ENERGY EXCHANGE AT ATMOSPHERE - EARTH INTERFACE

by

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ABSTRACT

Engineering construction in cold regions is greatly effected by the environment. The type of structure, its design, its erection and its operation and maintenance are all influenced by the surrounding meteorological conditions. Another consideration is of course the site on which the construction is to be erected. Before construction one has to determine, above others, how deep the soil below the surface is frozen and this requires heat transfer analysis on that particular site.

In this thesis heat flux for thirty-two sites are considered. These sites are chosen since their n-factors and soil properties are known experimentally. With weather data like air-temperature, dew-point temperature, cloud cover and wind speed supplied by the United States National Oceanic and Atmospheric Administration (NOAA), it is possible to calculate the net shortwave and longwave radiation, and the convective heat flux at the surface. For two of the sites; Fairbanks, Alaska and Boston, Massachussetts, data on radiation are available and they can be used to check the accuracy of the results obtained using the existing equations. For these two sites empirical relationships on the effect of cloud cover on shortwave and longwave radiation can also be obtained.

With the calculation of seasonal heat fluxes and the known soil properties it is possible to calculate the air and surface indexes,

the n-factor, and finally by using appropriate parameters, obtain an empirical relationship between the surface and the air indexes. It will also be seen how close the calculated results agree with the theory.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

NOMENCLATURE

Symbol	Meaning	Unit
a'	attenuation due to scattering only	dimensionless
a"	attenuation due to scattering and absorption	"
c_f	specific heat of the frozen layer of the soil	Btu/lb-F, cal/gm-C
c_p	specific heat at constant pressure	"
c_u	specific heat of the unfrozen layer of the soil	"
d	atmospheric dust attenuation for a specific location	dimensionless
e_o	atmospheric water vapour pressure	mb
f	ratio of the net shortwave radiation with clouds to the global clear sky radiation	dimensionless
g	earth's gravitational acceleration	ft/sec^2
h	convective heat transfer coefficient at the surface	Btu/ft^2-day-F
h'	convective heat transfer coefficient at the upper surface of the contact layer	"
i_b	black-body radiation for all wavelengths	Btu/ft^2-day, langleys/day
$i_{b,\lambda}$	black-body monochromatic radiation	"
k_f	thermal conductivity of the soil during the freeze season	Btu/ft-day-F
k_t	thermal conductivity of the soil during the thaw season	"
k_o	Von-Karman's constant	dimensionless
m	average daily optical air mass	"

NOMENCLATURE (cont'd)

Symbol	Meaning	Unit
n	n - factor	dimensionless
q_s	surface heat flux with the exception of convection	Btu/ft^2-day, langleys/day
q_T	total heat flux at the surface of the soil	"
r	radius of the sun	6.965×10^{10} cm
r_i	instantaneous distance of the sun from the earth	cm
r_m	mean distance of the sun from the earth	"
u	wind speed	knots, mph
u_*	friction velocity	mph
w	precipitable atmospheric water vapour	cm.
w'	fluctuation of velocity in the vertical direction	ft/sec
z	height	ft, cm

NOMENCLATURE (cont'd)

Symbol	Meaning	Unit
A	area	ft^2, cm^2
C_e	mean 24-hour average fraction of sky covered by clouds	dimensionless
C_s	mean daylight fraction of sky covered by clouds	"
D	date according to Julian calender (i.e. days numbered from Dec. 31)	days
E_e	radiation emitted by the earth's surface	Btu/ft^2-day, langleys/day
E_s	radiation emitted towards the earth by the atmosphere	"
H	hour angle	degrees
H_{sr}	hour angle at sunrise	"
I_a	air index	F-days
I_{as}	air index based on phase change season of the soil surface	"
I_e	effective temperature index	"
I_s	surface index	"
L_e	effective latent heat of the soil	Btu/ft^3
L	Monin - Obukhov length	ft
M	$= (k \times L_e) / h^2$	F-days
P	$= I_e$, the effective temperature index	"
Q_B	reflected shortwave radiation backcsattered to the surface	Btu/ft^2-day, langleys/day
Q_{BC}	consumption of energy due to biochemical processes	"

NOMENCLATURE (cont'd)

Symbol	Meaning	Unit
Q_E	energy flux due to evapo-transpiration	Btu/ft^2-day, langleys/day
Q_G	conductive transfer of heat through the ground	"
Q_H	convective heat flux at the surface	"
Q_N	net all-wave radiation at the surface	"
Q_{RE}	shortwave radiation reflected from the surface	"
Q_T	clear sky shortwave radiation; the total global radiation	"
Q_{TC}	part of Q_T that reaches the surface after going through cloud cover	"
R	longwave radiation loss from the surface for a cloudless atmosphere	"
R_c	net longwave radiation loss with the presence of clouds in the atmosphere	"
R_i	gradient Richardson number	dimensionless
R_f	flux Richardson number	"
S	fraction of possible sunshine	"
S_i	instantaneous solar constant	langleys/day
S_m	mean solar constant	"
S_D	daily direct solar radiation	"
T_a	air temperature	F, C
T_{as}	mean air temperature based on phase change season of the surface temperature	"

NOMENCLATURE (cont'd)

Symbol	Meaning	Unit
T_{dp}	dew point temperature	F, C
T_f	phase change temperature	"
T_o	mean temperature of the ground	"
T_s	surface temperature	"
Z_0	roughness height	ft, cm
Z_1	weather observation reference height	"

NOMENCLATURE (cont'd)

Symbol	Meaning	Unit
α	thermal diffusivity	ft^2/hr
α_e	longwave absorptivity for the surface	dimensionless
α_s	solar albedo for surface	"
β	stability parameter	"
Γ	adiabatic lapse rate	F/ft
δ	angle of solar declination	degrees
ϵ	depth of thaw or freeze	ft, cm
ϵ_a	effective emissivity of the atmosphere	dimensionless
ϵ_e	longwave emissivity of the surface	"
γ	unit weight of the soil	lb/ft^3
λ	wavelength of short and longwave radiation	cm, micron
μ	absolute viscosity of air	lb/hr-ft
ν	kinematic viscosity of air	ft^2/hr
ω	solid angle	dimensionless
ϕ	angle of latitude, north	degrees
Π_1	dimensionless parameter for the surface index	dimensionless
Π_2	dimensionless parameter for the effective (air) index	"
ρ	density of air	lb/ft^3
ρ'	fluctuations of the density of air	"
σ	Stefan - Boltzman constant	1.805×10^{12} watt/ $cm^2\ K^4$

NOMENCLATURE (cont'd)

Symbol	Meaning	Unit
θ	time	hr, day
θ_a	length of the phase change season based on air temperature	days
θ_s	length of the phase change season based on surface temperature	"
τ_a	transmission coefficient	dimensionless
ψ	zenith angle; the angle between the earth's surface normal and the sun's direction	degrees

CHAPTER 1

INTRODUCTION

Often, for construction purposes, one is interested in predicting the depth of thaw or freeze for a particular site and this requires the surface temperature history of the site to be known, as well as the characteristics of the surface and soil system itself. But unfortunately, surface temperature measurements are seldom taken at most meteorological stations, and the surface temperature is therefore evaluated by other means.

One method of predicting the depth of phase change is to determine the components of heat balance at the surface. To do this it is necessary to have a knowledge of the processes of solar and atmospheric radiation, the distribution of wind and temperature of the atmosphere, and the properties of the soil at and below the surface. The calculations for the short and longwave radiation requires the following weather data; daily air temperature, daily dew point temperature, average daily cloud cover and average cloud cover during the daylight hours. The theory of n - factor is introduced to predict the surface temperature and the depth of phase change of the soil.

1.1 The N - Factor

The parameter used to relate the surface temperature to the known air temperature is the n - factor which is defined as

$$n = \frac{\text{surface index}}{\text{air index}} = \frac{I_s}{I_a} \qquad (1)$$

The surface and the air indexes are further defined as follows

$$I_s = \int_0^{\theta_s} (T_s - T_f)\, d\theta \qquad (2)$$

$$I_a = \int_0^{\theta_a} (T_a - T_f)\, d\theta \qquad (3)$$

where

T_s - average daily surface temperature
T_a - average daily air temperature
T_f - phase change temperature (= 32 ^{o}F)
θ_s - length of the surface temperature season
θ_a - length of the air temperature season

Equations 2 and 3 are written for a thaw season, but they are valid for freeze by using ($T_f - T_s$) and ($T_f - T_a$), respectively. In a thaw season θ_s is the period during which the surface temperature increases from the phase change point and then eventually falls back to that temperature. θ_a is the period during which the air temperature increases from the phase change point and decrease again to that temperature. For a thaw season therefore, θ_s is usually several days longer than θ_a whereas for a freeze season, the opposite is true.

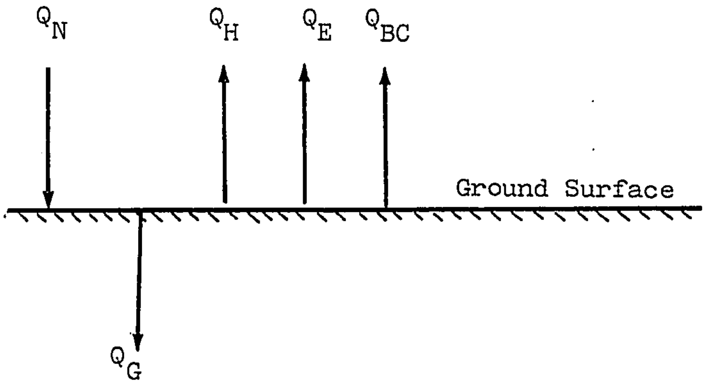
Since the value of n depends directly upon the surface temperature, any calculation of n is simply a calculation or prediction of the surface temperature, which is a function of the total heat transfer at the surface. Due to the changing meteorological conditions it is possible to have different n - values at different times even for the same site. Such range of values makes it very difficult to use the value or values of n found in the literature to determine the surface temperature or to predict the depth of thaw or freeze for a site, unless the actual site is used and the meteorological conditions are constant.

However, from the available weather data various parameters can be calculated and they can be correlated in such a way as to allow the n - factor to be estimated. This is the essential part of the thesis and it will be seen later how well, by using the available weather data and the known physical properties of the surface or soil, the calculated quantities using the site data fit the theory to be described in the following sections.

1.2 Energy Components at the Surface Layer

The energy balance at the surface layer of the soil can be idealised as follows

$$Q_N + Q_G - Q_H - Q_E - Q_{BC} = 0 \tag{4}$$



where

Q_N - net radiation received by the surface
Q_G - heat flux through the ground
Q_H - convective heat flux at the surface
Q_E - evapo-transpiration energy flux
Q_{BC} - consumption of energy due to biochemical and other processes

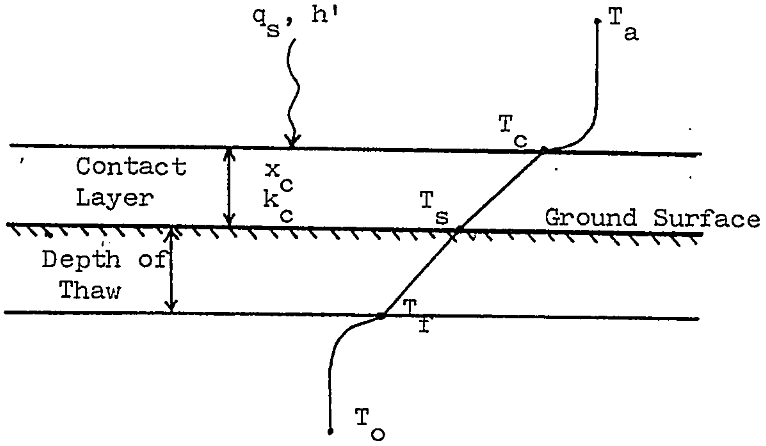
In Equation 4, components carrying heat toward the surface are positive, those carrying heat away from the surface are negative. Components like Q_N and Q_H may also flow in the opposite direction. Some of these components may be zero while others are made up of a number of other terms. Q_N, Q_H and Q_E, under natural conditions are more predominant than the other components. Evapo-transpiration, Q_E which is a heat loss, is often neglected when energy balances over paved surfaces are being considered. Photosynthesis, etc., Q_{BC} is neglected because no vegetation grows on slabs or pavements. Condensation which is always a heat gain is eliminated by assuming that energy added by condensation is lost again when the condensate evaporates. Q_G is small compared to Q_N or Q_H and its evaluation is imprecise due to the relative magnitude and uncertainty of the term.

N - factor data were obtained for numerous sites such as Ontario, Alaska, West Virginia, etc., and for most of these sites pavement surfaces are of interest for construction purposes. Table A1 (Appendix A) shows the phase change period and the geographical location of each of the sites considered in this work. These sites are studied because the n - factor data and the soil properties are known, and the surfaces are either asphalt or concrete surfaces, Table A2.

Since the surface types of the sites considered in this work are all paved surfaces, the only major energy components at the surface are therefore the radiation and convection. These components will therefore be analysed in fuller detail in the following chapters. Knowing the major energy components at the surface, the energy balance can be studied.

1.3 The Soil System

The basic problem of energy flow at the earth's surface with phase change may be visualised as shown in the diagram below for thawing



where

T_o - mean annual ground temperature

T_f - phase change temperature

T_s - surface temperature

T_a - air temperature

T_c - temperature above the contact layer

h' - surface coefficient at the surface of the contact layer

q_s - surface heat flux except for convection

The contact layer is simply a layer of snow, vegetation or any substance that separates the soil surface from the atmosphere. The upper surface of the contact layer has the temperature T_c

and surface coefficient h'. The thermal resistance of the air and the contact layer is therefore

$$h = \frac{1}{\frac{1}{h'} + \frac{x_c}{k_c}} \qquad (5)$$

The total heat flux at the upper surface of the contact layer is

$$q_T = q_s + h' (T_a - T_c) \qquad (6)$$

If the effective temperature is defined such that

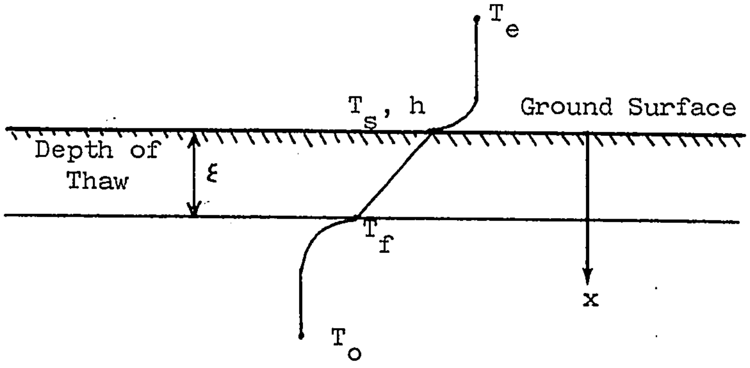
$$q_T = h'(T_e - T_c) \qquad (7)$$

Then from Equations 6 and 7

$$T_e = \frac{q_s}{h'} + T_a \qquad (8)$$

Note that if there is no contact layer or if the value of its thermal conductivity is large, then $h' = h$, the usual convective heat transfer coefficient of the surface, and $T_c = T_s$.

The heat transfer problem is now simplified as shown in the diagram on page 8. The ground temperature is initially at T_0. When warming begins the surface temperature increases from sub-zero to T_f, when thawing starts, and increases still further. When cooling begins T_s will fall again to T_f, when freezing commences, and gradually to sub-zero again. This is a simplified view of the phase change for a a soil system but is accurate enough for certain kinds of engineering design or estimation.



We will now look at the various equations involving the theory of n - factor both for thaw and freeze seasons.

1.4 Theoretical N - Factor, Thawing

Following the definitions in Equations 2 and 3, the surface and air indexes can respectively be written as

$$I_s = (\bar{T}_s - T_f) \times \theta_s \tag{9a}$$

$$I_a = (\bar{T}_a - T_f) \times \theta_a \tag{9b}$$

Similarly, the air index based on the surface temperature thaw season can be defined as

$$I_{as} = (\bar{T}_{as} - T_f) \times \theta_s \tag{9c}$$

and the effective temperature index is defined as

$$I_e = (\bar{T}_e - T_f) \times \theta_s \tag{9d}$$

The time average temperatures used in the above equations are defined as

$$\bar{T}_s = \frac{1}{\theta_s} \int_0^{\theta_s} T_s \, d\theta \tag{10a}$$

$$\bar{T}_a = \frac{1}{\theta_a} \int_0^{\theta_a} T_a \, d\theta \tag{10b}$$

$$\bar{T}_{as} = \frac{1}{\theta_s} \int_0^{\theta_s} T_a \, d\theta \tag{10c}$$

$$\bar{T}_e = \frac{1}{\theta_s} \int_0^{\theta_s} T_e \, d\theta \tag{10d}$$

Similarly, time average values will also be used for q_s and h. Thus

$$\bar{q}_s = \frac{1}{\theta_s} \int_0^{\theta_s} q_s \, d\theta \tag{11}$$

$$\bar{h} = \frac{1}{\theta_s} \int_0^{\theta_s} h \, d\theta \tag{12}$$

The actual phase change problem of the soil can be expressed by the following equation (diagram on page 8)

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \frac{\partial T}{\partial \theta} \tag{13}$$

The boundary conditions are

$$\left.\begin{aligned} -k_t\frac{\partial T}{\partial x} + k_f\frac{\partial T}{\partial x} &= L_e\frac{d\xi}{d\theta} \\ T &= T_f \end{aligned}\right\} \quad \text{at } x = \xi$$

and

$$k_t\frac{\partial T}{\partial x} = h\,(T - T_a) \qquad \text{at } x = 0$$

Due to the non-linearity of the boundary condition at $x = \xi$, the quasi-steady approximation was used. The details of the solution to the quasi-steady system is shown in Appendix B, and the surface temperature during the phase change period is given by the equation

$$T_s = T_e - \frac{(T_e - T_f)}{p}\frac{k_t}{h} \tag{14}$$

where

$$p^2 = \frac{2\,k_t}{L_e}\int_0^{\theta}(T_e - T_f)\,d\theta + \left(\frac{k_t}{h}\right)^2 \tag{15}$$

Since thawing occurs continuously throughout the thawing season θ_s, the time of phase change is now equal to θ_s. Equation 14 then becomes, for average values over the season

$$\bar{T}_s = \bar{T}_e - \frac{(\bar{T}_e - T_f)}{p}\frac{k_t}{\bar{h}} \tag{16}$$

and

$$p^2 = \frac{2\,k_t}{L_e}\int_0^{\theta_s}(T_e - T_f)\,d\theta + \left(\frac{k_t}{\bar{h}}\right)^2 \tag{17}$$

k_t and L_e are respectively the average thermal conductivity and effective latent heat of the soil during the thaw season. The effective latent heat is defined by

$$L_e = c_f (T_o - T_f) + L_v + c_u \frac{(T_s - T_f)}{2} \qquad (18)$$

where

c_f - specific heat of the frozen layer

c_u - specific heat of the unfrozen layer

T_o - mean ground temperature

L_v - volumetric latent heat of the soil

The effective latent heat is a method to evaluate the sensible heat effects which were dropped in the simple quasi-steady solution, because of the assumption that $T = T_f$ initially.

Using Equations 16 and 17, the surface index may be written as

$$I_s = \int_0^{\theta_s} (T_s - T_f)\, d\theta$$

$$= (\bar{T}_e - T_f)\, \theta_s - \frac{L_e}{\bar{h}} \sqrt{\left[\frac{k_t}{\bar{h}}\right]^2 + b\, \theta_s} - \frac{k_t}{\bar{h}} \qquad (19)$$

where

$$b = \frac{2\, k_t}{L_e} (\bar{T}_e - T_f)$$

Since $\quad I_e = \int_0^{\theta_s} (T_e - T_f)\, d\theta = (\bar{T}_e - T_f)\, \theta_s$

Equation 19 can be written as

$$I_s = I_e - M\left[\sqrt{1 + \frac{2\,I_e}{M}} - 1\right] \tag{20}$$

where

$$M = \frac{L_e\,k_t}{\bar{h}^2}$$

Equation 20 can be made dimensionless by dividing it by M. Hence

$$\frac{I_s}{M} = \frac{I_e}{M} - \left[\sqrt{1 + \frac{2\,I_e}{M}} - 1\right] \tag{21}$$

Further by using the following definitions

$$n = \frac{I_s}{I_a}$$

$$\Pi_1 = \frac{I_s}{M} = \frac{n\,I_a}{M} \quad , \quad \text{and}$$

$$\Pi_2 = \frac{I_e}{M}$$

the following relationship is obtained

$$\Pi_1 = \Pi_2 - \left[\sqrt{1 + 2\,\Pi_2} - 1\right] \tag{22}$$

The time average effective temperature can be written as

$$\bar{T}_e = \frac{1}{\theta_s}\int_0^{\theta_s} T_e \, d\theta$$

$$= \frac{1}{\theta_s}\int_0^{\theta_s} \left(\frac{q_s}{h} + T_a\right) d\theta$$

$$= \frac{1}{\theta_s}\int_0^{\theta_s} \frac{q_s}{h}\, d\theta + \frac{1}{\theta_s}\int_0^{\theta_s} T_a\, d\theta$$

$$= \frac{\bar{q}_s}{\bar{h}} + \bar{T}_{as} \tag{23}$$

The effective temperature index in Equation 19 can now be written as

$$I_e = (\bar{T}_e - T_f)\ \theta_s$$

$$= \left[\frac{\bar{q}_s}{\bar{h}} + \bar{T}_{as} - T_f\right] \theta_s$$

$$= \frac{\bar{q}_s\ \theta_s}{\bar{h}} + I_{as} \tag{24}$$

Since I_{as} and I_a are likely to be nearly equal and data are not available for I_{as}, the value of I_a is used rather than I_{as}. Using the letter P to denote I_e, Equation 24 can be written as

$$P = \frac{\bar{q}_s\ \theta_s}{\bar{h}} + I_a \tag{25}$$

Thus Equation 20 can also be written as

$$I_s = P - \left[\sqrt{M^2 + 2\ P\ M} - M\right] \tag{26}$$

1.4.1 Freezing

The equations for freeze cases are similar to that of thaw except for a few changes in signs. The following definitions are applicable for freeze seasons

$$I_s = (T_f - \bar{T}_s) \quad \theta_s$$

$$I_a = (T_f - \bar{T}_a) \quad \theta_a$$

$$I_{as} = (T_f - \bar{T}_{as}) \quad \theta_s$$

$$I_e = (T_f - \bar{T}_e) \quad \theta_s$$

where θ_s and θ_a are now the phase change periods based on the surface and air temperatures, respectively, of the freeze season.

The equation for $\bar{T}_s$ does not change for the case of freezing, but it can be written as follows

$$\bar{T}_s = \bar{T}_e - \frac{(\bar{T}_e - T_f)}{p} \quad \frac{k_f}{\bar{h}}$$

$$= \bar{T}_e + \frac{(T_f - \bar{T}_e)}{p} \quad \frac{k_f}{\bar{h}} \qquad (27)$$

where

$$p = \sqrt{b\ \theta_s + \left[\frac{k_f}{\bar{h}}\right]^2}$$

$$b = \frac{2\ k_f}{L_e} (T_f - \bar{T}_e)$$

k_f and L_e are now the thermal conductivity and the effective latent heat of fusion of the soil during the freeze season. For the same soil system these values may be different to those of thaw season.

Using the same procedure as for the thaw case, the same equation will be derived for I_s in terms of M, P, $\bar{q}_s$, θ_s and $\bar{h}$. Hence

$$I_s = I_e - M\left[\sqrt{1 + \frac{2\,I_e}{M}} - 1\right] \tag{28}$$

where for a freezing case

$$I_e = -\frac{\bar{q}_s\,\theta_s}{\bar{h}} + I_{as}$$

By the same reasoning as before, the value of I_a will be used instead of I_{as}. Using the same letter P to denote I_e, Equation 28 can be rewritten as

$$I_s = P - M\left[\sqrt{1 + \frac{2\,P}{M}} - 1\right] \tag{29}$$

Dividing Equation 29 by M yields

$$\Pi_1 = \Pi_2 - \left[\sqrt{1 + 2\,\Pi_2} - 1\right] \tag{30}$$

The equations derived in this chapter will be used in Chapter 5 to correlate the known n data and to compare the theory to the data.

In this work measurements are available of n and soil conditions for thirteen different locations listed in Appendix A. Each location may have one or more sites; Kotzebue, Alaska, for instance has eight different cases or sites with information on the surface types, soil properties and the n - factor.

The calculations for the net radiation and the surface coefficient require the following weather data: daily air temperature, daily dew-point temperature, amount of cloud cover and wind speed. These weather data are supplied by the U. S. National Oceanic and Atmospheric Administration (NOAA). However, some of the locations (West Virginia sites especially) whose weather data are supplied by NOAA do not exactly coincide with the locations whose n-factor data and soil conditions are known. Table A1 (Appendix A) shows the locations whose weather data are supplied by NOAA and the corresponding locations with data available on n and soil properties. The geographical location and the phase change period for each of the locations are also shown on this table. Table A2 shows the different sites for each location, with information on the n - factor, the period of phase change for the air and surface temperatures, the surface type and the soil properties.

Using the weather data provided, the daily and seasonal net radiation and surface coefficient can be calculated. For Fairbanks, Alaska and Boston, Massachussetts, measured quantities of the net shortwave radiation are known and these are useful for comparison purposes. The net longwave and all-wave radiation for Fairbanks are also known, providing further means to check the accuracy of the calculated quantities. The theoretical framework described earlier in this chapter will then be used to calculate the n - factor and other parameters and from the correlation of these data, we will be able to confirm the accuracy of the theory.

CHAPTER 2

RADIATION - PREDICTIVE EQUATIONS

2.1 Shortwave Radiation

Several methods are available for calculating incident solar radiation under cloudless skies, but the most accurate procedure is that outlined by Bolsenga (1964)[1]. The clear sky global radiation is calculated as a function of geographic latitude, declination of the sun, precipitable water content of the atmosphere and atmospheric dust attenuation of the solar beam. The result obtained is quite accurate, varying by a few percent from the measurements. However, the percentage of solar radiation that reaches the earth's surface in the presence of clouds varies from one site to another and for this reason local correlations for the effect of cloud cover should be known before the net solar radiation can be accurately calculated. In this chapter we shall see briefly how the final equations for calculating the amount of net shortwave and longwave radiation are arrived at.

2.1.1 The Solar Constant

The radiation for all wavelengths from a surface can be found from the Stefan - Boltzman law:

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[1] The name and year in parenthesis refers to references listed on pages 98 through 101.

$$i_b = \sigma \int_0^\infty i_{b,\lambda}\, d\lambda = \sigma T^4 \qquad (31)$$

where

σ - Stefan - Boltzman constant = 1.805×10^{-12} watt/cm^2-K^4

λ - wavelength of the radiation, cm

T - absolute temperature of the surface, ^{o}K

$i_{b,\lambda} = \dfrac{C_1}{\lambda^5 \left[e^{\left(\frac{C_2}{\lambda T}\right)} - 1 \right]}$, Plank's law for monochromatic radiation

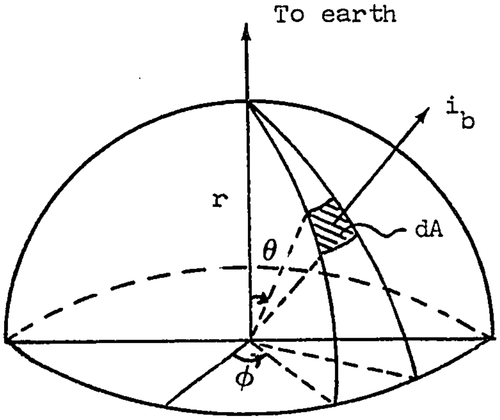
The constants C_1 and C_2 are

$$C_1 = 0.59544 \times 10^{-12} \text{ W-cm}^3$$

$$C_2 = 1.4388 \text{ cm-K}$$

The energy leaving an area dA of the sun which strikes a unit area of the earth is

$$dS = i_b \cos\theta\, dA\, d\omega \qquad (32)$$



where

dA - unit area = $r^2 \sin\theta \, d\theta \, d\phi$

$d\omega$ - solid angle subtended by unit area at distance of earth from sun

r - radius of the sun = 6.965×10^{10} cm

Integrating Equation 32 over the total solar hemisphere,

$$S_m = \int_0^{2\pi}\int_0^{\pi} \frac{T^4 r^2}{r_i^2} \cos\theta \sin\theta \, d\theta \, d\phi$$

from which

$$S_m = \frac{T^4 r^2 \sigma}{r_i^2} \pi \tag{33}$$

Using the distances given above and taking the solar surface temperature to be 5900 °K (about 10,000 °F), Equation 33 gives the value of 1.99 langleys per minute, where 1 langley is defined as 1 cal/cm^2. This value is generally accepted as the solar constant - the radiation falling on a surface perpendicular to the sun's rays at the top of the atmosphere. The solar constant however fluctuates slightly due to geometrical changes and changes of solar activity.

Stringer (1972) gave a relation for the solar constant at any time of the year

$$S_i = S_m \left[\frac{r_m}{r_i}\right]^2 \tag{34}$$

and

$$\frac{r_i}{r_m} = 1 - 1.6733 \times 10^2 \cos(0.9856\, D) \qquad (35)$$

where

S_m - mean solar constant = 1.99 langleys/day

r_m - mean distance of the sun from the earth = 1.4968×10^{13} cm

r_i - instantaneous distance of the sun from the earth

D - days numbered from Dec. 31 (Julian calender)

2.1.2 Extra-Terrestrial Radiation

From Equation 34 the daily direct solar radiation is therefore

$$S_D = \int_{\text{sunset}}^{\text{sunrise}} S_i \cos\psi \, dt \qquad (36)$$

The zenith angle ψ is given by the equation

$$\cos\psi = \sin\delta \sin\phi - \cos\delta \cos\phi \cos H \qquad (37)$$

where

δ - angle of solar declination

ϕ - latitude of the site

H - hour angle = $\frac{2\pi t}{24}$

t - hours measured from midnight

Degelman (1966) gives the relationship for the estimation of solar declination,

$$\delta = \sin^{-1}\left\{\sin 23.5 \cos\left[0.9863(D - 172)\right]\right\} \qquad (38)$$

From Equation 37, since $\cos\psi = 0$ at sunrise or sunset, the hour angle at sunrise is

$$H_{sr} = \cos^{-1}\left[\tan\delta \tan\emptyset\right] \qquad (39)$$

Equation 36 thus becomes

$$S_D = \int_{\text{sunrise}}^{\text{sunset}} (\sin\delta \sin\emptyset - \cos\delta \cos\psi \cos H)\, dt$$

$$= t_d \sin\delta \sin\emptyset - \frac{24}{\pi} \cos\delta \cos\emptyset \int_{H_{sr}}^{\pi} \cos H \, dH \qquad (40)$$

where

$$t_d - \text{length of daylight in hours} = 24\left(1 - \frac{H_{sr}}{\pi}\right)$$

After some substitutions and simplifications, Equation 40 can finally be written as

$$S_D = 60 \times 24\, S_i \left[\frac{180 - H_{sr}}{180} \cos H_{sr} + \frac{\sin H_{sr}}{\pi}\right] \cos\delta \cos\emptyset \qquad (41)$$

This is the daily direct radiation from the sun that would reach the surface of the earth with no atmosphere or clouds. This equation is valid for any latitude, month and any length of daylight hours.

2.1.3 Optical Air Mass

As mentioned earlier all solar rays reaching the earth's surface will have to transverse the atmosphere which therefore absorbs and scatters a considerable amount of the radiation. Computation of solar heat flux requires the use of the average daily optical air mass, or the average length of the path in the atmosphere through which the solar rays must pass as the sun travels across the sky. The relative optical air mass is defined as the ratio of the actual path transversed by the radiation to the shortest possible path. Since it is a ratio the relative optical air mass, usually denoted by m, is therefore dimensionless. The air mass ranges from unity at the zenith to about 27 at sunrise or sunset, Kennedy (1940).

Kasten (1964) calculated the optical air mass and obtained an empirical relationship which is quite accurate as follows

$$m = \frac{1}{\cos\psi + 0.15\left[\frac{\pi}{2} - \psi + 3.885\right]^{-1.253}} \qquad (42)$$

Figure 1 provides a means of determining the average air mass at any latitude for any day of the year. The figure only gives the values of m for the northern hemisphere, but it is applicable to the southern hemisphere by changing signs.

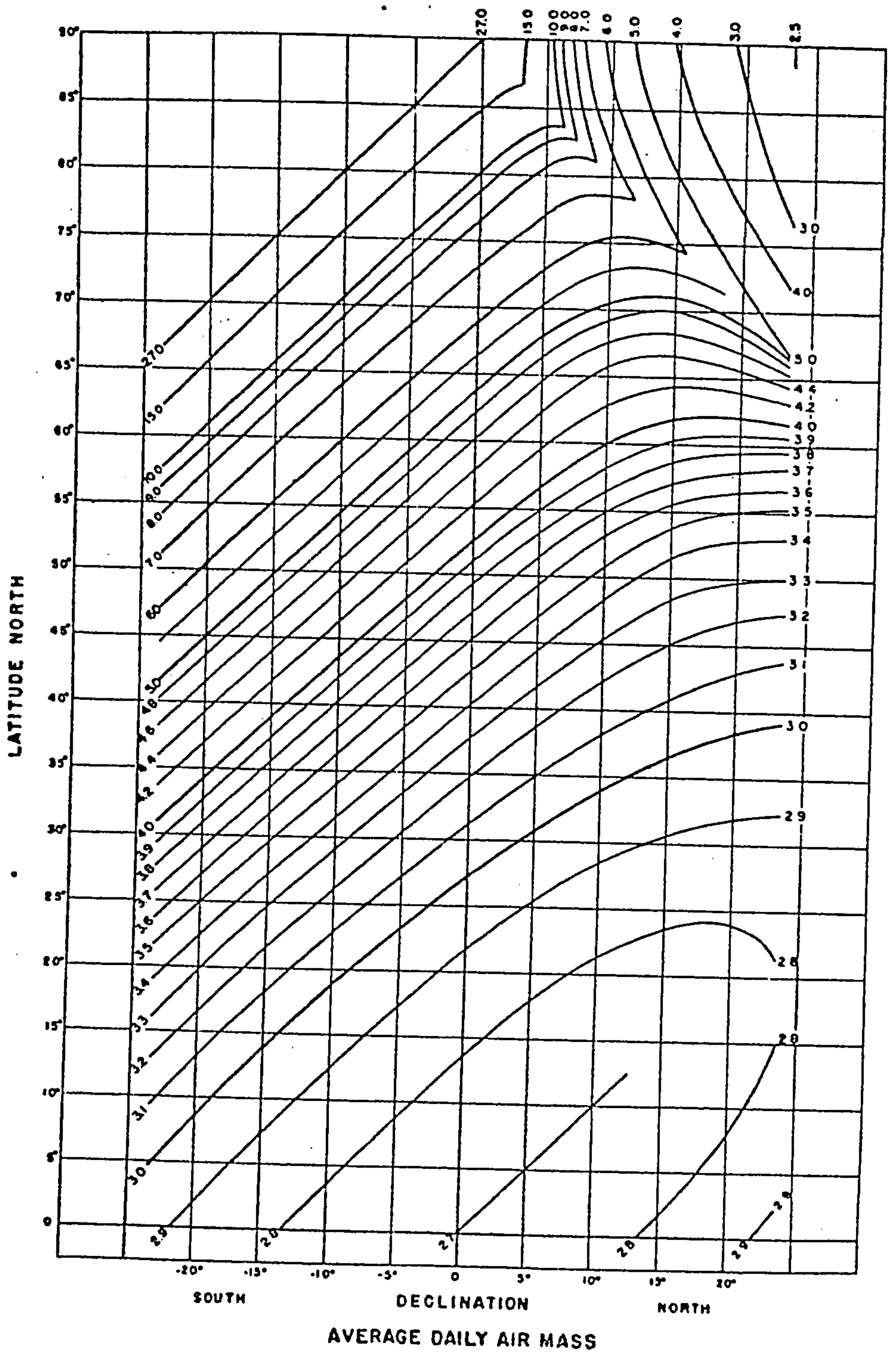


Figure 1 The Average Daily Air Mass for Different Latitude and Sun's Angle of Declination, Kennedy (1940)

2.1.4 Transmission Coefficient

Another quantity used in relation to the air mass is the transmission coefficient, τ_a. Its value depends upon the solar energy absorbed in the atmosphere which is due to the presence of water vapour, carbon dioxide, ozone and pollutants. Its value ranges from about 0.81 on a clear day to 0.62 on a cloudy day. The average value of 0.7 is generally used for a typical day. (The transmission coefficient is 1 if the atmosphere is transparent).

The instantaneous energy now reaching the horizontal surface is

$$I_i = S_i \tau_a^m \cos\psi \qquad (43)$$

Due to the difficulty of integrating the unknown scattering and absorption effects, etc., empirical relationships are used, following Bolsenga (1964). Equation 41 was obtained assuming the atmosphere to be transparent with the transmission coefficient assumed to be unity. With the absorption of the atmosphere, the direct radiation reaching the surface now becomes

$$Q_{TD} = a \int_{\text{sunrise}}^{\text{sunset}} S_i \cos\psi \, dt = a S_D \qquad (44)$$

where a is a parameter depending on the transmission coefficient, and is a function of the optical air mass, absorption and scattering.

The indirect, scattered or diffuse radiation reaching the surface is described in terms of a scattering coefficient β. Thus

$$Q_{TC} = \tfrac{1}{2} \beta S_D \tag{45}$$

The radiation reflected from the surface is

$$Q_{RE} = \alpha_s (a + \tfrac{1}{2}\beta) S_D \tag{46}$$

where α_s is the surface solar albedo or reflectivity.

The amount of reflected energy which is backscattered to the surface is one-half of the reflected scattered radiation. Thus

$$Q_B = \tfrac{1}{2} \beta Q_{RE} \tag{47}$$

Combining Equations 44 to 47 the total insolation (total global radiation) at the surface for clear sky condition is

$$Q_T = (a + \tfrac{1}{2}\beta)(1 + \tfrac{1}{2}\beta \alpha_s) S_D \tag{48}$$

It must be remembered that this is the shortwave radiation reaching the surface of the earth and not the energy absorbed. The amount of radiation absorbed by the surface depends upon its absorptivity.

2.1.5 Atmospheric Attenuation

Bolsenga (1964) gave empirical relationships for the coefficients a and β in Equation 48. He found

$$a = a'' - d \tag{49}$$

$$\beta = 1 - a' + d \tag{50}$$

where

a' - attenuation due to scattering only

a" - attenuation due to scattering and absorption

d - dust attenuation

Bolsenga (1964) also gave charts for a' and a" from which the following approximate equations were derived

$$a' = 1.041 \left\{ e^{-(0.095\ m\ +\ 0.039\ w)} \right\} \qquad (51)$$

$$a'' = 0.975 \left\{ e^{-(0.1263\ m\ +\ 0.0513\ w)} \right\} \qquad (52)$$

where

m - average daily optical air mass

w - precipitable atmospheric water vapour, cm

Reitan (1963) gave an empirical equation for the precipitable atmospheric water vapour

$$w = e^{(0.1102\ +\ 0.0614\ T_{dp})} \qquad (53)$$

where

T_{dp} - mean monthly surface dew point temperature, °C

Equation 53 has to be multiplied by 0.85 for daily calculation of shortwave radiation, Bolsenga (1964).

Table 1 gives the mean seasonal values of atmospheric dust attenuation for different sites and for different optical air mass m, Bolsenga (1964). The table only gives values of d for m values

General location	Station	Season	Optical air mass, m		
			m = 1	m = 2	m = 3
U.S.A	Lincoln, Nebraska	Winter	–	0.06	–
		Spring	0.05	0.08	–
		Summer	0.03	0.04	–
		Autumn	0.04	0.06	–
	Madison, Wisconsin	Winter	–	0.08	–
		Spring	0.06	0.10	–
		Summer	0.05	0.07	–
		Autumn	0.07	0.08	–
	Washington, D. C.	Winter	–	0.13	–
		Spring	0.09	0.13	–
		Summer	0.08	0.10	–
		Autumn	0.06	0.11	–
Atlantic Ocean	Trade-wind zone	Spring	–	–	neg.
	Equatorial zone	Spring	–	–	0.05
E. Atlantic	Cape Verde (Dunkelmeer)	Spring	–	–	0.20
	Canary Island	Summer	0.00	0.01	–
Arctic Ocean	Spitzbergen (Treurenberg)	Summer	–	0.02	–
South Pacific	Samoa (Apia)	Dry	0.08	0.06	–
		Wet	0.05	0.01	–
Europe	North Sea (North Temperate Zone)	Spring	–	–	0.10
Netherlands - East Indies	Celebes Sea (Equatorial Zone)	Year	0.00	0.01	0.03

Table 1 Mean Seasonal Values of Atmospheric Dust Attenuation, d, for Different Optical Air Mass, m, Bolsenga (1964)

of 1, 2 and 3, and these values are only accurate for the specified locations. The nearest tabulated site is chosen from those listed in the table for other sites. If m is higher than 3, the table must be inspected to approximate the change in atmospheric attenuation as a function of the optical air mass. Atmospheric attenuation values generally increase for increasing values of m, but the rise is not linear because a higher optical air mass corresponds to an increasingly longer path traversed by the solar rays.

2.1.6 Effect of Cloud Cover

If the sky is wholly or partially covered with clouds the radiation reaching the earth's surface is greatly reduced. A theoretical solution of the resulting problem has not been obtained because of difficulties involving height, type and distribution of clouds. By correlating measured total radiation with visual estimates of cloud cover, empirical relationships have been obtained.

The ratio of the actual radiation to the clear sky radiation is a function of the clouds. Thus

$$\frac{Q_{TC}}{Q_T} = f \qquad (54)$$

The relationship f depends upon the type , structure and extent of of the cloud cover. The function of f is also dependent on whether daily or mean monthly radiation values are being considered.

For daily correlations the function f can be specified as

$$f = a_1 - b_1 C_s^2$$

$$f = a_2 - b_2 C_s$$

$$f = a_3 - b_3 S$$

where

C_s - average fraction of sky covered by clouds during daylight hours

S - fraction of possible sunshine

The coefficients a and b in the above equations are determined empirically and vary from one location to another. Scott (1964) proposed that the following function

$$f = 1 - 0.67 C_s^2 \tag{55}$$

is generally acceptable for any site.

C_s and S are directly related to each other. Gorczynski (1945) found the relationship to be

$$S = (1 - C_s)(1 + 0.5 C_s) \tag{56}$$

while Scott (1964), in his work on Camp Tuto, Greenland, found the relationship to be

$$S = (1 - C_s)(1 + C_s) \tag{57}$$

2.1.7 Surface Albedos

The surface albedo for solar radiation is the ratio of the flux of radiation reflected by the surface to the flux incident upon it. Thus

$$\alpha_s = \frac{Q_R}{Q_{TC}} \tag{58}$$

In engineering terms α_s is usually called the reflectivity. Hence the solar energy available for energy transformation at the surface is

$$Q_{TC} - Q_R = (1 - \alpha_s)\, Q_{TC} \tag{59}$$

The factor $(1 - \alpha_s)$ is called the absorptivity of the surface.

The albedo of any surface is a function of the wavelength of the radiation; thus the same surface can have different albedo values for shortwave and longwave radiation.

Table 2 below gives a list of solar albedos for various types of surfaces.

Surface	Solar Albedo
Concrete	0.25
Gravel mixture	0.12
Crushed stone	0.14
Granite	0.15
Asphalt (black top, bituminous concrete)	0.10 - 0.15
Portland cement concrete	0.20 - 0.35

Table 2 Solar Albedos for Paved Surfaces, Van Wijk (1966)

2.2 Longwave Radiation

The wavelength of radiation depends upon the surface temperature of the body; thus the earth and atmosphere emit heat in the form of longwave radiation. The radiation emitted by the earth and atmosphere has longer wavelengths than solar radiation because the earth and atmosphere are much cooler. Nearly all the radiated energy of the earth has wavelengths greater than 4 microns. The actual amount of longwave radiation emitted by the atmosphere, downwards and received at the earth's surface, is a complex function of the atmospheric density and temperature variation above the surface. Therefore an empirical equation is used to determine the effective emissivity of the atmosphere.

2.2.1 Terrestrial Radiation

The surface of the earth emits radiation as a grey body,

$$E_e = \sigma \epsilon_e T_s^4 \tag{60}$$

where

σ - Stefan - Boltzman constant
T_s - absolute surface temperature
ϵ_e - emissivity of the surface

Kirchoff's law states that for grey bodies the monochromatic emittance is equal to the monochromatic absorptance. Thus the emissivity of the surface, considered as a grey body, is equal to the absorptivity for terrestrial or longwave radiation. Obviously this is not true for solar or shortwave radiation since the sun is at a temperature far higher than that of the surface.

Table 3 below gives the values of absorptivity (or emissivity) for different surfaces.

Surface	Emissivity
Asphalt	0.93
Concrete	0.94
Gravel	0.94
Gravel, darkened	0.94

Table 3 Longwave Emissivities (Absorptivities) for Paved Surfaces, Van Wijk (1966)

2.2.2 Clear Sky Atmospheric Radiation

The atmosphere itself, having a certain temperature will emit radiant energy towards the earth. The energy emitted is a function of the atmospheric temperature and water vapour pressure, hence

$$E_s = \epsilon_a(T_a, e_o) \; \sigma T_a^4 \qquad (61)$$

where

e_o - atmospheric water vapour pressure, mb

T_a - air temperature at a certain reference level, ^oF

ϵ_a - effective emissivity of the atmosphere

Brunt (1932) gave a simple relationship between ϵ_a and e_o as

$$\epsilon_a = a + b\sqrt{e_o} \tag{62}$$

The values of a and b depend on the local conditions and vary from site to site. Brunt recommended the values of a and b to be 0.52 and 0.057, respectively. A more recent work by Sellers (1965) however suggested the values to be 0.60 and 0.05, respectively.

2.2.3 Net Longwave Radiation

From Equations 60 and 61, the net longwave radiation loss from the surface for a cloudless atmosphere is

$$\begin{aligned} R &= E_e - \alpha_e E_s \\ &= \sigma T_a^4 \epsilon_e \left\{ \left[\frac{T_s}{T_a} \right]^4 - \epsilon_a \right\} \end{aligned} \tag{63}$$

As with shortwave radiation the presence of a cloud cover will decrease the net flux of terrestrial radiation and increase the incoming atmospheric radiation. Since there is no simple analytical method to account for the absorption, reflection and emission of clouds, empirical relations will again be used.

The ratio of net longwave radiation with cloud cover to that of clear sky is

$$\frac{R_c}{R} = a - b\,C_e \tag{64}$$

Since longwave radiation occurs night and day, C_e now is the 24-hour average fraction of sky covered by clouds. The coefficients a and b in Equation 64 are functions of the type and structure of the clouds. For low clouds b = 0.9, and for cirrus clouds it is 0.2; the average value of 0.8 usually being used for b and 1 for a, Lunardini (1977).

2.3 Net All-Wave Radiative Balance

Knowing the amount of net shortwave radiation absorbed and the net longwave radiation emitted by the surface, the resultant radiative energy retained by the surface for energy transformation is

$$Q_N = (1 - \alpha_s) Q_{TC} - R_c \qquad (65)$$

Most of the equations discussed in this chapter will be used in the next chapter for Fairbanks, Alaska and Boston, Massachussetts, and also in Chapter 5 where the daily and seasonal net radiation for all sites will be calculated.

CHAPTER 3

RADIATION - CALCULATIONS AND CORRELATIONS

3.1 Introduction

The meteorological data sheets and microfilms supplied by NOAA only furnish weather data like air temperature, dew point temperature, cloud cover for both 24-hour and daylight periods, and wind speed (see Appendix F). Though these data are sufficient to calculate the net shortwave and longwave radiation and the convective heat flux, more information like the surface temperature, shortwave and longwave radiation measurements are necessary to check the validity and accuracy of the equations discussed in Chapter 2.

With the exception of Fairbanks (Cases 1a, 1b and 1c)[1] and Boston (Cases 4a, 4b and 4c), the computed net radiation obtained could not be compared with the actual measured values since these values are not known. However as calculations for Fairbanks and Boston will prove, the results obtained for these two sites are quite reliable and accurate enough for engineering work. Thus the equations described should yield acceptable radiation values.

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[1] See Appendix A

3.2 Daily Radiation for Fairbanks, Alaska

For Fairbanks, Alaska, data on the daily values Q_T, Q_R, Q_{TC}, R_c and Q_N are provided by the U. S. Army (1971). From the incident and the reflected solar radiations, daily values of solar albedos can be obtained. Tables E1, E3, E5 and E6 (Appendix E) show data on daily solar albedo, net shortwave radiation, net longwave radiation and net all-wave radiation, respectively. These values will therefore be used to check the accuracy of the results obtained using the equations discussed in Chapter 2.

3.2.1. Calculated Radiation

3.2.1.1 Shortwave Radiation with Cloud Cover

As discussed in the previous chapter, the ratio of the daily solar radiation with cloud cover to that of clear sky is

$$\frac{Q_{TC}}{Q_T} = 1 - 0.67\, C_s^2 \qquad (55)$$

Workers like Gerdel (1954), Gabites (1950), and others came up with slightly different relationships. The equation above which was proposed by Scott (1964) gives a value close to the average of all the other results. For Fairbanks and Boston, the data are available for local correlations to be made on the effect of cloud cover. For other sites however Scott's relationship will have to be used.

A sample calculation for the calculation of the net shortwave, net longwave and the net all-wave radiations is shown in Appendix D. Figure 2 shows the correlation between the computed net shortwave radiation (Q_{TC}) using Scott's relationship for cloud cover, to that of the measured data. It is observed that the points are not evenly scattered between the 45-degree line, and in most cases the computed values fall short of the measured values.

3.2.1.2 Longwave Radiation with Cloud Cover

The equation used to calculate the longwave radiation on a clear sky day is

$$R = \sigma \epsilon_s T_a^4 \left\{ \left[\frac{T_s}{T_a} \right]^4 - \epsilon_a \right\} \qquad (63)$$

With the presence of clouds, the net longwave radiation loss is given by the equation

$$R_c = (1 - 0.8 C_e) \times R \qquad (66)$$

At best, the equation above only gives an estimation of the resultant longwave radiation loss for any site. The actual function of R_c / R may vary widely from one site to another and the local correlation is preferred if known for a particular site. Figure 3 shows the correlation between the computed values of R_c using Equation 66, and that of the measured values obtained from the data supplied by the U. S. Army (1971). It is observed that the scatter is not

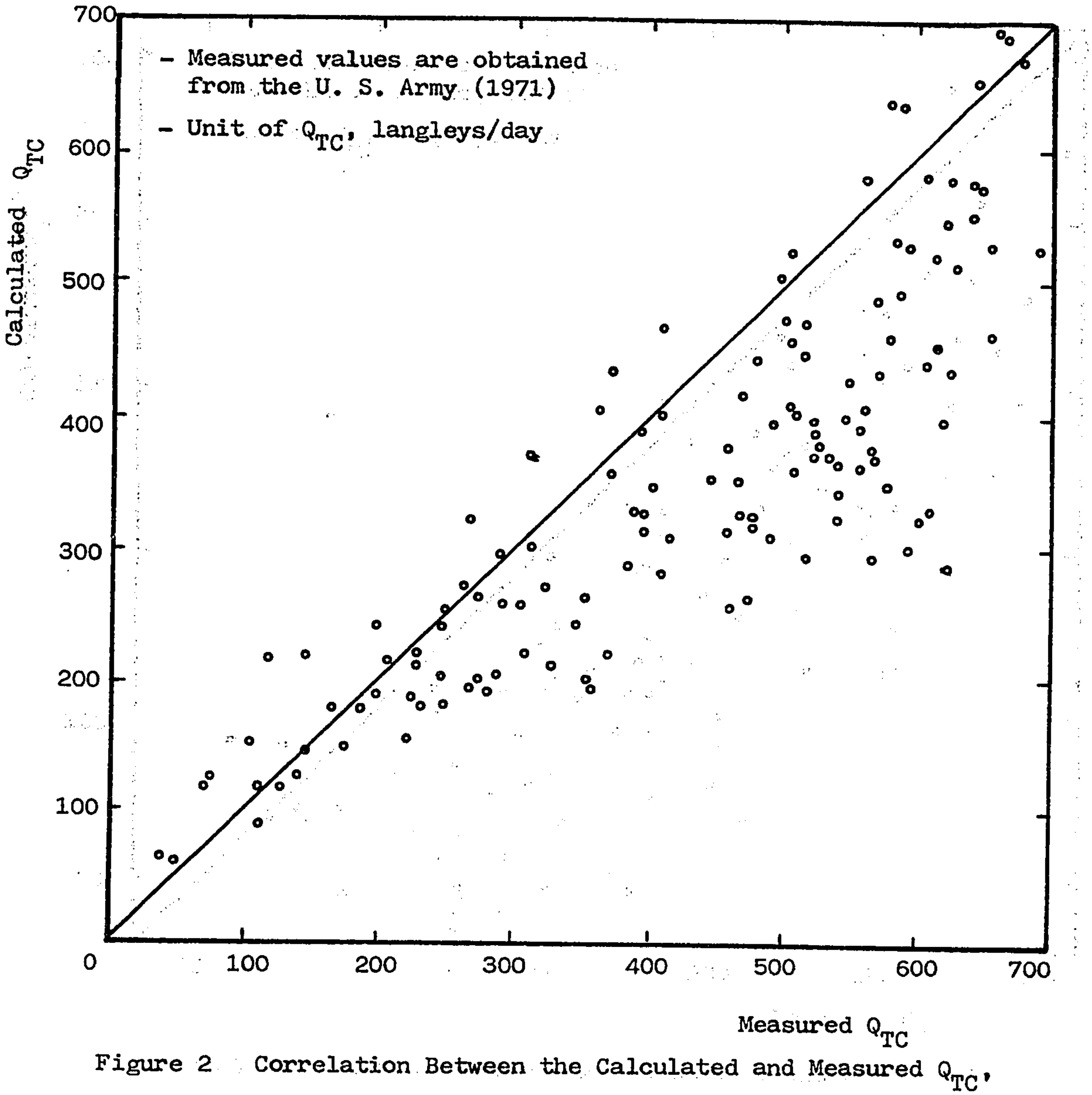


Figure 2 Correlation Between the Calculated and Measured Q_{TC}, Fairbanks

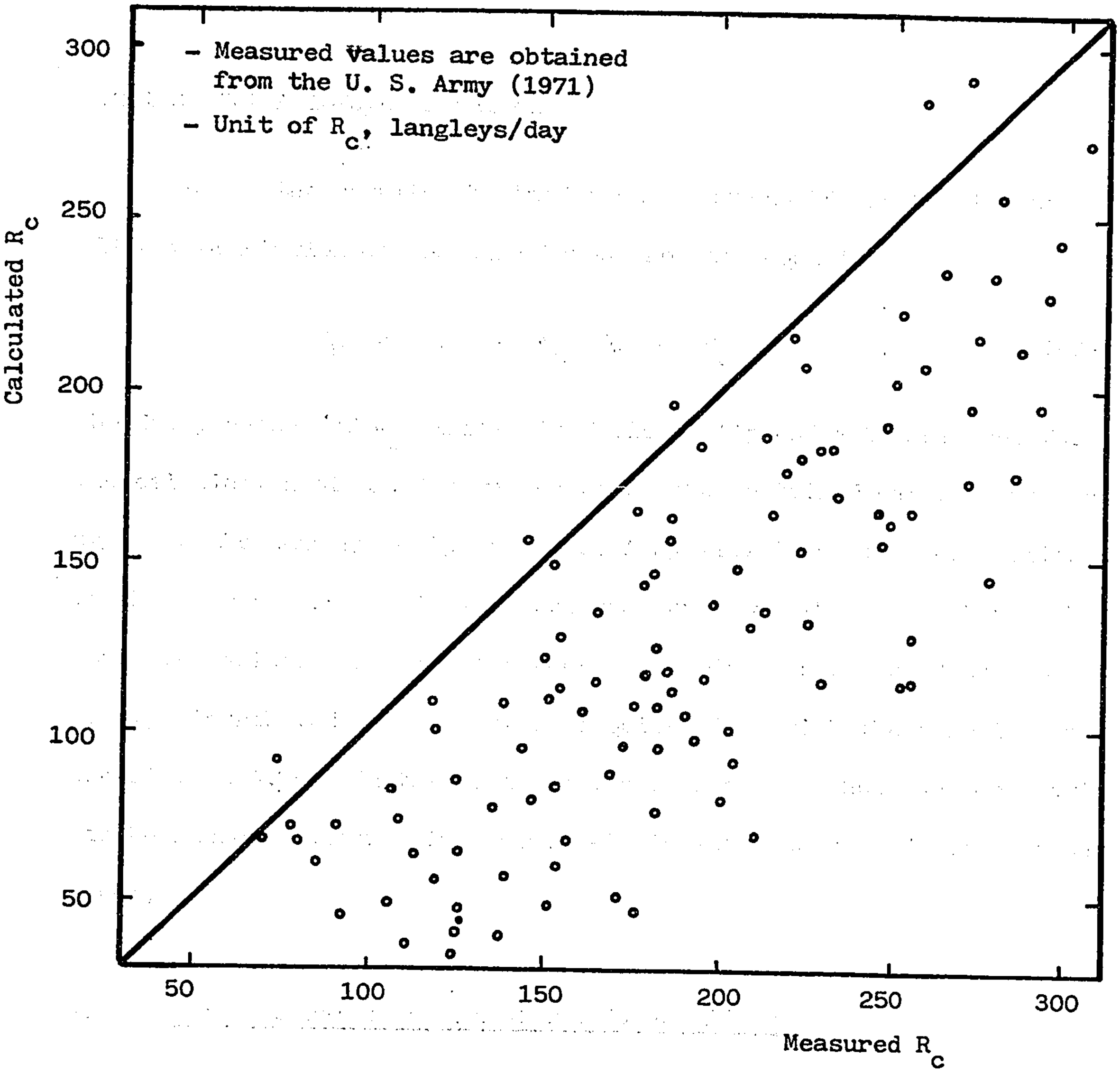


Figure 3 Correlation Between the Calculated and Measured R_c, Fairbanks

evenly distributed about the theoretical line. The correlation is very poor and in most cases the computed values fall short of the data.

3.2.1.3 Net All-Wave Radiation

Using the results obtained from Equations 55 and 66, the net all wave-radiation can be calculated from the equation

$$Q_N = (1 - \alpha_s) Q_{TC} - R_c \qquad (65)$$

The daily values of α_s listed in Table E1 (Appendix E) are used for the calculation of Q_N. The values of Q_N thus obtained can be compared again to the data given by the U. S. Army (1971) and the correlation is shown in Figure 4. A close observation shows that even though the longwave radiation results are poor, the points in Figure 4 are more evenly distributed. The scatter is quite high, with the correlation coefficient 0.76. In the next section we shall see how the correlation can be improved after using local relationships on the effect of cloud cover.

3.2.2. Local Correlations for Cloud Cover Effect

3.2.2.1 Shortwave Radiation

Since the values of net shortwave , net longwave and net all-wave radiations are known together with the cloud cover percentage,

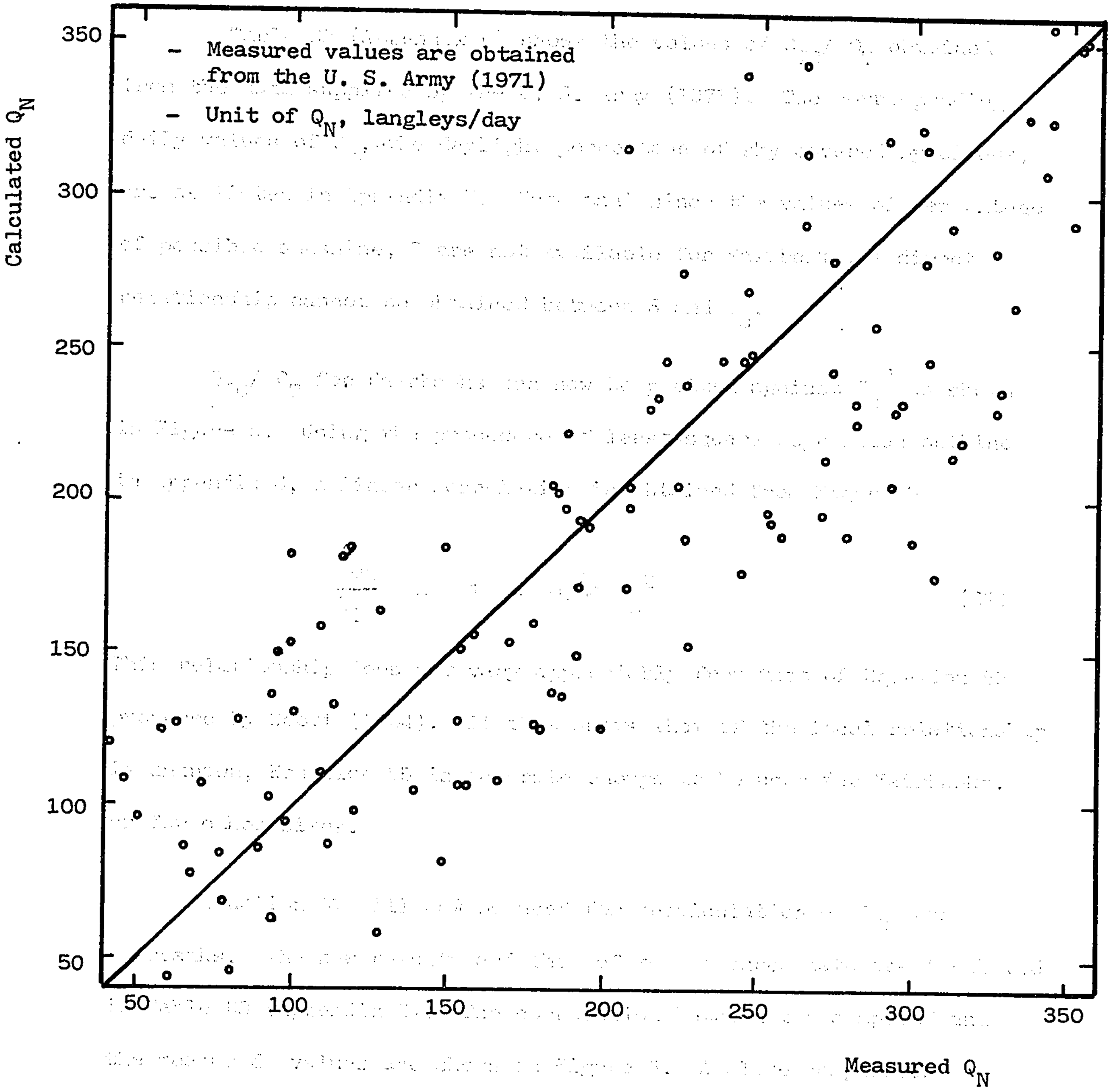


Figure 4 Correlation Between the Calculated and Measured Q_N, Fairbanks

it is therefore possible to derive a local empirical relationship for the effect of clouds on shortwave and longwave radiations.

Table E2 (Appendix E) shows the values of Q_{TC}/ Q_T obtained from the data supplied by the U. S. Army (1971). The corresponding daily values of C_s, the daylight percentage of sky covered by clouds, are as listed in Appendix F. Note that since the values of percentage of possible sunshine, S are not available for Fairbanks, a direct relationship cannot be obtained between S and C_s.

Q_{TC}/ Q_T for Fairbanks can now be plotted against C_s^2 as shown in Figure 5. Using the procedure of least-square regression outlined in Appendix C, a linear correlation is obtained from Figure 5

$$\frac{Q_{TC}}{Q_T} = 1 - 0.60 C_s^2 \qquad (67)$$

This relationship does not vary appreciably from that of Equation 55 proposed by Scott (1964). It thus shows that if the local relationship is unknown, Equation 55 is accurate enough to be used for Fairbanks, or for other sites.

Equation 67 will now be used for recalculation of Q_{TC} for Fairbanks. The new results and that of the measured data are tabulated in Table E3 (Appendix E). The correlation between the computed and the measured values are shown in Figure 6. A close comparison between Figure 6 and Figure 2 shows that there is some improvement of results in Figure 6.

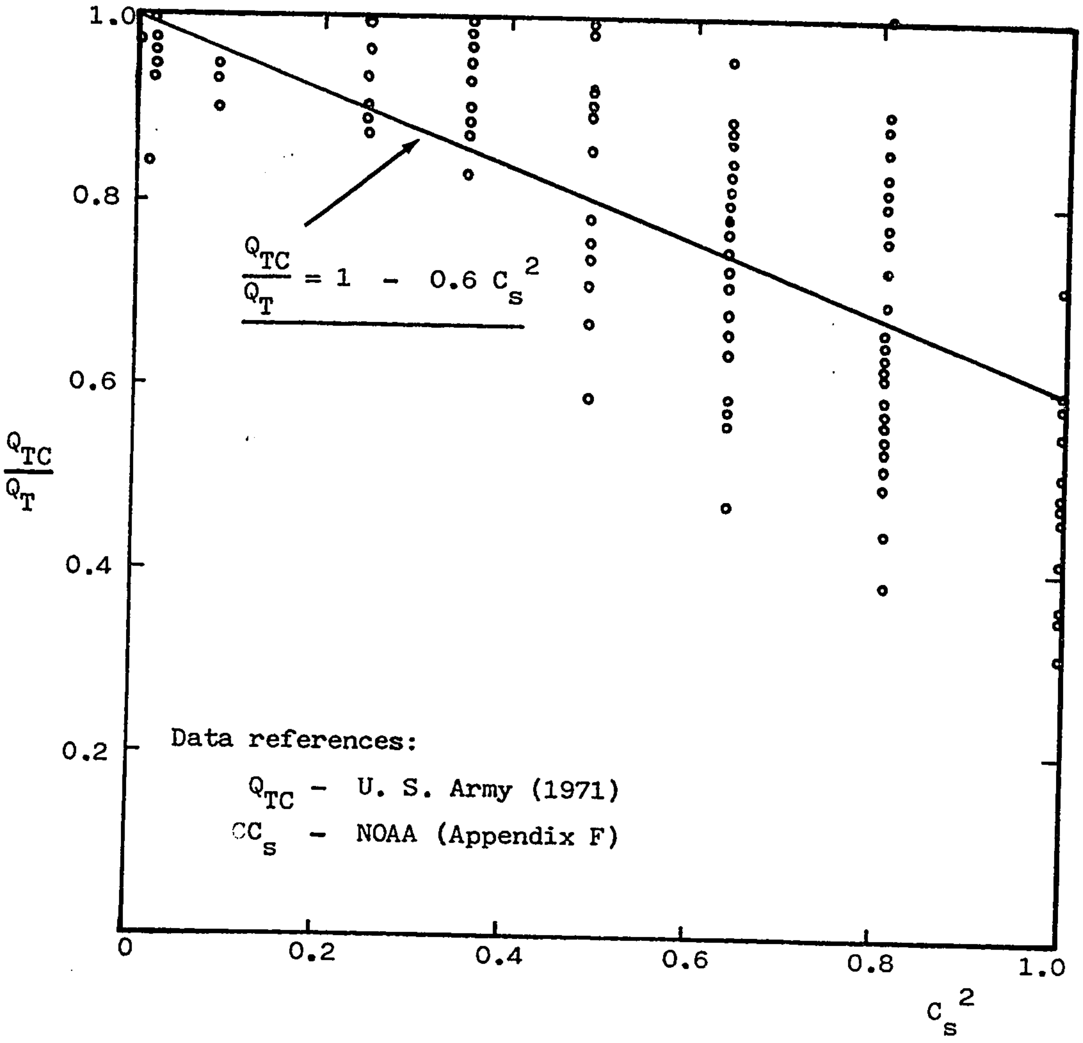


Figure 5 Plot of Q_{TC}/Q_T Against C_s^2, Fairbanks

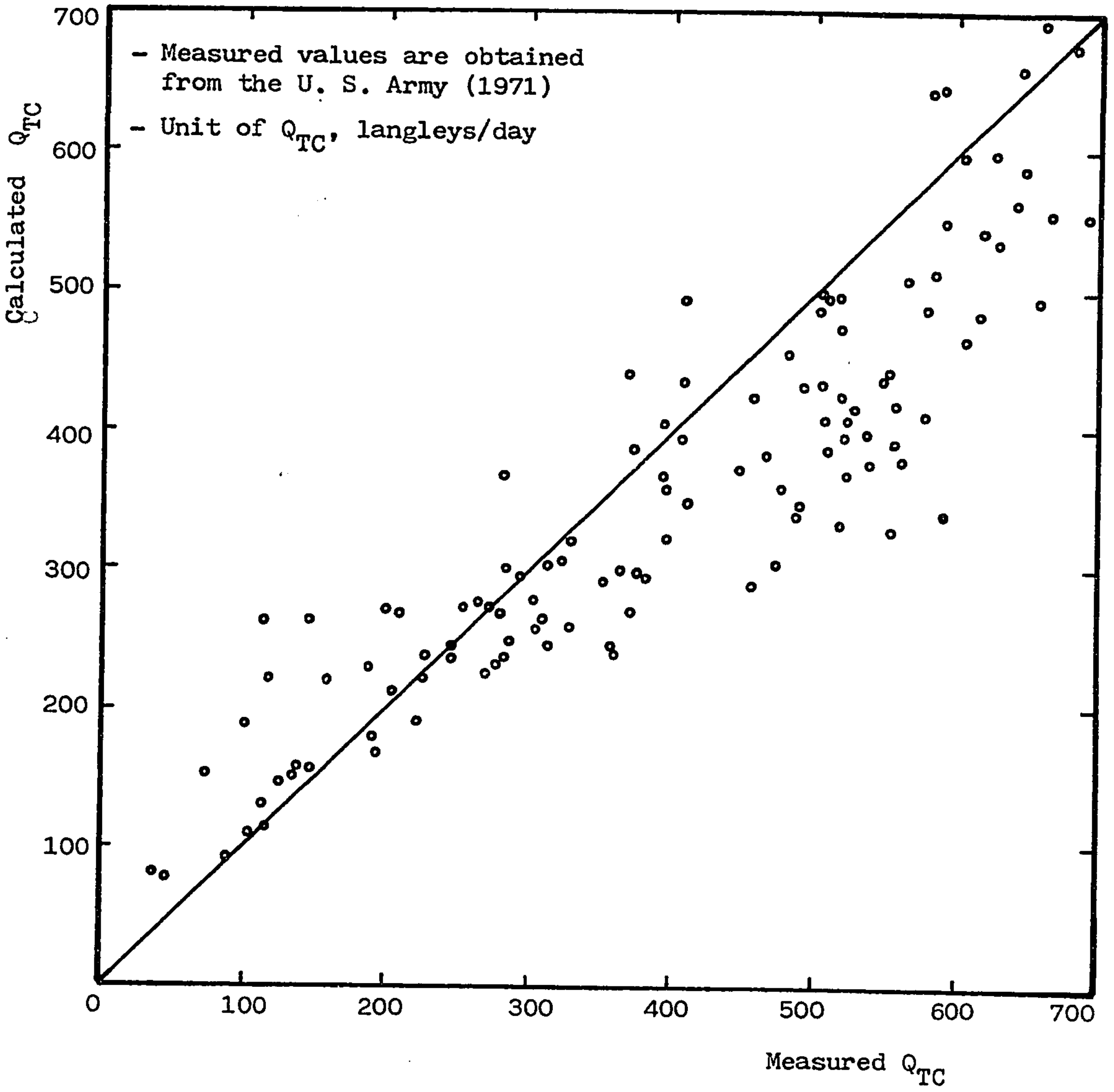


Figure 6 Correlation Between the Calculated and Measured Q_{TC} After the Local Cloud Cover Relationship is Used, Fairbanks

3.2.2.2 Longwave Radiation

The effect of clouds on longwave radiation for Fairbanks can also be empirically derived by plotting the values of R_c / R against C_e, the percentage of sky covered with clouds for a 24-hour period. The values of R_c are calculated from the data suplied by the U. S. Army (1971), whereas R is calculated using Equation 63. The values of C_e are listed in Appendix F. Table E4 (Appendix E) shows the daily values of R_c / R and these values are plotted against C_e as shown in Figure 7. Using the method of linear regression described in Appendix C, the following relationship is obtained

$$\frac{R_c}{R} = 1 - 0.4\, C_e \qquad (68)$$

Equation 68 differs considerably from the assumed relationship of Equation 66. But as discussed earlier in Chapter 2, the coefficient b in Equation 64 can vary from 0.2 to 0.9, depending on the type, height and structure of the clouds. Equation 68 will now be used to recalculate the values of R_c. The new computed values of R_c and the data are tabulated in Table E5 (Appendix E). The correlation between the computed and the measured values is shown in Figure 8.

It is observed that using the local relationship shown in Equation 68, there is a vast improvement over the previous correlation (Figure 3) in which the general relationship for cloud cover effect was used.

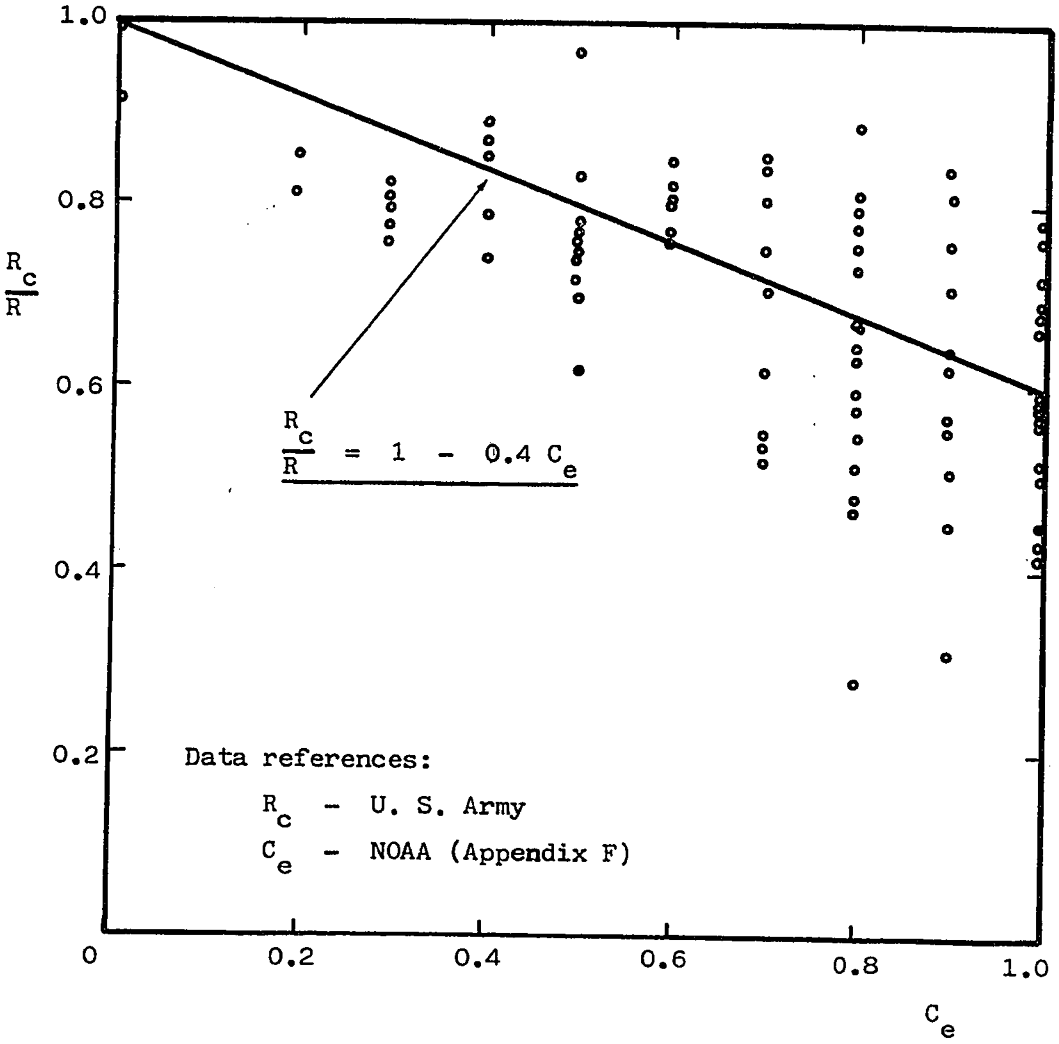


Figure 7 Plot of R_c/R Against C_e, Fairbanks

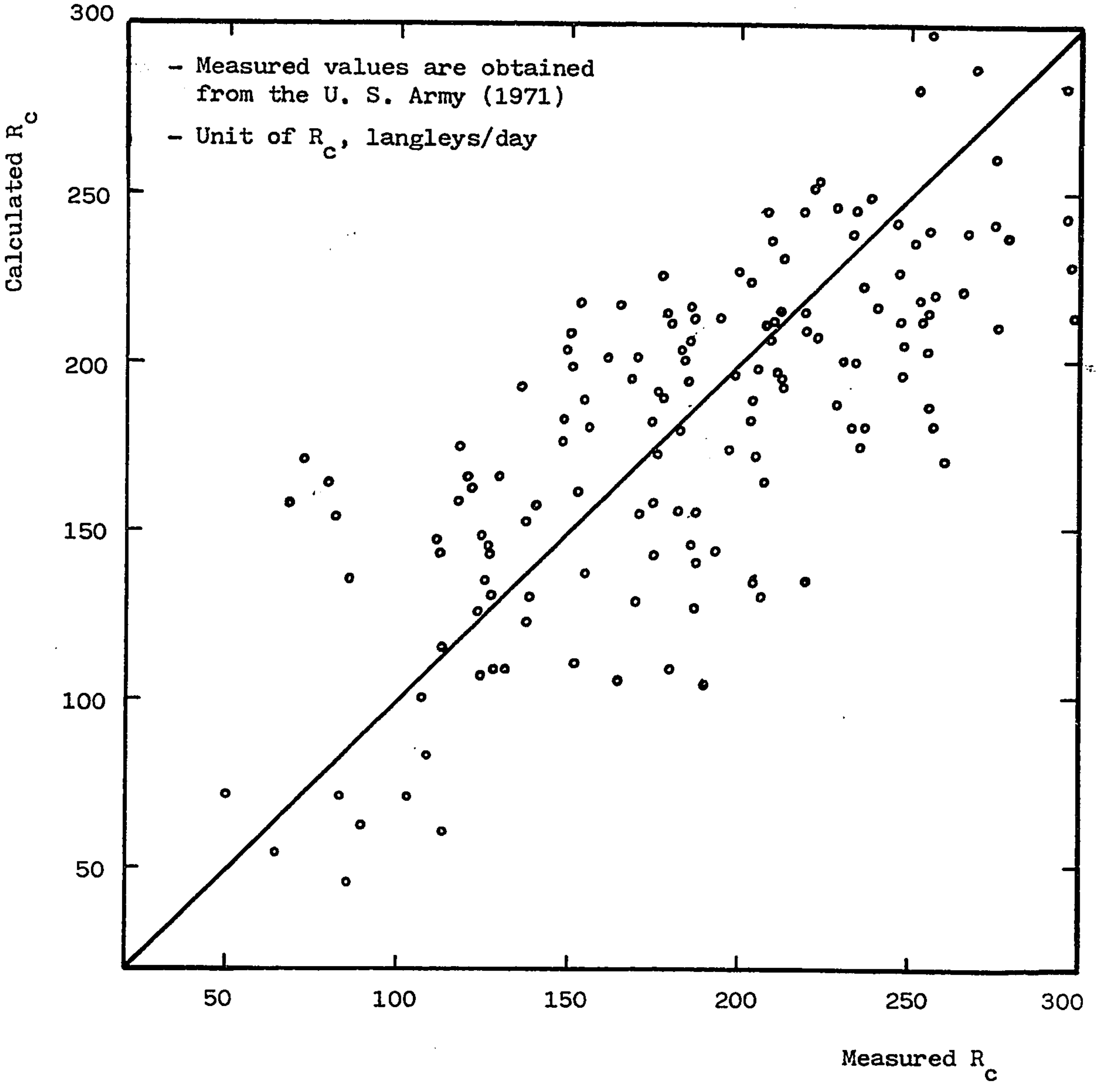


Figure 8 Correlation Between the Calculated and Measured R_c After the Local Cloud Cover Relationship is Used, Fairbanks

3.2.2.3 Net All-Wave Radiation

Using the new results of shortwave and longwave radiations obtained with local relationship on the effect of cloud cover, the net all-wave radiation Q_N can be calculated again using Equation 65. Table E6 shows the new values of Q_N and that of the data supplied by the U. S. Army (1971). Figure 9 shows the new correlation between the computed and the measured values.

Compared to Figure 4, Figure 9 shows an improvement on the correlation. The scatter is reduced and the points are more evenly distributed about the theoretical line. The correlation coefficient is improved from 0.76 in Figure 4 to 0.86 in Figure 9.

It must be mentioned that in the analysis so far, data from two different sources are being used. The weather data used to calculate the shortwave and longwave radiations are obtained from NOAA (Appendix F). The measured radiation data are supplied by the U. S. Army (1971). The two weather stations are at different places, and since weather conditions may vary considerably between two neighbourhoods, accurate local correlations for Fairbanks are therefore not expected.

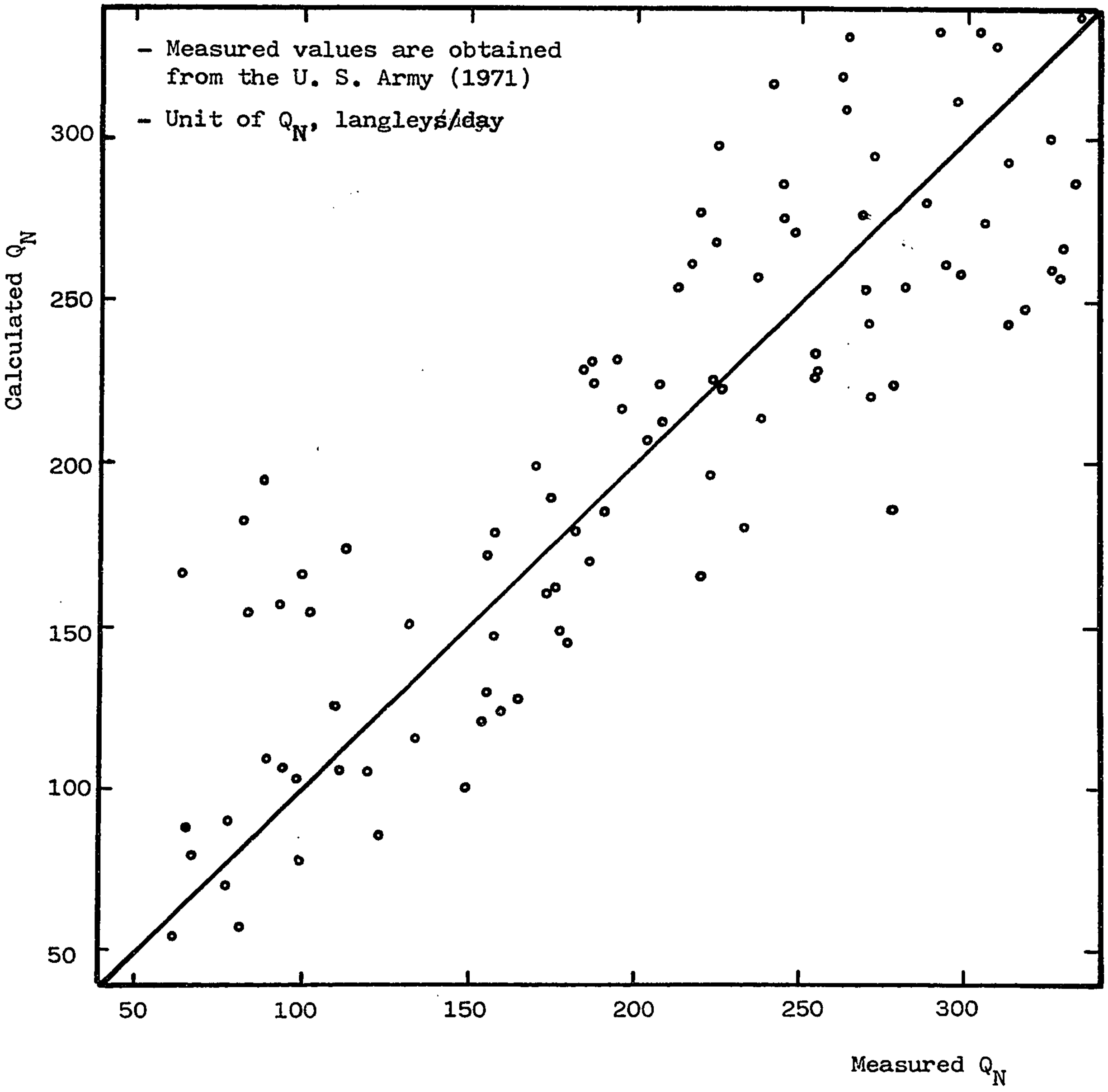


Figure 9 Correlation Between the Calculated and Measured Q_N After the Local Cloud Cover Relationship is Used, Fairbanks

3.3 Daily Radiation for Boston, Massachussetts

The same analysis for Boston, Massachussetts shows even better and more convincing results. Apart from the normal weather data, the meteorological data sheets supplied by NOAA also give additional data on S, the percentage of possible sunshine and Q_{TC}, the net shortwave radiation. For this reason better correlation is expected for Boston on the effect of cloud cover upon shortwave radiation. Further comparison however is not possible since measured data on net longwave and net all-wave radiation are not given.

Table E7 shows the daily values of Q_{TC}/ Q_T for Boston, for the months of December 1960, January 1961 and February 1961. As mentioned, the values of Q_{TC} are given together with the weather data. Q_T are calculated as usual using the equations outlined in Chapter 2.

3.3.1 Local Correlation for Cloud Cover Effect

Figure 10 shows the correlation between the calculated and measured values of Q_{TC}, the calculated quantities obtained using Scott's relationship (Equation 55). It is seen that the correlation is better than that of Fairbanks. The points are closely and evenly scattered about the theoretical line, except for lower values where the calculated values are considerably higher than the measured values.

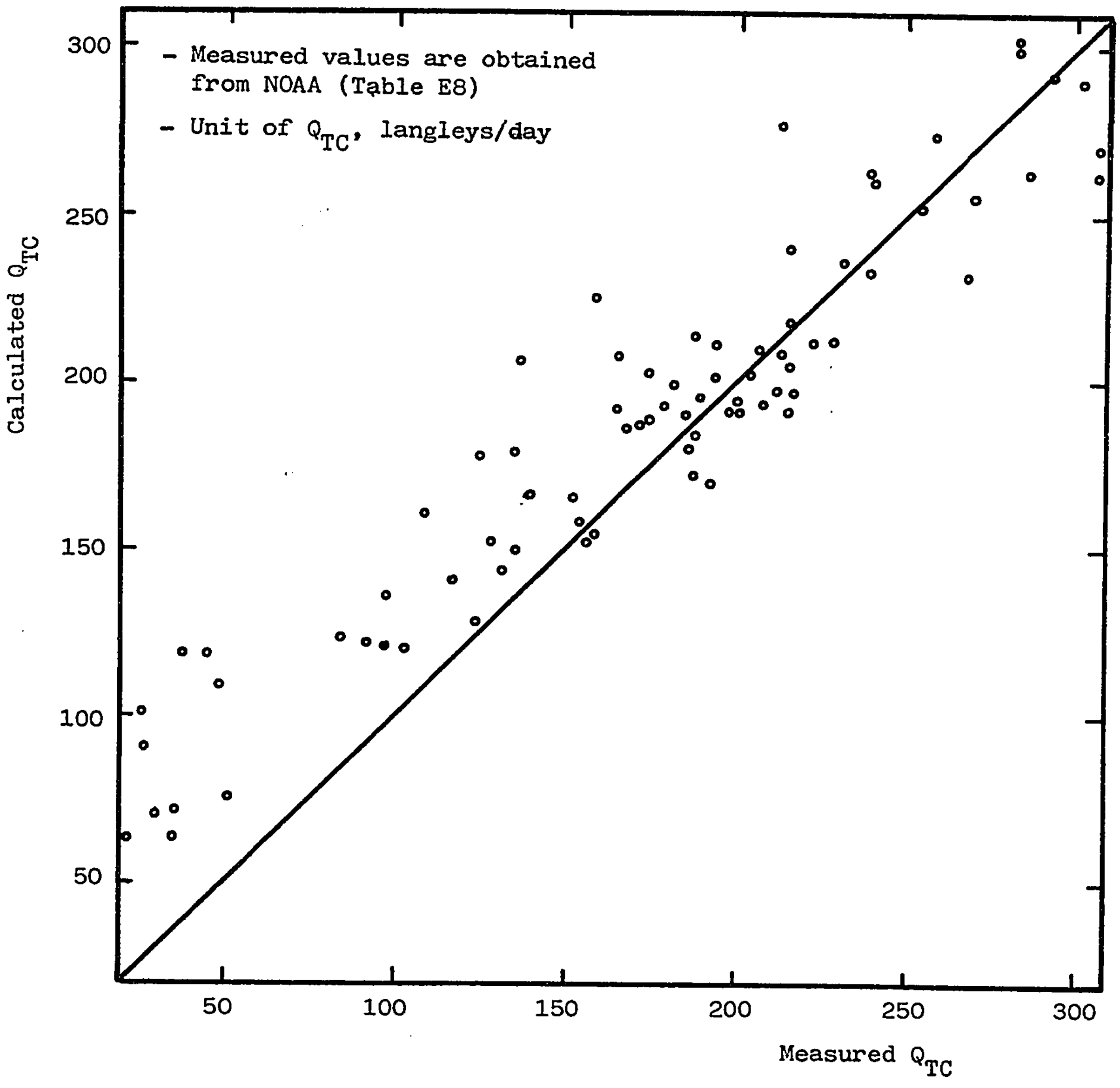


Figure 10 Correlation Between the Calculated and Measured Q_{TC}, Boston

Since both the values of C_s and S are known for each day, the daily values of Q_{TC}/Q_T in Table E7 can be plotted against C_s^2 or S, the results shown in Figures 11 and 12, respectively. Using linear regression, the following relationships are obtained:

From Figure 11

$$\frac{Q_{TC}}{Q_T} = 1 - 0.77\, C_s^2 \tag{69}$$

(with correlation coefficient = 0.78).

From Figure 12

$$\frac{Q_{TC}}{Q_T} = 0.16 + 0.84\, S \tag{70}$$

(with correlation coefficient = 0.86)

Note that Equation 69 does not differ very much from the general relationship proposed by Scott.

The daily values of S can also be plotted directly against C_s^2 to obtain a relationship between the two. A linear relationship is expected from the plots; however the points are widely scattered as seen in Figure 13. Using the linear regression method outlined in Appendix C, the following relationship is obtained which best fit the points

$$\begin{aligned} S &= 1 - 0.92\, C_s^2 \\ &= (1 - 0.96\, C_s)(1 + 0.96\, C_s) \end{aligned} \tag{71}$$

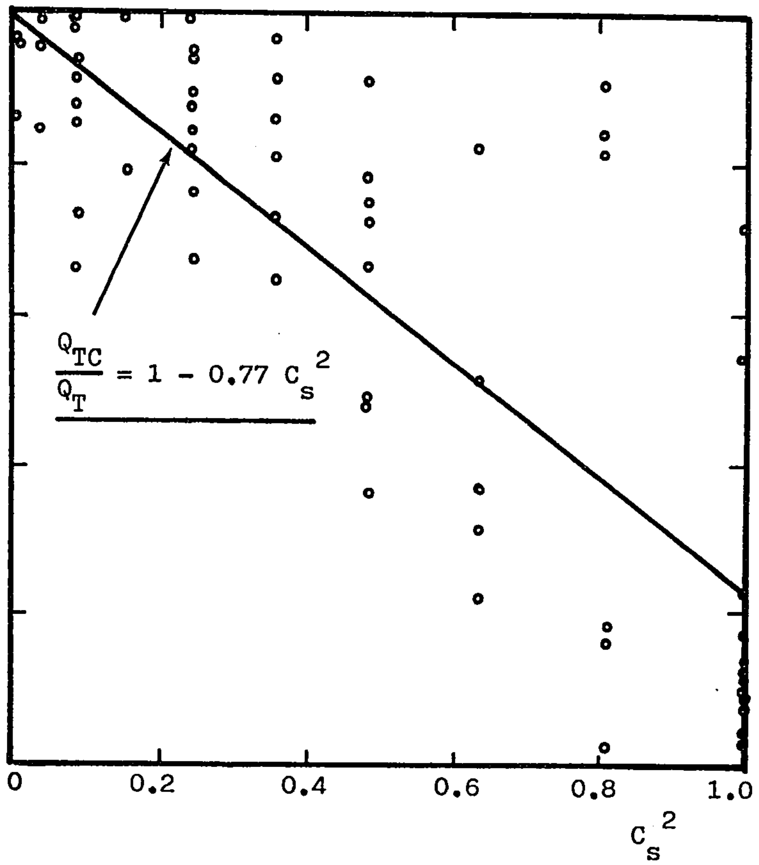


Figure 11 Plot of Q_{TC}/Q_T Against C_s^2, Boston

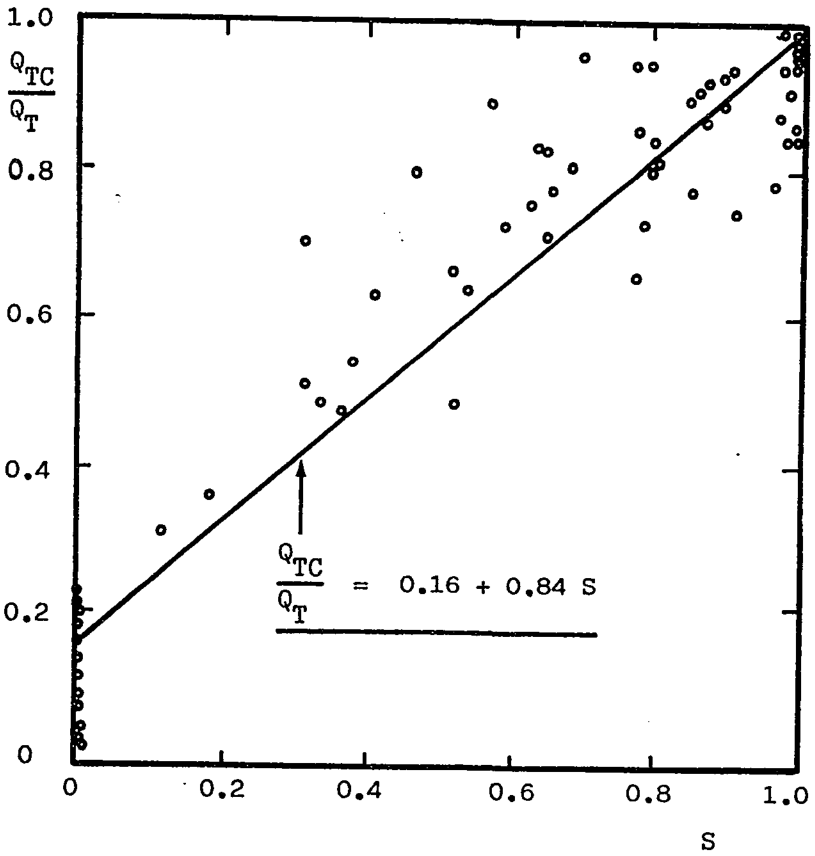


Figure 12 Plot of Q_{TC}/Q_T Against S, Boston

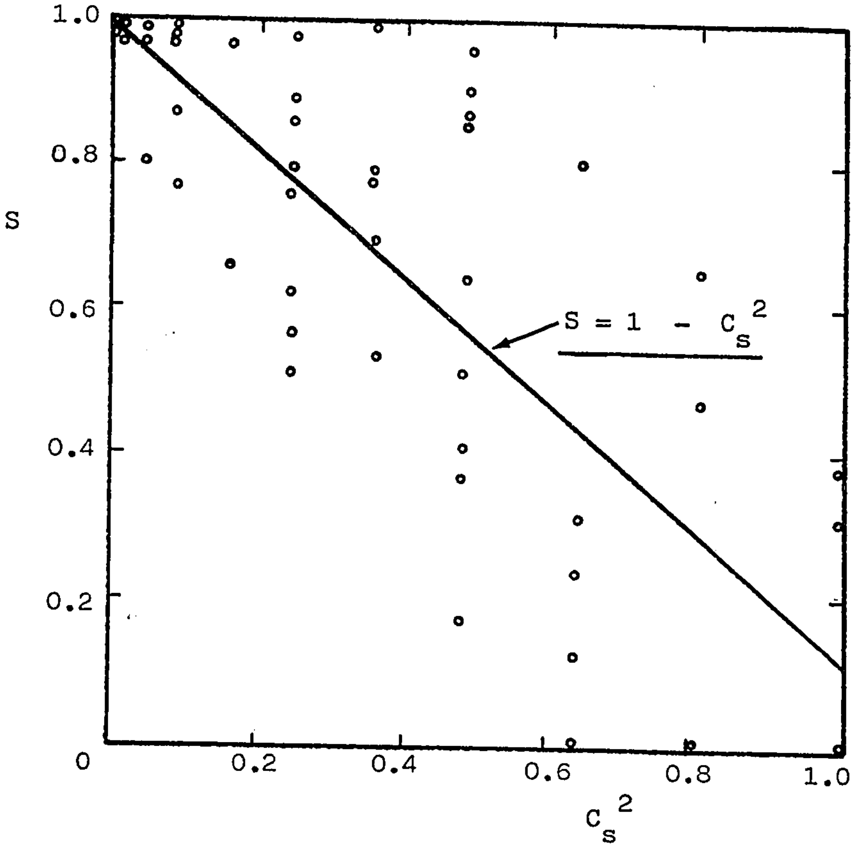


Figure 13 A Plot of S Against C_s^2, Boston

with the correlation coefficient = 0.81

This relationship is in agreement to the work of Scott (1964), who found for Camp Tuto, Greenland

$$S = (1 - C_s)(1 + C_s) \qquad (57)$$

The values of Q_{TC} for Boston can now be calculated again using the local relationship of Equation 69 or Equation 70. The new values of Q_{TC} and the measured data are tabulated in Table E8. The new correlation between the calculated and the measured values are shown in Figure 14, which gives a better correlation than Figure 10. The correlation coefficient is improved from 0.91 in Figure 10 to 0.95 in Figure 14.

3.4 Daily, Monthly and Seasonal Heat Flux

All heat fluxes considered previously were daily heat flux with the intention of comparing the calculated results to that of the available measured data. The equations used for the calculations are specifically for the computation of daily heat flux only, and some of these equations have to be modified when a period made up of a number of days is being considered. In this thesis however we are more concerned with the seasonal heat flux, and as will be seen in this section, the calculated heat flux will be more accurate as the number of days taken into consideration increases.

For this purpose, only the net shortwave radiation, Q_{TC} will be analysed since measured data on these values are available for both Fairbanks and Boston.

3.4.1. Fairbanks, Alaska

Table 4 on pages 59 and 60 shows the daily values of computed net shortwave radiation, the measured data and their

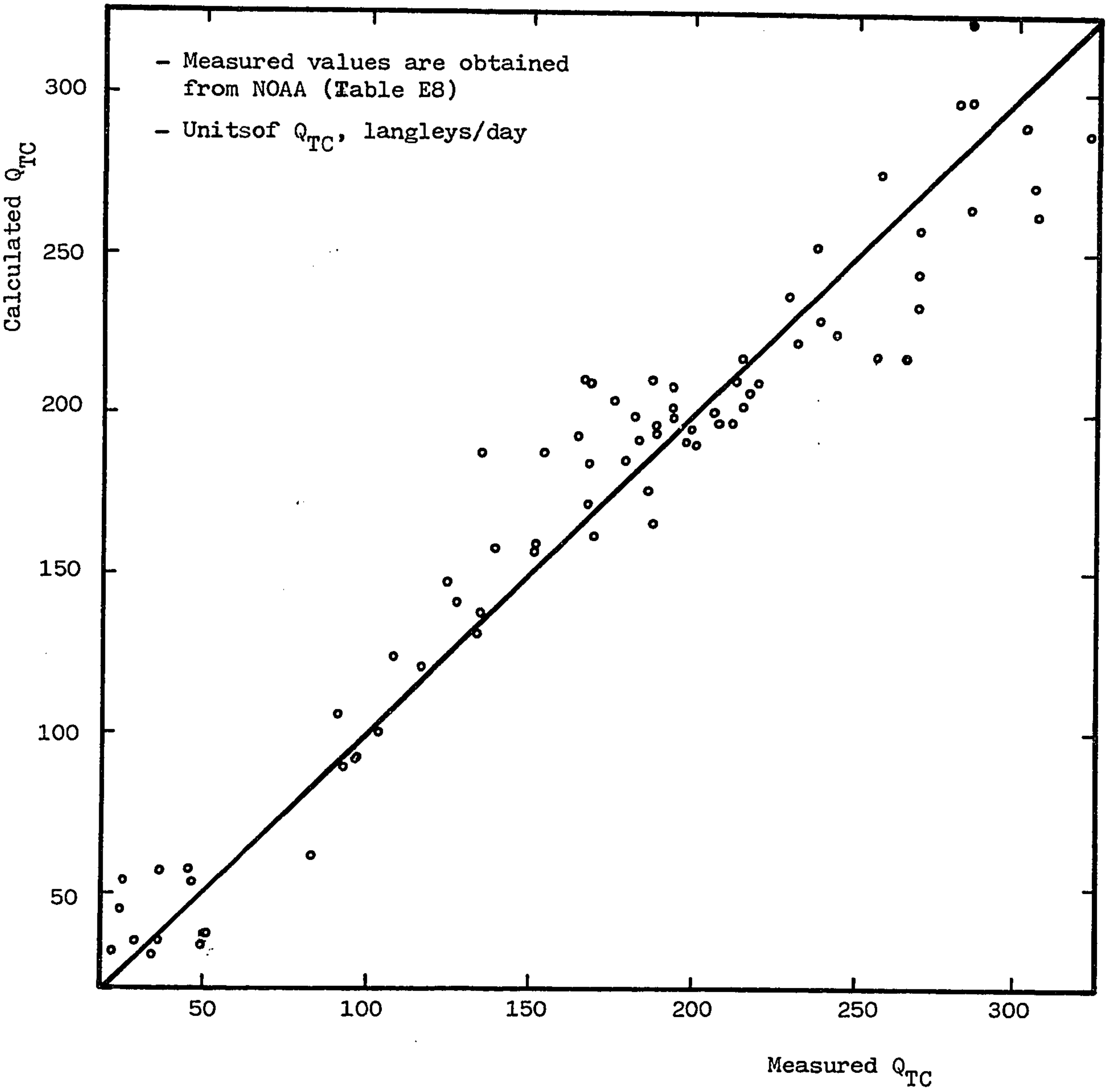


Figure 14 Correlation Between the Calculated and Measured Q_{TC} After the Local Cloud Cover Relationship is Used, Boston

percentage differences. It is seen that the daily percentage error between the calculated values and the data varies from 0% to a maximum of 120%, with the mean error of 21% over the months.

Tables 5a and 5b show the monthly and the seasonal net shortwave radiation, respectively. The maximum error for the monthly period is now reduced to 35.7%, with the mean error being 17.4% over the five months. For the seasonal period the error is reduced to 13.0%.

Tables 4 and 5 thus verify the fact that when heat flux over a surface is calculated over a longer period, the result obtained will be more accurate. This is because the daily calculated values fluctuate about the actual values. The positive and negative differences tend to cancel out each other over long time periods.

3.4.2 Boston, Massachussetts

The analysis is repeated for Boston and it will be seen that the expected results obtained are even more satisfactory.

Table 6 shows the daily computed and measured values of Q_{TC} for Boston. The percentage error varies from 0 to 50% with 13.1% as the mean difference over the three months. Tables 7a and 7b show respectively the monthly and seasonal values of Q_{TC}. For the monthly periods the error variation is only from 1.7 to 5.2%. The error for the seasonal period is still reduced to 2.9%.

Date	May 1971			June 1971			July 1971		
	Cal.	Data	%Δ	Cal.	Data	%Δ	Cal.	Data	%Δ
1	418	559	-25.2	581	-	-	435	407	6.9
2	380	566	-32.9	424	457	-7.2	432	525	-17.7
3	279	-	-	542	621	-12.7	596	606	-1.7
4	339	485	-30.1	589	648	-9.1	359	476	-24.6
5	393	566	-30.6	589	648	-9.1	429	618	-30.6
6	288	457	-37.0	543	705	-23.0	491	656	-25.1
7	224	199	12.3	660	644	2.5	487	578	-15.7
8	294	352	-16.5	634	703	-9.8	485	502	-3.4
9	357	609	-41.4	361	602	-40.0	482	618	-22.0
10	300	362	-17.1	497	515	-3.5	348	490	-29.0
11	303	471	-35.7	554	582	-4.8	267	206	29.6
12	238	356	-33.1	436	363	20.1	262	115	127.8
13	424	578	-18.1	643	578	11.2	264	146	80.8
14	375	540	-30.6	282	383	-36.4	268	308	-13.0
15	244	356	-31.5	366	540	-32.2	474	518	-8.5
16	245	313	-21.7	366	576	-36.4	410	527	-22.0
17	563	642	-12.3	440	681	-35.4	339	592	-42.7
18	323	623	-48.2	366	520	-29.6	513	580	-11.6
19	387	371	4.3	434	546	-20.5	508	567	-10.4
20	392	407	-3.7	493	410	20.2	256	327	-21.7
21	329	565	-41.8	430	491	-12.4	332	515	-35.5
22	397	524	-24.2	551	665	-17.1	546	592	-7.8
23	399	533	-25.1	598	625	-4.3	451	552	-23.5
24	401	524	-23.5	672	676	-0.6	388	507	-23.5
25	463	606	-23.6	698	662	5.4	320	328	-2.4
26	407	508	-19.9	645	588	9.7	438	470	-6.8
27	410	577	-28.9	553	692	-20.1	246	288	-14.6
28	267	370	-27.8	368	389	-5.4	379	466	-18.7
29	347	413	-16.0	367	467	-21.4	372	537	-30.7
30	534	627	-14.8	499	502	-0.6	308	321	-4.5
31	418	524	-20.2				235	280	-16.1

Unit of Q_{TC} [langleys/day]

Table 4 Percentage Error Between the Daily Calculated and Measured Values of Q_{TC} , Fairbanks

Date	August 1971			September 1971		
	Cal.	Data	%Δ	Cal.	Data	%Δ
1	232	266	-12.8	154	139	10.8
2	359	396	-9.3	154	75	105.0
3	299	375	-20.3	151	68	122.0
4	351	268	31.0	146	126	15.9
5	291	291	0	187	220	-15.0
6	223	225	-0.9	184	314	-41.4
7	218	189	15.3	180	291	-38.1
8	215	163	31.9	211	202	4.5
9	214	-	-	135	-	-
10	272	200	36.0	280	304	-7.9
11	374	447	-16.3	276	314	-12.1
12	269	345	-22.0	300	285	5.3
13	207	365	-43.3	302	314	-3.8
14	405	395	2.5	257	306	-16.0
15	510	498	2.4	268	279	-3.6
16	453	479	-5.4	275	262	5.0
17	304	409	-25.7	112	113	-0.9
18	299	407	-26.5	270	270	0
19	190	221	-14.0	165	194	-14.9
20	185	101	83.2	133	115	15.6
21	239	229	4.4	131	209	-37.3
22	234	245	-4.5	242	249	-2.8
23	278	304	-8.6	188	241	-22.0
24	274	254	7.9	120	135	-11.1
25	225	273	-17.6	90	90	0
26	266	324	-17.9	157	149	5.3
27	302	382	-20.9	110	108	1.8
28	357	403	-11.4	178	191	-6.8
29	324	399	-18.8	82	37	121.6
30	207	248	-16.5	80	47	70.2
31	203	231	-12.1			

Unit of Q_{TC} [langleys/day]

Table 4 Percentage Error Between the Daily Calculated and Measured Values of Q_{TC} , Fairbanks (cont'd)

Month (1971)	No. of days data available	Q_{TC} (langleys)		
		Cal.	Data	%Δ
May	30	9,333	14,523	-35.7
June	29	14,061	16,479	-14.7
July	31	12,521	14,218	-11.9
August	30	8,347	9,332	-10.6
September	29	4,846	5,647	-14.2

Table 5a Percentage Error for the Monthly Calculated and Measured Values of Q_{TC}, Fairbanks

Period	No. of days data available	Q_{TC} (langleys)		
		Cal.	Data	%Δ
May - September 1971	149	52,388	60,199	-13.0

Table 5b Percentage Error for the Seasonal Calculated and Measured Values of Q_{TC}, Fairbanks

Date	December 1960			January 1961			February 1961		
	Cal.	Data	%Δ	Cal.	Data	%Δ	Cal.	Data	%Δ
1	157	152	3.7	31	40	-22.5	261	306	-14.7
2	206	217	-5.1	198	208	-4.8	271	305	-11.1
3	204	176	15.9	194	179	8.4	188	136	38.2
4	202	194	4.1	185	171	8.2	44	25	76.0
5	199	182	9.3	202	214	-5.6	279	327	-14.7
6	188	155	21.3	100	103	-2.9	278	214	29.9
7	141	128	10.1	161	170	-5.3	287	320	-10.3
8	138	138	1.5	171	167	2.4	290	302	-4.0
9	197	212	-7.1	200	194	3.1	293	294	-0.3
10	102	97	5.2	210	213	-1.4	147	125	17.6
11	158	140	12.9	210	167	25.7	124	109	13.8
12	31	22	40.9	218	216	0.9	252	239	5.4
13	165	187	-11.7	159	193	-17.6	298	283	5.3
14	193	208	-7.2	121	117	3.4	92	98	-6.1
15	184	168	9.5	35	30	16.7	312	299	4.4
16	10	8	25.0	35	36	-2.8	323	286	12.9
17	191	215	-11.2	222	232	-4.3	296	282	5.0
18	190	201	-5.5	225	244	-7.8	53	47	12.8
19	105	92	14.1	210	188	11.7	217	266	-18.4
20	190	202	-5.9	37	52	-28.8	340	372	8.6
21	8	6	33.3	233	269	-13.4	346	336	3.0
22	190	202	-5.9	236	229	3.1	323	353	-8.5
23	191	198	-3.5	218	194	12.4	34	26	30.8
24	37	147	-74.8	218	159	37.1	57	46	23.9
25	113	122	-7.4	243	270	-10.0	58	38	52.6
26	191	185	3.2	200	207	-3.4	131	134	-2.2
27	193	165	17.0	229	239	-4.2	340	270	25.9
28	195	200	-2.5	253	253	0	61	84	-27.4
29	31	35	-11.4	156	270	-5.2			
30	176	186	-5.4	263	286	-8.0			
31	196	189	3.7	275	258	6.6			

Unit of Q_{TC} [langleys/day]

Table 6 Percentage Error Between the Daily Calculated and Measured Values of Q_{TC} , Fairbanks

Month	Q_{TC} (langleys)		
	Cal.	Data	%Δ
December 1960	4,647	4,727	1.7
January 1961	5,450	5,751	-5.2
February 1961	6,140	5,922	3.7

Table 7a Percentage Error for the Monthly Calculated and Measured Values of Q_{TC}, Boston

Period	Q_{TC} (langleys)		
	Cal.	Data	%Δ
December 1960 - February 1961	15,925	16,400	-2.9

Table 7b Percentage Error for the Seasonal Calculated and Measured Values of Q_{TC}, Boston

3.5 Conclusion

In the computations of net shortwave and longwave radiation the local relationships should be used if possible. As shown earlier in this chapter, by using local relationships on the effect of clouds upon shortwave and longwave radiation, the values of the calculated heat fluxes are closer to those of the measured ones. The correlation will be better if the heat fluxes are to be calculated over long time periods, and as seen in the previous section the more days are considered over a period, the lesser will be the error.

Calculations for Fairbanks however did not give as good results as that for Boston. For Fairbanks, the net radiation measured at one station is used to compare the radiation flux calculated from the weather data of a different station. Though the temperatures may not vary considerably, the amount of cloud cover present over one location may vary considerably from that of a neighbouring location. Since the amount of net radiation received on a surface is very much dependent on its surface properties and the amount of cloud cover, its value measured or calculated may vary considerably between the two stations. This explains a relatively poor correlation between the measured and the calculated values for Fairbanks.

For Boston, both the weather data and the heat flux measurements are recorded at the same weather station. For this reason a reasonable degree of accuracy is obtained between the calculated and the measured values of net shortwave radiation.

CHAPTER 4

THE CONVECTIVE HEAT FLUX AND SURFACE COEFFICIENT

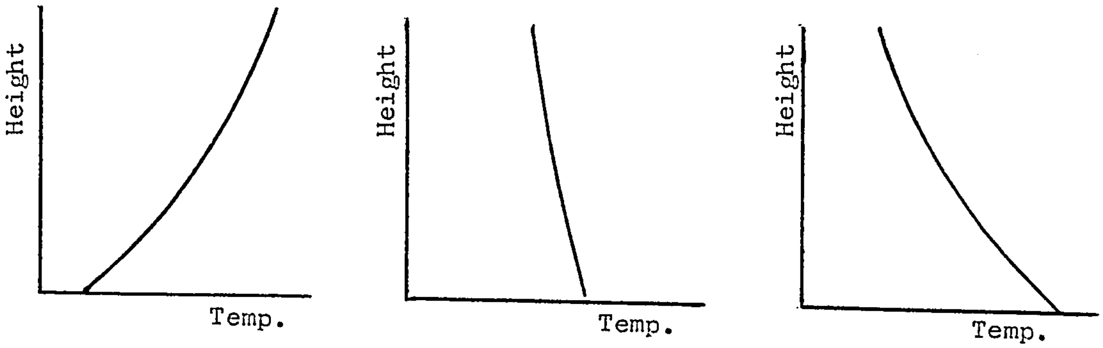
4.1 Introduction

The convective heat flux is due to the movements of fluid masses and is related to the changes in temperature, wind velocity and concentration values from one point to another. If the air is completely still and the ground is at a lower temperature than the air, the air nearest the surface will have the greatest density, and the air profile will be stable. In these conditions heat transfer downwards takes place by conduction only, and the conductance or surface heat transfer coefficient is obtained by dividing the thermal conductivity of the air by the distance between the surface and the reference height at which the temperature and wind speed are measured. On the other hand, if the surface is warmer than the higher layers, the air next to the surface has a lower density than the higher layers, and therefore it has a tendency to rise. The density profile is unstable, and for a large enough difference, convection currents will arise as the warmer air rises and cooler air flows down to replace it. Under these circumstances heat is transferred both by conduction and convection.

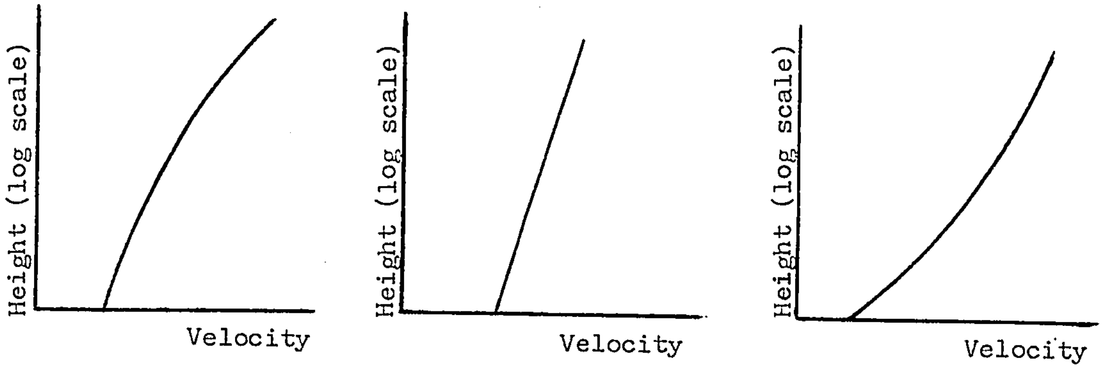
4.2 Atmospheric Stability

If the air over the ground surface moves horizontally, a mechanical turbulence is generated in the air by the irregularities in the surface profile. The total turbulence depends on the stability of the thermal profile, buoyancy effects or thermal turbulence, as well as the mechanical turbulence.

The diagrams below show the air temperature and velocity profiles for three cases of atmospheric stabilities; stable, neutral and unstable. In a typical day the temperature and the velocity profiles will be stable at night time as cooling of the ground takes place by longwave radiation. As the night ends, the ground surface begins receiving shortwave radiation and eventually with the heat of the sun, the air temperature attains a gradient near the adiabatic lapse rate, a condition of neutral stability. As the radiation increases, the



STABLE NEUTRAL UNSTABLE



surface temperature rises above that of the overlying air layers, and the air temperature and velocity profiles become unstable.

As will be briefly explained in the next section the measure of stability which is usually used is the Richardson number which depends on the ratio of the air temperature gradient to the square of the wind velocity gradient. The application of stability factors in the calculation of surface coefficient and the convective heat flux will also be discussed in this chapter.

4.3 Richardson numbers

The Richardson number is defined as the ratio of the buoyant force of the atmosphere to that of its eddy shear stress.
The flux Richardson number is defined as

$$R_f = \frac{g\,\overline{\rho' \ w'}}{\tau \frac{\partial u}{\partial z}} = \frac{g\,\overline{\rho' \ w'}}{\rho\, u_*^{\,2} \frac{\partial u}{\partial z}} \tag{72}$$

The gradient Richardson number is defined as

$$R_i = \frac{g\left[\frac{\partial T}{\partial z} + \Gamma\right]}{T\,(\frac{\partial u}{\partial z})^2} \tag{73}$$

where

ρ' - fluctuation in air density
w' - fluctuation in the velocity of the air
T - temperature of the air

τ - shear stress at the surface

z - height above the surface

$\frac{\partial u}{\partial z}$ - velocity gradient

u_* - friction velocity; the surface shear stress, a constant

u - wind velocity

Γ - adiabatic lapse rate $= \frac{1}{c_p} \frac{g}{g_c}$

Richardson numbers are used to characterise the stability of the atmosphere. R_i was originally used as a criterion for the onset of turbulence in a stably stratified flow but it is currently used as an indicator of the effect of thermal stratification on a turbulent flow. Brunt (1932) stated that when the Richardson number exceeded a certain value (¼ to 1), the turbulence will be completely damped out by the buoyancy effect of gravity.

4.4 Monin - Obukhov Length

This is another stability parameter and is defined as

$$L = \frac{\rho\, u_*^3}{k_o\, g\, \overline{\rho'\, w'}} = \frac{\rho\, c_p\, u_*^3\, T}{k_o\, g\, Q_H} \qquad (74)$$

where

k_o - Von Karman's constant $= 0.4$

Q_H - sensible heat flux at the surface

Monin - Obukhov length is always expressed in a dimensionless form z/L which relates the buoyant and frictional forces. This parameter is related to the flux Richardson number as

$$\frac{z}{L} = \frac{k_o z}{u_*} \frac{\partial u}{\partial z} R_f \tag{75}$$

The following values of parameters are often used as criteria for stability. The values however vary from system to system. Both R_f and z/L vary almost linearly with height. Lunardini (1977) obtained the following characteristic values for different stability cases:

Stability	$\frac{z}{L}$	R_i
Moderately stable	0.3	0.1
Neutral	0	0
Moderately unstable	-0.03	-0.08

The above relations show that either z/L or R_i can be used to denote the atmospheric stability.

4.5 Surface Roughness

The surface roughness height indicates irregularities in the surface and wind velocities are assumed zero at this level. The roughness Z_o is a function of stability but is usually evaluated from neutral conditions. Scott (1961) stated that the roughness Z_o for a paved surface can be taken to be 0.01 cm (0.0003 ft.). Table 8 below shows the values of surface roughness Z_o for various types of surfaces.

Surface Type	Surface Roughness (cm)
very smooth (mud flats, ice)	0.001
lawn grass up to 1 cm	0.1
downland thin grass up to 10 cm	0.7
thick grass up to 10 cm	2.3
thin grass up to 50 cm	5
thick grass up to 50 cm	9
smooth snow	0.5
smooth lawn	0.5

Table 8 Types of Surface and their Roughness Heights in cm, Van Wijk (1966)

4.6 Deacon's Equation for Velocity Profile

It is possible to represent the wind velocity profile by an equation which includes the effect of the stability of the air. Deacon (1949) chose an equation of the form

$$\frac{\partial u}{\partial z} = a\ z^{-\beta} \tag{76}$$

where β is a stability parameter and a, a function of the stability parameter.

The solution to Equation 76 is

$$u = \frac{a\,Z_o^{(1-\beta)}}{1-\beta}\left\{\left[\frac{z}{Z_o}\right]^{(1-\beta)} - 1\right\} \qquad (77)$$

Equation 77 is made to approach the logarithmic solution at heights close to the surface, where z/Z_o is small. This is because very close to the surface the effects of buoyancy are negligible.

If the parameter $a = \frac{u_*}{k_o\,Z_o}(1-\beta)$, the logarithmic or neutral solution is obtained as $z \rightarrow 0$. Hence

$$\frac{u}{u_*} = \frac{1}{k_o\,(1-\beta)}\left\{\left[\frac{z}{Z_o}\right]^{(1-\beta)} - 1\right\} \qquad (78)$$

Scott (1961) obtained the following values of β for each case of atmospheric stability. Although the values are generally accepted they are only estimates for a certain range of data.

Stability	β
Moderately stable	0.88
Neutral	1.0
Moderately unstable	1.08

4.7 Relationship Between Stability Parameters

The stability parameters mentioned so far can be related to one another as given in the three sets of equations derived by Lunardini (1977). These relationships can be summarised as follows

Flux Richardson number,
$$R_f = \begin{cases} \dfrac{\frac{z}{L}}{1 + 5\frac{z}{L}} & \text{neutral or stable} \quad (79a) \\[2ex] \dfrac{z}{L}\left[1 - 16\dfrac{z}{L}\right]^{\frac{1}{4}} & \text{unstable} \quad (79b) \end{cases}$$

Gradient Richardson number,
$$R_i = \begin{cases} R_f & \text{neutral or stable} \quad (79c) \\[2ex] \dfrac{z}{L} & \text{unstable} \quad (79d) \end{cases}$$

Stability parameter,
$$= \begin{cases} 1.00 & \text{neutral} \quad (79e) \\[2ex] 1 - \ln\left[1 + 5\dfrac{z}{L}\right] & \text{stable} \quad (79f) \\[2ex] 1 + \left\{\dfrac{\ln\left[1 - 16\frac{z}{L}\right]}{4\ln\frac{z}{z_o}}\right\} & \text{unstable} \quad (79g) \end{cases}$$

Finally the above stability equations can be tabulated for each case of stability:

Stability	$\frac{z}{L}$	R_f	R_i	β $(10<\frac{z}{L}<160)$
Neutral	0	0	0	1
Moderately stable	0.3	0.12	0.12	0.60 - 0.82
Moderately unstable	-0.03	0.033	-0.03	1.02 - 1.05

4.8 Aerodynamic Surface Coefficient Equations

From the definition of the eddy coefficient of momentum

$$\varepsilon_m = \frac{u_*^2}{\frac{\partial u}{\partial z}} = k_o \, u_* \, Z_0 \left(\frac{z}{Z_0}\right)^{\beta}$$

and from Equation 78, the following equation is obtained for the eddy coefficient of momentum

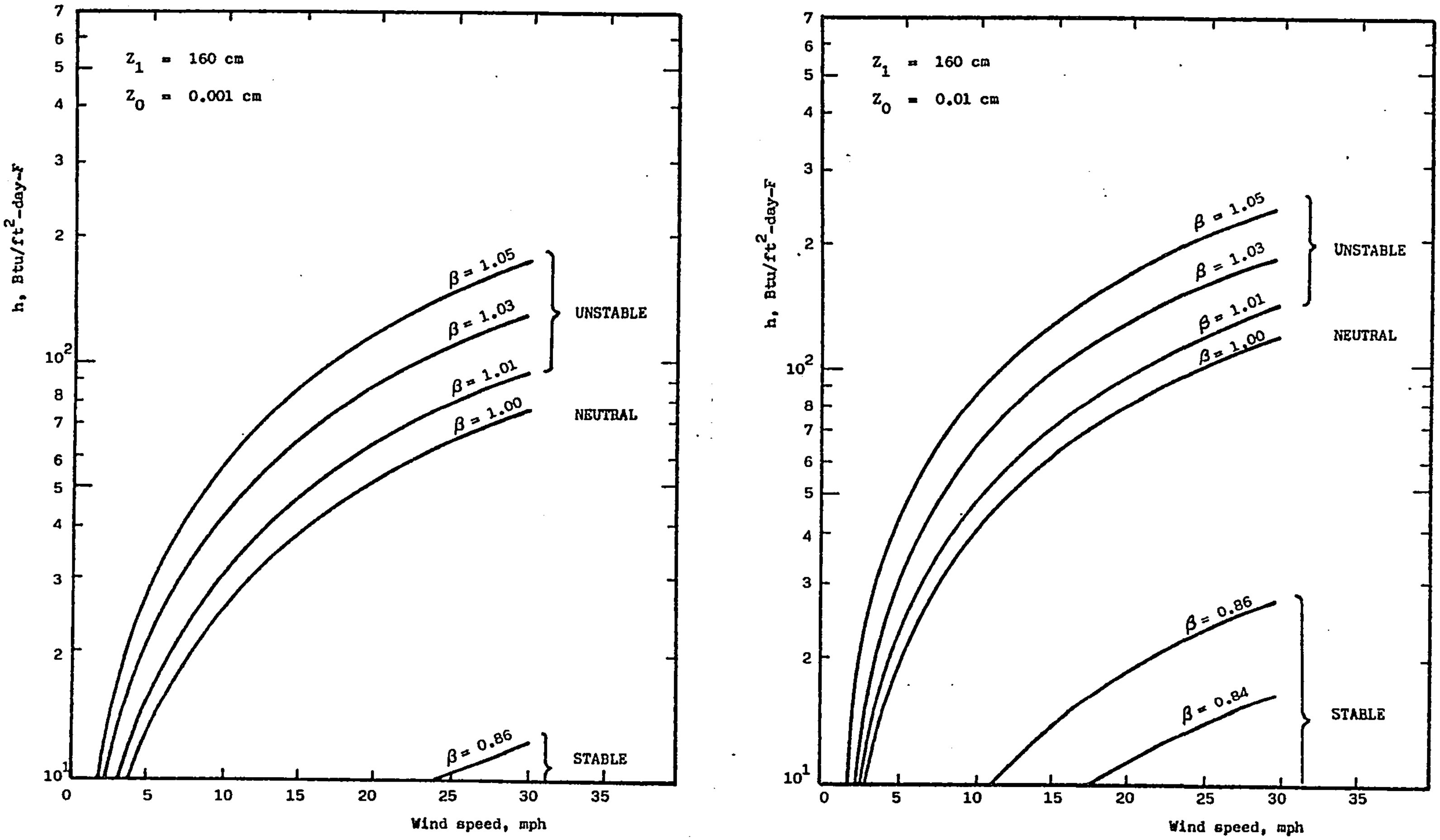
$$\varepsilon_m = \frac{k_o^2 \, Z_0 \, (1 - \beta) \left(\frac{z}{Z_0}\right)^{\beta} u_1}{\left(\frac{Z_1}{Z_0}\right)^{1 - \beta} - 1}$$

By analogy, the eddy coefficient of sensible heat, ε_h can be obtained and from the definition of the turbulent Prandtl number

$$P_t = \frac{\varepsilon_m}{\varepsilon_h}$$

the following surface heat transfer coefficient equations are finally obtained for each case of atmospheric stability, Lunardini (1977)

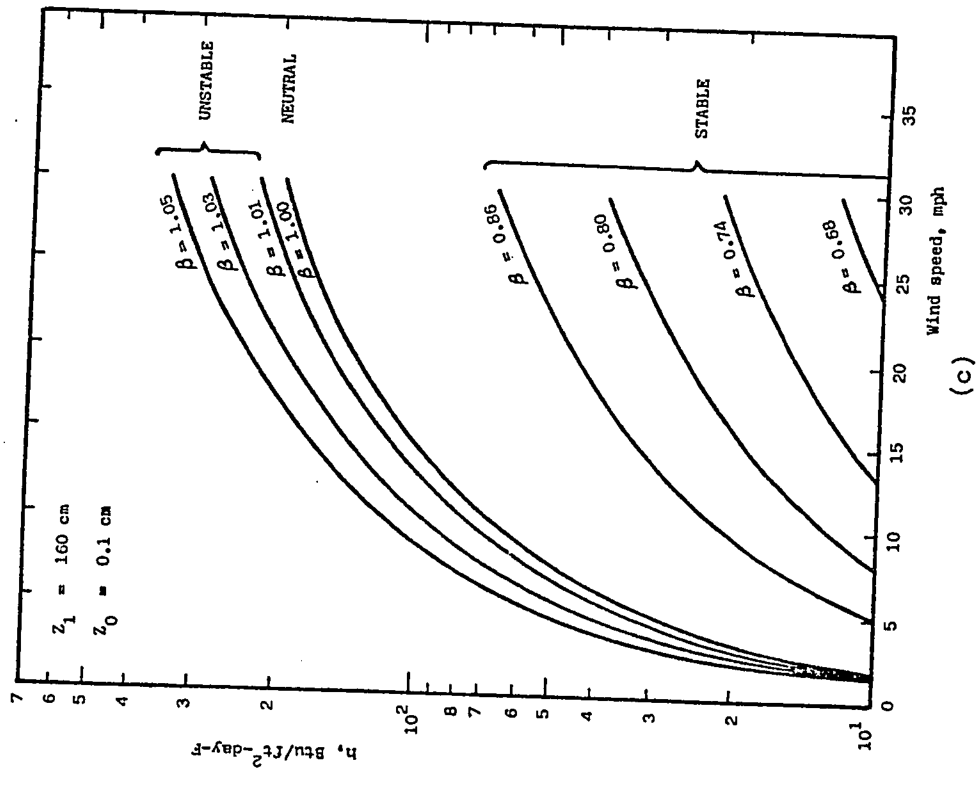
$$\frac{h}{\rho \, c_p \, k_o^2 \, u_1} = \left[\begin{array}{lll} \dfrac{1}{\ln^2\left(\dfrac{Z_1}{Z_0}\right)} & \text{neutral} & (80a) \\[3ex] \left[\dfrac{1 - \beta}{\left(\dfrac{Z_1}{Z_0}\right)^{(1 - \beta)} - 1}\right]^2 & \text{stable} & (80b) \\[3ex] \dfrac{2 \, (1 - \beta)^2}{\left[\left(\dfrac{Z_1}{Z_0}\right)^{(1 - \beta)} - 1\right]^2 \left[\left(\dfrac{Z_1}{Z_0}\right)^{(1 - \beta)} + 1\right]} & \text{unstable} & (80c) \end{array} \right.$$



(a)

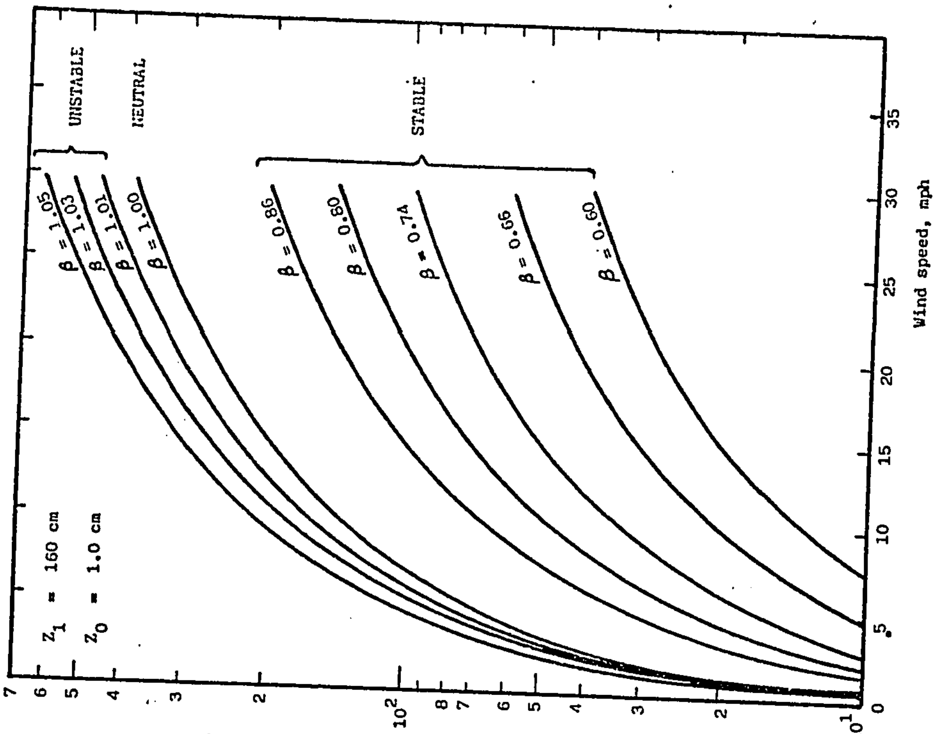
(b)

Figure 15 The Surface Coefficient Versus Wind Speed at Various Conditions of Stability for Four Surface Roughness



z_1 = 160 cm
z_0 = 0.1 cm
UNSTABLE
NEUTRAL
STABLE
β = 1.05
β = 1.03
β = 1.01
β = 1.00
β = 0.86
β = 0.80
β = 0.74
β = 0.68
h, Btu/ft^2-day-F
7
6
5
4
3
2
10^2
8
7
6
5
4
3
2
10^1
0
5
10
15
20
25
30
35
Wind speed, mph

(c)



z_1 = 160 cm
z_0 = 1.0 cm
UNSTABLE
NEUTRAL
STABLE
β = 1.05
β = 1.03
β = 1.01
β = 1.00
β = 0.86
β = 0.80
β = 0.74
β = 0.66
β = 0.60
h, Btu/ft^2-day-F
7
6
5
4
3
2
10^2
8
7
6
5
4
3
2
10^1
0
5
10
15
20
25
30
35
Wind speed, mph

(d)

Figures 15 show the charts of surface coefficient versus the wind speed for various values of β, for four different values of surface roughness, plotted from Equations 80. In these charts the values of air density and specific heat are taken as 0.08 lb/ft^3 and 0.24 Btu/lb-F, respectively. These are values at air temperature of 32 ^oF; an air temperature difference of ± 20 ^oF will result in a difference of less than 10% in h.

It is clearly observed that when the surface roughness increases the surface coefficient at the same wind speed and degree of stability increases considerably. For pavement surfaces of surface roughness Z_o = 0.01 cm (0.0003 ft), the surface coefficient for a typical day can vary from about 10 to 240 Btu/ft^2-day-F.

4.9 Other Surface Coefficient Equations

Equations 80, though accurate, are incovenient to use particularly if the daily or periodic surface coefficient is to be calculated. In a typical day the equation for neutral atmospheric condition is valid at sunset or sunrise, the equation for stable condition valid during the night, and the equation for unstable condition valid during the day time. Other workers therefore tried to simplify the aerodynamic equations or used empirical equations for the calculation of surface coefficient. The results obtained using different methods or equations vary so widely that it is difficult to estimate the best method.

4.9.1 Seller's Equation

Sellers (1965) proposed an aerodynamic equation for vertical heat flux by convection when wind velocity increases logarithmically with height

$$Q_H = \rho c_p k_o^2 \left\{ \frac{\Delta u \, \Delta T}{\ln^2 \left[\frac{Z_1}{Z_o} \right]} \right\} \tag{81}$$

where

Δu – difference in wind speed between heights Z_1 and and Z_o above the surface

ΔT – temperature difference between heights Z_1 and and Z_o above the surface

Since at roughness height Z_o the air velocity is assumed zero, Equation 81 can be written for the surface coefficient

$$h = \frac{\rho c_p k_o^2 u_1}{\ln^2 \left[\frac{Z_1}{Z_o} \right]} \tag{82}$$

Equation 82 is identical to Equation 80a for neutral atmospheric stability. Sellers obviously assumed neutral stability to simplify the calculation for daily surface heat transfer coefficient.

By taking the values of Z_1, the standard height for the measurements of weather data to be 160 cm (5.25 ft), the air density 0.08 lb/ft^3 and the specific heat of the air to be 0.24 Btu/lb-F, Equation 82 is reduced to

$$h = 4.1\ u_1 \tag{83}$$

where u_1 is the wind velocity at height Z_1 in miles per hour and h, the surface coefficient in Btu/ft^2-day-F.

4.9.2 Equation Proposed by the U. S. Dept. of the Navy

The U. S. Department of the Navy (1955) proposed an empirical equation for the determination of surface heat transfer coefficient

$$h = (9.1 + 2.3\ u_1)\ (T_s - T_a)^{0.25} \tag{84}$$

This equation does not consider the stability conditions of the atmosphere or the roughness of the surface, however it does require the temperature difference between the atmosphere and the surface to be known.

4.9.3 Equation Proposed by ASHRAE, 1961

ASHRAE (1961) proposed yet another empirical equation for the calculation of surface heat flux coefficient

$$h = 16 + 7.7\ u_1 \tag{85}$$

Clearly, for any value of u_1, Equation 85 will give considerably higher values of h than any of the previous equations. Looking carefully at the charts in Figures 15, this equation is approximately related to Equation 80c, the case for unstable atmospheric condition (for Z_o = 0.01 cm). The values of h determined from Equations 83, 84 and 85 under similar conditions vary over such a wide range that the average result of these equations must be used for the surface coefficient.

4.10 Calculation and Comparison

For comparison analysis in this chapter weather data for the months of December 1965 for Morgantown, W. Virginia will be used since the hourly weather values are also known for each day. This is because the three cases of aerodynamic equations are more appropriately used to calculate the hourly surface coefficients and the hourly convective heat flux. The surface coefficients calculated from the daily weather data using Equations 83, 84 and 85 could then be compared to that of the average of the result obtained from the hourly data using the three aerodynamic equations.

Table 9 shows the hourly results for the first three days of the month of December 1965 for Morgantown. However, only the stable and unstable conditions are assumed; the equation for neutral stability is omitted since this condition only occurs in a relatively short time compared to the other two cases and since the exact time of its occurence is not known.

The third, fourth and fifth columns of Table 10 show the daily values of surface coefficients using Equations 83, 84 and 85

Hour	Stability	Dec. 1		Dec. 2		Dec. 3	
		u_1	h	u_1	h	u_1	h
1	Stable	5.8	8.8	13.8	21.0	9.2	14.0
2		5.8	8.8	13.8	21.0	6.9	10.5
3		5.8	8.8	13.8	21.0	5.8	8.8
4		5.8	8.8	12.7	19.3	6.9	10.5
5		5.8	8.8	13.8	21.0	5.8	8.8
6		5.8	8.8	11.5	17.5	5.8	8.8
7	Unstable	6.9	32.6	12.7	59.7	8.1	38.0
8		6.9	32.6	15.0	70.5	9.2	43.4
9		11.5	54.3	16.1	76.0	13.8	65.1
10		12.7	59.3	15.0	70.5	12.7	59.7
11		13.8	65.1	13.8	65.1	13.8	65.1
12		15.0	70.5	15.0	70.5	11.5	54.3
13		15.0	70.5	13.8	65.1	20.7	97.7
14		16.1	76.0	13.8	65.1	13.8	65.1
15		16.1	76.0	17.3	81.4	11.5	54.3
16		13.8	65.1	11.5	54.3	11.5	54.3
17		11.5	54.3	13.8	65.1	18.4	86.8
18		11.5	54.3	11.5	54.3	12.7	59.7
19	Unstable	11.5	17.5	11.5	17.5	10.4	15.8
20		11.5	17.5	8.1	12.3	10.4	15.8
21		13.8	21.0	9.2	14.0	11.5	17.5
22		12.7	19.3	9.2	14.0	12.7	19.3
23		13.8	21.0	10.4	15.8	11.5	17.5
24		13.8	21.0	10.4	15.8	11.5	17.5

Units : u_1 [mph] , h [Btu/ft^2-day-F]

Table 9 Hourly Calculation of Surface Heat Transfer Coefficients for Morgantown, W. V., using the Complete Aerodynamic Equations

Date	Wind Speed mph	Sellers (1965)	U.S.Army (1955)	ASHRAE (1961)	Aerodyn. Equations
1	10.9	44.7	44.5	99.3	36.8
2	12.6	51.7	49.6	113.0	42.0
3	12.6	51.7	49.6	113.0	38.0
4	14.4	59.0	55.0	126.3	38.9
5	12.1	49.6	48.1	109.2	40.5
6	9.2	37.7	39.4	86.8	33.8
7	6.9	28.3	32.5	69.1	22.9
8	9.2	37.7	39.4	86.8	36.1
9	6.9	28.3	32.5	69.1	19.5
10	5.7	23.4	28.9	59.9	16.9
11	8.1	33.2	36.1	78.4	23.7
12	7.5	20.8	34.3	73.8	20.8
13	9.8	40.2	41.2	91.5	33.5
14	7.5	30.8	34.3	73.8	27.3
15	7.5	30.8	34.3	73.8	19.7
16	3.5	14.4	22.3	43.0	10.5
17	9.2	37.7	39.4	86.8	34.9
18	9.2	37.7	39.4	86.8	33.1
19	6.9	28.3	32.5	69.1	23.4
20	2.9	11.9	20.5	38.3	9.2
21	3.5	14.5	22.8	43.0	10.9
22	10.4	42.6	43.0	98.1	30.8
23	8.6	35.6	37.6	82.2	27.8
24	9.2	37.7	39.4	86.8	33.9
25	12.1	49.6	48.1	109.1	39.5
26	6.9	28.3	32.5	169.1	24.5
27	8.6	35.3	37.6	82.2	26.4
28	8.1	33.2	36.1	78.4	16.8
29	8.6	35.3	37.6	82.2	28.8
30	12.1	49.6	48.1	109.2	41.4
31	13.8	56.6	53.6	122.3	44.6

Unit of h $\left[\text{Btu/ft}^2\text{-day-F}\right]$

Table 10 Daily Surface Coefficients Using Different Equations for Morgantown, W. V., Dec. 1965 respectively, in Btu/ft^2-day-F. Equation 84 is simplified by taking the average temperature difference between the atmosphere and the surface to be 2.8 °F (see Table A2, Appendix A). The daily average of the hourly surface coefficients obtained from the aerodynamic equations are listed in the sixth column of Table 10 to enable comparison to be made with the other daily values. It is observed that the results obtained from the equations proposed by Sellers (1965) and the U. S. Dept. of the Navy (1955) are quite close, especially for higher values of wind speed. The average of the aerodynamic equations gives values about 20% lower than these two values. ASHRAE's equation gives the highest value, about three times that given by the average of the aerodynamic equations.

4.11 Conclusion

Of the several equations for computing the surface heat transfer coefficients, the aerodynamic equations are probably the most acceptable procedure since the equations take into consideration the aerodynamic properties and activities of the atmosphere, and also the roughness condition of the surface. These two conditions greatly affect the magnitude of the coefficient. Lunardini (1977) also outlined similarity equations for the determination of surface coefficients. However, these equations could not be used readily since they require the magnitude of Monin - Obukhov length L to be known, whereas, as seen earlier in Equation 74, the determination of L requires the sensible heat at the surface to be known earlier. One advantage of the similarity equations is that these equations do not depend upon the roughness condition of the surface.

CHAPTER 5

SEASONAL ENERGY BALANCE AND CORRELATION

5.1 Introduction

In the previous two chapters much emphasis has been given to Fairbanks, Alaska and Boston, Massachussetts, over the calculation of shortwave and longwave radiations, and also to Morgantown, W. Virginia over the calculation of surface heat transfer coefficient. Both chapters have given a rough idea on the degree of accuracy expected for the results obtained from the various equations used, except for h which is only a comparison of the calculation values.

In this chapter the seasonal radiation heat flux is calculated for each of the thirty-two sites listed in Appendix A, by summing up the daily net radiation flux received or absorbed by the surface within the specified period. The heat transfer coefficient is then obtained using the aerodynamic equations discussed in the previous chapter. The seasonal surface temperature, the air and surface indexes and the n - factor are also calculated and compared with the values already listed in Appendix A. The dimensionless parameters Π_1 and Π_2 are next calculated and plotted for each of the site and the best correlation would then be obtained for these calculated values which should agree, to a certain degree of accuracy to that of the relationship predicted in Chapter 1.

The flowchart for the computation of daily and seasonal heat flux for the sites is given in Appendix D, together with the computer programme. A printout of the programme for Sioux Falls, S. Dakota (see Table A2, Appendix A) is also shown in Appendix D. For further clarification, a sample calculation is demonstrated for Sioux Falls in the same Appendix. The raw weather data used in the computations are listed in Appendix F.

5.2 Calculation Results for the Sites

The sample calculation demonstrated in Appendix D shows the procedure for calculating the daily net radiation and the surface coefficient. These calculations are repeated for each day of the season and the mean seasonal values are calculated. Next, the air index, the surface index, the surface temperature, and other parameters like P, Π_1, Π_2, etc. defined in Chapter 1 are calculated to enable correlations to be made for all sites. The seasonal values obtained for each site are summarised in Table 11.

Columns 1 and 2 of Table 11 refer to the case number and location of the sites. Symbols are also drawn for each site for easy identification when the results are plotted on different figures. Column 3 gives the mean net all-wave radiation for the season $\bar{Q}_N$, in Btu/ft^2-day. Columns 4 and 5 give the air and surface indexes respectively, in ^{o}F-days. These values differ slightly from those listed in Appendix A because of the slight temperature differences

1 Symbol & Case no.		2 Site	3 $\bar{Q}_N$ Btu/ft^2 day	4 I_a F-day	5 I_s F-day	6 n	7 h Btu/ft^2 day-F	8 M F-day	9 P F-day	10 Π_1	11 Π_2
-⊗-	1a	Fairbanks	710.7	3249.0	6002.1	1.85	38.3	53.7	6422	111.8	119.4
-○-	1b	"	723.4	3249.0	6350.4	1.95	37.5	57.7	6895	110.0	119.5
○	1c	"	560.4	3249.0	3192.0	0.98	42.6	41.6	4499	76.7	108.1
●	2a	Fairbanks	-90.0	4966.5	3701.4	0.75	43.1	32.5	5381	113.9	165.6
●	2b	"	-87.0	4966.5	3778.8	0.76	42.9	45.2	5374	83.6	118.9
●	2c	"	-120.3	4966.5	4070.0	0.82	43.7	38.9	5476	104.6	140.8
●	2d	"	-115.1	4966.5	4255.0	0.86	43.7	44.3	5453	96.0	123.1
●	2e	"	-112.4	4966.5	3486.9	0.70	43.2	48.3	5479	72.0	113.2
◑	3a	Kotzebue	-140.5	6824.4	6456.0	0.95	29.8	60.6	8092	106.0	133.0
-◑-	3b	"	630.3	2046.0	3548.5	1.73	47.7	36.7	4041	96.7	110.1
◑	3c	"	-148.1	6321.5	6514.7	1.03	28.7	65.6	7802	99.3	118.9
-◑-	3d	"	610.4	2270.4	3843.7	1.69	46.0	39.4	4035	97.3	102.2
◑	3e	"	-140.5	6824.4	6360.0	0.93	29.8	60.9	8073	104.5	133.0
-◑-	3f	"	630.3	2046.0	4092.0	2.00	47.7	36.7	4041	111.5	110.1
◑	3g	"	-148.1	6039.5	6020.0	1.00	28.7	65.6	7484	91.8	114.1
-◑-	3h	"	610.4	1914.0	4087.2	2.14	46.0	39.4	3984	103.7	101.1

Table 11 Calculated Seasonal Data for the 32 Sites

1		2	3	4	5	6	7	8	9	10	11
Symbol & Case no.		Site	$\bar{Q}_N$	I_a	I_s	n	h	M	P	Π_1	Π_2
⬒	4a	Boston	-22.6	434.7	212.4	0.49	49.9	9.2	461	23.2	50.4
⊟	4b	"	-13.7	434.7	259.6	0.60	49.9	7.7	451	33.7	58.4
⊟	4c	"	10.6	434.7	415.8	0.96	52.3	9.5	422	43.8	44.4
✕	5	Beckley	103.1	265.5	93.1	0.35	44.8	41.1	222	2.3	5.4
✕	6	Charleston	148.2	84.7	23.4	0.28	29.0	63.6	54	0.4	0.8
✕	7	Elkins	109.6	316.1	109.2	0.35	36.5	64.3	253	1.7	3.9
✕	8	Morgantown	130.0	162.5	110.0	0.68	50.2	45.6	85	2.4	1.9
✕	9	Clarksburg	215.0	161.2	46.9	0.29	51.4	23.3	132	2.0	5.7
◫	10a	Waterloo	182.5	1196.0	764.4	0.64	51.0	19.8	845	38.6	42.7
◧	10b	"	165.5	1196.0	752.7	0.63	62.3	13.2	683	57.0	51.8
▼	11a	Sioux Falls	69.8	1160.0	892.0	0.77	53.5	38.0	1029	23.4	27.1
▽	11b	[illegible]	185.6	1160.0	632.4	0.55	53.5	12.9	831	49.0	64.4
⬓	12a	Saginaw	-30.5	1551.0	1701.2	1.10	65.9	26.6	1769	64.2	66.5
⬓	12b	"	-22.7	1475.1	1632.0	1.10	63.7	28.5	1699	57.3	59.6
↑	13a	Presque Isles	55.0	2028.6	2890.4	0.93	53.2	35.7	1920	52.9	53.8
+	13b	"	128.8	2028.6	1550.4	0.76	49.2	24.2	1730	64.0	71.8

Table 11 Calculated Seasonal Data for the 32 Sites (Cont'd.)

between those listed in Appendix A and those obtained from the weather data listed in Appendix F. Consequently, the n - factor, listed in Column 6, also differs slightly from those listed in Appendix A.

Column 7 gives the surface heat transfer coefficients obtained using the aerodynamic equations discussed in the previous chapter. The values of M and P as defined in Chapter 1 are listed in Columns 8 and 9, respectively. Note that the equation for P is

$$P = \pm \frac{\bar{Q}_N \theta_s}{\bar{h}} + I_a$$

where the positive sign is used for thaw season, and the negative sign for freeze. Columns 10 and 11, respectively show the dimensionless parameters Π_1 and Π_2.

A plot of the n - factors against the air indexes is shown in Figure 16. The scatter is so high in this figure that it is difficult to determine accurately a value of n for a particular known value of the air index. The relationship between n and the air index will be more clearly observed when the same results are plotted using different coordinates, as will be described in the following sections.

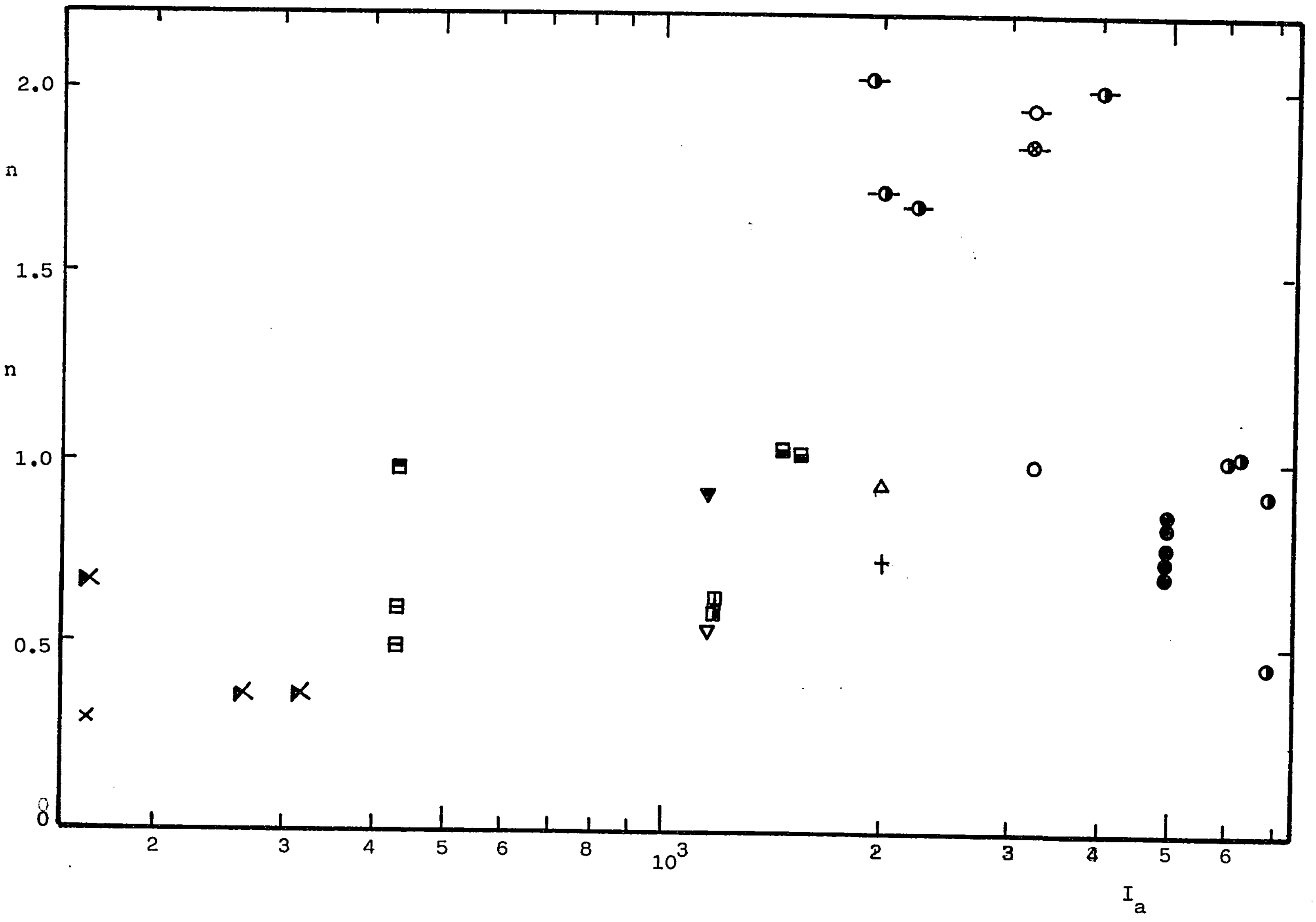


Figure 16 A Plot of n Against I_a for the Sites

5.3 Π_1 and Π_2 Relationship

As predicted in the theory in Chapter 1, the dimensionless parameters Π_1 and Π_2 are related by the equation

$$\Pi_1 = \Pi_2 - \left[\sqrt{1 + 2\Pi_2} - 1\right] \tag{22}$$

This theoretical relationship is represented in Figure 17 by the continuous line. The curve is almost linear except for the small curvature at lower values of Π_1 and Π_2. The calculated values of Π_1 and Π_2 from Table 11 when plotted on Figure 17 do not fall exactly on the theoretical curve; they are however distributed quite evenly about the curve. The figure shows that the theoretical relationship is particularly accurate for low values of Π_1 and Π_2 (W. Virginia sites). At higher values the points tend to fall off from the theory.

5.3.1 Correlation Between the Calculated Values of Π_1 and Π_2

An empirical correlation can be obtained which best represents the data of Π_1 and Π_2 shown in Figure 17.

Equation 22 can be rewritten as

$$\Pi_2 - \Pi_1 + 1 = \sqrt{1 + 2\Pi_2}$$

or

$$\ln(\Pi_2 - \Pi_1 + 1) = k_1 \ln(1 + 2\Pi_2) + k_2$$

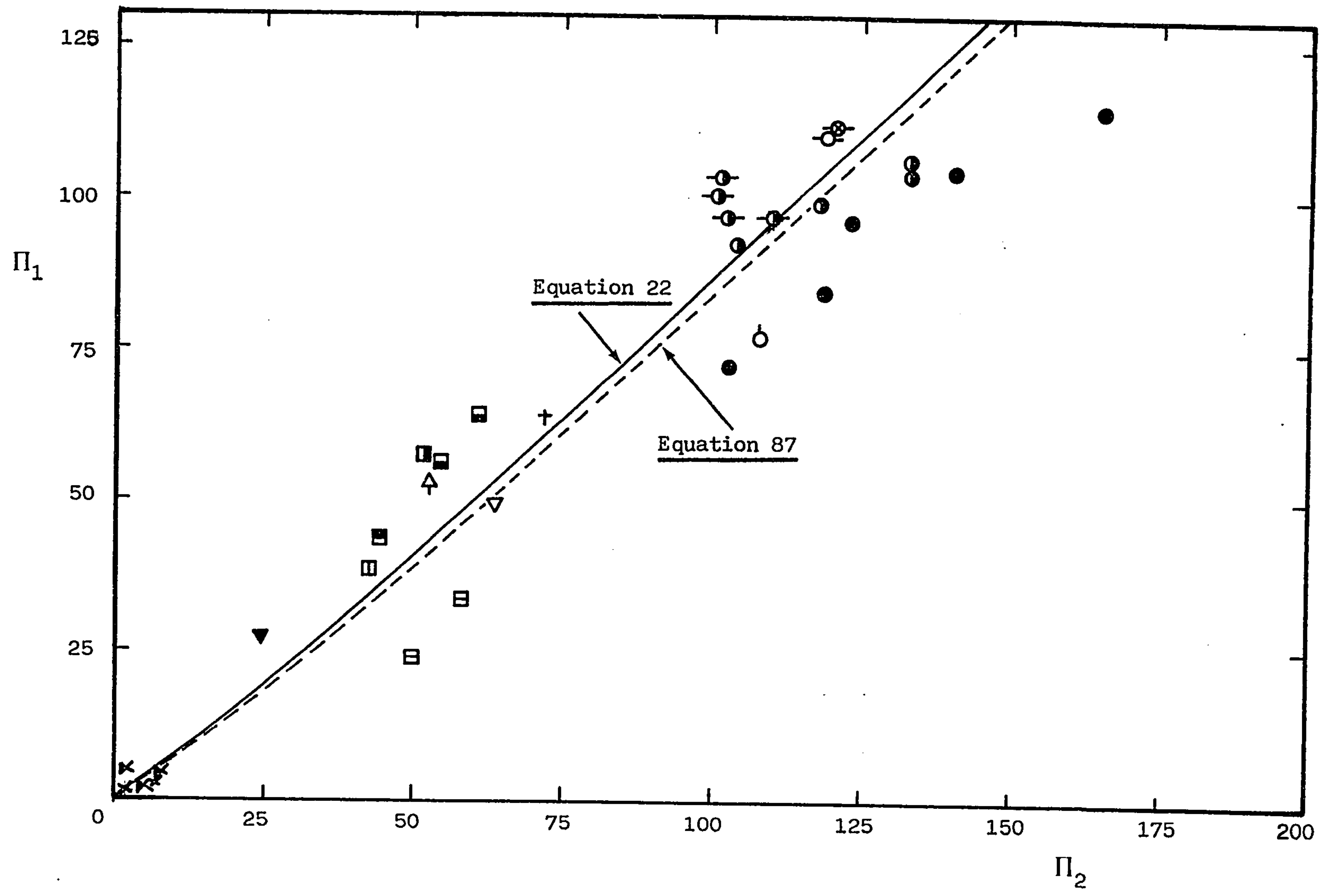


Figure 17 The Calculation Results Plotted on a Graph of Π_1 Against Π_2

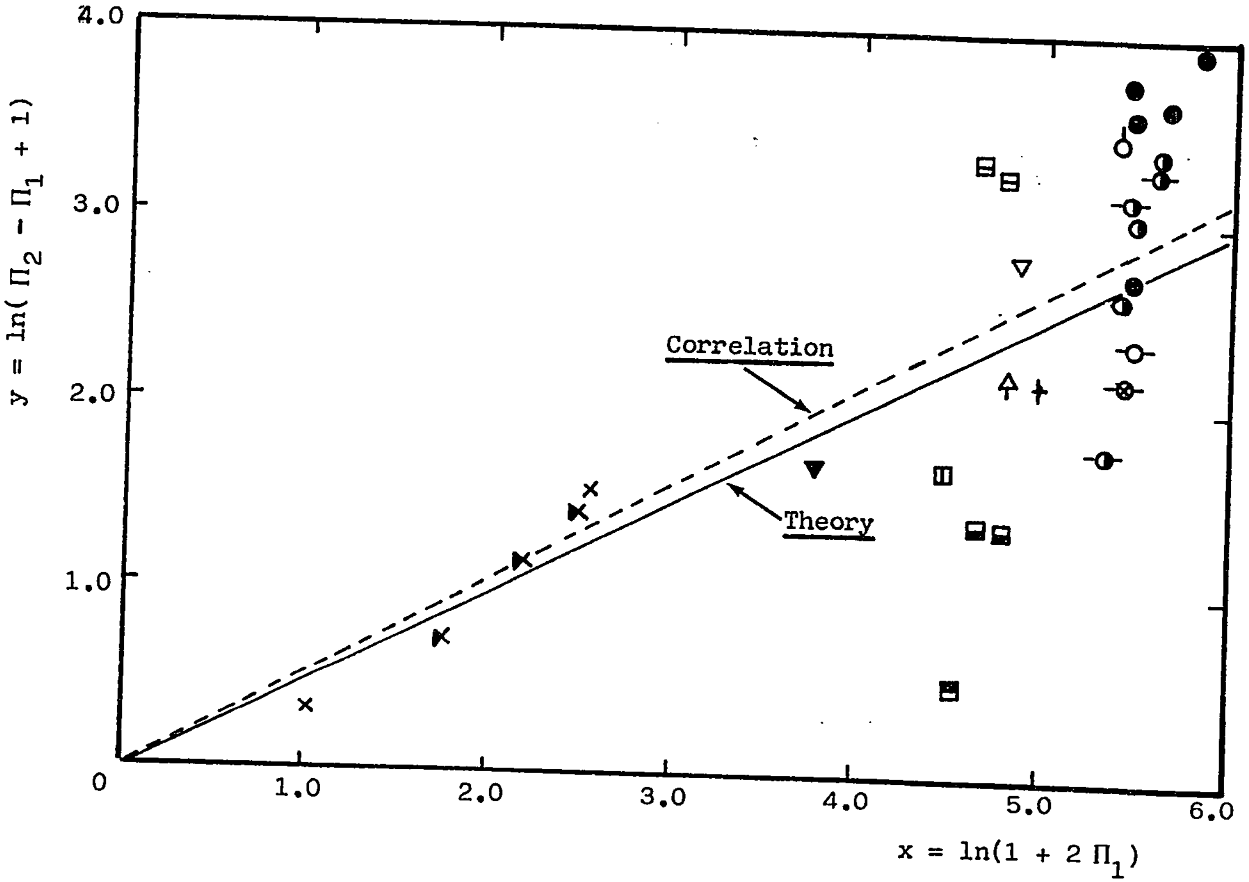


Figure 18 A Plot of $\ln(\Pi_2 - \Pi_1 + 1)$ Against $\ln(1 + 2\,\Pi_2)$

where from the theory, $k_1 = 0.5$ and $k_2 = 0$

Figure 18 shows the plot of $\ln(\Pi_2 - \Pi_1 + 1)$ against $\ln(1 + 2\Pi_2)$. Theoretically these points should fall on a straight line of slope 0.5 and passing through the origin. Using the linear regression method outlined in Appendix C, the best fitting line for these points is

$$\ln(\Pi_2 - \Pi_1 + 1) = 0.7 \ln(1 + 2\Pi_2) - 0.86$$

Since $\ln(2.36) = 0.86$, the equation above can be rewritten as

$$\Pi_2 - \Pi_1 + 1 = \frac{(2\Pi_2 + 1)^{0.7}}{2.36}$$

or

$$\Pi_1 = \Pi_2 - \left[\frac{(2\Pi_2 + 1)^{0.7}}{2.36} - 1\right] \qquad (86)$$

The coefficient of correlation for this relationship is 0.75

A more useful correlation is that which is more similar to its theory form. By taking a line joining the origin to the average of the x and y arrays of the points in Figure 18 (4.60 and 2.35, respectively), the following correlation is obtained

$$\ln(\Pi_2 - \Pi_1 + 1) = 0.53 \ln(1 + 2\Pi_2)$$

or

$$\Pi_1 = \Pi_2 - \left[(1 + 2\Pi_2)^{0.53} - 1\right] \qquad (87)$$

The empirical Equation 87 does not differ very much from the theory (Equation 22), and is represented in Figure 17 by the broken line. The line obtained lies quite close to that of the theory, strengthening the validity of the theoretical relationship derived.

5.4 The Curve of I_s against M and P

The same results tabulated in Figure 16 can also be plotted according to the equation

$$I_s = P - \left[\sqrt{M^2 + 2PM} - M\right] \qquad (26)$$

Although three parameters are involved here, the values of M do not greatly effect a change of I_s with a change in P. Therefore Equation 26 is best plotted with I_s and P as the coordinates. The continuous line shown in Figure 19 is that of Equation 26 with constant M of 38.4 °F-days, the algebraic mean of the values of M for the thirty-two sites. Since the changes of I_s with respect to P are insensitive to M, Equation 26 if drawn on Figure 19 with M varying from 7.7 to 65.6 (see Table 11) will produce curves very closely packed to each other, and this is therefore omitted.

The values of Is and P from Table 11 when plotted on Figure 19 show that the points lie quite close to that of the theoretical curve with M = 38.4 °F-day. The empirical relationship between Is, M and P based on the calculated values is obtained as described next.

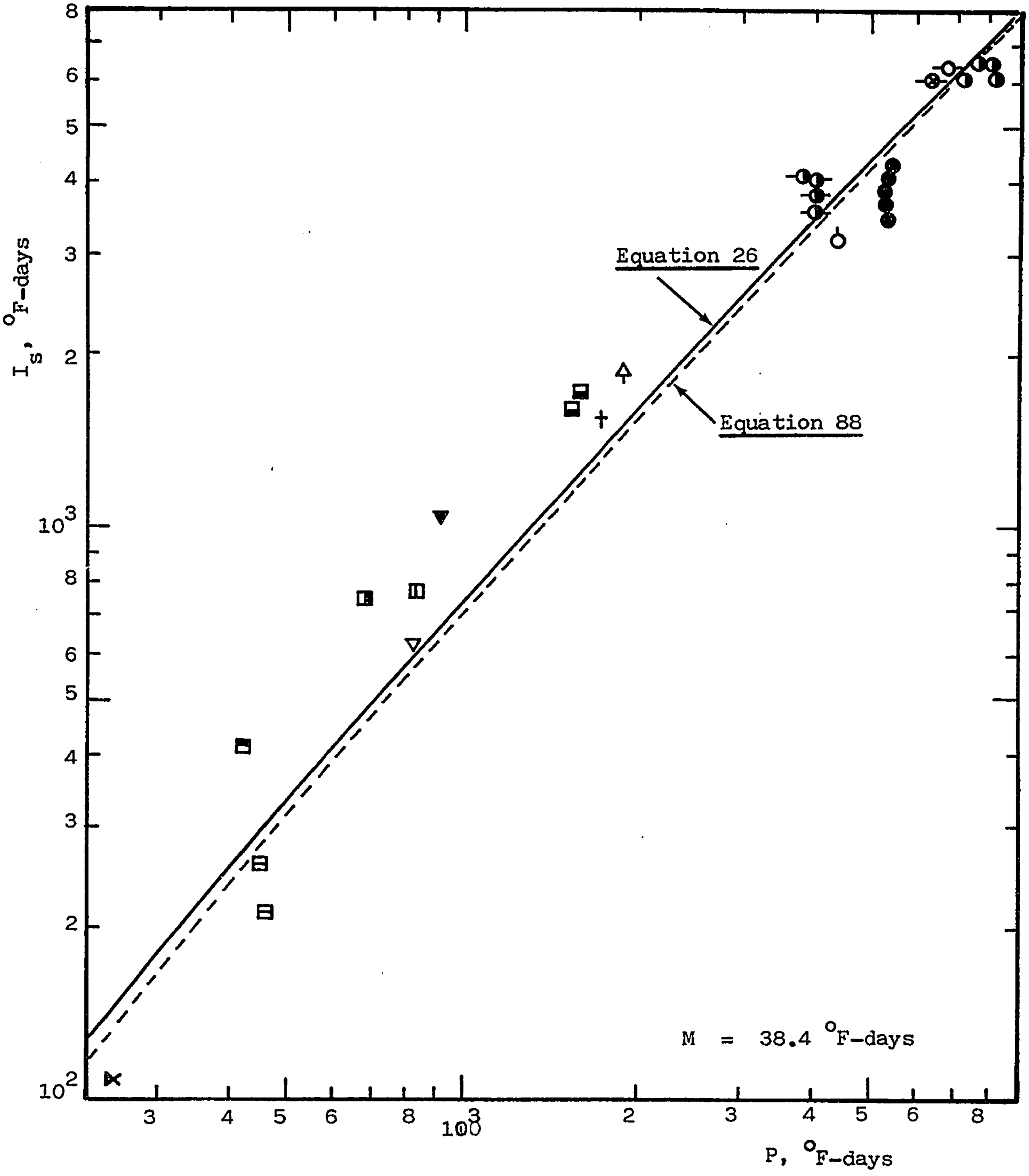


Figure 19 A Plot of I_s Against P for Constant M

5.4.1 Empirical Correlation of I_s Against M and P

Equation 87 from the previous section can be rewritten in its original form by substituting back the definition of Π_1 and Π_2. Noting that

$$\Pi_1 = \frac{I_s}{M}$$

and

$$\Pi_2 = \frac{I_e}{M} = \frac{P}{M}$$

Equation 87 now becomes

$$\frac{I_s}{M} = \frac{P}{M} - \left[(1 + 2\frac{P}{M})^{0.53} - 1\right]$$

which after some simplification becomes

$$I_s = P - \left[\frac{(M^2 + 2\,P\,M)^{0.53}}{M^{0.06}} - M\right] \tag{88}$$

Equation 88 is similar in form to Equation 26, except for the denominator $M^{0.06}$. However the values of $M^{0.06}$ only range from 1.13 to 1.28 for M varying from 7.7 to 65.6, respectively (see Table 11). Hence the empirical relationship obtained agrees well with that of the theory. Equation 88, represented by the broken line in Figure 19, therefore lies quite close to that of the theory.

5.5 Conclusion

Figure 16 shows the values of n - factor plotted against the air indexes. The scatter is too high in this figure to obtain any reasonable value of n for a particular air index value. By choosing proper coordinates, the relationship between n and the air index is better shown in Figures 17 and 19.

Figure 17 shows the same results plotted on the dimensionless parameters Π_1 and Π_2, verifying the theory discussed in Chapter 1. The calculated points are distributed quite evenly about the theoretical curve. Figure 19 actually shows the relationship between the surface and air indexes, since

$$P = \pm \frac{\bar{Q}_N \theta_s}{\bar{h}} + I_a$$

Knowing the value of I_a and M for a particular site, the corresponding value of I_s can be obtained from this figure; hence n is known.

Both Figures 17 and 19 are quite useful in permafrost zones to determine the depth of phase change in the soil. Knowing the value of n, the "modified Berggren equation" can be used to predict the depth of phase change below the surface of the soil, but this is beyond the scope of this work and therefore will not be discussed here.

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APPENDIX A

DESCRIPTION OF THE SITES

Table A1 Geographical Location of the Sites and Periods of Available Weather Data

Sites with Weather Data supplied by NOAA			Sites with N - Factor Quantities Known		
Location	Latitude (° N)	Period	Location	Latitude (° N)	References
1. Fairbanks, Alaska	64.8	May 1971 - Nov 1971	Fairbanks, Alaska	64.8	Berg (1973)
2. Fairbanks, Alaska	64.8	Oct 1947 - May 1948	Fairbanks, Alaska	64.8	U. S. Army (1950)
3. Kotzebue, Alaska	66.9	Sep 1970 - Apr 1973	Kotzebue, Alaska	66.9	Rhode (1976)
4. Boston, Mass.	42.3	Dec 1960 - Mar 1961	Waltham, Mass.	42.2	Quinn (1962)
5. Beckley, W. Virginia	37.8	Dec 1963 - Feb 1964	Beckley, W. Virginia	37.5	Moulton (1968)
6. Charleston, W. Virginia	38.4	Dec 1964 - Feb 1965	Nitro, W. Virginia	38.3	Moulton (1968)
7. Elkins, W. Virginia	38.9	Dec 1965 - Feb 1966	Rock Cave W. Virginia	38.8	Moulton (1968)
8. Morgantown, W. Virginia	39.6	Dec 1965 - Feb 1966	Grafton, W. Virginia	39.2	Moulton (1968)

Table A1 Geographical Location of the Sites and Periods of Available Weather Data (cont'd)

Sites with Weather Data Supplied by NOAA			Sites with N - Factor Quantities Known		
Location	Latitude (^{o} N)	Period	Location	Latitude (^{o} N)	References
9. Clarksburg, W. Virginia	39.3	Dec 1964 - Feb 1965	Flatwoods, W. Virginia	38.7	Moulton (1968)
10. Waterloo, Iowa	42.5	Nov 1963 - Apr 1964	West Union, Iowa	42.6	Oosterbaan (1965)
11. Sioux Falls, S. Dakota	43.6	Dec 1946 - Mar 1947	Sioux Falls, S. Dakota	43.3	U. S. Army (1950)
12. Saginaw, Michigan	43.4	Dec 1962 - Mar 1963	Midland, Michigan	43.4	Oosterbaan (1965)
13. Presque Isles, Maine	46.7	Nov 1945 - Mar 1946	Presque Isles, Maine	46.4	U. S. Army (1950)

Table A2 Seasonal Data for the Sites

Case no.	Season	n	Freeze/Thaw Index F-days		Phase Change Period days		Temperature °F		Surface Type	k Btu/ft-day-F	L_e Btu/ft^3
			I_a	I_s	θ_a	θ_s	T_a	T_s			
1a	T	1.72	3320	5710	171	-	51.4	-	Asphalt	18.8	4190
1b	T	1.96	3320	6507	171	-	51.4	-	"	19.4	4183
1c	T	0.98	3320	3254	171	-	51.4	-	"	20.6	3660
2a	F	0.74	5042	3730	215	199	8.8	13.3	Concr.	29.9	2023
2b	F	0.75	5042	3800	215	210	8.8	13.1	"	27.8	2994
2c	F	0.81	5042	4090	215	185	8.8	9.9	"	27.9	2665
2d	F	0.85	5042	4280	215	185	8.8	8.9	"	27.7	3052
2e	F	0.69	5042	3500	215	197	8.8	14.2	"	25.9	3484
3a	F	0.69	7279	6973	242	-	1.9	-	Asphalt	16.1	3357
3b	T	1.74	2052	3564	132	151	47.6	55.6	"	25.1	3326
3c	F	1.04	6549	6813	235	-	4.1	-	"	16.1	3357
3d	T	1.66	2386	3955	132	-	50.1	-	"	25.1	3326
3e	F	0.95	7279	6876	242	-	1.9	-	"	16.1	3357
3f	T	2.00	2052	4108	132	151	47.6	59.2	"	25.1	3326
3g	F	1.01	6543	6634	235	-	4.1	-	"	16.1	3357
3h	T	1.94	2386	4636	132	-	50.1	-	"	25.1	3326

Table A2 Seasonal Data for the Sites (cont'd)

Case no.	Season	n	I_a	I_s	θ_a	θ_s	T_a	T_s	Surface Type	k	L_e
4a	F	0.66	663	424	63	59	21.5	24.8	P.C.C.	20.9	1090
4b	F	0.71	663	471	63	59	21.5	24.0	"	17.9	1071
4c	F	0.98	663	643	63	63	21.5	21.8	"	24.7	1052
5	F	0.35	259	91	45	19	26.2	27.2	P.C.C.	38.4	2152
6	F	0.27	83	22	7	6	20.1	28.3	B.C.	32.2	1664
7	F	0.33	308	102	29	21	21.4	27.1	P.C.C.	27.7	3093
8	F	0.71	174	124	25	30	25.1	27.9	"	41.1	2798
9	F	0.29	166	45	26	7	25.6	25.1	B.C.	31.7	1938
10a	F	0.66	1461	964	130	-	20.8	-	P.C.C.	30.0	1713
10b	F	0.78	1461	1140	130	-	20.8	-	"	30.0	1713
11a	F	0.92	1314	1209	100	-	18.9	-	"	26.9	4044
11b	F	0.55	1314	723	100	-	18.9	-	Asphalt	24.4	3234
12a	F	0.97	1302	1263	110	-	20.2	-	"	42.2	2732
12b	F	1.00	1261	1261	99	-	19.3	-	"	42.2	2738
13a	F	0.95	2304	2189	126	-	13.7	-	P.C.C.	46.8	2158
13b	F	0.78	2304	1797	126	-	13.7	-	B.C.	27.8	2106

T - Thaw F - Freeze P.C.C. -. Portland Cement Concrete B.C. - Bituminous Concrete

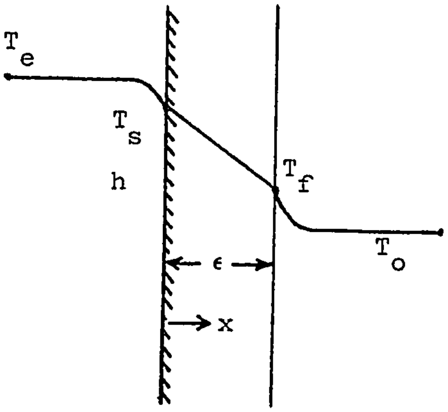
APPENDIX B

DERIVATION OF SURFACE TEMPERATURE EQUATION DURING PHASE CHANGE

APPENDIX B : DERIVATION OF SURFACE TEMPERATURE EQUATION DURING PHASE CHANGE

Lunardini (1977) simplified the actual heat transfer problem to that shown in the diagram below for the thawing case, and derived the surface temperature expression during the phase change. Initially the ground temperature is uniformly T_o and the surface temperature increases to T_f when thawing begins. As thawing continues, the surface temperature T_s will increase still further until freezing begins and the surface temperature will now decrease to T_f and consequently to sub-zero level.

B.1 Thawing



The basic problem of phase change can be expressed as follows:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial \theta} \qquad (B.1)$$

where

ϵ - depth of thaw

T - temperature

θ - time

α - thermal diffusivity

x - negative direction in which thawing occurs

The boundary conditions are

$$\left.\begin{aligned} -k_t\frac{\partial T}{\partial x} + k_f\frac{\partial T}{\partial x} &= L_e\frac{d\epsilon}{d\theta} \\ T &= T_f \end{aligned}\right\} \quad \text{at } x = \epsilon \qquad \text{(B.2)}$$

and

$$k_t\frac{\partial T}{\partial x} = h\,(T - T_a) \qquad \text{at } x = 0 \qquad \text{(B.3)}$$

The boundary condition at $x = \epsilon$ can be expressed as

$$dT = \frac{\partial T}{\partial x}\,dx + \frac{\partial T}{\partial \theta}\,d\theta$$

$$\left(\frac{dT}{d\theta}\right)_{x=\epsilon} = \frac{\partial T}{\partial x}\left(\frac{dx}{d\theta}\right)_{x=\epsilon} + \frac{\partial T}{\partial \theta} = 0$$

Thus

$$\left(\frac{dx}{d\theta}\right)_{x=\epsilon} = -\frac{1}{\left(\frac{\partial T}{\partial x}\right)_{x=\epsilon}}\left(\frac{\partial T}{\partial \theta}\right)$$

and

$$\frac{k}{L_e}\left(\frac{\partial T}{\partial x}\right)^2 = -\frac{\partial T}{\partial \theta} \qquad \text{at } x = \epsilon \qquad \text{(B.4)}$$

Due to the non-linearity of Equation B.4 the analytical solutions to most practical problems are impossible to determine. However, the quasi-steady approximation can be used if the Stefan number, defined as the ratio of the sensible heat to the latent heat of the soil, is small.

Using the quasi-steady approximation, Equation B.1 now becomes

$$\frac{\partial^2 T}{\partial x^2} = 0 \tag{B.5}$$

with boundary equations

$$\left.\begin{aligned} T &= T_f \\ -k_t \frac{\partial T}{\partial x} &= L_e \frac{d\epsilon}{d\theta} \end{aligned}\right\} \quad x = \epsilon \tag{B.6}$$

$$\epsilon = 0, \quad T = T_f, \quad \theta = 0 \tag{B.7}$$

$$k_t \frac{\partial T}{\partial x} = h\,(T - T_e), \quad x = 0 \tag{B.8}$$

The solution to Equations B.5 and B.8 is

$$T = a\left[x + \frac{k_t}{h}\right] + T_e \tag{B.9}$$

Then, from Equation B.6

$$\frac{d\epsilon}{d\theta} = \frac{k_t}{L_e}\,\frac{(T_e - T_f)}{(\epsilon + \frac{k_t}{h})} \tag{B.10}$$

and the solution to Equation B. 10 is

$$\left[\epsilon + \frac{k_t}{h}\right]^2 = p^2 = \frac{2\,k_t}{L_e}\int_0^{\theta} (T_e - T_f)\,d\theta + \left[\frac{k_t}{h}\right]^2 \tag{B.11}$$

Finally the surface temperature is given by the equation

$$T_s = T_e - \frac{(T_e - T_f)}{p} \frac{k_t}{h} \qquad (B.12)$$

B.2 Freezing

Basically the problem is the same as that for thaw except for some changes in signs:

$$\frac{\partial^2 T}{\partial x^2} = 0$$

$$\left. \begin{aligned} T &= T_f \\ k_f \frac{\partial T}{\partial x} &= L_e \frac{d\epsilon}{d\theta} \end{aligned} \right\} \qquad x = \epsilon$$

$$k_f \frac{\partial T}{\partial x} = h\,(T - T_e), \qquad x = 0$$

and the solution now becomes

$$T_s = T_e + \frac{(T_f - T_e)}{p} \frac{k_f}{h}$$

where

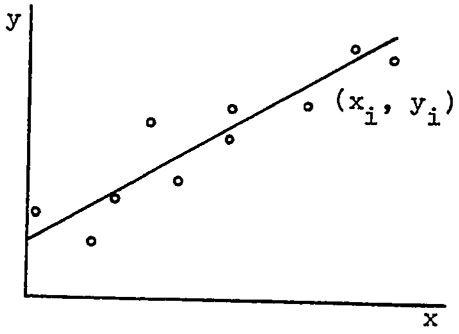
$$p^2 = \frac{2\,k_f}{L_e} \int_0^\theta (T_f - T_e)\,d\theta + \left[\frac{k_f}{h}\right]^2$$

APPENDIX C

METHOD OF LINEAR REGRESSION

APPENDIX C : METHOD OF LINEAR REGRESSION

The least-square linear regression is designed to minimise the sum the squares of the deviations of the actual data from the straight line of best fit. In practice a plot of the variables is essentially being constructed , and the best line drawn which uniformly divides the data points as shown below.



The linear curve obtained is in the form

$$y = m x + b$$

where

$$m = \frac{\dfrac{\sum^{N} x_i \sum^{N} y_i}{N} - \sum^{N} x_i \, y_i}{\dfrac{\left(\sum^{N} x_i\right)^2}{N} - \sum^{N} x_i^{\,2}}$$

The intercept is

$$b = \bar{y} - m \bar{x}$$

where

$$\bar{x} = \text{average of x arrays} = \frac{\sum^{N} x_i}{N}$$

$$\bar{y} = \text{average of y arrays} = \frac{\sum^{N} y_i}{N}$$

Variance of the x arrays is

$$\sigma_x^2 = \frac{\sum^{N} x_i^2}{N} - \bar{x}^2$$

Variance of the y arrays is

$$\sigma_y^2 = \frac{\sum^{N} y_i^2}{N} - \bar{y}^2$$

The correlation coefficient is

$$r = \frac{m\,\sigma_x}{\sigma_y}$$

APPENDIX D

COMPUTER PROGRAMME AND SAMPLE CALCULATION

```
FORTRAN IV G LEVEL  21                  MAIN                DATE = 78300          12/25/22
C
C
C      THIS PROGRAMME COMPUTES THE DAILY AND SEASONAL HEAT FLUX FOR A SITE.
C      THE SITE IS SPECIFIED FOR ITS LATITUDE, ATMOSPHERIC DUST ATTENUATION,
C      EFFECTIVE EMISSIVITY OF THE ATMOSPHERE, AND THE SOLAR ALBEDOA FOR THE
C      TYPE OF SURFACE OF THE SITE. THE SURFACE ROUGHNESS AND PHYSICAL PROPERTIES
C      OF THE  THE SURFACE AND SOIL ARE ALSO SPECIFIED.
C
C
       DIMENSION SPECS(7,20)
       REAL LAT, LH, NFCTOR
       INTEGER SEASON
       WRITE(6,10)
    10 FORMAT('1', ///////)
       DO 60 L = 1,7
       READ(5,20) (SPECS(L,M), M = 1,20)
    20 FORMAT(20A4)
       WRITE(6,55) (SPECS(L,M), M = 1,20)
    55 FORMAT(26X, 20A4, /)
    60 CONTINUE
       READ(5,65) LAT, DA, EPSLNS, ALFAS
    65 FORMAT(F5.2, 3X,F5.3, 3X, F5.3, 3X, F5.3)
       WRITE(6,70) DA, EPSLNS
    70 FORMAT(/////,26X,'APPROXIMATE VALUES ASSUMED:',//, 35X, 'DUST ATTE
      1NUATION FOR ATMOSPHERE    =     ', F5.3, //, 35X, 'EMMISSIVITY OF EAR
      2TH SURFACE        =     ',  F5.3)
       READ(5,72)    Z1, Z0, CONDTY, LH, THETAA, THETAS, SEASON
    72 FORMAT(F7.4, 1X, F7.4, 1X, F4.1, 1X, F6.1, 1X, F5.1, 1X, F5.1, 1X,
      @ I1)
       WRITE(6,74)
    74 FORMAT('1',/,10X,'DAILY COMPUTATION OF HEAT FLUX AND SURFACE COEFF
      $ICIENT', //)
       WRITE(6,75)
    75 FORMAT(10X,'-----------------------------------------------------------
      #----------------------------',/)
       WRITE(6,76)
    76 FORMAT(     10X, 'DAY    DATE     T-AIR        GT          QTC         R
      #        RC           QN      WMPH      HC',   /)
       WRITE(6,75)
C
C      INITIALISE SUM OF EACH PARAMETER EQUALS TO ZERO
C
       SD = 0.
       SDDAM = 0.
       STAIRF = 0.
       STDPF = 0.
       STSURF = 0.
       SCL = 0.
       SCS = 0.
       SWMPH = 0.
       SQT = 0.
       SQTC = 0.
       SR = 0.
       SRC = 0.
       SQN = 0.
       SHC = 0.
       I = 0
    79 J = 0
```

```
FORTRAN IV G LEVEL  21                  MAIN                 DATE = 78300          12/25/22

0041               80 I = I + 1
0042                  J = J + 1
                 C
                 C    READ THE FOLLOWING WEATHER DATA :  NO. OF DAYS AFTER DECEMBER 31, CPTICAL
                 C    AIR MASS, AIR TEMPERATURE, DEW POINT TEMPERATURE, CLOUD COVER BASED ON 24-
                 C    HOUR AND 12-HOUR PERIODS, AND WIND SPEED.
                 C
0043                  PEAD(5,85) D, DCAM, TAIRF, TDPF, CE, CS, WMPH
0044               85 FORMAT(3X, F5.1, 1X, F5.2, 1X, F6.1, 1X, F6.1, 1X, F4.2, 1X, F4.2,
                    # 4X,F4.1)
0045                  CALL SWR(D, DOAM, TAIRF, TDPF, CE, CS, LAT, I, DA, ALFAS, EO, TAIR
                    #K, QT, QTC, THETAA)
0046                  CALL LWR(TAIRF, CE, EPSLNS, TAIRK, EO, R, RC, TSURF)
0047                  CALL HCONV(Z1, Z0, WMPH, HC)
0048                  QN = (1. - ALFAS) * QTC - RC
0049                  WRITE(6,88) I, D, TAIRF, QT, QTC, R, RC, QN, WMPH, HC
0050               88 FORMAT(10X, I3, 3X, F5.1, 3X, F5.1, 3X, F7.1, 3X, F7.1, 3X, F7.1,
                    & 3X, F7.1, 3X, F7.1, 3X, F4.1, 3X, F5.1, /)
                 C
0051                  SD = D + SD
0052                  SDOAM = DOAM + SDCAM
0053                  STAIRF = TAIRF + STAIRF
0054                  STDPF = TDPF + STDPF
0055                  STSURF = TSURF + STSURF
0056                  SCE = CE + SCE
0057                  SCS = CS + SCS
0058                  SWMPH = WMPH + SWMPH
0059                  SQT = QT + SQT
0060                  SQTC = QTC + SQTC
0061                  SR = R + SR
0062                  SRC = RC + SRC
0063                  SQN = QN + SQN
0064                  SHC = HC + SHC
0065                  IF(J .NE. 25) GO TO 89
0066                  IF(J .EQ. 25) GO TO 81
0067               81 WRITE(6,74)
0068                  WRITE(6,75)
0069                  WRITE(6,76)
0070                  WRITE(6,75)
0071                  J = 0
0072               89 IF(I .LT. THETAA) GO TO 80
                 C
                 C    FIND THE AVERAGE WEATHER DATA, HEAT FLUX AND SURFACE COEFFICIENT
                 C    FOR THE SEASON
                 C
0073                  D = SD / FLOAT(I)
0074                  DOAM = SDCAM / FLCAT(I)
0075                  TAIRF = STAIRF / FLOAT(I)
0076                  TDPF = STDPF / FLCAT (I)
0077                  TSURF = STSURF / FLOAT(I)
0078                  CE = SCE / FLOAT(I)
0079                  CS = SCS / FLOAT(I)
0080                  WMPH = SWMPH / FLCAT(I)
0081                  QT = SQT / FLOAT(I)
0082                  QTC = SQTC / FLCAT(I)
0083                  R = SR / FLOAT(I)
0084                  RC = SRC / FLOAT(I)
0085                  QN = SQN / FLOAT(I)
```

```
            HC = SHC / FLOAT(I)
            WRITE(6,90)
         90 FORMAT('1',/,10X,' MEAN DAILY AVERAGE OF THE SEASON ', /)
            WRITE(6,75)
            WRITE(6,100) DOAM, TDPF,CE, CS
        100 FORMAT(/////,10X,'MEAN DAILY CPTICAL AIR MASS, DOAM = ', F7.2,
           @//,10X, 'MEAN DAILY DEW-PCINT TEMP, TDPF = ', F7.1,//, 10X, 'MEAN
           @24-HOUR PERCENTAGE OF CLOUD COVER, CE = ', F7.1, //, 10X, 'MEAN DA
           @YLIGHT PERCENTAGE OF CLCUD COVER, CS = ', F7.1, ////)
            WRITE(6,76)
            WRITE(6, 95) D, TAIRF, QT, QTC, R, RC, QN, WMPH, HC
         95 FORMAT(16X, F5.1, 3X,F5.1, 3X, F7.1, 3X,F7.1, 3X,F7.1,3X, F7.1, 3X
           @,F7.1, 3X, F4.1, 3X, F5.1, /)
            I = I + 1
            TFF = 32.
            GO TO(150, 250), SEASCN
      C
      C     FOR THAWING SEASON
      C
        150 TEF = QN / HC + TAIRF
            RX = CONDTY / HC
            BX = 2. * CONDTY * (TEF - TFF) / LH
            YX = BX * THETAS + RX ** 2
            IF(YX .LT. 0.) GO TO 200
            PX = SQRT(YX)
            TSF = TEF - (TEF - TFF) *  RX / PX
            GO TO 210
        200 TSF = TSURF
        210 XINDXA = (TAIRF - TFF) * THETAA
            XINDXS = (TSF - TFF) * THETAS
            XINDXE = (TEF - TFF) * THETAS
            NFCTOR = XINDXS / XINDXA
            XM = CONDTY * LH / (HC**2)
            PI1 = XINDXS / XM
            PI2 = XINDXE / XM
            P = XINDXA + (QN * THETAS) / HC
            GO TO 415
      C
      C     FOR FREEZING CASE CNLY
      C
        250 TEF =    QN/HC + TAIRF
            RX = CONDTY / HC
            BX = 2. * CONDTY * (TFF - TEF) / LH
            YX = BX * THETAS + RX ** 2.
            IF(YX .LT. 0) GO TC 400
            PX = SQRT(YX)
            TSF = TEF + (TFF - TEF) * RX / PX
            GC TO 410
        400 TSF = TSURF
        410 XINDXA = (TFF - TAIRF) * THETAA
            XINDXS = (TFF - TSF) * THETAS
            XINDXE = (TFF - TSF) * THETAS
            NFCTUR = XINDXS / XINDXA
            XM = CONDTY * LH / (HC ** 2)
            PI1 = XINDXS / XM
            PI2 = XINDXE / XM
            P =XINDXA - (QN * THETAS) / HC
        415 WRITE(6,420) TSF
```

```
FORTRAN IV G LEVEL  21                    MAIN                 DATE = 78300          12/25/22
 0134          420 FORMAT(///, 10X, 'SURFACE TEMPERATURE = ', F7.1, '  F' )
                   WRITE(6,500) XINDXA, XINDXS, XINDXE, NFCTCR, XM, PI1, PI2, P
 0136          500 FORMAT( /,  10X, 'AIR INDEX = ', F7.1,  '  F-DAY'  ,
                  2 //, 10X,   'SURFACE INDEX = ', F7.1,     '  F-DAY'  ,
                  3   //, 10X,  'EFFECTIVE INDEX = ', F7.1,    '  F-DAY',
                  4   //,    10X,    'N-FACTOR = ',     F7.2,
                  5      //, 10X, 'M = K * LH / (HC**2) = ', F7.2,    '  F-DAY',
                  6    //, 10X,  'PI1 = ',  F7.2,   //,  10X, 'PI2 = ', F7.2,
                  7   //,   10X,'P = AIR-INDEX + (QN * THETAS) / HC = ',F7.2, '  F-DAY
                  8 ')
 0137              WRITE(6,10)
 0138              STOP
 0139              END
```

```
FORTRAN IV G LEVEL  21                       MAIN               DATE = 78300          12/25/22
                  C
                  C       SUBPRCGRAM FOR SHCRTWAVE RADIATION COMPUTATION
                  C
  0C01                    SUBROUTINE SWR(D, DCAM, TAIRF, TDPF, CE, CS, LAT, I, DA, ALFAS,
                         @ EO, TAIRK, QT, QTC, THETAA)
  0CC2                    REAL LAT
  0003                    PI = 3.1415926
  0CC4                    CCNVR = 3.688517
  0CC5                    RAD = PI / 180.
  0C06                    S = (1. - CS) * (1. + CS* 0.5)
  00C7                    EO = 0.131 * EXP(-(26.39 * (420./ (460. + TDPF ) - 1.)))
  0008                    DELTA = (ARSIN(SIN(23.5 * RAD) * COS(0.9863 * RAD * (D - 172.))))
                         1 / RAD
  0CC9                    IF(DELTA .GE. 0.) GC TO 1100
  0C10                    DELTA = ABS(DELTA)
  0011                    HSR = - (ARCOS(TAN(DELTA * RAD) * TAN(LAT * RAD))) / RAD + 180.
  0012                    DELTA = - DELTA
  0C13                    GO TO 120C
  0C14               1100 HSR = (ARCOS(TAN(DELTA * RAD) * TAN(LAT * RAD))) / RAD
  0015               1200 RRM = 1. - (0.0016733 * CCS(0.9856 * D * RAD ))
  0C16                    RMR2 = (1. / RRM) ** 2
  0017                    TAIRK = ((TAIRF - 32. ) * (5./9.)) + 273.
  0C18                    TDPC = (TDPF - 32.) * (5./9.)
  0019                    IF(I .LE. THETAA) GO TO 1210
  002C                    W =          EXP(0.1102 + (0.0614 * TCPC))
  0021                    GO TO 1250
  0022               1210 W = 0.85 * EXP(0.1102 + (0.0614 * TDPC))
  0023               1250 APRIM1 = 1.041 * EXP(-(0.095 * DOAM + 0.039 * W ))
  0024                    APRIM2 = 0.975* EXP(-(0.1263 * DOAM + 0.0513 * W ))
  0025                    A = APRIM2 - APRIM1 / 2. + 0.5 - DA / 2.
  0026                    B = 1. + (ALFAS / 2.) * (1. - APRIM1 + DA)
  0C27                    AB = A * B
  0C28                    QT =  COS(DELTA * RAD) * COS(LAT * RAD) * (((180. - HSR ) / 180.)
                         1 * COS(HSR * RAD) + SIN(HSR * RAD) / PI) * 2865.6 * AB * RMR2
                         2 * CONVR
  0C29                    IF(I .GT. THETAA) GO TO 1300
                  C
                  C       FOR DAILY HEAT FLUX
                  C
  003C                    QTC = (1. - 0.67* CS ** 2) * QT
  0031                    GO TO 1500
                  C
                  C       FCR MCNTHLY HEAT FLUX
                  C
  0C32               1300 QTC = (.35 + .61 * S ) * QT
  0C33               1500 RETURN
  0034                    END
```

```
FORTRAN IV G LEVEL  21                    MAIN                 DATE = 78300           12/25/22
                   C
                   C      SUBPROGRAM FOR LONGWAVE RADIATION COMPUTATION
                   C
 0001                     SUBROUTINE LWR(TAIRF, CE, EPSLNS,TAIRK, EO, R, RC, TSURF)
 0002                     TSURF = TAIRF + 1.4
 0003                     SIGMA = 1.17E-7
 0004                     CONVR = 3.688517
 0005                     TSURK = ((TSURF - 32.) * (5./9.))+ 273.
 0006                     EPSLNA = 0.6 + 0.05 *  SQRT(EO)
 0007                     R  =  CONVR    *              SIGMA * EPSLNS * (TAIRK ** 4)* (( TSURK /
                        1 TAIRK ) ** 4 - EPSLNA)
 0008                     RC  =   (1. - 0.8 * CE)   *  R
 0009                     RETURN
 0010                     END

                   C
                   C      SUBPROGRAM FOR THE SURFACE COEFFICIENT COMPUTATION
                   C
 0001                     SUBROUTINE HCONV(Z1, Z0, WMPH, HC)
 0002                     REAL KO
 0003                     RHO = 0.08
 0004                     CP = 0.24
 0005                     KO = 0.4
 0006                     TFF = 32.
 0007                     DENOM = RHO * CP * (KO ** 2) * 5280. * 24. * WMPH
                   C
                   C      FOR MODERATELY UNSTABLE CASE
                   C
 0008                     ZLR1 = - 0.03
 0009                     BETA1 = 1. + (ALOG(1. - 16. * ZLR1) / (4. * ALOG(Z1/Z0)))
 0010                     FCTR1 = (2. * (1. - BETA1) ** 2) / ((((Z1 / Z0)
                        @    ** (1. - BETA1) -1.) ** 2) * ((Z1/Z0) ** (1. - BETA1) + 1.))
 0011                     HC1 = DENOM * FCTR1
                   C
                   C      FOR MODERATELY STABLE CONDITION
                   C
 0012                     ZLR2 = 0.3
 0013                     BETA2 = 1. -(ALOG(1. + 5. * ZLR2) / ALOG(Z1/Z0))
 0014                     FCTR2 = ((1. - BETA2) / ((Z1/Z0) ** (1. - BETA2) - 1. )) ** 2
 0015                     HC2 = DENOM * FCTR2
                   C
                   C      FOR NEUTRAL STABILITY
                   C
 0016                     BETA3 = 1.
 0017                     FCTR3 = 1. / ((ALOG(Z1/Z0)) ** 2)
 0018                     HC3 = DENOM * FCTR3
 0019                     HC = (HC1 + HC2 + HC3) / 3.
 0020                     RETURN
 0021                     END
```

```
*******************************************************
LOCATION       :  SIOUX FALLS, S. CAKOTA (SOIL : P.C.C.)
LATITUDE       :  43.57 DEGREES NORTH
LCNGITUDE      :  96.75 DEGREES WEST
PERIOD         :  DECEMBER 1946 - MARCH 1947
*******************************************************


APPROXIMATE VALUES ASSUMED:
      DUST ATTENUATION FOR ATMOSPHERE   =   0.060
      EMMISSIVITY OF EARTH SURFACE      =   0.940
```

DAILY COMPUTATION OF HEAT FLUX AND SURFACE COEFFICIENT

DAY	DATE	T-AIR	QT	QTC	R	RC	QN	WMPH	HC
1	335.5	17.5	731.5	729.1	668.3	502.6	26.0	11.0	37.8
2	336.5	23.0	725.1	304.9	684.8	268.4	-47.4	15.5	53.3
3	337.5	34.0	716.5	571.3	687.6	440.0	-25.9	7.0	24.1
4	338.5	41.5	709.4	341.3	693.3	232.9	14.5	8.0	27.5
5	339.5	35.0	706.3	474.4	687.1	340.8	3.2	4.5	15.5
6	340.5	39.5	700.5	508.3	689.2	386.0	-17.5	9.0	30.9
7	341.5	32.5	696.7	248.4	658.0	184.3	-4.2	7.5	25.8
8	342.5	35.0	691.2	255.5	644.8	216.6	-31.4	7.5	25.8
9	343.5	36.0	689.1	481.8	676.8	281.5	67.8	8.5	29.2
10	344.5	34.0	687.1	576.5	690.5	425.4	-7.4	9.5	32.7
11	345.5	41.0	682.9	529.0	707.6	334.0	49.5	13.5	46.4
12	346.5	26.0	683.4	544.9	688.1	280.7	114.3	17.0	58.5
13	347.5	15.5	683.4	328.8	680.3	174.2	64.2	6.5	22.3
14	348.5	18.5	679.6	224.3	663.9	132.8	29.8	7.5	25.8
15	349.5	23.5	675.4	222.9	647.3	129.5	32.1	6.5	22.3
16	350.5	20.5	676.0	441.2	672.9	339.2	-19.3	23.0	79.1
17	351.5	8.5	676.1	599.9	641.4	538.8	-103.8	20.0	68.8
18	352.5	11.0	674.8	616.2	648.6	446.2	0.5	10.5	36.1
19	353.5	19.0	672.8	666.3	666.7	517.4	-34.3	8.0	27.5
20	354.5	28.5	671.5	282.4	702.3	387.6	-182.9	11.0	37.8
21	355.5	22.5	671.4	404.7	664.0	340.0	-46.6	14.0	48.1
22	356.5	28.5	670.9	411.2	677.0	368.3	-70.1	10.0	34.4
23	357.5	26.5	673.1	624.0	690.9	442.2	10.2	14.5	49.9
24	358.5	26.0	674.0	582.5	678.5	526.5	-104.2	11.0	37.8
25	359.5	34.5	674.2	669.7	699.2	665.6	-180.1	6.0	20.6

DAILY COMPUTATION OF HEAT FLUX AND SURFACE COEFFICIENT

DAY	DATE	T-AIR	QT	QTC	R	RC	QN	WMPH	HC
26	360.5	22.0	678.8	520.5	677.0	400.8	-23.4	12.5	43.0
27	361.5	20.0	680.2	224.5	650.5	130.1	32.6	14.5	49.9
28	362.5	2.0	685.9	226.3	616.7	123.3	40.8	19.5	67.0
29	363.5	-6.5	690.2	671.7	602.5	457.9	29.1	16.5	56.7
30	364.5	-3.0	693.1	520.3	616.2	404.2	-27.0	13.0	44.7
31	365.5	-4.5	696.4	614.1	607.2	582.9	-137.7	11.5	39.5
32	0.5	9.0	695.0	564.2	644.1	365.9	43.2	11.5	39.5
33	1.5	3.5	699.4	230.8	628.8	125.8	41.6	13.0	44.7
34	2.5	-2.0	704.3	704.3	618.4	578.8	-68.2	12.0	41.3
35	3.5	9.0	707.2	569.1	650.3	483.8	-71.2	13.5	46.4
36	4.5	16.0	709.8	641.2	650.3	494.2	-29.4	13.0	44.7
37	5.5	24.0	713.1	326.1	665.0	218.1	18.3	11.5	39.5
38	6.5	27.5	717.4	532.6	668.8	374.5	11.6	12.5	43.0
39	7.5	29.5	722.3	427.9	671.5	284.7	25.5	11.5	39.5
40	8.5	28.0	728.2	633.7	666.2	437.0	22.5	9.0	30.9
41	9.5	35.0	732.3	537.5	671.4	273.9	115.8	8.0	27.5
42	10.5	27.5	741.7	476.9	674.1	339.7	6.0	12.0	41.3
43	11.5	24.0	749.2	247.2	665.0	133.0	46.2	13.0	44.7
44	12.5	28.0	754.9	249.1	657.9	173.7	6.9	23.5	80.8
45	13.5	17.0	767.1	766.9	671.2	655.1	-99.1	13.0	44.7
46	14.5	7.0	776.3	256.2	640.8	271.7	-86.0	10.5	36.1
47	15.5	19.0	783.1	774.2	678.6	640.6	-79.3	13.0	44.7
48	16.5	29.5	788.5	785.2	687.8	665.8	-96.5	9.0	30.9
49	17.5	33.5	796.9	652.5	699.3	531.4	-58.4	10.0	34.4
50	18.5	38.0	805.9	779.8	722.0	580.3	5.1	17.5	60.2

DAILY COMPUTATION OF HEAT FLUX AND SURFACE COEFFICIENT

DAY	DATE	T-AIR	QT	QTC	R	RC	GN	WMPH	HC
51	19.5	12.5	820.0	647.7	656.8	310.0	159.5	22.5	77.4
52	20.5	5.0	831.2	623.9	636.9	346.5	105.9	17.5	60.2
53	21.5	21.0	837.5	614.8	662.7	376.4	69.3	8.5	29.2
54	22.5	38.0	843.6	597.4	697.4	412.9	20.2	13.5	46.4
55	23.5	39.5	852.6	756.6	682.4	420.3	128.2	7.5	25.8
56	24.5	38.0	864.2	757.1	687.7	407.1	141.8	14.5	49.9
57	25.5	45.0	874.9	431.2	719.8	207.3	105.3	8.5	29.2
58	26.5	31.0	890.5	821.5	698.8	469.6	126.0	15.0	51.6
59	27.5	25.0	901.7	297.6	663.0	233.4	-17.6	14.5	49.9
60	28.5	19.5	915.3	302.1	652.3	130.5	88.5	26.0	89.4
61	29.5	10.5	930.4	469.3	639.1	189.2	151.1	18.5	63.6
62	30.5	5.5	943.9	651.5	628.3	321.7	150.6	10.5	36.1
63	31.5	-3.0	958.5	954.4	604.2	478.5	213.4	16.5	56.7
64	32.5	14.0	968.4	370.5	656.4	231.1	37.5	11.5	39.5
65	33.5	14.0	981.4	323.9	654.6	167.6	67.2	23.5	80.8
66	34.5	-2.0	998.6	993.2	619.5	569.9	150.2	19.0	65.3
67	35.5	4.5	1010.8	462.2	628.7	181.1	154.1	8.5	29.2
68	36.5	11.0	1022.8	364.7	640.1	204.8	59.5	24.0	82.5
69	37.5	-4.0	1040.7	343.4	606.7	121.3	127.6	34.5	118.6
70	38.5	2.0	1054.2	375.9	622.1	184.1	88.4	24.5	84.2
71	39.5	9.0	1067.1	736.5	639.4	250.6	283.3	16.0	55.0
72	40.5	14.0	1080.8	1054.6	652.8	412.6	352.0	7.0	24.1
73	41.5	25.5	1092.0	486.1	668.3	278.0	74.4	8.5	29.2
74	42.5	23.5	1108.1	380.5	667.1	293.5	-17.7	10.0	34.4
75	43.5	37.0	1118.4	470.3	682.2	207.4	133.6	11.0	37.8

DAILY COMPUTATION OF HEAT FLUX AND SURFACE COEFFICIENT

DAY	DATE	T-AIR	QT	QTC	R	RC	GN	WMPH	HC
76	44.5	32.5	1134.3	433.9	661.2	253.9	60.7	13.5	46.4
77	45.5	37.0	1150.8	483.9	682.2	158.3	192.6	14.5	49.9
78	46.5	34.5	1167.3	519.6	678.2	287.5	89.2	12.5	43.0
79	47.5	28.0	1187.5	871.7	676.8	335.7	296.3	14.5	49.9
80	48.5	15.0	1209.3	946.1	658.3	400.2	285.7	10.5	36.1
81	49.5	13.5	1226.1	469.0	644.5	273.3	66.8	9.0	30.9
82	50.5	3.0	1247.2	975.7	623.4	448.9	258.5	5.1	17.5
83	51.5	8.5	1264.0	483.5	643.0	252.0	98.5	6.5	22.3
84	50.5	3.5	1250.0	673.1	624.7	364.8	123.1	11.5	39.5
85	53.5	7.5	1300.4	594.7	646.4	289.6	141.6	21.5	73.9
86	54.5	16.5	1315.3	434.0	662.8	153.8	160.9	22.5	77.4
87	55.5	18.0	1332.5	475.1	665.2	170.3	174.1	18.5	63.6
88	56.5	14.5	1351.8	650.4	651.8	260.7	210.8	16.0	55.0
89	57.5	17.5	1370.7	524.3	668.3	149.7	230.4	6.0	20.6
90	58.5	16.5	1388.4	495.0	657.0	226.0	132.9	9.0	30.9
91	59.5	15.0	1407.8	538.5	656.4	220.6	169.9	16.5	56.7
92	60.5	16.0	1426.9	489.9	665.7	165.1	190.1	11.0	37.8
93	61.5	19.5	1442.6	659.7	665.3	170.3	308.0	5.5	18.9
94	62.5	23.5	1459.2	736.1	669.5	182.1	351.6	9.5	32.7
95	63.5	24.0	1479.7	1086.2	683.8	339.2	448.3	12.0	41.3
96	64.5	21.0	1499.2	1466.6	675.7	491.9	571.4	10.0	34.4
97	65.5	23.5	1516.4	898.3	674.2	194.2	457.1	5.5	18.9
98	66.5	24.0	1535.5	645.7	674.6	242.9	225.3	7.0	24.1
99	67.5	32.0	1549.6	511.4	685.2	137.0	233.7	9.0	30.9
100	68.5	32.5	1565.2	516.5	661.2	132.2	242.2	15.5	53.3

```
MEAN DAILY AVERAGE OF THE SEASON
-----------------------------------------------------------------------------------


MEAN DAILY OPTICAL AIR MASS, DCAM =    4.74
MEAN DAILY DEW-POINT TEMP, TDPF =    15.7
MEAN 24-HOUR PERCENTAGE OF CLOUD COVER, CE =     0.6
MEAN DAYLIGHT PERCENTAGE OF CLOUD COVER, CS =     0.7


DAY   DATE    T-AIR      QT        QTC        R         RC         QN     WMPH     HC
      132.4    20.4     931.9     554.4     662.3     323.1      69.8    12.8     53.3

SURFACE TEMPERATURE =    23.1  F
AIR INDEX =  1160.0  F-DAY
SURFACE INDEX =   893.0  F-DAY
EFFECTIVE INDEX =  1029.1  F-DAY
N-FACTOR =    0.77
M = K * LH / (HC**2) =    38.10  F-DAY
PI1 =   23.40
PI2 =   27.10
P = AIR-INDEX + (QN * THETAS) / HC = 1029.10  F-DAY
```

SAMPLE CALCULATION FOR SIOUX FALLS, S. DAKOTA

Daily Net Radiation

The total net radiation for the day of December 1, 1946 will be calculated for Sioux Falls, S. Dakota. The following are the data required for the calculation:

Latitude, ϕ = 43.57 °N

Days after December 31, D = 335.5

Average daily optical air mass, m = 5.15

Air temperature, T_a = 17.5 °F

Dew point temperature, T_{dp} = 12.0 °F

24-hour percentage of cloud cover, C_e = 0.31

Daylight percentage of cloud cover, C_s = 0.07

Solar albedo for the surface, α_s = 0.275

Emissivity of the surface, ϵ_e = 0.94

Atmospheric dust attenuation, d = 0.06

a) Solar declination on that day

$$\delta = \sin^{-1}\left[\sin 23.5 \ \cos\left(0.9863\ (D - 172)\right)\right]$$

$$= \sin^{-1}\left[\sin 23.5 \ \cos\left(0.9863\ (335.5 - 172)\right)\right]$$

$$= -22.18^{\circ}$$

b) Hour angle at sunrise

$$H_{sr} = \cos^{-1}\left(\tan\delta \tan \emptyset\right)$$

$$= \cos^{-1}\left(\tan(-22.18)\ \tan(43.57)\right)$$

$$= 112.8 \text{ degrees}$$

c) Ratio of the instantaneous sun - earth distance to its mean distance

$$\frac{r_i}{r_m} = 1 - 1.6733 \times 10^{-3} \cos(0.9856\ D)$$

$$= 1 - 1.6733 \times 10^{-3} \cos(0.9856 \times 335.5)$$

$$= 0.998$$

Therefore

$$\left(\frac{r_m}{r_i}\right)^2 = 1.001$$

d) Dew point temperature, $T_{dp} = 12.0\ ^{o}F = -11.11\ ^{o}C$.

Therefore the mean daily precipitable water vapour pressure

$$w = 0.85\ e^{(0.1102 + 0.0614\ T_{dp})}$$

$$= 0.85\ e^{(0.1102 + 0.0614 \times (-11.11))}$$

$$= 0.480 \text{ cm}$$

e) Atmospheric dust attenuation due to scattering only

$$a' = 1.041\ e^{-(0.095\ m\ +\ 0.039\ w)}$$

$$= 1.041\ e^{-(0.095 \times 5.15\ +\ 0.039 \times 0.480)}$$

$$= 0.626$$

f) Attenuation due to scattering and absorption

$$a'' = 0.975\ e^{-(0.1263\ m\ +\ 0.0513\ w)}$$

$$= 0.975\ e^{-(0.1263 \times 5.15\ +\ 0.0513 \times 0.480)}$$

$$= 0.496$$

g)
$$A = a'' - \frac{a'}{2} + \frac{1}{2} - \frac{d}{2}$$

$$= 0.496 - \frac{0.626}{2} + \frac{1}{2} - \frac{0.06}{2}$$

$$= 0.653$$

$$B = 1 + \frac{\alpha_s}{2}(1 - a' + d)$$

$$= 1 + \frac{0.275}{2}(1 - 0.626 + 0.06)$$

$$= 1.060$$

Therefore

$$AB = 0.653 \times 1.060 = 0.692$$

h)
$$\frac{Q_T}{2865.6 \times AB \times \left(\frac{r_m}{r_i}\right)^2} = \cos\delta \cos\phi \left[\frac{180 - H_{sr}}{180} \cos H_{sr} + \frac{\sin H_{sr}}{\pi}\right]$$

$$= \cos(-22.18)\ \cos(43.57) \times$$

$$\left[\frac{180 - 112.8}{180} \cos 112.8 + \frac{\sin 112.8}{\pi}\right]$$

$$= 0.0998$$

Therefore the global clear sky shortwave radiation is

$$Q_T = 2865.6 \times 0.692 \times 1.001 \times 0.998$$

$$= 198.2 \text{ langleys/day}$$

$$= 731.1 \text{ Btu/ft}^2\text{-day}$$

i) The net shortwave radiation reaching the surface in the presence of clouds

$$Q_{TC} = (1 - 0.67\, C_s^{\,2}) \quad Q_T$$

$$= (1 - 0.67 \times 0.07^2) \quad 198.2$$

$$= 197.6 \text{ langleys/day}$$

$$= 729 \text{ Btu/ft}^2\text{-day}$$

j) The atmospheric mean water vapour pressure at the reference level

$$e_o = 0.131\, e^{-26.39\left(\frac{420}{420 + T_{dp}} - 1\right)}$$

$$= 0.131\, e^{-26.39\left(\frac{420}{420 + 12} - 1\right)}$$

$$= 2.398 \text{ mb}$$

Therefore the effective emissivity of the atmosphere is

$$\varepsilon_a = 0.6 + 0.05\sqrt{e_o}$$

$$= 0.6 + 0.05\sqrt{2.398}$$

$$= 0.677$$

k) The longwave radiation loss from the surface for a cloudless atmosphere is

$$R = \sigma \epsilon_e T_a^4 \left[\left(\frac{T_s}{T_a} \right)^4 - \epsilon_a \right]$$

$$= 1.17 \times 10^{-7} \times 0.94 \times (264.9)^4 \left[\left(\frac{265.7}{264.9} \right)^4 - 0.677 \right]$$

$$= 181.2 \text{ langleys/day}$$

$$= 668.5 \text{ Btu/ft}^2\text{-day}$$

l) The net longwave radiation loss from the surface with the presence of clouds in the atmosphere

$$R_c = (1 - 0.8 C_e) \cdot R$$

$$= (1 - 0.8 \times 0.31) \quad 181.2$$

$$= 136.3 \text{ langleys/day}$$

$$= 502.6 \text{ Btu/ft}^2\text{-day}$$

m) Finally the net all-wave radiation received or absorbed by the surface is

$$Q_N = (1 - \alpha_s) Q_{TC} - R_c$$

$$= (1 - 0.275) \times 197.6 - 136.3$$

$= 6.96$ langleys/day

$= 25.7$ Btu/ft^2-day

It must be mentioned again that the net radiation Q_N obtained above is the daily resultant of the solar radiation received by the surface during the daylight hours and the loss of longwave radiation from the surface of the earth. To obtain the seasonal radiation flux, the daily values are added up for the number of days in the season.

The Daily Surface Coefficient

The aerodynamic equations discussed in Chapter 4 will be used rather than the empirical equations since the equations are more generally acceptable for any site and take into consideration the aerodynamic properties and effects of the atmosphere and also the degree of roughness of the surface. The empirical equations may be good for a certain site but uncertainty will arise when a different site with different surface type and local conditions is being considered.

The following are the values of the quantities required for the calculation:

Reference height of weather measurements, $Z_1 = 160$ cm $= 5.25$ ft

Surface roughness for pavements, $Z_0 = 0.01$ cm $= 0.003$ ft

Density of air (at 32 $^{\circ}$F), ρ = 0.08 lb_m/ft^3

Specific heat of air (at 32 $^{\circ}$F), c_p = 0.24 Btu/lb_m-F

Von Karman's constant, k_o = 0.4

Average wind speed on December 1, 1946, u_1 = 11.0 mph

a) The neutral atmospheric condition is first assumed and for this condition the stability parameter, β is 1.00. For neutral stability, the equation for surface coefficient is

$$\frac{h}{\rho c_p k_o^2 u_1} = \frac{1}{\ln^2\left(\frac{Z_1}{Z_0}\right)}$$

$$\rho c_p k_o^2 u_1 = 0.08 \times 0.24 \times (0.4)^2 \times (u_1 \times 5280 \times 24)$$

$$= 389.3\ u_1 \text{ Btu/day-ft}^2\text{-F}$$

Therefore

$$h = \frac{1}{\ln^2\left(\frac{5.25}{0.0003}\right)} \times 389.3 \times 11.0$$

$$= 44.7 \text{ Btu/ft}^2\text{-day-F}$$

b) The stable atmospheric condition is next assumed and for this condition the ratio Z_1/L can be taken as 0.3, where L is the Monin - Orbukhov length (see Chapter 4). Using the equation of β for a stable atmospheric condition,

$$\beta = 1 - \frac{\ln\left(1 + 5\frac{Z_1}{L}\right)}{\ln\left(\frac{Z_1}{Z_0}\right)}$$

$$= 1 - \frac{\ln(1 + 5 \times 0.3)}{\ln\left(\frac{5.25}{0.0003}\right)}$$

$$= 0.91$$

The equation of h for a moderately stable atmospheric condition is

$$\frac{h}{\rho c_p k_o^2 u_1} = \left[\frac{1 - \beta}{\left(\frac{Z_1}{Z_0}\right)^{1-\beta} - 1}\right]^2$$

The factor on the right side is

$$\left[\frac{1 - 0.91}{\left(\frac{5.25}{0.0003}\right)^{1-0.91} - 1}\right]^2 = 0.00408$$

Therefore

$$h = 0.00408 \times 389.3 \times 11.0$$

$$= 17.4 \text{ Btu/ft}^2\text{-day-F}$$

c) Finally the unstable atmospheric condition is assumed and for this case the ratio Z_1/L is taken as -0.03. Using the equation of β for this condition,

$$\beta = 1 + \frac{\ln\left[1 - 16\left(\frac{Z_1}{L}\right)\right]}{4 \ln\left(\frac{Z_1}{Z_0}\right)}$$

$$= 1 + \frac{\ln\left[1 - 16\ (-0.03)\right]}{4\ \ln\left(\frac{5.25}{0.0003}\right)}$$

$$= 1.01$$

The corresponding equation of surface coefficient is

$$\frac{h}{\rho\, c_p\, k_o^2\, u_1} = \frac{2\ (1 - \beta)^2}{\left[\left(\frac{Z_1}{Z_0}\right)^{1 - \beta} - 1\right]^2 \left[\left(\frac{Z_1}{Z_0}\right)^{1 - \beta} + 1\right]}$$

The factor on the right side is

$$\frac{2\ (1 - 1.01)^2}{\left[\left(\frac{5.25}{0.0003}\right)^{-0.1} - 1\right]^2 \left[\left(\frac{5.25}{0.0003}\right)^{-0.1} + 1\right]} = 0.0121$$

Therefore

$$h = 0.0121 \times 389.3 \times 11.0$$

$$= 51.7 \text{ Btu/ft}^2\text{-day-F}$$

d) From the three values obtained, the average surface coefficient of heat transfer is

$$h = \frac{44.7 + 17.4 + 51.7}{3}$$

$$= 37.9 \text{ Btu/ft}^2\text{-day-F}$$

The Seasonal Heat Flux and N - Factor

The following are the data required for the calculation of the n - factor and other related parameters:

Mean air temperature of the season, $\bar{T}_a = 20.4\ ^oF$
No. of days in the season, $\theta_a = 100$ days
Mean surface coefficient, $\bar{h} = 53.5$ Btu/ft^2-day-F
Mean net radiation flux, $\bar{Q}_N = 69.8$ Btu/ft^2-day
Thermal conductivity of the soil, $k_f = 26.9$ Btu/ft-day-F
Effective latent heat of the soil, $L_e = 4044$ Btu/ft^3

a) The air index is

$$I_a = (T_f - \bar{T}_a)\ \theta_a$$

$$= (32 - 20.4) \times 100$$

$$= 1160 \text{ F-days}$$

b) The mean effective temperature of the season is

$$\bar{T}_e = \frac{\bar{Q}_N}{\bar{h}} + \bar{T}_a$$

$$= \frac{69.8}{53.5} + 20.4$$

$$= 21.70\ ^oF$$

c) The effective temperature index is therefore

$$I_e = (T_f - \bar{T}_e)\ \theta_s$$

$$= (32 - 21.70) \times 100$$

$$= 1029 \text{ F-days}$$

d) $$b = \frac{2\ k_f}{L_e} (T_f - \bar{T}_e)$$

$$= \frac{2 \times 26.9}{4044} (32 - 21.7)$$

$$= 0.137 \text{ ft}^2/\text{day}$$

$$p = b\ \theta_s + \left(\frac{k_f}{\bar{h}}\right)^2$$

$$= 0.137 \times 100 + \left(\frac{26.9}{53.5}\right)^2$$

$$= 3.735 \text{ ft}$$

Therefore the mean surface temperature of the season is

$$\bar{T}_s = \bar{T}_e + \frac{(T_f - \bar{T}_e)}{p} \quad \frac{k_f}{\bar{h}}$$

$$= 21.7 + \frac{(32 - 21.7)}{3.735} \times \frac{26.9}{53.5}$$

$$= 23.08\ ^\circ\text{F}$$

e) The surface index can now be calculated as follows

$$I_s = (T_f - \bar{T}_s) \quad \theta_s$$

$$= (32 - 23.08) \times 100$$

$$= \quad 892 \text{ F-days}$$

f) The n - factor can now be obtained from the ratio I_s to I_a. Hence

$$n = \frac{I_s}{I_a} = \frac{892}{1160} = 0.77$$

g) The following parameters can now be calculated for correlation purposes:

$$M = \frac{k_f \times L_e}{\bar{h}^2} = \frac{26.9 \times 4044}{53.5^2} = 38.0 \text{ F-days}$$

$$\Pi_1 = \frac{I_s}{M} = \frac{892}{38.0} = 23.4$$

$$\Pi_2 = \frac{I_e}{M} = \frac{1029}{38.0} = 27.1$$

$$P = I_a - \frac{\bar{Q}_N \theta_s}{\bar{h}} = 1160 - \frac{69.8 \times 100}{53.5}$$

$$= 1029 \text{ F-days}$$

In Chapter 1 theoretical equations were derived on the relationship between Π_1 and Π_2, and also the relationship between I_s, M and P. The values obtained above, to a certain degree of accuracy, should then agree with these equations.

APPENDIX E

TABLES OF CALCULATION RESULTS IN CHAPTER 3

Table E1 Daily Solar Albedo for Asphalt Surface, Fairbanks, May - September 1971*

Date	May	June	July	August	September
1	0.120	-	0.123	0.079	0.036
2	0.122	0.117	0.130	0.130	-
3	-	0.120	0.134	0.123	-
4	0.100	0.120	0.142	0.089	0.020
5	0.101	0.118	0.137	0.113	0.093
6	0.090	0.120	0.135	0.102	0.086
7	0.040	0.123	0.134	0.071	0.084
8	0.080	0.132	0.141	0.046	0.059
9	0.090	0.131	0.138	-	-
10	0.080	0.143	0.129	0.087	0.094
11	0.089	0.126	0.109	0.122	0.118
12	0.099	0.139	0.052	0.114	0.089
13	0.108	0.131	0.092	0.105	0.084
14	0.110	0.107	0.122	0.119	0.072
15	0.095	0.139	0.136	0.122	0.099
16	0.075	0.128	0.140	0.118	0.109
17	0.104	0.130	0.138	0.110	0.035
18	0.106	0.130	0.135	0.108	0.091
19	0.089	0.123	0.132	0.090	0.064
20	0.101	0.116	0.118	0.005	0.026
21	0.103	0.118	0.138	0.085	0.069
22	0.094	-	0.131	0.065	0.080
23	0.105	-	0.135	0.110	0.054
24	0.101	-	0.132	0.122	0.056
25	0.100	-	0.128	0.126	0.022
26	0.104	0.138	0.140	0.123	0.077
27	0.113	0.143	0.132	0.126	0.023
28	0.107	0.076	0.140	0.117	0.058
29	0.121	0.154	0.140	0.120	-
30	0.132	0.141	0.115	0.073	-
31	0.104	-	0.104	0.091	-

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* Values are calculated from the incident and reflected solar radiation measurements supplied by the U. S. Army (1971)

Table E2 Daily Values of Q_{TC}/Q_T, Fairbanks, May – September 1971*

Date	May	June	July	August	September
1	1.00	–	0.58	0.46	0.36
2	1.00	0.66	0.75	0.68	0.19
3	–	0.90	0.87	0.65	0.18
4	0.88	0.94	0.69	0.47	0.35
5	1.00	0.94	0.89	0.52	0.61
6	0.46	1.00	0.95	0.41	0.88
7	0.36	0.93	0.84	0.35	0.83
8	0.62	1.00	0.74	0.31	0.59
9	1.00	0.86	0.91	–	–
10	0.62	0.73	0.73	0.38	0.93
11	0.80	0.83	0.31	0.85	0.97
12	0.60	0.51	0.12	0.66	0.90
13	0.86	0.82	0.22	0.71	1.00
14	0.89	0.55	0.46	0.77	1.00
15	0.58	0.76	0.78	0.98	0.94
16	0.51	0.81	0.79	0.96	0.90
17	1.00	0.96	0.90	0.83	0.41
18	1.00	0.73	0.89	0.84	0.98
19	0.59	0.78	0.88	0.47	0.73
20	0.64	0.59	0.51	0.22	0.44
21	0.88	0.71	0.80	0.49	0.83
22	0.82	0.95	0.93	0.54	1.00
23	0.83	0.89	0.86	0.68	1.00
24	0.81	0.95	0.81	0.57	0.58
25	0.93	0.93	0.53	0.63	0.40
26	0.77	0.83	0.76	0.75	0.67
27	0.87	0.99	0.47	0.90	0.51
28	0.56	0.54	0.76	0.96	0.91
29	0.61	0.66	0.71	0.97	0.18
30	0.93	0.71	0.54	0.62	0.24
31	0.76	–	0.48	0.59	

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* Values of Q_{TC} are obtained from the U. S. Army (1971)

Table E3 Calculated and Measured Values of Q_{TC}^{*} After Local Cloud Cover Relationship is Used, Fairbanks **

Date	May 1971		June 1971		July 1971		Aug 1971		Sep 1971	
	Cal.	Data	Cal.	Data	Cal.	Data	Cal.	Data	Cal.	Data
1	418	559	581	-	435	407	232	266	154	139
2	380	566	424	457	432	525	359	396	154	75
3	279	-	542	621	596	606	299	375	151	68
4	339	485	589	648	359	476	351	268	146	126
5	393	566	589	648	429	618	291	291	187	220
6	288	457	543	705	491	656	223	225	184	314
7	224	199	660	644	487	578	218	189	180	291
8	294	352	634	703	485	502	215	163	211	202
9	357	609	361	602	482	618	214	-	135	-
10	300	362	497	515	348	490	272	200	280	304
11	503	471	554	582	267	206	374	447	276	314
12	238	356	436	363	262	115	269	345	300	285
13	424	518	643	578	264	246	207	365	302	314
14	375	540	282	383	268	308	405	395	257	306
15	244	356	366	540	474	518	510	498	268	279
16	245	313	366	576	410	527	453	479	275	262
17	563	642	440	681	339	592	304	409	112	113
18	323	623	366	520	513	580	299	407	270	270
19	387	371	434	546	508	567	190	221	165	194
20	392	407	493	410	256	327	185	101	133	115
21	329	565	430	491	332	515	239	229	131	209
22	397	524	551	665	546	592	234	245	242	249
23	294	533	598	625	451	552	278	304	188	241
24	401	524	672	676	388	507	274	254	120	135
25	463	606	698	662	320	328	225	273	90	90
26	407	508	645	588	438	470	266	324	157	149
27	410	577	553	692	246	288	302	382	110	108
28	267	370	368	389	379	466	357	403	178	191
29	347	413	367	467	372	537	324	399	82	37
30	534	627	499	502	308	321	207	248	80	47
31	418	524			235	280	203	231		

* Unit of Q_{TC} is langleys/day

** Measured values of Q_{TC} are obtained from the U. S. Army (1971)

Table E4 Daily Values of R_c/R, Fairbanks, May - September 1971*

Date	May	June	July	August	September
1	-	-	0.89	0.99	0.56
2	-	0.60	0.62	0.99	0.79
3	-	0.74	0.76	0.88	0.68
4	-	0.78	0.73	0.95	0.59
5	-	0.75	0.79	0.81	0.29
6	-	0.85	0.84	0.80	0.57
7	0.52	0.78	0.81	1.00	0.72
8	0.51	0.79	0.69	0.99	0.31
9	0.81	0.76	0.81	-	-
10	0.65	0.75	0.71	1.00	0.62
11	0.55	0.77	0.58	0.88	0.75
12	-	0.73	0.72	-	0.81
13	0.77	0.93	0.98	0.74	0.85
14	0.67	0.45	0.76	0.89	0.83
15	0.43	0.69	0.63	0.91	0.70
16	0.66	0.81	0.92	0.78	0.85
17	0.74	0.89	0.79	0.65	1.00
18	0.60	0.84	0.77	0.69	0.82
19	0.55	0.80	0.83	0.74	0.53
20	0.54	0.53	0.78	1.00	0.87
21	0.64	0.75	0.80	0.54	0.50
22	0.55	0.69	0.87	0.56	0.81
23	0.51	0.98	0.81	0.70	1.00
24	0.49	0.79	0.85	0.28	0.69
25	0.71	0.76	0.81	0.34	0.58
26	0.55	0.89	0.85	0.49	0.72
27	0.63	0.80	0.76	0.65	0.41
28	0.50	0.63	0.74	0.70	0.72
29	0.45	0.58	0.82	0.70	0.72
30	0.81	0.99	0.72	0.61	0
31	0.49		0.90	0.67	

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* Values of R_c are obtained from the U. S. Army (1971)

Table E5 Calculated and Measured Values of R_c^{*} After Local Cloud Cover Relationship is Used, Fairbanks**

Date	May 1971		June 1971		July 1971		Aug 1971		Sep 1971	
	Cal.	Data	Cal.	Data	Cal.	Data	Cal.	Data	Cal.	Data
1	208	-	245	-	210	276	134	220	135	106
2	194	-	226	178	217	186	187	256	129	170
3	175	-	237	220	245	233	180	248	122	138
4	204	-	239	234	189	204	180	237	127	124
5	215	-	245	224	218	252	172	205	172	73
6	193	-	238	267	237	278	141	188	155	138
7	147	127	251	222	214	256	114	190	137	155
8	183	147	287	269	338	216	109	180	165	180
9	212	254	206	244	236	251	93	-	133	-
10	182	174	210	219	183	203	130	207	199	154
11	198	170	241	246	132	128	188	229	189	178
12	153	-	207	222	109	131	171	-	213	195
13	225	-	249	238	106	165	189	204	207	210
14	212	209	148	112	157	188	213	248	198	206
15	166	120	197	211	227	200	172	260	180	157
16	158	175	196	248	174	236	230	213	180	182
17	254	224	228	297	200	232	205	184	135	204
18	128	187	308	258	223	237	194	185	191	177
19	199	151	200	234	226	247	142	175	163	121
20	210	157	159	118	180	234	124	269	111	152
21	198	199	193	213	220	258	148	125	143	113
22	195	169	223	204	240	275	145	127	214	187
23	218	165	242	297	240	256	172	177	144	193
24	219	154	281	252	204	255	160	69	130	140
25	215	212	298	256	147	186	154	82	116	112
26	201	162	281	296	110	129	175	119	161	153
27	200	184	261	275	164	208	210	180	135	86
28	177	148	212	210	194	213	206	186	157	182
29	192	136	245	209	209	220	266	215	180	107
30	216	240	212	292	175	197	157	140	103	0.8
31	204	104			147	305	154	171		

* Unit of R_c is langleys/day

** Measured values of R_c are obtained from the U. S. Army (1971)

Table E6 Calculated and Measured Values of Q_N* After Local Cloud Cover Relationship is Used, Fairbanks**

Date	May 1971		June 1971		July 1971		Aug 1971		Sep 1971	
	Cal.	Data	Cal.	Data	Cal.	Data	Cal.	Data	Cal.	Data
1	160	-	337	-	270	81	169	-23	104	8
2	230	-	268	225	243	271	198	89	95	-103
3	192	-	299	326	333	292	183	81	95	-77
4	197	-	339	336	208	204	209	-33	101	0
5	239	-	336	342	254	281	167	53	79	127
6	178	-	317	353	280	289	153	14	100	149
7	166	64	362	343	308	244	165	-126	105	112
8	190	177	318	341	253	215	168	-182	126	110
9	212	300	224	279	254	282	161	-176	63	-
10	179	159	298	223	223	224	192	-25	105	121
11	189	259	319	263	194	-21	214	163	102	99
12	163	-	266	91	212	-124	164	-	89	65
13	251	-	373	264	204	-108	86	123	70	78
14	221	271	202	110	166	57	166	100	90	78
15	165	200	229	254	271	248	162	177	106	94
16	174	114	234	254	261	217	213	209	99	51
17	298	351	262	296	186	278	145	180	36	-95
18	177	369	252	194	308	264	149	178	80	68
19	231	187	275	245	286	245	125	26	55	61
20	224	208	339	134	166	51	143	-168	81	-40
21	209	307	277	220	170	186	154	84	59	81
22	274	305	341	302	259	239	155	102	28	49
23	242	312	355	264	226	222	156	94	79	35
24	248	317	360	254	229	185	171	154	56	-13
25	286	333	344	245	215	100	130	157	50	-24
26	258	293	326	208	310	175	126	165	35	-15
27	258	327	332	264	159	42	120	154	48	19
28	180	182	219	119	222	188	161	170	72	-2
29	221	227	185	192	217	196	124	161	39	-92
30	331	304	318	158	196	87	109	90	39	43
31	266	329			146	46	134	39		

* Unit of Q_N is langleys/day

** Measured values of Q_N are obtained from the U. S. Army (1971)

Table E7 Daily Values of Q_{TC}/Q_T, Boston*

Date	Dec 1960	Jan 1961	Feb 1961
1	0.73	0.02	1.00
2	1.00	1.00	1.00
3	0.86	0.90	0.49
4	0.96	0.85	0.09
5	0.91	1.00	1.00
6	0.78	0.51	0.75
7	0.65	0.84	1.00
8	0.67	0.81	1.00
9	1.00	0.93	1.00
10	0.49	1.00	0.71
11	0.72	0.79	0.36
12	0.11	0.98	0.78
13	0.96	0.90	0.91
14	1.00	0.55	0.31
15	0.87	0.17	0.94
16	0.04	0.16	0.88
17	1.00	1.00	0.86
18	1.00	1.00	0.14
19	0.48	0.82	0.80
20	1.00	0.23	1.00
21	0.03	1.00	0.97
22	1.00	0.97	0.94
23	1.00	0.81	0.08
24	0.76	0.66	0.13
25	0.64	1.00	0.10
26	0.96	0.84	0.36
27	0.85	0.95	0.73
28	1.00	1.00	0.22
29	0.18	1.00	
30	0.95	1.00	
31	0.96	0.94	

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* Values of Q_{TC} are obtained from the weather data obtained from NOAA (Appendix F)

Table E8 Calculated and Measured Values of Q_{TC}* After Local Cloud Cover Relationship is Used, Boston**

Date	Dec 1960		Jan 1961		Feb 1961	
	Cal.	Data	Cal.	Data	Cal.	Data
1	157	152	31	40	261	306
2	206	217	198	208	271	305
3	204	176	194	179	188	136
4	202	194	185	171	44	25
5	199	182	202	214	279	327
6	188	155	100	103	278	214
7	141	128	161	170	287	320
8	138	136	171	167	290	302
9	197	212	200	194	293	294
10	102	97	210	213	147	125
11	158	140	210	167	124	109
12	31	22	218	216	252	239
13	165	187	159	193	298	283
14	193	208	121	117	92	98
15	184	168	35	30	312	299
16	10	8	35	36	323	286
17	191	215	222	232	296	282
18	190	201	225	244	53	47
19	105	92	210	188	217	266
20	190	202	37	52	340	372
21	8	6	233	269	346	336
22	190	202	236	229	323	353
23	191	198	218	194	34	26
24	37	147	218	159	57	46
25	113	122	243	270	58	38
26	191	185	200	207	131	134
27	193	165	229	239	340	270
28	195	200	253	253	61	84
29	31	35	256	270		
30	176	186	263	286		
31	196	189	275	258		

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* Unit of Q_{TC} is langleys/day

** Measured values of Q_{TC} are given by NOAA (Appendix F)

A P P E N D I X F

DAILY WEATHER DATA FOR THE SITES

Supplied by the National Oceanic and Atmospheric Administration,
Weather Bureau, U. S. Department of Commerce

The explanations are as follows:

T-AIR - average air temperature, °F

T-DP - average dew-point temperature, °F

CE - average fraction of the sky covered by clouds in 24-hour period

CS - average fraction of the sky covered by clouds during daylight hours

S - average percentage of possible sunshine

U - average wind speed, mph

DAILY METROLOGICAL DATA FOR FAIRBANKS, ALASKA

LATITUDE = 64.82 DEG. NORTH

MONTH : MAY 1971

DATE	T-AIR	T-DP	CE	CS	U
1	38.0	20.0	0.70	0.60	6.6
2	43.0	28.0	0.80	0.70	6.9
3	43.0	28.0	1.00	0.90	13.8
4	42.0	24.0	0.80	0.80	9.4
5	43.0	22.0	0.80	0.70	6.8
6	48.0	27.0	0.90	0.90	9.6
7	38.0	30.0	1.00	1.00	12.8
8	37.0	24.0	0.90	0.90	11.1
9	40.0	22.0	0.80	0.80	5.3
10	45.0	24.0	0.80	0.90	7.8
11	48.0	27.0	0.90	0.90	7.9
12	49.0	31.0	1.00	1.00	10.4
13	49.0	28.0	0.70	0.70	10.8
14	46.0	24.0	0.80	0.80	8.8
15	44.0	31.0	1.00	1.00	8.6
16	42.0	33.0	1.00	1.00	7.5
17	45.0	24.0	0.40	0.40	7.5
18	52.0	24.0	0.80	0.90	9.8
19	50.0	30.0	0.70	0.80	7.3
20	50.0	25.0	0.70	0.80	7.2
21	50.0	27.0	0.90	0.90	10.1
22	49.0	28.0	0.90	0.80	9.5
23	48.0	30.0	0.80	0.80	5.9
24	54.0	34.0	0.80	0.80	6.9
25	55.0	30.0	0.70	0.70	7.9
26	53.0	29.0	0.80	0.80	11.4
27	53.0	30.0	0.80	0.80	9.8
28	56.0	33.0	1.00	1.00	8.2
29	53.0	27.0	0.90	0.90	11.9
30	52.0	26.0	0.70	0.60	12.7
31	58.0	32.0	0.80	0.80	10.8

MONTH : JUNE 1971

DATE	T-AIR	T-DP	CE	CS	U
1	57.0	28.0	0.50	0.50	15.5
2	51.0	26.0	0.80	0.80	13.1
3	52.0	28.0	0.50	0.60	6.0
4	56.0	31.0	0.50	0.50	8.6
5	65.0	36.0	0.50	0.50	6.5
6	68.0	36.0	0.60	0.60	9.5
7	68.0	38.0	0.30	0.30	11.9
8	63.0	36.0	0.40	0.40	6.8
9	68.0	38.0	0.90	0.90	6.6
10	72.0	41.0	0.70	0.70	10.6
11	66.0	35.0	0.60	0.60	10.6
12	60.0	39.0	0.80	0.80	10.4
13	52.0	33.0	0.50	0.40	12.5
14	54.0	43.0	1.00	1.00	5.6
15	58.0	40.0	0.90	0.90	7.1
16	61.0	38.0	0.90	0.90	8.3
17	63.0	36.0	0.80	0.80	5.6
18	64.0	41.0	0.90	0.90	6.8
19	63.0	50.0	0.80	0.80	8.2
20	66.0	56.0	0.70	0.70	6.6
21	70.0	58.0	0.80	0.80	6.5
22	68.0	50.0	0.60	0.60	6.3
23	74.0	48.0	0.50	0.50	10.4
24	77.0	37.0	0.30	0.30	12.5
25	76.0	37.0	0.30	0.20	11.9
26	73.0	40.0	0.40	0.40	7.8
27	73.0	38.0	0.60	0.60	10.2
28	65.0	34.0	0.90	0.90	8.8
29	53.0	35.0	0.80	0.90	10.8
30	51.0	34.0	0.70	0.70	8.8

# DAILY METROLOGICAL DATA FOR FAIRBANKS, ALASKA (CONT'D)
LATITUDE = 64.82 DEG. NORTH

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MONTH  :  JULY 1971                                       *  MONTH  :  AUGUST 1971
                                                          *
DATE  T-AIR   T-DP    CE     CS     U                     *  DATE  T-AIR   T-DP    CE     CS     U
                                                          *
  1   51.0    40.0   0.80   0.80    7.6                   *    1   61.0    53.0   1.00   1.00    6.0
  2   56.0    46.0   0.70   0.80    4.9                   *    2   59.0    48.0   0.70   0.80   10.4
  3   62.0    44.0   0.50   0.50    6.5                   *    3   55.0    39.0   0.90   0.90    9.8
  4   65.0    48.0   0.80   0.90    7.6                   *    4   53.0    44.0   0.70   0.80    8.2
  5   62.0    47.0   0.80   0.80    8.6                   *    5   51.0    45.0   0.80   0.90    5.0
  6   65.0    44.0   0.70   0.70    7.1                   *    6   55.0    49.0   1.00   1.00   10.9
  7   67.0    48.0   0.80   0.70    9.2                   *    7   57.0    52.0   1.00   1.00    9.9
  8   66.0    51.0   0.60   0.70    6.5                   *    8   58.0    53.0   1.00   1.00    8.6
  9   66.0    51.0   0.60   0.70    7.1                   *   10   58.0    52.0   0.90   0.90    9.5
 10   69.0    54.0   0.90   0.90    5.0                   *   11   58.0    47.0   0.70   0.70    5.8
 11   65.0    57.0   1.00   1.00   12.4                   *   12   58.0    46.0   0.90   0.90    4.8
 12   64.0    60.0   1.00   1.00    8.3                   *   13   58.0    42.0   0.80   1.00    7.9
 13   59.0    57.0   1.00   1.00    6.9                   *   14   53.0    34.0   0.40   0.60   11.5
 14   52.0    45.0   0.90   1.00    9.9                   *   15   54.0    35.0   0.00   0.00    9.8
 15   52.0    41.0   0.70   0.70    6.2                   *   16   57.0    40.0   0.40   0.40    6.2
 16   58.0    43.0   0.80   0.80    6.2                   *   17   60.0    42.0   0.70   0.80    6.2
 17   61.0    46.0   0.80   0.90    6.6                   *   18   60.0    43.0   0.70   0.80    6.2
 18   66.0    48.0   0.70   0.60    6.2                   *   19   60.0    49.0   1.00   1.00    5.9
 19   68.0    52.0   0.60   0.60    7.2                   *   20   51.0    44.0   1.00   1.00   11.5
 20   69.0    53.0   1.00   1.00    9.4                   *   21   50.0    41.0   0.90   0.90    7.6
 21   58.0    43.0   0.80   0.90   11.5                   *   22   56.0    45.0   0.90   0.90    7.6
 22   56.0    40.0   0.40   0.50    7.3                   *   23   59.0    47.0   0.80   0.80    5.6
 23   60.0    40.0   0.60   0.70    8.5                   *   24   57.0    47.0   0.90   0.80    5.8
 24   62.0    46.0   0.80   0.80    4.5                   *   25   57.0    48.0   0.90   0.90    6.2
 25   61.0    50.0   0.90   0.90    6.3                   *   26   57.0    47.0   0.70   0.80    4.9
 26   64.0    47.0   0.70   0.70    8.3                   *   27   53.0    41.0   0.60   0.70    5.9
 27   60.0    47.0   1.00   1.00   10.8                   *   28   56.0    41.0   0.50   0.50    5.2
 28   57.0    41.0   0.80   0.80   14.7                   *   29   56.0    40.0   0.50   0.60    4.6
 29   57.0    43.0   0.80   0.80    8.9                   *   30   53.0    43.0   0.80   0.90    6.5
 30   58.0    46.0   0.90   0.90    7.3                   *   31   54.0    45.0   1.00   0.90   11.2
 31   61.0    52.0   0.90   1.00    6.0                   *
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DAILY METROLOGICAL DATA FOR FAIRBANKS, ALASKA (CONT'D)

LATITUDE = 64.82 DEG. NORTH

MONTH : SEPTEMBER 1971

DATE	T-AIR	T-DP	CE	CS	U
1	50.0	40.0	1.00	1.00	7.1
2	44.0	38.0	1.00	1.00	7.1
3	43.0	37.0	1.00	1.00	8.9
4	44.0	37.0	1.00	1.00	8.6
5	46.0	35.0	0.80	0.90	6.3
6	48.0	35.0	0.90	0.90	5.6
7	54.0	35.0	0.90	0.90	11.2
8	50.0	32.0	0.90	0.80	8.9
9	45.0	35.0	0.90	1.00	6.0
10	47.0	35.0	0.50	0.50	7.2
11	48.0	32.0	0.50	0.50	8.3
12	45.0	29.0	0.30	0.30	6.9
13	44.0	27.0	0.20	0.20	4.9
14	43.0	27.0	0.50	0.50	4.8
15	46.0	30.0	0.50	0.40	7.2
16	56.0	31.0	0.40	0.30	14.7
17	44.0	35.0	0.80	1.00	7.8
18	46.0	33.0	0.30	0.20	7.8
19	45.0	30.0	0.70	0.80	3.9
20	45.0	37.0	0.90	0.90	5.0
21	46.0	35.0	0.90	0.90	5.2
22	44.0	32.0	0.20	0.20	3.6
23	42.0	31.0	0.60	0.60	4.6
24	45.0	35.0	0.90	0.90	12.8
25	46.0	34.0	1.00	1.00	8.9
26	41.0	31.0	0.60	0.70	11.2
27	39.0	28.0	0.90	0.90	5.6
28	38.0	25.0	0.70	0.50	7.3
29	36.0	27.0	1.00	1.00	5.9
30	40.0	35.0	1.00	1.00	5.2

MONTH : OCTOBER 1971

DATE	T-AIR	T-DP	CE	CS	U
1	37.0	32.0	1.00	1.00	5.8
2	33.0	22.0	1.00	1.00	6.2
3	29.0	18.0	1.00	1.00	7.2
4	27.0	17.0	1.00	1.00	7.1
5	25.0	18.0	1.00	1.00	7.9
6	25.0	15.0	1.00	1.00	6.9
7	36.0	24.0	1.00	1.00	9.9
8	48.0	31.0	0.90	0.90	10.4
9	39.0	25.0	0.80	0.70	9.9
10	43.0	24.0	0.80	0.80	5.8
11	33.0	23.0	1.00	1.00	6.0
12	29.0	20.0	1.00	1.00	5.8
13	30.0	22.0	1.00	1.00	6.6
14	29.0	18.0	0.90	0.80	7.2
15	36.0	21.0	0.90	0.90	5.6
16	38.0	29.0	1.00	1.00	10.2
17	37.0	30.0	1.00	1.00	11.2
18	32.0	26.0	1.00	1.00	8.8
19	28.0	21.0	0.90	0.80	5.0
20	22.0	11.0	0.00	0.00	5.3
21	17.0	7.0	0.90	1.00	5.0
22	18.0	7.0	1.00	1.00	5.2
23	15.0	7.0	0.90	1.00	1.9
24	16.0	7.0	1.00	1.00	8.5
25	15.0	6.0	0.90	0.80	5.3
26	23.0	14.0	1.00	1.00	4.2
27	24.0	14.0	1.00	1.00	3.6
28	25.0	16.0	1.00	1.00	6.9
29	20.0	10.0	1.00	0.90	4.5
30	22.0	13.0	1.00	1.00	2.2
31	21.0	11.0	1.00	1.00	9.8

DAILY METROLOGICAL DATA FOR FAIRBANKS, ALASKA (CONT'D)

LATITUDE = 64.82 DEG. NORTH

MONTH : NOVEMBER 1971

DATE	T-AIR	T-DP	CE	CS	U
1	19.0	9.0	1.00	1.00	6.9
2	7.0	3.0	0.70	0.40	3.3
3	3.0	-10.0	0.50	0.60	3.7
4	3.0	-9.0	0.80	1.00	2.9
5	11.0	1.0	0.90	1.00	2.5
6	11.0	2.0	0.60	1.00	2.6
7	6.0	-5.0	0.50	0.90	7.3
8	-5.0	-16.0	0.70	1.00	1.9
9	-1.0	-16.0	0.60	0.80	4.9
10	8.0	-4.0	0.90	1.00	7.6
11	13.0	5.0	0.90	0.80	4.0
12	13.0	5.0	1.00	1.00	1.3
13	12.0	6.0	0.60	0.40	5.2
14	6.0	-6.0	0.60	0.90	3.0
15	1.0	-8.0	0.70	0.90	4.2
16	8.0	0.0	0.60	0.70	3.0
17	13.0	5.0	0.90	0.90	3.7
18	16.0	14.0	0.60	0.60	4.0
19	5.0	-3.0	0.30	0.20	1.4
20	9.0	5.0	0.60	0.70	3.9
21	6.0	2.0	0.90	1.00	6.3
22	-11.0	-25.0	0.30	0.70	1.6
23	-2.0	-12.0	1.00	1.00	2.6
24	1.0	0.0	0.70	0.90	3.3
25	-10.0	-22.0	0.00	0.00	4.2
26	-28.0	-34.0	0.20	0.30	0.5
27	-27.0	-36.0	0.50	0.30	0.4
28	-22.0	-34.0	0.90	1.00	1.3
29	-20.0	-30.0	0.70	1.00	1.4
30	-27.0	-37.0	0.50	0.30	0.5

DAILY METROLOGICAL DATA FOR FAIRBANKS, ALASKA
LATITUDE = 64.82 DEG, NORTH

MONTH : OCTOBER 1947

DATE	T-AIR	T-DP	CE	CS	U
1	30.5	26.0	1.00	1.00	5.0
2	28.0	25.5	1.00	1.00	7.5
3	25.5	22.0	0.70	0.56	6.5
4	27.5	19.0	0.43	0.65	7.5
5	35.0	23.0	0.92	0.95	3.5
6	32.0	27.0	0.77	0.93	4.5
7	38.5	28.5	0.31	0.35	4.5
8	33.5	26.0	0.06	0.09	6.5
9	35.0	27.0	0.87	0.83	7.0
10	30.5	24.5	0.97	0.97	5.0
11	30.5	21.5	0.38	0.37	6.0
12	24.5	22.5	1.00	1.00	4.5
13	25.5	18.0	0.22	0.28	5.0
14	29.5	17.0	0.60	0.71	4.0
15	27.0	24.0	1.00	1.00	3.0
16	29.5	26.0	1.00	1.00	3.0
17	27.5	25.0	1.00	1.00	3.0
18	25.0	23.5	1.00	1.00	4.5
19	22.0	19.5	0.94	0.88	6.0
20	11.0	10.0	0.67	0.77	5.0
21	7.0	2.0	0.39	0.52	3.5
22	20.5	16.0	0.48	0.70	7.5
23	25.0	21.5	0.55	0.77	4.5
24	15.0	14.5	0.89	1.00	4.0
25	19.5	17.0	0.41	0.51	5.5
26	16.5	14.5	0.16	0.22	4.0
27	15.0	14.5	0.92	1.00	2.5
28	24.0	22.5	1.00	1.00	3.0
29	25.0	23.0	1.00	1.00	4.5
30	13.5	13.0	0.63	0.73	4.0
31	10.0	10.0	0.81	0.89	4.0

MONTH : NOVEMBER 1947

DATE	T-AIR	T-DP	CE	CS	U
1	2.0	-1.0	0.41	0.33	2.5
2	4.5	2.0	0.62	0.45	3.5
3	3.5	2.5	0.67	0.64	4.0
4	8.0	6.0	0.87	0.97	2.5
5	4.5	6.0	0.05	0.06	4.0
6	4.0	3.0	0.65	0.44	4.0
7	9.5	8.0	0.91	0.96	4.0
8	18.0	16.5	0.94	0.90	5.0
9	21.0	22.0	0.96	0.92	3.0
10	14.0	13.0	0.97	1.00	6.5
11	9.0	6.5	0.73	0.67	5.0
12	19.6	17.5	0.99	0.98	9.0
13	9.0	8.0	0.86	0.77	5.5
14	6.5	6.5	0.93	0.99	3.0
15	-7.5	-11.0	0.30	0.32	3.5
16	-9.0	-12.5	0.23	0.43	4.5
17	-12.5	-15.0	0.44	0.45	4.0
18	-5.5	-9.0	0.09	0.06	4.0
19	-5.0	-7.5	0.43	0.63	4.0
20	8.5	8.5	0.84	0.93	5.0
21	29.0	25.0	0.73	0.80	6.5
22	36.0	63.5	0.81	0.76	9.5
23	26.5	23.5	0.60	0.48	7.0
24	26.0	20.5	0.76	0.77	7.5
25	15.5	9.0	0.95	0.99	9.0
26	16.0	9.5	0.99	0.99	5.0
27	16.0	13.5	0.89	0.88	4.5
28	4.5	2.5	0.65	0.67	4.0
29	1.5	6.0	0.98	0.97	3.0
30	-7.0	-8.0	0.47	0.47	3.0

DAILY METROLOGICAL DATA FOR FAIRBANKS, ALASKA (CONT'D)

LATITUDE = 64.82 DEG. NORTH

MONTH : DECEMBER 1947

DATE	T-AIR	T-DP	CE	CS	U
1	4.0	2.5	0.98	0.96	5.0
2	10.0	8.0	0.94	0.99	4.5
3	19.5	17.5	0.95	0.91	5.5
4	24.6	23.0	0.95	0.91	7.0
5	18.5	17.0	0.85	0.85	5.5
6	21.0	20.0	0.93	0.87	3.0
7	13.0	12.5	0.74	0.57	4.5
8	14.5	14.0	0.92	0.93	4.5
9	1.0	-1.0	0.31	0.17	4.0
10	3.0	2.0	0.69	0.77	4.0
11	8.0	7.5	0.73	0.75	4.0
12	-0.5	-0.5	0.70	0.82	3.0
13	-0.5	-1.0	0.64	0.74	3.5
14	-8.0	-10.0	0.50	0.42	2.5
15	-6.5	-7.0	0.29	0.57	3.5
16	1.0	-0.5	0.69	0.75	3.5
17	-8.0	-10.0	0.58	0.69	4.5
18	-13.5	-14.0	0.70	0.74	2.5
19	-20.5	-22.0	0.11	0.17	2.5
20	-6.0	-7.0	0.70	0.73	4.0
21	-0.5	-1.0	0.73	0.77	4.0
22	-8.5	-9.0	0.44	0.17	4.0
23	-1.0	-2.5	0.88	0.87	4.0
24	-4.5	-6.0	0.69	0.77	4.0
25	-7.0	-8.0	0.70	0.70	6.0
26	-14.5	-15.5	0.09	0.11	4.5
27	-13.0	-13.5	0.56	0.17	6.0
28	-8.5	-8.5	0.93	1.00	4.5
29	-15.0	-15.5	0.66	0.53	3.5
30	-8.0	-9.0	0.95	0.93	4.5
31	-5.5	-7.0	0.91	0.93	3.0

MONTH : JANUARY 1948

DATE	T-AIR	T-DP	CE	CS	U
1	-16.0	-16.0	0.97	0.99	3.5
2	-12.0	-12.0	0.95	0.92	3.0
3	-14.5	-15.5	0.92	0.93	4.0
4	-22.0	-22.5	0.33	0.33	3.5
5	-30.0	-30.5	0.03	0.07	2.0
6	-27.0	-27.0	0.58	0.83	3.6
7	-20.0	-20.0	0.89	0.87	5.0
8	-19.0	-19.5	0.82	0.97	4.0
9	-24.0	-24.5	0.82	0.82	1.5
10	-33.0	-33.0	0.16	0.32	5.0
11	-20.0	-20.5	0.32	0.37	6.0
12	-5.5	-6.5	0.62	0.68	5.0
13	-13.3	-14.5	0.36	0.36	4.5
14	-13.0	-17.0	0.38	0.35	3.0
15	6.0	4.0	0.93	0.92	8.5
16	4.5	3.5	0.71	0.73	6.0
17	20.0	18.0	0.99	0.99	7.5
18	19.9	16.0	0.84	0.80	9.5
19	11.5	9.9	0.62	0.68	4.5
20	11.5	10.5	0.83	0.86	4.5
21	11.0	10.0	0.78	0.94	4.5
22	13.0	11.5	0.86	0.84	4.5
23	4.5	4.5	0.79	0.91	7.5
24	6.0	2.0	0.69	0.92	6.5
25	24.0	19.0	0.88	0.86	7.5
26	26.5	20.5	0.83	0.84	11.0
27	15.0	14.5	0.99	0.99	8.0
28	-6.0	-7.5	0.85	0.85	3.5
29	-13.5	-13.5	0.00	0.00	5.0
30	-12.5	-14.0	0.07	0.12	5.0
31	-4.5	-7.0	0.47	0.47	4.5

DAILY METROLOGICAL DATA FOR FAIRBANKS, ALASKA (CONT'D)

LATITUDE = 64.82 DEG. NORTH

MONTH : FEBRUARY 1948

DATE	T-AIR	T-DP	CE	CS	U
1	19.0	15.5	1.00	1.00	4.0
2	22.0	19.0	0.73	0.73	19.0
3	-1.0	2.0	0.54	0.67	7.5
4	12.5	8.5	0.95	0.99	5.5
5	20.0	13.5	0.90	0.86	6.0
6	1.0	-1.0	0.51	0.49	7.0
7	-2.5	-13.5	0.09	0.13	7.5
8	-6.0	-12.5	0.26	0.26	4.0
9	-6.0	-9.5	0.17	0.14	4.5
10	-4.5	-6.5	0.79	0.84	3.5
11	-2.5	-3.5	0.91	0.91	3.5
12	-13.0	-13.0	0.03	0.03	8.0
13	-22.5	-23.5	0.33	0.26	5.0
14	-24.0	-24.5	0.27	0.27	3.0
15	-26.0	-26.0	0.56	0.52	2.0
16	-23.0	-24.0	0.21	0.21	4.5
17	-26.0	-27.5	0.00	0.00	3.5
18	-21.0	-21.5	0.00	0.00	4.0
19	-22.0	-22.5	0.11	0.04	5.0
20	-17.5	-20.5	0.68	0.67	5.0
21	-12.5	-16.5	0.51	0.53	9.0
22	-9.5	-13.0	0.02	0.02	5.5
23	-8.5	-16.0	0.08	0.08	7.0
24	-1.0	-7.5	0.17	0.17	7.0
25	-6.0	-11.0	0.72	0.81	5.5
26	-3.0	-7.5	0.56	0.63	5.5
27	-4.0	-9.5	0.07	0.07	4.0
28	0.0	-7.0	0.00	0.00	9.0
29	-4.0	-9.5	0.00	0.00	3.5

MONTH : MARCH 1948

DATE	T-AIR	T-DP	CE	CS	U
1	-9.5	15.5	0.00	0.00	3.0
2	-14.0	-17.0	0.06	0.06	4.5
3	-16.5	-20.5	0.00	0.00	3.5
4	-11.5	19.5	0.00	0.00	10.0
5	-1.0	-8.5	0.04	0.07	10.5
6	3.5	-4.0	0.03	0.05	5.0
7	9.5	-0.5	0.03	0.05	5.5
8	13.5	5.5	0.03	0.05	4.5
9	15.0	7.5	0.19	0.18	5.5
10	10.5	7.5	0.84	0.91	4.0
11	4.5	3.0	0.76	0.79	10.0
12	4.5	-5.5	0.58	0.82	4.0
13	10.0	6.5	0.91	0.91	3.5
14	13.5	16.0	0.79	0.93	6.0
15	8.0	6.0	0.82	0.96	4.0
16	8.5	17.5	0.96	0.97	5.5
17	5.2	18.5	0.86	0.83	7.5
18	7.0	6.5	0.91	0.97	10.5
19	5.0	-0.5	0.39	0.63	5.5
20	6.5	1.5	0.65	0.71	11.0
21	-2.0	-7.5	0.75	0.83	8.5
22	-10.5	-16.5	0.43	0.67	4.0
23	-10.0	-16.5	0.14	0.07	5.0
24	-1.5	-13.0	0.00	0.00	5.0
25	3.0	-9.5	0.21	0.18	6.5
26	9.0	3.0	0.90	0.91	5.5
27	26.5	21.5	0.92	0.91	11.5
28	17.0	14.5	0.80	0.95	31.0
29	6.5	1.0	0.65	0.67	5.5
30	9.5	8.0	0.77	0.77	9.0
31	3.0	-0.5	0.40	0.36	8.5

DAILY METROLOGICAL DATA FOR FAIRBANKS, ALASKA (CONT'D)

LATITUDE = 64.82 DEG. NORTH

MONTH : APRIL 1948

DATE	T-AIR	T-DP	CE	CS	U
1	14.5	-12.5	0.96	0.92	18.0
2	30.0	27.5	1.00	1.00	20.0
3	29.5	24.0	0.91	0.91	13.5
4	26.0	20.5	0.76	0.87	10.5
5	26.5	23.5	0.91	0.91	15.5
6	33.0	27.5	0.82	0.83	13.0
7	34.0	32.5	1.00	1.00	15.0
8	33.5	29.0	0.90	0.90	16.5
9	31.5	26.0	0.95	1.00	17.0
10	33.0	28.0	0.87	0.83	16.5
11	31.5	25.5	0.94	0.93	13.5
12	27.0	24.5	0.80	0.92	7.5
13	35.5	32.5	0.87	0.97	22.0
14	31.5	26.0	0.63	0.75	12.0
15	16.5	11.5	0.77	0.75	16.5
16	5.5	-0.5	0.73	0.74	8.5
17	2.5	-4.5	0.10	0.10	5.5
18	3.0	-3.0	0.39	0.38	2.5
19	15.0	-7.5	0.87	0.87	8.0
20	20.0	14.0	0.76	0.87	11.0
21	14.5	10.0	0.54	0.75	11.0
22	6.5	-0.5	0.39	0.57	6.0
23	4.0	-5.5	0.00	0.00	5.0
24	9.0	-1.0	0.14	0.25	5.5
25	19.5	17.0	0.56	0.60	3.5
26	31.0	25.0	0.96	0.92	14.0
27	34.5	29.0	0.90	0.89	13.5
28	31.0	26.0	0.44	0.30	7.5
29	33.0	27.5	0.52	0.69	7.0
30	34.0	28.0	0.54	0.56	7.0

MONTH : MAY 1948

DATE	T-AIR	T-DP	CE	CS	U
1	29.0	22.5	0.40	0.35	9.5
2	24.0	16.5	0.13	0.18	9.5
3	22.5	18.0	0.97	1.00	8.0
4	27.0	22.5	0.31	0.08	5.0
5	37.0	29.0	0.29	0.29	4.5
6	25.0	30.0	0.77	0.86	5.0
7	36.0	30.0	0.73	0.74	8.0
8	39.5	31.5	0.66	0.62	5.5
9	45.5	37.5	0.58	0.74	9.5
10	47.5	39.5	0.50	0.51	6.0
11	48.5	37.5	0.71	0.66	8.5
12	46.0	40.0	0.42	0.47	7.0
13	47.0	40.5	0.18	0.12	10.5
14	52.0	43.5	0.50	0.48	8.5
15	50.5	41.5	0.33	0.29	7.0
16	51.5	42.0	0.62	0.75	8.0
17	55.0	42.0	0.73	0.57	8.0
18	53.0	45.0	0.72	0.60	7.0
19	46.0	38.0	0.73	0.85	14.0
20	47.0	37.5	0.19	0.29	8.5
21	50.0	39.0	0.32	0.34	8.0
22	49.5	42.5	0.75	0.88	8.0
23	49.0	41.5	0.71	0.82	10.5
24	51.0	41.5	0.75	0.92	13.0
25	59.5	48.0	0.84	0.82	9.0
26	61.0	54.0	0.87	0.90	11.5
27	57.0	53.5	0.74	0.73	6.5
28	50.5	46.5	0.53	0.52	12.5
29	51.5	44.0	0.76	0.83	6.0
30	50.5	47.0	0.69	0.72	11.0
31	52.5	46.0	0.47	0.37	5.5

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA

LATITUDE = 66.87 DEG. NORTH

MONTH : SEPTEMBER 1970

DATE	T-AIR	T-DP	CE	CS	U
1	46.0	41.0	0.50	0.50	9.4
2	44.0	41.0	1.00	1.00	13.7
3	48.0	40.0	0.60	0.60	11.1
4	44.0	36.0	0.30	0.30	17.8
5	42.0	32.0	0.10	0.10	20.0
6	38.0	31.0	0.40	0.50	25.2
7	37.0	29.0	0.70	0.80	20.4
8	40.0	34.0	0.80	0.70	10.5
9	41.0	35.0	0.80	0.90	11.5
10	43.0	34.0	0.90	1.00	11.4
11	43.0	41.0	1.00	1.00	15.1
12	45.0	42.0	1.00	0.90	10.4
13	41.0	34.0	0.80	0.70	20.6
14	41.0	33.0	0.30	0.20	14.0
15	38.0	33.0	0.30	0.20	9.1
16	40.0	34.0	0.50	0.80	12.9
17	34.0	29.0	0.50	0.70	25.3
18	35.0	30.0	1.00	1.00	18.7
19	35.0	28.0	1.00	1.00	19.1
20	33.0	28.0	1.00	0.90	17.7
21	32.0	26.0	1.00	1.00	12.9
22	33.0	28.0	1.00	1.00	10.5
23	30.0	24.0	0.20	0.10	11.2
24	30.0	20.0	0.00	0.10	10.8
25	30.0	25.0	0.30	0.50	7.1
26	30.0	25.0	0.30	0.30	17.3
27	25.0	16.0	0.00	0.00	23.6
28	24.0	15.0	0.00	0.00	10.8
29	25.0	16.0	0.00	0.00	11.8
30	23.0	14.0	0.20	0.30	15.5

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MONTH : OCTOBER 1970

DATE	T-AIR	T-DP	CE	CS	U
1	23.0	17.0	0.80	1.00	4.2
2	24.0	19.0	0.70	1.00	7.6
3	26.0	17.0	0.20	0.10	8.1
4	23.0	16.0	0.70	0.50	9.1
5	25.0	17.0	0.70	0.60	16.8
6	33.0	31.0	1.00	1.00	21.1
7	34.0	34.0	1.00	1.00	15.0
8	33.0	32.0	1.00	1.00	5.9
9	25.0	20.0	0.70	0.90	20.1
10	23.0	19.0	0.80	1.00	10.5
11	13.0	7.0	0.10	0.00	11.4
12	9.0	1.0	0.20	0.00	13.5
13	15.0	5.0	0.80	0.80	11.4
14	14.0	8.0	0.70	0.80	7.9
15	11.0	5.0	0.30	0.30	6.6
16	10.0	6.0	0.90	0.90	9.9
17	12.0	7.0	0.70	1.00	9.4
18	13.0	4.0	0.10	0.10	14.4
19	7.0	-2.0	0.00	0.00	14.9
20	0.0	-7.0	0.00	0.00	7.9
21	-2.0	-9.0	0.00	0.00	9.2
22	7.0	-3.0	0.00	0.00	14.7
23	1.0	-7.0	0.60	0.80	11.1
24	-3.0	-10.0	0.20	0.40	8.5
25	-7.0	-15.0	0.00	0.10	6.3
26	-5.0	-12.0	0.10	0.00	6.6
27	-2.0	-9.0	0.70	0.90	19.3
28	22.0	25.0	1.00	1.00	29.3
29	28.0	27.0	1.00	1.00	16.5
30	22.0	18.0	1.00	0.90	12.5
31	16.0	13.0	0.80	0.90	21.7

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG. NORTH

NOVEMBER 1970

DATE	T-AIR	T-DP	CE	CS	U
1	5.0	0.0	0.40	0.10	14.8
2	20.0	21.0	1.00	1.00	18.6
3	29.0	26.0	0.80	1.00	25.5
4	24.0	21.0	0.40	0.70	16.5
5	23.0	22.0	0.90	1.00	23.6
6	23.0	21.0	1.00	1.00	10.1
7	26.0	21.0	0.80	0.70	23.9
8	31.0	27.0	0.90	1.00	27.3
9	29.0	22.0	1.00	1.00	26.7
10	26.0	20.0	1.00	1.00	16.7
11	24.0	19.0	0.70	0.50	21.4
12	13.0	7.0	0.20	0.00	16.1
13	-1.0	-6.0	0.30	0.70	10.1
14	6.0	3.0	0.80	1.00	8.5
15	12.0	5.0	0.50	0.10	20.1
16	12.0	9.0	1.00	1.00	48.9
17	13.0	9.0	0.60	0.30	15.7
18	19.0	17.0	0.90	1.00	20.1
19	18.0	13.0	0.90	1.00	21.1
20	12.0	9.0	0.40	0.20	13.1
21	-3.0	-8.0	0.60	0.80	18.6
22	6.0	2.0	1.00	1.00	26.7
23	5.0	0.0	1.00	1.00	15.5
24	6.0	-2.0	0.90	1.00	26.2
25	0.0	-9.0	0.10	0.00	11.2
26	-1.0	-7.0	0.90	1.00	26.5
27	22.0	19.0	0.90	0.80	40.1
28	3.0	-2.0	0.60	1.00	8.8
29	-7.0	-13.0	0.60	0.50	8.6
30	-4.0	-10.0	0.60	1.00	19.7

MONTH : DECEMBER 1970

DATE	T-AIR	T-DP	CE	CS	U
1	-13.0	-20.0	0.00	0.00	9.2
2	-8.0	-14.0	0.80	1.00	9.1
3	-13.0	-21.0	0.10	0.00	3.5
4	-15.0	-25.0	0.60	0.40	6.5
5	-2.0	-9.0	0.30	0.00	6.3
6	-10.0	-20.0	0.00	0.00	2.0
7	-16.0	-28.0	0.00	0.00	3.9
8	-17.0	-28.0	0.00	0.00	2.5
9	-17.0	-26.0	0.00	0.00	2.5
10	-7.0	-19.0	0.00	0.00	3.7
11	-1.0	-11.0	0.00	0.00	9.1
12	-2.0	-11.0	0.80	0.90	3.9
13	6.0	-1.0	1.00	1.00	9.8
14	-2.0	-8.0	0.60	0.90	5.2
15	-1.0	-11.0	0.70	1.00	17.5
16	19.0	18.0	1.00	1.00	17.4
17	19.0	15.0	1.00	1.00	40.4
18	27.0	25.0	0.70	0.40	22.0
19	28.0	25.0	0.90	1.00	24.7
20	32.0	30.0	1.00	1.00	22.1
21	27.0	23.0	0.50	0.10	33.2
22	19.0	17.0	0.80	1.00	18.1
23	12.0	12.0	0.80	1.00	18.1
24	-8.0	-14.0	0.50	0.40	17.4
25	-19.0	-27.0	0.20	0.30	6.5
26	-15.0	-23.0	0.30	0.20	11.5
27	-17.0	-25.0	0.50	0.40	5.0
28	-19.0	-27.0	0.30	0.30	16.8
29	-18.0	-25.0	0.10	0.00	10.4
30	-12.0	-13.0	1.00	1.00	16.5
31	-23.0	-36.0	0.10	0.20	6.9

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG. NORTH

MONTH : JANUARY 1971

DATE	T-AIR	T-DP	CE	CS	U
1	-31.0	-39.0	0.00	0.00	1.0
2	-32.0	-43.0	0.20	0.30	4.5
3	-11.0	-18.0	0.70	1.00	7.1
4	-10.0	-15.0	0.60	1.00	11.7
5	-15.0	-25.0	0.00	0.00	19.1
6	-11.0	-16.0	0.80	1.00	17.4
7	-2.0	-8.0	0.50	0.60	8.2
8	-14.0	-23.0	0.00	0.00	16.8
9	-5.0	-15.0	0.60	0.80	29.0
10	5.0	0.0	0.90	1.00	29.5
11	8.0	3.0	1.00	1.00	17.7
12	11.0	5.0	1.00	1.00	25.2
13	11.0	5.0	0.90	0.80	29.5
14	5.0	-6.0	0.50	0.90	9.6
15	-2.0	-9.0	0.30	0.50	11.1
16	-1.0	-8.0	0.70	0.90	26.3
17	-10.0	-16.0	0.90	1.00	30.9
18	-22.0	-32.0	0.50	1.00	10.8
19	-32.0	-41.0	0.10	0.40	7.6
20	-32.0	-39.0	0.80	0.90	22.6
21	-30.0	-36.0	0.20	0.50	21.4
22	-32.0	-39.0	0.40	0.60	4.9
23	-35.0	-39.0	0.60	1.00	15.8
24	-21.0	-26.0	0.60	0.80	14.8
25	-7.0	-19.0	0.20	0.00	11.8
26	-23.0	-34.0	0.20	0.40	6.0
27	-20.0	-30.0	1.00	1.00	13.5
28	-17.0	-31.0	0.20	0.00	8.1
29	-21.0	-30.0	0.50	1.00	16.5
30	-17.0	-25.0	0.70	0.90	8.3
31	-16.0	-25.0	0.50	0.90	7.9

MONTH : FEBRUARY 1971

DATE	T-AIR	T-DP	CE	CS	U
1	-19.0	-30.0	0.00	0.00	4.0
2	-25.0	-35.0	0.00	0.00	3.5
3	-33.0	-41.0	0.00	0.10	5.0
4	-35.0	-43.0	0.20	0.20	3.5
5	-24.0	-36.0	0.60	0.70	5.0
6	-20.0	-27.0	0.20	0.10	7.9
7	-14.0	-28.0	0.60	0.90	6.9
8	11.0	11.0	1.00	1.00	17.4
9	12.0	8.0	1.00	0.90	6.0
10	1.0	-2.0	0.80	1.00	7.1
11	-11.0	-20.0	0.00	0.00	6.8
12	-8.0	-17.0	0.20	0.30	12.1
13	-7.0	-20.0	0.00	0.00	10.6
14	-19.0	-26.0	0.00	0.00	21.9
15	-30.0	-39.0	0.00	0.00	5.5
16	-24.0	-34.0	0.60	0.90	6.2
17	-22.0	-33.0	0.40	0.30	5.9
18	-17.0	-21.0	0.70	1.00	13.4
19	-19.0	-28.0	0.30	0.30	11.7
20	-18.0	-24.0	0.80	1.00	13.2
21	-16.0	-23.0	1.00	1.00	30.2
22	-23.0	-31.0	0.90	1.00	27.8
23	-28.0	-39.0	0.00	0.00	12.4
24	-34.0	-42.0	0.10	0.10	12.4
25	-33.0	-39.0	0.70	0.90	20.9
26	-19.0	-26.0	0.90	1.00	21.0
27	-25.0	-35.0	0.30	0.20	12.9
28	-35.0	-42.0	0.00	0.00	9.8

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG. NORTH

MONTH : MARCH 1971

DATE	T-AIR	T-DP	CE	CS	U
1	-31.0	-37.0	0.00	0.10	14.1
2	-22.0	-30.0	0.70	0.90	8.1
3	-22.0	-29.0	0.70	0.90	12.5
4	-30.0	-40.0	0.00	0.00	8.9
5	-31.0	-40.0	0.00	0.00	5.5
6	-32.0	-40.0	0.10	0.10	5.5
7	-18.0	-23.0	0.80	0.90	8.9
8	-19.0	-23.0	0.80	0.90	8.3
9	-29.0	-35.0	0.30	0.20	5.2
10	-37.0	-42.0	0.10	0.10	4.8
11	-34.0	-39.0	0.10	0.10	7.2
12	-31.0	-38.0	0.00	0.00	9.6
13	-29.0	-37.0	0.60	0.90	7.1
14	-30.0	-38.0	0.20	0.20	14.8
15	-26.0	-36.0	0.20	0.00	11.7
16	-4.0	-8.0	0.90	0.90	31.9
17	23.0	18.0	0.40	0.60	28.9
18	23.0	18.0	0.90	1.00	25.2
19	24.0	19.0	0.80	0.90	27.3
20	20.0	11.0	0.60	0.50	12.5
21	16.0	-8.0	0.50	0.60	6.6
22	11.0	-1.0	0.00	0.00	12.7
23	18.0	5.0	0.00	0.00	9.5
24	15.0	-6.0	0.70	0.80	20.3
25	13.0	-1.0	0.10	0.00	19.1
26	11.0	-1.0	0.00	0.00	13.8
27	6.0	-6.0	0.10	0.10	16.5
28	5.0	-5.0	0.10	0.10	15.7
29	4.0	-8.0	0.00	0.00	6.8
30	3.0	-6.0	0.30	0.50	5.0
31	4.0	-7.0	0.00	0.00	13.5

MONTH : APRIL 1971

DATE	T-AIR	T-DP	CE	CS	U
1	5.0	-9.0	0.00	0.00	14.8
2	7.0	-4.0	0.30	0.30	7.3
3	-2.0	-9.0	0.00	0.00	5.6
4	2.0	-6.0	0.70	0.80	7.2
5	5.0	-3.0	0.60	0.60	5.5
6	5.0	-2.0	0.50	0.60	6.2
7	3.0	-6.0	0.50	0.60	5.6
8	-5.0	-13.0	0.20	0.20	5.0
9	-6.0	-13.0	0.70	0.70	4.3
10	2.0	-7.0	0.10	0.00	9.5
11	2.0	-10.0	0.00	0.00	9.5
12	10.0	9.0	0.90	1.00	23.2
13	19.0	13.0	0.60	0.70	11.8
14	15.0	10.0	0.90	1.00	9.6
15	16.0	10.0	1.00	1.00	13.5
16	20.0	13.0	0.90	0.80	9.6
17	28.0	23.0	0.80	0.90	11.9
18	21.0	17.0	0.70	0.70	11.1
19	12.0	7.0	1.00	0.90	10.6
20	17.0	12.0	0.90	0.90	9.4
21	11.0	7.0	0.90	0.90	14.4
22	8.0	4.0	0.60	0.60	14.5
23	4.0	-3.0	0.40	0.50	6.0
24	5.0	0.0	0.10	0.10	3.5
25	20.0	12.0	0.20	0.20	9.1
26	19.0	13.0	0.50	0.60	8.9
27	15.0	10.0	0.20	0.20	15.0
28	8.0	3.0	0.00	0.00	24.4
29	14.0	2.0	0.00	0.00	14.8
30	12.0	2.0	0.10	0.10	7.1

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG. NORTH

MONTH : MAY 1971

DATE	T-AIR	T-DP	CE	CS	U
1	18.0	9.0	0.10	0.10	7.1
2	17.0	9.0	0.80	1.00	9.2
3	12.0	9.0	0.60	0.60	11.1
4	13.0	-9.0	0.90	1.00	6.5
5	28.0	28.0	1.00	1.00	9.5
6	31.0	29.0	0.90	1.00	8.2
7	18.0	13.0	1.00	1.00	8.9
8	21.0	20.0	0.70	0.70	7.8
9	20.0	19.0	0.70	0.70	8.3
10	17.0	11.0	0.30	0.40	7.1
11	13.0	-7.0	0.10	0.10	7.2
12	19.0	14.0	0.20	0.10	8.8
13	23.0	24.0	0.90	1.00	9.8
14	25.0	22.0	1.00	1.00	12.5
15	26.0	23.0	1.00	1.00	13.2
16	25.0	22.0	1.00	0.90	10.5
17	24.0	22.0	0.50	0.50	6.2
18	26.0	24.0	0.90	0.90	10.8
19	32.0	29.0	0.90	0.90	6.9
20	36.0	32.0	1.00	1.00	8.1
21	38.0	33.0	0.90	0.90	7.2
22	34.0	31.0	0.90	0.90	17.5
23	35.0	32.0	0.80	0.90	15.0
24	37.0	30.0	0.70	0.70	10.9
25	40.0	31.0	0.70	0.70	11.7
26	39.0	32.0	0.40	0.40	8.3
27	33.0	33.0	0.90	0.90	8.5
28	34.0	32.0	0.60	0.60	9.5
29	34.0	33.0	1.00	1.00	6.3
30	43.0	36.0	0.80	0.80	8.2
31	36.0	33.0	0.60	0.60	8.9

MONTH : JUNE 1971

DATE	T-AIR	T-DP	CE	CS	U
1	35.0	33.0	1.00	1.00	11.2
2	39.0	33.0	1.00	1.00	10.5
3	43.0	35.0	1.00	1.00	9.8
4	48.0	40.0	1.00	1.00	16.7
5	45.0	41.0	1.00	1.00	12.5
6	50.0	39.0	0.70	0.70	10.1
7	37.0	34.0	0.50	0.50	14.1
8	39.0	34.0	0.80	0.80	8.5
9	44.0	36.0	0.80	0.80	9.9
10	33.0	33.0	0.90	0.90	21.3
11	32.0	32.0	1.00	1.00	23.0
12	32.0	31.0	0.60	0.60	20.9
13	35.0	32.0	0.60	0.60	9.2
14	45.0	35.0	0.10	0.10	8.8
15	45.0	41.0	1.00	1.00	16.1
16	50.0	43.0	1.00	1.00	14.1
17	47.0	38.0	0.40	0.40	10.9
18	37.0	35.0	0.70	0.70	14.8
19	40.0	36.0	0.40	0.40	15.1
20	46.0	39.0	0.50	0.50	15.7
21	49.0	41.0	0.30	0.30	17.3
22	55.0	45.0	0.50	0.50	7.2
23	55.0	48.0	0.40	0.40	9.1
24	64.0	52.0	0.20	0.20	8.2
25	69.0	54.0	0.20	0.20	8.8
26	73.0	55.0	0.10	0.10	8.1
27	67.0	57.0	0.10	0.10	13.1
28	55.0	50.0	0.10	0.10	23.6
29	58.0	39.0	0.00	0.00	17.3
30	59.0	38.0	0.20	0.20	18.1

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG. NORTH

MONTH : JULY 1971

DATE	T-AIR	T-DP	CE	CS	U
1	59.0	42.0	0.10	0.10	15.0
2	59.0	49.0	0.00	0.00	11.9
3	60.0	48.0	0.60	0.60	19.3
4	55.0	50.0	1.00	1.00	15.1
5	57.0	47.0	1.00	1.00	8.8
6	62.0	49.0	0.70	0.70	8.5
7	61.0	52.0	0.90	0.90	9.6
8	64.0	53.0	0.90	0.90	8.2
9	57.0	52.0	1.00	1.00	9.9
10	57.0	54.0	1.00	1.00	14.4
11	53.0	50.0	1.00	1.00	11.8
12	51.0	47.0	1.00	1.00	15.0
13	49.0	43.0	1.00	1.00	15.1
14	46.0	42.0	1.00	1.00	20.6
15	46.0	39.0	1.00	1.00	11.8
16	52.0	42.0	0.90	0.80	9.1
17	56.0	48.0	0.70	0.70	10.6
18	59.0	51.0	0.90	1.00	13.5
19	66.0	55.0	0.70	0.80	8.6
20	66.0	57.0	0.90	0.90	11.1
21	57.0	46.0	0.90	0.90	11.9
22	58.0	47.0	0.40	0.50	12.8
23	60.0	47.0	0.90	0.90	14.2
24	61.0	50.0	0.70	0.70	8.1
25	61.0	52.0	0.80	0.80	9.8
26	56.0	52.0	1.00	1.00	18.3
27	55.0	46.0	0.80	0.80	12.1
28	53.0	46.0	0.90	0.90	16.1
29	47.0	42.0	1.00	0.90	18.3
30	50.0	43.0	1.00	0.90	15.1
31	48.0	39.0	0.40	0.40	19.3

MONTH : AUGUST 1971

DATE	T-AIR	T-DP	CE	CS	U
1	47.0	40.0	0.70	0.70	15.8
2	48.0	42.0	0.50	0.40	17.0
3	47.0	43.0	0.90	1.00	13.4
4	45.0	39.0	0.00	0.00	18.8
5	46.0	39.0	0.00	0.00	9.8
6	48.0	43.0	0.70	0.70	13.1
7	48.0	43.0	0.50	0.50	16.4
8	49.0	44.0	0.70	0.70	11.1
9	54.0	47.0	0.50	0.50	12.4
10	49.0	43.0	0.20	0.10	21.6
11	50.0	45.0	0.90	1.00	7.6
12	49.0	45.0	0.40	0.40	19.4
13	51.0	46.0	0.00	0.00	15.4
14	51.0	46.0	0.20	0.20	7.2
15	56.0	43.0	0.60	0.60	16.3
16	55.0	45.0	1.00	1.00	16.4
17	56.0	52.0	1.00	1.00	10.9
18	51.0	49.0	1.00	1.00	15.5
19	44.0	37.0	0.50	0.60	27.9
20	43.0	36.0	0.80	0.90	21.7
21	47.0	38.0	1.00	1.00	10.6
22	52.0	44.0	1.00	1.00	8.8
23	50.0	43.0	1.00	1.00	8.2
24	50.0	46.0	1.00	1.00	10.2
25	47.5	42.0	1.00	1.00	8.5
26	44.0	41.0	0.60	0.70	8.3
27	48.0	44.0	0.90	1.00	7.3
28	51.0	48.0	0.70	0.80	10.6
29	50.0	44.0	0.00	0.00	12.5
30	48.0	41.0	0.20	0.20	10.1
31	42.0	31.0	0.00	0.00	10.5

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG. NORTH

MONTH : SEPTEMBER 1971

DATE	T-AIR	T-DP	CE	CS	U
1	45.0	39.0	0.60	0.70	10.1
2	46.0	39.0	0.40	0.40	13.5
3	42.0	32.0	0.00	0.00	11.4
4	41.0	32.0	0.50	0.50	9.5
5	44.0	35.0	1.00	1.00	7.3
6	41.0	39.0	0.90	0.90	10.5
7	43.0	37.0	0.90	0.90	9.5
8	42.0	32.0	1.00	1.00	9.6
9	45.0	31.0	1.00	1.00	10.9
10	44.0	35.0	1.00	1.00	9.4
11	42.0	33.0	0.40	0.50	9.5
12	41.0	33.0	0.20	0.30	11.5
13	42.0	36.0	0.60	0.70	8.2
14	41.0	37.0	0.90	1.00	8.9
15	42.0	38.0	0.30	0.20	10.2
16	40.0	35.0	0.80	1.00	11.1
17	42.0	38.0	1.00	1.00	13.4
18	44.0	37.0	0.90	1.00	15.7
19	41.0	37.0	0.90	1.00	20.9
20	45.0	42.0	1.00	1.00	16.3
21	46.0	41.0	1.00	0.90	12.8
22	46.0	39.0	1.00	1.00	16.8
23	45.0	41.0	0.80	0.90	23.0
24	44.0	41.0	1.00	1.00	25.2
25	43.0	40.0	0.90	1.00	17.7
26	37.0	32.0	0.60	0.70	19.6
27	36.0	30.0	0.10	0.20	9.2
28	33.0	26.0	0.80	1.00	16.1
29	36.0	28.0	1.00	1.00	20.1
30	31.0	21.0	0.40	0.40	15.0

MONTH : OCTOBER 1971

DATE	T-AIR	T-DP	CE	CS	U
1	28.0	18.0	0.40	0.70	14.5
2	27.0	19.0	0.10	0.10	20.6
3	21.0	13.0	0.10	0.00	9.9
4	19.0	10.0	0.70	0.90	18.6
5	23.0	15.0	1.00	1.00	24.7
6	25.0	23.0	1.00	1.00	21.1
7	25.0	21.0	0.80	0.50	18.8
8	23.0	16.0	0.40	0.50	19.1
9	17.0	11.0	0.60	0.80	11.1
10	22.0	14.0	0.20	0.00	23.2
11	14.0	11.0	0.70	1.00	21.6
12	18.0	13.0	0.60	0.80	14.8
13	14.0	9.0	0.80	0.90	21.4
14	29.0	28.0	1.00	1.00	30.3
15	33.0	31.0	1.00	1.00	24.2
16	31.0	30.0	1.00	1.00	6.2
17	30.0	28.0	1.00	1.00	14.0
18	23.0	21.0	1.00	1.00	13.7
19	17.0	14.0	1.00	1.00	7.8
20	16.0	12.0	0.80	0.80	9.4
21	19.0	18.0	1.00	1.00	32.4
22	22.0	17.0	1.00	1.00	27.0
23	17.0	13.0	0.70	0.80	15.2
24	12.0	10.0	0.80	0.90	16.7
25	13.0	10.0	0.70	1.00	25.2
26	27.0	27.0	1.00	1.00	32.5
27	32.0	29.0	1.00	1.00	25.2
28	24.0	24.0	1.00	1.00	12.1
29	20.0	18.0	0.80	0.80	13.4
30	16.0	14.0	0.80	0.90	5.2
31	23.0	20.0	1.00	1.00	14.5

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG. NORTH

MONTH : NOVEMBER 1971

DATE	T-AIR	T-DP	CE	CS	U
1	13.0	13.0	0.70	1.00	22.6
2	7.0	3.0	0.70	1.00	11.9
3	6.0	-1.0	1.00	1.00	25.0
4	15.0	10.0	1.00	1.00	32.9
5	20.0	16.0	1.00	1.00	28.5
6	18.0	16.0	1.00	1.00	22.4
7	12.0	8.0	0.70	0.80	5.9
8	5.0	1.0	1.00	1.00	9.5
9	5.0	-2.0	0.60	0.80	20.1
10	4.0	-2.0	0.90	1.00	23.4
11	9.0	7.0	1.00	1.00	17.5
12	9.0	6.0	0.60	1.00	20.1
13	9.0	-5.0	0.70	0.50	23.4
14	19.0	15.0	0.90	0.70	30.8
15	21.0	17.0	1.00	1.00	25.2
16	16.0	-9.0	0.70	0.60	16.5
17	15.0	12.0	0.70	1.00	11.8
18	6.0	-1.0	0.00	0.00	7.8
19	-2.0	-8.0	0.30	0.00	7.5
20	-2.0	-8.0	0.20	0.30	10.4
21	-6.0	-13.0	0.00	0.00	13.4
22	-11.0	-11.0	0.00	0.00	14.0
23	8.0	2.0	0.90	1.00	29.9
24	14.0	8.0	0.70	0.30	15.2
25	6.0	-1.0	0.80	1.00	22.1
26	8.0	-1.0	0.50	0.70	13.4
27	0.0	-8.0	0.10	0.30	21.6
28	-7.0	-15.0	0.00	0.00	13.8
29	-8.0	-16.0	0.10	0.30	13.5
30	-16.0	-23.0	0.10	0.30	7.1

MONTH : DECEMBER 1971

DATE	T-AIR	T-DP	CE	CS	U
1	-20.0	-27.0	0.00	0.00	5.0
2	-20.0	-29.0	0.00	0.00	6.6
3	-20.0	-31.0	0.30	0.60	6.2
4	-18.0	-25.0	0.60	1.00	6.3
5	-16.0	-24.0	0.60	0.60	6.8
6	-4.0	-12.0	0.70	1.00	9.4
7	-5.0	-13.0	0.30	0.20	6.6
8	-12.0	-23.0	0.00	0.00	9.5
9	-11.0	-21.0	0.00	0.00	22.0
10	-5.0	-14.0	0.10	0.30	34.1
11	-5.0	-14.0	0.80	1.00	27.9
12	1.0	-7.0	0.90	1.00	32.8
13	1.0	0.0	0.80	0.90	11.4
14	5.0	1.0	0.90	1.00	28.6
15	11.0	7.0	1.00	1.00	17.0
16	-7.0	-13.0	0.60	0.00	22.1
17	8.0	4.0	0.90	1.00	34.9
18	5.0	-1.0	0.80	1.00	19.0
19	-13.0	-17.0	0.20	0.10	19.4
20	-16.0	-26.0	0.70	1.00	15.2
21	-5.0	-11.0	1.00	1.00	30.9
22	2.0	-4.0	1.00	1.00	47.0
23	13.0	9.0	1.00	1.00	37.2
24	22.0	20.0	1.00	1.00	27.3
25	27.0	24.0	0.90	0.80	17.3
26	24.0	22.0	1.00	1.00	15.7
27	22.0	19.0	0.90	1.00	24.2
28	21.0	20.0	0.80	1.00	23.9
29	16.0	15.0	0.80	0.70	15.0
30	2.0	-3.0	0.20	0.10	5.3
31	-2.0	-6.0	1.00	1.00	9.5

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG, NORTH

MONTH : JANUARY 1972

DATE	T-AIR	T-DP	CE	CS	U
1	-4.0	-9.0	0.50	0.30	8.3
2	8.0	-7.0	1.00	1.00	31.6
3	14.0	11.0	0.90	1.00	25.2
4	-3.0	-5.0	0.50	1.00	15.4
5	-11.0	-23.0	0.00	0.10	13.7
6	-20.0	-28.0	0.00	0.00	5.6
7	-18.0	-26.0	0.00	0.00	6.0
8	-14.0	-23.0	0.10	0.20	16.5
9	-20.0	-28.0	0.30	0.10	8.6
10	-18.0	-25.0	0.40	0.80	15.2
11	-13.0	-17.0	0.50	0.60	24.9
12	-20.0	-27.0	0.00	0.00	7.3
13	-27.0	-32.0	0.10	0.20	5.8
14	-24.0	-35.0	0.10	0.00	4.2
15	-18.0	-25.0	0.00	0.00	9.1
16	-22.0	-28.0	0.60	0.70	16.5
17	-10.0	-14.0	1.00	1.00	32.1
18	-4.0	-10.0	1.00	1.00	30.1
19	-1.0	-8.0	0.60	1.00	19.4
20	-8.0	-16.0	0.40	0.80	8.8
21	-14.0	-27.0	0.00	0.00	3.9
22	-17.0	-24.0	0.00	0.00	5.5
23	-9.0	-20.0	0.00	0.00	10.1
24	2.0	-6.0	0.40	0.10	29.3
25	10.0	3.0	0.80	1.00	32.2
26	23.0	20.0	1.00	1.00	25.9
27	27.0	25.0	1.00	1.00	17.3
28	26.0	26.0	1.00	1.00	20.4
29	15.0	16.0	1.00	1.00	22.1
30	14.0	9.0	1.00	1.00	24.3
31	11.0	11.0	0.60	1.00	12.8

MONTH : FEBRUARY 1972

DATE	T-AIR	T-DP	CE	CS	U
1	-7.0	-14.0	0.00	0.00	13.1
2	-21.0	-30.0	0.00	0.00	5.3
3	-15.0	-19.0	0.00	0.00	8.9
4	-5.0	-21.0	0.00	0.00	7.5
5	-3.0	-13.0	0.00	0.00	6.6
6	-12.0	-17.0	0.10	0.30	9.5
7	-24.0	-33.0	0.00	0.00	6.0
8	-20.0	-28.0	0.00	0.00	8.1
9	-13.0	-21.0	0.00	0.00	3.9
10	-11.0	-24.0	0.00	0.00	3.6
11	-11.0	-21.0	0.00	0.00	17.4
12	-14.0	-25.0	0.00	0.10	17.4
13	-22.0	-30.0	0.20	0.40	6.3
14	-24.0	-36.0	0.00	0.00	7.9
15	-12.0	-21.0	0.30	0.70	22.7
16	-14.0	-23.0	0.00	0.10	17.1
17	-19.0	-22.0	0.10	0.10	16.0
18	-29.0	-35.0	0.40	0.80	10.9
19	-21.0	-28.0	0.60	0.80	14.1
20	-6.0	-10.0	0.90	1.00	19.4
21	5.0	0.0	1.00	1.00	29.0
22	14.0	14.0	1.00	1.00	16.4
23	18.0	17.0	1.00	1.00	4.0
24	12.0	6.0	0.50	0.80	11.4
25	4.0	-1.0	0.90	0.90	14.2
26	9.0	3.0	0.50	0.70	9.4
27	0.0	-7.0	0.00	0.00	7.1
28	-8.0	-15.0	0.00	0.00	6.3
29	-7.0	-17.0	0.00	0.00	9.1

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG. NORTH

MONTH : MARCH 1972

DATE	T-AIR	T-DP	CE	CS	U
1	-12.0	-21.0	0.00	0.10	5.6
2	-2.0	-10.0	0.10	0.20	14.0
3	-9.0	-18.0	0.60	0.90	8.2
4	-7.0	-12.0	0.50	1.00	21.3
5	-14.0	-22.0	0.00	0.00	12.1
6	-18.0	-29.0	0.00	0.00	3.9
7	-26.0	-37.0	0.00	0.00	6.9
8	-22.0	-38.0	0.00	0.00	3.5
9	-22.0	-31.0	0.50	0.50	3.3
10	-10.0	-17.0	0.20	0.10	13.2
11	-6.0	-14.0	0.30	0.20	17.5
12	-8.0	-15.0	0.10	0.10	12.2
13	-11.0	-19.0	0.20	0.30	3.9
14	-15.0	-19.0	0.70	1.00	14.8
15	-7.0	-20.0	0.10	0.10	12.7
16	-15.0	-22.0	0.70	1.00	10.1
17	-19.0	-28.0	0.20	0.40	6.6
18	-18.0	-29.0	0.10	0.20	5.3
19	-16.0	-29.0	0.10	0.20	3.3
20	-22.0	-30.0	0.10	0.20	12.8
21	-20.0	-31.0	0.00	0.00	15.2
22	-15.0	-25.0	0.00	0.00	8.2
23	-15.0	-25.0	0.00	0.00	7.6
24	-11.0	-14.0	0.90	1.00	24.9
25	-7.0	-13.0	0.50	0.20	15.0
26	-16.0	-23.0	0.90	1.00	9.4
27	-10.0	-14.0	0.90	1.00	16.8
28	-14.0	-21.0	0.30	0.30	5.9
29	-15.0	-24.0	0.00	0.00	4.6
30	-11.0	-22.0	0.10	0.00	7.1
31	-6.0	-9.0	0.10	0.10	23.0

MONTH : APRIL 1972

DATE	T-AIR	T-DP	CE	CS	U
1	3.0	-4.0	0.50	0.90	15.5
2	5.0	0.0	0.80	0.90	26.9
3	15.0	14.0	1.00	1.00	21.4
4	3.0	-5.0	0.90	1.00	33.9
5	-1.0	-7.0	0.70	0.80	22.6
6	1.0	-9.0	0.00	0.00	15.1
7	-3.0	-17.0	0.00	0.00	5.9
8	-2.0	-9.0	0.60	0.60	22.6
9	14.0	12.0	1.00	1.00	37.1
10	20.0	16.0	1.00	1.00	22.6
11	12.0	11.0	0.70	0.90	9.8
12	6.0	1.0	0.70	0.70	14.7
13	-2.0	-7.0	1.00	1.00	14.8
14	-8.0	-15.0	0.80	0.70	11.8
15	-5.0	-11.0	0.30	0.30	17.4
16	1.0	-6.0	0.10	0.10	12.5
17	6.0	-4.0	0.40	0.40	10.8
18	8.0	-2.0	0.20	0.20	7.6
19	-1.0	-9.0	0.60	0.60	7.9
20	9.0	0.0	0.40	0.50	5.5
21	10.0	-2.0	0.00	0.00	6.2
22	9.0	0.0	0.00	0.00	13.5
23	17.0	7.0	0.00	0.00	19.0
24	19.0	9.0	0.60	0.70	7.2
25	12.0	2.0	0.60	0.60	10.8
26	8.0	0.0	0.20	0.20	15.8
27	7.0	3.0	0.50	0.50	7.6
28	13.0	10.0	0.00	0.00	15.5
29	22.0	17.0	0.70	0.90	18.7
30	27.0	23.0	0.90	1.00	17.8

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           DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)
                       LATITUDE = 66.87 DEG. NORTH

MONTH  :  MAY 1972                            * MONTH  :  JUNE 1972
                                              *
DATE  T-AIR  T-DP    CE     CS      U         * DATE  T-AIR  T-DP    CE     CS      U
                                              *
  1   28.0   26.0   0.90   0.90   13.8        *   1   34.0   33.0   1.00   1.00   18.4
  2   29.0   24.0   0.91   1.00   12.1        *   2   39.0   35.0   1.00   1.00   13.1
  3   32.0   24.0   0.30   0.30    4.5        *   3   40.0   33.0   0.70   0.70   16.7
  4   25.0   22.0   0.70   0.70    7.6        *   4   40.0   32.0   0.60   0.60    7.9
  5   36.0   31.0   0.90   0.90    8.3        *   5   33.0   32.0   0.90   0.90   23.6
  6   33.0   32.0   1.00   1.00   16.4        *   6   32.0   27.0   0.80   0.80   15.4
  7   33.0   27.0   0.80   0.90    7.1        *   7   38.0   29.0   0.90   0.90   11.2
  8   28.0   24.0   0.40   0.40   11.5        *   8   42.0   40.0   1.00   1.00   15.4
  9   35.0   26.0   0.00   0.00    8.3        *   9   48.0   39.0   1.00   1.00   10.5
 10   33.0   23.0   0.00   0.00    4.8        *  10   40.0   36.0   0.50   0.50   10.4
 11   31.0   23.0   0.10   0.10    4.6        *  11   42.0   35.0   0.50   0.50    8.5
 12   30.0   25.0   0.90   1.00    6.9        *  12   49.0   40.0   0.70   0.70    7.1
 13   34.0   29.0   0.50   0.50   10.5        *  13   38.0   34.0   0.90   0.90   13.5
 14   32.0   26.0   0.60   0.70   13.2        *  14   41.0   35.0   0.50   0.50   10.9
 15   28.0   21.0   0.80   0.80   10.9        *  15   45.0   39.0   0.70   0.70    9.9
 16   28.0   26.0   1.00   1.00    9.5        *  16   43.0   38.0   0.70   0.70    9.6
 17   26.0   23.0   0.80   0.80    7.3        *  17   51.0   39.0   0.60   0.60   14.1
 18   30.0   27.0   0.90   0.90   10.2        *  18   41.0   38.0   0.90   0.90    8.3
 19   36.0   32.0   1.00   1.00   14.4        *  19   48.0   39.0   0.70   0.70   12.8
 20   28.0   23.0   1.00   1.00    9.5        *  20   43.0   40.0   0.90   0.90    7.8
 21   26.0   20.0   1.00   1.00   10.4        *  21   44.0   41.0   0.80   0.80   11.8
 22   35.0   27.0   0.60   0.60   17.8        *  22   44.0   40.0   0.90   0.90   11.5
 23   42.0   31.0   0.30   0.30   18.0        *  23   41.0   40.0   0.90   0.90   20.3
 24   47.0   28.0   0.40   0.40   13.0        *  24   41.0   35.0   0.90   0.90   12.1
 25   47.0   30.0   0.50   0.50   11.2        *  25   52.0   44.0   0.90   0.90   11.9
 26   46.0   33.0   0.60   0.60   10.6        *  26   54.0   46.0   0.70   0.70   13.2
 27   50.0   35.0   0.40   0.40   14.1        *  27   46.0   42.0   0.20   0.20   21.9
 28   37.0   32.0   0.90   0.90    9.6        *  28   52.0   44.0   0.00   0.00   21.4
 29   39.0   31.0   0.90   0.90   16.8        *  29   49.0   41.0   0.00   0.00   18.0
 30   42.0   31.0   0.90   0.90   11.2        *  30   54.0   43.0   0.30   0.30   11.4
 31   36.0   31.0   1.00   1.00    7.3        *
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DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG. NORTH

MONTH : JULY 1972

DATE	T-AIR	T-DP	CE	CS	U
1	57.0	46.0	0.40	0.40	8.6
2	56.0	49.0	0.80	0.80	17.8
3	50.0	45.0	0.80	0.80	17.3
4	50.0	43.0	0.70	0.70	14.5
5	56.0	45.0	0.70	0.70	10.6
6	61.0	50.0	0.20	0.20	8.2
7	66.0	52.0	0.00	0.00	9.1
8	66.0	57.0	0.10	0.10	11.2
9	69.0	56.0	0.10	0.10	9.5
10	70.0	58.0	0.50	0.50	7.1
11	65.0	56.0	0.70	0.70	15.0
12	68.0	57.0	0.70	0.70	16.5
13	61.0	56.0	0.70	0.70	8.8
14	55.0	51.0	0.40	0.40	11.5
15	56.0	52.0	1.00	0.90	10.2
16	59.0	55.0	0.90	0.90	11.9
17	59.0	49.0	0.70	0.70	11.2
18	59.0	51.0	0.90	0.90	15.8
19	56.0	49.0	1.00	1.00	14.7
20	52.0	48.0	1.00	1.00	12.5
21	52.0	47.0	1.00	1.00	11.2
22	54.0	48.0	0.70	0.80	7.8
23	61.0	52.0	0.10	0.10	8.5
24	64.0	50.0	0.50	0.60	13.1
25	62.0	49.0	0.30	0.20	12.9
26	62.0	52.0	0.20	0.20	10.6
27	56.0	52.0	0.90	0.80	10.9
28	56.0	50.0	0.90	0.90	7.8
29	59.0	52.0	1.00	1.00	13.4
30	60.0	52.0	1.00	1.00	14.0
31	60.0	52.0	0.50	0.50	10.9

MONTH : AUGUST 1972

DATE	T-AIR	T-DP	CE	CS	U
1	63.0	54.0	0.10	0.10	12.7
2	66.0	54.0	0.30	0.20	9.5
3	65.0	56.0	0.30	0.30	9.6
4	60.0	57.0	0.60	0.70	13.2
5	51.0	46.0	0.60	0.60	24.3
6	50.0	45.0	1.00	1.00	11.1
7	48.0	42.0	0.80	0.70	9.4
8	56.0	51.0	0.70	0.80	12.4
9	56.0	50.0	0.70	0.60	11.7
10	57.0	50.0	0.60	0.50	11.8
11	56.0	51.0	1.00	1.00	8.3
12	58.0	54.0	0.90	0.80	11.8
13	59.0	54.0	1.00	1.00	9.4
14	58.0	55.0	1.00	1.00	7.1
15	58.0	55.0	1.00	1.00	8.9
16	58.0	54.0	0.90	0.80	10.1
17	57.0	50.0	0.90	0.90	9.4
18	56.0	51.0	1.00	1.00	23.4
19	55.0	48.0	0.90	0.80	20.9
20	52.0	48.0	0.90	0.90	14.2
21	54.0	51.0	0.90	1.00	13.2
22	57.0	52.0	0.80	0.90	9.2
23	55.0	51.0	0.60	0.70	11.9
24	52.0	51.0	1.00	1.00	24.4
25	51.0	48.0	0.70	0.80	25.6
26	50.0	42.0	0.80	0.90	10.5
27	52.0	46.0	0.60	0.70	9.9
28	54.0	44.0	0.40	0.50	11.7
29	55.0	48.0	0.50	0.50	12.7
30	46.0	41.0	0.70	0.80	12.2
31	47.0	46.0	1.00	1.00	19.1

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)
LATITUDE = 66.87 DEG. NORTH

MONTH : SEPTEMBER 1972

DATE	T-AIR	T-DP	CE	CS	U
1	51.0	50.0	1.00	1.00	11.8
2	57.0	50.0	0.90	0.90	12.2
3	53.0	51.0	1.00	1.00	10.4
4	50.0	48.0	1.00	1.00	8.3
5	52.0	47.0	0.90	0.90	10.9
6	52.0	49.0	0.20	0.10	9.4
7	48.0	45.0	0.60	0.70	10.6
8	50.0	40.0	0.70	0.80	23.7
9	45.0	39.0	1.00	1.00	25.2
10	47.0	43.0	0.90	0.80	14.5
11	49.0	43.0	0.80	0.70	8.6
12	45.0	39.0	0.70	0.90	8.9
13	41.0	36.0	0.80	0.80	10.6
14	38.0	34.0	0.90	0.90	17.7
15	38.0	31.0	0.60	0.70	23.4
16	37.0	29.0	0.40	0.60	24.2
17	38.0	32.0	0.60	0.70	17.4
18	36.0	26.0	0.00	0.00	10.5
19	35.0	23.0	0.10	0.00	10.2
20	35.0	26.0	0.80	1.00	8.3
21	38.0	30.0	1.00	1.00	13.8
22	39.0	37.0	0.90	0.90	5.9
23	41.0	37.0	0.30	0.40	9.5
24	36.0	32.0	0.70	0.90	8.9
25	37.0	32.0	0.70	1.00	14.4
26	34.0	27.0	0.60	0.70	16.1
27	37.0	33.0	1.00	1.00	18.6
28	30.0	26.0	0.00	0.00	15.4
29	26.0	19.0	0.70	0.80	22.4
30	25.0	17.0	0.90	1.00	24.9

MONTH : OCTOBER 1972

DATE	T-AIR	T-DP	CE	CS.	U
1	24.0	16.0	0.80	1.00	15.5
2	22.0	13.0	0.20	0.30	17.7
3	26.0	17.0	0.50	0.50	6.5
4	21.0	15.0	0.20	0.10	14.7
5	21.0	14.0	0.00	0.00	12.2
6	20.0	18.0	0.80	1.00	10.9
7	32.0	30.0	1.00	1.00	15.1
8	35.0	33.0	1.00	1.00	25.3
9	38.0	34.0	1.00	1.00	25.3
10	36.0	34.0	1.00	1.00	8.6
11	32.0	27.0	0.80	0.70	10.2
12	30.0	28.0	1.00	1.00	11.2
13	27.0	24.0	1.00	1.00	12.1
14	28.0	25.0	1.00	1.00	9.5
15	34.0	33.0	1.00	1.00	22.6
16	38.0	36.0	1.00	1.00	20.1
17	37.0	35.0	1.00	1.00	20.1
18	35.0	32.0	0.80	0.80	10.6
19	31.0	27.0	0.90	0.90	16.0
20	31.0	28.0	1.00	1.00	17.1
21	31.0	28.0	1.00	1.00	15.4
22	27.0	25.0	0.60	0.90	9.6
23	21.0	19.0	0.50	0.60	8.3
24	26.0	23.0	1.00	1.00	23.0
25	36.0	32.0	0.90	0.90	24.2
26	33.0	27.0	0.90	1.00	25.9
27	34.0	30.0	0.80	0.80	21.9
28	32.0	27.0	0.60	0.80	20.9
29	30.0	26.0	0.90	0.90	14.8
30	25.0	22.0	0.80	1.00	12.2
31	18.0	14.0	0.90	1.00	20.9

DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)

LATITUDE = 66.87 DEG. NORTH

MONTH : NOVEMBER 1972

DATE	T-AIR	T-DP	CE	CS	U
1	16.0	11.0	0.60	0.60	11.2
2	10.0	5.0	0.60	1.00	22.0
3	15.0	5.0	0.70	1.00	18.8
4	11.0	3.0	0.10	0.00	10.5
5	8.0	0.0	0.40	0.30	13.2
6	10.0	5.0	0.90	1.00	14.1
7	6.0	1.0	0.60	0.90	6.2
8	5.0	0.0	0.80	1.00	7.8
9	3.0	-4.0	0.50	0.80	8.2
10	2.0	-5.0	0.70	0.70	7.8
11	6.0	1.0	0.60	0.50	9.8
12	11.0	7.0	0.80	1.00	18.6
13	13.0	5.0	0.80	1.00	25.7
14	15.0	9.0	0.90	0.90	26.6
15	14.0	8.0	0.70	1.00	16.4
16	10.0	5.0	0.50	0.30	10.5
17	14.0	7.0	1.00	1.00	12.5
18	12.0	8.0	1.00	1.00	8.2
19	7.0	-3.0	1.00	0.90	12.1
20	3.0	-5.0	0.70	1.00	10.5
21	3.0	-5.0	0.80	1.00	9.8
22	3.0	-3.0	1.00	1.00	8.8
23	4.0	-1.0	1.00	1.00	8.2
24	6.0	-1.0	0.60	0.40	14.2
25	8.0	3.0	0.90	1.00	10.1
26	9.0	2.0	0.70	0.60	20.4
27	18.0	15.0	1.00	1.00	33.1
28	22.0	18.0	0.70	0.90	26.5
29	21.0	20.0	1.00	1.00	9.8
30	14.0	8.0	1.00	1.00	12.9

MONTH : DECEMBER 1972

DATE	T-AIR	T-DP	CE	CS	U
1	11.0	7.0	1.00	1.00	15.0
2	17.0	14.0	1.00	1.00	29.9
3	25.0	21.0	1.00	1.00	21.7
4	25.0	21.0	1.00	1.00	28.6
5	29.0	24.0	0.90	1.00	27.3
6	32.0	29.0	0.90	1.00	13.8
7	26.0	22.0	0.80	0.90	8.6
8	25.0	21.0	1.00	1.00	15.4
9	16.0	15.0	0.80	1.00	5.3
10	20.0	18.0	0.90	1.00	29.3
11	25.0	20.0	0.90	1.00	27.5
12	11.0	14.0	0.90	1.00	23.7
13	3.0	-3.0	0.60	0.80	19.7
14	-2.0	-11.0	0.00	0.00	17.0
15	-5.0	-15.0	0.10	0.20	3.0
16	2.0	-10.0	0.00	0.00	9.2
17	-4.0	-16.0	0.00	0.00	6.6
18	-15.0	-28.0	0.10	0.00	4.6
19	-14.0	-26.0	0.20	0.80	5.8
20	-4.0	-18.0	0.40	1.00	3.9
21	-9.0	-25.0	0.00	0.00	6.5
22	-10.0	-26.0	0.00	0.10	8.1
23	-14.0	-31.0	0.00	0.00	6.8
24	-16.0	-33.0	0.00	0.00	8.2
25	-18.0	-34.0	0.00	0.00	4.5
26	-22.0	-40.0	0.00	0.00	7.2
27	-21.0	-41.0	0.50	0.70	7.1
28	-20.0	-36.0	0.00	0.10	7.9
29	-12.0	-26.0	0.00	0.10	15.0
30	-16.0	-28.0	0.00	0.00	13.7
31	-14.0	-31.0	0.60	0.90	18.8

```
               DAILY METROLOGICAL DATA FOR KOTZEBUE, ALASKA (CONT'D)
                          LATITUDE = 66.87 DEG. NORTH

MONTH  :  JANUARY 1973                          * MONTH  :  FEBRUARY 1973
                                                *
DATE  T-AIR   T-DP    CE     CS      U          * DATE  T-AIR   T-DP    CE     CS      U
                                                *
  1    -0.0   -7.0   1.00   1.00   38.5         *   1    -1.0  -10.0   1.00   1.00   29.5
  2    14.0    9.0   1.00   1.00   33.4         *   2   -10.0  -22.0   0.60   0.70   21.3
  3    23.0   21.0   1.00   1.00   27.2         *   3    -2.0  -10.0   1.00   1.00   39.3
  4    25.0   22.0   1.00   1.00   33.6         *   4    21.0   16.0   0.90   1.00   31.3
  5    25.0   22.0   1.00   1.00   23.6         *   5    15.0    9.0   0.80   1.00   25.2
  6    17.0   13.0   0.80   0.60   16.7         *   6    16.0   10.0   0.90   1.00   16.7
  7    26.0   24.0   1.00   1.00   31.2         *   7    18.0   15.0   0.90   1.00   18.4
  8    26.0   21.0   0.50   0.20   23.6         *   8    15.0   12.0   0.70   1.00   21.0
  9    12.0    8.0   0.70   0.90   13.8         *   9     8.0    4.0   0.40   0.40    7.6
 10    -5.0  -13.0   0.30   0.80   12.7         *  10     2.0   -3.0   0.00   0.00   18.3
 11   -10.0  -24.0   0.00   0.00   18.0         *  11    -6.0  -14.0   0.00   0.00    9.1
 12   -20.0  -36.0   0.00   0.00    7.9         *  12    -7.0  -14.0   0.00   0.00   18.4
 13   -31.0  -40.0   0.20   0.50    9.6         *  13   -17.0  -24.0   0.00   0.00    8.2
 14   -29.0  -38.0   0.40   0.30    9.9         *  14   -21.0  -31.0   0.00   0.00    7.3
 15   -32.0  -41.0   0.00   0.00    6.3         *  15   -16.0  -25.0   0.00   0.00    6.9
 16   -24.0  -32.0   0.00   0.00    4.2         *  16   -19.0  -30.0   0.50   0.30    3.6
 17   -14.0  -34.0   0.30   0.00   10.1         *  17    -3.0   -6.0   1.00   1.00    6.2
 18   -17.0  -28.0   0.70   1.00   18.1         *  18     9.0    1.0   1.00   1.00   11.5
 19   -34.0  -43.0   0.10   0.10    6.6         *  19    17.0   12.0   1.00   1.00   16.1
 20   -36.0  -45.0   0.20   0.40    5.0         *  20    17.0   11.0   1.00   1.00    8.2
 21   -35.0  -44.0   0.60   0.30    5.8         *  21    14.0   10.0   1.00   1.00    8.2
 22   -33.0  -42.0   0.60   0.40    4.6         *  22    15.0   10.0   0.50   0.40   16.1
 23   -34.0  -43.0   0.10   0.70    1.7         *  23    15.0    9.0   0.40   0.70   15.8
 24   -37.0  -44.0   0.50   1.00   10.9         *  24    12.0    6.0   0.40   0.90   22.1
 25   -32.0  -41.0   0.60   0.90   28.9         *  25     2.0   -7.0   0.00   0.00   12.7
 26    -9.0  -18.0   0.60   0.30   36.8         *  26     5.0  -10.0   0.00   0.00    7.1
 27     1.0   -6.0   0.90   1.00   28.5         *  27    14.0    3.0   0.00   0.00   17.5
 28     3.0   -3.0   0.90   1.00   15.1         *  28     6.0   -5.0   0.10   0.00   11.9
 29   -11.0  -27.0   0.30   0.30   25.6         *
 30   -24.0  -39.0   0.70   0.90   24.6         *
 31   -14.0  -25.0   0.90   1.00   33.2         *
```

DAILY METROLOGICAL DATA FOR BOSTON, MASSACHUSSETTS

LATITUDE = 42.37 DEG. NORTH

MONTH : DECEMBER 1960

DATE	T-AIR	T-DP	CS	S	U
1	30.0	20.0	0.30	0.59	19.0
2	31.0	21.0	0.00	0.98	11.4
3	38.0	28.0	0.00	1.00	5.3
4	39.0	29.0	0.20	1.00	4.3
5	47.0	37.0	0.30	0.98	6.4
6	48.0	38.0	0.70	0.85	9.3
7	45.0	35.0	0.60	0.54	18.9
8	29.0	19.0	0.50	0.52	18.4
9	21.0	11.0	0.30	1.00	19.4
10	29.0	19.0	0.70	0.34	18.4
11	16.0	6.0	0.70	0.65	11.3
12	17.0	7.0	1.00	0.00	26.6
13	12.0	2.0	0.60	0.70	23.4
14	20.0	10.0	0.10	1.00	12.9
15	29.0	19.0	0.50	0.87	8.2
16	36.0	26.0	1.00	0.00	15.3
17	30.0	20.0	0.00	1.00	18.9
18	30.0	20.0	0.10	1.00	12.1
19	28.0	18.0	0.70	0.37	7.6
20	27.0	17.0	0.30	0.99	10.8
21	37.0	27.0	1.00	0.00	17.6
22	29.0	19.0	0.10	0.97	18.2
23	20.0	10.0	0.00	1.00	16.8
24	19.0	9.0	0.50	0.03	12.4
25	35.0	25.0	0.70	0.41	14.4
26	40.0	30.0	0.20	1.00	15.9
27	26.0	16.0	0.30	0.98	19.7
28	17.0	7.0	0.10	1.00	11.4
29	27.0	7.0	0.90	0.00	7.5
30	34.0	24.0	0.50	0.77	11.5
31	35.0	25.0	0.20	1.00	8.7

MONTH : JANUARY 1961

DATE	T-AIR	T-DP	CS	S	U
1	36.0	26.0	0.90	0.00	19.7
2	31.0	21.0	0.30	1.00	13.7
3	27.0	17.0	0.90	0.89	10.4
4	26.0	16.0	0.20	0.80	15.5
5	24.0	14.0	0.30	1.00	15.9
6	37.0	27.0	0.80	0.31	12.5
7	43.0	32.0	0.50	0.63	10.6
8	36.0	26.0	0.60	0.68	18.0
9	24.0	14.0	0.30	0.87	20.5
10	24.0	14.0	0.20	0.98	11.2
11	35.0	25.0	0.70	0.96	16.9
12	30.0	20.0	0.30	0.95	13.5
13	32.0	22.0	0.50	0.57	12.5
14	48.0	38.0	1.00	0.38	15.2
15	34.0	24.0	1.00	0.00	25.1
16	29.0	19.0	0.90	0.00	19.0
17	36.0	26.0	0.40	0.97	10.9
18	30.0	20.0	0.20	0.99	18.3
19	16.0	6.0	0.80	0.80	13.2
20	14.0	4.0	1.00	0.00	26.7
21	13.0	3.0	0.10	1.00	15.8
22	16.0	6.0	0.10	1.00	13.6
23	13.0	3.0	0.50	0.79	10.1
24	14.0	4.0	0.30	0.77	12.5
25	12.0	2.0	0.20	0.95	19.9
26	16.0	6.0	0.90	0.65	12.7
27	15.0	5.0	0.50	0.79	15.3
28	18.0	8.0	0.20	1.00	15.5
29	21.0	11.0	0.30	1.00	13.3
30	16.0	6.0	0.50	0.97	14.3
31	18.0	8.0	0.50	0.97	17.0

DAILY METROLOGICAL DATA FOR BOSTON, MASSACHUSSETTS (CONT'D)

LATITUDE = 42.37 DEG. NORTH

MONTH : FEBRUARY 1961

DATE	T-AIR	T-DP	CS	S	U
1	5.0	-5.0	0.10	0.90	19.0
2	6.0	-4.0	0.00	1.00	15.5
3	18.0	8.0	0.70	0.51	9.8
4	27.0	17.0	1.00	0.00	31.3
5	25.0	15.0	0.20	0.97	14.5
6	28.0	18.0	0.70	0.91	12.9
7	26.0	16.0	0.00	0.99	9.1
8	32.0	22.0	0.10	1.00	8.3
9	40.0	30.0	0.10	0.99	8.1
10	37.0	27.0	1.00	0.31	10.8
11	28.0	18.0	0.80	0.23	11.7
12	26.0	16.0	0.40	0.66	9.9
13	25.0	15.0	0.70	0.86	8.6
14	37.0	27.0	0.80	0.12	12.8
15	34.0	24.0	0.30	0.91	14.2
16	24.0	14.0	0.30	0.97	10.5
17	31.0	21.0	0.60	0.77	16.3
18	38.0	28.0	1.00	0.00	6.1
19	50.0	40.0	0.90	0.47	15.4
20	37.0	27.0	0.40	0.97	13.5
21	32.0	22.0	0.60	1.00	8.9
22	43.0	33.0	0.50	0.89	12.2
23	40.0	30.0	1.00	0.00	7.8
24	37.0	27.0	1.00	0.00	5.9
25	40.0	30.0	1.00	0.00	7.0
26	43.0	33.0	0.70	0.18	21.0
27	44.0	34.0	0.60	0.79	11.3
28	39.0	29.0	0.80	0.00	9.1

DAILY METROLOGICAL DATA FOR BECKLEY, WEST VIRGINIA

LATITUDE = 37.78 DEG. NORTH

MONTH : DECEMBER 1963

DATE	T-AIR	T-DP	CE	CS	U
1	25.0	16.0	0.80	1.00	10.8
2	31.0	22.0	1.00	1.00	8.2
3	28.0	19.0	1.00	1.00	8.0
4	27.0	18.0	0.70	0.30	3.9
5	32.0	23.0	1.00	1.00	2.4
6	34.0	25.0	0.40	0.30	7.0
7	44.0	35.0	0.30	0.30	9.1
8	35.0	26.0	0.70	0.90	11.7
9	24.0	15.0	1.00	1.00	12.0
10	25.0	16.0	1.00	1.00	9.3
11	29.0	20.0	1.00	1.00	5.9
12	36.0	27.0	1.00	1.00	7.0
13	33.0	24.0	1.00	1.00	2.6
14	20.0	11.0	0.90	0.90	9.6
15	10.0	1.0	1.00	1.00	8.5
16	10.0	1.0	0.60	0.80	5.0
17	14.0	5.0	0.50	0.50	5.7
18	17.0	8.0	1.00	1.00	11.9
19	10.0	-1.0	0.50	0.20	12.9
20	6.0	-3.0	0.70	0.60	6.8
21	8.0	-1.0	0.10	0.00	4.3
22	16.0	-7.0	0.50	0.40	3.7
23	22.0	13.0	1.00	1.00	11.2
24	22.0	13.0	0.80	0.70	9.2
25	27.0	18.0	0.50	0.60	10.0
26	39.0	30.0	0.00	0.00	11.5
27	31.0	22.0	0.90	0.90	10.7
28	21.0	12.0	0.80	0.90	6.3
29	18.0	9.0	0.40	0.20	5.5
30	15.0	6.0	0.40	0.10	3.8
31	18.0	9.0	1.00	1.00	10.3

MONTH : JANUARY 1964

DATE	T-AIR	T-DP	CE	CS	U
1	29.0	20.0	1.00	1.00	15.0
2	31.0	22.0	0.20	0.10	12.9
3	42.0	33.0	0.20	0.00	10.7
4	33.0	24.0	0.40	0.30	12.1
5	33.0	24.0	0.00	0.00	8.0
6	40.0	31.0	0.90	1.00	7.3
7	34.0	25.0	0.80	1.00	6.0
8	36.0	27.0	0.90	0.90	22.0
9	44.0	35.0	0.90	0.80	19.4
10	21.0	12.0	0.30	0.00	18.8
11	28.0	19.0	0.20	0.00	7.3
12	25.0	16.0	1.00	1.00	20.9
13	16.0	7.0	1.00	1.00	14.6
14	10.0	1.0	0.50	0.40	10.2
15	15.0	6.0	0.40	0.50	10.2
16	24.0	15.0	0.40	0.60	9.8
17	29.0	20.0	0.20	0.00	10.1
18	37.0	28.0	0.20	0.00	7.7
19	42.0	33.0	0.60	1.00	11.9
20	37.0	28.0	0.80	1.00	22.3
21	39.0	30.0	0.00	0.00	13.7
22	47.0	38.0	0.30	0.40	8.8
23	53.0	44.0	0.50	0.20	9.3
24	50.0	41.0	1.00	1.00	13.7
25	43.0	34.0	0.60	0.80	22.4
26	36.0	27.0	0.40	0.50	19.7
27	42.0	33.0	0.60	0.70	10.6
28	24.0	15.0	0.30	0.10	13.5
29	24.0	15.0	0.00	0.00	5.0
30	35.0	26.0	0.30	0.20	8.3
31	38.0	29.0	1.00	1.00	15.4

DAILY METROLOGICAL DATA FOR BECKLEY, WEST VIRGINIA (CONT'D)

LATITUDE = 37.78 DEG. NORTH

MONTH : FEBRUARY 1964

DATE	T-AIR	T-DP	CE	CS	U
1	36.0	27.0	0.90	1.00	12.5
2	31.0	22.0	0.60	0.60	13.7
3	27.0	18.0	0.00	0.00	5.5
4	28.0	19.0	0.00	0.00	4.2
5	42.0	33.0	0.40	0.20	9.8
6	39.0	30.0	1.00	1.00	18.9
7	32.0	23.0	1.00	1.00	13.7
8	24.0	15.0	0.60	0.70	15.8
9	29.0	20.0	0.90	0.90	9.0
10	30.0	21.0	1.00	1.00	10.2
11	20.0	11.0	0.80	1.00	8.7
12	21.0	12.0	0.70	0.90	4.8
13	34.0	25.0	1.00	1.00	10.6
14	27.0	18.0	0.60	0.80	10.8
15	29.0	20.0	0.90	1.00	15.6
16	31.0	22.0	1.00	1.00	16.7
17	30.0	21.0	0.10	0.00	11.5
18	33.0	24.0	1.00	1.00	10.3
19	28.0	19.0	1.00	1.00	13.4
20	24.0	15.0	1.00	1.00	13.5
21	21.0	12.0	1.00	1.00	11.5
22	17.0	8.0	0.90	0.90	6.5
23	17.0	8.0	0.50	0.20	7.5
24	27.0	18.0	0.60	0.70	10.9
25	32.0	23.0	0.70	1.00	10.3
26	32.0	23.0	0.60	0.80	12.2
27	26.0	17.0	0.60	0.60	9.1
28	26.0	17.0	1.00	1.00	13.2
29	29.0	20.0	0.70	0.30	9.9

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                DAILY METROLOGICAL DATA FOR CHARLESTON, WEST VIRGINIA
                          LATITUDE = 38.37 DEG. NORTH

MONTH : DECEMBER 1964                          *  MONTH  :  JANUARY 1965
                                               *
DATE  T-AIR   T-DP    CE     CS       U        *  DATE  T-AIR   T-DP    CE     CS       U
                                               *
  1   16.0    -5.0   0.40   0.30     4.5       *    1   37.0    33.0   0.90   1.00     7.2
  2   35.0    24.0   1.00   1.00     4.4       *    2   49.0    44.0   1.00   1.00    11.4
  3   45.0    34.0   1.00   1.00     6.1       *    3   31.0    21.0   0.50   0.50     9.1
  4   59.0    48.0   0.90   1.00     8.4       *    4   30.0    18.0   0.30   0.30     2.6
  5   41.0    30.0   1.00   1.00     8.2       *    5   37.0    22.0   0.70   0.40     6.6
  6   26.0    15.0   0.90   1.00     7.9       *    6   39.0    29.0   0.60   0.70     4.5
  7   27.0    16.0   0.50   0.80     5.7       *    7   44.0    33.0   0.80   0.90     5.8
  8   34.0    23.0   1.00   1.00     7.3       *    8   63.0    46.0   1.00   1.00    13.7
  9   33.0    22.0   0.60   0.80     5.6       *    9   50.0    39.0   1.00   1.00     9.8
 10   38.0    27.0   0.70   0.90     4.9       *   10   33.0    29.0   1.00   1.00     8.5
 11   55.0    44.0   1.00   1.00     6.5       *   11   28.0    25.0   0.90   1.00     4.9
 12   49.0    38.0   0.70   0.80     6.3       *   12   31.0    25.0   0.70   0.70     3.0
 13   46.0    35.0   0.90   0.80     8.0       *   13   35.0    28.0   0.90   1.00     9.1
 14   37.0    26.0   0.20   0.00    11.7       *   14   22.0     6.0   0.20   0.20     6.9
 15   26.0    15.0   0.30   0.40     7.0       *   15   28.0    15.0   0.80   0.80     7.3
 16   33.0    22.0   0.30   0.10     7.8       *   16   23.0    19.0   1.00   1.00     8.9
 17   42.0    31.0   1.00   1.00     8.7       *   17   14.0     6.0   0.90   0.70     8.6
 18   20.0    -9.0   0.60   0.60     9.4       *   18   21.0    11.0   0.90   1.00    15.0
 19   21.0    10.0   0.70   1.00     4.8       *   19   21.0     9.0   0.30   0.30     6.0
 20   36.0    25.0   1.00   1.00     6.5       *   20   34.0    17.0   0.50   0.70    12.1
 21   33.0    22.0   0.80   0.90     4.2       *   21   33.0    19.0   0.10   0.10     3.9
 22   37.0    26.0   0.90   1.00     5.0       *   22   45.0    33.0   0.40   0.60     6.5
 23   48.0    37.0   1.00   1.00     9.7       *   23   49.0    44.0   1.00   1.00     4.8
 24   66.0    55.0   0.70   0.80    13.8       *   24   50.0    45.0   1.00   1.00    10.5
 25   58.0    47.0   0.70   0.80     9.3       *   25   43.0    32.0   0.60   0.70     7.9
 26   53.0    42.0   1.00   1.00     7.0       *   26   50.0    35.0   0.70   0.60    16.7
 27   40.0    29.0   1.00   1.00     6.6       *   27   30.0    12.0   0.40   0.40    17.4
 28   34.0    23.0   0.90   1.00     4.0       *   28   31.0    16.0   0.80   1.00    13.2
 29   46.0    35.0   0.40   0.20     5.5       *   29   16.0     5.0   0.90   0.70     8.5
 30   53.0    42.0   0.80   0.90    10.7       *   30   15.0     5.0   1.00   1.00     7.8
 31   38.0    27.0   0.40   0.20     4.5       *   31    9.0    -4.5   0.30   0.10     7.2
```

DAILY METROLOGICAL DATA FOR CHARLESTON, WEST VIRGINIA (CONT'D)

LATITUDE = 38.37 DEG. NORTH

MONTH : FEBRUARY 1965

DATE	T-AIR	T-DP	CE	CS	U
1	18.0	14.0	1.00	1.00	7.9
2	12.0	2.0	0.40	0.40	11.8
3	14.0	0.0	0.10	0.20	11.5
4	16.0	3.0	0.30	0.20	8.2
5	24.0	9.0	0.30	0.30	6.9
6	46.0	28.0	0.70	0.80	4.9
7	55.0	51.0	1.00	1.00	6.8
8	57.0	51.0	1.00	1.00	7.1
9	55.0	48.0	1.00	1.00	7.5
10	60.0	53.0	0.80	0.90	11.2
11	56.0	48.0	0.90	1.00	5.8
12	52.0	43.0	0.90	0.90	14.8
13	30.0	17.0	0.90	0.90	7.2
14	26.0	21.0	0.80	1.00	5.8
15	31.0	21.0	0.50	0.60	3.6
16	36.0	22.0	0.90	0.90	3.3
17	42.0	28.0	0.80	0.90	4.3
18	43.0	24.0	0.40	0.20	12.4
19	35.0	16.0	0.60	0.60	16.3
20	29.0	8.0	0.20	0.50	6.2
21	38.0	26.0	0.70	0.90	10.8
22	21.0	11.0	0.40	0.40	13.1
23	25.0	12.0	0.30	0.50	7.5
24	39.0	31.0	0.80	0.90	14.2
25	33.0	26.0	1.00	1.00	18.4
26	19.0	8.0	0.70	0.80	14.8
27	35.0	20.0	0.10	0.00	7.1
28	53.0	38.0	0.30	0.40	7.6

```
                DAILY METROLOGICAL DATA FOR ELKINS, WEST VIRGINIA
                         LATITUDE = 38.88 DEG. NORTH

MONTH  :  DECEMBER 1965                         *  MONTH  :  JANUARY 1966
                                                *
DATE  T-AIR  T-DP    CE     CS      U          *  DATE  T-AIR  T-DP    CE     CS      U
                                                *
  1   28.0   17.0   0.40   0.40    6.2         *    1   54.0   47.0   1.00   1.00    8.1
  2   33.0   19.0   0.70   0.90    5.0         *    2   53.0   49.0   1.00   1.00    7.8
  3   40.0   29.0   0.90   1.00    7.5         *    3   41.0   30.0   0.90   1.00   13.9
  4   36.0   27.0   1.00   0.90   13.2         *    4   33.0   22.0   0.50   0.70    3.9
  5   40.0   25.0   0.60   0.60   11.8         *    5   32.0   27.0   1.00   1.00    2.3
  6   34.0   29.0   0.90   1.00   15.2         *    6   44.0   43.0   1.00   1.00    8.6
  7   21.0   18.0   0.70   0.70    8.3         *    7   40.0   30.0   1.00   0.90   12.7
  8   27.0   19.0   0.60   0.20    7.9         *    8   21.0   11.0   0.90   0.90   14.2
  9   40.0   28.0   0.70   0.50    4.3         *    9   20.0   13.0   0.60   0.70    4.2
 10   42.0   30.0   1.00   1.00    6.9         *   10   34.0   22.0   0.60   0.80   10.8
 11   48.0   46.0   1.00   1.00    4.7         *   11   19.0    9.0   0.10   0.10   13.2
 12   54.0   39.0   1.00   0.90    7.3         *   12   19.0   10.0   0.70   0.80    3.9
 13   46.0   46.0   1.00   1.00    8.6         *   13   33.0   29.0   1.00   1.00   11.6
 14   39.0   36.0   1.00   1.00    9.9         *   14   26.0   23.0   0.70   0.80    6.5
 15   38.0   35.0   1.00   0.90    4.5         *   15   25.0   22.0   0.80   1.00    3.9
 16   40.0   37.0   1.00   1.00    4.5         *   16   21.0   12.0   0.90   0.90   10.6
 17   36.0   30.0   1.00   1.00   12.9         *   17   16.0    9.0   0.90   1.00    9.2
 18   34.0   23.0   0.90   0.80    9.2         *   18   19.0   13.0   1.00   0.90    8.9
 19   27.0   20.0   1.00   0.90    8.9         *   19   16.0   10.0   1.00   0.90    8.1
 20   24.0   20.0   0.90   0.90    4.9         *   20   23.0   19.0   0.90   0.90    4.2
 21   29.0   27.0   1.00   1.00    5.5         *   21   26.0   19.0   0.10   0.10    0.9
 22   32.0   25.0   0.30   0.10    4.7         *   22   26.0   24.0   1.00   1.00    7.8
 23   36.0   30.0   0.70   1.00    3.3         *   23   23.0   22.0   1.00   1.00   13.5
 24   50.0   30.0   0.80   0.80    6.5         *   24   12.0    8.0   0.70   0.50    5.6
 25   44.0   38.0   0.90   1.00   17.3         *   25   22.0   14.0   1.00   1.00    3.9
 26   21.0   21.0   0.50   0.60   11.4         *   26   23.0   19.0   1.00   1.00    5.3
 27   26.0   15.0   0.50   0.70    7.3         *   27   17.0   12.0   0.90   0.90   12.4
 28   31.0   21.0   0.80   0.90    7.2         *   28    4.5  -11.0   0.30   0.20    7.9
 29   33.0   21.0   0.70   0.70    5.5         *   29    5.0   -1.0   1.00   1.00    3.7
 30   41.0   38.0   0.80   1.00    6.5         *   30    1.0   -9.0   0.90   0.90   15.2
 31   52.0   44.0   0.90   1.00    8.8         *   31    9.0   -6.0   0.50   0.40   12.2
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DAILY METROLOGICAL DATA FOR ELKINS, WEST VIRGINIA (CONT'D)

LATITUDE = 38.88 DEG. NORTH

MONTH : FEBRUARY 1966

DATE	T-AIR	T-DP	CE	CS	U
1	15.0	8.0	0.60	0.80	3.3
2	27.0	23.0	1.00	1.00	10.1
3	24.0	19.0	1.00	1.00	9.5
4	19.0	15.0	1.00	1.00	10.4
5	13.0	11.0	0.90	0.90	10.1
6	16.0	8.0	0.90	1.00	3.6
7	38.0	31.0	1.00	1.00	8.2
8	44.0	36.0	0.60	0.60	5.9
9	40.0	34.0	0.60	0.90	8.2
10	47.0	43.0	1.00	1.00	15.5
11	46.0	40.0	0.90	1.00	8.2
12	40.0	37.0	0.80	0.90	4.2
13	47.0	43.0	1.00	1.00	16.4
14	39.0	28.0	0.60	0.70	7.8
15	41.0	33.0	1.00	1.00	8.6
16	43.0	40.0	1.00	1.00	12.1
17	28.0	13.0	0.30	0.30	16.8
18	30.0	18.0	0.70	1.00	4.0
19	31.0	23.0	0.76	0.50	7.5
20	13.0	2.0	0.40	0.10	9.9
21	16.0	1.0	0.10	0.30	7.5
22	19.0	10.0	0.30	0.70	4.9
23	26.0	15.0	0.60	0.70	5.6
24	34.0	29.0	1.00	1.00	1.9
25	32.0	29.0	1.00	1.00	7.0
26	29.0	26.0	1.00	1.00	8.8
27	27.0	17.0	0.90	1.00	5.9
28	45.0	40.0	1.00	1.00	10.4

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                    DAILY METROLOGICAL DATA FOR MORGANTOWN, WEST VIRGINIA
                                LATITUDE = 39.63 DEG. NORTH

MONTH  :  DECEMBER 1965                           *  MONTH  :  JANUARY 1966
                                                  *
DATE  T-AIR  T-DP    CE     CS      U             *  DATE  T-AIR  T-DP    CE     CS      U
                                                  *
  1   29.0   19.0   0.41   0.33   10.9            *    1   56.0   47.5   1.00   1.00    6.9
  2   40.0   18.0   0.63   0.45   12.6            *    2   51.5   45.5   1.00   1.00    9.2
  3   47.0   27.0   0.65   0.64   12.6            *    3   44.0   33.0   0.66   0.80   12.1
  4   40.5   27.0   0.89   0.97   14.4            *    4   34.5   19.5   0.10   0.12    3.5
  5   38.5   25.5   0.07   0.06   12.1            *    5   38.0   31.5   0.90   1.00    4.6
  6   36.5   24.0   0.47   0.44    9.2            *    6   45.0   38.5   0.98   1.00    6.3
  7   29.5   19.5   0.91   0.96    6.9            *    7   36.0   27.0   0.99   0.98    8.6
  8   35.5   20.0   0.96   0.90    9.2            *    8   25.5   12.0   0.66   0.82   10.9
  9   38.5   25.0   1.00   1.00    6.9            *    9   27.0   14.5   0.41   0.53    8.6
 10   47.5   35.0   0.97   1.00    5.7            *   10   38.5   19.5   0.65   0.73   12.7
 11   51.0   46.0   0.73   0.67    8.1            *   11   28.0   14.5   0.30   0.53    9.2
 12   61.5   35.5   0.86   0.78    7.5            *   12   20.5   11.0   0.40   0.36    4.0
 13   52.0   42.5   1.00   1.00    9.8            *   13   33.5   27.5   0.98   1.00    8.1
 14   41.5   33.3   0.30   0.32    7.5            *   14   30.0   25.0   0.83   0.96    6.9
 15   39.0   33.5   0.87   1.00    7.5            *   15   27.0   19.0   0.68   0.78    6.9
 16   40.0   34.5   1.00   1.00    3.5            *   16   25.0    8.5   0.73   0.84    5.8
 17   35.5   27.0   1.00   1.00    9.2            *   17   21.0   12.0   0.98   0.98    8.6
 18   32.5   23.0   0.84   0.98    9.2            *   18   22.5   12.0   0.87   0.93    5.8
 19   28.0   18.5   0.82   0.93    6.9            *   19   21.0   12.5   1.00   1.00    8.6
 20   26.6   19.5   0.92   0.97    2.9            *   20   26.0   20.0   1.00   1.00    3.5
 21   30.0   22.5   1.00   1.00    3.5            *   21   29.0   17.5   0.13   0.05    4.0
 22   38.0   24.5   0.39   0.27   10.4            *   22   32.0   22.5   1.00   1.00    7.5
 23   48.5   27.0   0.72   0.91    8.6            *   23   28.0   20.5   1.00   1.00    9.2
 24   58.0   26.5   0.55   0.64    9.2            *   24   19.0   10.0   0.88   0.76    5.8
 25   46.0   38.0   0.91   0.99   12.1            *   25   17.5   10.0   0.91   0.93    6.3
 26   27.5   21.0   0.53   0.55    6.9            *   26   20.5   10.5   0.98   1.00    6.9
 27   31.0   16.5   0.57   0.63    8.6            *   27   17.5    6.5   0.81   0.88   12.7
 28   32.5   18.5   0.80   0.79    8.1            *   28    8.0  -10.0   0.16   0.23    7.5
 29   38.5   24.0   0.46   0.61    8.6            *   29    2.0   -5.0   1.00   1.00    5.8
 30   51.5   42.0   0.63   0.97   12.1            *   30    6.0   -3.5   0.93   0.94   12.7
 31   61.0   52.0   0.91   0.97   13.8            *   31   11.5   -1.0   0.75   0.95   13.2
```

DAILY METROLOGICAL DATA FOR MORGANTOWN, WEST VIRGINIA (CONT'D)

LATITUDE = 39.63 DEG. NORTH

MONTH : FEBRUARY 1966

DATE	T-AIR	T-DP	CE	CS	U
1	18.0	10.5	0.60	0.71	4.6
2	23.0	18.5	1.00	1.00	5.8
3	25.0	19.5	1.00	1.00	5.8
4	21.0	15.0	0.99	0.98	7.5
5	19.5	13.5	0.97	0.98	6.9
6	22.5	18.5	0.92	0.98	5.8
7	35.0	31.0	1.00	1.00	7.5
8	45.0	35.0	0.55	0.47	4.6
9	51.0	35.0	0.42	0.63	8.1
10	56.0	42.5	0.98	0.99	13.8
11	54.5	42.5	0.85	0.91	8.1
12	46.0	35.5	1.00	1.00	6.1
13	45.0	38.5	1.00	1.00	9.2
14	42.0	31.0	0.50	0.51	8.1
15	40.5	29.0	0.91	0.91	9.2
16	45.5	37.5	1.00	1.00	11.5
17	37.5	11.5	0.34	0.30	9.2
18	36.5	15.0	0.59	0.65	6.9
19	26.5	11.5	0.75	0.92	6.9
20	11.5	-1.0	0.17	0.33	6.9
21	20.5	3.0	0.10	0.19	5.2
22	25.0	12.5	0.82	0.97	4.0
23	31.5	16.5	0.38	0.23	7.5
24	38.0	25.0	1.00	1.00	5.8
25	34.0	28.5	1.00	1.00	5.8
26	35.0	25.5	0.89	0.97	5.8
27	36.5	21.0	0.48	0.47	4.0
28	47.5	37.0	1.00	1.00	8.6

DAILY METROLOGICAL DATA FOR CLARKSBURG, WEST VIRGINIA

LATITUDE = 39.28 DEG. NORTH

MONTH : DECEMBER 1964

DATE	T-AIR	T-DP	CE	CS	U
1	17.5	10.5	0.45	0.45	4.6
2	33.0	24.5	1.00	1.00	6.9
3	45.0	45.0	1.00	1.00	2.9
4	58.5	54.5	1.00	1.00	6.9
5	40.5	39.0	1.00	1.00	4.6
6	27.5	20.5	1.00	1.00	11.5
7	25.5	18.0	0.79	0.79	5.8
8	37.0	26.5	1.00	1.00	5.8
9	35.0	28.0	0.93	0.93	1.0
10	33.0	23.5	0.71	0.71	1.0
11	49.5	46.0	1.00	1.00	1.0
12	54.0	48.0	1.00	1.00	3.5
13	45.5	39.5	0.55	0.55	9.2
14	37.0	24.5	0.04	0.04	9.8
15	22.0	14.5	0.59	0.59	8.6
16	31.5	20.0	0.18	0.18	8.6
17	46.5	41.0	1.00	1.00	8.6
18	14.5	9.0	0.67	0.67	8.6
19	16.5	10.5	0.70	0.70	1.0
20	36.5	28.5	1.00	1.00	8.1
21	31.0	26.5	1.00	1.00	4.0
22	37.5	32.5	1.00	1.00	6.9
23	50.5	43.0	1.00	1.00	9.8
24	64.0	52.5	1.00	1.00	12.1
25	49.0	47.5	1.00	1.00	8.6
26	57.0	54.0	0.97	0.97	8.6
27	36.0	36.0	1.00	1.00	6.9
28	33.0	30.5	1.00	1.00	1.7
29	54.0	36.5	0.49	0.49	6.9
30	54.5	47.0	0.89	0.89	8.6
31	38.5	31.5	0.38	0.38	5.8

MONTH : JANUARY 1965

DATE	T-AIR	T-DP	CE	CS	U
1	34.5	30.0	1.00	1.00	5.8
2	55.0	51.5	1.00	1.00	15.5
3	31.5	21.5	0.19	0.19	8.1
4	28.5	20.5	0.25	0.25	5.8
5	36.5	25.5	0.45	0.45	7.5
6	39.5	28.0	0.68	0.68	1.0
7	40.0	35.0	0.79	0.79	5.2
8	60.0	54.0	1.00	1.00	13.4
9	47.0	45.0	1.00	1.00	8.1
10	29.5	29.5	1.00	1.00	5.8
11	28.0	24.5	1.00	1.00	8.6
12	30.5	27.5	0.53	0.53	3.5
13	32.0	29.5	0.98	0.98	10.4
14	16.5	12.5	0.28	0.28	5.8
15	24.5	20.0	0.96	0.96	5.8
16	24.0	21.5	0.93	0.93	11.5
17	11.0	7.5	0.28	0.28	5.8
18	20.5	13.5	1.00	1.00	8.6
19	18.5	15.0	0.60	0.60	5.8
20	31.5	30.0	1.00	1.00	9.8
21	32.0	23.5	0.00	0.00	5.8
22	45.5	37.5	0.61	0.61	5.2
23	43.3	41.0	1.00	1.00	4.6
24	53.0	45.0	1.00	1.00	8.6
25	37.5	32.0	0.84	0.84	6.9
26	53.0	45.5	0.86	0.86	13.2
27	25.0	19.0	0.95	0.95	10.4
28	27.0	22.5	1.00	1.00	10.4
29	13.5	4.0	0.65	0.65	9.8
30	15.5	10.5	0.80	0.80	6.9
31	6.0	0.0	0.03	0.03	6.9

DAILY METROLOGICAL DATA FOR CLARKSBURG, WEST VIRGINIA (CONT'D)
LATITUDE = 39.28 DEG, NORTH

MONTH : FEBRUARY 1965

DATE	T-AIR	T-DP	CE	CS	U
1	20.0	17.5	1.00	1.00	8.6
2	13.0	9.0	0.80	0.80	10.4
3	12.5	6.5	0.43	0.43	12.1
4	12.5	5.0	0.00	0.00	8.6
5	25.0	16.5	0.58	0.58	8.6
6	49.1	36.0	0.51	0.51	6.9
7	48.0	47.0	1.00	1.00	2.9
8	53.5	52.0	1.00	1.00	6.9
9	45.5	44.5	1.00	1.00	4.6
10	61.5	54.5	1.00	1.00	11.5
11	50.0	47.0	1.00	1.00	5.8
12	52.5	41.0	1.00	1.00	10.4
13	28.5	20.5	0.85	0.85	5.8
14	27.5	26.5	1.00	1.00	2.9
15	26.5	17.0	0.15	0.15	2.3
16	35.5	23.5	0.75	0.75	4.0
17	40.5	31.0	0.75	0.75	5.8
18	40.0	30.0	0.52	0.52	8.1
19	23.5	15.5	0.85	0.85	13.2
20	22.0	18.0	0.69	0.69	4.6
21	40.0	34.5	0.83	0.83	13.8
22	17.0	11.0	0.79	0.79	12.1
23	20.5	17.5	0.55	0.55	4.6
24	37.5	29.0	0.65	0.65	10.4
25	36.5	30.5	0.97	0.97	16.1
26	17.0	13.0	0.93	0.93	15.0
27	33.5	21.0	0.53	0.53	7.5
28	54.0	39.5	0.48	0.48	6.9

DAILY METROLOGICAL DATA FOR WATERLOO, IOWA

LATITUDE = 42.49 DEG. NORTH

MONTH : NOVEMBER 1963

DATE	T-AIR	T-DP	CE	CS	U
1	38.5	21.0	0.05	0.08	13.2
2	36.0	21.0	0.10	0.08	6.9
3	48.0	24.5	0.22	0.27	12.1
4	43.0	37.0	0.83	0.97	8.6
5	50.5	46.5	0.84	0.87	6.3
6	45.5	45.0	0.91	1.00	6.3
7	45.5	43.0	0.68	0.79	8.6
8	50.5	43.0	0.41	0.43	10.9
9	53.0	45.0	0.53	0.43	8.1
10	47.0	32.5	0.20	0.37	10.9
11	40.0	46.0	0.08	0.09	17.8
12	33.5	24.0	0.72	0.94	17.3
13	35.0	25.0	0.98	1.00	16.1
14	35.0	25.0	0.55	0.59	8.6
15	42.0	27.0	0.35	0.19	15.0
16	51.0	42.0	0.61	0.83	12.7
17	50.0	41.0	0.85	0.78	10.4
18	41.5	28.0	0.00	0.00	6.9
19	43.0	31.5	0.53	0.55	8.6
20	44.0	43.5	0.89	1.00	8.6
21	46.0	44.5	0.70	0.93	11.5
22	43.0	38.5	0.96	1.00	15.5
23	25.0	18.5	0.33	0.61	10.4
24	29.0	26.0	0.71	0.92	12.7
25	36.5	30.0	0.82	0.80	10.0
26	35.5	30.5	0.61	0.72	10.9
27	42.0	34.0	0.15	0.07	7.5
28	38.0	30.0	0.62	0.75	16.1
29	31.0	22.5	0.43	0.38	12.7
30	26.0	19.0	0.57	0.57	12.7

MONTH : DECEMBER 1963

DATE	T-AIR	T-DP	CE	CS	U
1	24.5	17.5	0.60	0.70	12.7
2	21.5	17.5	0.68	0.97	13.8
3	15.5	15.5	0.60	0.67	10.9
4	30.5	25.0	1.00	1.00	8.1
5	31.0	27.5	1.00	1.00	9.8
6	35.0	27.5	0.07	0.11	6.9
7	38.5	31.0	0.90	0.79	12.7
8	26.0	22.5	1.00	1.00	17.3
9	16.5	11.0	0.97	0.93	17.8
10	15.5	11.0	0.83	0.66	10.9
11	17.0	15.0	1.00	1.00	9.8
12	4.5	1.5	0.42	0.43	9.8
13	1.5	-8.0	0.14	0.28	17.3
14	-1.5	-9.5	0.20	0.23	12.1
15	-7.0	-14.5	0.03	0.05	9.8
16	-6.5	-13.0	0.15	0.11	4.6
17	3.0	-3.5	0.75	0.98	11.5
18	-6.0	-17.0	0.00	0.00	12.7
19	-6.0	-17.0	0.32	0.53	11.5
20	-7.0	-19.5	0.20	0.33	9.8
21	-10.2	-20.0	0.00	0.00	6.9
22	-9.0	-16.0	0.13	0.24	5.8
23	-4.0	-6.0	0.18	0.18	9.8
24	26.0	20.5	0.20	0.20	8.6
25	24.0	20.5	0.13	0.03	9.8
26	26.0	20.0	0.62	0.93	13.8
27	11.0	6.0	0.19	0.08	16.1
28	9.0	2.5	0.55	0.96	8.6
29	-1.5	-11.5	0.00	0.00	8.6
30	1.5	-9.0	0.13	0.05	7.5
31	11.5	3.5	0.46	0.43	13.8

DAILY METROLOGICAL DATA FOR WATERLOO, IOWA (CONT'D)

LATITUDE = 42.49 DEG. NORTH

MONTH : JANUARY 1964

DATE	T-AIR	T-DP	CE	CS	U
1	24.5	19.0	0.19	0.30	9.8
2	34.5	29.0	0.46	0.41	10.3
3	35.0	31.5	0.46	0.43	15.0
4	33.5	21.5	0.00	0.00	8.6
5	30.5	21.5	0.77	0.87	8.6
6	25.5	20.0	0.57	0.67	11.5
7	26.0	19.5	0.51	0.53	10.9
8	29.0	22.0	0.98	1.00	12.1
9	11.0	0.5	0.38	0.26	17.8
10	1.0	-9.0	0.48	0.48	9.2
11	15.0	6.0	0.94	0.88	19.0
12	10.0	0.0	0.56	0.56	21.3
13	2.0	-7.5	0.05	0.03	9.8
14	11.0	4.5	0.47	0.48	8.1
15	16.0	6.5	0.28	0.03	11.5
16	24.0	19.5	0.77	0.85	9.2
17	32.0	26.0	0.44	0.55	16.1
18	32.0	21.5	0.20	0.16	7.5
19	32.0	29.5	0.90	1.00	13.2
20	34.5	26.5	0.02	0.03	11.5
21	37.5	29.5	0.09	0.11	6.9
22	40.0	37.0	0.40	0.53	9.2
23	32.0	30.5	0.72	0.73	10.4
24	27.0	24.0	1.00	1.00	10.9
25	18.0	10.0	0.43	0.38	20.1
26	18.5	8.0	0.28	0.56	9.8
27	10.0	-2.5	0.13	0.06	12.7
28	11.5	-1.5	0.07	0.05	8.1
29	30.0	18.5	0.03	0.41	8.1
30	31.5	22.5	0.23	0.12	8.6
31	37.5	30.5	0.31	0.13	10.5

MONTH : FEBRUARY 1964

DATE	T-AIR	T-DP	CE	CS	U
1	32.0	25.0	0.03	0.05	5.8
2	31.0	22.5	0.66	0.60	9.2
3	32.5	22.0	0.28	0.08	6.9
4	35.0	24.5	0.05	0.05	8.1
5	38.5	26.5	0.03	0.02	5.8
6	27.0	21.0	0.64	0.87	16.1
7	13.0	9.0	0.50	0.51	17.8
8	16.5	6.5	0.21	0.17	7.5
9	22.0	14.0	1.00	1.00	3.5
10	21.0	15.5	0.47	0.55	5.8
11	24.0	14.5	0.22	0.07	13.8
12	33.5	24.0	1.00	1.00	14.4
13	26.0	21.0	0.52	0.54	10.4
14	26.0	16.5	0.25	0.18	8.6
15	23.5	20.0	0.75	0.98	6.3
16	19.5	12.5	0.08	0.08	9.8
17	33.5	25.0	0.48	0.58	11.5
18	30.5	26.5	0.48	0.65	9.2
19	28.6	20.0	0.90	0.83	9.2
20	20.5	12.0	0.53	0.58	12.7
21	17.0	5.0	0.00	0.00	7.5
22	22.0	12.0	0.30	0.15	11.0
23	10.0	0.5	0.43	0.49	10.9
24	22.5	1.5	0.24	0.38	12.7
25	19.0	12.0	0.77	0.88	10.4
26	9.5	-6.5	0.03	0.08	10.4
27	16.0	2.0	0.23	0.22	10.4
28	27.0	13.5	0.16	0.24	10.4
29	43.0	19.0	0.28	0.08	22.5

DAILY METROLOGICAL DATA FOR WATERLOO, IOWA (CONT'D)

LATITUDE = 42.49 DEG. NORTH

MONTH : MARCH 1964

DATE	T-AIR	T-DP	CE	CS	U
1	42.0	22.5	0.28	0.27	13.8
2	47.0	27.5	0.29	0.39	12.7
3	42.0	37.0	1.00	1.00	16.7
4	39.0	34.0	0.95	1.00	15.5
5	26.0	13.0	0.36	0.04	12.7
6	34.5	26.0	0.75	0.75	11.4
7	21.5	21.5	0.40	0.36	10.9
8	26.5	21.5	1.00	1.00	12.1
9	20.5	16.5	0.40	0.24	8.6
10	20.0	14.0	0.17	0.24	4.6
11	29.0	25.5	0.83	0.93	5.8
12	32.0	28.0	0.63	0.54	13.8
13	46.0	37.0	0.95	0.94	13.8
14	38.0	25.0	0.20	0.23	14.4
15	39.0	22.0	0.29	0.20	7.5
16	36.0	20.0	0.39	0.29	13.8
17	20.0	12.5	0.12	0.14	16.7
18	24.5	11.5	0.44	0.43	8.6
19	33.0	22.0	0.99	1.00	19.6
20	29.5	27.0	1.00	1.00	15.5
21	28.0	23.0	0.84	0.83	10.9
22	25.0	20.0	0.52	0.87	13.2
23	39.5	31.5	0.59	0.80	16.1
24	24.5	16.5	0.82	0.95	19.5
25	18.5	15.5	0.90	1.00	16.1
26	13.0	6.5	0.15	0.08	12.1
27	11.5	9.5	0.78	0.98	7.5
28	16.0	11.5	0.31	0.05	10.4
29	13.5	9.5	0.43	0.50	15.5
30	16.0	11.0	0.35	0.65	8.6
31	25.5	20.0	0.13	0.23	9.8

MONTH : APRIL 1964

DATE	T-AIR	T-DP	CE	CS	U
1	36.5	27.0	0.31	0.38	15.5
2	40.0	37.5	0.98	1.00	17.3
3	35.5	28.0	0.57	0.47	14.4
4	33.5	22.5	0.79	0.80	14.4
5	36.5	32.0	1.00	1.00	16.7
6	47.0	40.5	0.79	0.89	11.5
7	34.0	29.5	0.95	1.00	17.3
8	35.0	21.5	0.30	0.17	12.7
9	44.0	28.5	0.10	0.18	12.7
10	46.5	30.5	0.04	0.00	8.6
11	52.5	40.5	0.70	1.00	8.1
12	51.5	45.0	0.65	0.80	12.7
13	48.0	40.0	0.73	0.73	25.3
14	45.0	28.0	0.30	0.48	14.4
15	52.0	32.5	0.40	0.55	10.9
16	64.0	46.0	0.05	0.09	13.2
17	53.5	45.0	0.66	0.95	14.4
18	49.5	30.0	0.82	0.73	10.9
19	43.0	34.0	0.82	0.88	10.4
20	47.0	46.5	1.00	1.00	20.7
21	51.0	48.0	0.86	0.76	14.5
22	51.5	39.0	0.46	0.28	13.2
23	53.5	44.0	0.60	0.69	10.9
24	49.5	36.0	0.00	0.00	12.7
25	52.0	37.0	0.11	0.19	13.8
26	60.0	51.0	0.73	0.80	19.0
27	62.0	51.0	0.69	0.51	15.0
28	52.0	45.5	0.80	0.87	13.2
29	43.0	40.5	1.00	1.00	14.4
30	45.0	44.0	1.00	1.00	5.8

DAILY METROLOGICAL DATA FOR SIOUX FALLS, SOUTH DAKOTA
LATITUDE = 43.57 DEG. NORTH

MONTH : DECEMBER 1946

DATE	T-AIR	T-DP	CE	CS	U
1	17.5	12.0	0.31	0.07	11.0
2	23.0	15.5	0.76	0.93	15.5
3	34.0	27.0	0.45	0.55	7.0
4	41.5	32.5	0.83	0.88	8.0
5	35.0	28.0	0.63	0.70	4.5
6	39.5	31.5	0.55	0.64	9.0
7	32.5	30.5	0.90	0.98	7.5
8	35.0	34.5	0.83	0.97	7.5
9	36.0	30.5	0.73	0.67	8.5
10	34.0	26.5	0.48	0.49	9.5
11	41.0	30.0	0.66	0.58	13.5
12	26.0	18.5	0.74	0.55	17.0
13	15.5	-5.5	0.93	0.88	6.5
14	18.5	14.5	1.00	1.00	7.5
15	23.5	24.0	1.00	1.00	6.5
16	20.5	15.0	0.62	0.72	23.0
17	8.5	5.5	0.20	0.41	20.0
18	11.0	-7.5	0.39	0.36	10.5
19	19.0	14.5	0.28	0.12	8.0
20	28.5	18.5	0.56	0.93	11.0
21	22.5	19.5	0.61	0.77	14.0
22	28.5	23.5	0.57	0.76	10.0
23	26.5	18.5	0.45	0.33	14.5
24	26.0	20.5	0.28	0.45	11.0
25	34.5	25.5	0.06	0.10	6.0
26	22.0	16.0	0.51	0.59	12.5
27	20.0	19.5	1.00	1.00	14.5
28	2.0	-2.0	1.00	1.00	19.5
29	-6.5	-11.5	0.30	0.20	16.5
30	-3.0	-9.0	0.43	0.61	13.0
31	-4.5	-8.5	0.05	0.42	11.5

MONTH : JANUARY 1947

DATE	T-AIR	T-DP	CE	CS	U
1	9.0	5.5	0.54	0.53	11.5
2	3.5	0.5	1.00	1.00	13.0
3	-2.0	-7.5	0.08	0.01	12.0
4	9.0	3.5	0.32	0.54	13.5
5	16.0	14.5	0.30	0.38	13.0
6	24.0	21.0	0.84	0.90	11.5
7	27.5	24.0	0.55	0.62	12.5
8	29.5	25.5	0.72	0.78	11.5
9	28.0	25.0	0.43	0.44	9.0
10	35.0	30.5	0.74	0.63	8.0
11	27.5	23.0	0.62	0.73	12.0
12	24.0	21.0	1.00	1.00	13.0
13	28.0	26.5	0.92	1.00	23.5
14	17.0	10.5	0.03	0.02	13.0
15	7.0	3.0	0.72	1.00	10.5
16	19.0	11.5	0.07	0.13	13.0
17	29.5	22.5	0.04	0.08	9.0
18	33.5	24.5	0.30	0.52	10.0
19	38.0	25.0	0.28	0.22	17.5
20	12.5	7.5	0.66	0.56	22.5
21	5.0	0.5	0.57	0.61	17.5
22	21.0	18.0	0.54	0.63	8.5
23	38.0	29.0	0.51	0.66	13.5
24	39.5	32.5	0.48	0.41	7.5
25	38.0	30.5	0.51	0.43	14.5
26	45.0	31.5	0.89	0.87	8.5
27	31.0	22.0	0.41	0.34	15.0
28	25.0	22.5	0.81	1.00	14.5
29	19.5	18.5	1.00	1.00	26.0
30	10.5	9.5	0.88	0.86	18.5
31	5.5	4.5	0.61	0.68	10.5

DAILY METROLOGICAL DATA FOR SIOUX FALLS, SOUTH DAKOTA (CONT'D)

LATITUDE = 43.57 DEG. NORTH

MONTH : FEBRUARY 1947

DATE	T-AIR	T-DP	CE	CS	U
1	-3.0	-3.5	0.26	0.08	16.5
2	14.0	10.0	0.81	0.96	11.5
3	14.0	10.5	0.93	1.00	23.5
4	-2.0	-8.0	0.10	0.09	19.0
5	-4.5	-2.5	0.89	0.90	8.5
6	11.0	10.0	0.85	0.98	24.0
7	-4.0	-7.0	1.00	1.00	34.5
8	2.0	0.0	0.88	0.98	24.5
9	-9.0	-7.0	0.76	0.68	16.0
10	14.0	11.0	0.46	0.19	7.0
11	25.5	22.0	0.73	0.91	8.5
12	23.5	20.0	0.70	0.99	10.0
13	37.0	30.5	0.87	0.93	11.0
14	32.5	30.0	0.77	0.96	13.5
15	37.0	30.5	0.96	0.93	14.5
16	34.5	29.0	0.72	0.91	12.5
17	28.0	23.0	0.63	0.63	14.5
18	15.0	11.0	0.49	0.57	10.5
19	13.5	12.5	0.72	0.96	9.0
20	3.0	1.5	0.35	0.57	5.1
21	8.5	5.0	0.76	0.96	6.5
22	3.5	2.0	0.52	0.83	11.5
23	-7.5	-2.0	0.69	0.90	21.5
24	16.5	12.0	0.96	1.00	22.5
25	18.0	13.5	0.93	0.98	18.5
26	14.5	12.0	0.75	0.88	16.0
27	17.5	12.0	0.97	0.96	6.0
28	16.5	13.5	0.82	0.98	9.0

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MONTH : MARCH 1947

DATE	T-AIR	T-DP	CE	CS	U
1	15.0	11.5	0.83	0.96	16.5
2	16.0	10.5	0.94	0.99	11.0
3	19.5	15.5	0.93	0.90	5.5
4	23.5	19.5	0.91	0.86	9.5
5	24.0	17.0	0.63	0.63	12.0
6	21.0	15.0	0.34	0.18	10.0
7	23.5	18.5	0.89	0.78	5.5
8	24.0	19.0	0.80	0.93	7.0
9	32.0	25.5	1.00	1.00	9.0
10	32.5	30.0	1.00	1.00	15.5
11	36.0	35.0	1.00	1.00	12.5
12	35.5	33.0	1.00	1.00	9.5
13	27.0	24.5	0.89	0.93	15.0
14	15.0	12.5	0.79	0.83	23.0
15	19.5	11.5	0.29	0.28	16.0
16	23.6	21.0	0.58	0.97	7.0
17	23.0	19.5	0.49	0.48	9.0
18	34.5	26.5	0.62	0.68	8.5
19	30.0	26.5	0.88	1.00	7.0
20	36.0	29.5	0.95	0.95	17.5
21	32.0	24.0	0.67	0.66	18.5
22	51.5	35.0	0.33	0.56	9.5
23	47.0	36.5	0.86	0.94	16.5
24	37.5	27.0	0.59	0.62	23.5
25	23.5	17.0	0.40	0.76	20.0
26	24.0	16.0	0.64	0.78	6.0
27	32.5	37.5	0.64	0.75	15.0
28	40.0	24.5	0.28	0.38	17.5
29	31.0	22.0	0.27	0.17	12.5
30	40.5	25.0	0.97	0.94	14.0
31	39.0	36.0	1.00	1.00	11.0

DAILY METROLOGICAL DATA FOR SAGINAW, MICHIGAN

LATITUDE = 43.43 DEG. NORTH

MONTH : DECEMBER 1962

DATE	T-AIR	T-DP	CE	CS	U
1	48.0	38.0	0.43	0.68	5.2
2	42.5	34.5	0.48	0.61	6.9
3	47.5	36.5	0.50	0.55	8.6
4	43.5	34.5	0.60	0.51	11.5
5	39.0	34.5	0.94	0.93	10.9
6	30.5	27.5	1.00	1.00	17.8
7	31.5	25.5	1.00	1.00	17.8
8	25.0	20.0	0.74	0.58	11.5
9	19.0	18.0	0.94	0.95	9.7
10	15.5	9.0	0.74	0.87	15.5
11	5.0	-2.5	0.61	0.54	8.6
12	7.0	-1.5	0.36	0.40	15.5
13	9.0	3.5	0.91	0.93	17.3
14	14.0	10.0	0.91	0.92	9.8
15	20.5	16.0	0.96	0.93	10.4
16	20.0	18.5	0.78	0.82	14.4
17	31.5	28.0	0.98	1.00	12.7
18	32.5	28.5	0.69	0.69	7.5
19	31.0	24.0	0.95	0.95	10.9
20	16.5	8.0	0.55	0.82	15.0
21	14.0	9.0	0.88	0.89	9.8
22	23.5	20.5	0.97	0.93	12.7
23	22.0	18.0	0.88	0.87	24.8
24	9.5	5.0	0.54	0.73	11.5
25	17.5	14.5	0.98	0.99	12.7
26	11.0	4.0	0.29	0.15	15.5
27	12.0	6.5	0.81	0.98	15.5
28	20.0	15.5	0.48	0.47	13.2
29	22.0	15.0	0.59	0.58	17.8
30	6.0	-5.0	0.28	0.52	9.2
31	2.0	-8.0	0.16	0.11	7.5

MONTH : JANUARY 1963

DATE	T-AIR	T-DP	CE	CS	U
1	9.5	1.0	0.37	0.45	11.5
2	15.0	8.0	0.86	0.99	6.9
3	27.0	23.5	1.00	1.00	9.2
4	29.0	26.0	1.00	1.00	6.3
5	28.5	24.5	1.00	1.00	8.6
6	28.0	25.0	1.00	1.00	9.8
7	27.5	26.0	1.00	1.00	12.1
8	30.5	29.0	1.00	1.00	13.2
9	32.5	30.5	0.97	0.94	12.7
10	24.5	21.0	1.00	1.00	15.0
11	18.5	17.0	1.00	1.00	20.1
12	19.5	17.0	0.88	0.87	19.0
13	8.0	2.5	0.50	0.73	20.1
14	1.0	-5.0	0.33	0.49	15.0
15	-5.0	-14.5	0.03	0.06	12.1
16	1.5	-4.5	0.33	0.44	16.1
17	6.0	3.5	0.30	0.23	8.6
18	14.5	9.5	0.71	0.88	8.6
19	6.0	1.0	0.80	0.94	9.8
20	5.0	-0.5	0.69	0.83	15.5
21	-2.0	-10.5	0.24	0.24	16.7
22	3.5	-2.0	0.96	0.95	13.8
23	-4.0	-14.5	0.54	0.52	16.1
24	-1.5	-8.5	0.49	0.44	17.3
25	3.5	-1.5	0.52	0.53	12.1
26	7.0	2.0	0.88	0.93	6.8
27	6.0	-3.0	0.66	0.83	13.8
28	1.0	-7.0	0.34	0.53	10.4
29	5.0	-1.0	0.70	0.92	12.1
30	8.5	5.5	0.70	0.60	8.1
31	5.0	-0.5	0.29	0.24	12.1

DAILY METROLOGICAL DATA FOR SAGINAW, MICHIGAN (CONT'D)

LATITUDE = 43.43 DEG. NORTH

MONTH : FEBRUARY 1963

DATE	T-AIR	T-DP	CE	CS	U
1	18.0	15.0	0.99	1.00	17.3
2	17.5	13.5	0.87	0.87	16.7
3	1.0	-7.0	0.21	0.16	12.1
4	18.5	13.5	1.00	1.00	13.8
5	25.5	23.0	1.00	1.00	6.9
6	28.0	26.0	0.94	0.98	13.2
7	17.0	12.0	0.63	0.53	16.1
8	3.0	-5.5	0.58	0.73	8.6
9	7.0	-3.5	0.66	0.78	8.1
10	16.0	13.5	0.88	0.78	5.2
11	18.5	13.5	0.95	0.90	11.5
12	-9.0	-3.5	0.57	0.60	6.9
13	17.0	13.0	0.96	0.93	11.5
14	10.5	-3.5	0.88	0.93	17.5
15	3.5	-7.5	0.15	0.01	10.9
16	6.0	-0.5	0.50	0.51	10.9
17	25.5	21.0	1.00	1.00	15.5
18	32.0	27.5	0.87	0.73	10.4
19	25.0	24.0	1.00	1.00	13.2
20	14.0	-4.5	0.58	0.66	21.3
21	0.0	-12.0	0.10	0.53	17.3
22	-1.5	-4.5	0.65	0.84	15.5
23	12.0	7.5	0.73	0.89	13.2
24	14.0	-9.5	0.29	0.10	12.7
25	6.5	-1.0	0.38	0.39	12.1
26	1.5	-10.0	0.00	0.00	8.6
27	8.5	3.5	1.00	1.00	15.0
28	12.5	5.5	0.52	0.40	10.9

MONTH : MARCH 1963

DATE	T-AIR	T-DP	CE	CS	U
1	10.5	1.0	0.44	0.86	6.9
2	19.5	13.0	0.59	0.54	12.1
3	35.5	27.5	0.82	0.63	7.5
4	33.5	32.0	1.00	1.00	12.1
5	28.5	26.5	0.94	0.88	14.4
6	31.0	26.0	0.98	0.97	15.0
7	27.0	20.5	0.70	0.45	11.5
8	32.0	21.0	0.80	0.84	15.0
9	20.0	13.0	0.58	0.56	10.9
10	24.0	18.0	0.36	0.23	13.2
11	24.5	20.5	0.79	1.00	13.2
12	32.0	29.0	1.00	1.00	8.1
13	25.0	21.5	0.71	0.93	11.5
14	25.0	18.0	0.13	0.25	10.4
15	28.0	21.0	0.43	0.45	9.2
16	36.5	31.0	1.00	1.00	11.5
17	34.5	29.5	0.90	0.89	17.3
18	25.0	18.0	0.66	0.66	9.8
19	30.5	26.0	1.00	1.00	15.0
20	30.5	25.5	1.00	1.00	19.0
21	25.0	19.0	0.65	0.76	17.3
22	26.5	17.0	0.33	0.48	9.8
23	40.5	29.5	0.06	0.13	12.7
24	51.0	38.5	0.61	0.77	13.8
25	55.0	46.5	0.69	0.76	16.1
26	45.5	42.0	1.00	1.00	13.8
27	45.5	35.0	0.42	0.59	14.4
28	36.5	23.5	0.45	0.44	10.4
29	54.0	41.5	0.85	0.96	20.7
30	54.5	41.5	0.54	0.77	11.5
31	49.0	36.0	0.46	0.49	9.8

DAILY METROLOGICAL DATA FOR PRESQUE ISLES, MAINE
LATITUDE = 46.68 DEG. NORTH

MONTH : NOVEMBER 1945

DATE	T-AIR	T-DP	CE	CS	U
1	35.0	23.5	0.48	0.53	11.0
2	32.0	31.0	0.76	0.99	7.5
3	47.5	47.5	1.00	1.00	9.5
4	39.0	35.5	1.00	1.00	9.5
5	34.5	27.5	0.80	0.88	10.0
6	35.0	29.5	0.09	0.01	10.0
7	31.5	30.5	0.66	0.83	6.5
8	42.5	42.5	1.00	1.00	7.0
9	48.5	48.5	1.00	1.00	8.0
10	38.0	35.5	0.75	0.95	8.0
11	31.0	23.0	0.47	0.75	5.0
12	31.0	27.0	0.95	0.98	7.5
13	45.0	40.0	1.00	1.00	15.0
14	45.0	40.0	1.00	1.00	10.0
15	27.5	18.0	0.69	0.84	17.0
16	20.5	6.5	0.36	0.48	14.0
17	22.0	16.5	0.63	0.75	10.0
18	29.0	28.5	1.00	1.00	7.5
19	30.5	27.5	0.74	0.63	7.0
20	32.0	31.0	1.00	1.00	15.0
21	20.5	19.5	0.71	0.76	15.0
22	21.5	20.5	1.00	1.00	9.0
23	29.5	26.5	0.86	0.99	7.5
24	22.5	18.0	0.28	0.30	10.0
25	21.0	18.0	0.46	0.62	8.0
26	16.5	13.5	0.15	0.25	7.5
27	14.0	9.5	0.39	0.39	4.0
28	13.0	10.5	0.91	0.96	9.0
29	7.5	3.0	0.70	0.87	9.0
30	19.0	13.5	0.98	1.00	17.0

MONTH : DECEMBER 1945

DATE	T-AIR	T-DP	CE	CS	U
1	19.0	15.0	0.29	0.28	13.5
2	17.0	14.5	0.53	0.48	3.5
3	18.5	17.5	0.95	1.00	8.5
4	16.5	16.5	0.73	0.97	7.0
5	12.0	5.5	0.13	0.25	8.5
6	14.5	10.5	0.65	0.87	4.0
7	31.0	28.0	1.00	1.00	9.0
8	34.5	29.5	0.97	0.97	14.5
9	31.5	27.5	0.90	0.98	8.0
10	31.0	26.5	0.72	0.86	11.0
11	17.0	13.5	0.95	0.98	15.0
12	2.0	-2.0	0.43	0.61	21.5
13	0.0	-7.5	0.25	0.44	15.0
14	7.5	-0.5	0.36	0.70	8.0
15	16.0	12.5	0.53	0.35	8.0
16	17.5	11.5	0.88	0.97	10.0
17	6.0	1.0	0.58	0.80	14.5
18	-0.5	-6.0	0.32	0.29	8.5
19	0.0	-3.5	0.59	0.55	7.5
20	3.0	-2.0	0.77	0.71	9.0
21	-0.5	-3.0	0.57	0.66	8.5
22	2.0	-3.0	0.74	0.73	13.0
23	12.5	16.0	0.95	0.48	18.0
24	15.0	13.5	0.76	0.84	12.0
25	10.5	9.5	0.86	0.96	6.0
26	29.5	28.5	1.00	1.00	12.5
27	24.0	18.5	0.76	0.93	17.5
28	6.5	2.0	0.13	0.27	10.0
29	8.5	7.0	0.77	1.00	9.5
30	25.5	22.5	0.78	0.94	6.0
31	31.0	30.0	1.00	1.00	10.0

DAILY METROLOGICAL DATA FOR PRESQUE ISLES, MAINE (CONT'D)

LATITUDE = 46.68 DEG. NORTH

MONTH : JANUARY 1946

DATE	T-AIR	T-DP	CE	CS	U
1	20.5	20.0	0.91	0.98	13.5
2	3.0	0.5	0.56	0.76	10.0
3	2.0	-0.5	0.60	0.69	7.5
4	26.5	22.5	0.92	0.84	10.0
5	28.5	30.5	1.00	1.00	9.0
6	37.0	35.0	0.97	0.96	6.5
7	37.5	33.0	0.34	0.32	19.0
8	17.5	16.5	0.09	0.15	12.5
9	12.0	10.0	0.57	0.68	8.0
10	25.0	23.5	0.89	0.83	10.0
11	14.0	11.5	0.21	0.33	11.5
12	15.0	15.5	0.76	0.78	6.0
13	14.5	-8.0	0.89	0.92	19.0
14	-12.5	-20.0	0.31	0.23	16.0
15	-15.0	-22.5	0.32	0.25	5.5
16	-17.5	-26.5	0.08	0.12	10.0
17	-5.0	-6.5	0.93	0.93	9.0
18	3.0	1.5	0.53	0.54	8.0
19	8.5	-1.0	0.89	1.00	14.0
20	-7.0	-14.0	0.16	0.04	9.0
21	7.5	3.0	1.00	1.00	10.5
22	15.5	12.5	0.60	0.63	17.0
23	3.0	-2.0	0.31	0.60	8.5
24	13.5	13.0	0.73	0.93	11.5
25	24.5	22.5	0.85	0.99	19.5
26	15.0	11.5	0.61	0.86	19.0
27	-6.5	-6.5	0.14	0.02	11.0
28	6.5	5.0	0.73	0.94	6.5
29	5.5	-1.5	0.58	0.74	19.0
30	-10.0	-12.0	0.60	0.69	5.0
31	5.5	5.0	1.00	1.00	7.5

MONTH : FEBRUARY 1946

DATE	T-AIR	T-DP	CE	CS	U
1	9.0	6.5	0.87	0.95	11.0
2	0.5	-6.5	0.45	0.46	6.0
3	5.5	0.5	0.61	0.72	13.0
4	-1.0	-4.0	0.21	0.21	14.0
5	-3.5	-9.5	0.00	0.00	4.0
6	7.0	5.5	0.61	0.61	14.5
7	31.5	27.5	0.90	0.90	12.5
8	9.5	4.5	0.42	0.42	14.0
9	6.0	2.0	0.63	0.63	7.0
10	10.5	9.0	0.53	0.53	13.0
11	9.0	4.0	0.64	0.64	10.5
12	11.5	8.5	0.55	0.55	9.0
13	15.5	15.0	1.00	1.00	11.5
14	37.0	32.5	1.00	1.00	12.0
15	17.5	15.0	0.76	0.76	17.0
16	-3.5	-4.5	0.62	0.62	18.0
17	13.5	10.5	0.70	0.80	6.0
18	3.5	1.5	0.64	0.83	13.5
19	-2.5	-5.0	0.38	0.33	8.5
20	8.5	6.0	1.00	1.00	14.5
21	6.0	5.5	0.91	1.00	22.0
22	4.0	-0.5	0.20	0.29	16.5
23	8.0	3.5	0.84	0.86	6.5
24	1.0	-3.5	0.70	0.83	9.0
25	8.0	6.0	1.00	1.00	19.5
26	2.5	-6.0	0.19	0.12	10.5
27	5.5	0.5	0.93	0.91	9.5
28	19.0	15.0	0.83	0.99	10.5

DAILY METROLOGICAL DATA FOR PRESQUE ISLES, MAINE (CONT'D)

LATITUDE = 46.68 DEG. NORTH

MONTH : MARCH 1946

DATE	T-AIR	T-DP	CE	CS	U
1	15.0	10.0	0.21	0.21	8.0
2	29.5	22.0	0.85	0.85	15.5
3	33.5	27.5	0.83	0.88	11.5
4	30.0	23.5	0.45	0.74	9.5
5	18.5	15.5	0.60	0.57	6.5
6	22.5	19.5	0.79	0.75	13.0
7	37.0	33.0	0.96	1.00	13.0
8	38.0	28.0	0.58	0.64	5.5
9	30.0	27.5	0.98	0.96	10.0
10	16.5	13.0	0.88	0.94	10.5
11	12.5	8.0	0.38	0.43	7.5
12	12.0	8.0	0.60	0.69	10.0
13	40.0	30.0	0.96	0.95	13.0
14	40.5	34.5	0.71	0.78	6.5
15	32.0	25.0	0.30	0.13	11.5
16	31.0	21.5	0.03	0.03	9.5
17	30.0	22.0	0.04	0.08	9.0
18	26.5	16.0	0.00	0.00	9.0
19	24.0	16.0	0.35	0.27	3.5
20	35.5	22.5	0.47	0.64	7.5
21	42.5	30.0	0.21	0.20	8.0
22	44.0	31.0	0.83	0.83	16.0
23	25.5	17.0	0.15	0.12	16.0
24	31.0	22.0	0.35	0.59	21.5
25	37.5	28.0	0.48	0.45	11.0
26	45.0	35.5	0.83	0.79	6.0
27	41.0	32.0	0.83	0.83	13.0
28	37.5	26.0	0.59	0.45	13.5
29	39.0	29.0	0.92	0.92	9.5
30	28.0	20.0	0.23	0.18	7.5
31	15.5	5.5	0.22	0.22	14.5