Environment Canada Imaging Cover Page

Report N.: *TEC-667*

SKP Box Number: 672572427

T.L.H.

CANADA

DEPARTMENT OF TRANSPORT

METEOROLOGICAL BRANCH

Technical Memoranda

AN EVALUATION OF BRUNT'S COOLING FORMULA FOR MINIMUM TEMPERATURE PREDICTION AT FIVE PRAIRIE LOCATIONS

BY

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U.D.C. 551·509·323

TEC. 667
JANUARY 26, 1968

CANADA - DEPARTMENT OF TRANSPORT - METEOROLOGICAL BRANCH
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AN EVALUATION OF BRUNT'S COOLING FORMULA FOR MINIMUM TEMPERATURE PREDICTION AT FIVE PRAIRIE LOCATIONS

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ABSTRACT

In this study, Brunt's equation for predicting the decrease in temperature with time after sunset is applied to the short-range prediction of minimum temperatures at five locations in Western Canada. These locations are Edmonton, Calgary, Saskatoon, Regina and Winnipeg. In order to apply Brunt's method it was initially necessary to evaluate the product of the soil density, specific heat and the square root of the coefficient of termal conductivity. This was done empirically. Minimum temperature predictions were then made using data for a two month period at each of the five locations. In performing these predictions, nights during which temperature advection occurred were excluded from the test. However, cloud cover was taken into account using a scheme suggested by Reuter. Mean absolute errors between predicted and observed minimum temperatures varied from 2.3 degrees at Edmonton and Regina to 3.0 degrees at Calgary and the R.M.S. deviations ranged from 2.9 degrees at Regina to 4.0 degrees at Calgary.

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ÉVALUATION DE LA FORMULE DE REFROIDISSEMENT DE BRUNT EN VUE DE LA PRÉDICTION DE LA TEMPÉRATURE MINIMALE À CINQ ENDROITS DES PRAITIES

par

N. H. Kagawa

RÉSUMÉ

Dans cette étude, l'auteur applique l'équation de Brunt pour prédire la baisse de la temperature correspondant au temps écoulé après le coucher du soleil à la prévision à brève échéance de la température minimale à cinq endroits de l'Ouest canadien, soit Edmonton, Calgary, Saskatoon, Régina et Winnipeg. Afin d'appliquer la méthode de Brunt, il a fallu en premier lieu évaluer le produit de la densité du sol, de la chaleur spécifique et de la racine carrée du coefficient de conductibilité thermique, ce qui fut fait empiriquement. Des prédictions de température minimale ont alors été faites au moyen de données portant sur une période de deux mois à chacun des cinq endroits. Dans ces predictions, les nuits durant lesquelles une advection de température s'etait produite ont été exclues de l'épreuve. Toutefois, on a tenu compte de la nébulosité en utilisant un schème proposé par Reuter. Des erreurs moyennes absolutes entre les températures minimales prédites et celles qui ont été observées varièrent entre 2.3 degrés, à Regina, et 4.0 degrés, à Calgary.

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1. Introduction

Theoretical methods based on physical principles, and also empirical methods have been developed and successfully applied to the prediction of minimum temperatures. Such methods are preferred to purely subjective estimates since the latter requires skill based upon a large amount of experience in forecasting for a particular area. This is especially true of temperature forecasting since significant temperature variations within a supposedly homogeneous airmass can occur as a result of differences in topography (drainage effects), vegetation, the proximity of lakes, etc.

This study was made to determine whether a formula developed by Brunt could be applied to the short-range prediction of minimum temperatures in the absence of advection. Whereas, most methods which are based on physical principles have limited use since they are applicable only to nights when skies are clear, an attempt was made in this study to account for cooling under cloudy conditions and, thereby, make the method of more general use.

2. Theory

The surface of the earth may be considered as a boundary layer of zero thickness between the atmosphere and earth. Because it has zero thickness, its heat capacity is also zero. The local heat budget, neglecting horizontal fluxes of heat (advection) is shown schematically in Figure 1.

The equation for the local heat budget may be written as,

$$E(o) + S(o) + L(o) + B(o) + W(o) = 0 \qquad (1)$$

In this equation, the subscript (o) refers to the level $Z = 0$, i. e. the surface of the earth and,

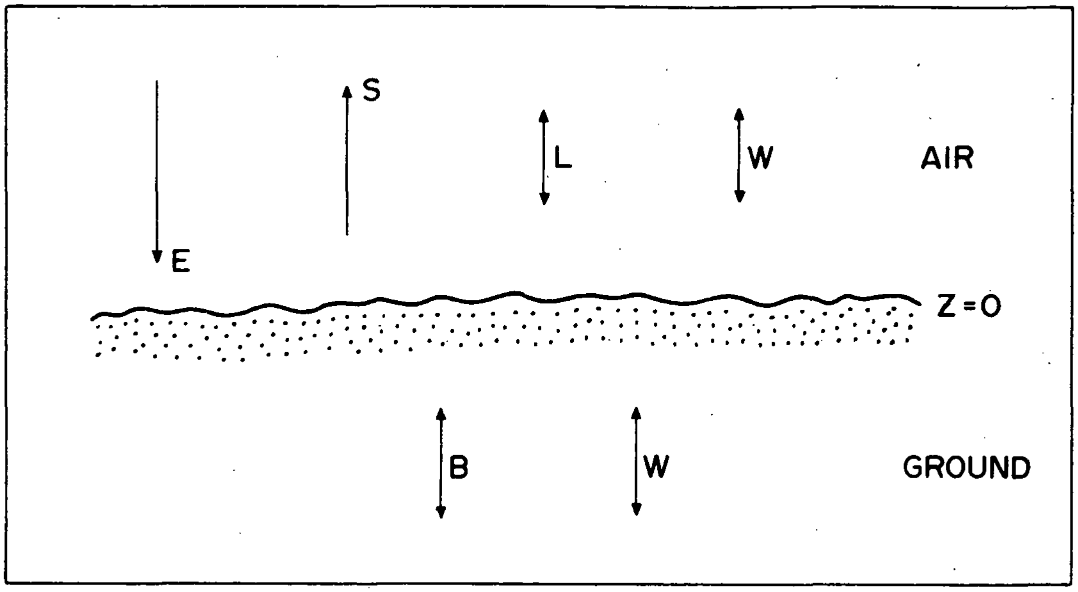


Figure I SCHEMATIC DIAGRAM ILLUSTRATING THE LOCAL HEAT BUDGET AT THE EARTH'S SURFACE NEGLECTING HORIZONTAL HEAT FLUXES

E = SHORT WAVE SOLAR RADIATION

S = LONG WAVE TERRESTRIAL RADIATION

L = SENSIBLE HEAT FLUX IN THE ATMOSPHERE AS A RESULT OF MOLECULAR AND TURBULENT DIFFUSION

B = HEAT FLUX IN THE GROUND DUE TO MOLECULAR CONDUCTION

W = HEAT FLUX IN THE ATMOSPHERE AND IN THE EARTH RESULTING FROM PHASE CHANGES OF WATER

E(o) = flux of incoming solar radiation (positive since it is directed toward the earth's surface).

S(o) = flux of outgoing terrestrial radiation (negative since it is directed away from the earth's surface).

L(o) = flux of sensible heat in the atmosphere as a result of molecular and turbulent diffusion. This term may be either positive or negative.

B(o) = flux of sensible heat in the ground due to molecular conduction. This term can also be positive or negative.

W(o) = sensible heat flux in the atmosphere and in the earth resulting from phase changes of water. This term can have either sign.

If the time period between sunset and sunrise only is considered, then E(o), the flux of heat from the sun is zero. Moreover, if it is assumed that (a) there is no condensation of water vapour or freezing of the ground and (b) winds are light such that heat diffusion in the atmosphere due to turbulence can be neglected, then W(o) and L(o) are also zero. The local heat budget equation then may be written in simplified form as:

$$|S(o)| = |B(o)| \qquad (2)$$

Equation (2) states that the emission of long-wave terrestrial radiation from the earth's surface must be balanced by the flux of heat upward from within the earth to its surface.

Brunt (1), has derived an equation to predict minimum overnight temperatures based on equation (2). His solution may be written as,

$$\Delta T \text{ (degrees C)} = \frac{2}{\sqrt{\pi}} \times \frac{S(o)}{\rho_s C_s \sqrt{K_s}} \times \sqrt{t} \qquad (3)$$

In equation (3),

ΔT = decrease in temperature from sunset to sunrise in ^{o}C.

t = time in hours between sunset and sunrise.

ρ_s = density of the ground.

C_s = specific heat of the ground.

K_s = coefficient of heat conductivity of the ground.

S(o) = flux of terrestrial radiation in cal cm^{-2} min^{-1}.

In Brunt's equation ρ_s, C_s, K_s depend on the type of soil and its moistness. If these soil parameters are considered constant for any particular location, then Brunt's equation can be expressed as,

$$\Delta T \text{ (degrees F)} = \frac{2}{\sqrt{\pi}} \times \frac{9}{5} \times C \times S(o) \times \sqrt{t}$$

$$= C \times S(o) \times 2.03 \sqrt{t} \qquad (4)$$

In equation (4),

ΔT = decrease in temperature from sunset to sunrise, now in degrees F.

$2.03 = 2/\sqrt{\pi} \quad \times 9/5$

$C = (\rho_s \, C_s \sqrt{K_s})^{-1}$

To solve equation (4), the three terms on the right side of the equation must be known or computed. "t" is easily found from sunrise and sunset tables and is a function of latitude only. The flux of terrestrial radiation S(o) in cal cm^{-2} min^{-1} can be computed using a formula derived empirically by Brunt. This formula which is applicable for clear skies is,

$$S(o)_o = \sigma T^4 (1 - a - b \sqrt{e}) \qquad (5)$$

Here σ = Stefan-Boltzman constant (0.136×10^{-11} cal cm^{-2} sec^{-1}).

T = absolute temperature of the earth's surface at sunset.

e = vapor pressure in millibars at sunset.

a = constant = 0.44.

b = constant - 0.08.

To account for the long-wave terrestrial radiation under cloudy conditions, a scheme suggested by Reuter (5) may be used. Under cloudy skies, this term will be less than under clear skies. To accomplish this, Reuter uses the equation,

$$S(o)_n = S(o)_o (1 - Kn) \qquad (6)$$

where,

$S(o)_n$ = flux of terrestrial radiation with n tenths of cloud

$S(o)_o$ = flux of terrestrial radiation with clear skies

K = constant depending on cloud type. K has a value 0.031, 0.063, 0.085 and 0.099 for cirrostratus, altostratus, stratus and nimbostratus respectively.

It remains, therefore, to determine C which is a characteristic of the soil. Since the density ρ_s, specific heat C_s, and the coefficient of thermal conductivity K_s of the soil are not usually known, C cannot be computed directly. However, it is possible to obtain a value for C statistically using past observational data. From these data ΔT, $S(o)$ and $\sqrt{t}$ can be determined and then C can be computed by a re-arrangement of equation (4), i.e.

$$C = \frac{\Delta T}{S(o) \times 2.03 \sqrt{t}} \qquad (7)$$

Once a value for C is found for a particular location, equation (4) can be applied directly to the prediction of a minimum temperature.

3. Determination of C

The soil characteristic term C was determined for the five locations of Calgary, Winnipeg, Edmonton, Saskatoon and Regina. These values are tabulated below.

Location	C	C^{-1} (cal/degrees cm^2 $sec^{1/2}$
Calgary	19	0.0526
Edmonton	15	0.0667
Winnipeg	16	0.0625
Saskatoon	17	0.0588
Regina	20	0.0500

The C values were found by applying equation (7) to cases selected from the hourly aviation weather reports for the period May - September, 1966. This time period was selected because the ground would not be snow covered. Ground which is snow covered would not radiate at the same rate as if it were bare because the density, specific heat and thermal conductivity terms which comprise C are different for the two surfaces. In addition, cases were selected from nights where skies were clear and temperature advection was negligible.

To simplify computations, Figures 2 and 3 were drawn. From Figure 2, $S(o)_o$ the flux of long wave terrestrial radiation under clear skies given by equation (5) may be found from the values of sunset temperature and dew point. Figure 3 shows the variation in the quantity $2.03\sqrt{t}$ with the time of year.

Values of C^{-1} or $(\rho_s C_s \sqrt{K_s})$ have been previously determined by Lettau (4) for various materials. His values were 0.0566 for concrete, 0.0358 for sandy clay with 15% moisture, 0.0194 for clayland pasture and 0.0140 for medium fine, dry, quartz sand. This comparison shows the C values determined here to be slightly lower than those computed by Lettau.

The values of C found using past observational data exhibited considerable scatter. However, when these values were grouped and a histogram drawn, a peak in the distribution was found. A value of C was, therefore, selected near where the distribution exhibited a maximum. The histogram for Saskatoon has been included (see Figure 4), to illustrate the manner in which a C value was selected at each of the five locations.

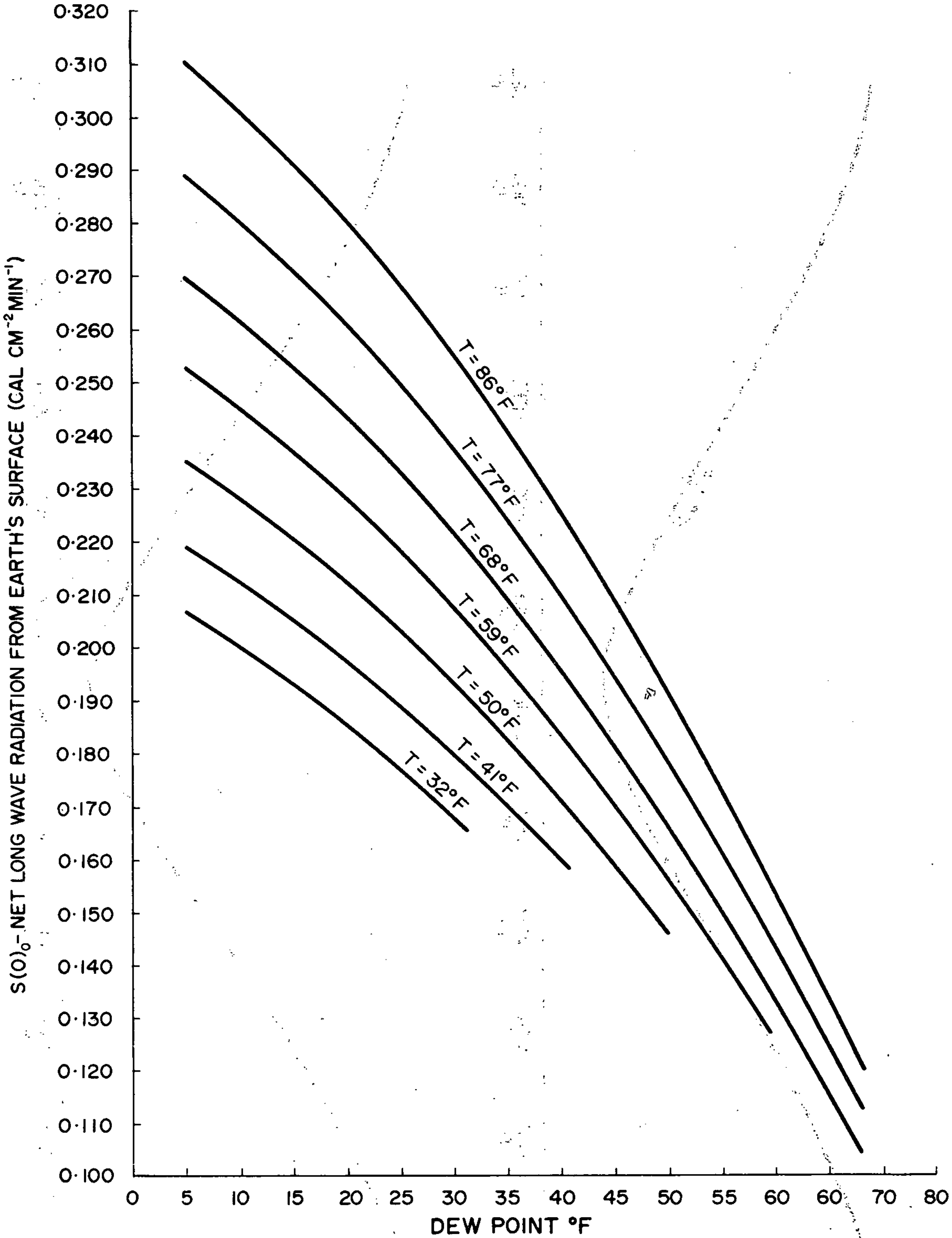
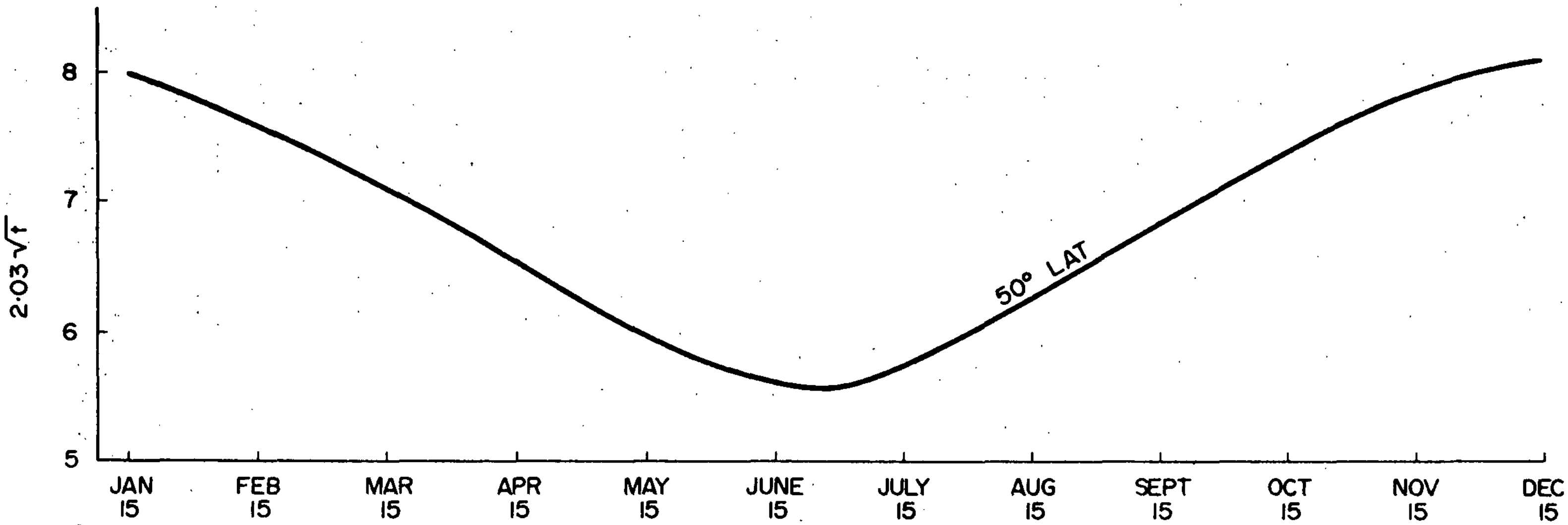


Figure 2 GRAPH TO FIND $S(O)_0$ THE NET LONG WAVE RADIATION FROM THE EARTH'S SURFACE FROM TEMPERATURE AND DEW PT. $S(O)=\sigma T^4(1-\cdot 44-\cdot 08\sqrt{e})$ (BRUNT'S EQUATION)



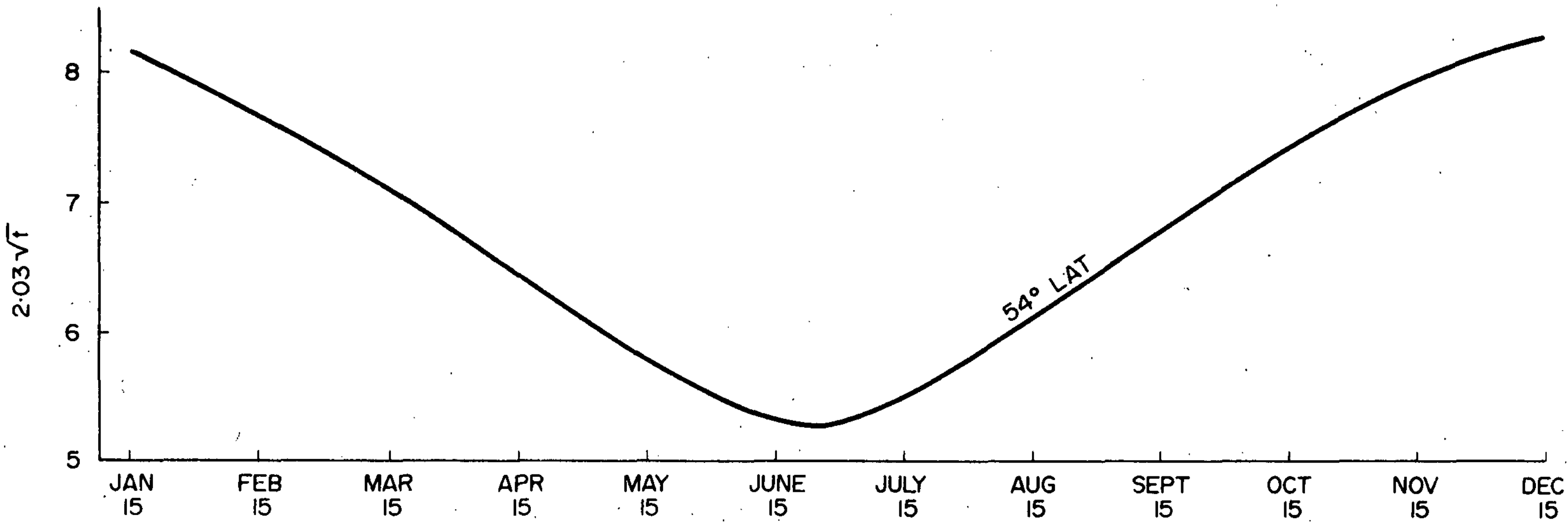


Figure 3 PLOT OF $2{\cdot}03\sqrt{t}$ vs. DATE FOR 50 DEGREES AND 54 DEGREES LATITUDE. "t" IS THE NUMBER OF HOURS BETWEEN SUNSET AND SUNRISE.

4. Experimental Results of Predictions

Using the values of C which were determined in the previous section, minimum temperature forecasts were made employing data for the two months of August and September, 1966. Minimum temperature predictions were made for nights during this period when the temperature advection was considered negligible. The decrease in temperature from sunset to sunrise was computed according to equation (4), i.e.

$$\Delta T = C \times S(o) \times 2.03 \sqrt{t}$$

In applying this equation, cloud cover was accounted for by reducing the value of S(o) for clear skies obtained from Figure 4. This reduction was performed using equation (6) which is rewritten below.

$$S(o)_n = S(o)_o \ (1 - kn)$$

The value of "K" was taken to be 0.063 for low and middle clouds whose bases were reported as 2500 feet or higher. For low clouds, the bases of which were reported at less than 2500 feet, a value of 0.085 was used. For this calculation, cirrus was neglected, i.e., long wave radiation form the earth's surface with high cloud present was taken to be the same as with clear skies.

The results of the predicted minimum temperatures were compared with the observed values and the results are tabulated below. The mean absolute error was computed as,

$$\bar{\varepsilon} = \frac{\sum |\text{observed min. temp. - predicted min. temp.}|}{n}$$

and the root-mean-square deviation was computed from the formula,

$$\text{RMS deviation} = \sqrt{\frac{\sum (\text{observed min. temp. - predicted min. temp.})^2}{n}}$$

Location	No. of Cases n	Mean ABS Error $\bar{\varepsilon}$	RMS Deviation
Calgary	43	3.0	4.0
Edmonton	37	2.3	3.1
Winnipeg	36	2.9	3.7
Saskatoon	36	2.7	3.3
Regina	29	2.3	2.9

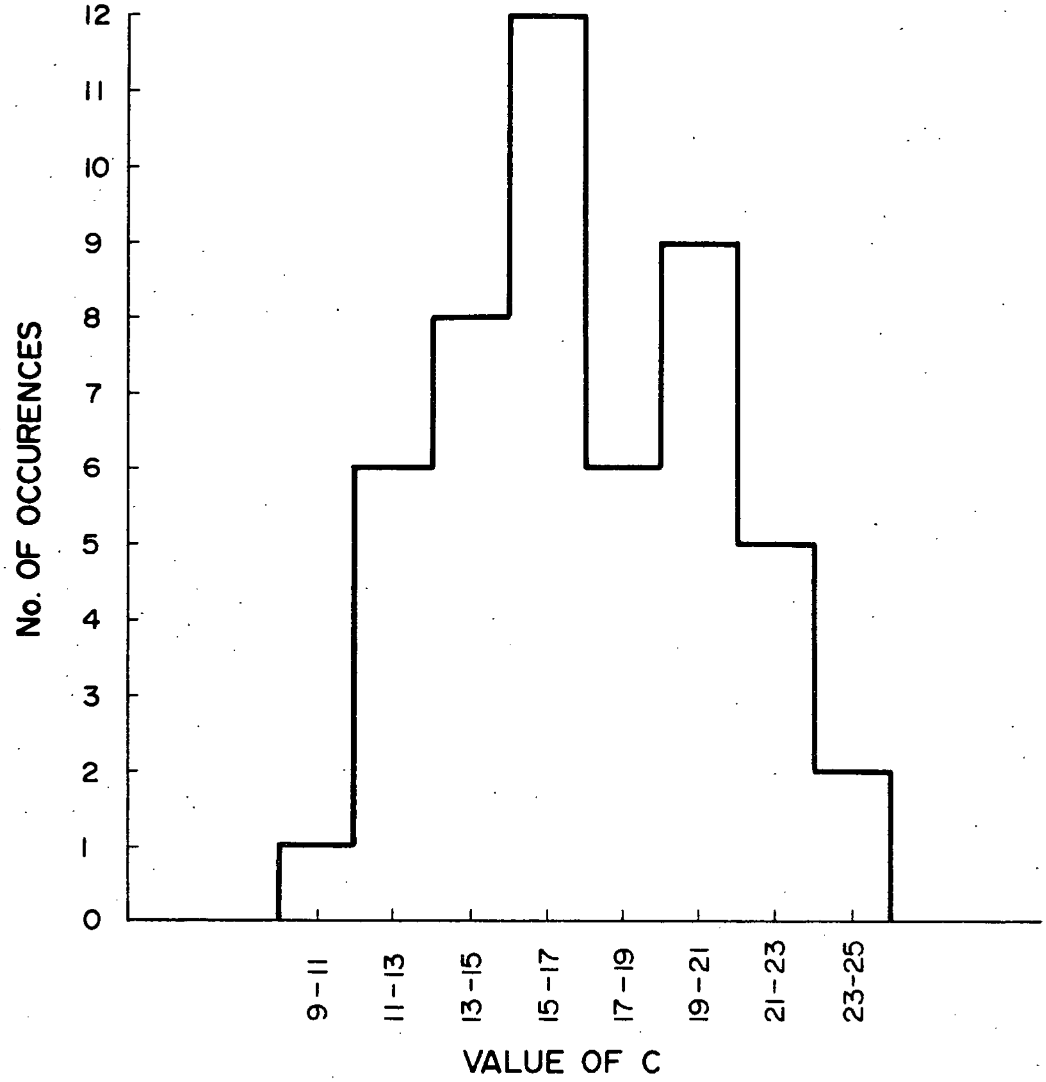


Figure 4 HISTOGRAM SHOWING SCATTER OF COMPUTED VALUES OF C FOR SASKATOON. A SINGLE VALUE OF C WAS SELECTED NEAR THE PEAK IN THE HISTOGRAM.

5. Summary

The results of the previous section show that useful forecasts are possible using Brunt's formula. This method has the advantage that (a) it is based on physical principles, (b) it is direct and can be easily and rapidly performed by the forecaster at his desk, (c) it can be applied more generally than previously developed theoretical methods which were restricted to use on nights when skies were clear, and (d) the method is quite general and can be applied at any location once a value of C has been determined for that site.

This technique is likely to yield poor results on nights when there is strong temperature advection. However, it is still useful since it will give a value from which one can adjust his forecast to account for the advection. For example, one can compute the minimum temperature as if there were no advection and then adjust this value upward or downward according to whether there is warm or cold advection respectively.

The application of this method requires that the average cloud cover in tenths of the sky between sunset and sunrise, the sunset temperature and the sunset dew point be predicted if the method is applied prior to sunrise. However, this should not be a serious disadvantage since many useful methods in meteorology use predicted input data.

An appendix has been included at the end of this paper to illustrate the manner in which computations are made using this method.

APPROVED,

J. R. H. Noble,
Director,
Meteorological Branch.

6. References

(1) Brunt, D., 1941: Physical and Dynamical Meteorology, Cambridge University Press, London.

(2) Dickey, Woodrow, J., 1960: U. S. Dept. of Commerce, Weather Bureau, Forecasting Guide No. 4, Forecasting Maximum and Minimum Temperatures, Washington, D. C.

(3) Johnson, J. C., 1954: Physical Meteorology, The Technology Press of M. I. T. and John Wiley and Sons, Inc., New York and London.

(4) Lettau, H., 1951: Trans. A. G. U., Vol. 32, p. 189.

(5) Reuter, H., 1950: Calculation of Minimum Temperatures and the Prediction of Ground Frost. CIR-1768, TEC-70, Meteorological Branch, Dept. of Transport, Canada.

(6) Reuter, H., 1951: Forecasting Minimum Temperatures. Tellus 3, p. 141-147.

APPENDIX

To illustrate the manner in which minimum temperature forecasts are made by this method, consider the synoptic situation for 0000Z June 13, 1967 shown in Figure 5. Examination of this chart snows a very weak pressure gradient across the Prairie provinces and, therefore, temperature advection can be considered negligible. If this is the case, then the method for predicting minimum temperature described in this paper can be expected to give acceptable results. Computations are made below for the five locations for which C values were determined. Input information for these calculations were taken from the hourly aviation weather reports for the period just prior to sunset on June 12, 1967 to just after sunset on June 13, 1967. These weather reports have been reproduced at the end of this section.

MINIMUM TEMPERATURE COMPUTATION AT CALGARY, ALBERTA

REQUIRED DATA

1. Sunset temperature and dew point = 54/36.

2. Average cloud amount in tenths between sunset and sunrise = 2/10ths with bases greater than 2500 ft.

PROCEDURE

1. Compute the net long-wave terrestrial radiation under clear skies $S(o)_o$, by entering Figure 2 with the values of the sunset temperature and dew point. Find $S(o)_o = 0.186$ cal cm^{-2} min^{-1}.

2. Reduce the net loss of long-wave terrestrial radiation under clear skies by accounting for cloud cover through the equation $S(o)_n = S(o)_o (1 - Kn)$. The value K = 0.063 is applicable for clouds with bases higher than 2500 feet with the exception of cirrus cloud which can be ignored. For clouds with bases below 2500 feet, K = 0.085 may be used. In this example,

$$S(o)_n = 0.186\ (1 - 0.063 \times 2) = 0.163 \text{ cal cm}^{-2} \text{ min}^{-1}$$

3. Find the value of $2.03\sqrt{t}$ by entering Figure 3 with the date and the latitude of the station.

$$2.03\sqrt{t} = 5.6$$

4. Compute ΔT, the change in temperature from sunset to sunrise.

$$\Delta T = C \times S(o)_n \times 2.03\sqrt{t} = 19 \times 0.163 \times 5.6 = 17 \text{ degrees F}$$

5. Compute T min. = Sunset temperature - ΔT

$$= 54 - 17 = 37 \text{ degrees F}$$

The actual minimum temperature reported on this date was 34 degrees F.

MINIMUM TEMPERATURE COMPUTATION AT EDMONTON, ALBERTA

REQUIRED DATA

1. Sunset temperature and dew point = 58/42
2. Cloud cover between sunset and sunrise = 0

PROCEDURE

1. $S(o)_o = 0.177$
2. $S(o)_n = S(o)_o$ since there is no cloud cover
3. $2.03\sqrt{t} = 5.35$
4. $\Delta T = C \times S(o)_n \times 2.03\sqrt{t}$

$$= 15 \times 0.177 \times 5.35 = 14 \text{ degrees F}$$

5. T min. = 58 - 14 = 44 degrees F

The reported minimum temperature at Edmonton (XD) on this date was 44 degrees F, the same as was predicted above.

MINIMUM TEMPERATURE COMPUTATION AT SASKATOON, SASKATCHEWAN

REQUIRED DATA

1. Sunset temperature and dew point = 57/48

2. Cloud cover between sunset and sunrise = 9/10ths of cloud with bases higher than 2500 feet.

PROCEDURE

1. $S(o)_o = 0.160$

2. $S(o)_n = 0.160\ (1 - 0.063 \times 9) = 0.069$

3. $2.03 \sqrt{t} = 5.5$

4. $\Delta T \doteq C \times S(o)_n \times 2.03 \sqrt{t}$

$= 17 \times 0.069 \times 5.5 = 6$ degrees F

5. T min. = 57 - 6 = 51 degrees F

The actual reported minimum temperature at Saskatoon on this date was also 51 degrees F.

MINIMUM TEMPERATURE COMPUTATION AT REGINA, SASKATCHEWAN

REQUIRED DATA

1. Sunset temperature and dew point 55/53

2. Cloud cover between sunset and sunrise = 10/10ths of low cloud with bases lower than 2500 feet.

PROCEDURE

1. $S(o)_o = 0.142$

2. $S(o)_n = 0.142\ (1 - 0.085 \times 10) = 0.021$

3. $2.03\sqrt{t} = 5.65$

4. $\Delta T = C \times S(o)_n \times 2.03\sqrt{t}$

   $= 20 \times 0.021 \times 5.65 = 2$ degrees F

5. T min. = 55 - 2 = 53 degrees F

The reported minimum temperature at Regina was 51 degrees F.

MINIMUM TEMPERATURE COMPUTATION AT WINNIPEG, MANITOBA

REQUIRED DATA

1. Sunset temperature and dew point = 55/54

2. Cloud cover between sunset and sunrise = 10/10ths of cloud with bases lower than 2500 feet.

PROCEDURE

1. $S(o)_o = 0.139$

2. $S(o)_n = 0.139 (1 - .085 \times 10) = 0.021$

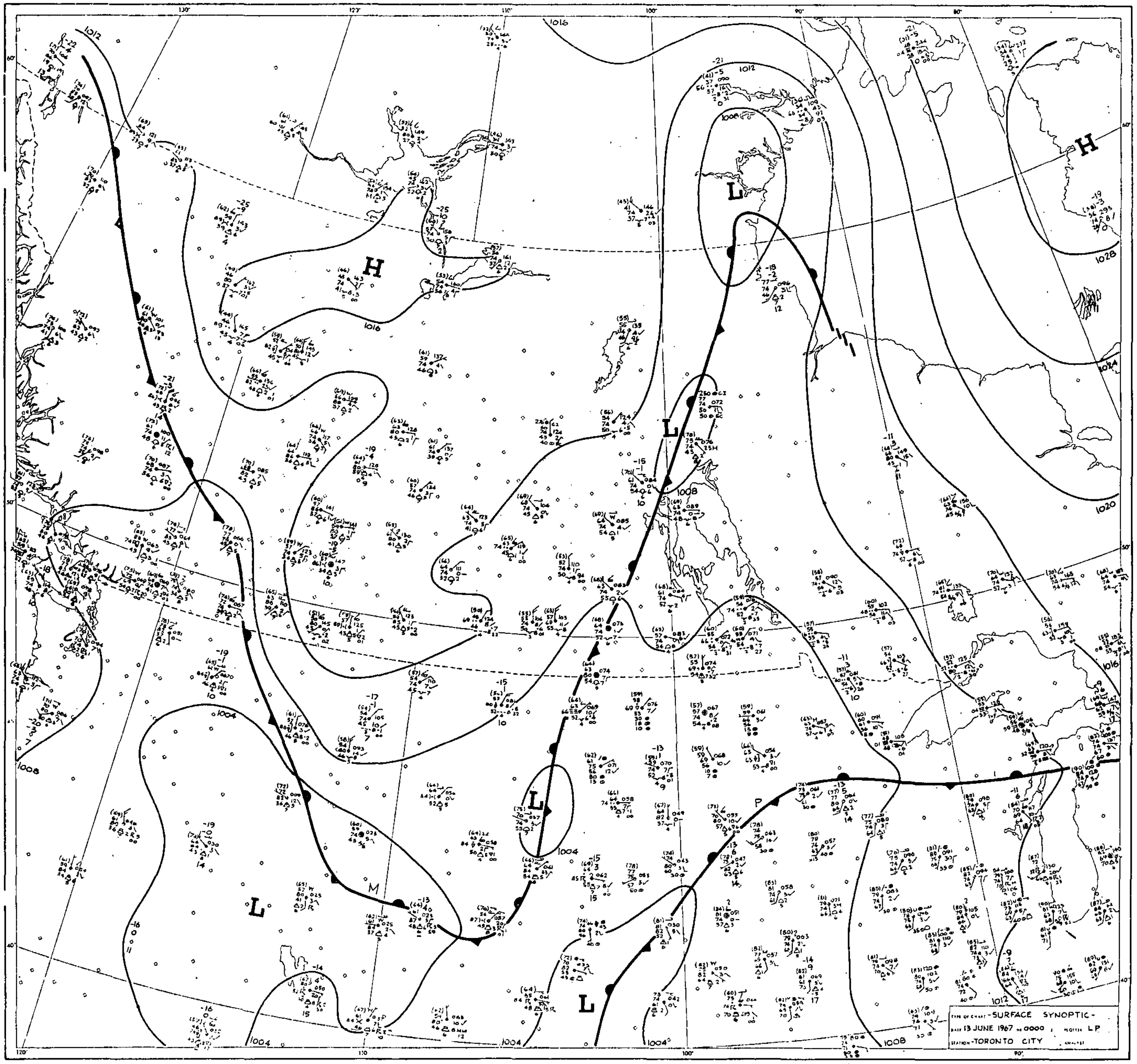
3. $2.03\sqrt{t} = 5.65$

4. $\Delta T = C \times S(o)_n \times 2.03\sqrt{t}$

   $= 16 \times .021 \times 5.65 = 2$ degrees F

5. T min. = 55 - 2 = 53 degrees F

The reported minimum temperature at Regina on this date was also 53 degrees F.


TYPE OF CHART -SURFACE SYNOPTIC-
DATE 13 JUNE 1967 TIME 0000 PLOTTER LP
STATION -TORONTO CITY ANALYST
H
L
1004
1008
1012
1016
1020
1024
1028

WEATHER REPORTS FOR CALGARY, ALBERTA - JUNE 12-13, 1967

0200 GMT	50ΦE90Φ40	147/56/33/2704/987/CU+3AC5
0300 GMT	60Φ100-Φ300-Φ40	139/55/35/0000/988/CU+1AC3CI
0400 GMT	60Φ90-Φ300-Φ40	142/53/36/0000/989/SC1AC4CI
0500 GMT	60Φ90-Φ300-Φ40	144/52/35/0000/990/SC2AC4CI
0600 GMT	60Φ300-Φ40	147/48/37/0000/990/SC1CI
0700 GMT	300-Φ40	149/41/ 36/3102/991/CI1
0800 GMT	300-Φ40	150/39/36/3407/991/CI1
0900 GMT	300-Φ40	153/38/36/0000/991/CI
1000 GMT	80Φ300-Φ40	152/37/36/3407/990/ACC1CI
1100 GMT	80Φ300-Φ40	152/36/35/3104/990/ACC1CI
1200 GMT	80Φ300-Φ40	161/35/32/3605/992/ACC1CI
1300 GMT	90Φ40	164/38/33/0000/993/ACC1

Sunset = 0344 GMT Sunrise = 1126 GMT

WEATHER REPORTS FOR EDMONTON, ALBERTA (XD) - JUNE 12-13, 1967

0200 GMT	50Φ100Φ15+	127/61/41/0913/CU1AC1
0300 GMT	50Φ100Φ15+	126/60/41/1312/987/CU1AC1
0400 GMT	100Φ300Φ15+	129/58/42/1512/989/AC1CI1
0500 GMT	80Φ300-Φ15+	131/58/41/1507/989/AC1CI1
0600 GMT	300-Φ15+	137/53/41/1605/990/CI
0700 GMT	300-Φ15+	139/51/41/1707/991/CI1
0800 GMT	300Φ15+	139/50/41/1804/991/CI1
0900 GMT	300Φ15+	140/48/41/1905/991/CI1
1000 GMT	100Φ300Φ15+	141/47/ 41/1804/992/AC1CI1
1100 GMT	100Φ300Φ15+	142/44/39/2005/992/AC1CI1
1200 GMT	100Φ300Φ15+	147/44/40/2102/993/AC1CI1
1300 GMT	120Φ300Φ15+	150/46/41/2204/994/AC1CI1

Sunset = 0405 GMT Sunrise = 1101 GMT

WEATHER REPORTS FOR SASKATOON - JUNE 12-13, 1967

0200 GMT	45Φ70ΦE80Φ15	121/61/44/0306/983/SC1AC1AC7
0300 GMT	40Φ70ΦE90Φ15	120/58/49/3107/984/SC1ACC1AC7
0400 GMT	40Φ70ΦE90Φ15	120/57/48/3506/984/SC2AC1AC6
0500 GMT	40ΦE90Φ15	122/57/48/3610/984/SC2AC7
0600 GMT	40ΦM130Φ15	129/57/48/0000/985/SC2AC7
0700 GMT	30ΦE120⊕15R--	134/56/48/2804/987/SC5AC5
0800 GMT	30ΦM6⊕15R--	134/53/49/3004/987/SC3SC7
0900 GMT	E50⊕15R-	136/52/49/3205/988/SC10
1000 GMT	25ΦE50⊕12R-	137/51/50/3603/988/SC4SC6
1100 GMT	25ΦE50Φ100Φ15	137/52/50/0709/988/SC1SC6AC2
1200 GMT	120Φ40ΦE80Φ250⊕15	135/53/51/0904/988/SF1SC2ACC6CI

Sunset = 0327 GMT Sunrise = 1045 GMT

WEATHER REPORTS FOR REGINA, SASKATCHEWAN - JUNE 12-13, 1967

0200 GMT	B9⊕12	110/56/54/3616/981/SC10
0300 GMT	A10⊕15	115/55/53/3412/981/SC10
0400 GMT	M10⊕15	115/54/52/3612/981/SC10
0500 GMT	M7⊕15	120/54/52/3308/983/SC10
0600 GMT	M6⊕15	124/53/51/3508/984/ST10
0700 GMT	M5⊕8	125/52/51/3306/984/ST10
0800 GMT	M3⊕8	125/52/51/3305/984/ST10
0900 GMT	M2⊕7	126/52/51/3208/984/ST10
1000 GMT	M2⊕8	129/52/51/3108/986/ST10
1100 GMT	B3⊕8	128/52/51/3310/985/ST10
1200 GMT	B4⦶40⊕10	129/52/51/3409/986/ST9SC1
1300 GMT	B4⊕8	138/52/51/3308/988/ST10

Sunset = 0306 GMT Sunrise = 1049 GMT

WEATHER REPORTS FOR WINNIPEG, MANITOBA - JUNE 12-13, 1967

0200 GMT	M7⦶20⊕4L--F	069/55/54/0109/SF9SC1
0300 GMT	M4⊕5L--F	069/55/54/0106/971/SF10
0400 GMT	M3⊕7L--	073/54/53/3407/972/ST10
0500 GMT	1⦶M2⦶12⊕11/2L-F	080/54/53/3004/974/SF2SF5SC3
0600 GMT	2-⦶M4⦶6⊕21/2L-F	081/54/53/2906/974/SF2SF4SC4
0700 GMT	M3⦶6⦶18⊕6F	073/54/53/2908/975/SF6SF2SC2
0800 GMT	3⦶14⦶M38⊕12	085/53/53/2706/975/SF3SF2SC5
0900 GMT	M2⦶70⊕12	085/53/52/2707/975/SF8AC2
1000 GMT	3⦶M9⦶20⊕12	085/54/53/2908/975/SF3SF5SC2
1100 GMT	E9⦶14⦶37⊕8	095/54/53/2605/978/SF6SC1SC2
1200 GMT	7⦶M28⦶38⊕10	104/55/54/2507/981/SF1SC5SC3
1300 GMT	2⦶M21⦶38⊕12	111/56/54/2307/983/SF3SC4SC3

Sunset = 0237 GMT Sunrise = 1019 GMT

WORK SHEET FOR MINIMUM TEMPERATURE COMPUTATIONS

REQUIRED DATA

Station Latitude ________________
Sunset Temperature ________________
Sunset Dew-Point ________________
Estimated Average Cloud Amount in Tenths Between Sunset and Sunrise n = ________________

PROCEDURE

1. Calculate $S(o)_o$

   Enter Figure 2 with the sunset temperature and dew-point.

   $$S(o)_o = \_\_\_\_\_\_\_\_\_\_\_\_ \text{ cal cm}^{-2} \text{ min}^{-1}$$

2. Calculate $S(o)_n$

   For cloud bases below 2500 feet use K = 0.085
   For cloud bases at or above 2500 feet use K = 0.063

   $$S(o)_n = S(o)_o (1 - Kn)$$

   = ________________ (1 - ________ x ________)

   = ________________ cal cm^{-2} min^{-1}

3. Calculate $2.03 \sqrt{t}$

   Enter Figure 3 with date and station latitude.

   $2.03 \sqrt{t}$ = ________________

4. Compute ΔT

   $$\Delta T = C \times S(o)_n \times 2.03 \sqrt{t}$$

   = ________ x ________ x ________

   = ________ degrees F

5. Compute T min

   T min = Sunset temperature - ΔT

   = ________ - ________

   = ________ degrees F

6. Actual Minimum Temperature = ________ degrees F.

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26 January 1968

CANADA

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315 Bloor St., W., - Toronto 5, Ontario

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15 pps. 5 figs. 6 refs.

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3. Edmonton.
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