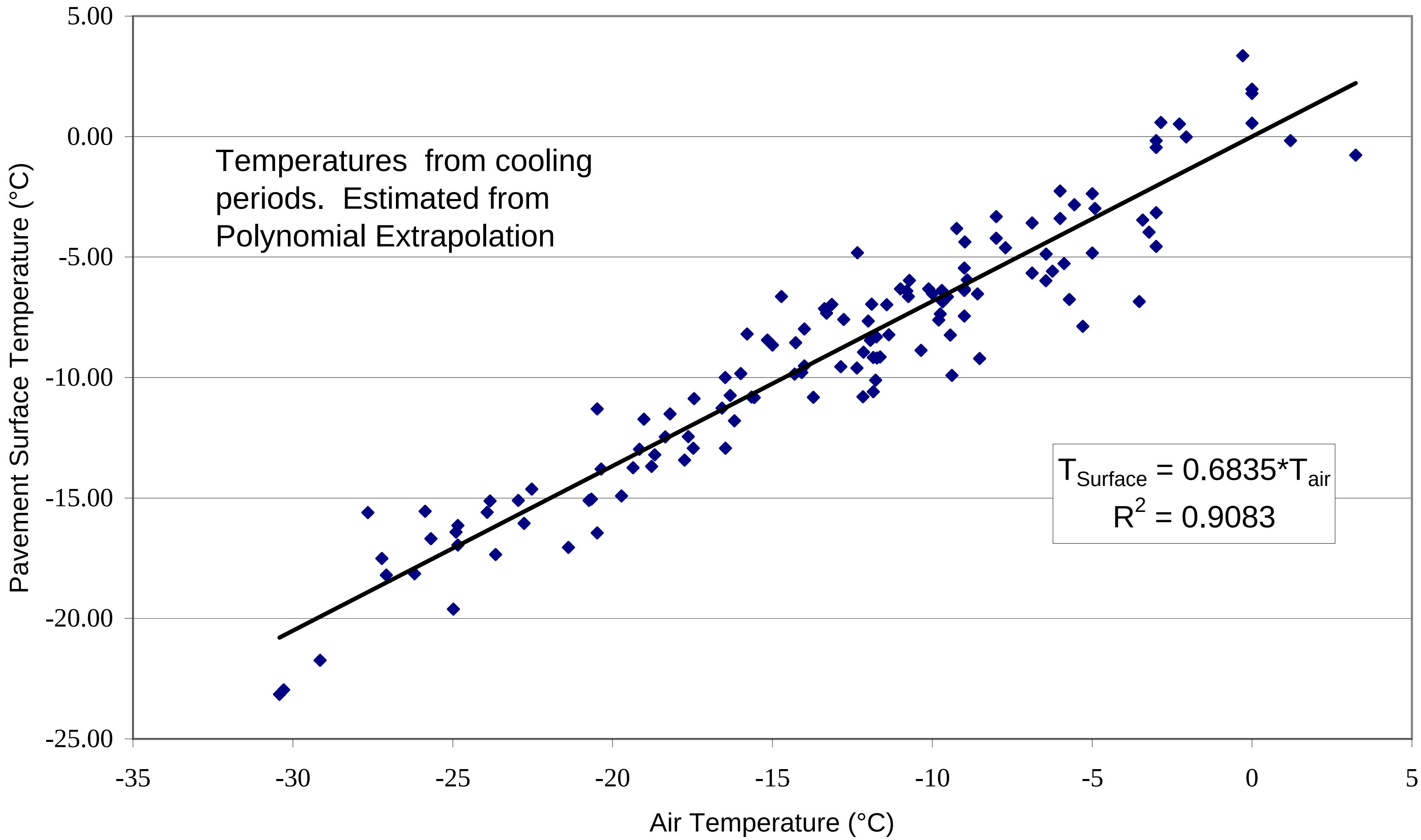
## Figure 22 1999/2000 Comparison of Calgary Based Equations and TAC Equation



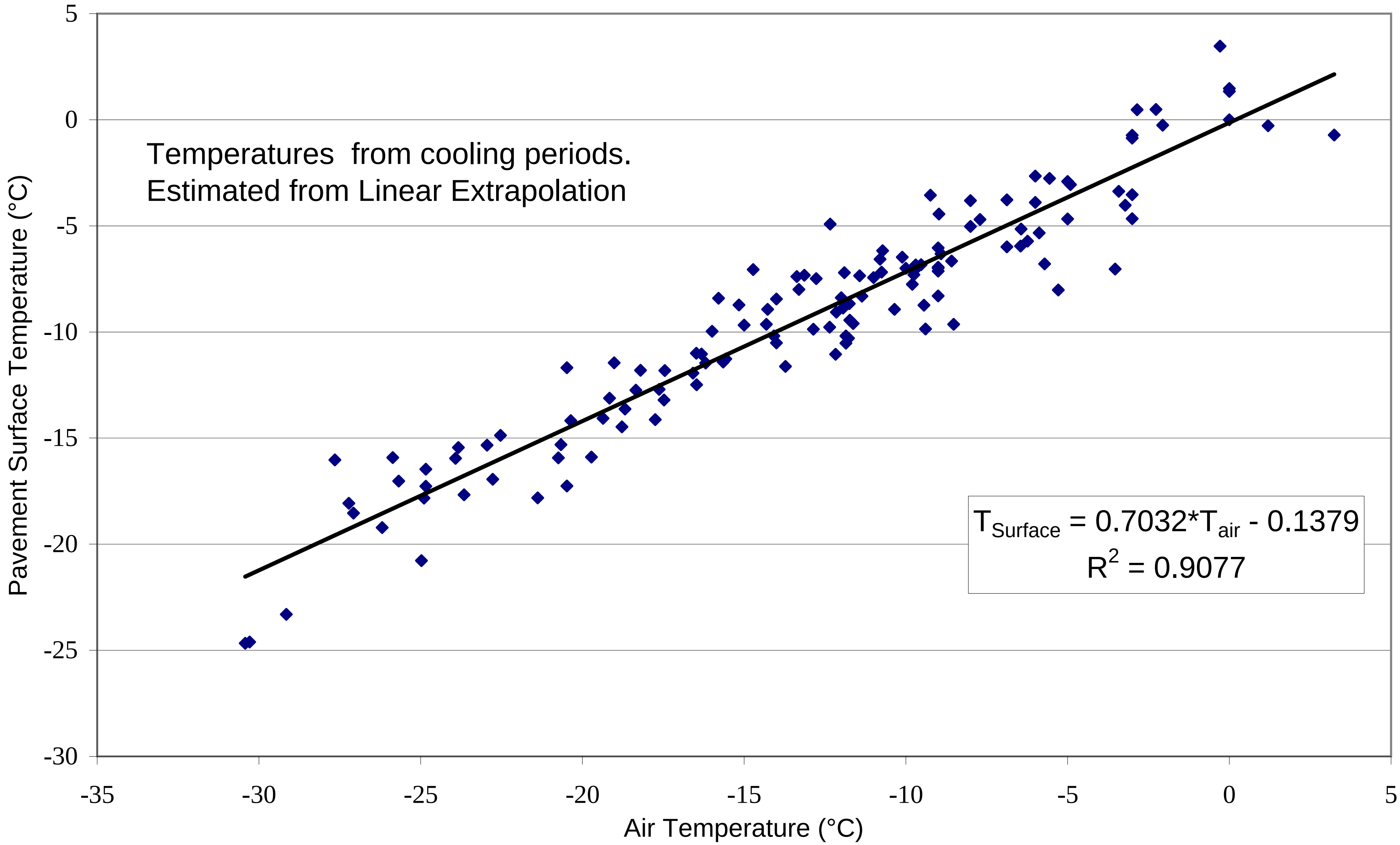
## Figure 23 Pavement Surface Temperature Versus Air Temperature
## Taxi "J"
**1998/1999 and 1999/2000 Data**



# Figure 23A Pavement Surface Temperature Versus Air Temperature
## Taxi "J"
### 1998/1999 and 1999/2000 Data



## Figure 24 Pavement Surface Temperature Versus Air Temperature
## Taxi "J"
**1998/1999 and 1999/2000 Data**



# Figure 24A Pavement Surface Temperature Versus Air Temperature
## Taxi "J"
### 1998/1999 and 1999/2000 Data

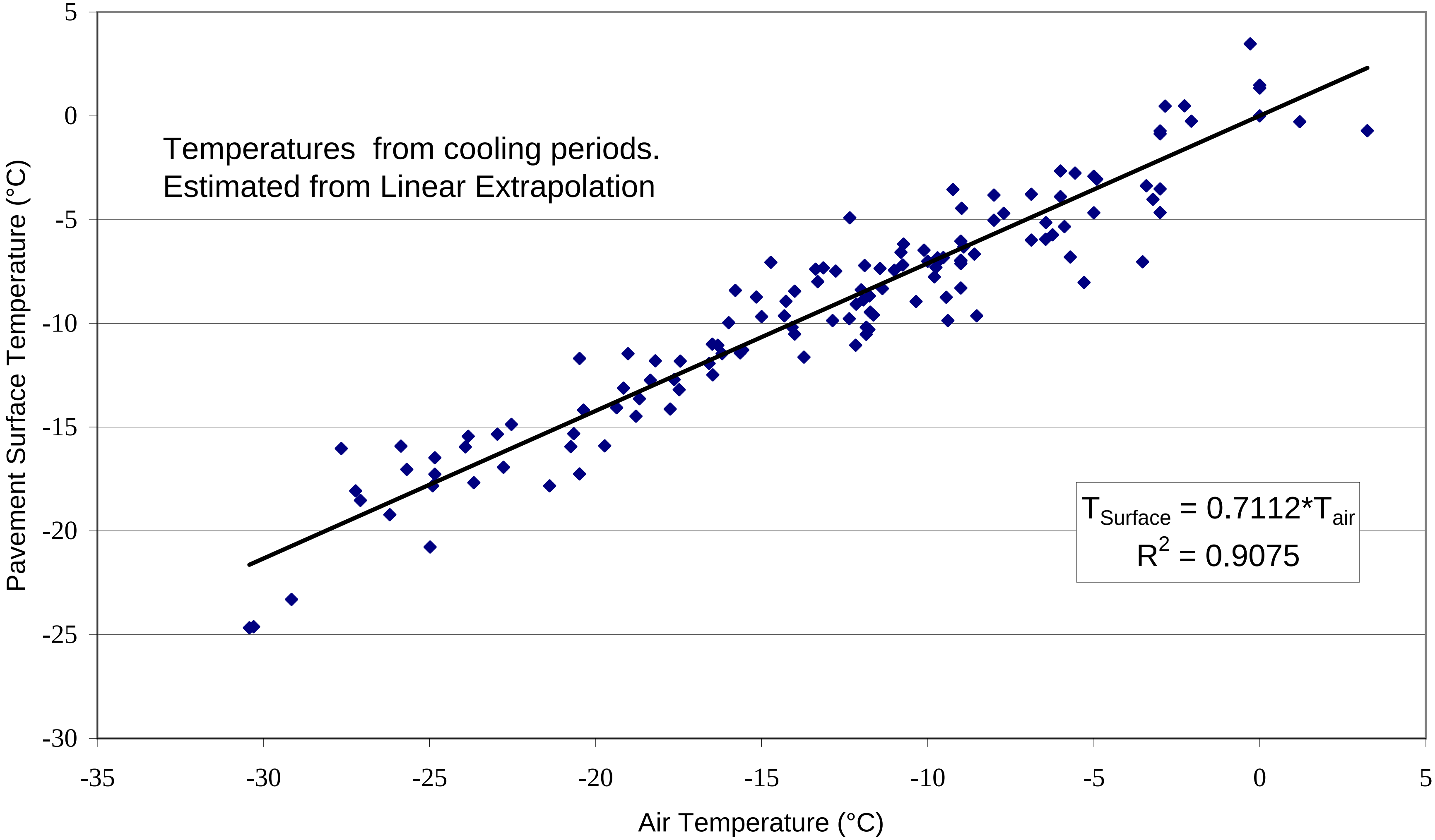
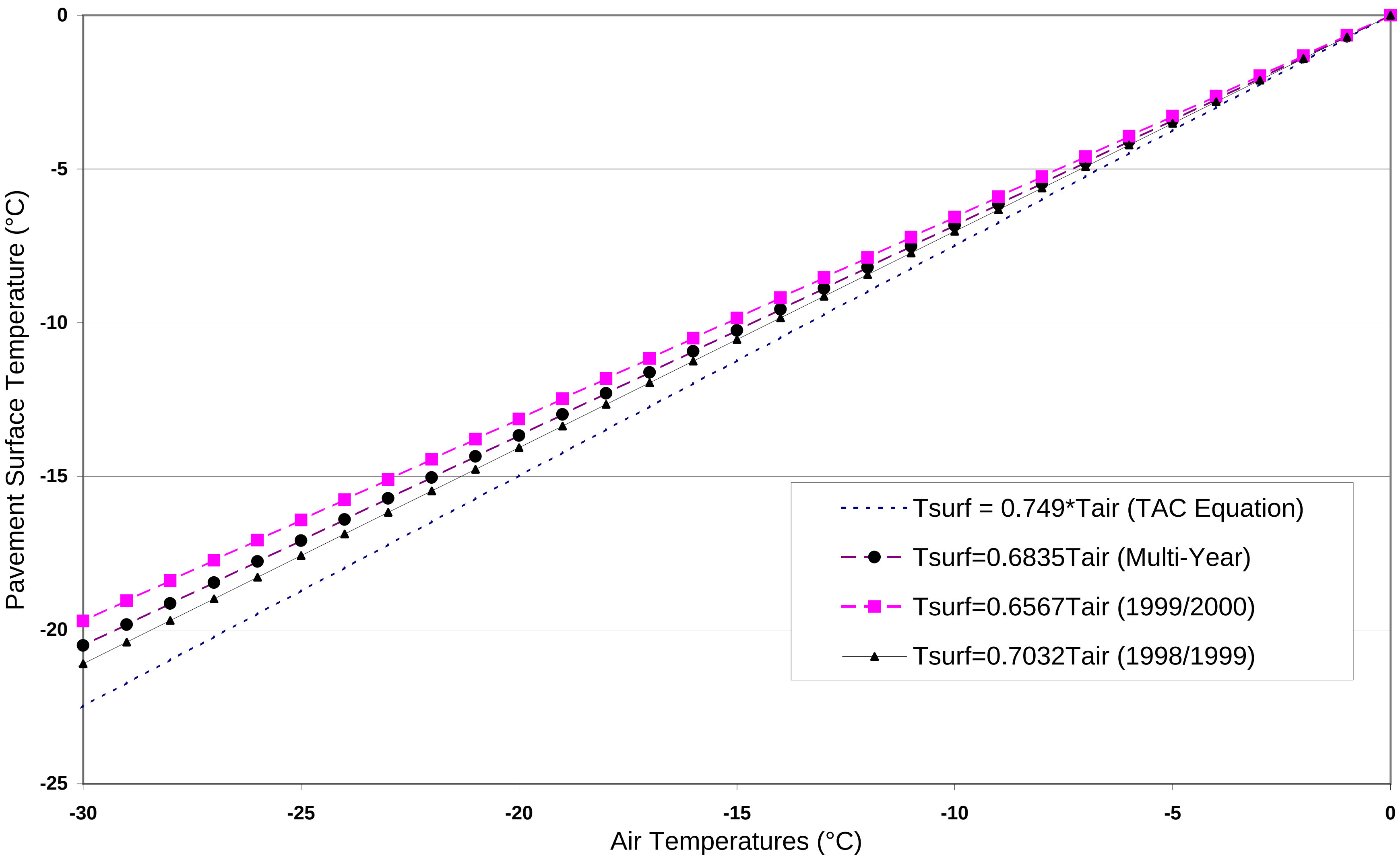
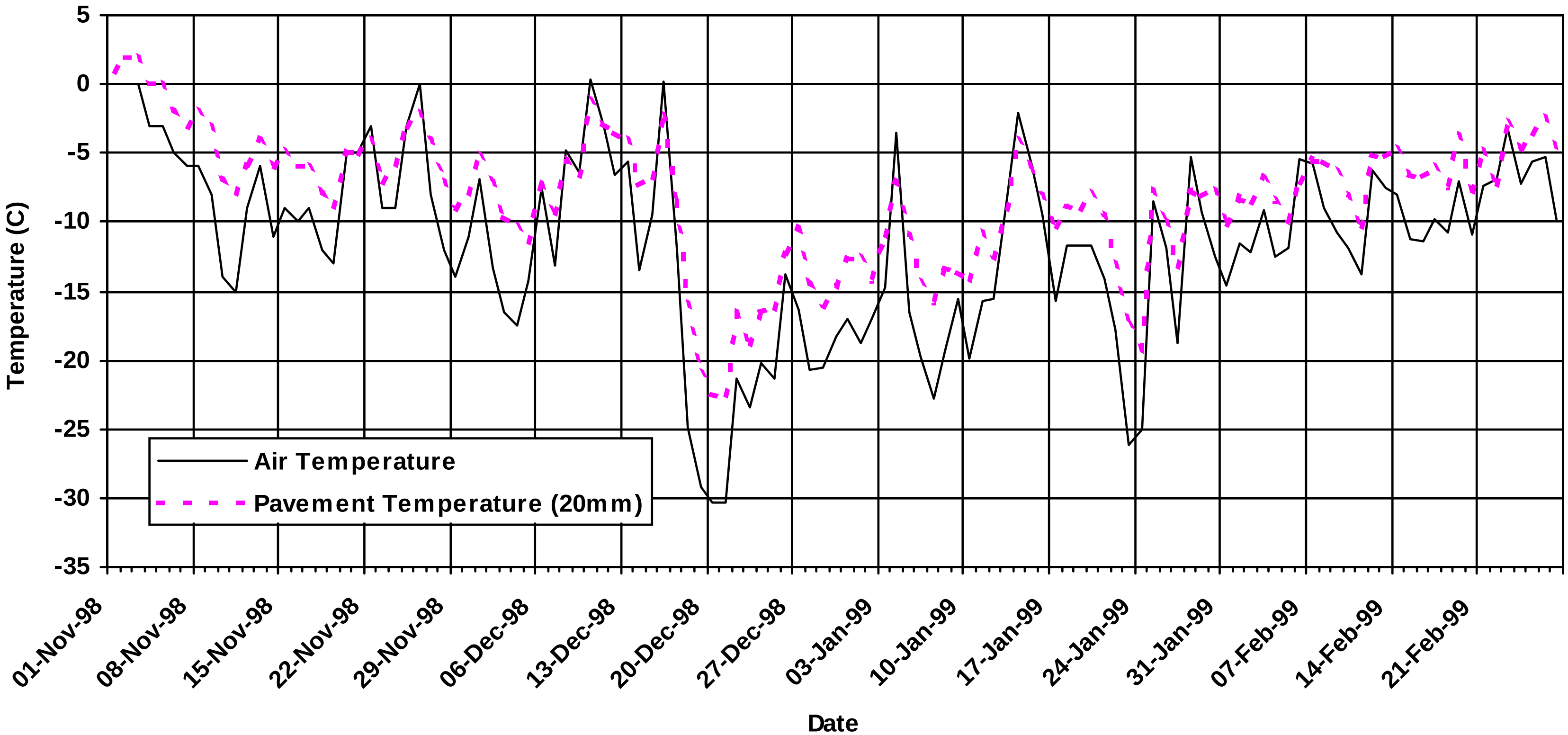


**Figure 25 Comparison of Calgary Based Equation(s) and TAC Equation**

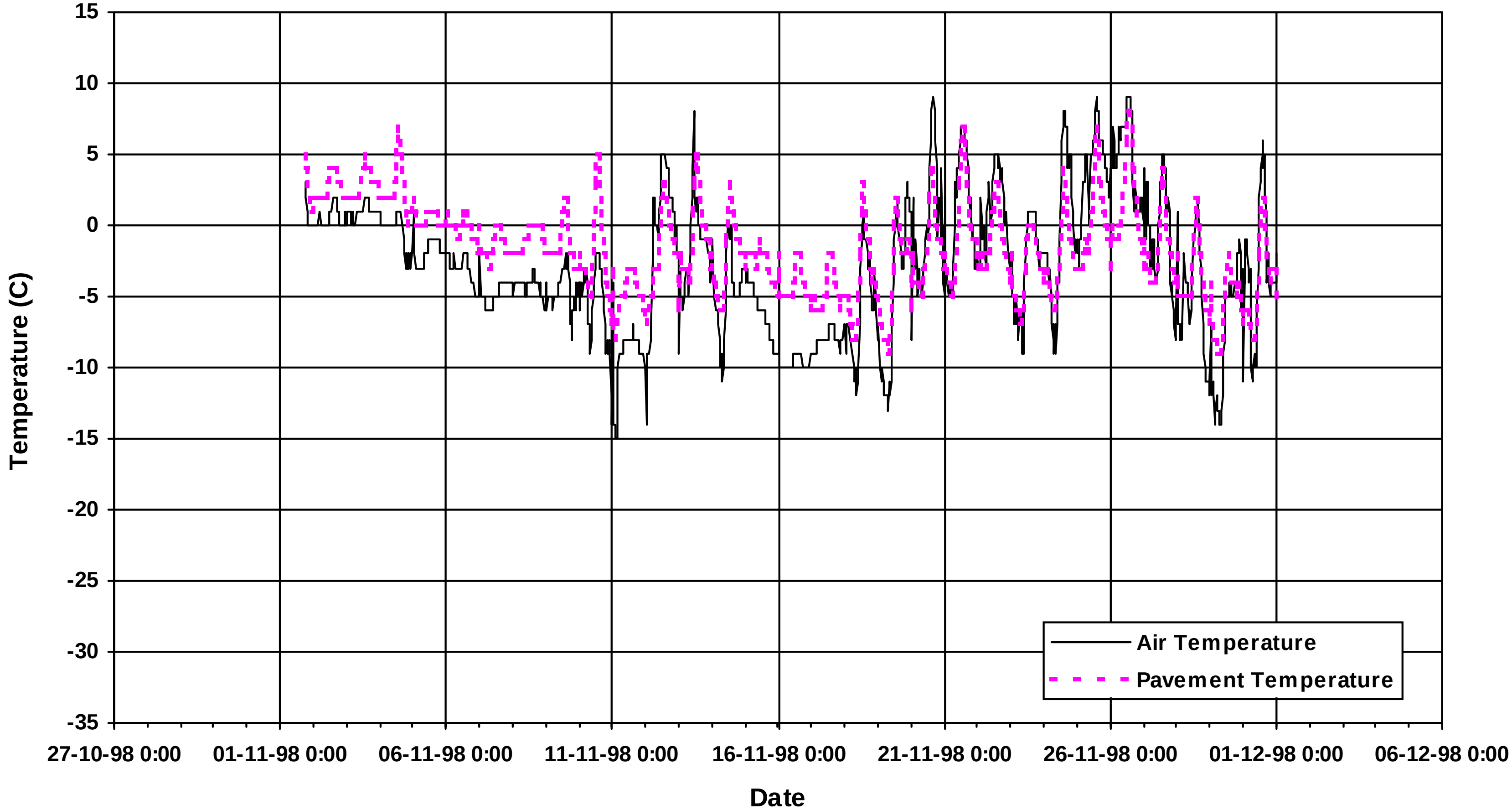


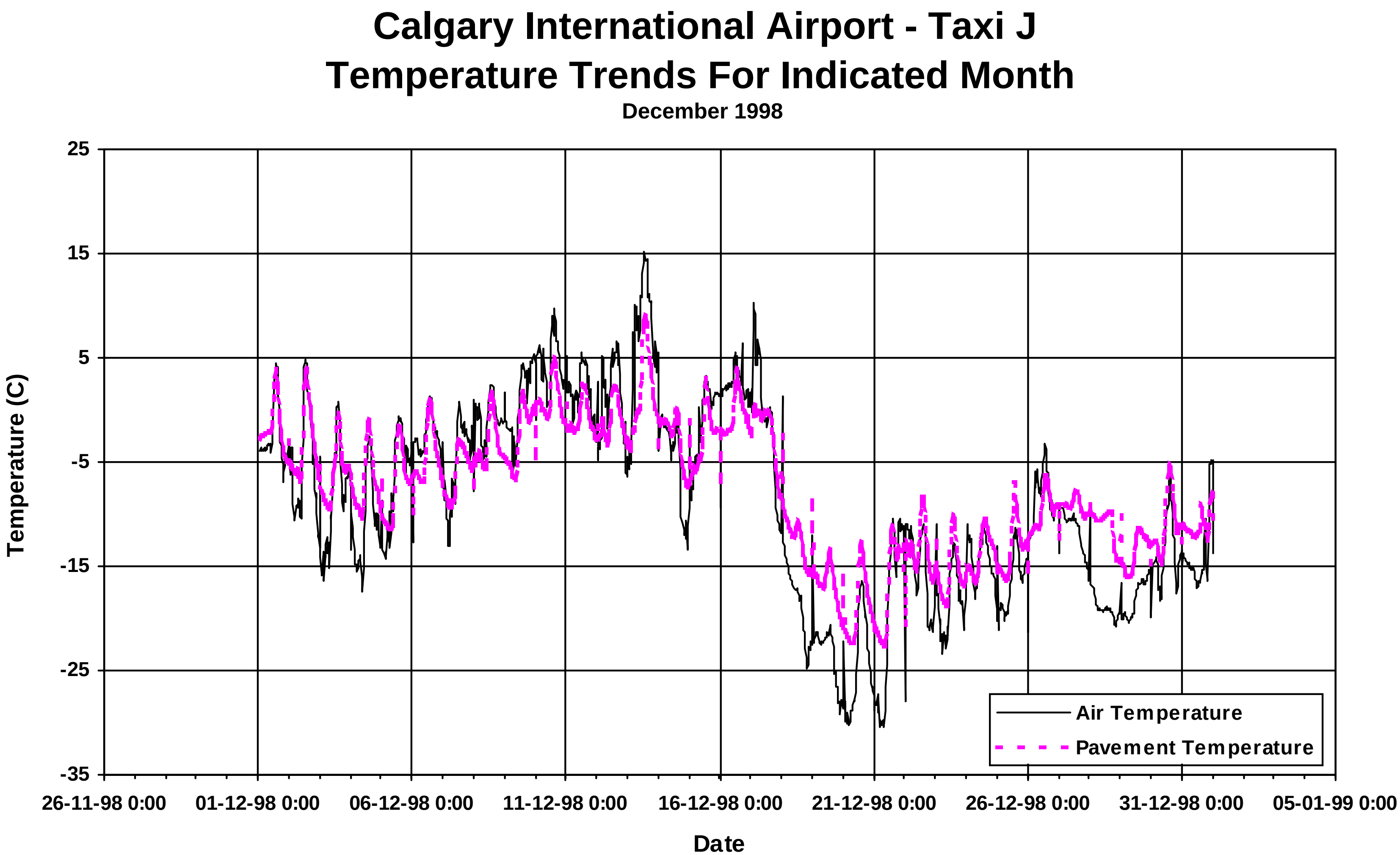
# Appendix A
1998/1999 Monthly Temperature Data

# Calgary International Airport - Taxi J
# Minimum Daily Temperatures Winter 1998/1999



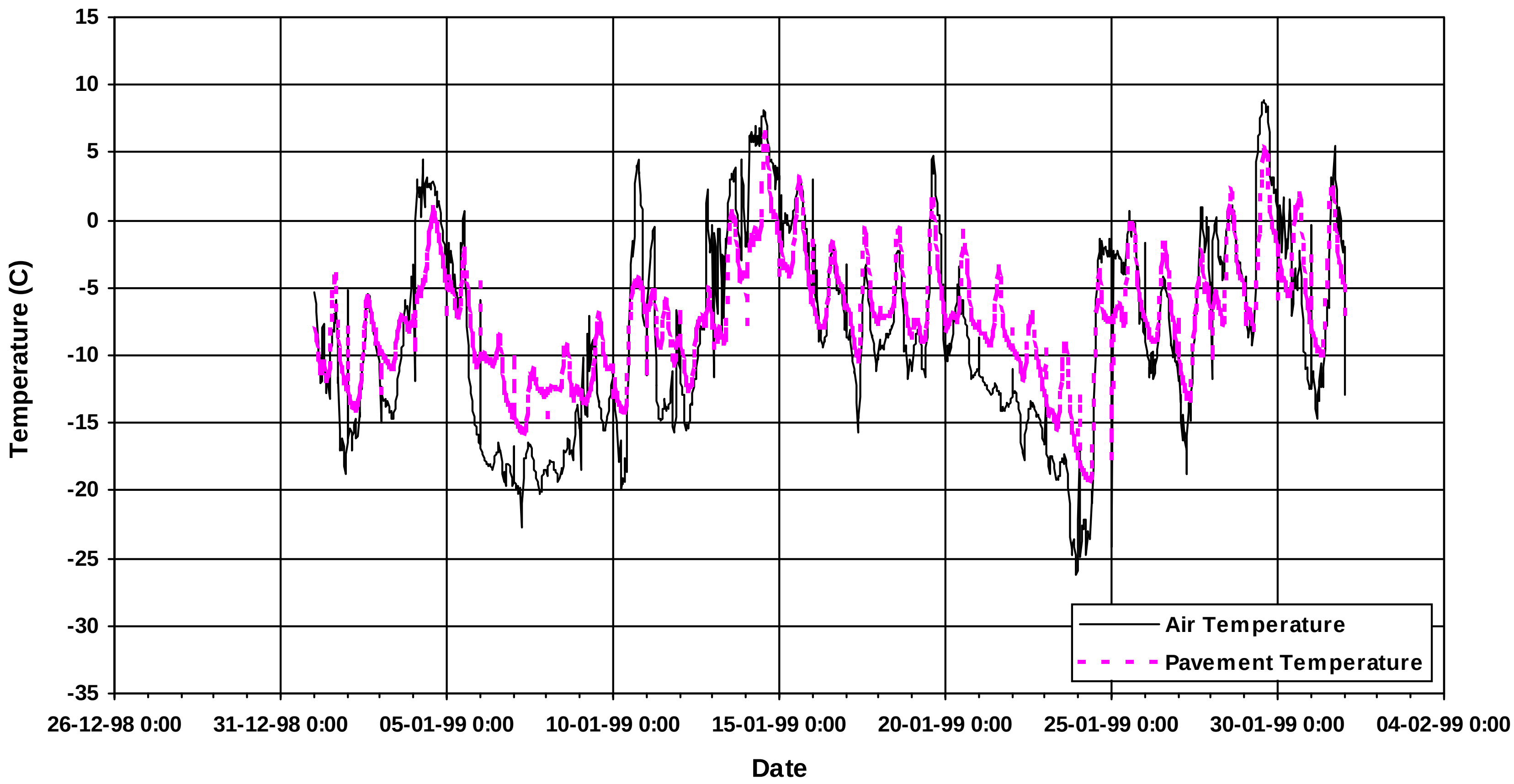
## Calgary International Airport - Taxi J
## Temperature Trends for Indicated Month
**November 1998**

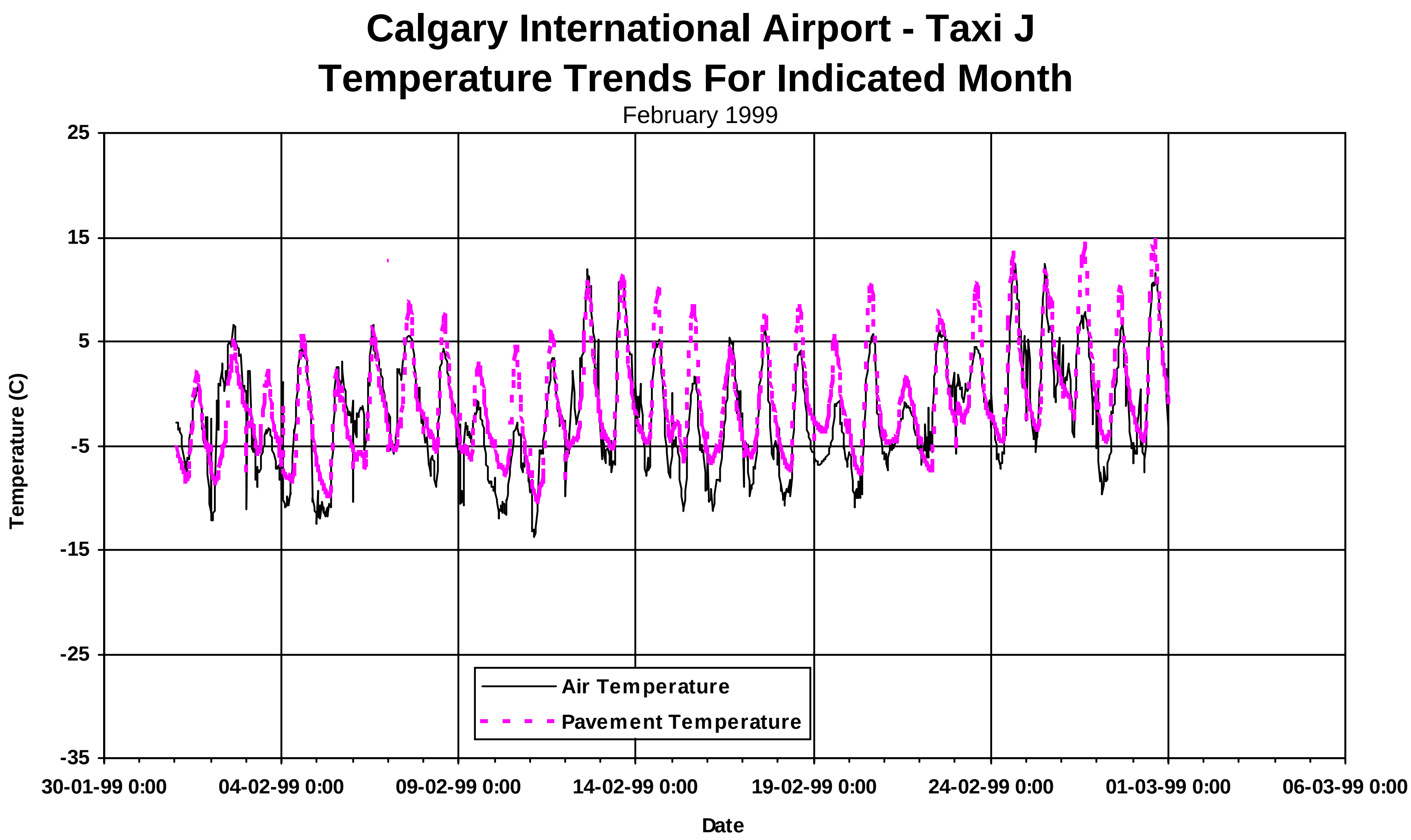



Calgary International Airport - Taxi J
Temperature Trends For Indicated Month
December 1998
Temperature (C)
25
15
5
-5
-15
-25
-35
26-11-98 0:00
01-12-98 0:00
06-12-98 0:00
11-12-98 0:00
16-12-98 0:00
21-12-98 0:00
26-12-98 0:00
31-12-98 0:00
05-01-99 0:00
Date
Air Temperature
Pavement Temperature

# Calgary International Airport - Taxi J
# Temperature Trends For Indicated Month

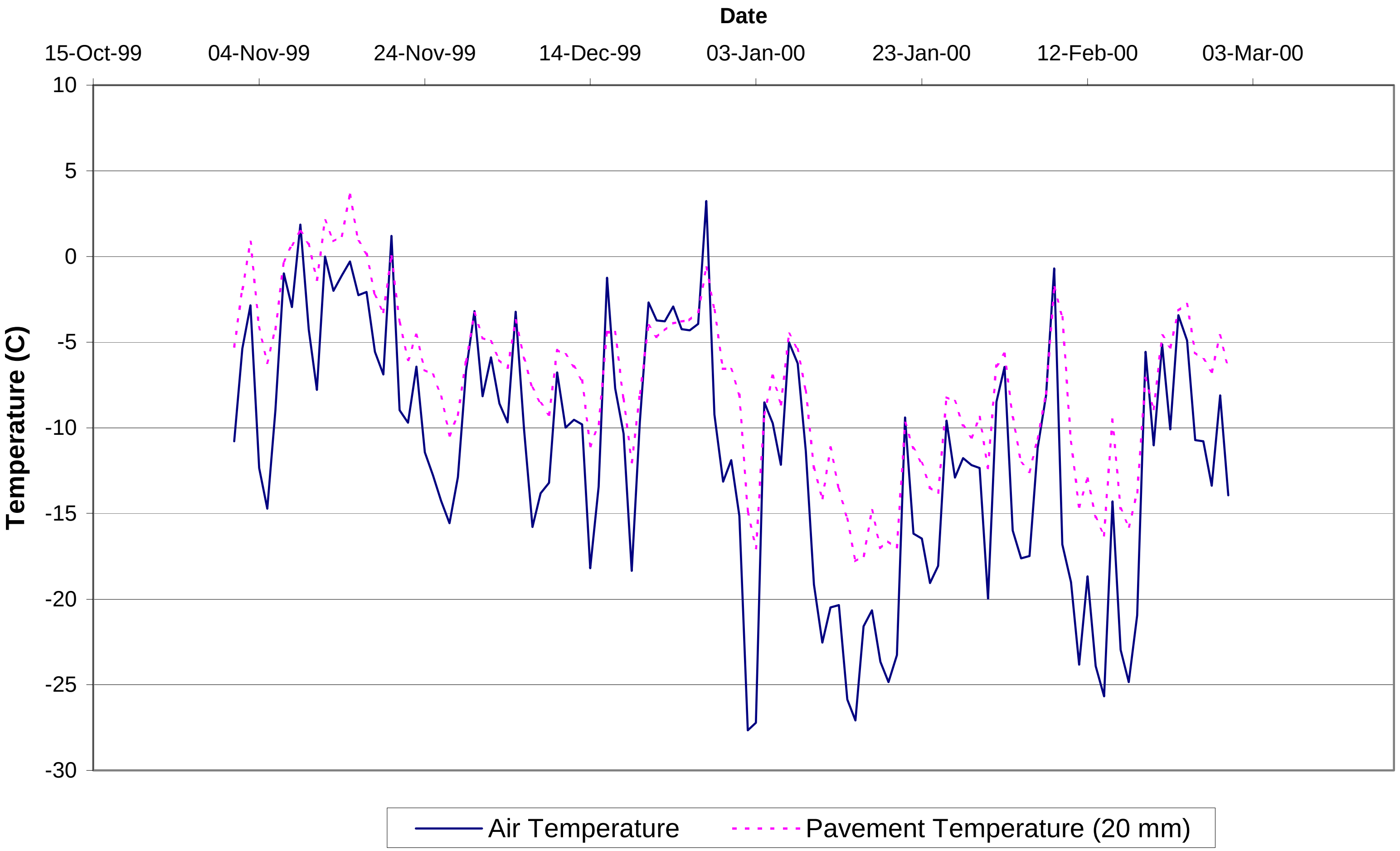
January 1999



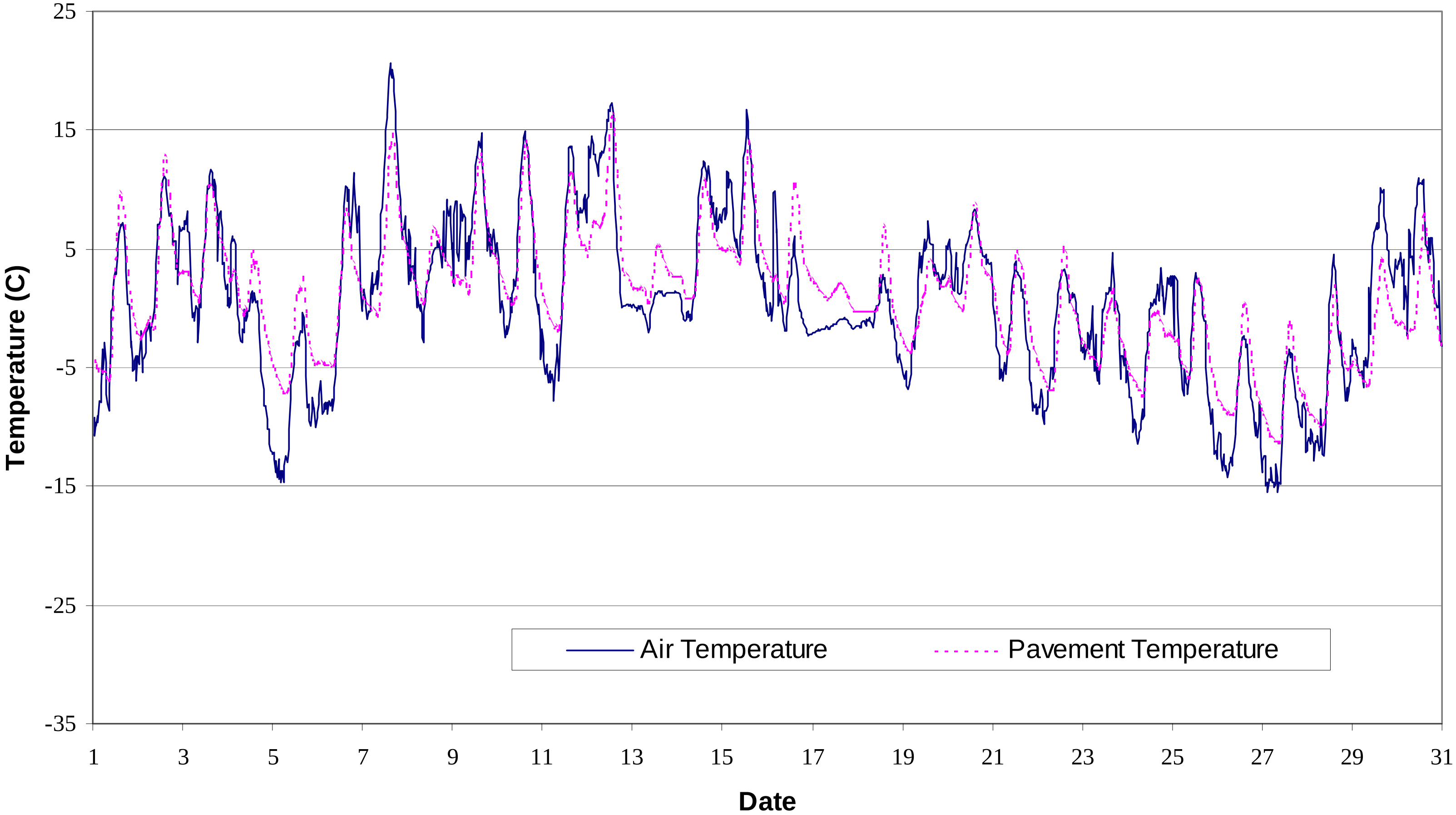

Calgary International Airport - Taxi J
Temperature Trends For Indicated Month
February 1999
Temperature (C)
25
15
5
-5
-15
-25
-35
Date
30-01-99 0:00
04-02-99 0:00
09-02-99 0:00
14-02-99 0:00
19-02-99 0:00
24-02-99 0:00
01-03-99 0:00
06-03-99 0:00
Air Temperature
Pavement Temperature

# Appendix B
1999/2000 Monthly Temperature Data

# Calgary International Airport - Taxi J Minimum Daily Temperatures Winter 1999/2000



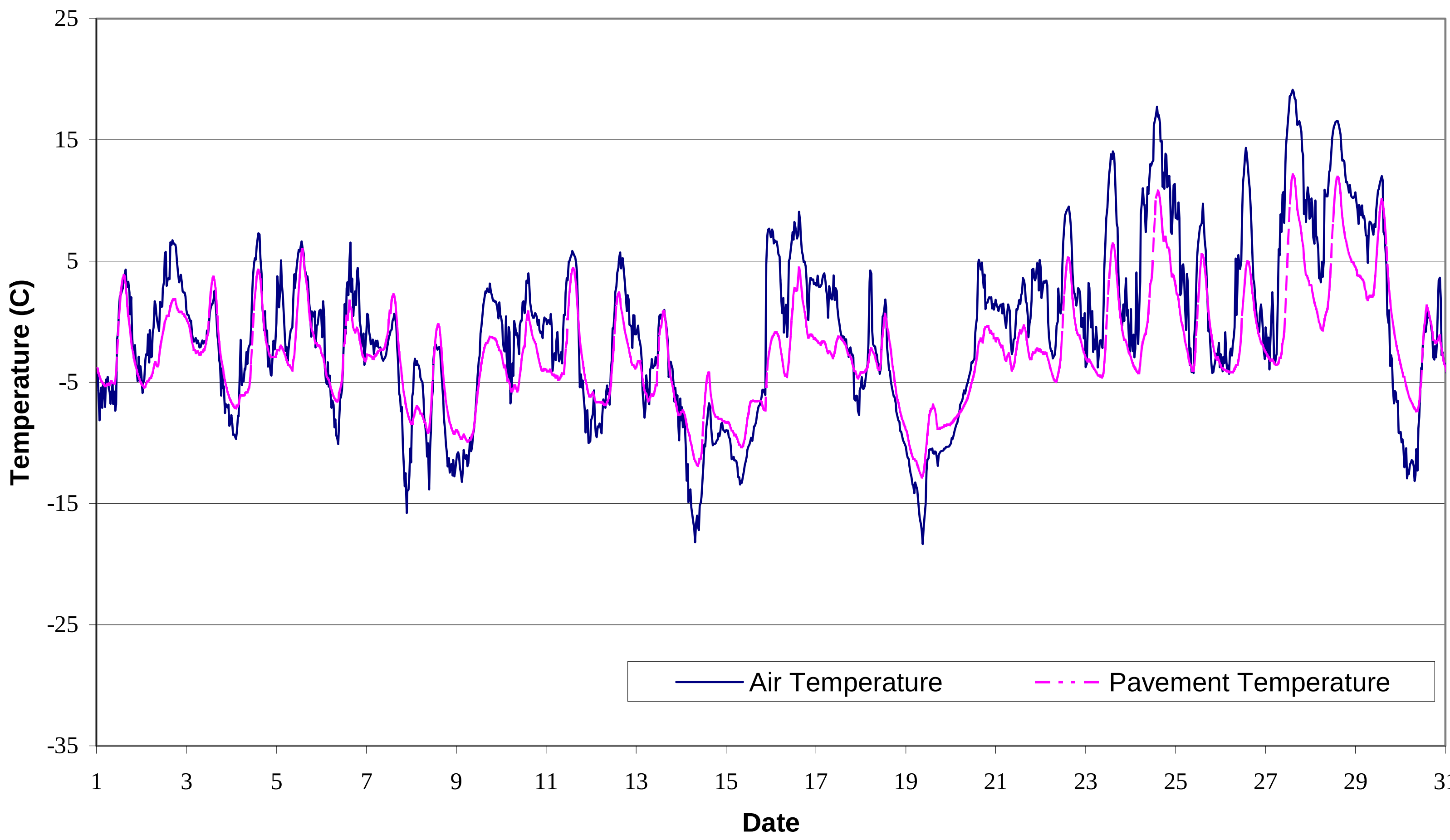
**Calgary International Airport - Taxi J**
**Temperature Trends for Indicated Month**
November 1999



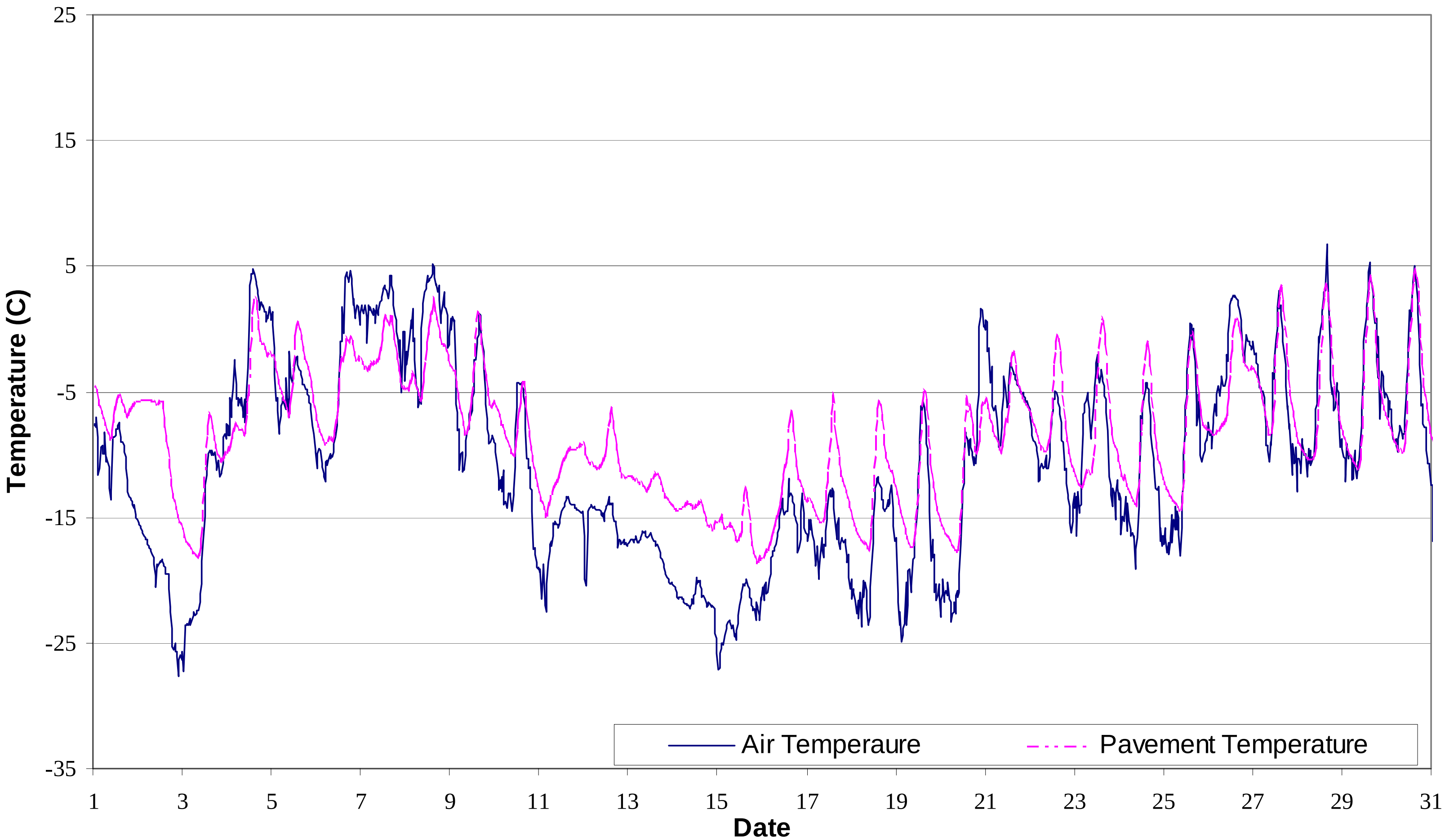
Public Works and Government Services Canada
Real Property Services Branch
Architectural and Engineering Services

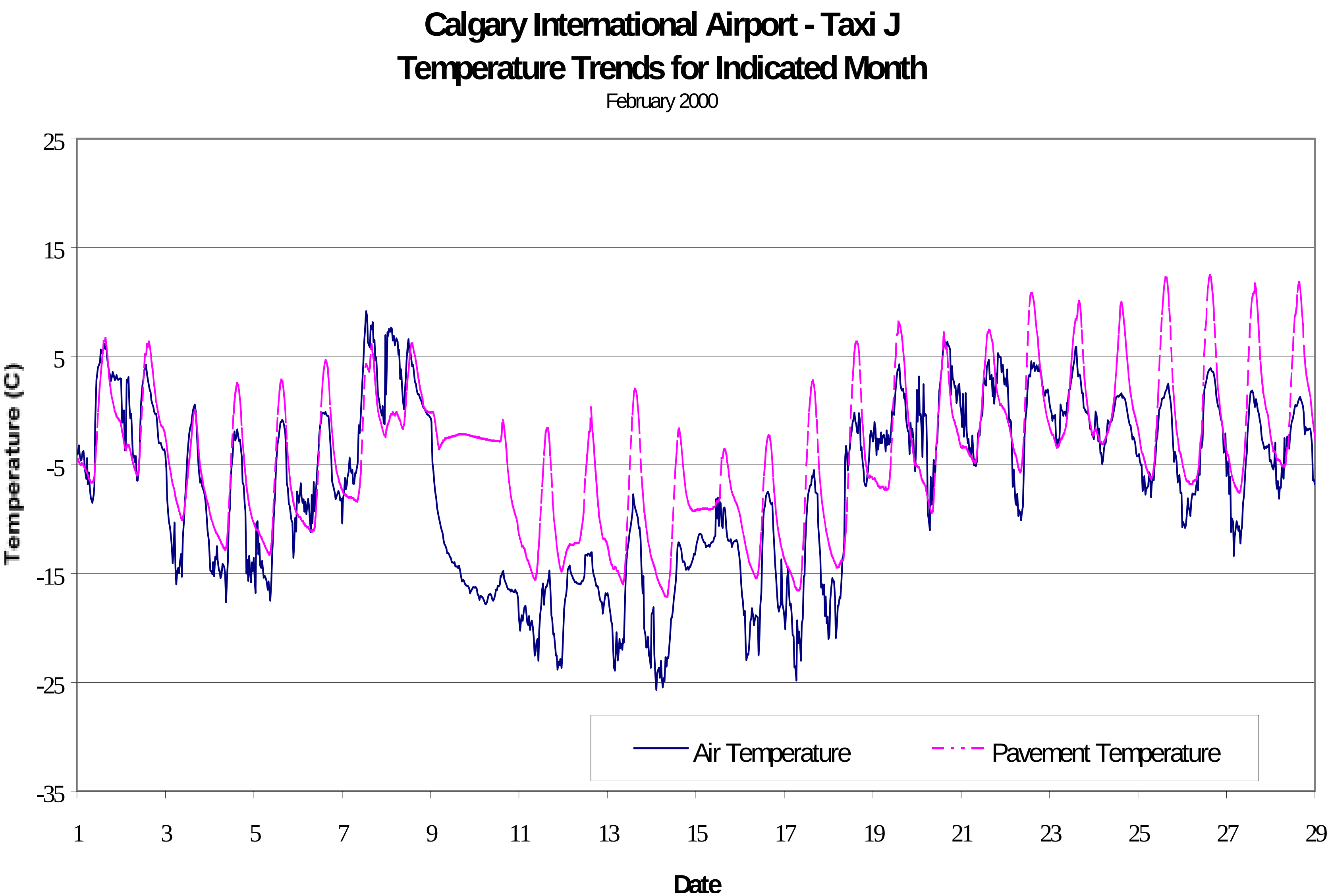


**Calgary International Airport - Taxi J**
**Temperature Trends for Indicated Month**
December 1999



**Calgary International Airport - Taxi J**
**Temperature Trends for Indicated Month**
January 2000




Calgary International Airport - Taxi J
Temperature Trends for Indicated Month
February 2000
Temperature (C)
25
15
5
-5
-15
-25
-35
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
Date
Air Temperature
Pavement Temperature